Soil Organic Matter Dynamics in Eurasian Steppes
ユーラシア・ステップにおける土壌有機物のダイナミックス
--地球温暖化・砂漠化対策としての土地利用の適正化とは何か？--

Final Report on Research Project
(Number: 13460032)
under Grant-in-Aid for Scientific Research (B)(2)
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Takashi Kosaki
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Preface

Eurasian steppe - it sounds so exotic, romantic, wild, and extensive and is calling me to visit. I have dreamed many times of wondering around in the steppe with patches of farms and birch forests since I started learning soil science in the university. Whatever textbook of soil science you pick up, you can find the name of V.V. Dokuchaev, The Father of Modern Soil Science, together with the name of Chernozem, one of the most productive soils in the world. As you know, he studied soils in the Southern Russian Plain under steppe and forest-steppe vegetation and published his classic work "Russian Chernozems" in 1883, since then it became the bible of soil science. We learned soil-forming factors and processes, soil classification, etc. according to his ideas and their modification done by his successors in various countries. Yes, I did in Japan as well, but mostly in a textbook only. Unfortunately, our climate is too humid to learn his ideas under field condition of Japan. We never observe carbonate accumulated B horizon in a soil profile. One of the motivations with which we started this research project is to learn what steppe soils are and what processes are going on there in the classroom of Eurasian Steppe.

As I mentioned above, Chernozem soils are one of the most productive soils and thus they have been used for agricultural production, mainly of upland crops such as wheat, barley, sugar beet, corn, sunflower, etc. We should, however, remind us of their vulnerability as well which has been shown as "dustbowl" in 1930s of the United States. Chernozem soils have been converted from virgin steppe vegetation into mechanized farm for upland crop cultivation since the beginning of the 20th century and now land degradation such as soil organic matter decline can be observed in many of Chernozem soils. Particularly in the end of the last century, the former Soviet Union collapsed and most of the upland farms converted from Eurasian Steppe were exposed to privatization and swallowed in the world trading system. Not a small numbers of farms are now poorly maintained and/or exploited without proper soil and land management. Soil degradation in Eurasian Steppe is one of the urgent issues to cope with for world food security and consequently for stability of the countries independent from the former Soviet Union in terms of their political as well as economical situation. We, the Japanese, are responsible for assisting the re-establishment of appropriate land use systems protecting against land degradation, because Japan was the member of the allied forces to promote the reformation of Russia and eastern countries. This is the second motivation for this project.

The third motivation was to discuss with local scientists, shared the ideas with them, and make them open to the world for further discussion. The soil scientists in the former Soviet Union and eastern European countries were thought to be well trained and accumulated a lot of research outcomes, but unfortunately most of them were published in Russian and/or local languages only and thus they were quite difficult for us to access. We took an opportunity of the collapse of the former Soviet Union to start collaborative research firstly with Kazakhstan, next with Ukraine and finally with Hungary. In the course of the joint research, we were very lucky to be introduced a few very knowledgeable soil scientists with high potential. They were very well trained in Russian School of soil science and did a lot of valuable work in their places. They were not only reliable collaborators but also superb teachers and/or supervisors for us in this research topics. Frankly speaking, we still can find some gaps in understanding the concepts about the processes of land degradation and recognizing parameters to evaluate and predict them. I would say, however, that it is one of the best outcomes to find those gaps in our project.

This is just the beginning of collaborative research with our colleagues in Kazakhstan, Ukraine and Hungary, and hopefully shall be expanding into Russia and other countries in Central Asia, Baltic and Eastern Europe. We do hope the articles published here shall provide the readers with a variety of ideas and concepts which are from classical ones developed by Dokuchaev through newly and uniquely modified and/or developed ones by his successors in Kazakhstan, Ukraine, Hungary, and Japan. We would very much appreciate any comments and criticism from all of you. I am sure all of them should contribute to our research and I would be pleased if you could join us together in the next phase. You may hear what Eurasian Steppe whispers to you;

"Hey, come and step on me like Prof. Dokuchaev did! It's a fun!"

March, 2005

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Chapter 1

Introduction

Shinya Funakawa and Elmira Karbozova-Saljnikov

1.1. Significance of soil organic matter in Chernozem soils

Accumulation of soil organic matter (SOM) is a quite significant process in terrestrial ecosystems. It is widely accepted that the SOM is indispensable for increasing soil fertility. In addition to such a traditional aspect, SOM has recently drawn considerable attention in terms of both the large source and sink of carbon dioxide in relation to the problem of "global warming". It is said that approximately 15% of atmospheric CO_2 cycles between terrestrial ecosystems including soils and atmosphere annually (Stevenson, 1986) and, hence, it is very important to understand quantitatively such SOM/CO_2 dynamics in individual ecosystems. In this sense, Chernozem soils, or Mollisols, which can store a huge amount of SOM, are one of the most important resources from both the agricultural and environmental viewpoints (Paustian et al., 1997). The area of Chernozem soils in the territory of former Soviet Union amounts 189×10^6 hectares that is 48% of that kind of soils in the word (Kaurichev and Gromyko, 1974).

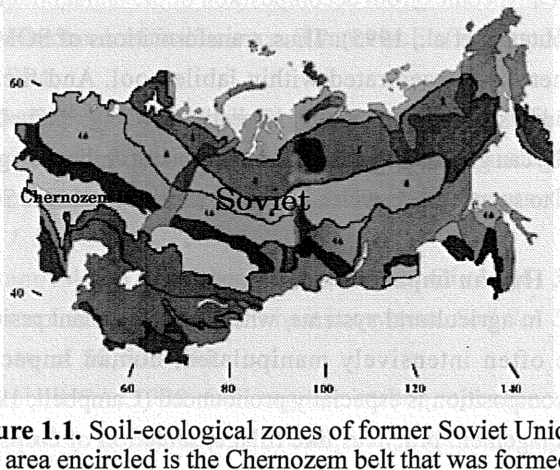

Figure 1.1. Soil-ecological zones of former Soviet Union. The area encircled is the Chernozem belt that was formed in forest-steppe and steppe zones.

Table 1.1. Amount of organic C in natural and agro-ecosystems (from Titlyanova, et al., 1982).

Organic carbon resource	Natural ecosystem	Agro ecosystem
	(g m^{-2})	
Detritus	340	67
Microorganisms	166	100
Humus	5359	4768

1.2. General characteristics of Chernozem soils

Chernozem soils were mainly formed in forest steppe and steppe zones (Fig. 1.1), under virgin steppe vegetation with non-percolative water regime (Prasolov, 1939) that is characterized with dry period in summer-autumn and water saturated period in winter-spring.

The main grass vegetation in forest steppe zone is presented with *Salvia pratensis, Carex humilus*, *Artemisia armeniaca*, and *A. latifilia*. In steppe zone *Stipa* and *Festuca* associations dominate as natural vegetation: *S. ucrainica*, *S. lussingiana*, *S. capillata*, *S. rubens*, *S. kirghisorum,* and *F. sulcata*. Rich steppe vegetation annually leaves in the soil large amount of organic substrate (0.6-1.4 Mg ha^{-1}) (Gromyko et al., 1974). Subsequently, steppe vegetation annually retrieves from the soil large amount of nutrients that are involved in plant biomass and thus are not leached out from the soil. Subsequently, the large amounts of nutrients are involved into biological cycle annually that continuously accumulated in the surface layer of the soil.

Chernozem soil is characterized with high activity of microbiological processes. Most intensively these processes take place in spring and early in summer, when the soil has optimal temperature regime and enough water reservoir that favor humus formation processes. Drying of soil in summer and freezing in winter causes attenuation of biochemical processes that leads to denaturation of SOM, compaction and transformation of molecules of humic acids into less labile forms.

The largest part of the chernozem belt is formed on plain to undulating landscape. Parent materials of the chernozem zone vary widely. Most of them are rich with calcium and magnesium carbonates (carbonaceous rocks such as limestone, dolomite, marl, and different clays). Most spread parent materials are loess (Ukrainian chernozems) and light to heavy loess-loam and clay (northern Kazakhstan chernozems).

1.3. Factors determining organic C levels

Steppe ecosystems provide soil with 30 to 40 Mg ha^{-1} of plant biomass, where 70 to 90% is concentrated belowground (Titlyanova and Nurmedov, 1982). Tillage of virgin lands with subsequent cultivation of agricultural crops causes extensive reorganization of annual cycles of plant input and SOM dynamics. According to Titlyanova and Nurmedov (1982), the total amount of plant biomass in arable lands of northern Kazakhstan decreased 3 to 4 folds, accounting for approximately 10 Mg ha^{-1} (Table 1.1).

The amount of organic carbon (organic C) contained in a particular soil is a function of the balance between the rate of deposition of plant residues in or on soil and the rate of mineralization of the residue carbon by soil biota (Baldock and Nelson, 2000). The mechanisms through which soil organic C can be biologically stabilized depend on properties of the soil mineral phase and the chemical structure of the organic residues added to the soil.

Climate: Climate impacts on soil organic carbon (SOC) content primarily through the effects of temperature, moisture, and solar radiation on the array and growth rate of plant species, and on the rate of SOC mineralization. Post et al. (1982) found that amounts of SOC were positively correlated with precipitation and, at a given level of precipitation, negatively correlated with temperature.

Soil mineral parent material: The structural condition of a soil can exert significant control over processes of biological decomposition by limiting the accessibility of SOC to decomposer microorganisms and of microorganisms to their faunal predators. This limitation results from the ability of clays to encapsulate organic materials (Tisdall and Oades, 1982); the burial of organic carbon within aggregates (Golchin et al., 1997; Golchin et al., 1994) and the entrapment of organic carbon within small pores (Elliott and Coleman, 1988).

Vegetation and soil organisms: All organic carbon in soils can serve as a substrate. Vegetation can influence SOC levels as a result of the amount, placement and biodegradability of plant residues returned to the soil. The fate of surface deposited residues depends on the activity of soil microorganisms and fauna and their ability to mix these residues into surface mineral horizons. Microorganisms are the major contributors to soil respiration and are responsible for 80-95% of the mineralization of carbon.

Mechanical disturbance: Mechanical disturbance of soil is one of the most significant factors that determine deterioration of soil humus under intensive agricultural use. Number of authors concluded that losses of humus under agricultural use are determined by biological (domination of mineralization processes over humification) and by mechanical (reduction of thickness of humus layer caused by erosion processes) factors (Chesnyak, 1981; Nosko et al., 1987; Buyanovsky et al., 1986; Anderson et al., 1986).

1.4. Decomposition of organic matter

Decomposition of plant and animal remains in soil constitutes a basic biological process in that carbon is recirculated to the atmosphere as carbon dioxide; nitrogen is made available as ammonium (NH_4^+) and nitrate (NO_3^-) (Stevenson, 1986). During decomposition by microorganisms, some of the carbon is released to the atmosphere as CO_2 and the remainder becomes part of the SOM. Part of the native humus is mineralized concurrently.

SOM is highly heterogeneous, consisting of fractions varying in turnover time from hours to many centuries. Gregorich et al. (1994) reported that more than 75% of SOM exists as compounds that are only slowly decomposable and the remainder is readily decomposable or “mineralizable” compounds. The amount of mineralizable organic matter in a soil is an indicator of organic matter quality, because it affects nutrient dynamics within single growing seasons, organic matter content in soils under contrasting management regimes, and carbon sequestration over extended periods of time.

Fresh plant litter decomposes quickly; consequently, though it represents only a small fraction of carbon in soil, about half of the carbon dioxide (CO_2) output from soil, globally, comes from decomposition of the annual litter fall (Couteaux et al., 1995). Thus, transformations of SOM are generally concentrated within labile pool. And the end products of organic matter mineralization (e.g., CO_2, NO_3, NH_4) can give us valuable information about ability of a given soil to supply plants with nutrients or ability to stabilize SOM.

1.5. Human impact on decomposition

In agricultural systems, where soil and plant residues are often intensively manipulated, human impact on decomposition is especially pronounced (Campbell, 1978). Management practices like tillage, selection of crops and cropping sequences, and fertilization can alter decomposition rates by their effects on soil moisture, soil temperature, aeration, composition and placement of residues.

Organic carbon and nitrogen retention in soil is influenced by crop rotation (Biederbeck et al., 1984), tillage (Campbell and Souster, 1982), residue management (Rasmussen et al., 1980) and fertility (Biederbeck et al., 1984; Rasmussen et al., 1980).

1.6. Objectives of the study

Factors that can influence SOM/CO_2 dynamics in natural and/or agricultural ecosystems in the territory of former Soviet Union is thus considered to be quite variable. In the present study, we will analyze the carbon dynamics in the area in order to: reveal factors that can affect SOM dynamics in steppe/agricultural ecosystems in Eurasian steppes, propose possible frameworks of ecological models that describe SOM dynamics after influence of agricultural practices, and discuss land use strategy that can satisfy both the requirements from the viewpoints of agricultural production and environmental soundness in post-Soviet period.

In the following chapters, studies relating SOM dynamics in each region of Ukraine and Kazakhstan will be presented in Chapters 2 to 6 and Chapters 7 to 12, respectively. Then the quality of different steppes will be compared in Chapters 13 to 17 and necessary factors that should be taken into consideration in SOM dynamics model will be clarified.

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Chapter 2

Characteristics of soils in Ukraine and their classification with special reference to dynamics of soil organic matter - actual problem of fundamental and applied soil sciences

Nikolai Ivanovich Polupan

Eurasian steppe zone in central Europe is distributed insularly and occupies the river valleys of Morava, Vltava and Laba, as well as the vast plains of Mid-German low hills. In the southeastern part it lays as a large continuous massive within Lower-Danube lowland and in the west - within the system of Middle Danube lowlands. Eurasian steppes continuously spread from the western border of Ukraine, including Moldova, through Northern Caucasus, Lower Volga, southern Ural, Kazakhstan, Mongolia, and southern Siberia to northern China. Total surface area of Eurasian steppe is about 700×10^6 ha.

Lands with predominated steppe communities, which consist predominantly of perennial microthermic xerophytic (frost- and drought-resistant) grassy plants (mostly *caespitose gramineous*) (Kononova, 1968), fall into the zone. In addition to the steppe zone itself, a part of forest-steppe is included here, since in the latter the steppes occupied up to 40-50% of total area in the past (Lavrenko, 1956).

Formation of steppe landscapes is conditioned mainly by climate and first of all by water insufficiency, whereas in the forest-steppe physico-geographical zone, which receives more water, it is conditioned by a geomorphologic factor, namely by the poor drainage of the territory. In the sufficiently moistened central Europe steppe complexes correspond to the location of loess insular where steppe relicts such as *Stipa capillata* is present (Shishov et al., 1985). Aside from nature of soil formation in some places, formation of steppe landscapes is related to a local climate deviation. So, Magdeburg low hills are located in a rainy shadow west of the Garts mountain range.

A unique characteristic of steppe ecosystems, unlike forest ecosystems, is that they are in an unstable state of balance and are very dynamic. They are formed under deficiency of water and influence of periodic animal grazing and fire. Unlike forests where accumulation of biomass prevails falls, in steppes about 80% of biomass annually dies off and is quickly mineralized, which specifies the elemental cycling and formation of original soils.

According to the contemporary concepts, steppes are a particular type of environment within the sub-boreal physico-geographical belt (Kononova, 1968; Ponomareva and Nikolaeva, 1965; Chesnyak et al., 1983). Steppe landscapes are characterized with sub-humid or semi-arid climate (Berg, 1952; Budyko, 1965), predominance of grassy vegetation, absence of forests in watersheds, and presence of Chernozems and Chestnut soils.

Sub-boreal steppe regions are righteously called the main granary of the mankind. Proportion of ploughed lands reaches 30% in average, 70% for Chernozems and 50% for Chestnut soils. It follows that soil forming process on most of the territory, which is the most important part of the zone, takes place not under natural vegetation but in conditions of agro-ecosystems that is absolutely not adequate to the original virgin steppes.

Organic matter is a main, the most active and powerful factor in soil formation and soil fertility. This is because the soil formation process controls formation and accumulation of humic materials in the soil. They are a function of interactions between the biological factors and parent materials in certain hydrothermal conditions and are one of the sections of a continuous chain of trophic links between different life forms, serving as a last and a first section at the same time. The "last" means that they contain the main nitrogen stock, nearly half of phosphorus, significant parts of sulphur and other macro- and micronutrients. During mineralization of humic materials the nutritional elements are gradually released into plant available forms. In addition, quality and quantity of soil organic matter (SOM) influences a number of important agronomic properties of soils, e.g. water-physical, physico-chemical, etc. Also, SOM directly influences growth and development of plants.

Quantity of humus in steppe soils is determined by hydrothermal conditions of vegetative period, represented by the hydrothermal coefficient (HTC), particle-size distribution, amount and assimilation of precipitation during cold period (Table 2.1).

Due to an enormous extension from west to east and from north to south, Eurasian steppes are characterized with a great variety of moisture conditions as well as of soil particle-size distribution, which are naturally reflected in the geography of dynamics of SOM content. It is necessary to point out that today there is no unique opinion about the spatial regularity of the steppe. The most spread statement is that quantity of humus in soils of Chernozems area increases from west to east due to the increase of climate continentality in this direction. This statement is based on the study of V.V. Dokuchaev and is presented on the map of European part of Russia in the monograph "Russian Chernozem" (Dokuchaev; shown in Fig. 2.1) as the isohumus stripes. This is the first and the last generalizing work that covers a huge region. Many researchers consider Dokluchaev's data on humus content as a benchmark that can serve as a source when studying evolution of humus in agro-ecosystems. However, discussion about the influence of climate continentality upon humus accumulation and on the validity of humus content data in chernozems is arguable. According to our analysis, soil samples that are taken for determination of humus contents are often not comparable due to different thickness of humus horizon; therefore the results are also not comparable in many points. And the main point is that particle-size distribution was not taken into account because at that time there was no data on classification and no methods of its determination.

Analysis of the geography of particle-size distribution of chernozems within the European part of the steppe shows that in its western region there is a predominance of light-middle loam types, in the central - heavy loam, and in Ural region - middle clay types. Chernozems with similar particle-size distribution within the whole zone are characterized with insignificant deviation in the humus content (Table 2.2).

There is no published information concerning the regularity of spatial distribution in the humus content in soils of Asian part of the steppe that occupies more than 2/3 of European zone. This is due to the absence of summarizing works on soil characteristics in this region though there are enough numbers of published monographs on some of its parts.

In order to reveal more clearly the most important genetic properties and regularities of distribution of these soils on the basis of natural diversity, systematization of soil characteristics of European steppe in relation to physico-geographic regions is in urgent necessity. This requires development of soil-ecological zonation using quantitative criteria of allocation of territorial units. Herewith, a special attention should be given to revealing the regularities of spatial distribution of SOM as well as to determining factors of that regulation. It is getting more important to solve the problem of evolution of organic matter in agro-ecosystems, because large areas of steppe soils are being used as ploughed field.

Table 2.1. Humus content in Ap horizon of Chernozems depending on hydrothermal coefficients of warm period, amount of rainfall and its assimilation during cold periods and particle-size distribution (Polupan et al., 2001).

Type of Chernozems	Hidro-thermal coefficient (HTC)		Rainfall		Depth of soil profile (cm)	Particle size distribution		Humus content (%)
	V-VII	VIII-IX	XI-III (mm)	Assimilation (%)		< 0.01 mm (%)	< 0.001 mm (%)	
Typical	1.05	0.77	120-140	65	120-130	63±3	43±2	6.3±0.2
	- " -	- " -	- " -	- " -	125-135	55±2	36±1	5.4±0.3
	- " -	- " -	140-160	52	130-140	33±3	22±3	4.1±0.3
	- " -	- " -	- " -	52	115-125	54±2	34±2	5.6±0.2
	- " -	- " -	160-180	47	115-125	65±4	40±3	6.5±0.3
	1.25	1.05	120-140	52	150-160	30±4	19±3	3.7±0.2
	- " -	- " -	- " -	52	- " -	33±3	21±2	4.2±0.3
	1.35	1.25	140-160	58	130-140	37±2	21±4	5.2±0.4
	- " -	- " -	- " -	58	130-140	43±2	22±4	5.5±0.3
Ordinary	0.85	0.61	120-140	65	80-90	57±5	37±3	4.6±0.3
	0.85	0.69	140-160	52	85-95	54±4	32±3	4.7±0.2
	0.95	0.69	120-140	65	105-115	63±2	32±3	5.9±0.3
	- " -	- " -	- " -	- " -	110-120	57±2	37±3	5.4±0.3
	0.95	0.77	160-180	47	100-110	55±5	36±4	5.4±0.3
	- " -	- " -	- " -	- " -	95-105	65±3	40±3	6.1±0.2
	- " -	- " -	- " -	58	120-130	64±1	38±3	6.0±0.3
Southern	0.77	0.45	120-140	80	65-75	53±1	31±3	2.9±0.2
	0.77	0.54	140-160	65	70-80	56±1	36±2	3.5±0.3
	- " -	- " -	- " -	- " -	65-75	62±2	41±3	3.7±0.3
	0.85	0.54	120-140	80	80-90	57±2	36±3	3.7±0.2

Since the early period of genetic soil science, discussion about our attitude to humus has been continuing. It had started from the time of Dokuchaev-Kostychev. Dokuchaev considered that humus must be preserved in soils, while Kostychev was a supporter of the idea that humus must be included into general cycles in order to receive as much "active capital" as possible that allows to apply "more capital goods not only for supporting soil fertility but also for increasing it" (Kostychev, 1951).

Today soil science possesses enough data to prove that almost everywhere loss of soil humus is observed due to plowing of soils under extensive agricultural practices. The rate of humus loss in soils in first years after reclamation is more significant, following decrease of loss until humus

Table 2.2. Humus content in 0-30 cm layer in Typical chernozems under relatively similar particle-size distribution in the regions with different climate continentality.

Index		Sites				
		Frunzovka (Odessa region)	Kharkov	Kursk (Afanasieva, 1966)	Lipetsk (Akhtyrtsev and Sushko, 1983)	Saransk (Kolos, 1978)
Averagr monthly	January	-4.0	-7.5	-8.8	-10.3	-11.7
temperature (°C)	July	20.4	20.3	19.9	19.8	19.8
Clay content (%)		63±2	63±2	53.0	60±2	66.0
$HTC_{V\text{-}IX}$		0.9-1.1	0.9-1.1	1.1-1.2	1.1-1.2	1.1-1.2
Humus content (%)		6.3±0.3	6.2±0.3	5.8	6.4±0.3	7.5

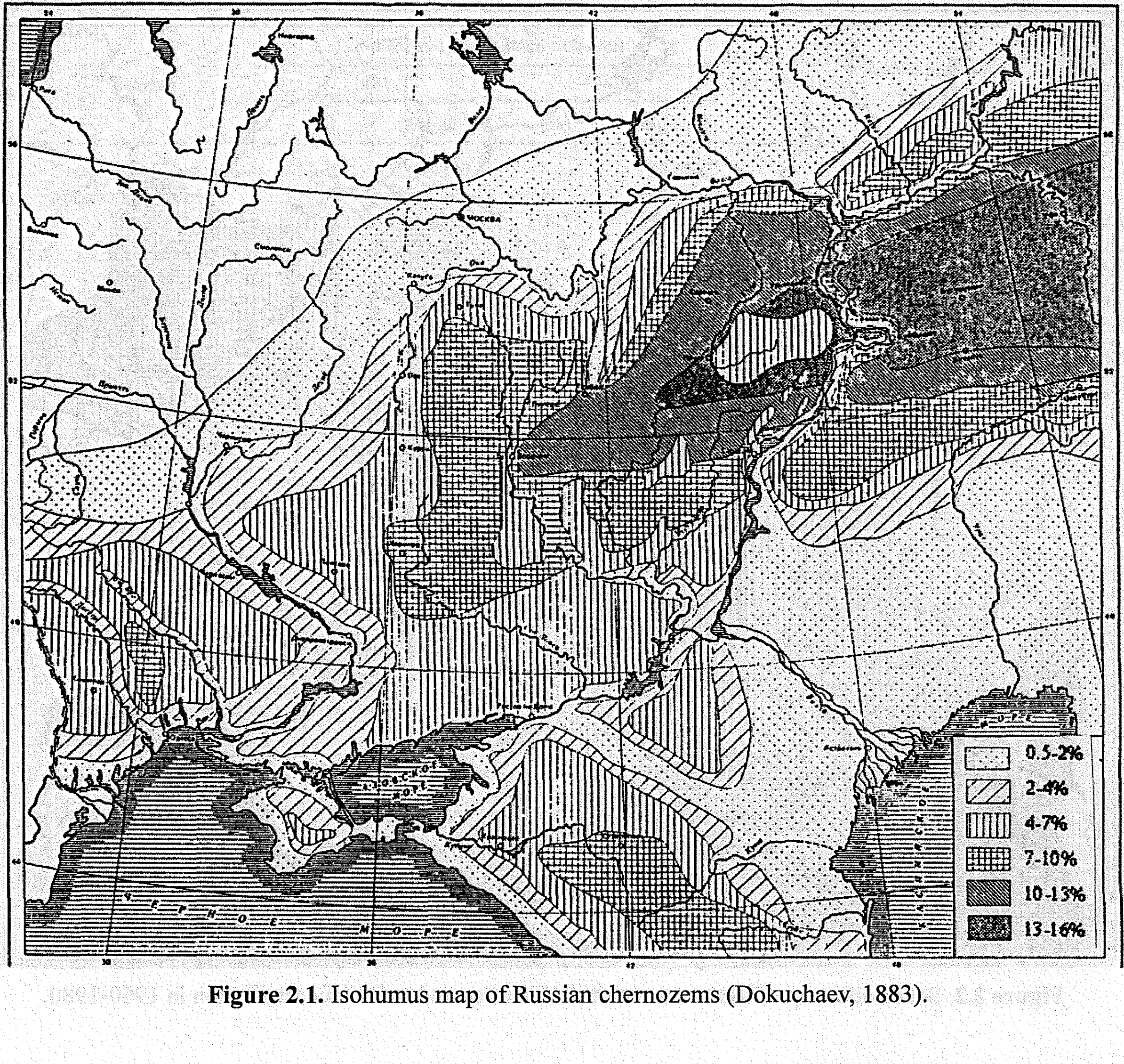

Figure 2.1. Isohumus map of Russian chernozems (Dokuchaev, 1883).

content is nearly stabilized but on a low level.

As mentioned above, data on humus content of V.V. Dokuchaev of chernozems of European part of former Soviet Union has been considered as a benchmark by many scientists and, therefore, there was an attempt to calculate the amount of losses of humus stock from the plow layer during 100 years (Fig. 2.2; Table 2.3). The losses are huge and amounted 20-69% of the initial contents. The isohumus stripes of Dokuchaev were significantly transformed.

It is not reasonable to criticize the data of Dokuchaev because it was the first attempt ever. However, data on humus in Fig. 2.2 need some comments. First of all they do not reflect the type of soil formation, hydrothermal regime and particle size distribution that all together regulate parameters of humus accumulation. As far as discussing for Ukraine, there is no clear point why in northern part soils have 0.5-2% humus in plow layer, then 2-3% and in most of the parts 4-7%. Generally, data presenting on Ukraine do not show spatial distribution pattern of humus content that is actually observed. This is the same for the rest of the territory. According to some authors humus losses for long period in Chernozems reach 4-41% of the initial stock (Afanasieva, 1966; Aderikhin, 1964; Gusev and Kolesnichenko, 1958; Kononova, 1968; Polupan et al., 2001), in Dark chestnut soils - 0-40% (Lavrenko and Prozorski, 1935; Sochaeva, 1970; Kolos, 1978). Such large ranges of changes in humus contents when using soils for agriculture should be drawn attention. This is partially caused by methodical errors when measuring the humus losses. Parameters for correction on the changes of humus contents under different land use and soil meliorations can be obtained under the condition of precise determination of genetic properties of the compared pairs of soils, adequacy of the content of fine particle-size fractions of the soils and parameters of profile thickness, as well as water supplying properties mainly due to topographic factors (Polupan et al., 2001).

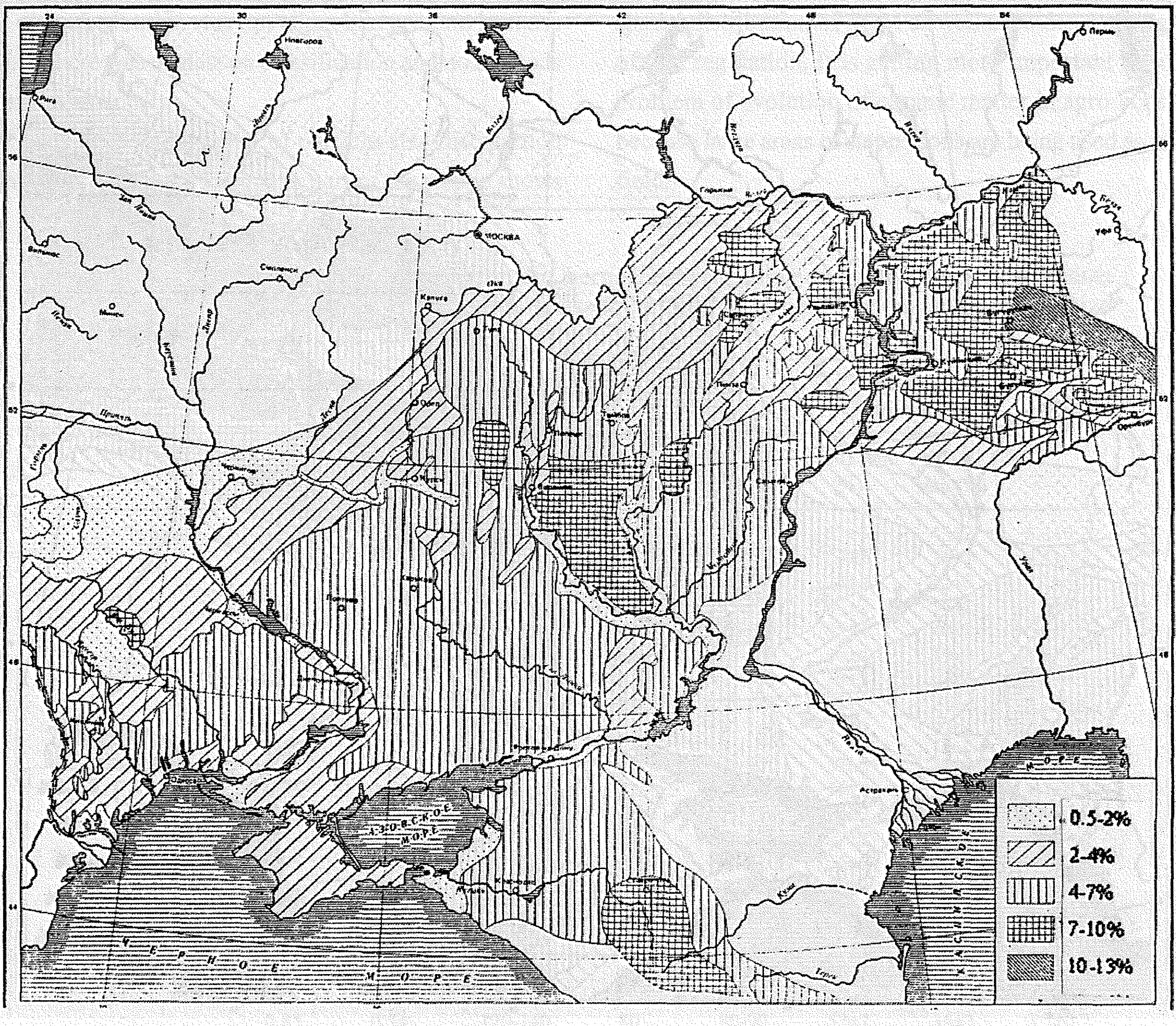

Figure 2.2. Schematic map of the humus content in surface soils of chernozem region in 1960-1980.

Today it is well known that determination of genetic status of soil only based on morphology of soil profile does not ensure its identification. This is why in soil science there has been a search for quantitative criteria of determination of genetic attribute of soil. Humus as an index of ecological/ genetic status of soil is one of the perspective approaches in this direction (Laktionov et al., 1982).

Every type of soil formation together with the combination of genetic horizons is characterized with distribution pattern and contents of humus in the profile (Fig. 2.3). It is necessary to point out the presence of subjectivism in field observation such as determination of genetic horizons or qualitative morphological properties due to influence of many factors that cannot always be controlled. On the contrary, the quantity of humus in a profile can be measured and practically fixed constant. Every type of soil is characterized with certain parameters of humus accumulation. Its reflection is represented by the following factors: the coefficient of profile humus accumulation (CPHA) and the coefficient of profile humus content (CPHC). The first is the ratio between the quantities of humus in soil profile and the quantity of physical clay (< 0.01 mm); the second is the humus content at a certain profile thickness and equals to CPHA times profile thickness in cm.

These factors are in itself practically the same, but they complement each other; CPHC more clearly and quantitatively reflects the genetic properties of SOM-profile and whole typology of soil attribute (Table 2.4).

Soil is a function of ecological conditions in its formation. This is the main paradigm of genetic soil science that is recognized worldwide. Therefore, soil, as a natural-historical body and a product of human activity as well as the main field of agricultural production, cannot be separated from the geographical conditions of its formation. This

Table 2.3. Changes of humus content and its losses in plow layer (0-30cm) of Chernozems of European part of former Soviet Union for 100 years.

Sub-types of chernozems	Region	Content and whole stock of humus				Humus loss for 100 years (Mg ha-^{1})	Annual humus loss (Mg ha^{-1})	Percentage of humus loss against initial stock (%)
		1881		1981				
		(%)	(Mg ha^{-1})	(%)	(Mg ha^{-1})			
Typical	Tambov and Voronezh	10-13	300-390	7-10	210-300	90	0.9-0.9	23-30
Typical	Kursk and Kharkov	7-10	221-315	4-7	142-248	67-79	0.7-0.8	21-36
Leached	Stavropol	7-10	231-330	4-7	150-263	67-81	0.7-0.8	20-34
Ordinary	Voronezh	7-10	221-315	4-7	150-263	52-71	0.5-0.7	17-32
Ordinary	Moldova	4-7	126-221	2-4	75-150	51-71	0.5-0.7	32-40
Typical	Kuibushev	13-16	390-480	8-10	240-300	150-180	1.5-1.8	38-39
Ordinary	Orenburg	9-11	270-330	6-8	180-240	90	0.9	27-33
Leached	Ul'yanovsk	13-16	390-480	4-7	120-210	270	2.7	56-69

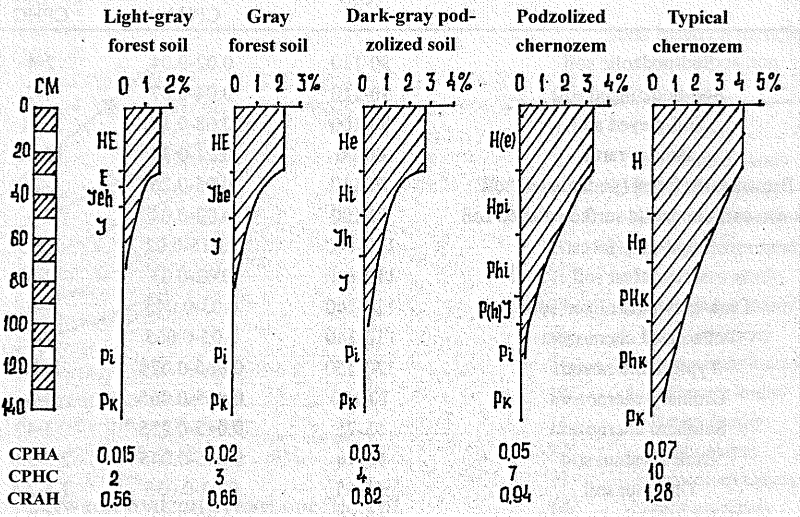

Figure 2.3. Humus contents in different types of Chernozems.

functional dependence of genesis and soil properties on factors of soil formation is the main law of soil formation, which lays in unity of soils and environment. This law came in soil science as a teaching framework of soil zones. Hence in soil classification zonal principles must be fully used.

The reflection of genetic attributes of soil as a function of ecological conditions is the soil profile. Genetic status of soil is determined depending on its construction of genetic horizons. Today, diagnosis based on qualitative combination of genetic horizons in profile is given to priority, irreplaceable and recognizable worldwide. This is the fundamental basis on which soil classification is constructed. The classification where the above-mentioned points of genetic soil science are not reflected is artificial but not of natural construction.

In field conditions at zonal aspect every type of soil formation is diagnosed based on genetic horizons and is quantified using the parameters of intensity of humus accumulation.

The structure of soil cover in zones is differentiated into regional sub-zones where either certain types of soil formation predominate or they are characterized by different appearances of humus accumulation. In Ukraine, in the Forest-steppe zone there are allocated 6 sub-zones, in the Typical steppe zone - 4 and in the Dry steppe zone - 2 (Polupan et al., 2002).

Therefore, as a basis for subtype differentiation of soils using field diagnostic morphological/genetic properties, intensity of humus accumulation in upper 0-30 cm layer, that is, the coefficient of relative accumulation of humus (CRAH) is taken. It is a ratio between humus content in 0-30 cm and quantity of physical clay. A close relationship between the values of CRAH and $\mathrm{HTC}_{\mathrm{V-IX}}$ is determined; i.e. R=0.91-0.92 for Chestnut, Dark chestnut, Dark-grey podzolized and Grey forest soils, R=0.94 for Podzolized chernozem, R=0.97-0.98 for Southern, Ordinary and Typical chernozems, and R=0.71 for Light-grey forest soil (Fig. 2.4).

For each type of soil formation corresponding sub-typical gradations of CRAH are developed (Table 2.5). It is necessary to point out that gradation of CRAH within each sub-zone does not coincide among different types of soil formation. For example, among sub-zones in the Forest-steppe zone with $\mathrm{HTC}_{\mathrm{V-IX}}$ of 1.40-1.48, the intensity of humus accumulation is very high (1.40-1.45) in Typical chernozems, high (1.03-1.07) in Podzolized chernozems, moderately high (0.88-0.92) in Dark-grey podzolized soils, medium (0.71-0.74) in Grey forest soils, and poorly moderate (0.64-0.67) in Light-grey forest soils. This is the reflection of different characters of carbon cycling in these ecosystems.

An important characteristic of soil is its humus content. Its absolute parameter is determined by the intensity of humus accumulation under a given particle-size composition. For example, at the same Forest-steppe zone upon 26-30% of physical clay, Typical chernozems contain 3.6-4.4% of humus, Podzolized chernozems - 2.7-3.2%, Dark-gray podzolized soils - 2.3-2.8%, Grey forest soils - 1.8-2.2% and Light-grey forest soils - 1.7-2.0%. Hence, particle size

Table 2.4. Diagnostic factors of zonal types of soil formation.

Soil types	Profile thickness (cm)	Diagnostic factors	
		CPHA	CPHC
Sod-podzolic soil	90-110	0.02-0.04	2-4
Sod-podzolized soil	90-110	0.04-0.07	4-7
Sod-gleyed soil	80-100	0.08-0.11	8-11
Brown-earth	60-90	0.21-0.34	15-27
Brown-earth forest (podzolized) soil	70-110	0.05-0.26	4-25
Brown-earth podzolic surface-gleyed soil	80-100	0.02-0.04	2-4
Light-grey forest	110-140	0.015-0.02	1.5-3
Grey forest soil	110-140	0.02-0.03	2-4
Dark-grey podzolized soil	110-140	0.03-0.045	4-6
Podzolized chernozem	110-140	0.05-0.065	7-8
Typical chernozem	120-150	0.066-0.075	8-10
Ordinary chernozem	70-130	0.055-0.065	4-8
Southern chernozem	55-75	0.045-0.055	3-4
Dark chestnut soil	60-70	0.035-0.045	2.5-3.0
Chestnut soil	55-65	0.03-0.035	1.5-2.5
Solonetzic chestnut soil	50-60	0.02-0.03	1-2

composition, or soil texture, is laid in the basis of differentiation of each subtype of soils into typological sorting level (Table 2.6).

Hydrothermal properties of warm period fully characterize parameters of relative humus accumulation of soils on type- and sub-type-levels, while sorts are reflected by the texture in its absolute values. However, for energy of soil formation and agronomic potential of lands, water accumulation during cold period has an important value. It is determined by absolute quantity of precipitation and its assimilation by soils.

The functional dependence between length of frosty period and assimilation of precipitation by soils is established. It is reflected in the thickness of the soil profile, which usually varies between 25-200 cm. Analysis of functional dependence between the profile thickness and the soil formation within each sort by texture allowed to develop natural differentiation of soils based on the parameters of profile classes (Table 2.7).

Every subtype of soil formation has ecologically-determined differentiation in profile class based on thickness of the profile. Within Ukraine, 2 profile classes are differentiated in the Dry steppe zone and the Southern steppe sub-zone (belonging to the Typical steppe zone), and 3 profile classes are in the other sub-zones in the Typical steppe zone and the Forest-steppe zone.

Above given parameters of soil differentiation into the profile classes in the hierarchical system are typical for plakor

Table 2.5. Differentiation of soil types into subtypes upon humus accumulation through CRAH parameters.

Gradation of humus accumulation	Soil types								
	Light grey forest soil	Grey forest soil	Dark grey podzolized soil	Chernozemhs				Dark chestnut soil	Chestnut soil
				Podzolized	Typical	Ordinary	Southern		
Very high	-	-	-	-	1.40-1.45	-	-	-	-
High	-	-	-	-	1.21-1.37	-	-	-	-
Very good	-	-	-	1.07-1.25	1.12-1.20	-	-	-	-
Good	-	-	0.92-1.00	1.03-1.07	0.98-1.10	-	-	-	-
Moderately good	-	0.74-0.90	0.88-0.92	0.92-1.01	-	0.90-0.97	-	-	-
Medium	0.67-0.82	0.71-0.74	0.77-0.87	0.87-0.91	-	0.80-0.89	-	-	-
Moderately weak	0.64-0.67	0.60-0.69	0.71-0.82	0.80-0.90	-	0.68-0.78	-	-	-
Weak	0.53-0.61	0.55-0.66	0.63-0.74	-	-	-	0.55-0.66	-	-
Low	0.49-0.52	0.43-0.57	-	-	-	-	-	0.45-0.54	-
Very low	0.42-0.51	-	-	-	-	-	-	-	0.35-0.43

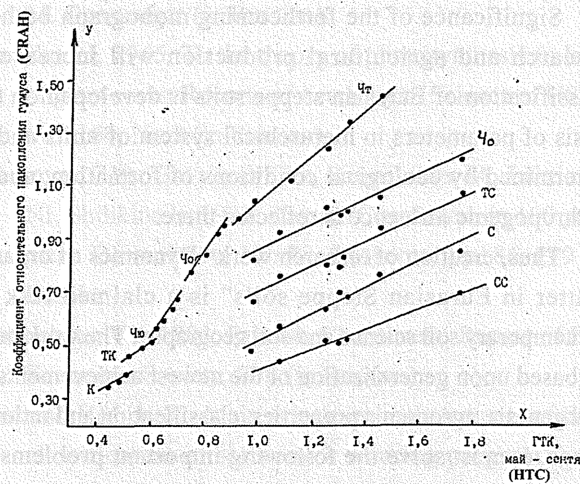

Figure 2.4. Relationships between hydrothermal coefficient (HTC) and coefficient of relative accumulation of humus (CRAH) for different types of soils.

Table 2.6. Typological sorts of soils using particle size distribution.

No	Sorts based on particle-size composition	Content of physical clay (< 0.01 mm) (%)
1	Sandy	0-5
2	consolidated-sandy	6-10
3	Light loam sandy	10-15
4	Heavy loam sandy	16-20
5	Sandy-light loam sandy	21-25
6	Light loam sandy	26-30
7	Light medium loamy	31-35
8	Medium loamy	36-40
9	Heavy medium loamy	41-45
10	Light heavy loamy	46-50
11	Heavy loamy	51-55
12	Light clayey	56-60
13	Light medium clayey	61-65
14	Medium clayey	66-70
15	Heavy clayey	71-75

automorphic conditions. Deviations are derived from variations in hydromorphic and xeromorphic conditions.

Within soil-ecological sub-zones of the Forest-steppe, Typical steppe and Dry steppe zones of Ukraine, with an increase in humidity, the values of CRAH are increased by 108-125% relative to background soils, thickness of profile by 110-130%, and humus content in plow layer up to 105-125%. Under lowered humidity all these parameters are decreased relative to background values; weakly-xeromorphic types have parameters of CRAH 75-90%, thickness of profile 75-90% and humus 88-92%, respectively; moderately-xeromorphics of 65-75%, 75-50%, and 65-88%, respectively; and strongly-xeromorphics of 55-65%, 30-50%, and 50-65%, respectively.

On the type level described above, soils are further divided depending on the degree of alkalinity, salinity, macadam and stoniness according to quantitative indicators.

Variants reflect change of soil properties as a result of their exploitation in agriculture. Virgin and cultivated soils are divided separately as modal, tamed, eroded, secondary alkalinized, over-deep plowed, reclaimed, secondary hydromorphic etc., according to corresponding parameters. Parent rocks are taken into consideration for the litho-particle-size series.

Approach to soil classification on the basis of parameterization of their properties and forming conditions together with indication of their genetic nature can fully characterize the qualities of the soils from agro-industrial viewpoints and allow its utilization in different ways.

Now there should be something said to comment about selection of criteria for soil classification. According to general rules of classification, the selection of criteria is more valid when considering collection of numerous characteristics of the objects. This rule worked in soil science as well (Khvorov and Onokhova, 1969; Fridland, 1982). However, soil is a specific natural body where properties depend on causal relationships; and herewith it is desirable to have a set of independent properties. In 60-80's so-called quantitative classification was being developed. Attempt to find parametric criteria of similarity and difference between types of soil formation on the basis of formalization of numerous (30-64) digital values of soil properties was undertaken. However, this attempt did not work because the principal of 'unity of difference' was unsatisfied. It is impossible to compare types of soils with different particle-size composition that determine parameters relating to many properties.

Table 2.7. Differentiation of soils into profile class based on thickness of profile.

No	Profile thickness, cm	Profile class
1	<25	Shallow
2	25-45	Short
3	45-65	Non-deep
4	65-85	Medium-deep
5	85-105	Moderately deep
6	105-125	Deep
7	125-145	Highly deep
8	>145	Extremely deep

There is no room for argument about the existence of close relationships between soil properties, soil processes, and factors. This axiom is for genetic soil science. However, nobody succeeded in formalization with general criteria of these relationships using full spectrum of data of the triad (soil properties-soil processes-factors). Therefore, we started searching priority of selected factor parameters in formation of zonal types of soils and intensity of its manifestation. Causal relationships between hydrothermal conditions of May-September, humus accumulation and type of soil formation under a certain particle-size composition were established.

Therefore, humus is considered to be an index of typological and ecological memory. Its reflection is manifested in peculiarities of organo-profile and humus content together with the system of genetic horizons.

Under precise determination of genetic status, soil is characterized by relatively compact parameters indicating other properties as well together with humus content.

Significance of the forthcoming monograph both in research and agricultural production will increase if classification of Eurasian steppe soils is developed on the basis of parameters in hierarchical system of units and is determined by ecological conditions of formation, and if anthropogenic influence is reflected there.

Thus, creation of research work "Dynamics of organic matter in Eurasian Steppe soils" is a claimed task of contemporary soil science and soil geography. The work must be based upon generalization of the newest achievements in soil genesis, agronomic properties, classification and rational usage. It must solve the following important problems of fundamental and applied significance:

- Soil-ecological plotting based on adequacy of parameters of soil properties and conditions for their formation, which in turn are the most important from the agronomic point of view. This is fundamental basis that influences genetic diversity of soil cover and its rational usage.

- Soil classification as a determined functional/ecological construction where every type of soil formation is characterized with certain parametric properties in a system of hierarchical units, while their deviation depends on conditions of formation and anthropogenic influences.
- Characterization of steppe types based on vegetation cover correspondingly plotted soil-ecological territorial units.
- Dynamics of organic matter in soils with systematic list of investigated regions under natural ecosystems and controlling factors.
- Evolution of organic matter in agro-ecosystems of Eurasian steppes.
- Emission of carbon dioxide in natural and agricultural ecosystems and dynamics of organic matter.
- Ways for controlling organic matter content in zonal aspect in Eurasian steppes.

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Chapter 3

Soil-ecological zonation of Eurasian steppes and soil classification according to quantitative principles - scientific base for solving the problem of soil organic matter dynamics

Nikolai Ivanovich Polupan

3.1. Typology of steppes of European part based on floristic composition

During the last century a significant transformation of nature and steppe landscapes took place. Virgin steppes are today preserved only in natural reserves: "Mihailovskaya steppe", "Homutovskaya steppe", "Stone graves", "Derkulskaya steppe", "Streltsovskaya steppe", "Aksaniskaya steppe" and others (Ukraine), Chernozem reserve (Kursk), "Talovskaya steppe", Burzhinskaya steppe", "Aituarskaya steppe" and others (Russia). They represent vegetation associations of the steppe regions. Available virgin pastures and hayfields are very much altered by human activities and differ from the original vegetation associations.

Preserved natural reserves give information about early historical steppe ecosystems. At present their geography was reconstructed with high accuracy based on soil materials since soil and vegetation have direct correlation.

Large extension of European steppe zone from west to east and from north to south conditions variability of climatic characteristics, which has influenced the characteristics of distribution of vegetation cover.

Meadow steppes and steppened meadows as the most water-resistant type of steppe landscapes (HTC$_{V-IX}$ of 0.90 to 1.48) are spread over the territory of the Forest-steppe zone. This type of steppes is combined with deciduous forests and is attached to low weakly-divided watersheds (Krasnov, 1881; Dokuchaev, 1891).

Composition of grassy vegetation of meadow steppes and steppened meadows was predominated by turf-cereals: feather grass (*Stipa capillata* and *Stipa stenophylla*), tipchak (*Festuca sulcata*), tonkonog (*Koeleria*), myatlik (*Poa* sp.) and others, as well abundant colorful motley grass: *Filipendula steposa*, *Salvia pratensis, Trifolium montanum* and many others. In total herbage, motley grass occupy up to 80%, with population of more than 200 species of steppe associations (Keller, 1931). Typical grass for them is sedge (*Carex humilis*). The surface free from cereals was covered with moss (*Thuidium abietnum*). Vegetation cover was quite dense, evolution during whole vegetation period was uniform, and therefore, ephemerals were insignificantly present.

In the herbage of steppened meadows motley grass and rhizome cereals were predominant, while meadow turf cereals were less, and xerophyte steppe cereals (*Festuca, Stipa* etc.) occur as admixture. Main place in meadow steppes was occupied by turf cereals (*Festuca, Stipa, Koeleria*, etc.) with insignificant quantity of rhizome cereals.

In the vegetation composition of steppened meadows and meadow steppes of eastern regions many plants disappear or become rare (*Bromus* sp., *Carex*, etc.), and eastern species (*Artemisia armeniaca, A. Latifolia*, etc.) appear.

In the meadow steppes of humid climate of Central Europe, many species that was observed in East-European steppes were lacking (*Plantago urvilleana, valiria rossica, Salvia nutaus*, etc.), but alpine elements such as *Sesleria coerulea, Saxifraga aizoon, Daphne cneorum*, etc. could be found, as well as sub-mediterranean species such as orchids etc. (Valter, 1975).

In the Typical steppe zone that occupies vast territories of Eastern Europe and also in lowlands of middle and lower Danube in southeastern Europe, vegetation cover was more represented by xerophytes due to dry climate, which led to increase of quantity of turf cereals and decrease of water resistance rhizome cereals and sedges. The period of "half-hibernation" that falls in middle summer appears in the evolution of typical steppes when the herbage was more rarefied; therefore the quantity of ephemerals increased in the vegetation composition.

Unequal moisture conditions due to vast extension of steppe from north to south conditioned formation of vegetation cover where motley-tipchak-feathergrass, tipchak-feathergrass and wormwood-tipchek-feathergrass steppes were predominant.

Motley-tipchak-feathergrass typical steppe is extended in northern part of the Typical steppe zone with HTC$_{V-IX}$ of 0.61-0.89. It extends continuously from Budapest through Danube valley across southern part of Moldova till Ural, and occupies southern part of Crimea and Pre-Caucasus because here reverse latitudinal zonality is observed. In the last region they occupy almost whole Kuban-Azov plain.

Vegetation cover of this steppe was dominated with narrow leaved turf cereals: *Stipa capillata, S. stenophylla, S. rubens, S. lessingiana, S. ucrainica, Festuca sulcata, Koeliria gracilis, Avena desertorum* etc., with mixture of motley grass: *Adonis wolgensis, Grambe tatarica, Statice latifolia, Salvia nutans*, etc. Following species are also found: steppe brushwoods of blackthorn (*Prunus spinosa*), steppe cherry (*Prunus chamaecerasus*), almond (*Amygalus*), etc., on the slopes of gullies - bairak oak forests.

In eastern part many of plant species disappear, ephemerals become few, while new species characteristics for Kazakhstan and Siberian steppes appear. Based on this Lavrenko (1956) distinguishes motley-tipchak-feathergrass steppes of eastern bank Volga into independent Volga-Kazakhstan province.

In western part of motley-tipchak-feathergrass steppes herbage contains large weight of Mediterranean and Pannonian species. They penetrated into southeastern Europe from Balkan peninsula, and include: *Quercus pubescens, Coronilla emerus, Amelanchier ovalis* and many others. According to Shabanova (1972), among cereals palearctic cereals occupy 26.9%, Mediterranean 26.2%, Pontic 16.7%, golarctic 14.3%, European 8.8%, subarctic 4.7% and cosmopolitan 2.4%.

Tipchak-feathergrass steppe extends only in Eastern Europe over three regions: Black Sea coast, Caucasus-Lower Don and eastern bank of Volga. It was characterized with domination of xerophile dense-turf cereals (*Stipa, Festuca, Koeleria*, etc.). Motley grass is represented by more xerophyle species: *Linosyris villosa, Statice, Galium*, etc.

Characteristic feature of this steppe was the presence of ephemerals that occupy free spots among main components: *Tulipa, Gagea pusilla, Veronica verna, Allyssum minimum, Erophila verna*, etc. Aboveground litter contained many lichens and blue-green algae. In 1923, totally 365 species of plants were found in Askania steppe (Pachoski, 1923), while at present there are 478 plant species (Vedenkov and Drogobych, 1998). *Stipa ucrainica* disappears from Volga steppes, but *Stipa rubens, S. sareptana* and *S. korshinski* appear.

Wormwood-tipchak-feathergrass steppe is typical for the Dry steppe zone and is extended along the coast of Sivash in Ukraine, on eastern Caucasus-Low Don sections and Volga coast. Major difference between the tipchak-feathergrass and this steppes is the presence of significant quantity of xerophile semi brushes in the latter: *Artemisia taurica, A. boschnickiana, Agropyron pectiniforme, Poa angustifolia, Artemisia incana* and, east from Don, *Kochia prostrata, Camforos ma monspeliacum*, etc. This steppe is abundant in ephemerals and there are many lichens and blue-green algae.

In southern part of tipchak-feathergrass and especially in wormwood-tipchak-feathergrass steppe, steppened-desert and desert vegetation cover, which was conditioned by solonetz and solonchak spots, could be found (Lavrenko and Prozorovski, 1939).

On solonetz soils together with turf cereals, there is a significant amount of subshrub wormwood (*Artemisia maritima*) and subshrub prutnyak (*Kochia prostrata*), or they dominate in vegetative cover. On solonchak soils there are halophyte subshrubs: *Obiona verrucifera, Halocnemum strobilaceum*, etc.

Beside zonal (climatic) distribution of vegetation cover of steppes described above, litho-chemical composition of soils, different forms of macro- and meso-relief, and/or hydrological conditions also exerted an influence on its specific diversity. On stony and macadam soils on eluvium of hard rocks, petrophyte (stony) steppes with rarefied herbage were formed. Beside turf cereals, petrophile species such as *Oposma stellatum, Teucrium, Achillea nobilis, Sedum, helianthemum*, etc. were typical for the stony steppes.

On Donetsk kryazh that is situated in the typical motley-tipchak-feathergrass steppe zone due to specific moisture conditions, large quantity of plant species of the meadow steppes were observed; this is the reason why many botanists consider it belonging to the Forest-steppe zone although in fact this is Typical steppe zone. Therefore, flora of higher plants here counted 422 species (Beregovoi et al., 1972).

In zone of tipchak-feathergrass and wormwood-tipchak-feathergrass steppes on plains of non-drained or weakly-drained territories, “pods” (“estuaries”) can be found, which are vast (till 16 km in diameter) shallow (0.5-20 m) locked depressions that serve as an accumulator of surface flow water; therefore, usually in spring, they are sporadically flooded with water. Therefore, their vegetation cover is very dynamic.

In ‘pods’ with deep ground waters in dry years, when they were not flooded for many years, steppe and meadow vegetation grows: *Festuca sulcata, Falcria rivini, Statice tatarica, Galium pedemontanum, Agropyron pseudocaesium, Alopecurus pratensis, Carex praecox, Inula britannica, Vicia villosa, V. hirsute*, etc.

During flood, steppe elements of vegetation disappear and typical meadow and marshy plants cover the pods: *Botomus umbellatus, Carex gracilis, Eleocharis mamillata, Phalacrachena inuloides, Prumex crispuc, Phlomis* *tuberosa*, etc. (Korotkov, 1957; Lavrenko and Prozorovski, 1939; Pachoski, 1923; Shalyt, 1930).

For 'pods' with shallow strongly mineralized ground water and strongly salinized soils solonchak, following vegetation is typical: *Salicornia herbacea, Statice caspia, S. meyerri, Holocemum strobilaceum, Artemisia salsoloids*, etc. (Bilik, 1963; Shalyt, 1949).

Steppe regions are also characterized by the existence of meadows attached to river flood-lands. Duration of high water, level of moistening and salinity of soil determine their vegetation composition.

In the driest parts of flood-lands that predominantly consist of sandy soils, rarefied grass vegetation that consists of *Agrostis, Phleum phleoides, Festuca ovina*, etc. is common. On the most part of flood-lands with short-flood regime (spring tide is less than 20 days) of small rivers and in central part of flood-lands with middle-flood regime (tide is 25-30 days) of middle and large rivers, the typical (moist) meadows are common that predominantly contain cereals: *Alopecurus, Poa pratensis, P. palustris*, and also legumes: *Trifolium pratense, Vicia cracca*, etc.

Differences due to salinity of the typical steppes are observed in southern part of flood-lands of the steppe. In the composition of vegetation cover halophyte cereals are predominant: *Atropis maritime, A. convoluta* and *Agropyron orientale*, as well solonchak sedge and motley-grass: *Aster tripolium, Statice tripolium*, etc.

Wet (marshy) meadows are located at near-terrace parts of flood-lands. Typical plant species for these meadows are *Agrosis stolonifera, Beckmannia, Glyceria, Carex, Runux crispus, Phragmites communis, Scirpus*, etc. The latter plants are also typical for lower flows of large rivers (Danube, Dnieper, Dniestr, Kuban, etc.) with long flood-land regime (50-60 days). There, three types of vegetation could be found. In halophyte types of waterlogged meadows *Scirpus maritimus* and *Juncus maritimus* are predominate.

The main regularity of vegetation distribution is closely related to geography of soil cover of the steppe region. According to reference sources, Leached chernozems are predominantly formed under the steppened meadows, Typical chernozems are under the meadow steppes, Ordinary chernozems are under the motley-tipchak-feathergrass, Southern chernozems are under the tipchak-feathergrass, and Chestnut soils are under the tipchak-feathergrass-chestnut steppes, respectively. On flood-lands of riverbeds Alluvial turf soils were formed, under the true meadows - Alluvial meadow soils, in southern part of the steppe their salty types and on waterlogged meadows - Alluvial meadow-marshy and Marshy soils.

3.2. Productivity, relationship between aboveground and belowground biomass, and humus accumulation in the steppes soils

Individual steppe ecosystems are characterized with different ratio of root to aboveground biomass: it increases from north to south. It is equal to 2-3, 4-5, and 6-10 in the steppened meadows and the meadow steppes, the typical motely-tipchak-feathergrass steppes, and the tipchak-feathergrass and the wormwood-tipchak-feathergrass steppes, respectively (Rodin and Bazilevich, 1965). In the same direction, quantity of aboveground biomass decreases. Productivity of aboveground biomass is 1.5-8.3, 1.0-3.2, 0.8-2.4, and 0.3-2.5 Mg ha^{-1} for the meadow steppes (Afanasieva, 1966; Bolotina and Korovikna, 1960; Keller, 1931; Lavrenko et al., 1955; Rodin and Bazilevich, 1965), the motley-tipchak-feathergrass steppes (Kulakov, 1960; Lavrenko et al., 1955; Novopokrovski, 1925; Shalyt, 1950), the tipchak-feathergrass and the dry wormwood-tipchak-feathergrass steppes (Lavrenko et al., 1955; Larin, 1936; Pershina and Yakovleva, 1960; Shalyt, 1950), respectively.

Large fluctuations in productivity within one steppe are mainly caused by study conditions in meteorologically different years. According to Korotkov (1957), for example on the tipchak-feathergrass steppes, the productivity of aboveground biomass was 0.7-2.7 Mg ha^{-1} in droughty years, whereas it reached 4.5-6.2 Mg ha^{-1} in moist years. Nevertheless, according to the quoted data there is a clear regularity in decrease of aboveground biomass from the meadow steppes to the dry steppes. However, by summarizing numerous data on actual biomass of different steppes, Rodin and Bazilevich (1965) pointed out that there was a little change in biomass upon single type of steppes since the portion of roots in total stock of biomass increased from north to south.

The distribution patterns of root biomass in soils of the steppes are also worth attention. In more humid meadow steppes root biomass distributes mainly in upper soil layers, and as climate is getting drier the depth of root concentration is deepen as well (Fig. 3.1).

In these steppes different biological cycles are observed. Annually, in steppened meadows and meadow steppes 50-55% of total biomass entered the soil as a fall, in temperate droughty and droughty steppes - about 45%, and in dry steppes - about 40% (Rodin and Bazilevich, 1965). In the

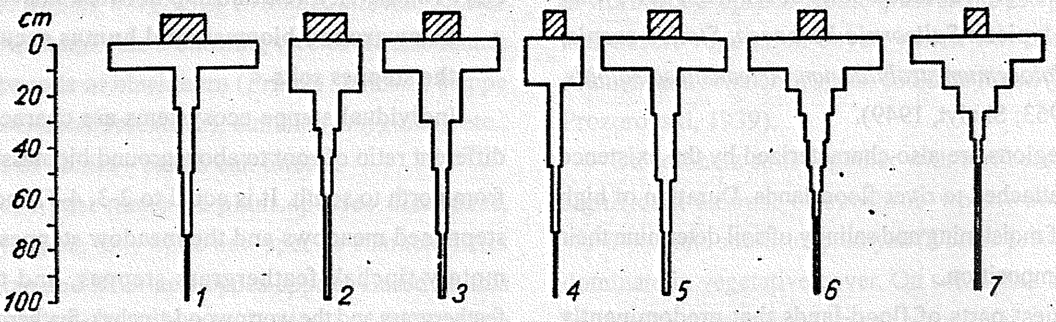

Figure 3.1. Quantity of above- and below-ground biomasses and their distribution along profile in virgin soils; 1: Typical chernozem (Central-chernozem National Reserve), 2: Ordinary chernozem (Khomutovskaya steppe), 3: Dark chestnut soil (Askania steppe), 4: Solonetzic chestnut soil (Askania steppe), 5: Chestnut soil, 6: Light chestnut soil and 7: Solonetzic light chestnut soil (Afanasieva, 1966; Totowa 1972; Shalyt, 1949; Shalyt, 1950).

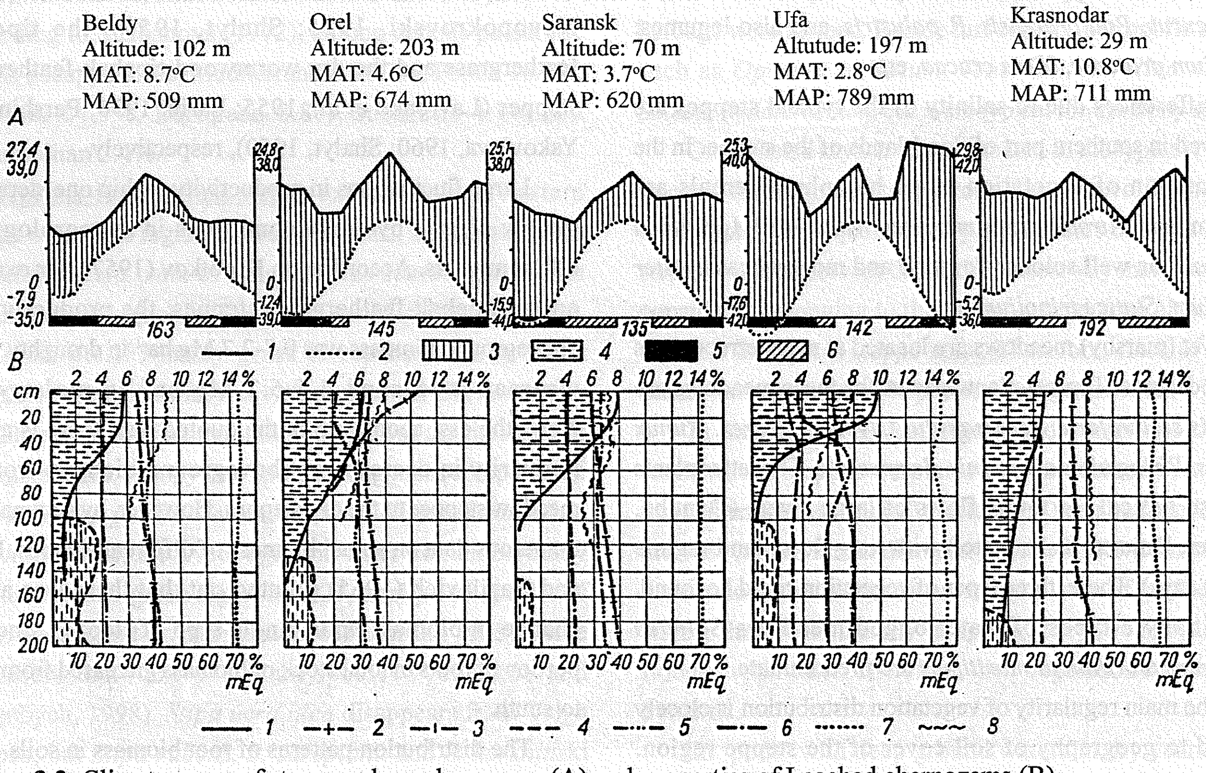

Figure 3.2. Climatograms of steppened meadow zones (A) and properties of Leached chernozems (B).

The values in the upper figures (A) are: e.g. at Beldy, 27.4 - average temperature of the warmest month; 39.0 - absolute maximum temperature; -7.9 - average temperature of the coldest month; -35.0 - absolute minimum temperature; 163 - mean duration (days) of frost-free period.

In the upper figures (A), 1 (solid line) is monthly precipitation (1 point of scale is 20 mm); 2 (dotted line) is monthly temperature (1 point of scale is 10°C); 3 (area in the figures) means moistened period in a year; 4 is period of droughts in a year (but not seen in this region); 5 is the period with mean daily minimum temperatures of below 0°C; and 6 is the period with absolute minimum temperature of below 0°C.

In the lower figures (B), 1 (solid line) represents humus content in the agricultural soils (with upper scale); 2 shows humus content in virgin land (with upper scale); 3 is pH (H_2O) also with upper scale; 4 is $CaCO_3$ in % with lower scale; 5 is the content of particles of < 0.001 mm (with lower scale); 6 is the content of R_2O_3; 7 is the content of SiO_2; and 8 is sum of exchangeable $Ca^{2+} + Mg^{2+}$.

first case, green parts of plants predominantly fall, while in the latter cases root biomass is predominantly added to soils as detritus.

Decomposition rate of plant residues in all the types of steppes lags after input, but rate of mineralization increases towards south and as a result amount of residue input decreased in this direction. It was 8.0-10.0, 6.0, and 3.0 Mg ha^{-1} in the steppened meadows and the meadow steppes, the motley-tipchak-feathergrass steppes, and the tipchak-feathergrass steppes, respectively (Afanasieva, 1966; Rodin and Bazilevich, 1965; Semenova-Tian-Shanskaia, 1960).

The water-resistant steppes were characterized with most active biological cycle; 50-60% of mineral elements and nitrogen in biomass annually returned into soils, while in other steppes the ratio fell to 40-45% (Rodin and Bazilevich, 1965).

Different productivity of the steppes and especially distribution of root biomass in soil profile was reflected in humus accumulation and its distribution in the profile.

Every type of soil is tied up with a certain ecosystem productivity, which depends on moisture conditions and trophic environments of substrates. In steppe ecosystems with soils having similar particle-size distribution, the productivity decreases as follows: the meadow, the motely-tipchak-feathergrass, the tipchak-feathergrass and the dry wormwood-tipchak-feathergrass associations. According to references, annual productivity of natural vegetation of Typical chernozems with physical clay of 50-55% and humus content of 7.3-7.7% in 0-30 cm layer or 600-650 Mg ha^{-1} in humified layer is 8.4 Mg ha^{-1} in average. Based on our research on Ordinary chernozems of northern steppe (physical clay 56-60%, humus content of 5.7-5.9% in 0-30 cm layer or of 480-530 Mg ha^{-1} in humified layer), the annual productivity was 6.9 Mg ha^{-1}. It was 3.1 Mg ha^{-1} in Southern chernozems (correspondingly, 56-60%, 3.6-3.8% and 220-240 Mg ha^{-1}), 2.8 Mg ha^{-1} in Dark chestnut soils (56-60%, 3.3-3.5% and 180-220 Mg ha^{-1}), and 2.0 Mg ha^{-1} in Chestnut soils (56-60%, 2.3-2.5% and 140-160 Mg ha^{-1}) (Polupan and Solovei, 2001). Correlations between productivity and humus content in any pair of ecosystems are relatively high, indicating a close relationship between soil humus and productivity of natural ecosystems. In relation to this fact, based on soil humus content, it is possible to predict average indexes of productivity of steppes of different geographic regions with high probability.

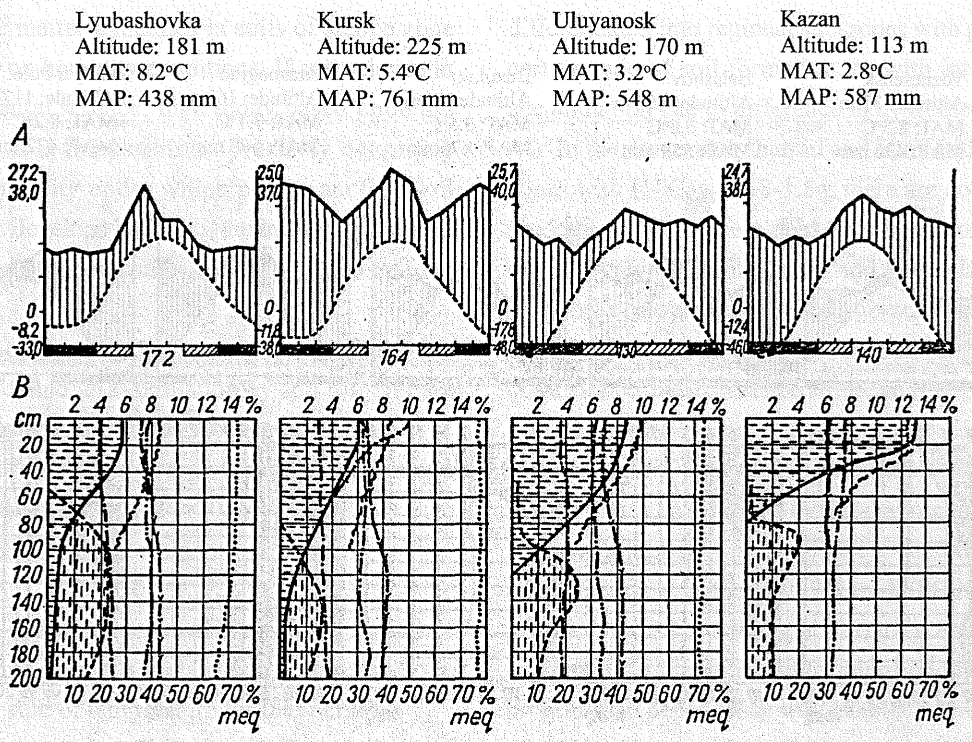

Figure 3.3. Climatograms of the meadow steppe zones (A) and properties of Typical chernozems (B). Legends are same as for Fig. 3.2.

3.3. Hydrothermal coefficient, amount of precipitation during cold period and its assimilation by soil - priority criteria of resources of water supply and energy of soil formation

Today practically nobody disputes that soil science refers as fundamental science among natural sciences. Its founder V.V. Dokuchaev as well foresaw it. He noted that on the beginning stage of its evolution soil science has qualitative level due to lack of information, but as time passes soil science becomes exact science. It conditions limit numbers of quantitative indexes when characterizing different soil phenomenon and regularity of their development. Such terms as 'humid', 'more humid', 'less humid' etc. can't reflect the precise essence of the subject without parameterization of certain indexes.

Climate is the most important factor for soil formation

Table 3.1. Dependence of humus accumulation on hydrothermal coefficient in steppe soils of Ukraine.

Chernozems	HTC V-IX	HTC including V-VI	HTC including VIII-IX	Precipitation [mm] XI-III	Precipitation [mm] % assimilated	phase	Profile thickness (cm)	Physical clay (<0.01 mm) (%)	Humus content (0-30 cm) (%)	CRAH	CPAH	Total humus stock (Mg ha^{-1})
Typical	1.26-1.36	1.40-1.40	1.20-1.30	140-160	58	III	140-150	30-35	4.0-4.6	1.32	0.074	468
	1.06-1.16	1.10-1.20	1.00-1.10	120-140	52	II	135-145	30-35	3.5-4.1	1.16	0.075	433
	0.96-1.06	1.00-1.10	0.91-1.00	140-160	47	I	135-140	30-35	3.1-3.5	1.01	0.071	405
	0.90-0.98	1.00-1.10	0.74-0.80	120-140	65	IV	130-140	56-60	5.9-6.3	1.05	0.067	610
	0.90-0.98	1.00-1.10	0.74-0.80	160-180	47	I	120-130	56-60	5.8-6.2	1.03	0.066	580
Ordinary	0.80-0.89	0.91-1.00	0.64-0.73	120-140	65	IV	100-110	56-60	5.4-5.7	0.94	0.061	490
	0.80-0.89	0.91-1.00	0.64-0.73	180-210	47	I	110-120	56-60	5.2-5.8	0.95	0.061	500
	0.74-0.83	0.81-0.90	0.64-0.73	120-140	65	IV	85-95	56-60	4.8-5.1	0.85	0.058	410
	0.74-0.83	0.81-0.90	0.64-0.73	120-140	52	II	75-85	56-60	4.7-5.1	0.84	0.058	380
	0.74-0.83	0.81-0.90	0.64-0.72	140-160	47	I	75-85	56-60	4.8-5.1	0.84	0.058	390
Southern	0.60-0.68	0.74-0.80	0.40-0.49	120-140	80	VI	65-75	56-60	3.1-3.3	0.55	0.045	230
	0.64-0.70	0.74-0.80	0.50-0.57	120-140	65	IV	56-65	56-60	3.3-3.6	0.6	0.053	250

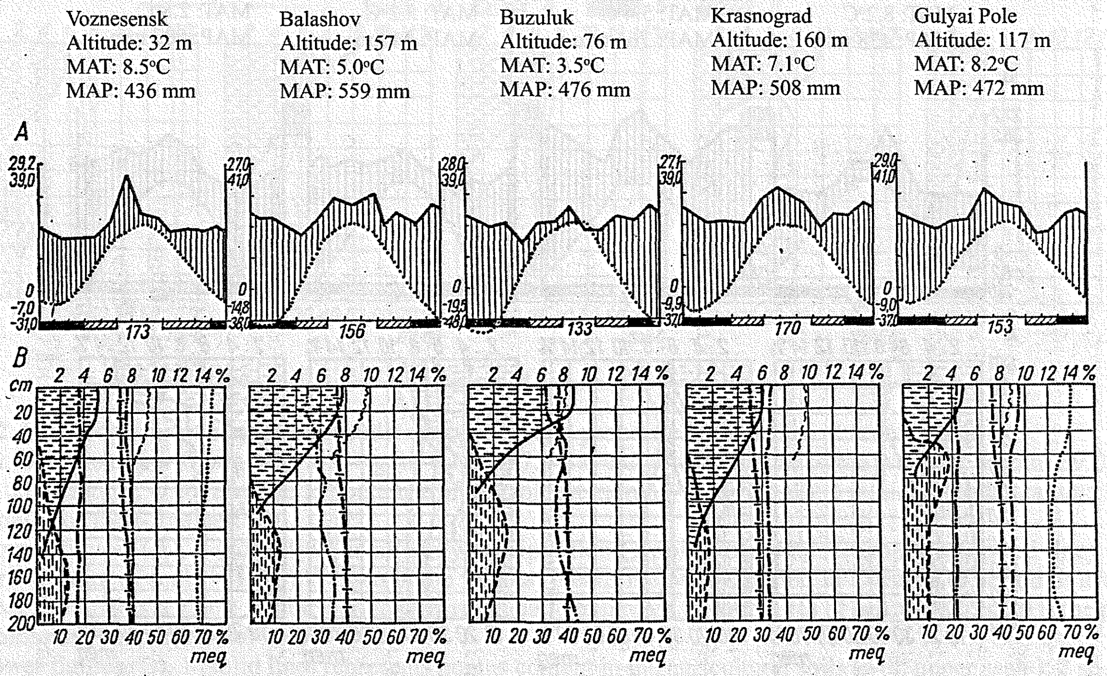

Figure 3.4. Climatograms of the typical motley-fescue-feather grass steppe zones (A) and properties of Ordinary chernozems (B). Legends are the same as for Fig. 3.2.

and soil fertility. Analysis of literature sources showed that its parametric indexes upon characteristics of individual territories are usually presented in the form of: average annual precipitation and its monthly dynamics, average air temperature and its monthly dynamics, average temperature of the warmest and coldest months, length of non-frost period, etc. The main climate indexes used today are presented as climatogram for some chernozem subtypes from west to east together with their parametric characteristics in Figs. 3.2, 3.3 and 3.4.

In the previous sections we pointed out that existence of the steppes as a natural phenomenon and its typological differentiation based on vegetation composition is conditioned by the level of humidity. Generally, according to the figures, we can qualitatively confirm that the zone of Leached chernozems (Fig. 3.2) is more humid than the zone of Typical chernozems (Fig. 3.3); such pattern is also true for Typical chernozems when comparing with Ordinary chernozems (Fig. 3.4). At the same time, however, large difference in humidity within each subtype is observed, that is not expected at first sight. In addition, similar humidity parameters can be found in all the regions of the chernozem subtypes listed above, which is theoretically not acceptable. Attempt to correlate the climatic indexes with energy of soil formation, as in the case of humus accumulation, was not successful. Therefore, it is impossible to correctly reveal the reason of organic matter dynamics in soils of steppe zone depending solely on humidity conditions. If soil science in fact is a fundamental science, then today based upon the climatic indexes it is impossible to precisely determine parameters of humidity under which one or another soil formation process develops including the intensity of humus accumulation. The problem can be solved on a quantitative level.

We determined that $HTC_{V\text{-}IX}$, amount of precipitation during cold period, and its assimilation by soil fully reflect resources of humidity of territories. Consequently, they have very high correlation both with type of soil formation and humus accumulation as well ($R = 0.94\text{-}0.98$; Table 3.1; Polupan et al, 1999).

$$HTC = \Sigma P_{10} / \Sigma T \times 10$$

where HTC is the hydrothermal coefficient, ΣP_{10} is sum of precipitation for the period when air temperature is above 10°C, and ΣT is sum of temperature for that period.

These indexes can be applied when differentiating soil cover into uniformly humid territories (Polupan and Solovei, 1997; Polupan, et al., 2001).

3.4. Soil-ecological zonation of steppe part of Ukraine and pattern of spatial dynamic of organic matter in the soils

Main principle of soil-ecological zonation is: spatial differentiation of territory into homogeneous natural habitants of soil cover, components of which have certain morphogenetic parameters because of commonness of ecological conditions of their formation that at the same time are agronomically important parameters. This is a principle of adequacy of soil bodies to the conditions of environment.

The indexes of climatic conditions for soil formation are $HTC_{V\text{-}IX}$, amount of precipitation during cold period, and its assimilation by soil, whereas that of soil characteristics is mainly humus content.

The concept of HTC for May-September was further divided into two parts: those for May-July and August-September. This was done for precise characterization of ecological advantages of the territories assigned for agricultural crops with short vegetative period, and in whole for long vegetating crops.

Steppe zone of Ukraine is clearly divided into 4 soil-ecological zones; each of them is characterized by inherent parameters of hydrothermal conditions, type of soil formation, and quantitative indices of humus accumulation (Fig. 3.5; Table 3.2).

Structure of soil cover in the individual zones is differentiated into regional sub-zones with predominance of certain type of soil formation, or with intensity of humus accumulation due to difference in hydrothermal conditions.

In the moderately humid and humid forest-steppe sub-zones with $HTC_{V\text{-}IX}$ 1.48-1.84, there are no steppe soils but predominantly surface-gleyed Gray forest soils with inclusion of Dark-grey podzolized soils and Podzolized chernozems.

Soil-ecological zones and sub-zones are differentiated into phases based on peculiarities of soil formation that were conditioned by difference in thermal regime of the cold period. In the phase level, soils are discriminated by morphological parameters as a result of different water regime that is conditioned by thermal regime of cold period. For example, heavy loamy Typical chernozems at average air temperature in January -7.0 to -8.0°C have thickness of profile 115-125 cm, while at -5.6 to -6.8°C they have 130-140 cm under the same soil forming condition. An inversely proportional dependence was established between thickness of soil profile and length of frosty period. There is an almost linear functional dependence between the frosty period (x) and an average temperature of January (y):

$$y = -0.0112x + 7.025$$

This dependence is valid only for plain part of Ukraine. It is divided into 6 phases (see Table 3.1). Correlation between given phases and the assimilation of winter precipitation is established, and is expressed for whole profile. This allowed the development of standards for absolute absorption of precipitation by soil on the territory of the phase.

Basic unit of soil cover distribution on relatively homogeneous territory is province. It is distinguished within individual sub-zones and is characterized with the same indices of both humidity and soil properties.

This gives a possibility to establish pattern of humus accumulation in soils depending on ecological conditions of soil formation and to develop their typology based on humus content. We developed empirical model for determining humus content steppe soil profiles:

$$Y = 9.07X_1X_3 + 0.05X_2X_3 - 4.9X_3$$

where Y is total humus content in soil profile (Mg ha^{-1}), X_1 is HTC$_{V\text{-}IX}$, X_2 is thickness of humified profile (cm), and X_3 is the content of physical clay (%).

Coefficient of the multiple regression (R) is 0.96,

Table 3.2. Soil-ecological zones and subzones of steppe soils in Ukraine, parameters of their hydrothermal conditions, and intensity of humus accumulation.

Code in the map	Period					Temperature in Jan (°C)	Annual precipitation (mm)	Intensity of humus accumulation	
	May-Jul		Aug-Sep		Nov-Mar				
	Precipitation (mm)	HTC	Precipitation (mm)	HTC	Precipitation (mm)			CPAH	CRAH
ЛС	**FOREST-STEPPE ZONE OF TYPICAL CHERNOZEM**								
	165-280	**1.00-1.90**	**75-160**	**0.72-1.70**	**130-220**	**-7.9- -3.8**	**450-760**	**0.066-0.075**	**0.98-1.45**
	FOREST-STEPPE ZONE; SUB-ZONES								
ПЛС-1	Forest-steppe; extremely humid								
	235-280	1.60-1.90	120-160	1.40-1.75	140-210	-5.5- -3.8	590-760	-	-
ПЛС-2	Forest-steppe; very humid								
	220-240	1.50-1.60	110-120	1.10-1.30	140-160	-5.5- -4.5	560-610	0.066-0.075	1.40-1.45
ПЛС-3	Forest-steppe; well- and sufficiently-humid								
	185-220	1.20-1.50	105-120	1.00-1.30	120-210	-7.9- -4.5	500-590	0.066-0.075	1.21-1.37
ПЛС-4	Forest-steppe; highly humid								
	180-190	1.10-1.20	100-110	1.00-1.10	120-180	-7.9- -5.6	490-560	0.066-0.075	1.12-1.20
ПЛС-5	Forest-steppe; humid								
	180-200	1.10-1.20	80-100	0.81-1.00	140-180	-7.9- -4.5	470-560	0.066-0.075	1.05-1.15
ПЛС-6	Forest-steppe; moderately humid								
	165-175	1.00-1.10	75-90	0.74-1.00	120-180	-7.9- -4.5	450-520	0.066-0.075	0.98-1.10
С	**TYPICAL STEPPE ZONE OF ORDINARY CHERNOZEM**								
	125-175	**0.67-1.00**	**60-90**	**0.42-0.80**	**120-210**	**-7.9- -0.7**	**370-520**	**0.055-0.065**	**0.69-0.97**
	STEPPE ZONE; SUB-ZONES								
ПСС-1	North steppe; insufficiently humid								
	160-175	0.91-1.00	70-90	0.64-0.80	120-210	-7.9- -3.3	440-520	0.055-0.065	0.90-0.97
ПССЦ-2	North-central steppe; moderately droughty								
	150-165	0.81-0.90	65-75	0.64-0.73	120-210	-7.9- -2.0	400-500	0.055-0.065	0.80-0.89
ПСЮЦ-3	South-central steppe; droughty								
	140-155	0.74-0.81	60-70	0.50-0.64	120-210	-5.5- -0.7	400-460	0.055-0.065	0.68-0.79
СЮ	South steppe; moderately dry, typical for Southern chernozem								
	125-140	0.67-0.74	55-60	0.42-0.57	120-160	-4.4- -0.7	370-430	0.045-0.055	0.55-0.66
СС	**DRY SEPEPPE ZONE OF CHESTNUT SOIL AND SOLONETZ**								
	90-125	**0.47-0.70**	**50-60**	**0.40-0.50**	**120-140**	**-4.4- -2**	**310-390**	**0.035-0.045**	**0.35-0.53**
	DRY STEPPE ZONE; SUB-ZONES								
ПССТ-1	Dry steppe; dry, typical for Dark chestnut soil								
	105-125	0.57-0.70	50-60	0.40-0.49	120-140	-4.4- -2.0	340-390	0.035-0.045	0.45-0.53
ПССК-2	Dry steppe; very dry, typical for Chestnut soil and Solonetz								
	90-105	0.47-0.57	50-60	0.40-0.49	120-140	-3.2- -2.0	310-345	0.035-0.045	0.35-0.44

Charcteristics of provinces: The combination of numbers in the map represents $HTC_{V\text{-}VII}$, $HTC_{VII\text{-}IX}$, $Precipitation_{XI\text{-}III}$.

Code	Degree of moistness	HTC
1	Очень сухая	0.40-0.49
2	Сухая	0.50-0.57
3	Умеренно сухая	0.57-0.64
4	Засушливая	0.64-0.73
5	Умеренно засушливая	0.74-0.80
6	Недостаточно увлажненАЯ	0.81-0.90
7	Умеренно увлажненная	0.91-1.00
8	Увлажненная	1.00-1.10
9	Повышено увлажненная	1.10-1.20
10	Хорошо увлажненная	1.20-1.30
11	Достаточно увлажненная	1.30-1.40
12	Сильно увлажненная	1.40-1.50
13	Очень сильно увлажненная	1.50-1.60
14	Умеренно влажная	1.60-1.75
15	Влажная	1.75-1.90

Code	Precipitation, Nov-Mar (mm)
а	120-140
б	140-160
в	160-180
г	180-210

Code of phases	Frosty period during winter (days)	Assimilation of winter precipitation (%)
I сильно холодная	120 – 133	47
II Зимне-холодная	111 – 123	52
III Зимне-умеренно холодная	100 – 113	58
IV Зимне-холодно-теплая	85 – 100	65
V Зимне-умеренно Теплая	75 – 90	72
VI Зимне-теплая	<75	80

Figure 3.5. Soil-ecological zones of Ukraine divided by hydrothermal conditions, type of soil formation, and quantitative indices of humus accumulation.

determination (R^2) is 0.92, and standard deviation is ± 21 Mg ha^{-1}.

Verification of the model upon the actual data in geographical aspect both in Ukraine and in European part of Russia showed good conformity to natural realities; difference between calculated and actual values of humus content did not exceed 10%.

Based on the measured data of organic matter content in soil profiles in the steppe zones, total stock of organic matter was calculated (Fig. 3.6). The parameters increase along with the increase in fine particles and the increase of humidity. The latter, besides HTC, determines the vegetative period, by the amount of precipitation during the cold period and by its assimilation to soils. It is found that under the same HTC values additional assimilation of 10 mm of winter precipitation results in an increase of humus stock up to 30 Mg ha^{-1} due to increase of thickness of humified layers; but that the humus contents in upper layers of soils are practically not changed. Humus accumulation in soils is related to the humidity both in the warm and the cold periods. The parameters increase as winter temperature increases from very cold to warm due to increase of assimilation of precipitation from soil surface.

On the basis of natural distribution and zonal condition, 11 classes of humus stock parameters are separated: < 80, 80-140, 140-180, 180-230, 230-280, 280-340, 340-400, 400-480, 480-540, 540-650 and more than 650 Mg ha^{-1}, respectively. Humus amounts within the range of 40-80 Mg ha^{-1} are characteristics for light-loamy Chestnut soils, sandy-loamy Dark chestnut soils and sandy Southern chernozems. The amounts within 80-140 Mg ha^{-1} are typical for Solonetz, heavy-textured Chestnut, medium-loamy Chestnut, light-loamy Chestnut and loamy Southern chernozem soils. Similarly humus amounts within the ranges of 140-180, 180-230 and 230-280 Mg ha^{-1} are typically found among clay-textured Chestnut soils, Dark chestnut soils, and Southern chernozems, respectively. Humus content of 280-340 Mg ha^{-1} is a most widespread parameter of heavy-textured Ordinary chernozem of South-central steppe sub-zone, as well medium-loamy Ordinary chernozems in moisture-

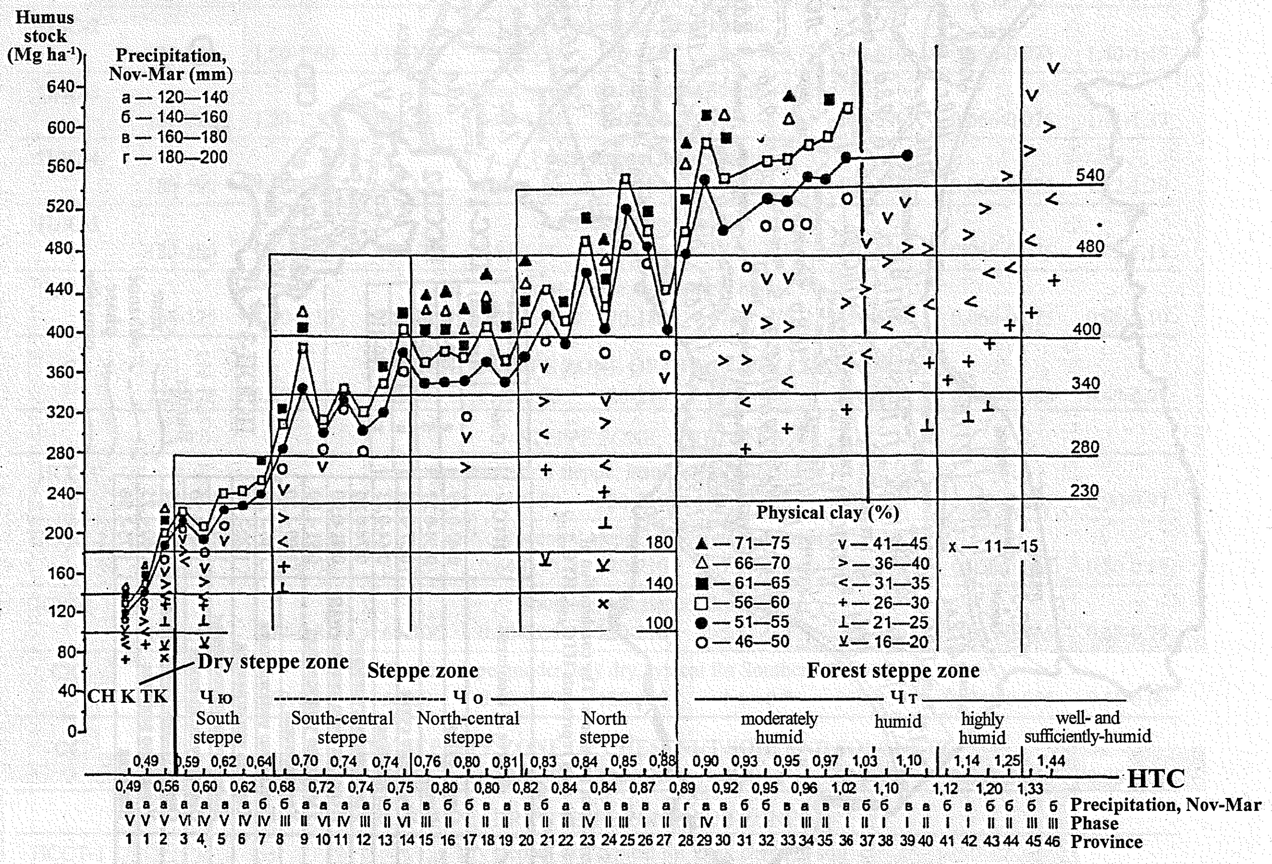

Figure 3.6. Dynamics of total humus stock in soils of the steppe zones in Ukraine.
CH, Solonetzic chestnut soils; K, Chestnut soils; TK, Dark chestnut soils; Ч ю , Southern chernozems; Ч о , Ordinary chernozems; and Ч т , Typical chernozems.

deficient North steppe sub-zone of the Typical steppe zone, and light-loamy Typical chernozems of well-and-sufficiently humid Forest-steppe sub-zone. Humus amounts within the range of 340-400 and 400-480 Mg ha^{-1} are typical for heavy-loamy and light-clayey Ordinary chernozems of moderately-droughty North-central steppe sub-zone of the Typical steppe zone and also upper limit of humus content in heavier-textured soils, respectively. Humus amounts of 480-540 and 650 Mg ha^{-1} are the limits for Ordinary chernozems of North steppe sub-zone of the Typical steppe zone and for Typical chernozems of the Forest-steppe zone, respectively.

It should be emphasized that peculiarities of natural potential of Typical chernozems are correlated both with wide range of humidity (HTC$_{V-IX}$: 0.90-1.45), and with specificity of distribution of parent materials having different textures. Moderately-humid part of the Forest-steppe (HTC$_{V-IX}$: 0.90-1.00) is characterized with predominance of loess layer of heavy texture that resulted in 'a peak' in humus stock. Well-and-sufficiently humid part of the Forest-steppe is characterized with predominance of parent materials of light- and medium-loamy textures; therefore, absolute values of humus contents decrease a little. However, in Typical chernozems of very humid part of the Forest-steppe, humus accumulation reaches its maximum values, i.e. 650 Mg ha^{-1}.

Cited patterns of humus accumulation and its standard indices are typical for soils of a plateau. However, it is well known that both on slopes and on plateau water supply is not the same due to different meso- and micro-relief. On plain watersheds water is redistributed through the system of negative shallow depressions, while on slopes - through flow-forming system of micro-relief, resulting in an difference in temperature regime, parameters of which

Table 3.3. Differentiation of soils upon parameters of humus accumulation and thickness of the profile at the same texture within provinces.

Code of province*	Climatic parameters		Temperature of January (^{o}C)	Physical clay (%)	Soil regime**	Amount of soil profiles	Humus content		Profile thickness		Humus stock	
	HTC	precipitation during the cold period (mm)					(%)	% of background	(cm)	% of background	(Mg ha^{-1})	% of background
12	0.74±0.02	120-140	-6.8…-5.6	56-60	1	15	4.5±0.3	100	65±6	100	320	100
				56-60	2	2	5.2±0.2	115	77±3	118	370	115
				56-60	3	6	4.0±0.2	89	57±4	88	250	78
				56-60	4	4	3.4±0.3	76	50±4	77	173	54
				56-60	5	2	2.7±0.3	60	35±3	54	120	38
				51-55	1	9	3.9±0.3	100	70±5	100	300	100
				51-55	2	3	4.6±0.2	118	80±5	114	350	116
				51-55	3	6	3.3±0.3	85	60±5	86	230	77
				51-55	4	2	2.9±0.3	74	52±5	74	150	50
				51-55	5	1	2.3	59	38	54	110	37
19	0.81±0.02	120-140	-6.8…-5.6	56-60	1	18	5.0±0.3	100	85±5	100	390	100
				56-60	2	4	5.8±0.3	116	100±5	118	460	118
				56-60	3	13	4.2±0.4	84	67±5	79	280	72
				56-60	4	3	3.7±0.2	74	55±5	65	200	51
				56-60	5	2	2.9±0.3	58	40±5	47	140	36
				51-55	1	8	4.4±0.3	100	90±5	100	375	100
				51-55	2	1	5.0	114	106	118	430	115
				51-55	3	2	3.8±0.2	86	70±4	78	260	69
				51-55	4	3	3.4±0.2	77	50±8	56	185	49
				51-55	5	2	2.8±0.2	64	42±5	47	130	35
26	0.87±0.02	160-180	-8.0…-6.9	56-60	1	21	5.3±0.3	100	105±5	100	500	100
				56-60	2	8	5.5±0.2	104	125±5	119	580	116
				56-60	3	17	4.5±0.3	85	85±10	81	370	75
				56-60	4	9	3.8±0.2	72	60±10	57	250	51
				56-60	5	5	3.4±0.4	64	45±5	43	150	30
				51-55	1	8	5.0±0.3	100	110±5	100	480	100
				51-55	2	3	5.4±0.2	108	130±5	118	530	110
				51-55	3	5	4.2±0.3	85	90±10	82	360	75
				51-55	4	3	3.5±0.3	70	65±10	59	240	50
				51-55	5	2	3.1±0.2	62	48±10	44	200	42

* See Fig. 3.6.

** 1, background; 2, increased humidity; 3, weakly-xeromorphic; 4, moderately-xeromoriphic; and 5, strongly-zeromorphic.

depends on exposition and forms of slopes (Polupan, 1998; Polupan et al., 2000).

Five regimes of soils were discriminated relative to background on humus content and thickness of humified horizon on plateau (Table 3.3; Polupan et al., 1999).

The first regime consists of soils analogical to background soils and they are spread on different locations of relief. Soils of the second regime are spread in different depressions of plateau and also in lower parts of slopes that receive additional moisture. As a result, they have higher content of humus in plow layer, i.e.105-125 % referring to background soils, and increased thickness of the profile for 10-30%. Therefore, they are attributed to soils with increased humidity. The remaining three regimes of soils are characterized with decrease of water supply due to location on slopes of straight and convex forms. They are separated into weakly-, moderately- and strongly-xeromorphic regimes by the level of dryness. Weakly-xeromorphics (3rd regime) are characterized by lowered content of humus in plow layer by 8-12% relative to background soil and by less thickness of humified profile by 10-25%, moderately-xeromorphics, correspondingly, by 22-35% and 25-30%, strongly-xeromorphics, 35-50% and 50-70%, respectively.

Hence, even within a province humus content is quite variable. For example, in steppe part of Kharkov region (province 26, Fig. 3.6), humus stock in plakor Chernozems of light clay texture is in average 500±50 Mg ha^{-1}, which is within a typological gradation of 480-540 Mg ha^{-1}. Soils of increased humidity are characterized by the stock of organic matter of 580±20 Mg ha^{-1}, which is within the gradation of 540-650 Mg ha^{-1}. Weakly-xermorphic Chernozems are in average 370±70 Mg ha^{-1}, which is within the 340-400 Mg ha^{-1} gradations. Similarly humus contents in moderately- and strongly-xeromorphic Chernozems are 250±50 and 150±50 Mg ha^{-1}, which are fallen into the 230-280 Mg ha^{-1} and more minimal gradations, respectively. Therefore, within one

Table 3.3. Continued.

Code of province*	Climatic parameters		Temperature of January (°C)	Physical clay (%)	Soil regime**	Amount of soil profiles	Humus content		Profile thickness		Humus stock	
	HTC	precipitation during the cold period (mm)					(%)	% of background	(cm)	% of background	(Mg ha^{-1})	% of background
32	0.95±0.02	140-160	-8.0…-6.9	56-60	1	19	5.5±0.3	100	125±5	100	565	100
				56-60	2	4	6.3±0.3	115	140±7	112	650	115
				56-60	3	8	4.8±0.3	87	100±10	80	430	76
				56-60	4	4	3.9±0.4	71	70±10	56	300	53
				56-60	5	2	3.2±0.3	58	50±8	40	210	37
				51-55	1	26	5.0±0.3	100	130±5	100	530	100
				51-55	2	5	5.8±0.3	116	145±5	111	600	113
				51-55	3	13	4.3±0.3	86	105±5	81	420	79
				51-55	4	6	3.6±0.3	72	78±10	60	250	47
				51-55	5	2	3.2±0.3	64	55±5	42	200	38
36	1.02±0.02	160-180	-8.0…-6.9	56-60	1	5	6.2±0.2	100	125±5	100	620	100
				56-60	2	2	7.0±0.4	117	145±5	116	700	113
				56-60	3	3	5.2±0.4	84	100±10	80	480	77
				56-60	4	2	4.5±0.3	73	85±10	68	320	48
				56-60	5	2	4.0±0.2	65	65±10	52	250	40
				51-55	1	12	5.7±0.3	100	130±5	100	570	100
				51-55	2	4	6.4±0.3	112	150±10	115	630	111
				51-55	3	8	4.9±0.3	86	110±5	85	400	70
				51-55	4	3	4.3±0.3	75	85±10	65	300	53
				51-55	5	3	3.7±0.3	65	70±10	54	230	40
				46-50	1	4	5.1±0.3	100	135±5	100	530	100
				46-50	2	2	5.6±0.2	110	150±5	111	580	109
				46-50	3	3	4.1±0.2	80	125±10	93	380	72
				46-50	4	4	3.7±0.2	73	80±10	67	270	51
				46-50	5	5	3.2±0.3	63	75±10	56	200	38
				36-40	1	6	4.0±0.2	100	140±10	100	430	100
				36-40	2	4	4.7±0.3	118	150±10	107	480	112
				36-40	3	5	3.2±0.2	80	110±10	79	300	70
				36-40	4	3	2.8±0.2	70	75±10	54	200	47
				36-40	5	2	2.4±0.2	60	50±10	36	140	33

* See Fig. 3.6.

** 1, background; 2, increased humidity; 3, weakly-xeromorphic; 4, moderately-xeromoriphic; and 5, strongly-zeromorphic.

province on the same-textured parent materials we have differentiation from typological gradation, which ranges from 540-650 Mg ha^{-1}, being peculiar for Typical chernozems, to 140-180 Mg ha^{-1}, that is, parameters for soils on the Dry steppe zone.

In addition there are semi-hydromorphic soils in the steppe zones; Meadow chestnut soils in the Dry steppe zone and Meadow chernozems in the chernozems (Typical or Ordinary) zones. Due to additional water supply they are characterized with increased capacity of biological cycle, usually 30-50% higher relative to background soils. This was reflected in humus stock. For example, in Southern chernozems with heavy-loamy texture, average humus stock is 180-230 Mg ha^{-1}, while in Meadow chernozems it amounts 240-300 Mg ha^{-1}. In Typical chernozems of medium-loamy (41-45% of physical clay) under very humid areas, humus stock reaches 650 Mg ha^{-1}, while in Meadow chernozems 750 Mg ha^{-1}.

Within each soil-ecological province, fluctuations of total humus content in soils, depending on water supply relative to background soil, are: 130±10% in Meadow chernozems (or in Meadow chestnut soils), 115±5% under increased humidity, 100±10% in background soils, 75±15% under weakly-xeromorphic, 50±10% under moderately-xeromorphic, and 30±10% under strongly-xeromorphic conditions, respectively.

Thus, spatial variation of total content of organic matter in soils of Ukrainian steppe areas is determined by comfortability of ecological environment and proportionally depends on the complex of the factors: content of physical clay, hydrothermal condition during the warm period, amount of precipitation during the cold period (November-March), and surface properties of soils or water assimilation. Deviation in the humus accumulation in soils within a province is a result of difference in water accumulation due to additional water supply by surface flow or vice versa, increase of drought due to water loss and exposure effect of slopes. Gradations of natural potential of humus content relative to the background, based on xeromorphic levels and increased humidity, are developed. Background soils are divided into 11 classes based on humus stock in the profile. However, even in the territories of these classes of soils, differentiation on humus content toward increase and decrease take a place that is caused by additional moistening and drying.

3.5. Quantitative diagnostics of soil formation type - it is promising precise determination of ecological/genetic status of soils and their humus stocks

In early stages of soil science, determination of genetic properties of soils was realized only on a basis of morphological diagnosis. There was no alternative. A detailed diagnostics of genetic status of soils on morphological properties were developed (Field soil determinant, 1981;

Table 3.4. Ecological/genetic status of Chernozems of southwestern part of the Steppe zone (Moldova) on morphological diagnostics and quantitatively corrected criteria.

Depth (cm)	Chernozems (12)											
	Typical		Leached		Podzolized						Xerophyte-forest	
	1*	2**	1*	2**	1*	2**	1*	2**	1*	2**	1*	2**
0-30	68	4.8	65	5.6	59	4.2	62	5.0	64	5.6	46	5.3
30-40	64	3.9	63	4.4	61	2.8	63	3.2	64	4.1	41	4.6
50-60	64	3.3	64	2.4	61	1.6	64	1.4	65	3.3	43	3.0
70-80	63	2.5	58	1.2	68	0.9	64	1.0	63	2.4	43	1.8
90-100	65	1.9	-	1.1	59	-	65	0.8	65	2.1	46	1.0
100-110	61	-	-	1.1	59	0.7	63	-	-	-	-	-
110-120	-	-	68	-	58	-	61	-	-	1.1	46	0.7
Diagnostic indexes												
CPAH	0.055		0.052		0.037		0.040		0.056		0.067	
CRAH	0.71		0.86		0.71		0.80		0.87		1.15	
Genetic status	Ordinary; medium weakly-accumulative		Ordinary; moderately-accumulative		Dark gray; medium weakly-accumulative				Podzolized; moderately-accumulative		Typical; highly-accumulative	

* Physical clay (<0.01 mm) in %.

** Humus content (%)

Classification and diagnosis of USSR soils, 1977; Classification of USSR soils, 2000). It is necessary to note that to correctly determine diagnostic properties in field condition is very difficult because their status depends on many factors that cannot be taken into account. Therefore, in practice it results in errors in determination of genetic properties of soils. This is represented in discrepancy of parametric characterization of given genetic types, when originally different soils have the same quantitative properties or vice versa, in spite of similarity in genesis soils have different properties.

In Ukraine, two tours of large-scale soil survey were conducted. Its analysis based on quantitative criteria of diagnostics showed that actual consistency of soil cover structure on large-scale (1:10,000 and 1:25,000) maps is 30-50% (Polupan and Solovei, 1998). This is typical not only for Ukraine. Let us show discrepancy between genetic properties of soils based on morphological determination and those based on detailed quantitative parameters of diagnostic properties in regional aspect.

We shall discuss southwestern part of steppe zone using the data of I.A. Krupennikov "Chernozems of Moldova" (Krupennikov, 1974). Table 3.4 shows significant divergence in ecological/genetic properties of soils on two methods of determination. Typical and Leached chernozems as the Forest-steppe individuals (classified in the upper) in fact are the North-steppe types of the Ordinary chernozems according to quantitative parameters (lower). This is confirmed not only by quantitative characteristics but also by the presence of "white eyes" in parent materials and by forms of carbonates typical for the soils in the Typical steppe zone (Field soil determinant, 1981). The same type of parametric humus profile both in the average and maximum/minimum deviation after statistical calculation of data 310 and 318 presented in the monograph indicates that the Typical and Leached chernozems actually belongs to one category of Ordinary chernozems.

Leached chernozems as representatives of the Forest-steppe refuge correspond to their group or to the Ordinary chernozems. And xerophyte-forest chernozems in fact are Typical chernozems.

Very large discrepancy between typological classifications by different methods of determination is observed among chernozems of sub-Caucasian region (Table 3.5; Chernozems of USSR (sub-Caucasus and Caucasus), 1985). Ordinary, Typical and Leached chernozems of west part of sub-Caucasus in fact are Southern chernozems. There is no similarity in soils of central and eastern sub-Caucasus. Only 15-25% of soils in the monograph agreed with our classification based on the quantitative parameterization.

Table 3.5. Ecological/genetic status of soils of central European part of Forest-steppe based on morphological diagnostics and corrected based on quantitative criteria.

Depth (cm)	Chernozems (32)															
	West Caucasus						Central and east Caucasus									
	Ordinary		Typical		Leached		Podzolized		Leached		Leached		Typical		Ordinary	
	1*	2**	1*	2**	1*	2**	1*	2**	1*	2**	1*	2**	1*	2**	1*	2**
0-30	70	4.2	61	4.0	63	4.2	63	4.2	58	7.0	66	4.3	54	4.4	50	4.9
30-40	68	3.9	61	3.5	63	3.4	62	3.6	58	5.3	67	3.5	51	4.2	49	4.3
50-60	68	3.4	61	3.1	63	2.9	67	1.9	59	4.6	71	2.0	50	2.9	48	3.1
70-80	68	3.2	59	2.3	63	2.5	67	1.5	58	3.8	73	1.3	49	2.3	51	2.8
90-100	65	2.9	59	2.0	62	2.3	68	1.0	58	2.6	74	1.2	50	2.0	50	1.9
100-110	66	2.7	59	1.8	63	2.2	64	0.8	58	2.0	65	1.0	53	1.3	50	1.5
110-120	63	2.3	58	1.6	65	2.1	-	0.7	59	1.5	-	0.9	53	0.8	48	1.2
120-130	62	2.2	59	1.5	65	1.7	65	0.6	60	1.1	60	0.8	53	0.6	51	0.8
	Diagnostic indexes															
CPAH	0.049		0.046		0.045		0.032		0.068		0.031		0.053		0.063	
CRAH	0.60		0.65		0.66		0.66		1.20		0.65		0.81		0.98	
Genetic status	Southern; weakly-accumulative						Dark gray; weakly-accumulative		Typical; highly-accumulative		Dark gray; weakly-accumulative		Ordinary; moderately-accumulative		Ordinary; moderately well-accumulative	

* Physical clay (<0.01 mm) in %.

** Humus content (%)

Big difference between genetic natures of soils diagnosed on morphological properties and on the basis of quantitative criteria is typically found for central European part of the Forest-steppe zone (Table 3.6; Akhtyruev and Serikov, 1983). Here, soil cover is very complex and is represented by Light-gray forest soil, Gray forest soil, Dark-gray podzolized soil and Podzolized, Leached and Typical chernozems. Every soil occupies certain ecological niche that is well shown by the quantitative diagnostic indices of humus accumulation. The analysis of data from the monograph showed that Gray forest soils are diagnosed by morphological properties for 70-80%, Dark-gray podzolized soils for 50-60%, and Podzolized chernozems for 50%. Under such genetic status of soils, it is impossible to correctly solve the problem of content of organic matter in the soils and to clarify the factor that controls it.

Table 3.6. Ecological/genetic status of soils of central European part of Forest-steppe based on morphological diagnostics and corrected based on quantitative criteria.

Depth (cm)	Soils (2)																	
	Gray forest soil		Dark gray forest soil		Dark gray podzolized soil		Chernozems											
							Podzolized		Podzolized		Leached		Leached		Typical		Typical	
	1*	2**	1*	2**	1*	2**	1*	2**	1*	2**	1*	2**	1*	2**	1*	2**	1*	2**
0-30	53	2.9	57	4.2	57	3.6	64	5.8	56	3.9	56	5.9	57	5.1	59	6.7	63	6
30-40	58	2.1	59	3.3	60	3.3	63	4.2	63	3.2	58	4.9	58	3.9	59	5.9	63	5
50-60	63	1.1	62	1.9	63	2.3	64	2.9	64	2.5	59	3.6	61	2.8	60	4.6	64	3.4
70-80	63	0.8	64	1.1	64	0.8	61	2.1	64	1.6	61	2.5	65	2.2	62	2.9	65	2.4
90-100	63	0.6	60	0.7	69	0.1	64	1.3	63	1.0	62	1.8	65	1.4	62	1.8	64	1.2
100-110	51	0.5	61	0.5	55	0.1	69	1.1	61	0.9	62	1.5	65	1.1	62	1.3	65	0.6
	Diagnostic indexes																	
CPAH	0.026		0.038		0.032		0.051		0.039		0.065		0.050		0.072		0.056	
CRAH	0.55		0.73		0.63		0.90		0.69		1.05		0.89		1.13		0.95	
Genetic status	Gray; weakly-accumulative		Dark gray; moderately /weakly-accumulative		Dark gray; weakly-accumulative		Podzolized; moderately-accumulative		Dark gray; weakly-accumulative		Typical; well-accumulative		Podzolized; moderately-accumulative		Typical; highly-accumulative		Podzolized; moderately-accumulative	

* Physical clay (<0.01 mm) in %.

** Humus content (%)

Table 3.7. Ecological/genetic status of soils of Forest-steppe, sub-Volga and sub-Ural based on morphological diagnostics and corrected diagnostics based on quantitative criteria.

Depth (cm)	Chernozems (33)															
	Volga basin										trans-Volga and sub-Ural					
	Podzolized				Leached				Typical		Podzolized		Leached		Typical	
	1*	2**	1*	2**	1*	2**	1*	2**	1*	2**	1*	2**	1*	2**	1*	2**
0-30	51	5.7	55	7.0	60	7.8	64	9.6	56	7.3	52	7.1	52	8.0	66	8.6
30-40	51	3.2	54	4.7	58	7.3	64	5.6	57	6.2	51	4.8	61	3.6	63	6.1
50-60	55	2.1	52	3.4	60	4.2	63	3.0	58	4.0	58	1.3	60	1.4	61	3.6
70-80	49	1.3	51	1.2	58	2.0	63	1.2	59	2.0	58	1.0	56	0.8	62	2.2
90-100	51	0.8	51	1.1	57	1.2	61	1.0	54	1.3	58	0.6	54	0.4	61	1.6
100-110	48	0.5	51	0.9	56	0.5	62	0.7	54	0.6	56	0.3	53	0.3	63	1.0
	Diagnostic indexes															
CPAH	0.059		0.073		0.077		0.075		0.072		0.060		0.059		0.077	
CRAH	1.11		1.25		1.30		1.50		1.30		1.36		1.55		1.36	
Genetic status	Podzolized; highly-accumulative		Typical; highly-accumulative		Typical; highly-accumulative		Typical; highly-accumulative		Typical; highly-accumulative		Podzolized; highly-accumulative		Podzolized; extremely highly-accumulative		Typical; highly-accumulative	

* Physical clay (<0.01 mm) in %.

** Humus content (%)

Analogous picture is typical also for soils of the Forest-steppe zone of Volga and sub-Ural regions (Table 3.7; Chernozems of USSR (sub-Volga and sub-Ural), 1978). Precision of determination of genetic properties based on morphological properties is within the above-mentioned limits of parameters for central part. Morphological diagnostic in general is characterized with substantial shortcomings that practically cannot be eliminated. This has nothing to do with level of proficiency of the researchers because big team of authors took a part in preparing the references. All the errors are due to methodology of determination of morphological criteria, which cannot be precisely standardized. As a proof we cite results of forest-steppe soils of Orenburg region of Russia (Table 3.8; Lavrenko, 1956).

According to the cited both morphological and quantitative soil properties, Chernozems belong to one category. The reasons why the presented Chernozems are diagnosed into three categories are unclear.

There are many similar examples. In informative world discrepancy between genetic status of soil and its quantitative properties is more a rule than exception. Therefore, in order to solve the problem of dynamics of organic matter in soils of Eurasian steppes, it is necessary to research and develop quantitative criteria for diagnosis types of soil formation. On the basis of these diagnostic criteria, available information about soils of studied region will be corrected in order to precisely determine their genetic status and will be correctly determined their parametric properties.

Table 3.8. Genetic-diagnostic properties of Chernozem in Orenburg region (Lavrenko, 1956).

Morphological properties	Podzolized	Leached	Typical
Depth of chernozem (cm)			
Ao	5	5	5
Ao+A	30	29	28
Ao+A+AB	99	98	86
Parent rock C	143	132	130
Humus content (%)			
Ao	15.8	14.6	13.9
A	11.0	12.8	11.6
AB	8.6	8.1	8.0
B	5.0	5.4	4.0
Humus stock in 0-100 cm (Mg ha^{-1})	638	630	619
Effervescence from HCl (cm)	108	97	65
Depth of carbonates (cm)	136	125	102
CEC (cmolc kg^{-1})			
Ao	49	52	54
A	46	50	51
AB	42	46	48
pH (H_2O) in A horizon	6.7	7.0	7.3
N (%) in A horizon	0.44	0.52	0.50

Soil-ecological mapping and classification of soils on quantitative principles is scientific basis to solve the problem of geography of humus accumulation in steppe soils of Eurasian region. There is no alternative.

3.6. Conclusions

1) Based on available information, structure of soil cover of Eurasian steppes meets the real situation for 35-50%. This is conditioned not by correctness of determination of genetic status of soils based on morphological properties, but also by discrepancy among ecological conditions for their formation. As a result, significant inconsistency between soil properties and their genetic nature is observed. Therefore, huge information on soil characteristics cannot be used for solving the problem of soil organic matter dynamics in the area studied. It needs a correction towards establishing the real precise genetic nature of soils and differentiation of steppe territory onto homogeneous regions from ecological point of view.
2) Existence of the steppe as a natural phenomenon is determined by water condition. However, its separation and internal typological differentiation both on floral composition and soil cover have qualitative level today. This is because the moisture indices used do not completely reflect resource water. The moisture indices do not make possible precise determination of the steppe parameters at which certain floral type of vegetation is formed, and beneath it type of soil formation and intensity of humus accumulation is formed.

   The most complete reflectors of water supply and energy for soil formation are hydrothermal coefficient (HTC_{V-IX}) for the period with air temperature above 10°C, amount of precipitation during the cold period and its assimilation by soil. Therefore, they can be used for mapping of Eurasian steppes into moisture-homogeneous territories. Results of the researches done in Ukraine indicate that there is a close correlation between these indices and humus contents in soils ($R>0.9$).
3) Based on HTC_{V-IX}, amount of precipitation during November to next March and its assimilation by soil, steppe zone of Ukraine is clearly differentiated into 4 soil-ecological zones, where each of them is characterized by inherent hydrothermal parameters, type of soil formation and quantitative indices of humus accumulation.

Soil ecological zones are divided into sub-zones on quantitative demonstration of humus-accumulating intensity that is conditioned by differentiation of hydrothermal conditions.

Soil-ecological zones and sub-zones are further differentiated into 6 phases, which are characterized by certain parameters of assimilation of winter precipitations into soils that is reflected in depth of humified horizon.

Basic unit for distribution of soil cover onto relatively homogeneous territories is a province. Province is situated within sub-zones and is characterized by the same indices of both water supply and soil properties.

4) It is necessary to research quantitative criteria of diagnosis of soil formation type within study area. On the base of that, available information about the soil for research will be corrected in order to precisely establish genetic status of soils and correct determination of parameters.
5) Spatial dynamics of organic matter in soils of steppe territories in Ukraine is determined by comfortability of ecological environment and proportionally depends on the complex of factors: content of physical clay (particle < 0.01 mm), parameters of hydrothermal index for May to September (HTC_{V-IX}), amount of precipitation for the cold period (November to March), and its assimilation by soil. The humus stock in background soils increases with the increase in fine particles in the textural composition and the increase of humidity, and it also reflects winter temperature from very cold to moderately cold due to increase of assimilation of winter precipitation. In total 11 classes are detected: i.e. <80, 80-140, 140-180, 180-230, 230-280, 280-340, 340-400, 400-480, 480-540, 540-650 Mg ha^{-1} and higher. However, within these provincial standards, certain deviations is observed in the humus content, which are caused by the difference in supply of water resources due to additional water feed by surface flow or contrary increase of drought by water loss due to expositional effect of slopes. It is established that deviations of total humus content against background soils within each soil-ecological province are, depending on water supply: 130±10% for Meadow chernozems (or Meadow chestnut soils) with semi-hydromorphic, 115±5% for soils with increased humidity, 100±10% for the background, 74±15% for weakly-xeromorphics, 50±10% for moderately-xeromorphics, and 30±10% for strongly-xeromorphics.
6) <u>Soil-ecological mapping</u>, which is based on HTC coefficient, amount of precipitation for the cold period and its assimilation ability by soil as priority criteria for resource water supply and energy for soil formation as well as soil classification on quantitative principles using humus as index of ecological/genetic status of soil formation, <u>is scientific base</u> to solve the problem of geography of humus accumulation in soil cover of Eurasian steppes, productivity of soils of natural and agro-ecosystems. Today there are no other alternatives.

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Chapter 4

Processes and regimes in soils under *Festica-Stipa* steppe and reclaimed agricultural land in Askania, southern Ukraine, with special reference to dynamics of soil organic matter

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4.1. General information about Askania steppe

Steppe biosphere, natural reserve of Askania Nova, is situated within north part of the Dry Steppe zone. In grass stand composition of the steppe, zonal turf-cereal vegetation is dominant in placor conditions. This vegetation occupies about 70% of the area, including fescue, stipa, and sedge (*Carex praecox*) associations, followed by *Artemisia austridca* etc. The fescue associations occupy 45-55%, whereas stipa associations, which include *Carex praecox, Poa angustifolics, Festuca valesiaca* etc., distribute 25-35% of the area of zonal turf-cereal vegetation. The third group consists of rhizome-cereal and sedge associations and their proportion is 10-30%.

In horizontal structure of vegetation cover, the relation with relief and soil cover is well observed.

Askania steppe is characterized by large diversity of flora. In 1923, 310 naturally growing species were registered, and they increased later to 357 in 1954, 436 in 1975 and 478 in 1990. They are combined into 15 leading families. In bio-morphological spectrum of flora, perennial grasses predominate (51%). The basis of this group is long-vegetating perennials (47%). Annuals constitute 38%; followed by two-year vegetating plants (9%) and semi-shrubs (1%). Rod-root grasses dominate among the steppe grasses (63%).

In ecological structure of flora, larger areas are occupied by meso-xerophytes (37.8%), mesophytes (20.3%), and xerophytes (18.9%). Dominant species are representatives of two (spring-summer and summer) phyto-rhythm plants (62.4%). Based on ecological analysis eight coenomorphs are allocated. The most spread group is steppants (one of steppe plants) constituting 65.2%. The volume of steppe species (36%) exceeds all others.

There is a large proportion of meadow-steppe species (22%) because of the presence of numerous depressions in steppe (Vedenkov and Drogobych, 1998; Vedenkov and Vedenkova, 1998).

The fescue, stipa and meadow-steppe associations, the dominant groups of natural steppe vegetation, are encompassed by a research station for studying soil regimes and processes in Askania nova. It was situated in strictly controlled reserve, where human activity has been prohibited from about 100 years ago. Therefore, this research station can be considered as a standard of virgin fescue-stipa steppe of Ukraine. Following researches were conducted in 1967-1974.

4.2. Characteristics of soils at the station

Soils under fescue-stipa associations are represented by Dark chestnut soils, which have depth of humus horizon 55-65 cm with 56-60% content of physical clay. Effervescence after treating by 10% HCl is from 45-56 cm depth, 'white eye' carbonates present from 65-70 cm till 95-105 cm, and gypsum is from 180-220 cm.

Under the meadow-steppe associations in negative shallow depressions ('saucer'), soils have increased depth of humus layer to 70-80 cm, lower depth of effervescence, usually, under humified layer, 'white eye' carbonates from 90-100 cm, and gypsum at 220-250 cm or often there is no gypsum in the profile at all.

On cultivated Dark chestnut soils, plot with similar profile thickness and particle-size composition to the soils in the virgin lands was selected for the present study.

Profile description:

Hed -	0-8 (10) cm	Humus-turf, dark-gray when moist and gray when dry; structure is crumby-granular-powdery; eluviated; structural separates have glassy powdering of SiO_2; light-clay; gradual transition to
H(i) -	8 (10) - 25 (28) cm	Humified, dark-chestnut, crumby-granular-nutty, compacted, clay, gradual transition to
Hpi -	25 (28) - 38 (42) cm	Upper transitional, dark-chestnut with brown tone, crumby-granular, compacted, clay, structural separates have weak colloidal lacquering, many crotovinas, gradual transition to
Phi -	38 (42) - 55 (65) cm	Lower transitional, dark-brown, dark-gray bands, crumby-nutty-prismatic, compacted, carbonated from 45-56 cm, crotovinas, clay, gradual transition to
Pk(h) -	55 (65) - 65 (70) cm	Loess, weakly humified, straw-brown with gray tones;
Pk -	65 (70) - 160 cm and deeper	Loess, straw-brown, crumby, compacted, porous, clay.

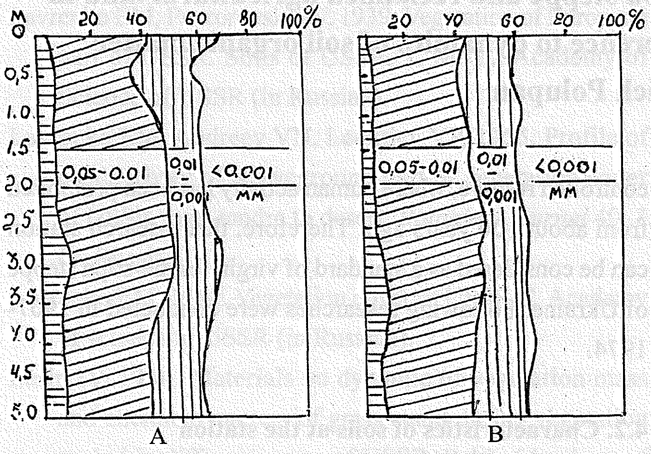

Figure 4.1. Distribution of particle size (0.25-0.05, 0.05-0.01, 0.01-0.001 and < 0.001 mm) of soils from virgin (A) and cultivated (B) lands.

The characteristics of soils from the virgin and the cultivated lands are presented in Table 4.1 and Figs. 4.1 and 4.2. There were no significant differences in physical properties and particle-size composition of both the soils (Table 4.2; Fig. 4.1).

Thus, properties of the studied soils are practically the same. Therefore, it is possible to assume their similarity at initial stage.

4.3. Climatic conditions during the experiment

Many researchers (Buchinskii, 1963; Predtechenskii, 1957; Schwartsbach, 1955; Shnitnikov, 1969; Shulgin, 1972; and others) indicate the presence of centuries-cyclic changes of climate by periods from 1800 till 3000 years. On the background of those changes centuries and inter-centuries changes occur with different duration of cycles. During these

Table 4.1. Characteristic of Dark chestnut soils at the study plots.

Background	Depth (cm)	Humus content (%)	Bulk density (g cm^{-3})	Exchangeable cations					pH		Heavy metals								
				Ca	Mg	Na	K	Sum	in water	in salt solution	B	Cu	Zn	Co	V	Cr	Ni	Sr	Pl
				(cmolc kg^{-1})							(mg kg^{-1})								
Profile depth 55-65 cm, physical clay – 56-60%																			
virgin	0-30	3.4±0.2	1.22	22	7	0.4	1.2	30.6	6.7	5.8	30	37	60	16	56	84	33	130	26
	30-40	2.1±0.2	1.37	23	8	0.5	0.9	32.4	6.9	6.0	46	30	62	16	50	100	38	140	24
	40-50	1.9±0.2	1.42	26	5	0.8	0.7	36.5	7.3	6.4	32	29	-	16	56	100	32	150	27
	50-60	1.2±0.2	1.48			1.0			7.9	7.2	38	30	-	15	56	90	30	150	34
	60-70	0.9±0.2	1.50			1.2			8.0	-	-	-	-	-	-	-	-	-	-
	70-80	-	1.51			1.3			8.2	-	26	-	-	-	-	-	-	-	-
	80-90	-	1.50			1.5			8.2	-	26	19	-	14	50	90	27	160	25
	90-100	-	1.51			3.8			8.2	-	26	17	-	17	58	110	32	150	25
cultivated	0-30	2.9±0.2	1.28	21	7	0.2	1.0	29.2	6.9		38	34	60	18	58	91	37	120	27
	30-40	2.0±0.2	1.38	23	7	0.3	0.9	31.2	7.1		-	-	-	-	-	-	-	-	-
	40-50	1.8±0.2	1.43			0.5			7.4		37	35	61	18	63	86	40	120	28
	50-60	1.3±0.2	1.50			0.8			7.9		-	-	-	-	-	-	-	-	-
	60-70	0.8±0.2	1.50			0.9			8.0		34	31	-	16	58	90	32	134	30
	70-80	-	1.53			1.2			8.1		-	-	-	-	-	-	-	-	-
	80-90	-	1.51			1.3			8.1		-	-	-	-	-	-	-	-	-
	90-100	-	1.52			1.5			8.2		27	26	-	16	54	84	33	145	30
Profile depth 70-80 cm, physical clay – 56-60%																			
virgin	0-30	4.1±0.2	1.24	26	8	0.3	1.4	35.7	6.5										
	30-40	2.5±0.2	1.38	27	9	0.4	1.0	37.4	6.7										
	40-50	2.3±0.2	1.41	26	10	0.5	0.8	37.3	6.9										
	50-60	1.9±0.2	1.50			0.6			9.0										
	60-70	1.6±0.2	1.51			0.7			7.2										
	70-80	1.1±0.2	1.53			0.8			7.3										
	80-90	-	1.50			0.8			7.4										
	90-100	-	1.55			1.1			7.8										
cultivated	0-30	3.4±0.2	1.28	25	8	0.2	1.4	34.2	6.4										
	30-40	2.3±0.2	1.40	24	9	0.3	1.0	34.3	6.6										
	40-50	2.1±0.2	1.42			0.4			6.8										
	50-60	1.8±0.2	1.45			0.4			6.9										
	60-70	1.5±0.2	1.50			0.5			7.0										
	70-80	1.2±0.2	1.51			0.5			7.6										
	80-90	0.8±0.2	1.53			0.6			7.8										
	90-100	-	1.52			0.7			8.0										

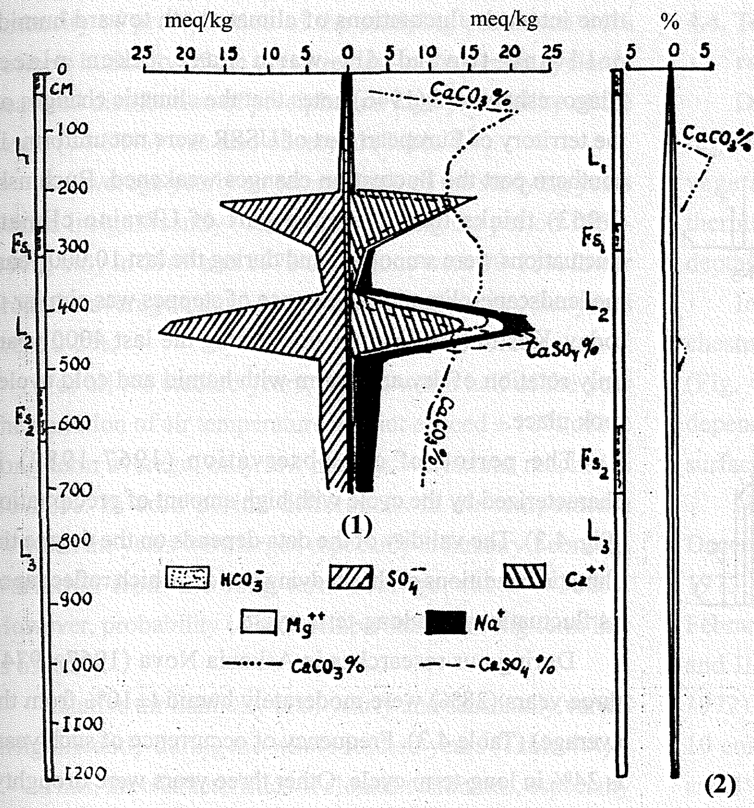

Figure 4.2. Composition of water-soluble ions of the loess-derived soils from virgin land (1) and pod (2), and contents of $CaCO_3$ and $CaSO_4$.

Table 4.2. Physical properties of the study soils.

Depth (cm)	Bulk density (g cm^{-3})		Particle density (g cm^{-3})		Total porosity (%)		Field water-holding capacity (%)		Moisture content at the capillary-braking point (temporary wilting point) (%)		Moisture content at the permanent wilting point (%)	
	1*	2*	1*	2*	1*	2*	1*	2*	1*	2*	1*	2*
0-10	1.15	1.25	2.72	2.71	56.3	53.8	32.2	32.0	18.2	18.0	12.3	12.0
10-20	1.20	1.28	2.73	2.72	54.6	52.9	30.3	31.6	18.6	18.1	12.0	12.0
20-30	1.25	1.30	2.75	2.73	53.2	53.4	27.5	28.0	18.3	18.0	13.8	12.6
30-40	1.31	1.37	2.74	2.74	50.9	50.0	25.3	26.0	18.4	18.1	13.6	13.3
40-50	1.40	1.42	2.75	2.75	47.6	48.3	23.9	24.0	17.3	18.0	12.5	12.7
50-60	1.44	1.44	2.70	2.70	46.7	46.7	22.0	21.9	17.4	17.1	12.3	12.1
60-70	1.45	1.46	2.69	2.70	46.1	45.9	21.7	21.0	17.5	17.3	11.8	12.0
70-80	1.48	1.48	2.69	2.69	45.0	45.1	21.8	22.0	16.3	16.8	11.1	11.4
80-90	1.48	1.48	2.71	2.71	45.4	45.4	21.7	21.6	16.0	16.3	11.2	11.3
90-100	1.50	1.50	2.73	2.73	45.1	45.0	21.0	21.4	16.2	16.5	11.2	11.5
100-110	1.52	1.50	2.73	2.72	44.3	44.3	21.5	21.0	16.4	16.5	11.2	11.1
130-140	1.49	1.50	2.72	2.73	45.2	44.9	21.3	21.2	16.0	16.1	11.8	11.5
150-150	1.50	1.52	2.73	2.73	45.1	44.1	21.4	21.0	16.3	16.1	11.9	11.8
160-170	1.57	1.50	2.75	2.74	42.9	43.6	21.9	21.0	16.1	16.1	12.0	11.9
190-200	1.47	1.61	2.74	2.74	46.2	40.1	21.2	21.0	16.9	16.3	12.0	11.9
220-230	1.48	1.52	2.75	2.75	43.2	42.1	20.6	21.3	15.8	16.0	12.1	12.0
250-260	1.55	1.55	2.73	2.72	44.3	44.0	20.3	20.6	15.6	15.3	12.1	12.0
280-290	1.52	1.54	2.73	2.73	46.4	46.0	19.3	20.1	14.8	15.0	11.9	12.0
310-320	1.47	1.50	2.74	2.74	45.4	43.2	18.8	20.3	14.5	15.0	11.7	12.0
340-350	1.48	1.51	2.74	2.74	45.1	43.5	19.3	19.4	14.8	15.0	11.9	12.0
370-380	1.50	1.51	2.73	2.74	46.7	45.9	19.6	19.5	15.1	15.3	11.7	11.9
400-410	1.45	1.49	2.72	2.73	46.7	43.2	20.3	19.9	15.6	15.4	12.8	12.1
430-440	1.45	1.49	2.72	2.72	46.4	45.3	20.6	19.6	15.7	15.3	13.8	12.6
460-470	1.47	1.52	2.74	2.74	46.4	45.3	20.8	19.3	15.8	15.2	13.6	13.0
490-500	1.48	1.50	2.73	2.73	45.8	44.3	21.0	19.8	16.1	15.6	14.9	13.0

* 1: virgin land; 2: cultivated land

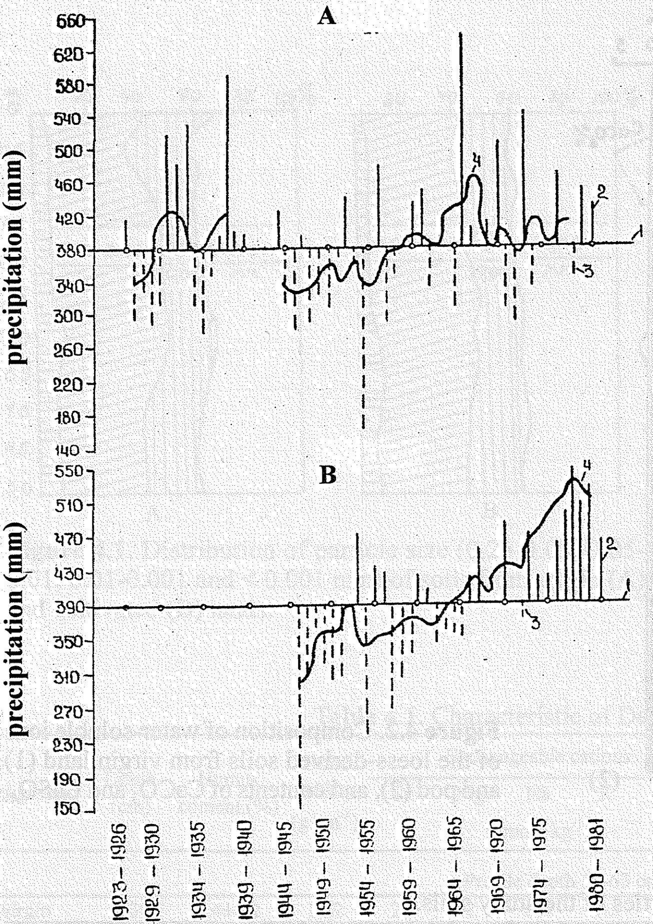

Figure 4.3. Analysis of long-term fluctuation of annual precipitation at meteorological stations of Askania Nova (A) and Kherson (B).

time intervals fluctuations of climate both toward humid-cold and toward dry-warm have taken place. Blagoveshchenski (1946) notes that the climatic changes on the territory of European part of USSR were not uniform; in southern part the fluctuation changes weakened. Buchinski (1963) thinks that in steppe part of Ukraine climate fluctuations were smoother; and during the last 10,000 years the landscape-climatic appearance of steppes was similar to today. Kostin (1965) notes that during the last 4000 years only rotation of dry and warm with humid and cold cycles took place.

The period of our observation (1967-1982) is characterized by the cycle with high amount of precipitation (Fig. 4.3). The validity of the data depends on the degree the climatic conditions of the studying period, which reflect upon its fluctuations in a long-term cycle.

During our researches in Askania Nova (1967-1974), three years (38%) were moderately humid (±10% from the average) (Table 4.3). Frequency of occurrence of such years is 34% in long-term cycle. Other three years were droughty; amount of precipitation was 10-30% less than the long-term average. Probability of such years on the studying territory is 32% in long-term cycle. Two years (24%) were extremely humid; amount of precipitation was 30-40% higher than the average. Such years constitute up to 15% in long-term cycles.

Table 4.3. Frequency of occurrence of annual or periodical precipitation in long-term basis (1925-1981) and for years of our research (1967-1974); at meteorological station of Askania Nova (without 1941-1943).

		Relative amounts of precipitation in individual years against long-term average (%)									
		<60	60-70	70-80	80-90	100±10	110-120	120-130	130-140	>140	Sum
Throughout one year; 380 mm in average											
Long-term basis (1925-1981)	No. of observation	1	-	7	10	19	5	2	6	3	53
	percentage (%)	2	-	13	19	36	10	4	11	5	100
Research years (1967-1974)	No. of observation	-	-	1	2	3	-	-	2	-	8
	percentage (%)	-	-	12	25	38	-	-	25	-	100
Cold half of a year; 171 mm in average											
Long-term basis (1925-1981)	No. of observation	3	4	4	14	18	-	3	-	7	53
	percentage (%)	5	8	8	27	34	-	5	-	13	100
Research years (1967-1974)	No. of observation	-	1	1	3	2	-	-	-	1	8
	percentage (%)	-	12	12	39	25	-	-	-	12	100
Warm half of a year; 209 mm in average											
Long-term basis (1925-1981)	No. of observation	5	1	6	10	13	8	-	-	10	53
	percentage (%)	9	2	11	19	8	15	-	-	19	100
Research years (1967-1974)	No. of observation	-	1	-	2	3	1	-	-	1	8
	percentage (%)	-	12	-	25	39	12	-	-	12	100

Intensity of precipitation of the studying period on 84% reflects humidity of the given region in long-term cycle. In seasonal distribution of precipitation high probability of the years (74-84%) was also observed (Table 4.4).

An average yearly air temperature of the studying years varied insignificantly (Table 4.4). During the period 1967-1974, only in 1969 and 1973 deviations were 10-12% lower from the average annual norm, and deviations in other years were 0-2%.

For all the studied years, during warm half of the year the variation of air temperature did not exceed ± 10% of the long-term average; only few months' variations reached ± 20-22%. In cold period differences in air temperature between the years were larger, especially in January-February. Variation from the long-term average was ± 7-386%. However, probability of such temperatures in long-term line is 63-82%.

Relative air humidity both yearly and seasonally varied insignificantly during the whole studied years (Table 4.4).

Thus, the characteristics of climate conditions, especially yearly and seasonally distribution of precipitation in 1967-1974, practically completely covered their variation in long-term line. This allows interpretation of results of observation of water and other regimes during these years with high confidence.

4.4. Temperature regime of the soils during the period of research on water balance

Dynamics of soil moisture depends on its temperature regime to some degree. It was measured under natural vegetation with extensible thermometers. For plotting thermoisoplets soil temperatures of decades were used on depths: 10, 20, 40, 120, 160, 240 and 320 cm.

In a yearly cycle of soil temperature regime of Dark chestnut soils there are two periods: warming and cooling (Fig. 4.4). Duration of these periods had been changing depending on income and consumption time of heat on soil surface from soil moisture and other factors.

Negative temperature in soil started from III decade of December (1970) and from January (from I decade in 1971-1973, II in 1969 and III in 1967 and 1974), and ended in February (in I decade in 1970 and 1974, II in 1971 and 1974, and III in 1967) and in March (in II decade in 1969 and 1972). Depth of frosting fluctuated significantly; it's up to 10 cm (1971), 20 cm (1970), 30 cm (1968), 40 cm (1967 and 1974), 50 cm (1973), 70 cm (1969) or 120 cm (1972). Cooling of soil up to 5°C reached 130-240 cm and to 8°C 260-320 cm depth.

Soil warming started in different decades of March: in I (1970 and 1973), in II (1967, 1968 and 1971), in III (1969, 1972 and 1974). Heat from surface till 40-50 cm depth was

Table 4.4. Mean annual air temperature and relative humidity on studied plots in long-term average and in the studied year.

Year	Month												Average
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
	Air temperature (°C)												
Long-term average	-2.9	-2.8	2.0	9.3	16.7	20.8	23.5	22.5	16.6	9.8	4.5	-0.1	9.9
1967	-4.8	-4.8	1.6	9.9	17.1	18.9	23.0	23.2	17.7	12.3	6.6	-0.6	10.1
1968	-4.1	-1.2	3.7	11.0	18.9	20.5	22.0	21.1	17.5	9.3	4.3	-1.0	10.1
1969	-6.7	-4.4	-0.2	8.2	15.2	19.8	20.5	22.1	15.7	8.1	6.5	-0.5	8.7
1970	-1.3	0.2	4.0	11.9	15.2	18.5	24.2	20.1	15.7	8.2	5.1	-0.3	10.1
1971	-0.2	-0.2	1.6	8.4	16.0	20.0	23.2	23.0	17.2	8.5	5.7	1.4	10.2
1972	-11.8	-4.3	1.5	12.5	17.1	23.1	23.3	23.5	16.4	9.8	5.7	0.3	9.9
1973	-6.0	1.4	2.1	10.1	15.0	18.5	22.1	19.1	14.2	9.4	1.5	0.4	9.0
1974	-4.9	0.4	2.9	6.9	14.0	19.2	21:2	21.7	17.6	14.2	4.3	2.5	10.0
	Relative humidity (%)												
Long-term average	87	86	81	72	67	62	58	58	65	77	87	89	74
1967	87	86	86	63	65	66	50	53	56	76	88	91	73
1968	86	90	76	56	55	54	54	61	67	81	91	88	72
1969	82	87	83	73	68	62	67	56	63	65	84	90	73
1970	88	86	78	70	76	69	57	63	60	79	86	91	75
1971	87	83	82	58	68	58	59	50	65	71	88	89	72
1972	79	82	69	67	63	52	54	56	63	80	86	86	70
1973	81	88	81	72	67	70	64	67	66	74	88	87	75
1974	85	87	70	72	73	63	63	49	62	79	87	92	73

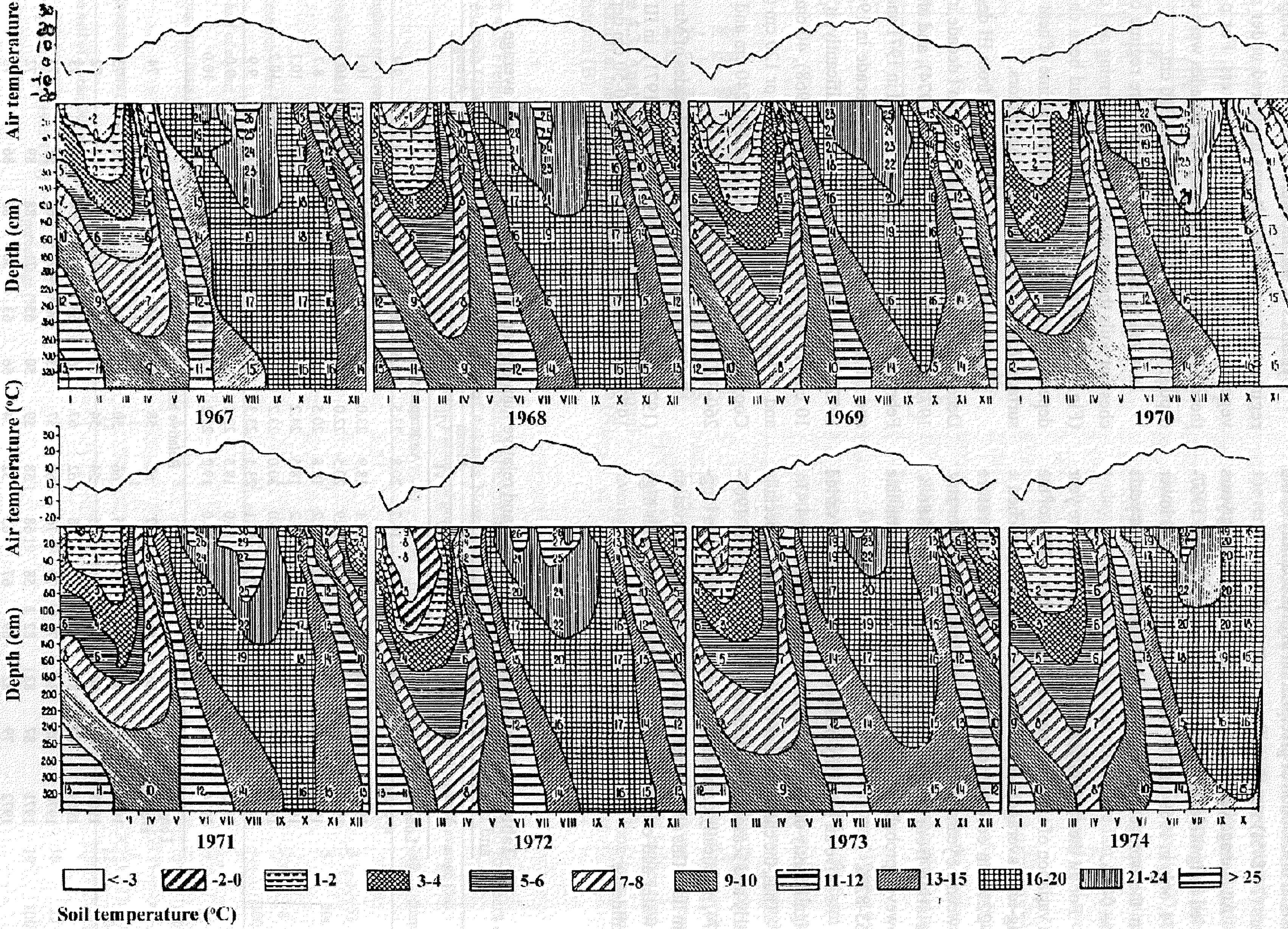

Figure 4.4. Chronoisoplets of temperature of the Dark chestnut soil on virgin land.

spread quickly, because thermoisoplets were set up almost vertically. Warming above 5°C on 20 cm depth, in most of the cases, happened in III decade of March or I decade of April. Slow temperature increase was observed only in 1969 when soil at 20 cm depth was warmed up in II decade of April.

Increase of temperature in this depth happened within 10 to 20 days, except 1974, when this period lasted about 40 days. The increase sometimes falls in I-II decade of April, while extreme cases that coincide with humid springs fall in III decade of April or I decade of May. At the end of April to I decade of May and sometimes II decade of May, temperatures of upper soil horizons reach 15°C. Growth of temperature from 10 to 15°C proceeds fast, which is well shown on the presented figures where intervals between thermoisoplets are narrow.

Up to 20°C the soil is warmed relatively slow. This temperature level in the surface soil takes place at the end of May to beginning of June. Spreading of heat into deep layers depends on the moisture content in the soil and the amount of precipitation in summer period. In humid years (1969, 1973 and 1974) soil temperature of 20°C was recorded at 90-120 cm depth at the end of July and I-II decades of August; in other years at 160 cm soil depth.

In July-August, when soils under virgin vegetation are dried up to the wilting moisture, the layer of 40-50 cm is warmed up above 25°C.

Decline of soil temperature begins from September; it is declined till 15°C in I decade of October, in less cases in II decade; till 10°C between II-III decades of October and I decade of November; and till 5°C in II-III decades of November - I decade of December.

Duration of the period with temperatures above 10°C at 20 cm depth constitute 202 (193-214) days; above 15°C - 160 (142-173) days.

Many authors established that vegetation cover shading soil serves as a thermo-insulator. The more a soil is shaded by vegetation the lower is the temperature of surface layers. Cultivation results in an increase of summer temperature of ploughed field from 2 to 15 degrees higher than that of virgin land (Ikotnikova, 1965; Kolosov, 1924; Shulgin, 1972). Therefore, temperature regime of the studied cultivated lands, which may varies depending on cultivated crops, can be characterized also by large values, especially after harvest when the whole surface remains open.

In yearly cycle of soil temperature regime, fluctuations take place. In the cold period temperature gradient between 20 and 160 cm soil depths is 6.7°C (5-11°C), 20 and 320 cm - 13.2°C (10-16°C). Positive inter-soil gradient directs heat flux upward from deeper layers to surface (Dimo, 1970). In warm period the gradient is negative; in the warmest month between the above-mentioned layers the gradient is 8.2°C (7-10°C) and 12.7°C (11-15°C), respectively, and heat flux is directed from soil surface to deeper layers.

Thermal gradients move moisture along soil profile at the same time (Abramova, 1968; Globus, 1962; Panfilov and Yuriev, 1968; Chizhikov, 1967; and others). Flux of moisture in autumn-winter period is directed from warm to cold layers. In warm period moisture mainly moves toward moisture gradient, to drying surface. Heat and moisture conductivities have reverse directions, but it doesn't significantly influence moisture balance. Quantitative changes of moisture under influence of thermal gradients on studied treatments will be given further in corresponding sections.

4.5. Moisture regime under natural condition

Soil moisture was studied by the following method: till 5 m soil moisture was determined in 4 terms: April, June, August and October; till 3 m - in every decade during warm period. Samples were taken every 10 cm till 110 cm, and every 20 cm in deeper layers. Soil moisture was determined by thermostat-weighing method in 4 replications.

Coefficient of variation of moisture did not exceed 10%, except in the upper 10 cm and the horizons located on lower border of the zone of maximum soil moistening where it was 15%. Accuracy of determination of the replications was within 5%.

Yearly regime of moisture in the Dark chestnut soil under virgin vegetation has two periods: accumulation (water absorption) and consumption (drying). The first period falls in autumn-winter-spring and lasts from November till March; and the second period falls in spring-summer. The water budget in the individual periods is summarized in Table 4.5.

Average assimilation of precipitation during the cold period in the virgin land was 82% with fluctuation from 47 to 125% (the last value is due to inflation of snow from neighboring plots). Absolute value is 67-234 mm. This moisture penetrated into 40-230 cm depth.

High percentage of assimilation of precipitation by soils during cold periods is mainly caused by their dry condition at the end of vegetation period. Correlation between depth of freezing and assimilation of precipitation was not observed. However, there is a correlation between moisture accumulation and length of period with soil temperatures of

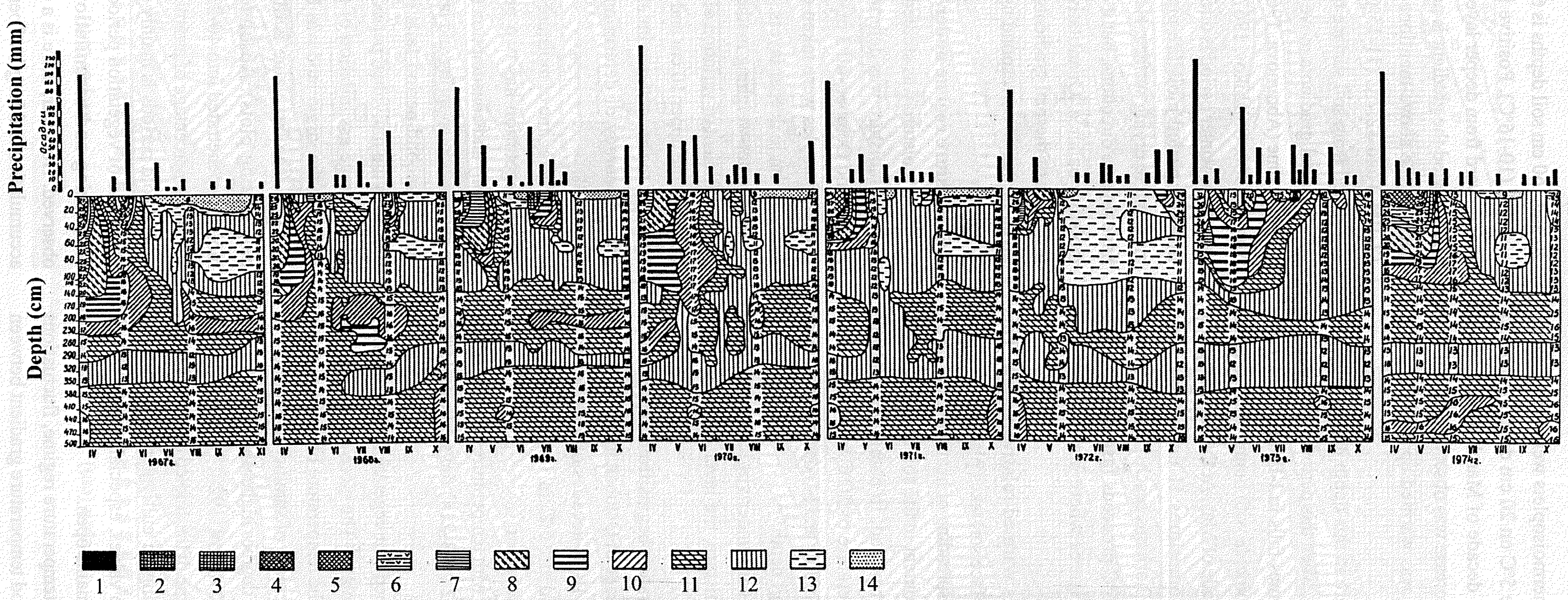

Figure 4.5. Dynamics of moisture content in the Dark chestnut soil on virgin land.
1, >34%; 2, 32-33%; 3, 30-31%, 4, 28-29%; 5, 26-27%; 6, 24-25%; 7, 22-23%; 8, 20-21%; 9, 18-19%; 10, 16-17%; 11, 14-15%; 12, 12-13%; 13, 10-11%; 14, <9%.

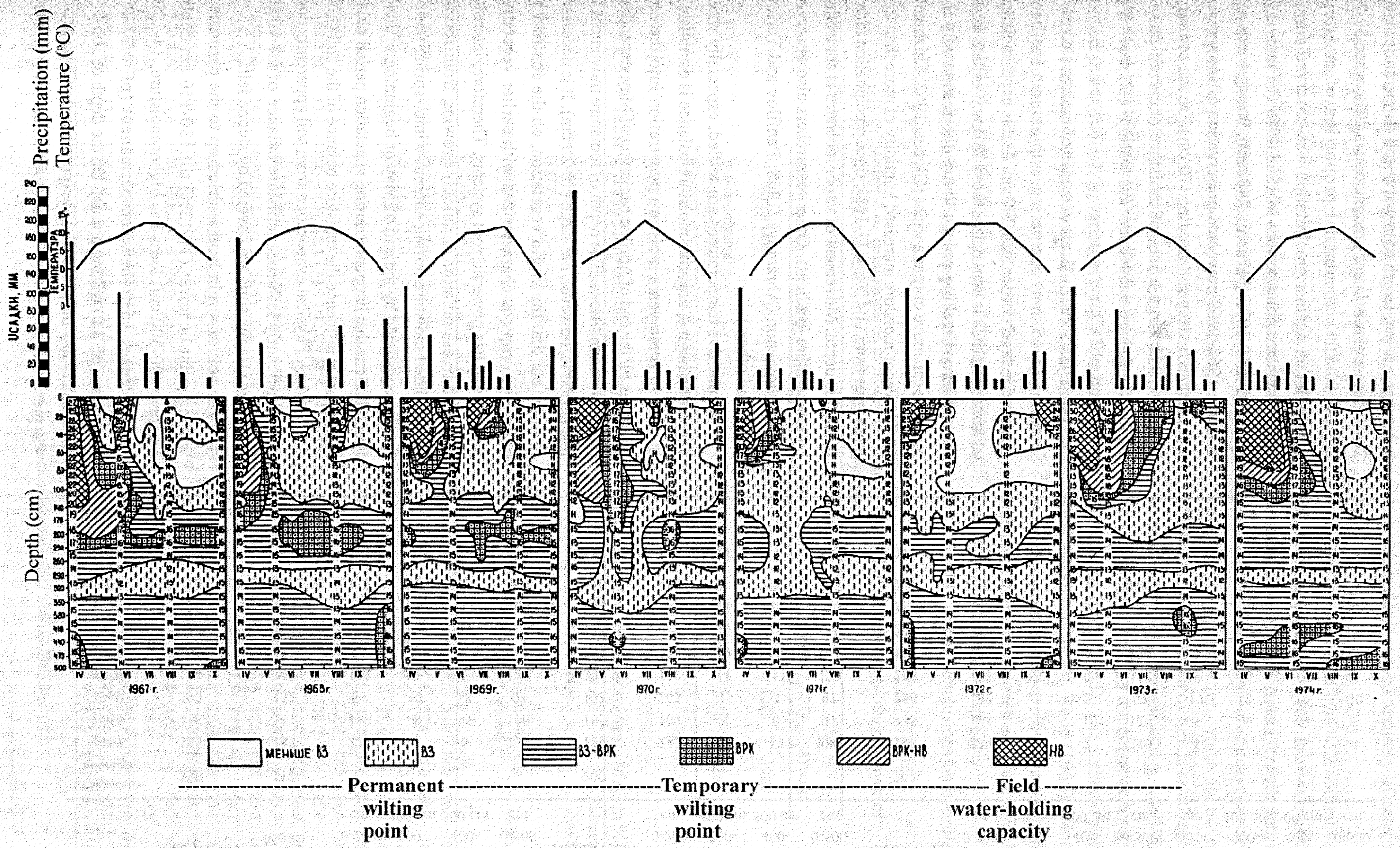

Figure 4.6. Chronoisoplets of moisture content in the Dark chestnut soil on virgin land.

Table 4.5. Water balance in the Dark chestnut soils under virgin vegetation.

Year	Precipitation throughout one year	Precipitation during November-March	Moisture accumulation at different layers of soil during November-March (mm)				Precipitation during April-August (mm)	Moisture consumption from different layers of soil during April-August (mm)				Precipitation during April-October (mm)	Moisture consumption from different layers of soil during April-October (mm)				Yearly water balance by the end of October (mm)			
			0-200 cm	200-400 cm	400-500 cm	0-500 cm		0-200 cm	200-400 cm	400-500 cm	0-500 cm		0-200 cm	200-400 cm	400-500 cm	0-500 cm	0-200 cm	200-400 cm	400-500 cm	0-500 cm
Long-term average	380	118					200					262								
1967	385	187	224	10	0	234	176	243	20	17	280	198	230	8	2	240	-4	2	-2	-4
1968	416	181	139	-4	-5	130	165	101	-4	0	97	235	144	-10	-10	124	-5	6	5	6
1969	390	132	85	-10	-8	67	173	103	-15	3	91	258	102	-7	2	97	-17	-3	-10	-30
1970	534	248	122	10	-15	117	228	120	14	-11	123	286	103	15	0	118	19	-5	-15	-1
1971	267	132	99	1	1	101	114	126	19	19	164	135	102	18	0	120	-3	-17	1	-19
1972	328	103	82	24	-3	103	125	95	36	18	149	225	32	49	12	93	50	-25	-15	10
1973	523	140	102	18	-12	108	314	145	11	20	176	383	128	12	22	162	-26	6	-32	-52
1974	336	125	117	24	23	164	160	154	4	5	163	211	108	2	1	106	9	26	24	59
Average	397	156	121	9	-2	128	182	136	11	9	156	241	118	10	3	131	3	-1	-5	-3
Water balance for 8 years of the study																	23	-10	-44	-31

below zero. When length of negative soil temperatures lasts 20-40 days assimilation of precipitation is 80%, when 50-70 days - 50-70%. A minimal proportion of moisture accumulation against precipitation was observed during autumn-winter-spring periods of 1968-1969 (67 mm / 132 mm) and 1969-1970 (117 mm / 248 mm). Strong winds and frosts in 1968-1969 prevented preservation of snow cover and resulted in deep soil freezing (70 cm). On the contrary, in 1969-1970 large losses of moisture occurred due to frequent and sharp temperature fluctuations (-21 and +8°C or -12 and +10°C).

For 7 years insignificant decrease of moisture content in spring (5-15 mm) comparing with autumn has been observed in layer deeper than 200 cm. At this depth moisture of loess materials is kept below the temporary wilting point (or capillary-breaking point); that is the reason why the moisture can move only as a vapor (Globus, 1962; Chizhikov, 1967). Vapor moisture increased humidity of more than 2 m loess layer from 11-12% to 13-14%, since precipitation didn't reach this depth. Movement of vapor moisture is controlled by temperature gradients. Other researchers also observed this phenomenon (Abramova, 1968; Panfilov and Yuriev, 1968; and others).

As positive temperatures are settled, especially when vegetation begins, negative moisture balance is established in soil. In some years moisture penetration into the soil continues till the end of April or beginning of May, depending on weather conditions. The depth of moisture movement in this period is, however, not large (10-20 cm). It is necessary to point out that the virgin vegetation, on the contrary to cultivated crops, is characterized with earlier vegetative periods and has powerful root systems. Therefore, intensity of moisture assimilation is quickly growing from spring; accumulated moisture during autumn-winter-spring period is fully consumed by the end of May or beginning of June. Precipitations that happened during vegetation period didn't significantly influence the moisture balance of the soil (Figs 4.5 and 4.6). Physical evaporation from soil apparently does not significantly influence moisture balance of the virgin lands because the soils are covered by steppe felt.

The soil of virgin land is dried up to the permanent wilting point or lower (11-13%) till 130-150 cm depth. Deeper (290-300 cm) loess has higher moisture, 14-15%, and as lenses 16% (between permanent (pF 4.2) and temporary (pF 3.0) wilting points). On the depth of 300-350 cm constant low moisture 12-13% (permanent wilting point) was preserved, deeper than 350 cm soil moisture was constant at 14-15% and few spots -16% (between permanent and temporary wilting points) during the studied years.

In the warm period moisture movement is mainly directed upward due to the influence of drying gradients. However, in small amounts, as vapor, it moves into lower layers in direction of heat flux. Due to this moisture, relatively constant moisture is preserved below the moisture percolation zone in spite of its losses during the cold months.

By the end of vegetative period the moisture content in 5-m depth on virgin land practically was constant for all the studied years (Table 4.6), variation was not greater than ± 4.9-5.3% that is within the limits of error for determination.

Based on comparison of inputs and outputs, water balance on the virgin land is suggested to be close to zero, while deeper than 200 cm it is negative, which is an evidence not of accumulation but of consumption of water. But the last values don't exceed accuracy of determination (Table 4.5).

Thus, on the virgin land with natural vegetation cover, moisture distribution in soil follows classical hydrologic profile established by Vysotski for soils with non-percolation water regime. Active moisture circulation covered whole the zone of spring percolation, which did not exceed 200-250 cm depth. Deeper soil moisture is relatively constant, close to moisture at the permanent wilting point. This horizon fully corresponds to "dead" or impermacide according to Vysotski (1962) and Rode (1965). The authors related its origin to vital activity of plants. Rode (1965) pointed out that the activity of plant with deep roots that penetrate till the "dead" horizon completely closes moisture circulation from the below, except for water vapor.

Validity of our conclusions on hydrology of the soils

Table 4.6. Total stock of moisture (in mm) at the end of October in 0-500 cm layer of the Dark chestnut soils of different ecosystems.

	Years								
	1967	1968	1969	1970	1971	1972	1973	1974	Average
Virgin land	1048	1070	1030	1005	984	1016	985	1043	1022
Non-irrigated cultivated land	1195	1331	1360	1370	1119	1183	1325	1238	1265

Table 4.7. Moisture content in soils under natural and cultivated vegetation (April-May, in %).

Depth (cm)	Southern chernozem										Dark chestnut soil						Solonetzic chestnut soil			
	Ascania steppe				Crimea steppe						Ascania steppe						Novotroitsk steppe			
	1973				1977						1973	1981		1973	1981		1973			
	virgin		cultivated		virgin		cultivated for 15 years		cultivated for long period		virgin			cultivated for long period			virgin		cultivated for long period	
	1	2	1	2	1	2	1	2	1	2	1	1	2	1	1	2	1	2	1	2
0-10	21.0	13.0	20.4	10.3	28.0	16.1	23.1	15.0	26.4	15.4	22.8	26.4	10.4	24.6	28.3	14.2	19.6	8.9	20.7	10.8
20-30	23.0	16.2	21.9	13.1	18.6	15.3	21.2	14.6	25.6	14.9	25.5	25.8	14.6	24.6	27.4	15.0	20.4	16.3	22.5	16.4
50-60	19.2	16.5	19.4	12.0	17.4	14.4	20.3	14.1	20.6	13.2	20.1	24.3	11.8	20.6	23.1	14.0	18.8	12.5	19.1	14.2
70-80	18.5	14.7	19.0	11.4	16.9	14.0	19.4	13.8	19.8	13.4	19.3	21.3	11.8	19.2	22.4	14.2	17.0	14.8	16.6	13.5
90-100	18.0	15.1	19.2	12.1	15.4	13.7	18.9	13.6	21.0	13.1	13.9	20.0	12.2	20.8	21.3	14.6	16.8	16.8	16.4	13.6
130-140	15.1	15.5	20.0	13.0	12.3	13.3	18.6	13.5	21.8	13.4	13.8	16.4	12.0	16.3	21.0	13.9	15.6	16.9	16.4	13.9
160-170	13.4	15.0	19.3	12.4	12.9	13.2	18.2	13.8	20.8	13.6	14.2	14.9	12.7	16.1	20.0	-	15.9	-	16.2	-
190-200	14.8	14.8	18.3	12.3	14.1	13.5	17.8	13.2	20.0	13.8	14.5	14.0	12.1	16.4	20.0	14.5	16.0	16.4	16.0	-
220-230	14.7	14.6	18.3	-	14.8	13.6	17.8	13.0	20.0	-	13.8	12.7	12.1	17.0	19.8	-	15.7	-	16.5	-
250-260	14.3	14.2	17.2	11.5	14.5	13.7	17.0	13.5	19.2	13.8	14.0	13.6	11.9	17.0	19.6	13.8	16.5	16.1	16.1	14.4
280-290	13.0	10.8	15.8	11.8	14.6	13.5	16.9	13.2	19.8	13.5	13.6	13.4	12.1	17.1	18.9	-	15.7	15.0	16.1	-
310-320	13.8	11.0	16.2	11.0	15.1	13.5	16.8	13.0	19.5	13.6	14.0	13.6	11.9	16.3	18.9	13.8	15.3	-	17.5	-
340-350	13.8	11.5	16.0	10.7	14.8	13.0	16.7	12.6	18.8	-	13.6	13.9	11.7	16.5	19.0	13.0	15.3	15.8	16.8	13.9
370-380	13.6	12.0	16.0	11.3	14.7	13.1	16.9	12.4	18.5	13.4	13.8	14.0	-	16.8	19.3	-	14.7	15.8	18.0	14.0
400-410	13.4	12.1	16.7	11.1	15.5	12.9	16.8	12.7	18.5	-	14.4	14.2	-	17.0	19.4	-	13.8	-	18.5	-
430-440	13.0	12.0	16.8	12.1	14.6	13.1	16.9	13.0	19.0	13.6	14.7	15.0	15.8	17.0	18.4	14.8	13.6	14.1	18.1	-
460-470	13.1	12.4	16.5	-	15.3	13.6	16.9	13.1	19.8	-	14.4	15.0	-	17.0	18.6	-	15.0	-	17.7	-
490-500	13.4	12.7	16.8	11.5	15.5	13.8	17.0	14.2	20.0	14.8	14.7	14.9	15.9	16.9	18.9	15.4	16.3	15.0	18.2	15.3

1 – Actual moisture content.

2 – Moisture retention at the wilting point, which was determined by maximum hygroscopicity with coefficient of 1.34.

studied is confirmed by data of water distribution in 5-m depth at different plots, which was determined only once in April-May from 5 points on relatively virgin plot of Askania steppe on Southern chernozem, from 1 point on absolutely virgin plot of Southern chernozem in Krasnogvardeisk district of Crimea region, from 10 points of the whole perimeter of absolutely virgin part of Askania Nova on Dark-chestnut soils, from 6 points of virgin pastures of Solonetzic chestnut soil of Novotroitsk district of Kherson region. Averaged data on water distribution are presented in Table 4.7. In all the virgin plots water contents below 150-200 cm is close to those at the wilting point or a little higher.

The outlined analysis yields the conclusion: South and Dry Steppe zones were dominated by non-percolative water regime before their cultivation by human.

4.6. Moisture regime of cultivated non-irrigated soils

Data on the moisture balance in the cultivated land is summarized in Table 4.8. Assimilation of precipitation by soil in the cold period on the non-irrigated studied plot was in average 72 (18-140) %; in the absolute value it is 113 (24-208) mm. The least proportion of water against precipitation was accumulated under non-favorable climate conditions in 1968-1969 (67 mm / 132 mm) and 1969-1970 (100 mm / 248 mm), as already explained in the previous section for the virgin land. The water accumulation was also low in 1970-1971 (24 mm / 132 mm) and 1972-1973 (79 mm / 140 mm) because of high water contents in the surface layers of soil in the preceding autumn period. On the contrary, higher amounts of water was assimilated in 1966-1967 (170 mm / 180 mm), 1967-1968 (208 mm / 181 mm) and 1971-1972 (144 mm / 103 mm) under the conditions of the low initial soil moisture content that was close to the wilting point, or in 1973-1974 (115 mm / 125 mm) due to warm weather condition in autumn-winter period.

Initial content of water in soils influences assimilation of precipitation in the cold period because when moisture is at near the permanent wilting point, the soil is the most porous and is very cracked. Therefore, water penetrates to lower horizons relatively easily. On the contrary, when moisture is at near the temporary wilting point, water penetration is highly obstructed (Rode, 1959). Such a drop in assimilation of precipitation under high soil moisture conditions was also obtained by Protserov (1948a, b).

The depth of water penetration on the cultivated land at the beginning of the warm period widely fluctuated - 40-500 cm or more. It should be noted that downward movement of water is continuing after appearance of positive temperatures. The period of percolation is determined by type of crops, but anyway it is longer than on the virgin land. Under cropping of winter and early spring cereals this period continues till the middle or end of May, while under corn and fallow - even till August - depending on climate conditions (1969 and 1973; see Figs. 4.7 and 4.8). Therefore, the depth of water percolation fluctuated in wide range of 30-200 cm comparing with early-spring term.

Water movement in the cold period under the influence of thermo-gradients on the cultivated land was found only in 1972, when soil freezing reached 120 cm and water percolation - 40 cm. Apparently, it took place in the other years as well, but was leveled by deep percolation of precipitation water.

Moisture consumption on the cultivated land depends on the type of crops and climatic conditions during vegetation period. The highest amount of moisture is consumed by winter cereals and sudan grass, less by spring cereals and corn (Table 4.8). Yet, cultivated crops consume less water than natural plants. In some years part of water accumulated during the cold period was left non-used, especially in deep layers that leads to positive water balance on the cultivated lands in many years. So, yearly water balance in 0-500 cm by the end of October was in 1968 - 100 mm, 1970 - 26 mm, 1972 - 58 mm, 1973 - 157 mm. High positive balance in 1968 is due to the fact that in spring much water was accumulated along the whole profile, while consumption of water by spring barley was not much due to its biological properties; in 1973 the field was under bare fallow and the year was humid with 523 mm precipitation, where 383 mm fell for vegetation period.

Under cultivation upper zone of drying till 12-13 % level was limited to 30-40 cm depth and only in droughty years it reached 110-140 cm. At the depth 100-200 cm moisture changes during the crop vegetation varied mainly within 2-4 %, and deeper -1-2%. It is necessary to underline that in droughty years (1971 and 1972) moisture that was accumulated deeper than maximum moisture circulation layer (100-150 cm) was consumed by crops. In 1971 24 mm of moisture was accumulated, but winter wheat used 241 mm. Sudan grass planted after winter wheat further out dried the loess depth.

After the harvest at July (August) until October, 20-78 mm of moisture was lost from the soil due to physical evaporation. Especially large losses were observed in years when the soil had much residual moisture. Therefore, agro-

Table 4.8. Moisture balance in soils under cultivated crops in non-irrigated conditions.

Year	Precipitation throughout one year (mm)	Precipitation during November-March (mm)	Moisture accumulation at different layers of soil during November-March (mm)				Precipitation for crop vegetation period (mm)	Moisture consumption from different layers of soil at the day of harvest (mm)				Precipitation during April-October (mm)	Moisture consumption from different layers of soil during April-October (mm)				Yearly water balance by the end of October (mm)			
			0-200 cm	200-400 cm	400-500 cm	0-500 cm		0-200 cm	200-400 cm	400-500 cm	0-500 cm		0-200 cm	200-400 cm	400-500 cm	0-500 cm	0-200 cm	200-400 cm	400-500 cm	0-500 cm
Ascania study site. Solonetzic dark chestnut soil																				
1967	385		Winter barley					Winter barley**												
		187	150	20	0	170	158	144	18	0	162	198	150	30	0	180	0	-10	0	-10
1968	416		Plowed in autumn					Spring barley*												
		181	145	42	21	208	66	120	0	0	120	235	102	6	0	108	43	36	21	100
1969	390		Plowed in autumn					Corn for green forage***												
		132	67	0	0	67	212	62	17	11	34	258	100	9	3	112	-33	-9	-3	-45
1970	534		Plowed in autumn					Corn for green forage***												
		248	118	-8	-10	100	228	94	15	8	71	286	103	20	7	76	15	14	-3	26
1971	267		Winter wheat					Winter wheat**												
		132	44	-20	0	24	103	210	21	10	241	135	177	27	8	212	-133	-47	-8	-188
1972	328		Plowed in autumn					Sudan grass***												
		103	105	25	14	144	125	102	33	23	158	225	13	53	20	86	92	-28	-6	58
1973	523		Plowed in autumn					Bare fallow												
		140	71	8	0	79	389	33	53	18	104	389	27	37	14	78	98	45	14	157
1974	336		Winter wheat					Winter wheat**												
		125	44	48	23	115	150	156	21	0	177	211	142	40	0	187	-98	8	23	-67
Average	397	156	93	14	6	113	179	107	1	0	108	241	95	12	1	108	-2	2	5	5
Water balance for 8 years of the study																	-16	9	39	31

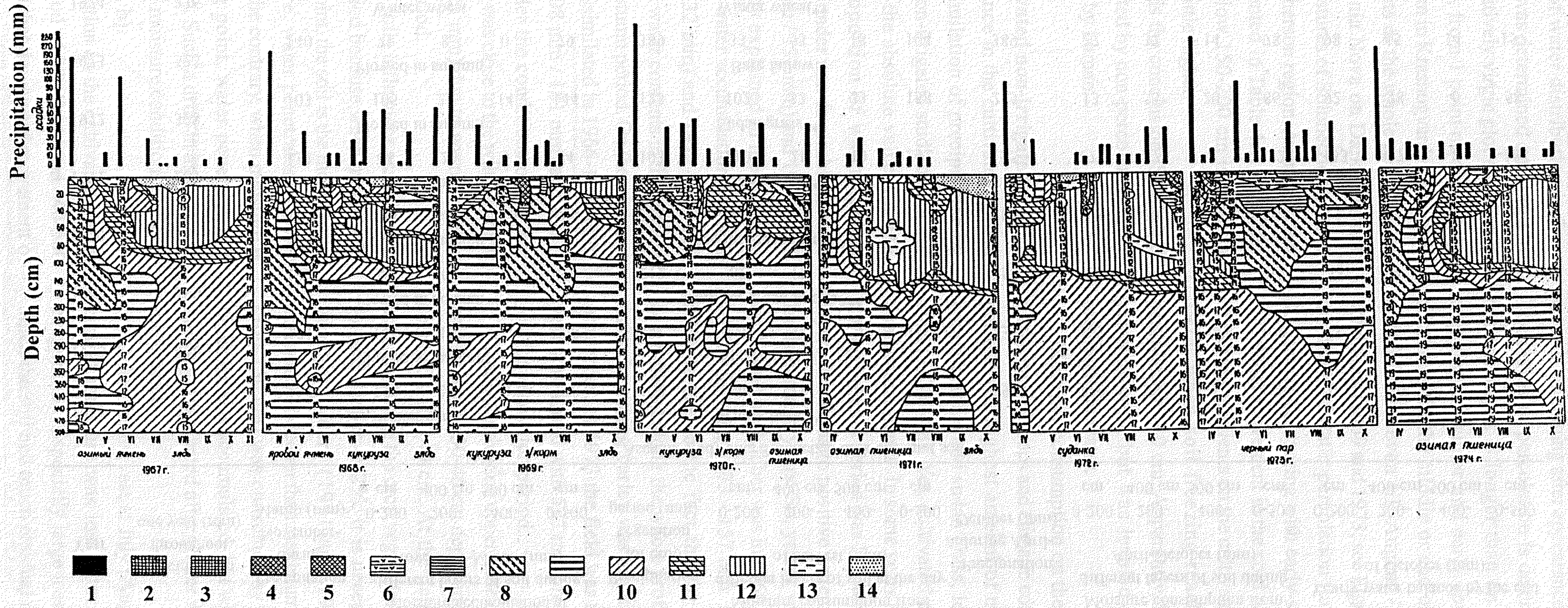

Figure 4.7. Dynamic of moisture content in the Dark chestnut soil on cultivated land.
1, >34%; 2, 32-33%; 3, 30-31%, 4, 28-29%; 5, 26-27%; 6, 24-25%; 7, 22-23%; 8, 20-21%; 9, 18-19%; 10, 16-17%; 11, 14-15%; 12, 12-13%; 13, 10-11%; 14, <9%.

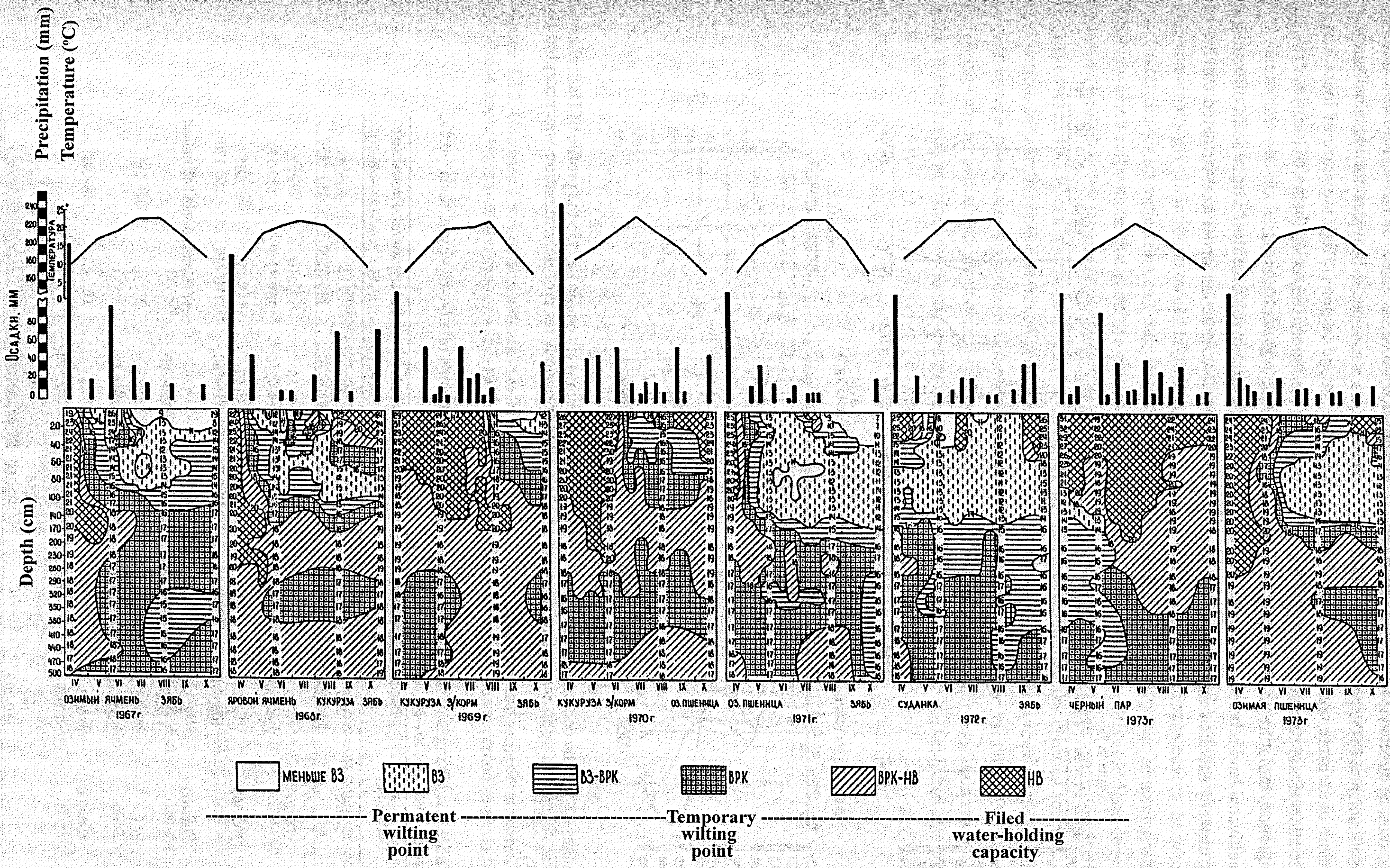

Figure 4.8. Chronoisoplets of moisture content in the Dark chestnut soil on cultivated land.

technical measures must be directed toward preservation and accumulation of soil moisture in the post-harvest period.

A unique feature of moisture regime on the cultivated land is deep penetration of moisture from precipitation.

As a consequence, moisture at the depth of loess materials in the cultivated land is between the level of field moisture-holding capacity and the temporary wilting point; and Vysotski-Rode's "dead" horizon is absent. The last phenomenon is assumed to be typical for whole the Southern and Dry Steppe regions. High moisture of loess makes premises for sporadically deep (below 500 cm) moistening of soil depth in the cold period.

Therefore, involvement of virgin soils of southern Ukraine into cultivation under non-irrigated conditions

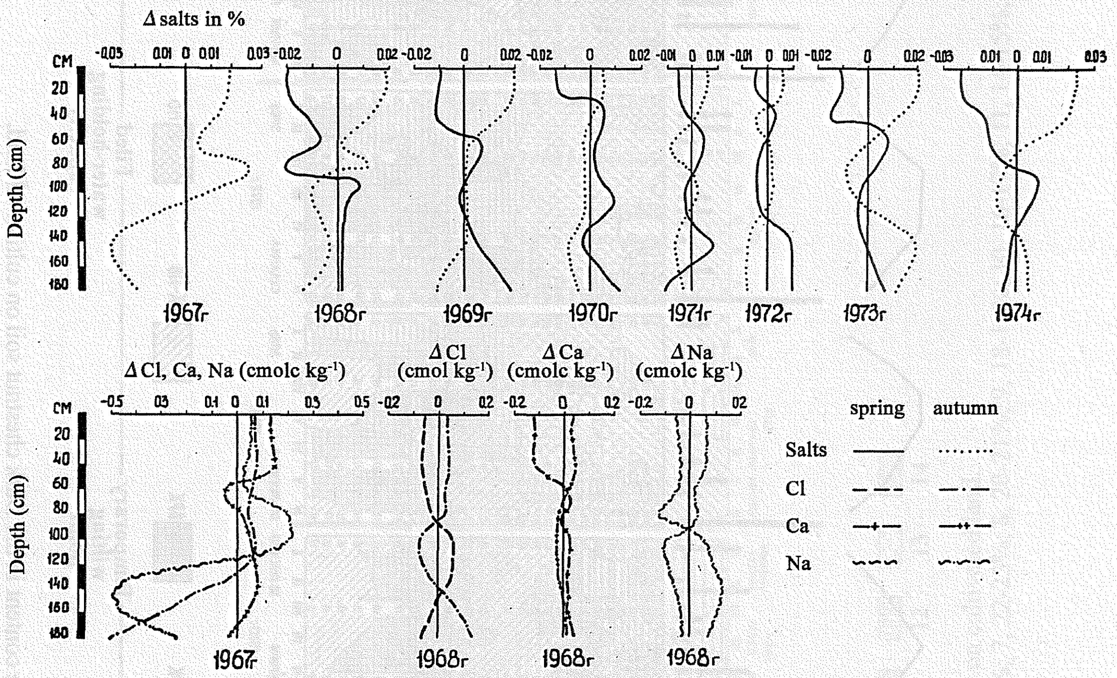

Figure 4.9. Changes (±) in the contents of salts (in %) and representative ions (in cmolc kg^{-1}) in the profile of Dark chestnut soil under natural vegetation upon seasons of the year of 1967-1974 (previous term of determination was accepted as a conditional zero).

Table 4.9. Changes of the Cl and Na contents in cultivated lands relative to virgin lands (in %; upper, average; lower, range).

Depth (cm)	Southern chernozem		Dark chestnut soil		Solonetzic dark chestnut soil	
	Cl	Na	Cl	Na	Cl	Na
0-100	200 130-500	168 130-250	232 110-400	142 110-170	2122 140-8800	454 130-1450
100-200	765 500-20000	170 150-220	655 280-920	168 140-210	2210 250-4230	227 170-350
200-300	352 160-600	124 110-150	254 120-360	140 110-180	180 170-240	165 150-170
300-400	215 130-300	103 100-106	207 180-220	139 130-150	not determined	not determined
	131 120-170	159 140-170	181 160-200	103 100-110	-“-	-“-
400-500	282 250-300	128 110-200	156 150-160	155 140-160	-“-	-“-
	127 110-200		256 240-260	103 100-110	-“-	-“-

resulted in the change of water regime from non-percolative to sporadically percolative.

4.7. Evolution of salt regime in agro-ecosystem

Salt regime was studied by determining composition of water extract in 4 terms, 4 replications. In this report, data on two terms are presented: spring and autumn, which representatively give description on salt migration.

Under the virgin vegetation salt migration occurs in relatively small soil volume that is determined by depth of moisture circulation. For 8 years of the study. The dynamics of salts covered 40-230 cm layers of the soil (Fig. 4.9). For cold period, salts from upper part of soil profile leach out, while in lower horizons of spring moistening they accumulate. For spring-summer period salts are drawn up with water flow to the surface that is well shown in the figures. Average yearly losses of salts, i.e. 0.0062%, for the studied period from 0-50 cm layer in fact were equal to the income in vegetation period (0.0068 %).

In Fig. 4.9 the dynamics of particular ions by seasons on the virgin land reflect the pattern of migration of whole salts.

On the cultivated land under non-irrigated conditions geochemical cycle of salts covers the whole studied (5 m) depth of soil (Fig. 4.10). But, comparing with the virgin land, on upper parts of cultivated land leaching of salts is predominant. So, average yearly losses of salts from one-meter depth of the Dark chestnut soil in Askania site during the 8 years' experiment were 0.0076 %, while income during spring-summer period was only 0.0033 %.

Thus, under virgin vegetation seasonal reversible cycle of water-soluble salts is established that occurs within small

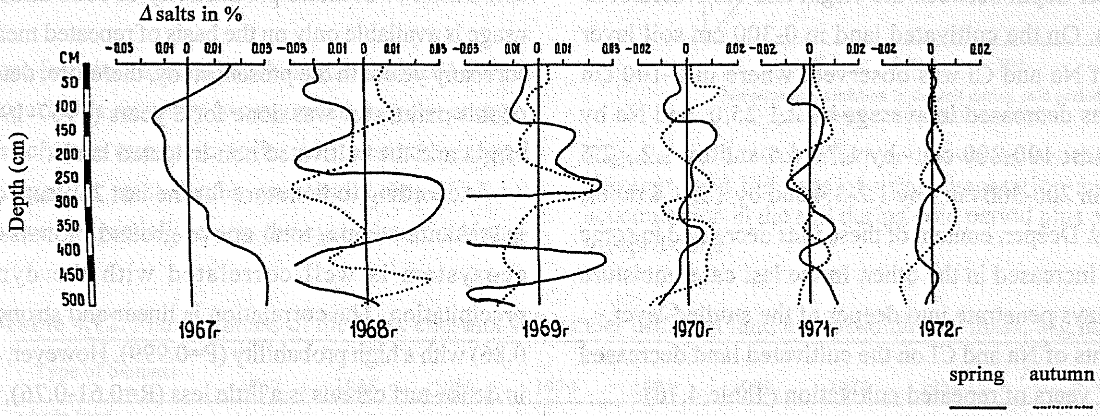

Figure 4.10. Changes (±) of salt contents (in %) in the profile of Dark chestnut soil under cultivation in non-irrigated conditions upon seasons of the year of 1967-1972 (previous term of determination was accepted as a conditional zero).

Table 4.10. Changes of the Cl and Na contents in the cultivated lands after 17-27 years (in %; upper, average; lower, range).

Depth (cm)	Southern chernozem		Dark chestnut soil		Solonetzic dark chestnut soil	
	Cl	Na	Cl	Na	Cl	Na
0-100	190	330	138	142	110	408
	130-400	200-410	110-210	120-280	105-170	270-810
100-200	856	276	193	175	504	430
	450-1040	260-300	140-300	120-270	170-1310	290-620
200-300	606	132	230	170	538	230
	470-940	120-160	120-330	110-215	140-1610	180-390
300-400	166	112	245	222	301	154
	150-170	110-120	110-370	120-312	120-600	140-170
400-500	161	107	612	160	130	106
	150-165	105-115	110-1014	110-210	110-240	100-140
			122	110		
			110-130	106-120		

soil volumes, which is determined by the moisture regime there. On the cultivated land whole the five-meter depth of soil is involved into the cycling of salts (deeper was not studied) with predominance of their leaching. This determined decrease of water-soluble salts on the cultivated land in the 0-300 (500) cm layer.

For confirmation of the last conclusion, an associated research on the contents of water-soluble salts was done in paired virgin and cultivated soils. Research was conducted on 3 points of Southern chernozems, 6 points of Dark chestnut soils and 3 points of Chestnut soils, all of which involved both virgin and cultivated lands. In every point three auger holes were set for soil collection. The soils from all the holes were analyzed for the contents of water-soluble salts. Differences in the contents of Na and Cl in the soils deeper than 50 (70) cm between the studied variants are valid at confidence level of 0.99 in most cases, and rarely at 0.95.

There is a clear difference in the contents of Na and Cl in five-meter depth between the virgin and cultivated soils (Table 4.9). On the cultivated land in 0-300 cm soil layer decrease of Na and Cl was observed; where in 0-100 cm layer Cl was decreased in average by 2.1-25.0, and Na by 1.4-6.6 times; 100-200 cm - by 1.7-14.6 and by 1.2 - 2.6 times; and in 200-300 cm - by 1.2-3.4 and by 1.2-1.4 times, respectively. Deeper, content of these ions decreased in some places and increased in the other. In the last case, moisture did not always penetrate into deeper of the studied layer.

Contents of Na and Cl on the cultivated land decreased after 17-27 years of repeated cultivation (Table 4.10).

Presented data about changes of water-soluble salts in the cultivated land relative to the virgin land confirms the data on evolution of water regime during the cultivation.

Consequence of the changes of salt content in the cultivated lands, especially Na, is a decrease of amount of absorbed Na (Table 4.11).

4.8. Productivity of plant biomass of virgin and cropped ecosystems

Plant biomass was measured according to the method of Remezov (1960) and Remezov et al (1963). Aboveground biomass was determined on 1 m x 1 m plots in 5-7 replications. Biomass of cultivated crops was differentiated into stubble residues and harvested part, where harvested part was separated into main and side products.

Belowground biomass was measured by sampling monoliths of 0.25 and 0.36 m^2 in three replicates. They were sampled from every 20 cm till one-meter depth. The roots collected were washed on 0.2 mm Capron meshes for eliminating mineral soils. Possibility of losses of fine plant materials was carefully avoided. Then the roots were differentiated into live and dead parts. Only living plant biomass was counted after drying at 105°C and then absolute dry matter was calculated.

According to the research of Remezov (1960), estimation of biomass productivity of soils under different usage is available only on the basis of repeated measurements for many years. In the present study, therefore, determination of this parameter was done for 8 years (1967-1974) on the virgin and the cultivated non-irrigated lands.

According to literature for the last 25 years of research in Askania steppe, total above-ground biomass of plakor ecosystem is well correlated with the dynamics of precipitation. The correlation is linear and strong (R=0.75-0.86) with a high probability (P=0.999). However, correlation in dense-turf cereals is a little less (R=0.61-0.76), in *Festuca valesiaca* Gand is even less (R=0.41-0.67). At the same time biomass of feather grass does not correlate with precipitation (R=0.10-0.17). Productivity of *Koeliria cristata* significantly depends on precipitation (R=0.68-0.84), motley-grass is satisfactory at high probability (R=0.48-0.74). Dependence of productivity of sedge-wheatgrass association "saucers" is medium (R=0.52) (Vedenkov and Vedenkova, 1998).

Table 4.11. Seasonal change in the contents of exchangeable cations (average for 1967-1974).

Depth (cm)	Contens of exchangeable cations in different month (cmol$_c$ kg^{-1})							
	Ca		Mg		Na		K	
	IV	X	IV	X	IV	X	IV	X
virgin								
0-30	20.0	20.7	6.8	7.4	0.3	0.4	1.3	1.2
30-40	21.8	22.1	8.2	8.9	0.4	0.5	0.9	0.8
cultivated								
0-30	21.5	21.9	6.3	6.8	0.2	0.2	1.0	0.9
30-40	23.0	23.4	7.3	7.5	0.2	0.3	0.9	0.9

Determination of productivity of the aboveground biomass was done on associations of fescue and stipa in two replications, and of couch grass - sedge association "saucer" in one replication. Such approach represented the surface area corresponding to individual vegetation associations and their total productivity.

Productivity of the aboveground biomass was 2.81 Mg ha^{-1} in average where significant yearly variation was included (1.90-3.60 Mg ha^{-1}) (Table 4.12), which was a result of fluctuation of moisture accumulation during the cold period in the soils and the amount of precipitation for April-July (Fig. 4.11). Correlation between the index and plant biomass stock is 0.80. Other authors also obtained similar results of total amount of biomass for Askania steppe (Bazilevich, 1962; Shalyt, 1950). The ratio between the belowground and the aboveground biomasses varied within 6.8-9.0.

Most of the root biomass is concentrated in the upper part of the profile. In 0-20 cm there is 57.2 (48.1-66.2) % of roots.

In steppe formations not all the biomass produced during vegetation period is annually incorporated into the energy/elements-exchange cycles in soils. All the aboveground biomass, except for semi-shrubs, practically dies off. Root biomass, however, partially enters the cycle due to its long-term evolution. Today, there is no established methodology for counting yearly cycles of biological circulation of the belowground biomass. Yearly roots dying-off are assumed to be the amount of root-fall in total root biomass. According to literature, in the motley-fescue-stipa steppes yearly roots dying-off is 32-35% (Bystritskaya and Osychnyuk, 1975; Rodin and Bazilevich 1965).

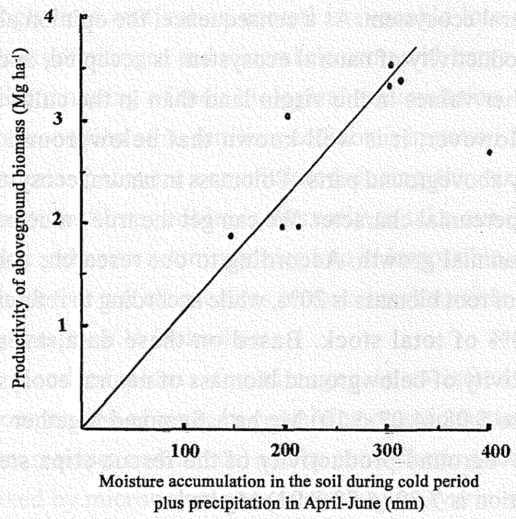

Figure 4.11. Correlation between productivity of aboveground biomass of virgin vegetation and moisture accumulation in the soil during cold period plus precipitation in April-June.

Table 4.12. Plant biomass of the Dark chestnut soils under different land use (absolute dry mass, Mg ha^{-1}).

Type of biomass	Year 1967	1968	1969	1970	1971	1972	1973	1974	Average
virgin land									
Aboveground	2.88	2.01	3.20	3.43	2.04	1.90	3.60	3.40	2.81
Belowground	24.01	18.24	23.03	18.34	16.61	15.40	25.00	22.30	20.36
0-10	7.20	6.71	9.04	7.52	6.33	6.24	9.60	8.50	7.61
10-20	4.06	2.07	6.20	3.64	3.54	3.58	4.40	3.00	3.81
20-40	6.52	5.51	4.56	3.63	3.90	2.49	6.36	6.00	4.83
40-60	3.00	2.45	2.02	2.64	2.00	2.06	2.70	2.43	2.40
60-80	2.90	1.16	0.82	0.53	0.60	0.35	1.30	1.40	1.34
80-100	1.33	0.63	0.41	0.34	0.24	0.68	0.74	0.70	0.72
Non-irrigated cultivated land									
Crops	Winter barley	Spring barley	Corn for green forage		Winter wheat	Sudan grass	Bare fallow	Winter wheat	Average
Aboveground	6.88	4.43	3.60	3.04	7.61	1.56	-	8.44	4.51
Harvested	6.09	4.05	3.00	2.50	6.61	0.83	-	7.34	3.80
Stubble residue	0.79	0.88	0.60	0.54	1.00	0.73	-	1.10	0.71
Belowground	3.15	8.68	2.73	2.10	4.56	2.40	-	3.80	3.43
0-20	1.80	6.69	1.98	1.14	2.18	1.55	-	1.65	2.12
20-40	0.67	1.10	0.39	0.44	1.06	0.48	-	1.02	0.65
40-60	0.38	0.55	0.14	0.34	0.68	0.20	-	0.58	0.36
60-80	0.20	0.22	0.16	0.15	0.40	0.12	-	0.36	0.20
80-100	0.10	0.12	0.06	0.02	0.25	0.05	-	0.19	0.10

Amount of the root biomass for the studied years varied in a wide range - 15.4-25.0 Mg ha^{-1}, implying that the rootfall in average makes about 20% (((25.0-15.4)/2) / (15.4+25.0)/2)). The later value would be, at the same time, a mean value of yearly roots production. In a humid year after droughty years, it reached sometimes even 39.4% of the root biomass.

At the present time most researchers consider the stock of total plant biomass as a value of biomass productivity of the natural ecosystem. As a consequence, the opinion about high productivity of natural ecosystem is accepted, and we get higher values in the virgin land than in the cultivated land. However, it is well known that belowground and partially aboveground parts of biomass in natural ecosystems have a perennial character. We can get the true value based on the annual growth. According to our research, annual growth of root biomass is 20%, while according to references it is 30% of total stock. Based on these data, average productivity of belowground biomass of natural ecosystem equals to 5.08 (4.07-6.10) Mg ha^{-1}. Summed together with the aboveground productivity of the fescue-stipa steppe association is 7.89 (6.88-8.91) Mg ha^{-1}.

As mentioned above, active decomposition of plant residues start with a certain time lag after their input and that leads to decrease of the residues. It is very important to know which part of biomass is incorporated annually into the energy-mass-exchange in soils. Energy of decomposition on virgin land was in average 34.6% (This value was obtained from the decomposition experiment of cellulose sheet, described later in the section 4.10). Hence, in the natural ecosystem about 3 Mg ha^{-1} is involved in the annual energy-mass-exchange.

Cultivated crops are different from natural plants in the ratio of aboveground and belowground parts. In most of the cultivated crops aboveground biomass predominates (Egorov and Dyuryagina, 1973; Levin, 1972; Stankov, 1972). This is a normal phenomena because root systems of annual cereals and leguminous is weakly developed, while high productivity of aboveground biomass is well developed by breading. Ratio of aboveground to belowground parts in cultivated crops depends on the yield; the higher yield the higher is the ratio. During the studied years ratio of aboveground to belowground biomass in spike cereal crops was 1:0.4-0.6, in corn - 1:0.3-0.8. Only for perennial grasses the ratio was higher than one; in sudan grass - 1:1.5 and in alfalfa - 1:1.5-1.9.

Our results on the productivity of biomass of some crops comply well with results of other researchers (Danilevskii, 1967; Levin, 1972; Samtsevich, 1968; Tukalova and Zapsha, 1976; Shalyt, 1950; and others).

On non-irrigated cultivated field the amount of aboveground biomass is in average 1.6 times higher than that on the virgin land.

However, total amount of roots in agro-ecosystem is significantly lower: non-irrigated lands have 5.9 times, and irrigated -3.2 times less than in the virgin lands. But comparison should be done upon net growth that in natural ecosystem makes 20-30% of the total root biomass. Considering the latter, biomass productivity of the non-irrigated cultivated land will be less only by 1.2-1.8 times comparing with virgin land; and on irrigated land it is even higher by 1.1-1.6 times.

On the cultivated land, same as on the virgin land, main root biomass is concentrated in upper part of soil profile. In 0-20 cm layer it is 59.4 (43.4-77.0) %. This is well in agreement with data of other researchers.

Mean productivity of the non-irrigated field was 7.94 Mg ha^{-1}; on the virgin land - 7.89 Mg ha^{-1} as mentioned before (Table 4.12).

Important characteristics of the biological cycle in the agro-ecosystem are that a part of biomass is removed with harvest. On non-irrigated land in average 3.80 Mg ha^{-1} (47.8%) of biomass is taken away with harvest.

On the cultivated land organic matter is incorporated into soils as stubble and roots. It amounted 4.14 Mg ha^{-1} yr^{-1} for 8 years of our research in average

Income of organic residues into soil depends on the type of crops. Perennial grasses leave the highest amount of residues and then cereals follows; among them winter crops leave more, and spring crops leave less; row crops leave the least residues. However, average amount of organic residues for crop rotations of different purpose under non-irrigated conditions of Chernozem zone is the same- 4.97 - 5.47 Mg ha^{-1} (Bisovetskii, 1966; Byaluii, et al., 1953; Sidorov, 1958) that evidences weakly developed zonality of organic residue input in agro-ecosystems.

In our research, based on the data on the productivity of plant biomass mentioned above and the biological activity analyzed in section 4.10, in average 2.91 Mg ha^{-1} of plant biomass (4.14 Mg ha^{-1} times 70.3%) participates in the annual energy-mass-exchange of the non-irrigated field.

At present numerous researchers established that the characteristics of exchange of nitrogen and mineral elements on cultivated land was significantly changed relative to virgin land. Biological cycle of elements under the fescue-feathergrass association in Askania Nova is characterized by the following order: $SiO_2 > N > Ca > K > Mg > Al > Cl > P > Fe > Na$ (Bazilevich, 1962). Biogeochemical cycle of elements in other types of steppes is close to the given series (Egorov and Dyuryagina 1973; Rodin and Bazilevich, 1965).

Crop properties for involving of nitrogen and mineral elements into biological cycle are the following (Egorov and Dyuryagina, 1973; Levin, 1972; Tukalova and Zapsha, 1976; and others):

Winter wheat,	$SiO_2 > N > K > Ca > P > Mg > Na > Fe > Al$
Spring barley,	$N > SiO_2 > K > Ca > P > Mg > Na > Al > Fe$
Corn,	$N > K > Ca > SiO_2 > Mg > P > Na > Fe > Al$
Peas,	$N > Ca > K > SiO_2 > P > Mg > Al > Fe$
Sunflower,	$N > K > Ca > Mg > P > SiO_2 > Na > Fe > Al$
Alfalfa,	$N > Ca > K > Mg > P > Na > SiO_2 > Fe > Al$

Using the data on the contents of nitrogen and mineral elements (Bazilevich, 1962; Tukalova and Zapsha, 1976; Tomme, 1968), their quantity in biomass was calculated on the studied fields (Table 4.13).

The characteristics of nitrogen and mineral elements cycle on the virgin land are analogous to the above-mentioned. Capacity of biological cycle on the virgin ecosystem is by 1.4 times lower than that on non-irrigated cultivated land.

According to data by Tyurin (1956), Kononova (1963), Levin (1972), etc., discriminative property of mineral exchange on cultivated land is the significant excess of nitrogen output and deficiency of macro- and microelements upon their return. In our research on the non-irrigated land in average 56% of nitrogen and 30% of mineral elements are taken out. However, their amounts in the annual cycle of the cultivated field is not less than of the virgin land.

In virgin condition all the synthesized biomass of plant organic matter is incorporated into soils after dying and enriches upper soil horizons with humus, nitrogen and mineral elements. Cultivated land loses large parts of humus, nitrogen and mineral elements with harvest. By the opinion of many researchers, from the moment when virgin land is brought into cultivation annual irrevocable loss of large amounts of nitrogen and mineral elements with harvest results in discontinuing of their biological accumulation, and soil in the condition of no fertilizer addition is impoverished with elements that were accumulated during the virgin soil formation. "Impossible, is eternally to take out from the pocket and never return anything into it! Impossible, is really, to think that our chernozems possess inexhaustible stock of nutrients!" - V.V. Dokuchaev.

Need of plants for nitrogen is satisfied by the decomposition of nitrogen-containing organic matters in soil (plant residues and humus) and by atmospheric nitrogen that is fixed by microorganisms. According to Tyurin's opinion (1956) after cultivation of virgin soil, balance of bound nitrogen is significantly changed: instead of accumulation decrease of nitrogen together with decrease of humus happens because nitrogen output is larger than the input. According to Tyurin's calculation every kilogram of nitrogen lost by soil turn in decrease of 0.02 Mg ha^{-1} of humus. In our study of non-irrigated cultivated land annual output of nitrogen averaged 69 kg. Difference in humus content between virgin

Table 4.13. Biological cycle of nitrogen and mineral elements in different ecosystems on Dark chestnut soils (average for 1967-1974 at Askania site; in kg ha^{-1}).

Index of cycle*	N	SiO_2	P	Ca	Mg	Fe	Al	K	Na	S	Sum
Virgin land											
1	290	368	18	151	35	23	31	101	5	15	1037
2	99	135	8	41	11	6	10	49	1	6	366
4	34	47	3	14	4	2	4	17	1	2	128
Non-irrigated cultivated land											
2	124	178	15	27	19	21	7	99	15	24	529
3	69	32	9	11	8	1	1	48	4	9	192
4	55	146	6	16	11	20	6	51	12	15	338
5	41	102	5	11	8	14	4	36	8	11	240

*1, total plant biomass; 2, net primary production of plants; 3, amounts that are taken away as crop yield; 4, amounts that are incorporated into soils; 5, amounts that contribute annual exchange in the soil-ecosystems.

and cultivated land is 16.26 Mg ha^{-1}. This amount of humus, based on Tyurin's calculation, can compensate harvested nitrogen only for 12 years. But the soil is actually used in agriculture for more than 100 years. Therefore, it is difficult to agree with Tyurin that nitrogen used by cultivated crops mainly derived from humus. The fact that nitrogen output is occurring with harvest does not mean inevitable large losses of nitrogen and humus after cultivation of virgin land (Levin, 1972). This is confirmed by results on dynamics of humus and nitrogen in long-term experiments. Under the 50-100-years cereal monoculture without fertilization, contents of humus and nitrogen in soils were not decreased, in some cases even increased (Egorov, 1962; Lyubarskaya, 1960; Montulyak, 1960; and others).

There are another sources that also compensate the nitrogen output by agricultural crops: it is first of all plant residues that are decomposed more easily and quickly than humus. Therefore, when large amount of crop residues are left, following crops will consume first of all nitrogen from crop residues of the preceding crops but not from humus.

Apart from the fact that crop residues contain a lot of nitrogen and mineral elements, they contribute to evolution of microbiological processes as well as mobilization of nutrients into plant available forms, including fixation of atmospheric nitrogen. The latter phenomenon in the cultivated soil is observed more intensively than in virgin land (Karnaukhov, 1957; Mishustin and Teplyakova, 1957; Mishustin et al., 1968; Sidorenko, 1966; and others).

At present there are about 200 species of non-leguminous crops that are able to assimilate atmospheric nitrogen in symbiosis with the microorganisms (Mishustin et al., 1968). Therefore, accumulation of nitrogen in soils through fixation of atmospheric nitrogen by microorganisms has important value in balance of biological cycle.

Plants get mineral nutrients not only from soils. Their biological cycle on virgin land has closed cyclic nature. On cultivated land balance of mineral nutrients is negative because part of them is taken out with harvest. Herewith, capacity of biological cycle of mineral elements does not decrease (Table 4.13).

Thus, from the aspect of bio-productivity, the cultivated soils under non-irrigated conditions are close to their virgin analogues. Practically the same amount of biomass takes part in the annual energy-mass-exchange in the virgin and the cultivated non-irrigated land. Capacity of cycles of nitrogen- and mineral-elements on the cultivated land is higher than on the virgin land. However, due to output with harvest, a large part of biomass and stock of energy and elements that have been accumulated in organic and mineral components of soils during virgin soil formation period will be decreasing on cultivated land without addition of organic and mineral fertilizers.

4.9. Peculiarities of microbiological processes in the study zone

From north to south together with the increase of intensive sunshine and heat, energy of summary expression of biological processes increases (Williams, 1939). Therefore, soils of south and dry-steppe zones are characterized by high biosynthesis and high activity of microbiological processes (Egorova, 1966; Mikhnovskaya, 1981; Mishustin, 1954; Petrenko and Glushenko, 1965; Torzhevskii, 1968; and others).

Samtsevich (1955; 1966) noted that the activity of microorganisms in southern soils continues round the year; in winter months at the condition of enough moisture and temperature higher than 0°C their activity does not decrease completely. Maximum evolution of microbiological processes is observed at the first half of vegetation period, with a subsequent decrease in summer when soil is dry. In southern Ukraine, amount of microorganisms in the second half of summer is 2 to 3 times less than in spring and early summer period (Torzhevskii, 1972). In spite of decrease of microbial population in summer, biochemical processes in soils do not weaken. Different kinds of enzymes that are released during cell activity continues to run the processes (Mishustin, 1949).

Soils of the Southern and Dry steppe zones are characterized by high energy of transforming processes: ammonification, nitrification, nitrogen fixation, decomposition of cellulose etc (Mamchenko, 1970a; Mishustin and Teplyakova, 1957; Petrenko and Glushenko 1965; Sidorenko, 1966; and others).

It was determined that cultivated soils are characterized by greater amount of microorganism spores and by different ratio of specified groups of microorganisms (Mamchenko, 1970b; Mishustin and Teplyakova, 1957; Petrenko and Glushenko 1965; Torzhevskii, 1968; and others). In the soil processes role of bacteria and bacillus is increased, while role of actinomycetes and fungi is decreased.

Specific weight of fungi population in the studied soils is not significant; on the virgin lands is 0.3-1.2%, on the cultivated - 0.3-0.4%. But their role in elemental cycle in soil is large, especially in decomposition of cellulose and plant residues (Vaksman, 1934). Teplyakova (1952) notes that cellulose-forming activity of fungi in chestnut soils of Kazakhstan is much greater than cellulose-destroying activity of bacteria. Considering the small sizes of bacterial cell comparing with fungi spore or vegetating fungi, the total weight of fungi often outnumbers weight of bacteria (Vysotski, 1962).

Many researchers consider ratios of the different microorganisms that use organic and mineral nitrogen as an index of intensity of mineralization processes. In the cultivated lands of our research it is significantly higher than under the virgin vegetation (Mamchenko, 1970b; Mikhnovskaya, 1981; Torzhevskii, 1968).

Amount of microorganisms in the soils of the southern Dry steppe zone is decreasing down the profile (Egorova, 1966; Torzhevskii, 1968; Chulakov, 1961). Herewith relative amount of bacteria and mildew fungi is decreasing with depth, while the relative amount of actinomycetes is increasing. Such distribution is typical both for the virgin and the cultivated lands. Many scientists explain decrease of microbial population with depth in a soil profile by decrease of organic matter as an energetic source.

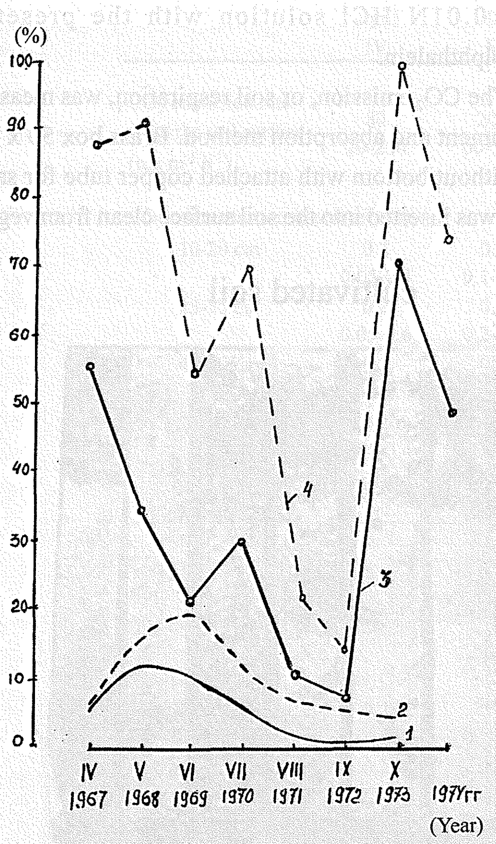

Figure 4.12. Mean data of cellulose decomposition in Dark chestnut soil along months for the studied years (1967-1974) (1, 2) and for the whole warm period of the years (3, 4) on the virgin land (1, 3) and the cultivated non-irrigated land (2, 4).

In conclusion of the brief literature review it is necessary to point out, that in soils of south Ukraine of different ecological conditions microflora is identical, that evidences the unitypicity of biological processes in them. Increase of the total amount of microorganisms and separate physiological groups is an indicator of the change of their activity and intensity.

4.10. Biological activity

Biological activity was studied during the warm period of year under the virgin and the cultivated vegetation with no irrigation, by the method of Vostrov and Petrova (1961). On every plot a trench was dug; walls were carefully leveled and 21 stripes of cellulose textile of 10 x 80 cm were placed on them. The textile was liberated from starch and every stripe had an exact weight. Textile stripes were covered by a film to prevent contact with backfilling soil. At the end of every month (± 3-5 days) three stripes of textile were taken out from soil, dried and weighed by an analytical balance. Decrease of weight indicated the energy of cellulose decomposition. Every following year walls of trench were freshened and the experiment was repeated.

Averaged data of biological activity for the individual months or whole the period of warm months in a year are shown in Fig. 4.12 for 1967-1974.

The smaller activity of decomposition was observed in the Dark chestnut virgin soil than in the cultivated soil. In the virgin soil, amount of decomposed cellulose during whole the warm period in a year was 34.6% in average, with fluctuations between 6.4-71.2%. The highest biological activity was observed in the humid year (1973 - 523 mm), the least in dry years (1971 and 1972 - 267 and 328 mm, respectively).

Low biological activity under virgin ecosystem is also typical for another steppe regions. According Egorov and Dyuryagin (1972), in West Siberia biological activity never exceeded 30%, while on cultivated land in average 60% of cellulose was decomposed.

During the warm period of a year, the highest amount of cellulose was decomposed during May-June when soil had relatively favorable conditions of water and temperature regimes. In July, and sometimes in August, decomposition of the cellulose was undertaken mainly ephemerally, when precipitation occurred and their moisture penetrated into 10-20 cm layer or deeper of soils. From August to October textile was practically not decomposed. In this period soil moisture content in the virgin land was close to the wilting point level.

Thus, biological activity on the Dark chestnut soils on the virgin land is mainly determined by their water regime. This is because water regime is a main factor in evolution of microbial systems under virgin vegetation (Torzhevskii, 1968; Torzhevskii, 1972).

In the Dark chestnut soils of non-irrigated cultivated land the biological activity is significantly higher than in the virgin land (Fig. 4.13). Average amount of annually-decomposed cellulose is 70.3%, with fluctuations -14.3-130.2%. The least activity was observed in dry and the highest in humid years. Herewith, in a humid year (1973) the experimental field was under bare fallow. Due to favorable water and temperature regimes on fallow the textile was practically completely decomposed till 50 cm by the end of July. Therefore, new textile was set in the trench.

Today the fact of such intensive decomposition of organic residues in cultivated soil is well established. Depending on hydrothermal conditions of soil and quality of plant biomass, their decomposition varies within 50-87% (Egorov and Dyuryagina, 1972; Kononova, 1951; Kulakov, 1960; Sultanov, 1972; and others).

Cultivated crops did not exert a direct influence on biological activity. Their effect was exerted through water regime. Under favorable conditions, energy of cellulose decomposition was the same both under cereals and row crops.

Based on these results we can conclude that the biological activity in the soils of studied region is determined by the water regime. Under virgin vegetation due to fast water consumption by evapotranspiration, cellulose decomposition is short-termed, and occurs in spring and early summer time; the total activity of decomposition is not so high. In the soils of non-irrigated cultivated lands, the biological activity and decomposition rate increased by 2 times due to the improved water regime.

4.11. Carbon-dioxide regime in soil gas phase and its emission

Concentration of CO_2 in the soil air was determined by the method of Makarov (1959). On the experimental plot copper tubes of 3-5 mm in diameter with open ends were set in 4 replications at depths of 10-20, 25-35, 40-50, 70-80 and 150-160 cm. Samples of soil air were taken monthly from early April till late October in three replicates from every point between 8 a.m. and 1 p.m. Convergence of parallel determinations both from one tube and between tubes was high, deviation did not exceed 0.5-6.5%. Carbon dioxide was then absorbed by 0.01 N $Ba(OH)_2$, followed by the titration with 0.01N HCl solution with the presence of phenolphthalein.

The CO_2 emission, or soil respiration, was measured by enrichment and absorption method. Brass box 50 x 50 x 30 cm without bottom with attached copper tube for sampling of air was inserted into the soil surface clean from vegetation.

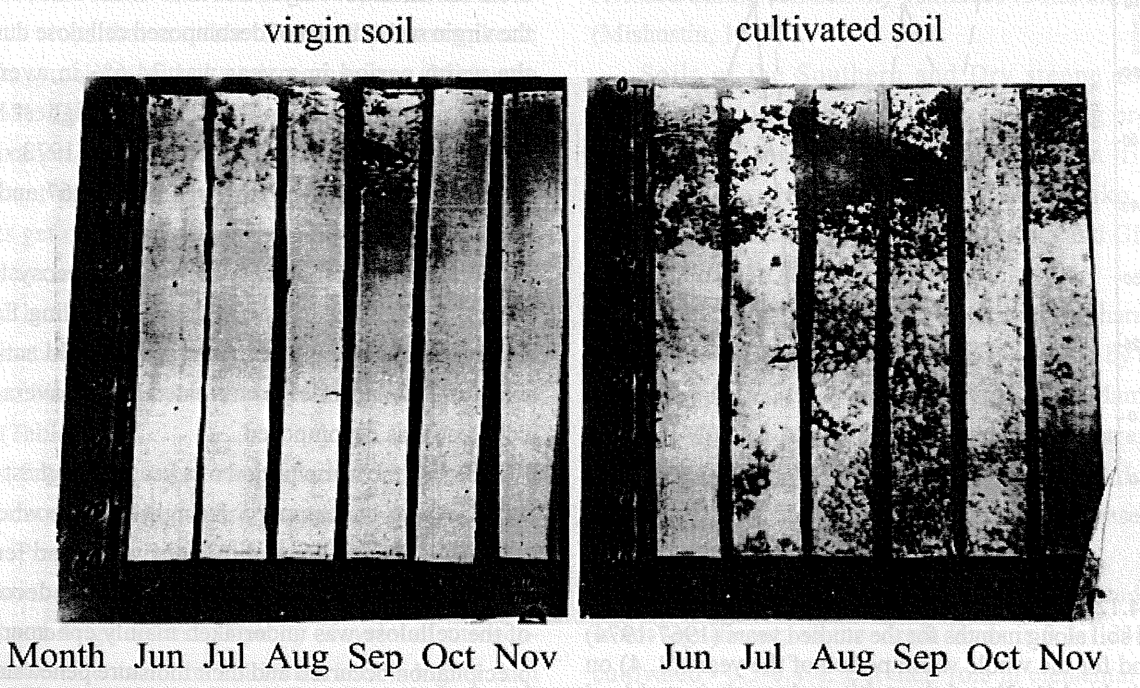

Figure 4.13. Fragment of dynamic of cellulose decomposition on the virgin and the fallowed land (1967).

Soils around the box were compacted to prevent from gas exchange with external air. Exposition time was set for 30 min. Then, through the copper tube air probe was sucked out using Makarov equipment where 0.01N $Ba(OH)_2$ solution was placed; then the solution was titrated with 0.01N HCl solution. Before determination of soil respiration initial concentration of CO_2 in the box was measured.

Intensity of CO_2 emission (mg m^{-2} h^{-1}) from soil was calculated according to following equation:

$$D = ((a-b) \cdot 0.22 \cdot V_1 \cdot 60) \ / \ (V_2 \cdot S \cdot t)$$

where a is the volume of 0.01N HCl solution consumed for the titration of $BaCO_3$ after absorption of CO_2 at the beginning of determination (mL); b is also the volume of 0.01N HCl solution spent for the titration of $BaCO_3$ after absorption of CO_2 at the end of determination (mL); V_1 is the volume of air in the box (L); 0.22 is the volume of CO_2 equivalent to 1 mL of 0.01N HCl (mL); V_2 is the volume of air taken for determination of CO_2 (L); S is the area of soil surface under the box (m^2); and t is exposition time (min).

"Soil air, together with soil solution, forms integral and composite part of soil that participates and even determines the whole life of soil" (Doyarenko, 1926). Presently it is established that soil air composition is characterized by the intensity and direction of biochemical processes in the soil. It is determined by genetic nature of soils and their status depending on season of the year and other factors. According to numerous literature sources, carbon dioxide in soil is formed due to the activity of microorganisms, soil fauna, root respiration and biochemical processes.

The soils studied in our research are scarcely known in terms of carbon dioxide regime of the soil air. This gap was filled by specially undertaken soil investigations. The task was to study dynamics of CO_2 in the soil air seasonally and its variation under different land usage.

Table 4.14. Concentration of CO_2 (%) in the soil air and its emission rate from the soil surface (mg m^{-2} h^{-1}) in the Dark chestnut soils of Askania experimental site (upper - mean for 1967-1974, lower fluctuations).

	Month						
	April IV	May V	June VI	July VII	August VIII	September IX	October X
virgin land							
CO_2 emmision rate from the soil surface (mg m^{-2} h^{-1})	80 20-200	200 60-360	330 50-680	180 50-650	70 20-200	60 20-160	30 10-60
CO_2 concentration in soil air (%)							
10-20 cm	0.2 0.05-0.4	0.4 0.1-0.8	0.6 0.1-1.2	0.3 0.1-1.3	0.1 0.03-0.3	0.1 0.03-0.2	0.06 0.03-0.1
25-35 cm	0.2 0.05-0.6	0.5 0.2-1.0	0.7 0.1-1.3	0.4 0.1-1.3	0.2 0.03-0.6	0.2 0.03-0.3	0.09 0.03-0.2
40-50 cm	0.3 0.05-0.6	0.6 0.2-1.1	0.7 0.1-1.5	0.5 0.1-1.3	0.3 0.05-0.8	0.3 0.05-0.5	0.13 0.03-0.4
70-80 cm	0.2 0.05-0.4	0.5 0.1-0.8	0.6 0.2-0.9	0.7 0.1-1.1	0.5 0.2-1.0	0.4 0.1-1.1	0.18 0.07-0.4
150-160 cm	0.2 0.1-0.6	0.4 0.2-0.7	0.5 0.3-0.8	0.6 0.4-0.9	0.7 0.3-1.2	0.6 0.2-0.8	0.27 0.1-0.5
cultivated land							
CO_2 emmision rate from the soil surface (mg m^{-2} h^{-1})	80 20-120	260 80-540	280 50-680	300 50-590	160 80-360	100 40-200	40 10-100
CO_2 concentration in soil air (%)							
10-20 cm	0.2 0.05-0.3	0.6 0.2-0.8	0.5 0.1-1.2	0.6 0.1-1.0	0.4 0.2-0.6	0.2 0.05-0.4	0.06 0.02-0.1
25-35 cm	0.2 0.07-0.3	0.6 0.2-1.8	0.6 0.1-1.3	0.6 0.1-1.2	0.4 0.1-1.2	0.3 0.1-0.6	0.11 0.03-0.4
40-50 cm	0.3 0.1-0.4	0.7 0.4-1.3	0.6 0.1-1.5	0.6 0.1-1.3	0.5 0.2-1.1	0.3 0.1-0.5	0.18 0.03-0.4
70-80 cm	0.2 0.1-0.3	0.6 0.2-1.0	0.6 0.2-1.2	0.8 0.2-1.3	0.8 0.3-1.3	0.6 0.2-1.0	0.38 0.1-0.8
150-160 cm	0.2 0.1-0.5	0.5 0.2-0.8	0.6 0.4-1.1	0.8 0.5-1.3	0.8 0.5-1.5	0.9 0.4-1.4	0.61 0.2-1.0

Average data is presented in Table 4.14 and Fig. 4.14. In all the treatments, concentration of CO_2 in the soil air increases from spring towards summer and decreases towards autumn. Differences in the quantity of CO_2 between the sites were observed.

On the virgin land in spring, in April, the CO_2 concentration in the soil air along profile was even with insignificant predominance in lower parts in some years. In May and June increase of CO_2 concentration by 2 to 3 times or more was observed, that was a result of increased activity of biological processes. In this period soils are characterized with the highest activity of organic residue decomposition. Besides, natural vegetation in this period intensively grows with exuding carbonic acid into soil that decomposes into CO_2 and H_2O. Combined effect of these two processes promotes a sharp increase of partial pressure of carbon dioxide in the soil air.

In the second half of summer CO_2 concentrations gradually decreased due to cease of biological activity both of microorganisms and of plants. In the upper part of soil profile losses of CO_2 occur faster than the lower layers due to gas diffusion into the air, while in the lower part the CO_2 concentration is increased due to downward flux of CO_2 as a heavier gas (Nikolaeva, 1964).

In autumn, the virgin land contains minimum amount of CO_2 in the soil air because of very weak biological processes. The concentration of CO_2 in the upper part of the soil profile is drawn near concentrations of CO_2 in atmosphere.

On the cultivated land, dynamic of CO_2 concentration in the soil air under different crops follows general rules, namely - the concentration of CO_2 as well as CO_2 emission from the soil surface increases from spring to summer and decreases by autumn.

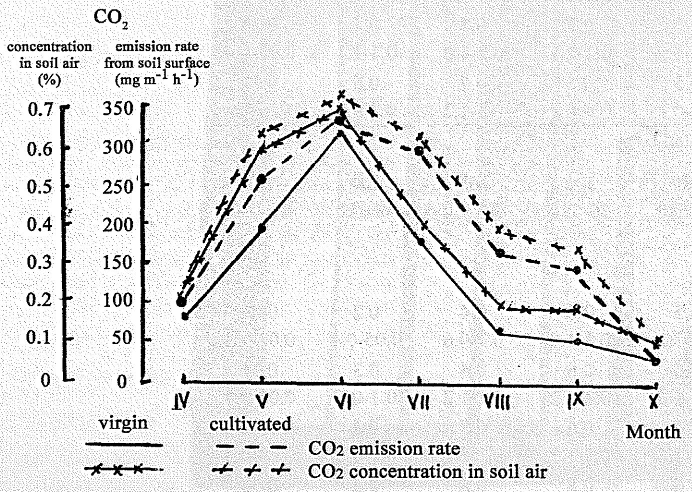

Figure 4.14. Dynamics of CO_2 concentration in 0-40 cm layer of Dark chestnut soil on the virgin and the cultivated land and the rate of CO_2 emission into the atmosphere.

In April differences in the CO_2 concentration between the studying sites are not significant. On the non-irrigated cultivated land it is practically the same as on the virgin land. The CO_2 concentration increased in May, and then reached maximum values in June and July. In this period the concentration of CO_2 in the soil air on the non-irrigated cultivated land was by 1.3-1.5 times higher than on the virgin land in average.

From August, the concentration of CO_2 in the cultivated land gradually decreased but was still high enough. In the profile of the non-irrigated soils, the CO_2 concentration in August-September is 2.2-1.3 times larger than that of the virgin land. In October, the concentration of CO_2 in the upper part of the soil profile on the non-irrigated land is similar as that on the virgin land, while deeper than 50 cm the soils in the non-irrigated land contains 2 times higher CO_2 than the others.

The accumulation of CO_2 in the soil air is related to both the microbiological activity and its production by cultivated crops. On the bare fallow, increase of CO_2 concentration occurs due only to activation of microflora.

Dynamics of cellulose decomposition activity is well correlated with the concentration of CO_2 in the soil air. In 1973, cellulose decomposition activity under the bare fallow in April was 6.8%, and the concentration of CO_2 in the soil air in the 0.5-m layer was 0.36%, respectively: in May - 11.4% and 0.86%, in June - 43.3% and 1.50%, in July - 33.7% and 1.53%, in August - 13.4% and 0.86%, in September - 10.8% and 0.60% and in October - 9.8% and 0.45%, respectively. Under corn in the first half of vegetative period due to its slow development, formation of CO_2 depends mainly upon the microbiological activity. In May-June, CO_2 concentration under corn on the non-irrigated land was 0.4-0.6%, the activity of cellulose decomposition reached 10.4-18.2%. In July, the activity of the cellulose decomposition was 16.8-19.0%, while the concentration of CO_2 increased by 0.5 times, which is related to CO_2 production by corn as a result of intensive growth of vegetation.

There is a close relationship between the harvest weight, CO_2 accumulation in the soil and the water supply to the crops. This can be observed on the example of the same crops grown under non-irrigated and irrigated conditions.

For example, under non-irrigated winter barley at the flowering phase in 10-80 cm there was 0.66% of CO_2, whereas under irrigated winter barley that has 1.5-2.0 times higher plant biomass there was 1.14% CO_2. At flowering phase of non-irrigated corn, the CO_2 concentration of the soil air was 0.79% with green mass harvest 15-20 Mg ha^{-1}, under irrigated corn - 2.00% with green mass harvest 55-60 Mg ha^{-1}.

On the plots of the long-term bare fallow, the CO_2 concentration was approximately by 1.5 times higher than that on the above-mentioned treatments, which indicate a high biological activity of the soil under proper water supply (Kisel and Polupan, 1975). However, the concentration of CO_2 in the fallow decreased with years. In the first year of observation, the concentration of CO_2 was 2.8%, in the second - 2.3%, and in the third year - it was 1.4%. In spite of the significant reserves of productive moisture under fallow and the favorable temperature regime, decrease of the activity of cellulose decomposition is observed. Most probably it is caused by the decrease of available substrates in the soil, necessary for life activities of microorganisms. Thus, the results of our research convincingly indicate about the influence of characteristics of soil usage on the regime of the soil air CO_2. On the non-irrigated cultivated land, the amount of CO_2 in the soil air is larger than that on the virgin land throughout the whole warm period.

The process of CO_2 emission from soil surface into the atmosphere was named "soil respiration" by Lundergardh (1924, 1927). Soil respiration characterizes the intensity of gas exchange between soil and the atmosphere and is one of the indicators of biological activity in the soil.

Many researchers determined changes of intensity of gas exchange between soil and the atmosphere during a year and a direct correlation coefficient between CO_2 concentration in the soil air and its emission into the atmosphere (Matskevich, 1950; Makarov, 1952; Bondarev, 1962; Shkurinov, 1975; and others).

Average CO_2 emission from the soil surface on the virgin and the cultivated lands is practically the same for the studied years from April till June. Second half of vegetation period is, however, characterized with the higher CO_2 emission on the cultivated land. This is a natural phenomenon because on the virgin land biological processes and growth of natural vegetation cease due to the lack of available moisture, while on the cultivated land more favorable water regime promotes development of microbiological processes and growth of agricultural crops with a long vegetative period. There is a direct correlation between the CO_2 concentration in the soil air of upper layers and its emission rate into the atmosphere, which is graphically presented in Fig. 4.14. In autumn, both the CO_2 emission rates into the atmosphere and its concentration in the soil air are practically the same for both the soils studied.

Thus, CO_2 regime in the soil air and intensity of gas exchange changed during the vegetative period depending on hydrothermal conditions for the plant evolution. The highest CO_2 concentration and its emission rate are observed in the first half of the warm period as a result of intensive plant growth and high biological activity of the soils. In the second half of vegetative period, CO_2 concentration in the soil air and the intensity of soil respiration significantly decreased due to decrease of plant growth or absence of it and decline of the biological activity in the soil as a result of deterioration of soil water regime. According to literature sources and our results, the amount of CO_2 in the soil air and the intensity of its emission into the atmosphere from the soil depends upon plant composition. On cultivated lands, these parameters are higher under perennial grasses and corn planting comparing with cereals; and also higher under all the mentioned crops than under bare fallow. In average for 8 years of our study, quantitative indices of CO_2 concentration in the soil air and the soil respiration rates for the first half of vegetation period on the virgin and the non-irrigated cultivated land are practically the same; in the second half of vegetation period, the cultivated land has higher indices due to better water regime and favorable microbiological activity and plant growth with long vegetative period.

The patterns of seasonal fluctuation in the CO_2 concentration in the soil air and the intensity of soil respiration comply with fluctuation of biological activity and plant growth that is determined by dynamic of changes of water regime.

From the beginning of warm period, CO_2 concentration in the soil air increased in the upper layers of soil, reaching its maximum in June, then in deeper layers to the end of vegetation CO_2 concentration in the soil air decreased in the same sequence. According to Remezov (1952), Mina (1957), Kachinskii (1975) and others, increase in the CO_2 concentration in lower layers of soil is explained by "downward flux" of CO_2 into deeper soil horizons as heavier gas. Makarov (1988) does not agree with this opinion. He explains this process with different degree of gas exchange in upper and lower parts of soil profile. According to Makarov, CO_2 cannot flow down because it disagrees with rules of gas dynamics, because gas diffusion occurs towards low gas concentrations.

Indicators of the CO_2 regime in the autumn period are the same for the virgin and the cultivated non-irrigated lands.

4.12. Spatial heterogeneity of humus content in soils of Askania steppe and factors determining it

In Askania steppe, spatial heterogeneity of plant cover is well observed, that is determined by well-developed meso- and micro-relief, which in turn determines the redistribution of the surface-flow and the differences in water regime of soils. We have studied morphological/genetic properties of soil profile, considering microrelief of placor steppe and content of humus in the soils. About 50 profiles were surveyed in all around the Askania steppe; soil samples were taken and analyzed for humus content, particle size distribution and other properties. Such work was done for cultivated land as well around the virgin steppe on different distances from the steppe. Forty soil profiles were surveyed and analyzed.

Upon the thickness of humified layer of soils, both the virgin and the cultivated land were separated into two groups: those with 55-65 cm and 70-80 cm; and within the groups the soils were further divided into 5 and 6 groups according to particle size distribution of the soils (Table 4.15).

Natural heterogeneity of the soils on humus contents within the two groups of the profile depth is 27%, and total for the steppe is 48%. On cultivated land there is an analogous picture.

Therefore, when studying evolution of organic matter in soils of the cultivated land relative to the virgin, it is very important to consider the depth of humified layers and similarity of particle size distribution of the soils. Analysis of huge numbers of literature sources, where data of humus content changes during cultivation of virgin land is presented, revealed the absence of these important characteristics when comparing with studying pairs. Therefore, there is a huge parametric bias of humus changes in the cultivated soils. For example, accidental comparison of Dark chestnut virgin soil

Table 4.15. Spatial variation of humus contents in Askania steppe depending on depth of humified layers and particle size distribution of the soils.

Depth (cm)	Physical clay (%)					
	66-70	61-65	56-60	51-55	46-50	41-45
Humus contents in soils with depth of humified layers: 55-65 cm (%)						
virgin land						
0-30	4.1±0.2	3.8±0.2	3.4±0.2	3.2±0.2	3.0±0.2	-
30-40	2.5	2.3	2.1	1.9	1.8	-
40-50	2.2	2.1	1.9	1.8	1.6	-
50-60	1.4	1.4	1.2	1.2	1.2	-
60-70	0.8	1.0	0.9	1.0	1.0	-
70-80	0.6	0.7	-	0.7	0.7	-
cultivated land						
0-30	3.4±0.2	3.2±0.2	2.9±0.2	2.7±0.2	2.5±0.2	-
30-40	2.4	2.4	2.0	1.9	1.7	-
40-50	2.1	2.0	1.8	1.7	1.4	-
50-60	1.5	1.4	1.3	1.3	1.2	-
60-70	0.7	0.8	0.8	1.1	1.0	-
70-80	0.6	0.6	-	0.6	0.8	-
Humus contents in soils with depth of humified layers: 70-80 cm (%)						
virgin land						
0-30	4.8±0.2	4.5±0.2	4.1±0.2	3.9±0.2	3.5±0.2	-
30-40	2.9	2.7	2.5	2.3	2.1	-
40-50	2.4	2.3	2.3	2.0	1.9	-
50-60	1.6	1.8	1.9	1.7	1.7	-
60-70	1.3	1.3	1.6	1.1	1.3	-
70-80	0.8	0.9	1.1	1.0	1.1	-
cultivated land						
0-30	3.8±0.2	3.6±0.2	3.4±0.2	3.2±0.2	2.9±0.2	2.2±0.2
30-40	2.8	2.6	2.3	2.2	2.2	1.7
40-50	2.2	2.1	2.1	2.0	1.8	1.2
50-60	1.5	1.9	1.8	1.8	1.6	1.0
60-70	1.4	1.4	1.2	1.4	1.3	0.9
70-80	0.9	1.0	0.8	1.2	1.1	0.7

with 70-80 cm depth and 66-70% in the content of physical clay with cultivated soil of 55-65 cm depth and 46-50% of physical clay results in humus losses of 48%, while using the methodical approach mentioned above it is only 21%. Generally, under correct comparison decrease of humus content in cultivated relative to virgin lands is 15-21%, while with inappropriate estimation it can be 45% (Ushacheva, 1998). Lack of scientific approach of the later author in determination of changes of humus content in the zone of our research indicates the fact of coincidence of quantitative parameters given by us at accidentally comparison (48%) and given by Ushacheva pairs (45%).

4.13. Characteristics and intensity of humus formation in the virgin and the cultivated Dark chestnut soils of fescue-stipa steppe

According to literatures, intensity of humus mineralization during cultivation of virgin lands is influenced by bioclimatic conditions. Clear decrease of decomposition of soil humus is observed from water resistant to dry steppes (Aderikhin, 1964; Belchikova, 1951; Egorov and Dyuryagina, 1972; Kononova, 1951; Titova, 1972).

According to Tyurin (1937), soil organic matter consists of actual humic substances and detritus or linohumates. The later is semi-decomposed plant residues that lost its initial forms. In virgin soils there is 38.3% of detritus (Tyurin 1937), in soils cultivated for more than 100 years - 26.0% (Grinchenko et al., 1968).

Based on our research, amounts of detritus in the soils of the South and Dry steppe zones is 34-38% in 0-30 cm layer on the virgin land, on cultivated land - 22-26% (Table 4.16).

Today, numerous studies established that losses of organic matter after cultivation of virgin lands occur mainly due to the mineralization of the least stable components, and that is detritus. Our results also confirm this statement (Table 4.16). At the beginning, fresh plant residues are predominantly decomposed. In the first year 18-35%, in the second - 35-55%, in the fifth - 76-79% of the initial amount of fresh plant residues are mineralized (Kulakov, 1960; Rubinstein, 1959).

Presence of seasonal fluctuation of total humus content is an established fact (Aderikhin, 1964; Breus and Mikhnovskaya, 1976; Gertsyk, 1959). However, rhythm of its changes during the vegetative period has a contradictory feature according to literature. Some authors (Breus and Mikhnovskaya, 1976; Gertsyk, 1959) state that humus content is decreasing from spring to summer and again increasing up to its initial level by autumn; according to others - it is decreasing in spring relative to the winter period, increasing during summer, and in autumn its content is restored till the spring level (Aderikhin, 1964).

Authors explain the decrease of the humus content in spring and in the beginning of summer by mineralization of humus and subsequent consumption of the mineralized products by growing plants. By the end of vegetative period, when the consumption of nutrients sharply reduces, incorporation of photosynthetic products into soil takes place as root exudates, which are source of labile forms of humus (Samtsevich, 1968; Ponomareva and Plotnikova, 1980).

According to our research, for all the treatments amount of humus increases by the end of spring - beginning of summer; and at the second half of vegetative period its content is equal to the initial (Table 4.17). There, fluctuating patterns of the humus content are the same for soils with plants (natural and cultivated) and without plants in continuous bare fallow. For all the studied treatments, increase of humus is approximately the same; in the upper part of profile it is 10-15%, in the lower - 15-30%. According to data of Gertsyk (1959), seasonal fluctuation of the humus

Table 4.16. Contents of humic substances and plant detritus in soils under natural vegetation and cultivation.

	Depth (cm)	Humus content (%)	Including: Inherent humic substances (%)	Plant detritus (%)
Southern chernozems in Ascania steppe				
virgin	0-30	3.7	2.3	1.4
	30-40	2.6	-	-
	40-50	2.2	-	-
	50-60	1.8	-	-
cultivated	0-30	3.2	2.4	0.8
	30-40	2.6	-	-
	40-50	2.1	-	-
	50-60	1.7	-	-
Southern chernozems in Crimea steppe				
virgin	0-30	2.9	1.9	1.0
	30-40	2.0	-	-
	40-50	1.5	-	-
cultivated	0-30	2.3	1.8	0.5
	30-40	1.9	-	-
Dark chestnut soils in Ascania steppe				
virgin	0-30	3.4	2.1	1.3
	30-40	2.1	-	-
cultivated	0-30	3.0	2.2	0.8
	30-40	2.0	-	-
Solonetzic chestnut soils in Ascania steppe				
virgin	0-30	2.4	1.5	0.9
	30-40	1.4	-	-
cultivated	0-30	2.0	1.5	0.5
	30-40	1.4	-	-

contents in the upper part of profile of Typical chernozem, on the virgin land, was 22-25%, while according to Breus and Mikhnovskii (1976), the changes in plow layer of the same soils were only 12%.

Dynamics of the humus content in our research complies well with the rhythm of the microbiological activity. In early summer, an intensive decomposition of organic matter takes a place that likely forms some compounds, which occupy an intermediate position between real humic substances and plant litter at different degree of decomposition. The existence of these compounds is the reason of increase of the humus content at the moment. However, the processes of their further humification continue; they undergo transformations and polymerizations and interact with mineral components of soil, becoming less mobile (Kononova, 1951). According to the opinion of Mishustin and Teplyakova (1957), at this moment the significant role in the humification processes belongs to fermentation.

We also have done a research on seasonal fluctuations of the content of humic substances that are freely or loosely bonded with soil mineral components. They were extracted with 0.1 M sodium pyrophosphate solution (Aleksandrova, 1960). Sodium pyrophosphate solution is weakly alkaline. To extract the most loosely bonded organic matter with soil, the pH of the solution was adjusted up to 7. Soil-to-solution ratio was 1:20. Extraction of labile organic matter was done at natural moisture condition in 36 replications. Samples were taken into vinyl bags, carefully packed and brought into laboratory during the day.

The content of labile organic matter in Dark chestnut soils complies with changes of total humus. Quantitatively, there were no significant differences between the studied treatments (Table 4.18).

Results of water analysis, which was carried out for water samples from lysimeter, indicate a higher mobility of organic matter at early summer time (Table 4.19).

Kokovina (1965, 1967) obtained large amounts of organic matter in summer in lysimetric waters along profile of Typical chernozem on virgin land of Streletsk steppe. According to her results, there is 2.6-3.3 times higher organic matter in summer lysimetric waters than in spring, and 1.3-1.5 time more than in autumn.

Also, results of fractionation using extraction technique on organic matter deserve an attention. Fulvic acids (FA) predominate over humic acids (HA) with a ratio of $C_{HA} : C_{FA} < 1$ (Table 4.20). In spring and the end of summer, amounts of HA and FA are practically the same in the composition of free and weakly bonded organic matter. In early summer time, an increasing tendency of HA and decrease of FA is clearly observed that results in an increase of their ratio. This indicates that main transformations of organic matter are taking place at the moment when soil exhibits the highest biological activity. Today biochemical nature of humification process and participation of microorganisms in the process

Table 4.17. Seasonal fluctuation of total humus content in Dark chestnut soils on Askania site (average for 1968-1971; in %).

Depth (cm)	Month				Confidence level on the difference observed in June
	IV	VI*	VIII	X	
		virgin			
0-10	4.00	4.40	3.88	4.09	0.95-0.995
30-40	2.07	2.31	2.04	1.98	0.995
50-60	1.15	1.32	1.20	1.15	0.95
70-80	0.74	1.00	0.83	0.78	0.995
		cultivated without irrigation			
0-10	2.92	3.30	3.07	3.07	0.99-0.995
30-40	1.85	2.10	1.95	1.85	0.95
50-60	1.07	1.30	1.12	1.10	0.95
70-80	0.66	0.87	0.68	0.70	0.995
		continuous bare fallow			
0-10	2.90	3.13	2.90	2.87	0.995
30-40	2.06	2.25	2.07	2.00	0.95
50-60	1.18	1.36	1.09	1.16	0.95-0.995
70-80	0.72	1.00	0.85	0.84	0.95-0.995

* Difference in the humus content between each term (month) is statistically significant only for the data in June.

Table 4.18. Seasonal fluctuation of labile humus content in Dark chestnut soils on Askania site, using extraction with 0.1 M sodium pyrophosphate at pH 7 (average for 1968-1971; in %).

Depth (cm)	Month				Confidence level on the difference observed in June
	IV	VI*	VIII	X	
		virgin			
0-10	0.46	0.60	0.37	0.30	0.995
30-40	0.22	0.40	0.21	0.16	0.995
50-60	0.18	0.26	0.15	0.20	0.995
70-80	0.10	0.18	0.09	0.08	0.995
		cultivated without irrigation			
0-10	0.30	0.54	0.27	0.24	0.995
30-40	0.16	0.30	0.18	0.16	0.95
50-60	0.11	0.25	0.10	0.11	0.95
70-80	0.08	0.15	0.09	0.08	0.95
		continuous bare fallow			
0-10	0.33	0.49	0.29	0.21	0.995
30-40	0.19	0.31	0.15	0.11	0.95
50-60	0.12	0.21	0.13	0.11	0.995
70-80	0.07	0.14	0.09	0.07	0.99

* Difference in the humus content between each term (month) is statistically significant only for the data in June.

is universally recognized. According to Aleksandrova (1975) in 3-30 days after beginning of decomposition process (depending on chemical composition of plant residues) HA is formed as a result of partial carboxylation of plant residue components. In the following phases of humification, aromatization of HA molecules and their fixation in the soil profile in a form of organo-mineral complexes take place.

Fractionation ratios of humus of Eurasian steppes are determined in individual zonal types of soil formation. In all the soils, HA is predominant in composition of organic matter.

Table 4.19. Concentration of dissolved organic matter in lysimetric water along profiles of Dark chestnut soils on Askania site (average for 1967-1969; in mg L^{-1}).

Depth (cm)	Month IV	VI	X
	virgin		
10-15	46.8	86.1	-
30-35	25.3	47.0	-
60-65	30.4	40.1	-
80-90	29.7	43.0	-
	cultivated without irrigation		
30-35	33.5	54.8	29.4
60-65	36.4	62.6	-
80-90	40.1	51.2	-

However, the ratios of HA/FA are different. In the upper layer of Southern chernozems it is 2.0-2.4, in Dark chestnut soils - 1.9-2.0 and in Chestnut soils - 1.2-1.5 (Table 4.21).

By fractional composition, these soils differ slightly. Cultivation of virgin lands practically did not affect the fractional composition of humus.

The characteristics of humus formation on cultivated soils underwent insignificant changes, if any. Amount of humus in them is decreased relative to virgin; herewith, decrease took place in account of the least stable components - detritus. In the soils studied, decrease of the later is 15-21%; according to literature sources, in accumulative type of soils difference of detritus ratio in virgin and cultivated soils is 10-18%.

Decrease of organic matter after cultivation of virgin soils is a natural phenomenon. In natural ecosystems, soil formation tries to reach a balance with exo- and endo-genic factors with time. Therefore, it is described by exponential dependence to maximum. All the macro- and micro-processes of whole soil formation process, including humus formation, depend on this regularity. Based on up-to-date results, process of formation of quasi-equilibrium status of humus in soil profile had been taking place hundreds or thousands years depending on zones. Humans interfered evolution of soil

Table 4.20. Seasonal fluctuation of fractionated organic matter (humic acid and Fulvic acid) in Dark chestnut soils on Askania site, using extraction with 0.1 M sodium pyrophosphate at pH 7 (upper, % in weight; lower, % in labile organic matter).

Depth (cm)	Month IV		VI		X	
	HA	FA	HA	FA	HA	FA
			virgin			
0-10	0.16	0.30	0.26	0.34	0.14	0.23
	35	65	43	57	38	62
30-40	0.08	0.14	0.16	0.24	0.08	0.12
	36	64	40	60	38	62
50-60	0.06	0.12	0.14	0.12	0.07	0.13
	33	67	54	46	35	65
			cultivated without irrigation			
0-10	0.13	0.17	0.23	0.31	0.12	0.15
	43	57	43	57	44	56
30-40	0.07	0.09	0.14	0.16	0.06	0.12
	44	56	47	53	33	67
50-60	0.05	0.06	0.10	0.15	0.04	0.06
	45	55	40	60	40	60
			continuous bare fallow			
0-10	0.15	0.18	0.25	0.24	0.12	0.17
	45	55	51	49	41	59
30-40	0.09	0.10	0.18	0.13	0.06	0.09
	47	53	58	42	40	60
50-60	0.05	0.07	0.11	0.10	0.04	0.09
	42	58	52	48	30	70

formation - humus accumulation on the half way of the curve. Therefore, quasi-equilibrium status is established very fast, i.e. within 3-6 (10) years depending on zones. The cultivation of virgin soil destroys the balance between all the factors of soil formation. Soil forming conditions had been changed due to improved water regime, increase of biological activity and other processes and regimes. In a relatively short period (3-10 years), soil formation reaches new state of balance. As mentioned in the previous sections, the amount of plant biomass involved into cycle on the cultivated soils without irrigation is generally close to the virgin soil. However, it takes some time to form a new cycle of organic matter. Therefore, in first years there are 10-20% losses of organic matter in virgin soils that is determined by intensity of anthropogenic activities. However, process of soil-humus formation both at natural and natural-anthropogenic environment is always directed to establish the balance between ecological conditions, anthropogenic activities and soil properties. Systematic application of anthropogenic pressure will lead to stabilization of changes at a certain level.

Processes of humification of organic matter in agro-ecosystems occur, likely, in the same way as in natural ecosystems. It is indicated by the same patterns of dynamic of total and labile humus on the studied treatments. An increase occurs in early summer time that is well agreed with the rhythm of microbiological activity.

Same characteristics in humus formation in the cultivated and the virgin soils are indicated by the results of fractional composition of humus of both the total and labile forms.

Table 4.21. Fractional composition of humus from virgin and cultivated soils (average data; in % to total C; Ponomareva and Plotnikova, 1968).

Depth (cm)	C (%)	Humic acid fraction (% in total C)				Fulvic acid fraction (% in total C)					Residue, not extracted (% in total C)	HA/FA
		1	2	3	Sum	1a	1	2	3	Sum		
Southern chernozems												
virgin soil												
0-10	3.09	4.2	25.7	10.1	40.0	1.9	6.7	5.4	5.8	19.8	40.2	2.0
10-20	2.18	2.9	29.2	9.2	41.3	2.1	4.8	7.8	6.5	21.2	37.5	1.9
30-40	1.60	2.0	29.9	9.0	40.9	2.8	2.5	8.4	8.1	21.8	37.3	1.9
40-50	0.93	1.1	26.7	8.4	36.2	3.4	1.8	11.7	11.8	28.7	35.1	1.3
60-70	0.71	-	23.2	8.2	31.4	4.5	0.6	9.1	14.4	28.6	40.0	1.1
90-100	0.29	-	19.2	6.5	25.7	5.1	0.1	7.3	21.0	33.5	40.8	0.8
cultivated soil												
0-10	1.61	4.1	28.8	8.9	41.8	2.1	2.7	6.2	6.3	17.3	40.9	2.4
30-40	1.23	2.9	27.4	8.3	38.6	2.8	2.0	9.0	9.6	23.4	38.0	1.6
40-50	0.94	2.0	25.0	8.4	35.4	3.2	2.3	7.8	10.0	23.3	41.3	1.5
50-60	0.72	1.3	20.0	7.5	28.9	2.8	2.0	17.4	5.5	27.7	43.4	1.0
60-70	0.46	-	17.8	7.1	24.9	3.0	5.6	18.0	1.7	28.3	46.8	0.9
Solonetzic dark chestnut soils												
virgin soil												
0-10	2.67	6.3	20.9	10.1	37.3	2.5	6.6	4.3	6.6	20.0	40.7	1.9
10-20	1.76	4.5	25.0	10.1	39.6	2.5	2.5	5.9	7.6	18.5	41.9	2.1
20-30	1.46	1.9	25.1	11.8	38.8	2.7	2.4	5.0	8.9	19.0	42.2	2.0
30-40	1.00	1.3	22.6	11.3	35.2	2.8	1.3	3.8	15.6	23.5	41.3	1.5
45-55	0.79	0.6	13.6	6.4	20.6	4.0	1.8	2.1	16.5	24.4	55.0	0.8
75-85	0.37	-	15.4	7.7	23.1	2.7	0.3	19.2	15.2	37.4	39.5	0.6
cultivated soil												
0-10	1.55	3.1	25.1	11.3	39.5	3.0	4.5	5.1	6.0	18.6	41.9	2.1
30-40	1.20	2.0	22.6	9.8	34.4	3.7	2.5	6.6	10.2	23.0	42.6	1.5
40-50	0.78	0.8	21.0	10.5	32.2	4.3	2.0	9.5	14.5	30.3	37.4	1.0
Solonetzic chestnut soils												
virgin soil												
0-10	1.57	3.4	17.5	13.5	34.4	3.4	4.9	7.3	13.1	28.7	36.9	1.2
10-20	1.21	2.9	20.1	15.4	38.4	3.2	2.0	12.1	16.3	36.3	28.0	1.2
30-40	0.97	1.8	15.4	11.0	28.2	4.4	1.6	8.8	13.5	28.3	43.5	1.0
50-60	0.64	0.5	14.9	9.0	24.4	2.5	0.5	18.1	24.1	45.2	30.4	0.5
cultivated soil												
0-10	1.27	4.5	20.8	10.8	36.1	3.0	6.8	6.0	8.5	24.5	36.4	1.5
30-40	0.95	1.6	24.5	7.8	33.9	4.4	3.8	9.6	10.6	28.4	37.7	1.2
40-50	0.82	1.0	18.3	6.8	26.1	4.2	0.6	10.4	15.0	30.2	43.7	0.9

4.14. Conclusion

1) In zones of the Southern and Dry steppes under natural vegetation, non-percolative water regime is established; in its yearly balance outcomes exceed incomes.

   The cultivated soils are characterized with more favorable water conditions. In some years positive yearly water balance is formed in them that makes possible sporadically deep (> 500 cm) percolation of soil depth in the cold periods.

2) Salt regime in the soils under the virgin vegetation is characterized by seasonally reversible cycle of water-soluble ions that occurs in small volumes depending on depth of moisture cycle. On the non-irrigated cultivated soils, salt cycle covers whole 5-m soil depth (deeper was not studied) with predominance of desalinization processes. This led to several times decrease in the contents of water-soluble salts in 0-300 (500) cm layers as compared to the initial state.

3) Natural and agro-ecosystems without irrigation are characterized by the almost same bio-productivity. On the virgin and the cultivated soils without irrigation, practically the same amount of biomass takes place in the annual energy-mass-exchange. Capacity of cycles for nitrogen and mineral elements on the cultivated system is higher than those on the virgin soil. However, partial removal of biomass along with harvest on the cultivated soils leads to a decrease of the energy reserves and materials accumulated in the soils during the virgin soil formation period.

4) Biological activity in the soils of the studied zone is determined by the water regime. Under the virgin vegetation, due to fast consumption of water for evapotranspiration the biological activity is small, and it concentrates in spring and early summer time; the sum of the values for cellulose decomposition throughout a year is not so high.

   In cultivated soils with no irrigation, the biological activity including the activity of cellulose decomposition increases by almost 2 times, which is determined by the improved water regime.

5) CO_2 regime in the soil air and the intensity of gas exchange vary during the vegetative period depending upon the hydrothermal conditions and plant development. Maximum concentrations of CO_2 and intensity of its emission rate were achieved in the first half of the warm period as a result of intensive plant growth and high biological activity of the soils. In the second half of vegetation period, CO_2 concentration in the soil air as well as intensity of soil respiration significantly decreases, that is determined by a decrease in the plant growth, or by its absence, and by cease of the biological activity in the soils, due to deterioration of their water regime. According to literature sources and based upon our results, amounts of CO_2 in the soil air and intensity of its emission into the atmosphere from the soil surface depend upon plant composition. On the cultivated soils, these parameters are higher under perennial grasses and corn than under cereals; and higher under all these crops than under bare fallow. According to the average for 8 years of our study, quantitative indices of CO_2 concentration in the soil air and soil respiration rate for the first half of vegetative period on the virgin and the cultivated non-irrigated soils are practically the same. For the second half, however, they are higher in the cultivated land relative to the virgin land, which is determined by a better water regime and hence by a more favorable microbiological activity and development of plant with a long vegetative period.

   The pattern of CO_2 concentration curves in the soil air and intensity of soil respiration rate complies with the same pattern as those of the biological activity and plant growth that are determined by the dynamics of water regime fluctuation. Right from the beginning of the warm period, CO_2 concentrations in the soil air is increasing in the upper soil layers, reaching its maximum in June, then in the deeper layers, by the end of vegetation period CO_2 concentration in the soil air is decreasing in the same order. Indices of CO_2 regime in autumn on the virgin and the cultivated non-irrigated soils are practically the same.

6) Soils of Askania steppe are characterized by spatial heterogeneity of the humus content. Based on the humified layer of soil, both on the virgin and the cultivated soils, two soil groups are separated: i.e. 55-65 cm and 70-80 cm; and within both the groups, on the virgin land there are 5 and on the cultivated land there are 6 groups are divided based on their particle size distribution. Natural heterogeneity of the soils on the humus contents within the two groups of the profile depth is 27%, and total for the steppe is 48%. The same picture is for cultivated soils. Therefore, when studying changes of organic matter due to cultivation of virgin soils it is necessary to select pairs (virgin, cultivated) with the same depth of humified layer and content of physical

clay.

7) In cultivated soils amounts of humus decreased by 10-20% relative to the virgin, herewith decrease occurred due to decrease of the least stable form - detritus.

8) Fundamental changes in humus formation in the cultivated soils of different level of intensity relative to virgin analogues were not found. The amount of plant biomass incoming into the cycle on the non-irrigated cultivated soil is close to the virgin. Processes of humification on the studied treatments practically do not differ, that is confirmed by the same characteristics on seasonal dynamics of total and labile humus. Increase of humus is taking place in early summer time that is well agreed with rhythm of microbiological activity. Results of fractional composition of both the total and the labile forms of humus indicate the same characteristics of humus formation both in the cultivated and the virgin soils.

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Chapter 5

Effect of fertilization and manure application on soil organic matter dynamics of Chernozem soils in Ukraine

Elmira Karbozova-Saljnikov and Takashi Kosaki

5.1. Background

In Ukraine, chernozem soils are fundamentals of national agriculture: area of cultivated chernozems in Ukraine is 21.4×10^6 ha (67.7% of total cultivated land in the country). The main crops grown are winter wheat (65-68%), corn for grain (89-93%), sunflower (95-99%) and sugar beet (80-85%). Experimental sites were located in three different soil-ecological regions (Fig. 5.1).

Mineral fertilizers are determinative for obtaining contented yield of agricultural crops. Nosko (1987) reported that application of high rates of mineral fertilizer accelerates mineralization of humus of Typical Chernozem and promotes depletion of nitrogen. However, Maximov and Kobozev (1983) and Kuszevski and Zabetowicz (1986) showed that application of mineral fertilizer significantly increases effective fertility of Chernozems and decreases losses of humus comparing with non-fertilized controls.

The role of organic fertilizer in sustaining no deficit balance of humus in soil is irreplaceable. Most of the scientists agree that prolonged application of manure either stabilizes the initial content of humus or increases its content, depending on the rates of manure application (Kononova et al., 1949; Chesnyak, 1981; Chesnyak et al., 1983; Anderson et al., 1986; Voroney, 1988; Kuszewski and Zabetowicz, 1986; Pare et al., 1999).

Proper use with the aim to conserve and restore the fertility of Chernozem soils is a most important responsibility both of scientists and practicing farmers. The main objective of this research is to study agronomic impact via fertilization, manure application and irrigation on soil organic matter (SOM) changes, both total and labile, of Chernozems in Ukraine.

5.2. Soil sampling and analytical methods

Soil survey on Ukrainian chernozem soils was carried out in spring-summer 2000, after planting the crops. Soil was collected from three field replicates, where each sample was composed of five sub-samples. Soil samples were divided into two parts. Half of each composite sample was air-dried. The remainder was stored in field-moisture condition at 4°C for subsequent biological analysis.

The air-dried soils were ground and analyzed for total N concentration using a full automatic analyzer (Shimadzu NC-800-13N). Organic C was determined by dichromate oxidation method (Nelson and Sommers, 1996). Soil mineral N (min-N) as NO_3^- and NH_4^+ ions was analyzed after extraction with 2 M KCl solution. Nitrate N was analyzed after reduction of NO_3^- ion to NO_2^- by passing the extract through a Cd column. Ammonium N was analyzed by salicylate nitroprusside method (Keeny and Nelson, 1982). Mineral N was measured colorimetrically using Shimadzu Spectra MAX-190. Because at the time of sampling soil was almost air-dried the amount of NH_4^+ was negligible for all the treatments, we plotted soil mineral N as a sum of NO_3^- and NH_4^+.

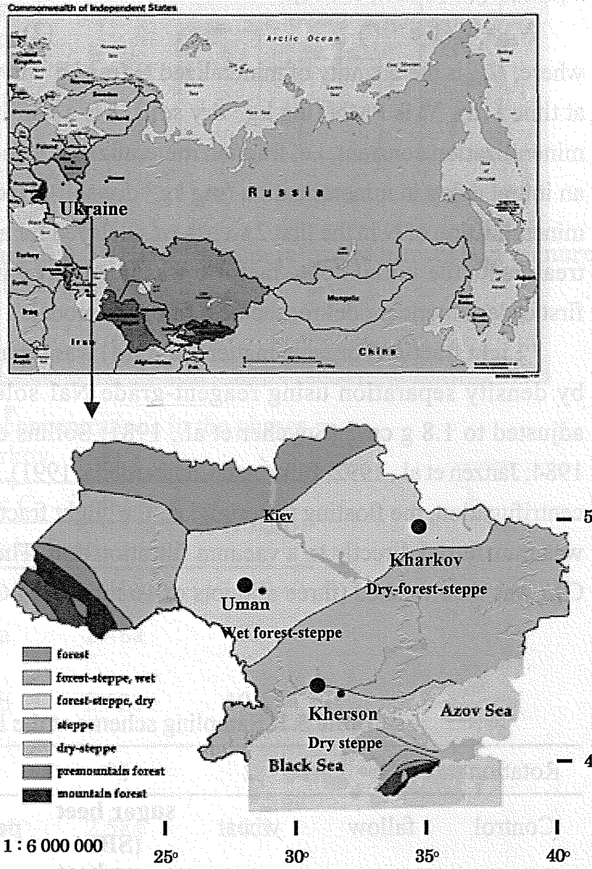


Figure 5.1. Locations of Ukrainian experimental sites in selected soil-ecological zones.

The soils were assayed for labile OM content using laboratory incubation techniques with a constant temperature of 30°C and moisture of 50% of WHC for 70 days. $C_{\min}$ was measured every 14 days after incubating soil in square-plastic jar (500 mL). The evolved CO_2 was trapped in an alkali solution (10 ml 1 M NaOH) and measured by titration (0.5 M HCl). The alkali trap was replaced every 14 days. Potentially mineralizable C (PMC) was estimated from the rate of CO_2-C evolution during 70 days of incubation using non-linear regression according to the following equation (SPSS Inc., 1998a):

$$C_{\min}=C_0(1-e^{-kt}) \qquad (1)$$

where, $C_{\min}$ is the quantity of mineralized C (mg kg^{-1} dry soil) at time t (d), C_0 is PMC (mg kg^{-1} dry soil), and k is a non-linear mineralization constant, i.e. fraction mineralized d^{-1}.

$N_{\min}$ was determined after incubation of soils for 14-, 28-, 42-, 56- and 70-d and analyzed for NO_3^- and NH_4^+ - N. Nitrate N was analyzed after reduction of NO_3 ions to NO_2 by passing the extraction through cadmium column. Ammonium N was analyzed by salicylate nitroprusside method (Keeny and Nelson, 1982). Non-linear regression was used to describe N mineralization potential (PMN) according to the following equation (SPSS Inc., 1998a):

$$N_{\min}=N_0(1-e^{-k(t-c)}) \qquad (2)$$

where, $N_{\min}$ is the quantity of mineralized N (mg kg^{-1} dry soil) at time t (d), N_0 is PMN (mg kg^{-1} dry soil), k is a non-linear mineralization constant, i.e. fraction mineralized d^{-1}, and c is an initial delay in mineralization (mg kg^{-1} dry soil). Because mineralization of N in the first 2 weeks was delayed for all the treatments the initial delay factor c was introduced in the first order kinetic model for the best fit of the model.

"Light fraction" organic matter (LF-OM) was separated by density separation using reagent-grade NaI solution adjusted to 1.8 g cm^{-3} (Spycher et al., 1981; Sollins et al., 1984; Janzen et al., 1992; Elliot and Cambardella, 1991). After centrifugation, the floating material, i.e., the "light fraction", was transferred directly to a vacuum filtration unit. The LF-OM was then washed (three aliquots of 10 ml 0.01M $CaCl_2$ followed by three aliquots of distilled water), dried at 70°C for 15 h and weighed. The residue was resuspended and the procedure was repeated to ensure complete collection of the LF. The composite LF was finely ground and analyzed for total N and C concentrations.

Microbial biomass was retrieved by fumigation-extraction method and calculated by subtraction of values before and after fumigation and dividing by coefficient k_{ec} - 0.68 (Jenkinson and Powlson, 1976). Extracting reagent was 1 M K_2SO_4 solution in the ratio 1 to 5. Content of organic C in the K_2SO_4 extract was determined with a total organic carbon analyzer (Shimadzu, TOC-5000), whereas the content of total N in the extract was determined photometrically at 220 nm after potassium peroxodisulfate oxidation treatment (Japanese Industrial Standards Committee 1991).

All variables were subjected to a one-way analysis of variance using SYSTAT software (SPSS Inc., 1998b). Where significant treatment effects were observed (p=0.001), LSD analyses were performed to permit separation of means.

5.3. Effect of manure application in Kharkov experimental site

Sampling scheme in Kharkov experimental site is shown in Table 5.1. Soils from two treatments that are control and manure application were collected from two phases of the 9-y rotation that are sugar beet (**SB** in control and **SB+O** in manured rotation) and pea (**P** in control and **P+O** in manured rotation). Manure was applied twice a rotation after harvest of sugar beet 30 Mg ha^{-1}, and after harvest of sunflower 30 Mg ha^{-1}.

5.3.1. Soil organic carbon and total nitrogen

Amount of organic carbon and total nitrogen is shown in Table 5.2. Total nitrogen levels were not significantly changed under the long-term application of manure as shown by the same letters, whereas amount of organic carbon was higher under crops in manured rotation (**SB+O** and **P+O**) compared to the control (**SB** and **P**).

Table 5.1. Sampling scheme at the Kharkov experimental site for 9-year crop rotation.

Rotation	1	2	**3***	**4***	5	6	7	8	9
Control	fallow	wheat	**sugar beet (SB)**	**pea (P)**	wheat	corn	barley	millet	sunflower
Manured	fallow	wheat	**sugar beet (SB+O)**	**pea (P+O)**	wheat	corn	barley	millet	sunflower

* Sampled sites are bold.

Higher amount of organic carbon in manured rotation is due to composition of manure. Cattle manure contains wheat straw that has wide C-to-N ratio (20-25/1) (Ilyaletdinov, 1988), which contributes to the soil organic carbon after being transformed into humic substances.

5.3.2. Soil mineral nitrogen

Enhanced mineralization processes under sugar beet are also well presented by the data of soil mineral nitrogen (min-N) (Fig. 5.2). Significantly higher accumulation of min-N was observed under sugar beet phase (**SB** and **SB+O**) than under pea phase (**P** and **P+O**) in both control and manured rotations. Application of manure did not show high accumulation of mineral N because soil sampling was done shortly after application of manure and readily mineralizable N of the manure was released after sampling during incubation showing high PMN.

5.3.3. Nitrogen mineralization potentials

Amount of mineralized nitrogen (PMN) during 70 days of laboratory incubation of Typical Chernozem (Kharkov) was too small to fit the first order kinetic model. Therefore, in this section absolute data of PMN is presented in Fig. 5.3. The greatest amount of PMN was under manured pea (**P+O**), followed by non-manured pea (**P**), and significantly less PMN was under sugar beet, both manured (**SB+O**) and control (**SB**). Amount of PMN was not different under sugar beet in the control and manured rotations (**SB** and **SB+O**). However, it was significantly different under pea in the control and manured rotations (**P** and **P+O**).

Manure was applied at pea phase (**P+O**), while sugar beet (**SB+O**) was the most distant crop from manure application. Manure itself a great source of labile organic matter, containing large amounts of readily mineralizable nitrogen fractions. Subsequently, applied manure greatly

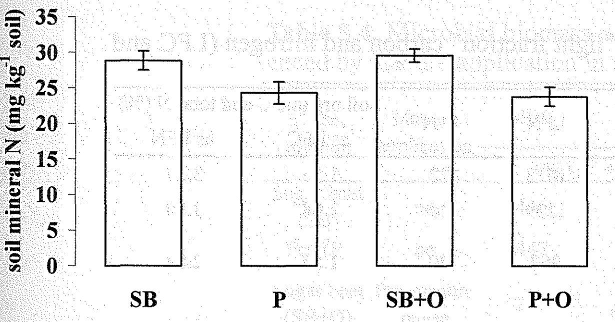


Figure 5.2. Soil mineral nitrogen under manured and control rotation.Same letter above bars indicates statistically non-significance between treatments.

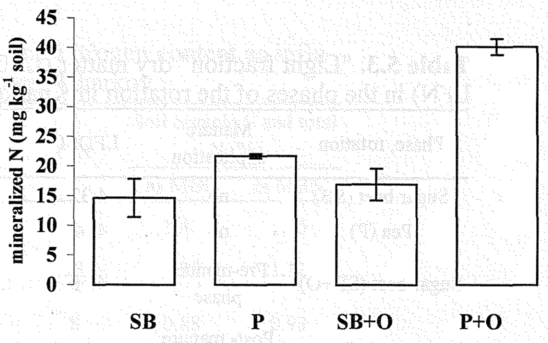


Figure 5.3. Potentially mineralizable nitrogen in manure application experiment.

Table 5.2. Organic carbon and total nitrogen concentrations in the phases of the rotation upon manure application, Kharkov.

Phases	Treatments	Manure application	Organic C	Total N	C/N ratio
			g kg^{-1} soil		
SB	Sugar beet	no	21.9a	2.41a	9
P	Pea	no	24.8a	2.48a	10
SB+O	Sugar beet (manured rotation)	Pre-manure phase	26.4b	2.52a	10.5
P+O	Pea (manured) rotation	Post-manure phase 30 Mg ha^{-1} for rotation	27.1b*	2.58a	10.5

* The same letters denote statistically non-difference.

contributed to the amounts of PMN in **P+O** treatment by quickly decomposing during incubation and exerting a short-term effect on the accumulation of PMN. However, by the time of planting sugar beet (that is 9 years after the manure application) most of the manure was decomposed. Therefore, values of soil mineral N under **SB** and **SB+O** were nearly the same.

5.3.4. Carbon mineralization potentials

Potentially mineralizable carbon (PMC) was estimated from the rate of CO_2-C evolved during 70 days of laboratory incubation using non-linear regression according to the following equation (SPSS Inc., 1998a): $C_{min}=C_0(1\text{-}e^{-kt})$, where, C_{min} is a quantity of mineralized carbon (mg kg^{-1} soil) at time t (days), C_0 is amount of PMC (mg kg^{-1} soil), and k is the non-linear mineralization constant, i.e. fraction mineralized per day.

Carbon mineralization pattern of Kharkov experimental site is shown in Fig. 5.4. In both control and manured rotations the pea phase (**P** and **P+O**) maintained the higher values of PMC than the sugar beet phase (**SB** and **SB+O**). The values of PMC under sugar beet in both control and manured were nearly the same (657 and 670 mg kg^{-1} soil) correspondingly. And values of PMC under pea in control and manured rotations were also nearly the same (995 and 1001 mg kg^{-1} soil). Manure was applied after harvest of the sugar beet that is nearly 32 months passed before planting of next season sugar beet. During those 32 months N was either released from the applied manure and utilized by plants and/or stabilized and became a part of soil organic matter (Aleksandrova, 1980; Kharin, 1993). This explains the similar values of PMC in control and manured rotation under sugar beet.

However, under pea the amount of PMC was also nearly the same in control and manured rotations (**P** and **P+O**). This suggests that carbon mineralization was more affected by the technology of crop cultivation rather than by application of the manure. Sugar beet is a row crop with wide inter-row

Table 5.3. "Light fraction" dry matter (LFDM), "light fraction" carbon and nitrogen (LFC and LFN) in the phases of the rotation in Kharkov.

Phase, rotation	Manure application	LFDM	LFC	LFN	C/N	Soil organic C and total N (%) as LFC	as LFN
Sugar beet (SB)	no	4.32	46.9	1013	22	1.56	3.27
Pea (P)	no	4.92	63.4	1239	20	2.08	3.80
Sugar beet (SB+O)	Pre-manure phase	4.56	49.3	967	20	1.56	2.84
Pea (P+O)	Post- manure phase	7.85	105.8	1714	16	3.38	4.91

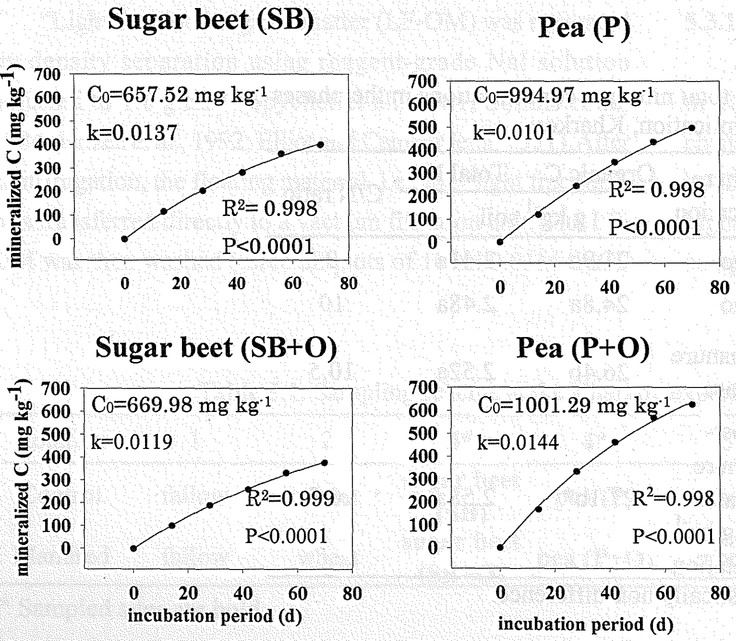


Figure 5.4. Fitting curves of C mineralization in fertilization experiment as described with the first order kinetic model: $C_{min}=C_0(1\text{-}e^{-kt})$, where C_{min} is a mineralized C at time t, C_0 is a potentially mineralizable C (PMC), k is the mineralization rate constant.

spaces; therefore the technology of its cultivation includes multiple cultivation of the field during the vegetation season in order to prevent weed infestation. Such intensive mechanical disturbance promotes mineralization of both SOM and manure. Also, row crops leave few residues on the filed. In the contrary, pea is a dense crop that is not cultivated during growing season, and that leaves much more plant residues, especially roots that contributes to the SOM as easily mineralizable source of C.

5.3.5. "Light fraction" organic matter

The data of "light fraction" organic matter (LFOM) is shown in Table 5.3. Although the amount of LFOM accounted only for 1.6-3.4 % of the organic C and 2.8-4.9 % of the total N, LFOM was highly responsive to the phase of the rotation. Both, "light fraction" C (LFC) and N (LFN) and their proportions in the total SOM were significantly higher under pea than under sugar beet in both control (**P** and **SB**) and manured (**P+O** and **SB+O**) rotations. Noticeably, similar as for PMC, LFC and LFN were more influenced by the rotation phase rather than by application of manure. The highest amounts of LFC and LFN and "light fraction" dry matter (LFDM) were observed under manured pea (**P+O**). This is due to the composition of the applied cattle manure that consists of straw and animal remains in different stages of decomposition that contributes to the "light fraction" weight in soil.

5.3.6. Microbial biomass

Data on microbial biomass analysis are shown in Table 5.4. Microbial biomass was significantly affected by the manure application, but was not affected by the phase of the rotation. Pea after manure application (**P+O**) showed the highest content of microbial biomass carbon (MBC) and microbial biomass nitrogen (MBN), while sugar beet in manured rotation (**SB+O**) showed the lowest content of MBC and MBN. The increased amount of microbial biomass, in the treatment after application of manure, was expected.

Table 5.4. Microbial biomass carbon and nitrogen content as influenced by manure application in a rotation, Kharkov.

Phase, rotation	Manure application	MBC	MBN	C/N	Soil organic C and total N (%)	
		mg kg^{-1} soil			as MBC	as MBN
Sugar beet (SB)	no	446	34.98	13	1.42	1.15
Pea (P)	no	447	33.89	13	1.38	1.12
Sugar beet (SB+O)	Pre-manure phase	297	29.39	8	0.88	0.93
Pea (P+O)	Post-manure phase	544	37.34	19	1.56	1.2

Table 5.5. Sampling scheme in Uman experimental site from 10-year crop rotation.

Rotation, treatment	fertilizer	Clover (sampled)	wheat	s. beet	corn grain	peas	wheat	corn silage	wheat	s. beet	barley+clover	sum of the rotation
M1 $N_{45}P_{45}K_{45}$	$(NH_4)_2SO_4$		45	90	50	10	45	50	45	90	25	450 kg N ha^{-1}
M3 $N_{135}P_{135}K_{135}$	$(NH_4)_2SO_4$	50	135	180	200	60	135	200	135	180	75	1350 kg N ha^{-1}
O	manure			45				45		45		135 Mg ha^{-1} (675 kg N ha^{-1})
OM1	$(NH_4)_2SO_4$		22.5	30	50		22.5	22.5	22.5	30	25	225 kg N ha^{-1}
	manure			15				15		15		45 Mg ha^{-1} (225 kg N ha^{-1})
OM3	$(NH_4)_2SO_4$		67.5	90	150	20	67.5	75	67.5	90	47.5	675 kg N ha^{-1}
	manure			45				45		45		135 Mg ha^{-1} (675 kg N ha^{-1})

Cattle manure contains a large amount of microorganisms that contribute to the soil microbial biomass.

5.3.7. Discussion

The presented results are agree with other findings reporting that manure application increases amount of labile forms of organic matter in soil, because it contains “ready” humic compounds that include both soluble and insoluble forms. Soluble forms are partially decomposed by microorganisms and partially fixed and stabilized in soil. Also, application of manure tends to accelerate mineralization of soil organic matter as well, (Aleksandrova, 1980; Kharin, 1993) due to addition of large number of microorganisms that reside in manure.

5.4. Effect of fertilization and manure application at Uman experimental site

Sampling scheme of Uman experimental site is shown in Table 5.5. Soils in Uman were collected from treatments with different rates of organic and mineral fertilizers: 1) control (**CON**, no fertilization); 2) low rate mineral fertilization (**M1**), 3) high rate mineral fertilization (**M3**), 4) manure application (**O**), 5) combination of low rates of mineral and organic fertilization (**MO1**) and 6) combination of high rates of organic and mineral fertilizers (**MO3**). One Mg of cattle manure contains approximately 5 kg of N. Therefore, total N applied with fertilizer and manure in the treatments were: M1=450 kg ha^{-1} rotation^{-1}; M3=1350 kg ha^{-1} rotation^{-1}; O=675 kg ha^{-1} rotation^{-1}; OM1=450 kg ha^{-1} rotation^{-1}; OM3=1350 kg ha^{-1} rotation^{-1}.

5.4.1. Soil organic carbon and total nitrogen

Content of organic carbon and total nitrogen in differently fertilized treatments is shown in Table 5.6. The content of soil organic carbon was not increased after 36 years application of fertilizers in most of the treatments, compared to the control. However, application of high rates of manure (**O**) alone maintained the higher soil organic carbon content.

Manure contains humic acids (Aleksandrova 1980). Therefore, application of manure results in accumulation of humic acids in soil and favors humification processes (Kononova, 1951, 1956; Mamontov, 1971). As this experiment has been performed since 1964, the long-term input of high rates of manure contributed to SOM via direct inputs of humic acids into the soil, showing the higher soil organic C than in other treatments without manure application. Content of total nitrogen in the treatments was not statistically different as indicated by the same letters in Table 5.6.

Insignificant effect of the mineral fertilizers on the accumulation of soil organic C and N is probably due to quick depletion of mineral fertilizer in the soil either by means of microbial utilization (Ilyaletdinov, 1988) and by plant consumption, or by direct losses via leaching and/or volatilization.

5.4.2. Soil mineral nitrogen

Data of soil mineral nitrogen (min-N) is shown in Fig. 5.5. The highest content of min-N was obtained in **OM3** and **M3** treatments, followed by **O**, **OM1** and **M1** treatments. As shown in Table 5.5, **M3** and **OM3** treatments received the highest rate of N that was 1350 kg of N per ha per rotation

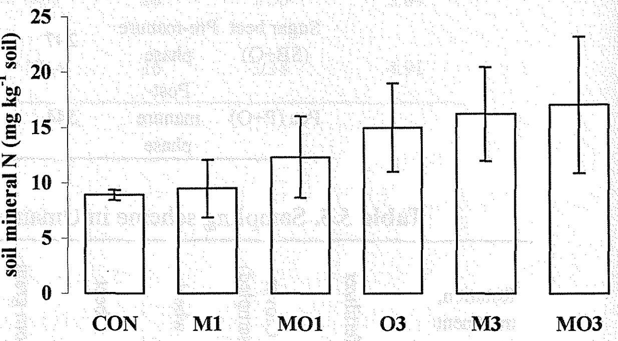


Figure 5.5. Soil mineral nitrogen as influenced by different rates of fertilization, Uman.

Table 5.6. Organic carbon and total nitrogen concentrations as influenced by application of different rates of mineral fertilizer and manure.

Treatments	Fertilization rates kg ha^{-1} year^{-1}	Organic C	Total N	C/N ratio
		g kg^{-1} soil		
CON	no	20.4a	1.64a	12
M1	$N_{45}P_{45}K_{45}$	19.6a	1.62a	12
M3	$N_{135}P_{135}K_{135}$	20.8a	1.76a	12
O	Manure $N_{67.5}$	21.9b	1.77a	12
OM1	$N_{22}P_{34}K_{18}$ + manure $N_{22.5}$	20.4a	1.71a	12
OM3	$N_{22}P_{34}K_{18}$ + manure $N_{67.5}$	20.1a	1.72a	12

that was the reason of the increased amount of min-N.

Generally, min-N was distributed proportionally to the amount of applied N. But some difference was observed between application of mineral N alone and combination of N applied with mineral fertilizer and manure. For example, **M1** and **OM1** treatments received the same amount of N in whole rotation, where **M1** treatment received only mineral N, and **OM1** treatment received 50% N from the mineral fertilizer and 50% N from the manure. Similar pattern was observed in the case of **M3** and **OM3**. This is due to quick depletion of applied fertilizer N (discussed earlier in this chapter), while N of the manure was decomposed more slowly supplying the soil with min-N longer period.

5.4.3. Nitrogen mineralization potentials

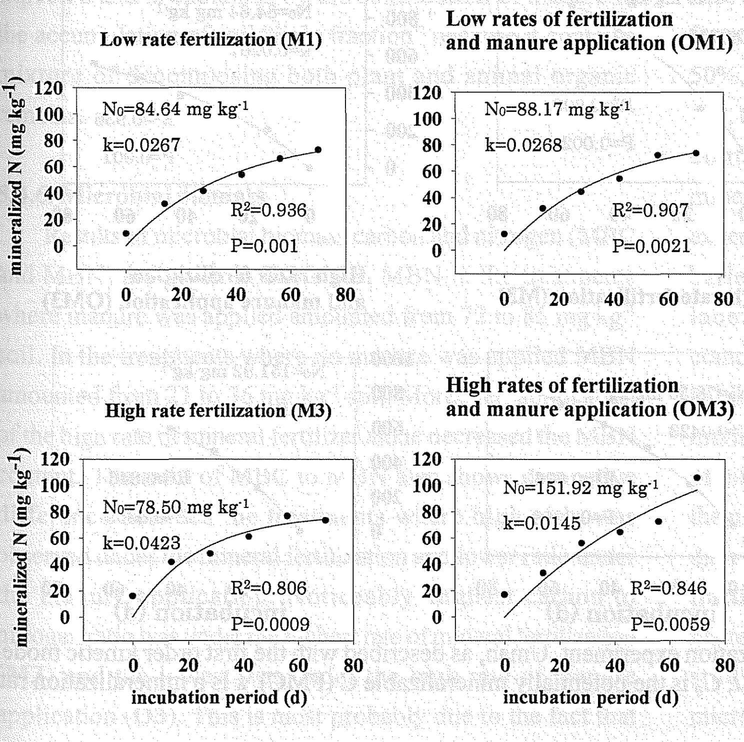
Data on potentially mineralizable nitrogen (PMN) were obtained after fitting the data of mineralized N to the first order kinetic model by using the following equation (SPSS Inc., 1998b): $N_{min}=N_0(1-e^{-kt})$), where, N_{min} is a quantity of mineralized N (mg kg^{-1} soil) at time t (days), N_0 is PMN (mg kg^{-1} soil), k is a non-linear mineralization constant, i.e. fraction mineralized per day.

Nitrogen mineralization pattern is shown in Fig. 5.6. Mineralization rate among the treatments varied significantly ($p<0.05$). The treatments where the high rates of manure were applied showed higher mineralization rate. This is most probably explained by the manure composition that contains organic substances, which have higher potentials to release mineral N under laboratory conditions. All treatments but **OM3** have lowered their mineralization rate by the end of incubation (56-70 days). **OM3** is the treatment that received mineral fertilizer and high rate of manure. Nitrogen of the mineral fertilizer might serve as an easy available substrate for microorganisms at the beginning of the incubation.

Then, after the available mineral nitrogen was depleted by microbial utilization, the nitrogen of the manure was

Table 5.7. Soil labile carbon and nitrogen in fertilization treatment, Uman.

Treatment	Fertilization rates	PMC	PMN	C/N	Soil organic C and total N (%)	
	kg ha^{-1} year^{-1}	mg kg^{-1} soil			as PMC	as PMN
CON	no	960	75.6	12.7	4.7	4.6
M1	$N_{45}P_{45}K_{45}$[ii]	729	84.6	8.6	3.7	5.2
M3	$N_{135}P_{135}K_{135}$[iii]	1195	78.5	15.2	5.7	4.5
O	Manure $N_{67.5}$	1159	96.4	12.0	5.3	5.4
OM1	$N_{22}P_{34}K_{18}$ + manure $N_{22.5}$	1207	88.2	13.7	5.9	5.2
OM3	$N_{22}P_{34}K_{18}$ + manure $N_{67.5}$	1036	151.9	6.8	5.2	8.8


Low rate fertilization (M1)

Low rates of fertilization and manure application (OM1)

High rate fertilization (M3)

High rates of fertilization and manure application (OM3)

Figure 5.6. Fitting curves of nitrogen mineralization in fertilization experiment in Uman, as described with the first order kinetic model: $N_{min}=N_0(1-e^{-kt})$, where N_{min} is the mineralized N at time t, N_0 is the potentially mineralizable N (PMN), k is the mineralization rate constant.

exposed to microbial attack showing high mineralization rate after 70 days of incubation, while in O treatment, manure was attacked from the beginning because no mineral N was added to the soil. Manure consists of labile as well as of non- labile fractions of organic compounds. After the labile fractions of manure (mainly fulvic acids) were mineralized, the mineralization rate was slowed down thus showing lowered rate after eight weeks of incubation.

Potentially mineralizable nitrogen content was the highest in the treatments where high rates of manure were applied that are **O** and **OM3** (Table 5.7). Manure was applied about 19 months before the soil sampling (after harvest of sugar beet). During about 8 months the soil was frozen and no microbial activity was undergoing. According to studies of Kharin (1993), it takes about 275 days to start releasing mineral N from manure, and about 391 days for complete mineralization or for reaching the stabilization point. By the time of sampling manure had been releasing N for about 90 days, therefore, during the laboratory incubation manure continued to release mineral N, showing higher PMN in **O** and **OM3** treatments.

5.4.4. Carbon mineralization potentials

Potentially mineralizable carbon (PMC) is shown in Fig. 5.7. Generally, distribution of PMC didn't correlate with the applied N. Distribution of PMC among the treatments was different from the distribution of PMN, having significantly higher PMC content in **O** than in **OM3** treatment. The lowest amount of PMC was obtained under **OM1** treatment, where low rates of both mineral and manure nitrogen was applied.

Table 5.8. "Light fraction" dry matter (LFDM), "light fraction" carbon and nitrogen (LFC and LFN) in manure application and fertilization experiment, Uman.

Treatment	Fertilization rates kg ha^{-1} year^{-1}	LFDM g kg^{-1} soil	LFN mg kg^{-1} soil	LFC mg kg^{-1} soil	C/N	Soil organic C and total N (%) as LFN	Soil organic C and total N (%) as LFC
CON	no	4.21	58.2	1025	18	3.3	4.7
M1	$N_{45}P_{45}K_{45}$[ii]	4.04	54.6	909	17	3.1	4.2
M3	$N_{135}P_{135}K_{135}$[iii]	4.15	60.4	915	15	3.2	4.1
O	Manure $N_{67.5}$	6.09	82.8	1333	16	4.3	5.6
OM1	$N_{22}P_{34}K_{18}$ + manure $N_{22.5}$	5.71	60.1	994	17	3.2	4.5
OM3	$N_{22}P_{34}K_{18}$ + manure $N_{67.5}$	6.25	80.7	1459	18	4.3	6.7

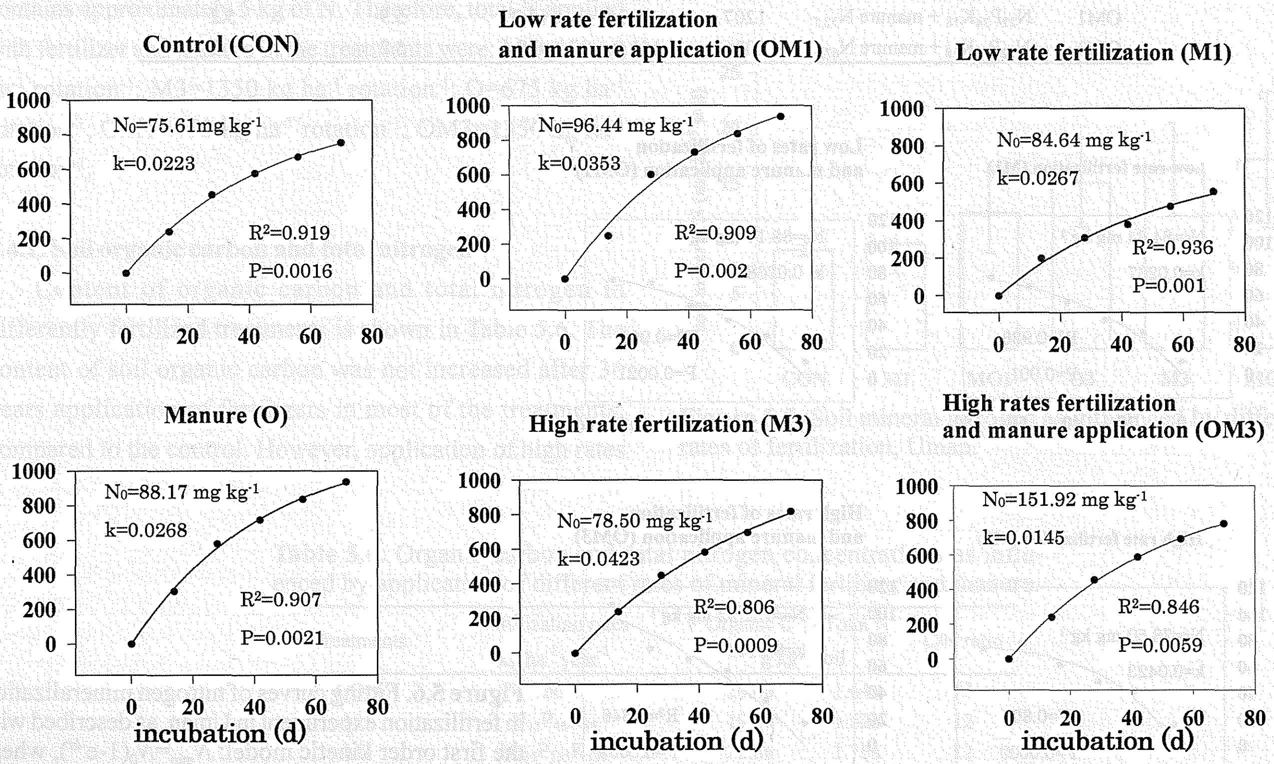


Figure 5.7. Fitting curves of C mineralization in fertilization experiment, Uman, as described with the first order kinetic model: $C_{min}=C_0(1-e^{-kt})$, where C_{min} is the mineralized C at time t, C_0 is the potentially mineralizable C (PMC), k is a mineralization rate constant.

Table 5.9. Microbial biomass in fertilization experiment, Uman.

Treatment	Fertilization rates kg ha^{-1} year^{-1}	MBC	MBN	C/N	Soil organic C and total N (%)	
		mg kg^{-1} soil			as MBC	as MBN
CON	no	459a	33.3a	14.0	2.09	2.02
M1	$N_{45}P_{45}K_{45}$[ii]	586b	35.5a	17.0	2.72	2.19
M3	$N_{135}P_{135}K_{135}$[iii]	531c	21.3b	25.0	2.35	1.21
O	Manure $N_{67.5}$	566bc	85.3c	7.0	2.40	4.81
OM1	$N_{22}P_{34}K_{18}$ + manure $N_{22.5}$	585b	71.5d	8.0	2.64	4.19
OM3	$N_{22}P_{34}K_{18}$ + manure $N_{67.5}$	677d	69.6d	10.0	3.10	4.05

The distribution of PMC and PMN among the treatments was poorly correlated (r=0.36). In studies of Ilyaletdinov (1988), the amount of mineralized C also did not correspond to applied nitrogen. He found that after adding 0, 10, 30 and 100% N with straw, 18, 22, 18 and 19% of the applied N mineralized, respectively.

Content of SOC, amount of PMC and proportion of PMC in total organic carbon were higher in **O** treatment. Therefore, suggestion is that under prolonged application of high rates of manure, both humification and mineralization processes are intensified. Similar observations were made by a number of other authors (e.g., Kharin, 1988; Mamilov 1998; Ilyletdinov, 1988; Broadbent, 1968).

5.4.5. "Light fraction" organic matter

The data of "light fraction" organic matter (LFOM) are given in Table 5.8. Both LFC and LFN and their proportions in the SOM were the highest in the treatments where high rates of manure were applied that are **O** and **OM3**. This was expected and is explained by the contribution of manure to the accumulation of soil "light fraction" because it contains mixture of decomposing both plant and animal organic remains.

5.4.6. Microbial biomass

Results of microbial biomass carbon and nitrogen (MBC and MBN) are given in Table 5.9. MBN in the treatments where manure was applied amounted from 72 to 85 mg kg^{-1} soil. In the treatments where no manure was applied MBN amounted from 21 to 36 mg kg^{-1} soil. Moreover, application of the high rate of mineral fertilizer alone decreased the MBN content. The ratio of MBC to MBN also shows distinctive difference between the treatments where high ratio was observed under the mineral fertilization and lower ratio under the manure application. Noticeably, highest carbon to nitrogen ratio was under the highest rate of mineral fertilization (**M3**) and the lowest was under the high rate of manure application (**O3**). This is most probably due to the fact that mineral fertilizer causes intensive utilization of added nitrogen by microorganisms.

Table 5.10. Sampling scheme in Kherson experimental site from 7-year crop rotation.

	irrigation	no irrigation
fertilization	IF	F
no fertilization	I	CON

5.4.7. Discussion

To synthesize protein cell substances microorganisms intensively utilize ammonia and nitrate N that enters soil with fertilizer. Manure consists of large amount of LFOM that is easily accessible to microbial attack thus contributing to the release of mineral N, and at the same time the humic substances, originally present in the manure might directly contribute to the soil humus. Although the amount of microbial biomass is negligible in the total pool of SOM, microbial tissue might contribute to the synthesis of humic substances. In his study of N transformations Tarvis (1973) found that if the percentage of utilized nitrogen amounts to 50%, as much as 30-40% of the total N is immobilized.

Concentration of PMN and PMC in soil is greatly controlled by mechanisms of immobilization and mineralization of SOM by microorganisms. In Broadbent's experiment (1968) on nitrogen immobilization in soil with added barley straw and labeled ammonium sulfate, most of the labeled nitrogen was included into complex organic compounds of humic and fulvic acid type. Ilyaletdinov (1988) in his study established that in the initial period (10-30 days), mixing of straw with mineral nitrogen decreases the content of mineral nitrogen, while the amount of organic nitrogen in the non-distillable acid-soluble fraction is increase. After 10 days as much as 38.9% of nitrogen was included in this hard fraction and 13.4% was included in other fractions of organic matter. Therefore, there is a high probability that in the present study the PMN was subjected to immobilization by microorganisms after 56 days of incubation.

5.5. Effect of fertilization and irrigation in Kherson experimental site

Sampling scheme of the Kherson experiments is given in Table 5.10. Soils from: 1) irrigated plus fertilized treatment (**I+F**), 2) irrigated only (**I**); 3) fertilized only (**F**) and 4) control that was neither fertilized nor irrigated (**CON**); were sampled from 7-year crop rotation experiment initiated in 1967. The crop rotation was 1.alfalfa, 2. ***alfalfa*** (sampled phase), 3. alfalfa, 4.wheat, 5. corn, 6.wheat, and 7. corn. Samples were taken from the second year of the rotation that is alfalfa second year stand. Fertilization rate: $N_{120}P_{120}K_{120}$ kg/ha; Irrigation rate: 3200 m^3 ha^{-1} (alfalfa).

5.5.1. Soil organic carbon and total nitrogen

Analysis of variance showed that soil organic carbon (SOC) and total nitrogen (TN) were not statistically different among treatments. However, some differences were observed among the treatments in accumulating SOM (Table 5.11). Contents of SOC and TN were by 7.19% and 9.30%, respectively, greater in **I+F** treatments than in the control (**CON**). The higher accumulation of SOC and TN under **I+F** treatment is due to higher biomass production that contributes to SOM. Fertilization (**F**) or irrigation (**I**) alone maintained similar amount of organic C and total N.

Table 5.11. Organic carbon and total nitrogen concentration in irrigation experiment, Kherson.

Treatments	Applied treatment	Organic C	Total N	C/N
		g kg^{-1} soil		
I+F	Irrigated and fertilized	16.7a	1.29a	13
F	Fertilized	16.4a	1.25a	13
I	Irrigated	15.8a	1.24a	13
CON	no	15.5a	1.17a	13

*Fertilizer was applied as $N_{120}P_{120}K_{120}$ for every fertilization treatment at rates indicated as subscripted mark.

*Irrigation water was applied at rate of 3200m^3 ha^{-1} for every irrigated treatment.

In dry conditions with limited amount of rainfall, fertilization is not effective for biomass production because the applied fertilizer cannot be dissolved and be available for plant consumption.

5.5.2. Soil mineral nitrogen

Data on soil mineral nitrogen (min-N) is shown in Fig. 5.8. Soil min-N was different among the treatments at p=0.1. The greatest differences were observed between **I+F** with non-irrigated treatments (**F** and **CON**).

Irrigated treatment accumulated higher min-N than the non-irrigated because irrigation of dry soil results in

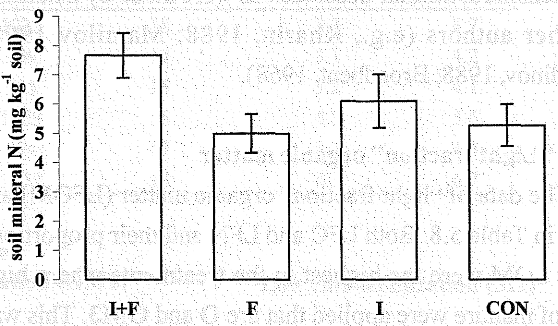


Figure 5.8. Soil mineral nitrogen in irrigation experiment, Kherson.

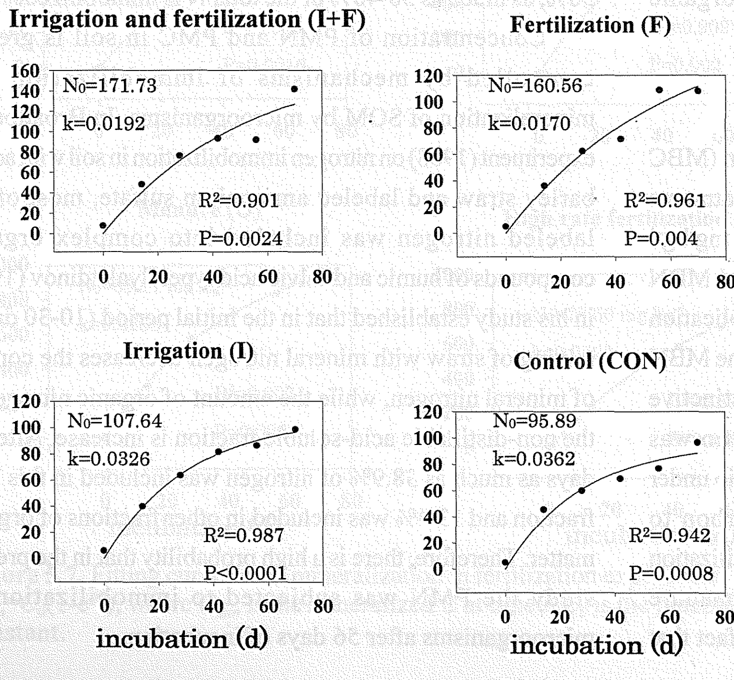


Figure 5.9. Fitting curves of nitrogen mineralization in fertilization experiment, Kherson, as described by the first order kinetic model: $N_{min}=N_0(1-e^{-kt})$, where N_{min} is the mineralized N at time t, N_0 is the potentially mineralizable N (PMN), k is the mineralization rate constant.

heightened microbial biomass that accelerates mineralization processes in soil. The drying and moistening of soil can explain another reason of the higher accumulation of min-N under irrigation. Moistening of dry soil causes disruption of organic compounds as well as soil particles that may contain organic substances. Subsequently, the disrupted organic material is more sensitive for microbial attack. Alternate drying and moistening increases the mobility of organic matter and results in the release of N as ammonium and amides (Ilyaletdinov, 1988).

5.5.3. Nitrogen mineralization potentials

Potentially mineralizable nitrogen (PMN) was significantly different (p=0.01) among the treatments with the highest mineralization rate under **I+F** treatment (Fig. 5.9). The highest accumulation of mineralizable N (PMN) was also obtained under the **I+F** treatment (Table 5.12), while all other treatments maintained statistically not different amounts of PMN.

I+F treatment maintained higher plant biomass that returned and accumulated on soil surface. And when the soil was placed under the favorable laboratory conditions, those accumulated residues were subjected to mineralization showing higher PMN.

Fertilization alone (**F**) had suppressed mineralization on the field because of deficiency of water necessary for microbial activity. But when the soil was placed under favorable laboratory conditions it mineralized available organic substrate, thus giving nearly the same amount of PMN as the irrigated treatment.

5.5.4. Carbon mineralization potentials

Irrigated plus fertilized treatment (**I+F**) showed the highest carbon mineralization rate as well as amount of PMC in 70 d (Fig. 5.10; Table 5.12). Irrigation of dry soil disrupts soil structure thereby making previously sequestered carbon available for microbial utilization (Lundquist et al., 1999). Bottner (1985) found that soil drying destroyed 1/3 to 1/4 of biomass, and after remoistening the biomass was progressively restored to approximately the same size as

Table 5.12. Mineralizable carbon and nitrogen (PMC and PMN) in irrigation experiment, Kherson.

Treatment	Applied treatment	PMC	PMN	C/N	Soil organic C and total N (%)	
		mg kg^{-1} soil			as PMC	as PMN
I+F	Irrigated and fertilized	1522	171.7	8.9	9.11	13.31
F	Fertilized	1416	160.6	8.8	8.63	12.84
I	Irrigated	1105	107.6	10.2	6.99	8.68
CON	no	858	95.9	8.9	5.53	8.20

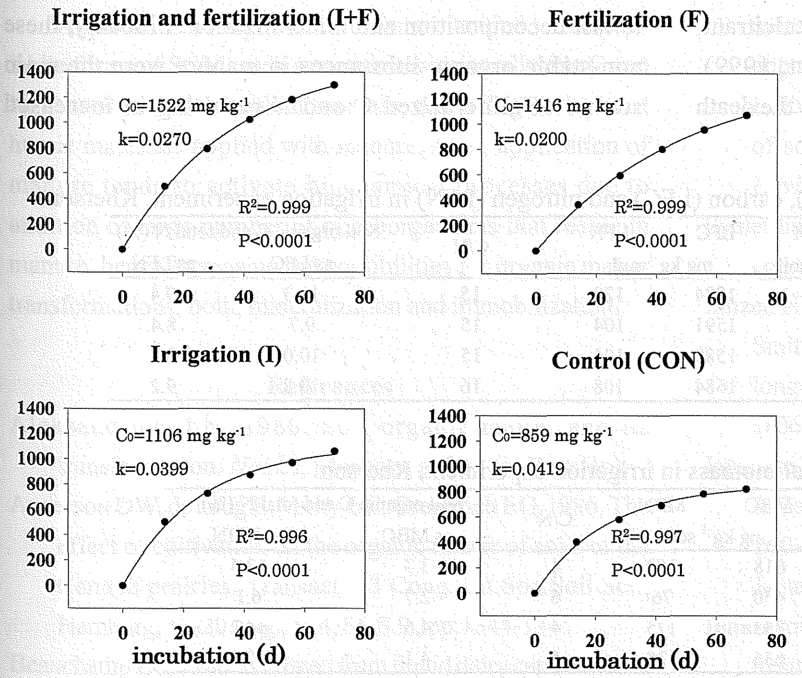


Figure 5.10. Fitting curves of carbon mineralization in fertilization experiment, Kherson, as described by the first order kinetic model: $C_{\min}=C_0(1-e^{-kt})$, where $C_{\min}$ is the mineralized C at time t, C_0 is the potentially mineralizable C (PMC), k is the mineralization rate constant.

before drying.

In this study, the desiccation of soil and high temperatures has probably caused death of microorganisms that were immobilized during desiccation via adsorption on clay surfaces and/or transformation into another forms of organic compounds. Then, the following irrigation revived microbial community and disrupted soil clay particles that released stabilized organic matter. van Gestel (1993b) reported that extra mineralized ^{14}C, due to soil desiccation, came from nonliving residues, likely to be those that were stabilized by adsorption to clay surfaces.

Proportions of mineralizable fractions of carbon and nitrogen (PMC and PMN) are shown in Table 5.12. The highest percentage of PMC and PMN were under I+F treatment. This is in accordance with the earlier discussion and confirms the hypothesis that there are at least two reasons responsible for it: firstly, irrigation of dry soil causes enhanced mineralization of soil organic matter, and secondly, fertilization of irrigated soil provides higher plant biomass that contributes to the accumulation of labile organic matter.

5.5.5. "Light fraction" organic matter

"Light fraction" dry matter (LFDM), carbon (LFC), nitrogen (LFN) and their proportions in soil organic carbon (SOC) and total nitrogen (TN) was the highest under **I+F** treatment (Table 5.13). One of the reasons is, as discussed earlier, higher biomass production in this treatment, hence higher organic substrate added with residues. Desiccation that caused the death of a large number of microorganisms, followed by immobilization and condensation of their dead tissues in such way increasing the amount of recalcitrant, soluble organic C is another reason (Lundquist, 1999). Moreover, irrigation of desiccated soil also causes the death of microorganisms due to the osmoregulatory shock (van Gestel, 1993a) that also could contribute to the LFOM.

5.5.6. Microbial biomass

Microbial biomass carbon (MBC) and nitrogen (MBN) significantly differed among the treatments (Table 5.14). The highest MBC and MBN were obtained under the irrigation alone (**I**) treatment followed by the irrigated plus fertilized (**I+F**) treatment. And the least microbial biomass was obtained under the fertilized alone (**F**) treatment.

Such distribution of microbial biomass was expected because moisture conditions are a major factor controlling survival and activity of microorganisms in the soil. (Pulleman and Tietema, 1999). Drying and remoistening of soils strongly influences microbial biomass and activity (Lund and Goksoyr, 1980; Orchard and Cook, 1983; Bottner, 1985). After remoistening of dried soil, available C components were assimilated and transformed partly into new biomass C, and partly involved into CO_2 that evolved into the atmosphere (van Gestel et al., 1993a).

5.5.7. Discussion

Cattle manure contains "ready" humic substances that can be directly and immediately involved in immobilization processes. At present, there is a little information about the quantity of humic substances in manure. According to Aleksandrova (1980), there are about 38% of humic substances in manure. Chesnyak (1986) reported that "ready" humic substances applied with manure might be thermodynamically non-stable and therefore be subjected to fast decomposition and mineralization. Probably, these non-stable organic substances in manure were the main source of mineralized C and N resulting in increased

Table 5.13. "Light fraction" dry matter (LFDM), carbon (LFC) and nitrogen (LFN) in irrigation experiment, Kherson.

Treatment	Applied treatment	LFDM	LFC	LFN	C/N	Soil organic C and total N (%)	
		g mg^{-1} soil	mg kg^{-1} soil			as LFC	as LFN
I+F	Irrigated and fertilized	9.27	1884	122	15	11.3	9.4
F	Fertilized	8.52	1591	104	15	9.7	8.4
I	Irrigated	6.49	1589	104	15	10.0	8.4
CON	no	6.82	1684	108	16	10.8	9.2

Table 5.14. Microbial biomass in irrigation experiment, Kherson.

Treatment	Applied treatment	MBC	MBN	C/N	Soil organic C and total N (%)	
		mg kg^{-1} soil			as MBC	as MBN
I+F	Irrigated and fertilized	618	160	4	3.7	12.4
F	Fertilized	450	76	6	2.7	6.1
I	Irrigated	733	175	4	4.6	14.2
CON	no	636	128	5	4.1	10.9

accumulation of labile forms of C and N under the manured treatments.

5.6. General discussion

Many researchers recorded positive effects of manure application on SOM (Kononova, 1949, 1951; Chesnyak, 1973, 1981; Chsnyak et al. 1983; Kulagina, 1991; Beauchamp, 1980; Anderson et al., 1986; Voroney, 1988; Kuzsewski and Zabetowicz, 1986). For example, in Nebraska, annual application of 13.5 Mg ha^{-1} of manure (dry matter) during 31 years on irrigated land has increased content of humus from 0.98 to 1.67% (Chesnin, 1980).

Kharin (1993) found out that increased application of manure resulted in intensification of C mineralization, especially the C that is included in fulvic acids, and in lesser extent in humic acids. Based on the results of biological analysis, he concluded that application of high rates of manure activates the biochemical processes, which is controlled by particular microbiological community that has ability for active transformations not of only simple organic substances (e.g. fulvic acids), but also of more complex and hardly decomposable substances (e.g. humic acid).

Increased microbial activity in irrigated treatments in Kherson has been ascribed to the rapid metabolization of biomass-derived substrate resulting from the death of part of the microbial community during drying (Bottner, 1985; van Gestel et al., 1991; van Gestel et al., 1993a,b) or rapid rewetting of the desiccated soil material (Kieft et al., 1987).

5.7. Conclusions

Application of high rates of manure tended to increase labile forms of SOM, such as potentially mineralizable C and N, as well as soil microbial biomass, due to higher input of humic materials applied with manure. Also, application of manure tends to activate biochemical processes due to addition of large number of microorganisms that reside in manure, hence increasing the possibilities for organic matter transformations, both, mineralization and immobilization.

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Chapter 6

Carbon flux in semi-arid grassland ecosystems and its dependence on soil temperature and moisture in Ukraine

Atsunobu Kadono

6.1. Background

Soil respiration, i.e. carbon dioxide (CO_2) emission from soils, has been studied widely, as a major process of carbon dynamics between atmospheric carbon (780×10^9 Mg C: Houghton et al., 2003) and soil organic carbon (1550×10^9 Mg C: Eswaran et al., 1995; Schlesinger, 1991). Raich and Schlesinger (1992) summarized values of soil respiration from various ecosystems as $(68 \pm 4) \times 10^9$ Mg C y^{-1} globally. In order to simulate the dynamics of carbon under various ecosystems, several models have been developed, e.g. Roth-C (Jenkinson, 1990), CENTURY (Parton et al., 1987), etc. Since there are uncertainties on the carbon dynamics in terrestrial ecosystems (IPCC, 1996), however, further assessment is required for different soil types, geological regions and climatic zones (Kudeyarov and Kurganova, 1998). Schimel et al. (2001) reported that non-tropical land areas in the Northern hemisphere showed net carbon sink ranged about -2 to -4×10^9 Mg C y^{-1} for 1990's, and that sink size in Eurasia was twice the size in North America.

In Eurasia, Chernozem and Kastanozem soils, which develop under short- or tall-grass steppe vegetation, spread out from areas near the Black Sea to northern Kazakhstan in a belt. These soils are important not only because of their high productivity of crops but also of their high accumulation of carbon. For instance, the carbon accumulation in 1 m depth of Mollisols, which is roughly equivalent to the Chernozem or Kastanozem soils, was estimated to 131 Mg C ha^{-1} for whole Mollisols; 714, 190, 141 and 32 for Albolls, Udolls, Xerolls and Ustolls, respectively (Eswaran et al., 1995). Chernozem or Kastanozem soils widely destibute in Ukraine (Fig. 6.1). Chernozem soils occupy about 24.8×10^6 ha (41 % of Ukrainian land area), of which almost 20×10^6 ha of these areas are cultivated for crop production, whilst Chestnut (Kastanozem) soils occupy about 2×10^6 ha and 1.3×10^6 ha are cultivated (by the old soil classification system of USA: Makhov and Stebelsky 1993). Since these soils have been developed under the grassland ecosystems, cultivation causes degradation of soil organic carbon. Shikula (2000) showed 54 years of agricultural use degraded the surface (0-20cm) humus content of Typical Chernozem soil from 163 to 126 Mg C ha^{-1}. It is important to study SOM dynamics under semi-natural grassland ecosystems.

In addition to the study of *in vitro* mineralization of soil organic carbon, it is required to determine the relationship between *in situ* carbon flux from soils and factors regulating the flux, such as soil temperature or moisture.

So the objectives of this study are 1) to determine a dependence of *in situ* carbon flux on soil temperature and moisture, and 2) to estimate annual amount of carbon flux from Chernozem and Kastanozem soils in Ukraine.

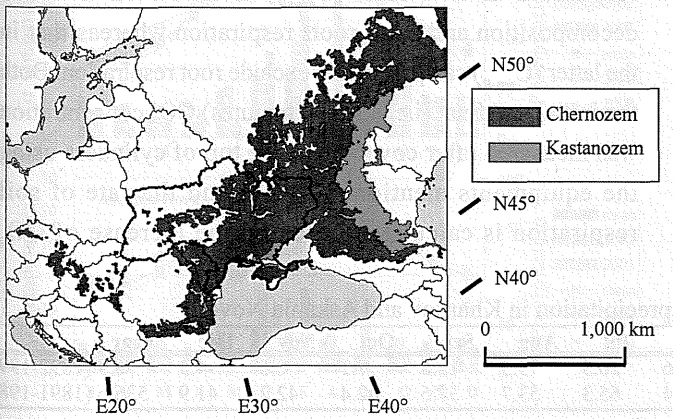

Figure 6.1. Distribution of soils in Ukraine (bold line) based on the classification of World Reference base for Soil Resources.

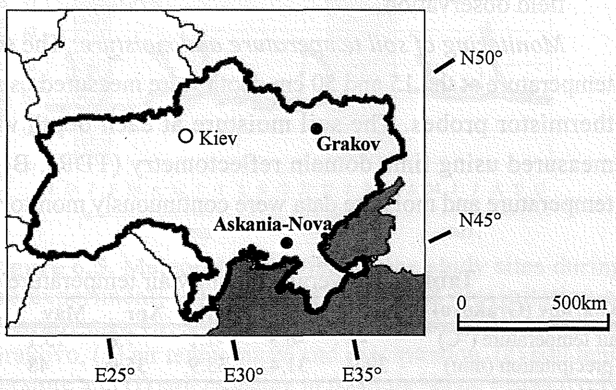

Figure 6.2. Location of Grakovo Experimental and Askania Nova Biosphere Reserve.

6.2. Materials and methods

Experimental sites: Two natural grassland sites were selected to monitor CO_2 flux and soil temperature and moisture (Fig. 6.2). Average monthly air temperature and precipitation are shown in Table 6.1.

1) Grakovo Experimental Field (N49° 44', E36° 56', Alt: 154 m) is located about 60 km southeast of Kharkov city. The meteorological data were assumed to be the same as this city. Mean annual temperature (MAT) and mean annual precipitation (MAP) were 6.9°C and 536.6 mm, respectively. Dominant plant species were *Festuca sulcata, Agropyron repens* and *Artemisia austriacea*, and temporally *Salvia verticillata, Matricaria inodora* etc. were observed in spring. This experimental field belongs to Institute for Soil Science and Agrochemistry Research. According to the USDA soil classification system, the soil was classified into Pachic Haploxerolls (Soil Survey Staff, 1998), which corresponds to the Typical Chernozem soils in the Ukrainian classification system. Soil texture of the surface layer was classified as LiC by field observation.
2) Askania Nova Biosphere Reserve (N46° 27', E33° 53', Alt: 27m) is located about 100 km east of Kherson city. MAT and MAP were 9.5°C and 386.4 mm, respectively. The virgin fescue-feather grass steppe have been reserved for more than 100 years. The feather grass steppe was dominated by *Stipa lessingiana, S. ucrainica* and *S. capillata* together with fescue (*Festuca sulcata* and *F. valesiaca*) and crested hair grass (*Koeleria cristata*). According to the USDA soil classification system, the soil was classified into Calcic Haploxerolls (Soil Survey Staff, 1998), which corresponds to the Dark Chestnut soils in the Ukrainian classification system. Soil texture of the surface layer was classified as LiC by field observation.

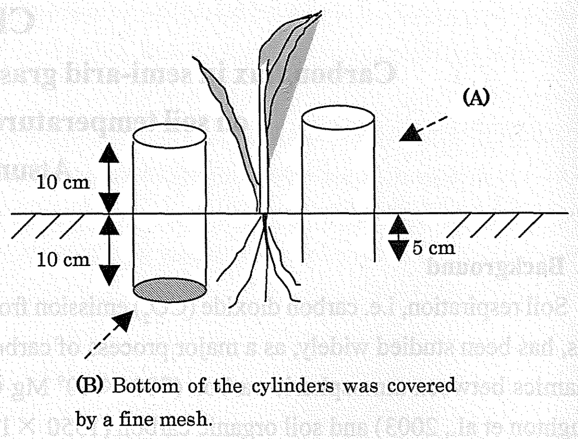

Figure 6.3. Closed-chamber method for determination of *in situ* soil respiration rate.
(A) Whole soil respiration including root respiration and (B) soil respiration excluding root respiration.

Monitoring of soil temperature and moisture: The soil temperature at the 15 and 50 cm depth were measured using thermistor probes. The soil moisture at each depth was measured using time domain reflectometry (TDR). Both temperature and moisture data were continuously monitored for each site using a datalogger system (CR-10X, Campbell Scientific Inc., Logan, USA).

Measurement of soil respiration: Soil respiration was measured several times during growing season in 2002 and 2003 by a closed-chamber method (Anderson, 1982) using handy type Infrared CO_2 analyzer (Anagas CD98, Environmental Instruments, Leamington Spa, UK) or CO_2 monitor (GH-250E, Sensonix japan). There was no difference in measured values by both the equipments. Two series of cylinders (diameter: 10.5 cm, height: 20 cm) were prepared in each five replications (Fig. 6.3). One series were inserted to the soils until 5 cm depth, and the others were until 10 cm depth in order to exclude the respiration of living root (only in 2003). The bottom of the latter cylinders was later covered with fine mesh to support inner soils and further with a plastic sheet to prevent CO_2 invasion originated from plant-root respiration on each measurement. We suppose that soil respiration in the former (C_{em+R}) include both the SOM decomposition and plant-roots respiration whereas that in the latter (C_{em-R}) can practically exclude root respiration. Both the initial and final (i.e. after 30 minutes) CO_2 concentration was measured after coverage of the top of cylinders using the equipments mentioned earlier and the rate of soil respiration is calculated based on the increase of CO_2

Table 6.1. Average monthly air temperature and precipitation in Kharkov and Askania Nova.

Kharkov (Grakovo)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
air temperature (°C)	-7	-6.3	-1.1	7.8	15.1	18.6	20.3	19.3	13.8	7.1	0.6	-4.3	6.9 (1892-1990)
precipitation (mm)	39.9	31.4	33.9	35.9	48	64	65.3	53.7	37.6	42.4	42.2	41.9	536.6 (1891-1988)

Askania-Nova	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
air temperature (°C)	-3.3	-2.7	1.6	9.1	15.5	20	22.7	21.9	16.4	9.7	4.1	-0.3	9.5 (1925-1990)
precipitation (mm)	29.8	24.7	20.9	25.9	40.5	43.8	46.4	32.9	23.9	31.2	30.9	35.1	386.4 (1910-1986)

concentration during 30 minutes. The root respiration was calculated by (C_{em+R}-C_{em-R}).

Measurement of plant biomass: In Grakovo, aboveground and belowground (100cm depth) biomasses in the area of 15 cm × 50 cm were collected and weighed after drying in oven (110°C), whilst in Askania Nova those in the area of 30 cm × 30 cm till 40 cm depth were measured. This experiment was conducted in two replications in 2003.

6.3. Air temperature, precipitation, soil temperature and moisture

Monthly average air temperature and precipitation in 2002 and 2003 for each site were shown in Fig. 6.4. The daily average of air temperature, daily precipitation, soil temperature and moisture at 15 and 50 cm depth for each sites were shown in Fig. 6.5.

In Kharkov (referenced meteorological station for Grakovo), mean annual temperature and precipitation in 2002 and 2003 were 8.7°C, 543.8 mm, 7.4°C and 672.6 mm, respectively. Compared to the mean values, annual temperature in 2002 was relatively higher, whilst annual precipitation in 2003 was much higher than in normal years. As shown in Fig. 6.4, climatic condition in 2002 and 2003 was characterized as follows: the early spring and hot summer in 2002, followed by the very severe winter, and the very rainy summer in 2003. Affected by the daily precipitation pattern, the soil moisture decreased continuously during summer in 2002, whilst several rewetting events were occurred in 2003 at the 15 cm depth. Duration of soil temperature below 0°C in 2002/2003 winter was longer than 2001/2002 winter. The winter in 2002/2003 was so severe that winter wheat production in

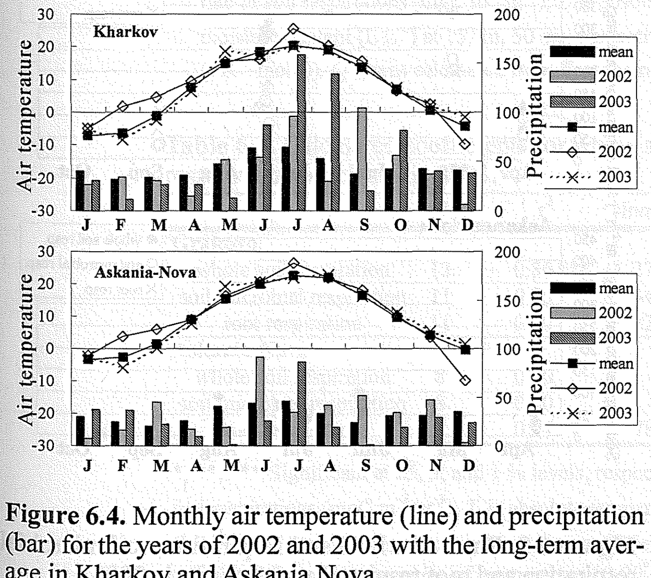

Figure 6.4. Monthly air temperature (line) and precipitation (bar) for the years of 2002 and 2003 with the long-term average in Kharkov and Askania Nova.

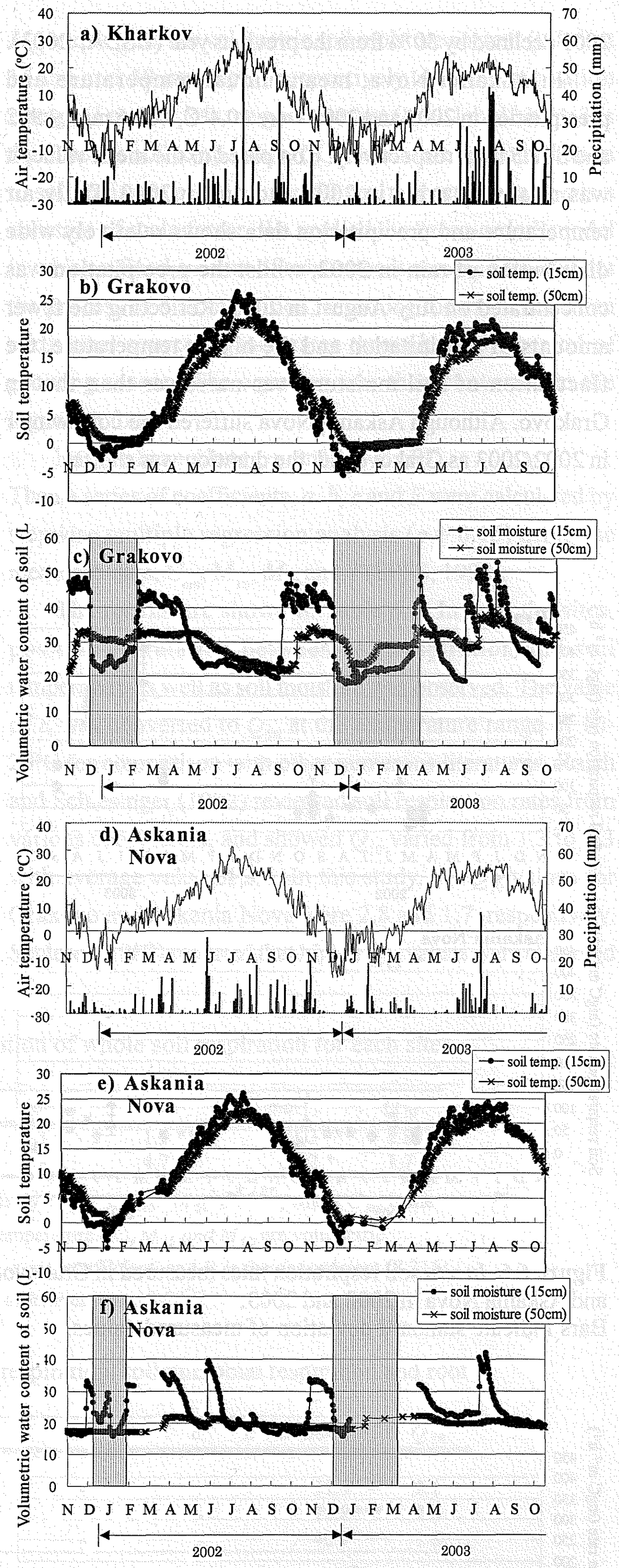

Figure 6.5. Meteorological data of the study sites during the experiment; (a) air temperature and precipitation at Kharkov city, (b) soil temperature and (c) soil moisture at Grakovo, (d) air temperature and precipitation, (e) soil temperature and (f) soil moisture at Askania Nova, respectively, from 1 Nov. 2001 to 31 Oct 2003.
Shaded area indicates the period in which soil temperature at 15 cm depth is below zero.

2003 declined by 50 % from the previous year (USDA, 2003).

In Askania Nova, mean annual temperature and precipitation in 2002 and 2003 were 10.4°C, 408.6 mm, 9.9°C and 311.5 mm, respectively. Compared to the mean value, it was relatively rainy in 2002 and dry in 2003. Daily air temperature and precipitation data shows relatively wide distribution of rain in 2002, whilst the precipitation was concentrated on July-August in 2003. Reflecting the fewer amounts of precipitation and the higher temperature, the fluctuation of soil moisture was narrower than that in Grakovo. Although Askania Nova suffered the cold winter in 2002/2003 as Grakovo did, the duration was shorter.

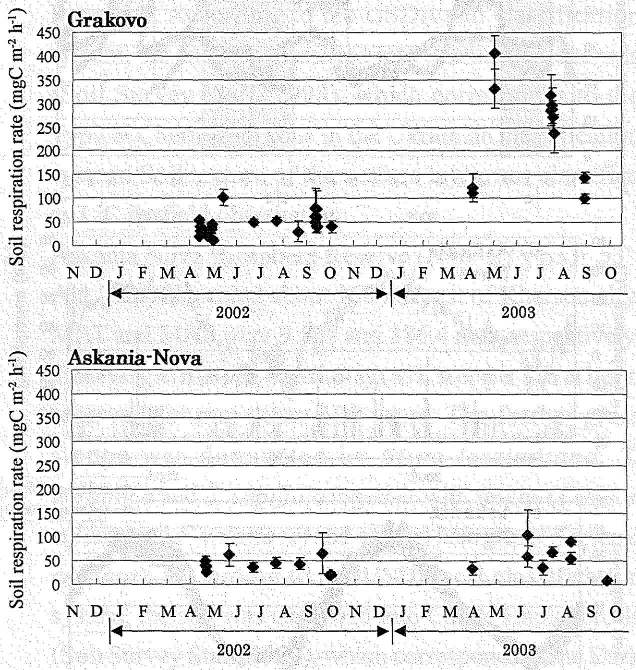

Figure 6.6. *In situ* soil respiration rates measured in Grakovo and Askania Nova in 2002 and 2003.
Bars indicate standard deviation of measured values.

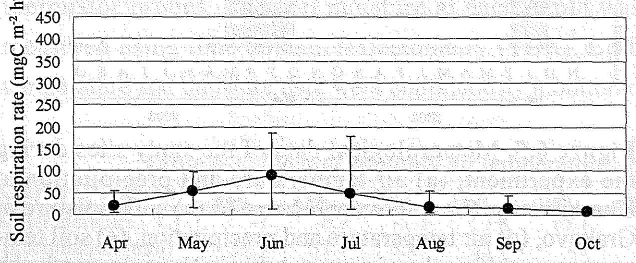

Figure 6.7. Average soil respiration rates during the years of 1967-1974 in Askania Nova virgin steppe (in Chapter 4).
Bars indicate maximum and minimum values.

6.4. *In situ* soil respiration rates

Fig. 6.6 shows *in situ* soil respiration rates (C_{em+R}) measured for each site in 2002 and 2003. In Grakovo, inter annual variation of soil respiration was much higher than in Askania Nova. Despite the difference in the amount of the respiration, the maximum value for each year was recorded in May. It would be due to optimal condition for the decomposition of organic matter with high soil moisture even though soil temperature in spring was lower than in summer. Although such a seasonal pattern was not clear in Askania Nova, the distribution of daily precipitation might affected it, i.e. the relatively even distribution in 2002, whilst the concentrated distribution throughout a year of 2003 (Fig. 6.5). Similar trend and respiration rate in this virgin steppe area was reported by Polupan (in Chapter 4) and was shown in Fig. 6.7 for comparison.

6.5. Amount of the whole soil respiration, soil microbial respiration and root respiration measured in 2003

The amounts of whole soil respiration (C_{em+R}), soil microbial respiration (C_{em-R}) and plant root respiration (C_{em+R}-C_{em-R}) are given in Fig. 6.8. In Grakovo, the average proportion of root respiration in whole soil respiration was 53.2%, with ranging from 30.8 to 73.4%, whereas in Askania Nova, the average was 37.2% except for one negative value. Raich and Tufekcioglu (2000) summarized values of soil respiration from various ecosystems and reported the percentages of root respiration in whole soil respiration from temperate grassland ecosystems as 17-40%. Our result in Askania Nova was

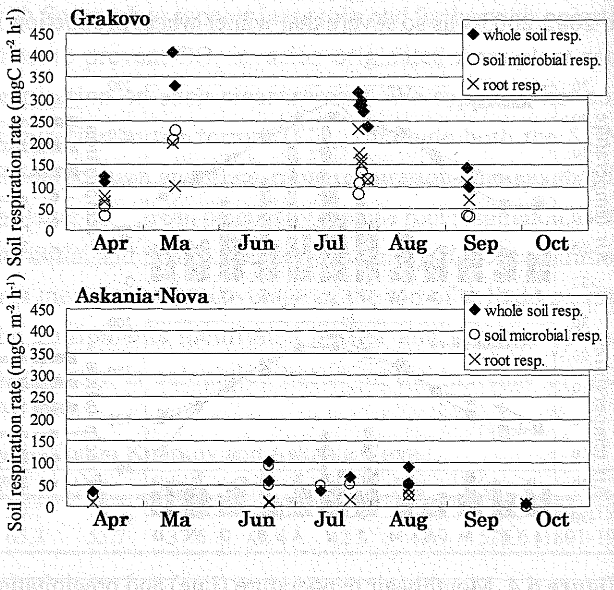

Figure 6.8. Rates of whole soil respiration, soil microbial respiration and root respiration in each site in 2003.

consistent with the value, whilst in Grakovo we observed higher values. It would be due to relatively higher vegetative activity caused by the exceptionally higher precipitation in that year.

In Grakovo, the maximum value of the root respiration was recorded in mid-summer, whereas the microbial respiration was the highest in spring. This trend was also observed in Askania Nova. This might be due to the difference in major factors regulating the activities of soil microbes and plants, i.e. soil moisture for microbes, whilst soil temperature for plants.

6.6. Dependence of the soil respiration on soil temperature and moisture

For determining the total annual soil respiration, we firstly derived an equation that describes the relationship between the *in situ* soil respiration rate and/or soil temperature and moisture by multiple regression analysis (Funakawa et al., 2004). The total soil respiration was then calculated by the equation with application of the monitored soil temperature and moisture data. First of all, we assumed that the Arrhenius relationship between the soil temperature and soil respiration rate was as follows:

$$C_{\mathrm{em}} = aM_{15}^{\ b}\, M_{50}^{\ c}\, \mathrm{e}^{-E/RT}$$

where C_{em} is the hourly soil respiration rate (mg C $\mathrm{m^{-2}\ h^{-1}}$), M_{15} and M_{50} are the volumetric soil moisture content (L $\mathrm{L^{-1}}$) at 15 cm and 50 cm depth, respectively, E is the activation energy (J $\mathrm{mol^{-1}}$), R is the gas constant (8.31 J $\mathrm{mol^{-1}\ K^{-1}}$), T is the absolute soil temperature (K), b and c are the contribution to soil moisture at 15 cm and 50 cm, respectively and a is a constant of scale factor. We applied the "zero-order" model in which a fixed amount of substrates is assumed throughout the process of decomposition, assuming the existence of an additional source of substrates throughout the period of growing season. The equation was then converted to the logarithm form:

$$\ln C_{\mathrm{em}} = \ln a + b\ln M_{15} + c\ln M_{50} - E / RT$$

Then a series of coefficients, a, b, c and E were calculated by stepwise multiple regression analysis ($p = 0.15$) using the measured data, C_{em}, $\mathrm{M_{15}}$, M_{50} and T (SPSS, 1998).

The results are shown in Table 6.2. In both the sites, positive correlation between soil respiration and soil temperature as well as soil moisture was observed. The value of E was converted to Q_{10} at the temperature range of 10-20°C for comparison with other numerous literatures. Raich and Schlesinger (1992) reviewed soil respiration rates from various ecosystems, and showed Q_{10} varied from 1.3 to 3.3 with average value of 2.4. In this study, the Q_{10} values for Grakovo and Askania Nova were 2.8 and 1.7, respectively. Schleser (1982) reported that higher Q_{10} values were observed

Table 6.2. Calculated coefficients in the equation of whole soil respiration for each site throughout the years of 2003 and 2003.

	N	r^2	ln*a*	*b*	*c*	*E* (kJ $\mathrm{mol^{-1}}$)	Q_{10}
Grakovo	35	0.33 ***	38 ***	1.3 *	1.9 **	71.3 ***	2.8
Askania-Nova	19	0.20 *	26 **	-	4.7 *	36.2 *	1.7

*, **, *** Significant at 25, 5, and 1 % levels, respectively. $C_{\mathrm{em}} = aM_{15}^{\ b}\ M_{50}^{\ c}\ \mathrm{e}^{-E/RT}$, where C_{em} is the rate of soil respirations (mgC $\mathrm{m^{-2}\ hr^{-1}}$), T is absolute temperature (K), M_{15} *and* M_{50} are volumetric moisture content (L $\mathrm{L^{-1}}$) at 15 cm, 50 cm, respectively, a is a coefficient, and R is the gas constant (8.315 (J $\mathrm{K^{-1}\ mol^{-1}}$)). Q_{10} was calculated from E at the range of temperature 10-20°C .

Table 6.3. Calculated coefficients for whole soil respiration, soil microbial respiration and root respiration in each site in 2003.

	N	r^2	ln*a*	*b*	*c*	*E* (kJ $\mathrm{mol^{-1}}$)	Q_{10}
Grakovo							
whole soil respiration	12	0.86 ***	27 ***	-	-	51.0 ***	2.1
soil microbial respiration	11	0.75 ***	34 ***	-	-	70.8 ***	2.8
root respiration	11	0.70 ***	22 ***	-	-	40.9 ***	1.8
Askania-Nova							
whole soil respiration	8	0.00	-	-	-	-	-
soil microbial respiration	8	0.00	-	-	-	-	-
root respiration	7	0.94 **	78 ***	-2.2 **	23.7 **	98.1 ***	4.1

*, **, *** Significant at 25, 5, and 1 % levels, respectively. $C_{\mathrm{em}} = aM_{15}^{\ b}\ M_{50}^{\ c}\ \mathrm{e}^{-E/RT}$, where C_{em} is the rate of soil respirations (mgC $\mathrm{m^{-2}\ hr^{-1}}$), T is absolute temperature (K), M_{15} *and* M_{50} are volumetric moisture content (L $\mathrm{L^{-1}}$) at 15 cm, 50 cm, respectively, a is a coefficient, and R is the gas constant (8.315 (J $\mathrm{K^{-1}\ mol^{-1}}$)). Q_{10} was calculated from E at the range of temperature 10-20°C .

for lower temperature-sites, which was also observed in this study.

As was the case of the whole soil respiration, the dependence of the microbial respiration or the root respiration on soil temperature and moisture was determined (Table 6.3). In Grakovo, only the value of *E* could explain the fluctuation of whole soil respiration, soil microbial respiration and root respiration. This would be due to the high precipitation and enough amount of available water at the site in 2003. The *E* and Q_{10} values for the soil microbial respiration were 70.8 kJ mol^{-1} and 2.8, respectively, whilst those values for the root respiration were 40.9 kJ mol^{-1} and 1.8, respectively. It is reported that Q_{10} value of root respiration is higher than that of microbial respiration (Boone et al., 1998). Since the higher values in the microbial respiration in this study was due to the large amount of CO_2 emission in spring with low temperature, it might be suggested that another factors affected the emission rate, such as dissolved organic matter content due to cutting of root in the experiment procedure. Seto and Yanagiya (1983) reported the *in situ* soil respiration rate was well explained by temperature as well as dissolved organic matter in soils. In Askania Nova, only the root respiration could be explained by soil temperature and moisture. As mentioned above, the *E* and Q_{10} values of 98.1 and 4.1 were consistent to the values ever reported (Boone et al. 1998). The volumetric water content at 15 cm contributed negatively whilst that value at 50 cm did positively. It might be due to the higher root activity at the deeper soil layer.

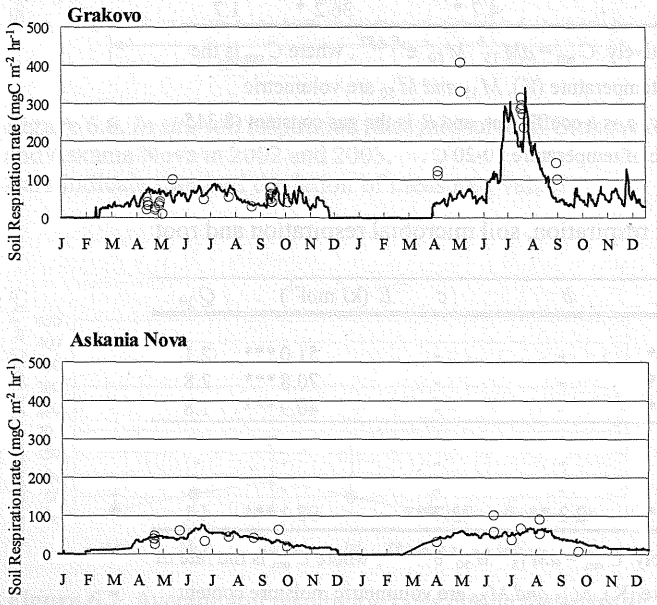

Figure 6.9. Estimated (line) and measured (circle) soil respiration rate for each site in 2002 and 2003.

6.7. Estimation of annual total soil respiration using monitored soil temperature and moisture data

Using the relationship between the soil respiration and soil moisture and temperature and monitored logger data during the two years, we calculated daily soil respiration and summed up to annual soil respiration rate for each year. The daily respiration estimated were plotted with the measured values for each site (Fig. 6.9), assuming the CO_2 emission below 0°C could be neglected. Annual soil respiration for each year was shown in Table 6.4.

In Grakovo, the annual soil respiration rates in 2002 and 2003 were 3.61 and 5.74 Mg C ha^{-1}, respectively. As shown in Fig. 6.9, the simulated values for 2003 were underestimated the measured values, especially in spring. The estimated value of 3.61 Mg C ha^{-1} in 2002 was similar to previous reports. Though Raich and Schlesinger (1992) summarized values of soil respiration in temperate grassland ecosystems as 4.42 Mg C ha^{-1}, with widely varied among literatures from 1.32 to 8.30 Mg C ha^{-1}. Coleman et al. (1976) reported 2.30 Mg C ha^{-1} for short grass prairie in Colorado (MAP: 310 mm, MAT: 9°C). Kucera and Kirkham (1971) reported 4.57 Mg C ha^{-1} for tall grass prairie in Missouri (MAP: 1000 mm, MAT: 12.8°C). The observed value in Grakovo (MAP: 537 mm, MAT: 6.9°C) would be in the range of this climosequence. In Askania Nova (MAP: 386 mm, MAT: 9.5°C) the annual soil respiration rates in 2002 and 2003 were 2.52 and 2.54 Mg C ha^{-1}, respectively. This observed value was consistent to the value in Colorado (Coleman et al., 1976).

The simulated whole soil respiration rate, soil microbial respiration rate and root respiration rate in 2003 for each site were shown in Fig. 6.10. Due to the failure of regression, soil microbial respiration rate was not plotted for Askania Nova. Annual amount of these respirations were summarized in Table 6.5. In Grakovo, despite the little underestimate in spring, simulation of the trend was improved for whole soil respiration. The sum of annual soil microbial respiration (4.80 Mg C ha^{-1}) and root respiration (7.07 Mg C ha^{-1}) exceeded the whole soil respiration (9.76 Mg C ha^{-1}). This might be due to the relatively higher temperature in winter, i.e. in reality plant respiration would not last at that time. In Askania Nova, the

Table 6.4. Calculated annual soil respiration for each year.

	N	r^2	Annual soil respiration 2002	2003
			(Mg C ha^{-1})	
Grakovo	35	0.33	3.61	5.74
Askania-Nova	19	0.20	2.52	2.54

N; the number of values of soil respiration that was used for regression.

estimated annual root respiration was 1.19 Mg C ha^{-1}. The proportion of the root respiration in whole respiration was 51% ((9.76-4.80)/9.76) in Grakovo and 47% in Askania Nova. These values implied relatively high plant activity in each site, compared to the values in literature (Raich and Tufekcioglu, 2000).

6.8. Comparison of above- and below-ground biomasses with soil respiration rates

The above- and below-ground biomasses in each site is shown in Fig. 6.11. In addition to the data that we measured, biomass data measured by Polupan (in Chapter 4) in Askania Nova during 1967-1974 was also shown in the figure. The measured values in 2003 was not different with the older data. The aboveground biomass in Grakovo and Askania Nova was 4.1 and 2.8 Mg C ha^{-1}, respectively, whilst the belowground biomass in upper 100 cm was 19.6 and 20.7 Mg ha^{-1}, respectively. Sims and Coupland (1979) reported almost same range of belowground biomass in short grass prairie as we observed. In upper 10 cm, we observed 10.1 and 9.5 Mg ha^{-1} in Grakovo and Askania Nova. Those values were almost half of the contents in 100 cm depth.

Assuming carbon content of the dry matter as 45% (Kudeyarov and Kurganova, 1998), we can conclude that the belowground biomass C in 10 cm (4.5 Mg C ha^{-1}) was almost equivalent to the amount of soil microbial respiration (4.8 Mg C ha^{-1}) in Grakovo, 2003, whilst in Askania Nova the microbial respiration (1.4 Mg C ha^{-1}) was approximately one-third of belowground biomass in 10 cm (4.3 Mg C ha^{-1}). This result suggested that relatively large amount of carbon can be mineralized if the condition was suitable for decomposition, such as the case of Grakovo in 2003.

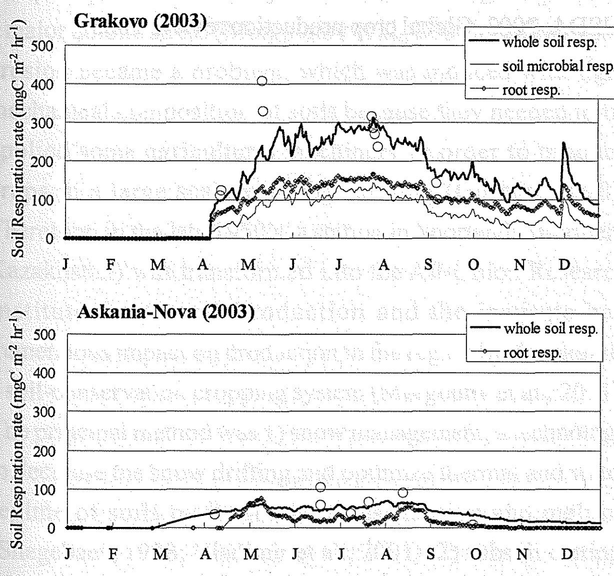

Figure 6.10. Estimated (line) and measured (circle) amount of whole soil respiration, soil microbial respiration and root respiration in 2003.

6.9. Conclusion

The dependence of *in situ* soil respiration on soil temperature and moisture in two representative steppe soil areas (Chernozem and Kastanozem) was studied. In Grakovo (Chernozem), annual whole soil respiration in 2002 and 2003 was 3.61 and 9.76 Mg C ha^{-1}, respectively, whilst in Askania Nova (Kastanozem) 2.52 and 2.54 Mg C ha^{-1}, respectively. The difference in Grakovo in the two years would not be explained solely by yearly fluctuation of meteorological factors; another factors such as dissolved organic matter could contribute the occasionally accelerated soil respiration.

Table 6.5. Calculated annual whole soil respiration, soil microbial respiration and root respiration in 2003.

	N	r^2	Annual soil respiration (Mg C ha^{-1})
Grakovo			
whole soil respiration	12	0.86	9.76
soil microbial respiration	11	0.75	4.80
root respiration	11	0.70	7.07
Askania-Nova			
whole soil respiration$^{1)}$	19	0.20	2.54
root respiration	7	0.94	1.19

N; the number of values of soil respiration that was used for regression
1) This value was same as in Table 6.4.

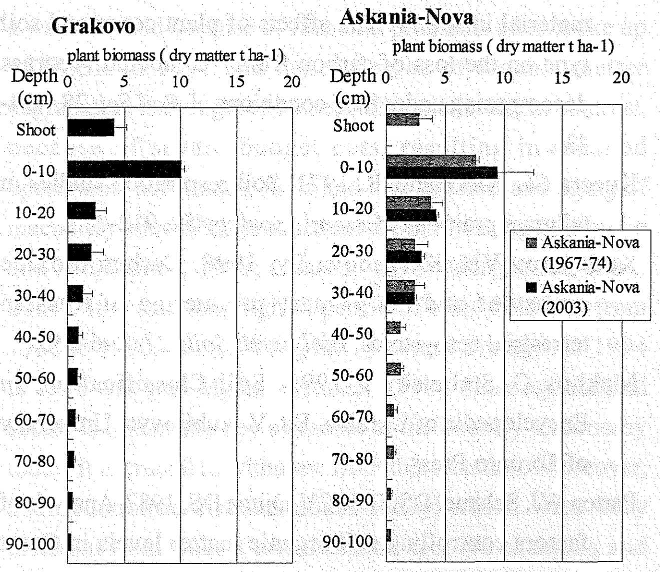

Figure 6.11. Above- and below-ground plant biomasses in each site.
Data for Askania-Nova in 1967-74 were measured by Polupan (in Chapter 4).

The root respiration contributed about half of the whole soil respiration in each site. The soil microbial respiration in Grakovo was equivalent to the belowground biomass in the surface 10 cm, whilst that in Askania Nova was approximately 30% of the belowground biomass in 10 cm.

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Chapter 7

General outline of soil properties and agriculture in Kazakhstan steppe

Shinya Funakawa and Azusa Mishima

7.1. General background

In Kazakhstan, Chernozem soils occupy 32.1×10^6 ha or 11.8% of the country territory (GUGK, 1982). Because of political reasons, the natural grass forb steppes of the area have disappeared over the last decades and have largely been replaced by arable land mainly spring wheat due to Khrushchev's Virgin Lands Agricultural Program from 1954 to 1960 (Medvedev, 1987). Accordingly, these areas are the main agricultural regions of Kazakhstan as is widely alleged to be most productive (Glukhovtse and Yermekbayeva, 2001). It is said that 26.5×10^6 (GUGK, 1982; Morgounov and Zuidema, 2001) or 24.6×10^6 (Gossen, 1998) Chernozem soils in Kazakhstan are converted to arable land. However, Chernozem soils in northern Kazakhstan not only sustain crop production in our world, but also store 130-160 Mg ha^{-1} of organic matter in the top 20 cm, which functions as a huge source and sink of carbon dioxide (Kudeyarov et al., 1995). In this sense, Chernozem is one of the most important resources for both agricultural and environmental aspect.

7.2. Historical background of rainfed agriculture in northern Kazakhstan

Although these areas are rich in soil fertility, climatic condition is generally severe in that there is only about 300 mm precipitation within a year and hence drought represents a major abiotic stress (Morgounov et al., 2001). At first, wind erosion became a problem, which was induced with light mechanical composition of soils because they needed to be applied some agricultural machinery in order to produce crops in a large scale with dry farming (Gossen, 1998). Therefore, in the late 1950's, a station in Shortandy (northern Kazakhstan) was transformed into the All-Union Research Institute for Cereal Production and the institute had tremendous impact on production in the region by developing a soil-conservation cropping system (Morgounv et al., 2001). The principal method was 1) snow management, a technology to decrease the snow drifting and optimize thermal and water regime of soils by its spatial redistribution and melting (Shegebaev, 1998; Vladimir et al., 2001), 2) subsoil cutting, a technology to guarantee good penetration of melt-water as well as to prevent evaporation by cutting capillary rise by cutting subsoil (Shegebaev, 1998), 3) summer fallow, a technology to protect weed hazard, to capture soil moisture, and to accelerate mineralization of organic matter for nutrient replenishment by not cultivating one year (Shegebaev, 1998).

Even though it was a strategy for soil-conservation, the result of managing this kind of technology uniformly and intensively during the period of former Soviet Union was rather focused on production, which often came at the expense of sustainability (Srivastava and Meyer, 1998). Various problems of sustainability were essentially inevitable from these practices, i.e., decline in soil fertility, soil erosion, soil compaction (Srivastava and Meyer, 1998) and consequently various changes in soil properties (Sorokina and Kogut, 1997). There is an observation that organic carbon and total nitrogen in the top 10-cm soils reduced 38-43% and 45-53%, respectively, over the last 25-30 years in continuously cropped field of Chernozem soils in Russia (Mikhailova et al., 2000), or that the transition of virgin soils to arable land caused up to 50% reduction in organic matter content during the first years of cultivation (Buyanovsky et al., 1987). Also the soil fertility has declined up to 50% in Chernozem soils in former Soviet Union (Srivastava and Meyer, 1998).

However, in Kazakhstan, it is not managed at present in a way they did because of financial problems after broke up of USSR in 1991 and hence degree of organic matter degradation is thought to be becoming moderate. In contrast, because of severe budget cuts, resulting in reduced operations, herbicides, fuels and low salaries, and aging of machinery after 1991; productions are diminishing (Longmire and Moldashev, 1999; Gossen, 1998; Morgounov et al., 2001). It is said that highest period of crop yield was from 1986 to 1990, i.e., 1.00 Mg ha^{-1}, whereas average for 1994 to 1996 was 0.65 Mg ha^{-1} (Gossen, 1998). Since agricultural sector is one of the key elements of the country's economy today, it is crucial to withdraw from this situation. Moreover, socioeconomic circumstances today, which were very different from what it was a decade ago, are changing and people who lived and worked in a number of state- and collective-farms have the right to work individual plots of lands (Meng and Morgounov, 2000). The agricultural technology system (research, education, and extension) in Kazakhstan entered to new era. A different kind of innovative approach for land management must be reorganized to be responsive and effective (Morgounov et al., 2001).

In this context, the theory of N.K. Azarov should be focused, which indicated that geography has correlation with snow depth, humus contents, moisture contents and cereal productivity and showed opportunity to grow cereals in the best agricultural landscapes (Gossen, 1998). This is the possibility to change from soil conservation system to adaptive landscape system with contour organization of the fields. Azarov defined this as an agrolandscape agricultural system from his results. In addition to that, Wolf (2000) observed that soil organic carbon is determined by the effect of topography, which controls soil genesis through moisture redistribution or wind erosion for example. Moreover, concept of site-specific management, which is a technique that divides a field to small cells for more careful management, proposed by a soil scientist, Prof. H.H. Cheng in the Minnesota University (Shibusawa, 1999), is focused as well. These theories can be applied to an alternative agricultural system that would satisfy both the agroeconomic and environmental concerns on the agriculture here. A possibility of "the site-specific management" will also be analyzed in Chapters 11 and 12 in the present study.

7.3. Materials and methods

Macrolandscape of Kazakhstan is characterized by an east-to-west extension of central desert zone along with Lake Balkhash, Aral Sea and Caspian Sea and surrounded steppe zones both in the north and the south (Fig. 7.1). The southern foothill steppes of Mt. Alatau are situated under s relatively high temperature as well as high rainfall, not like as a northern steppe, which is characterized by severe drought in summer and cold climate in winter (Fig. 7.2).

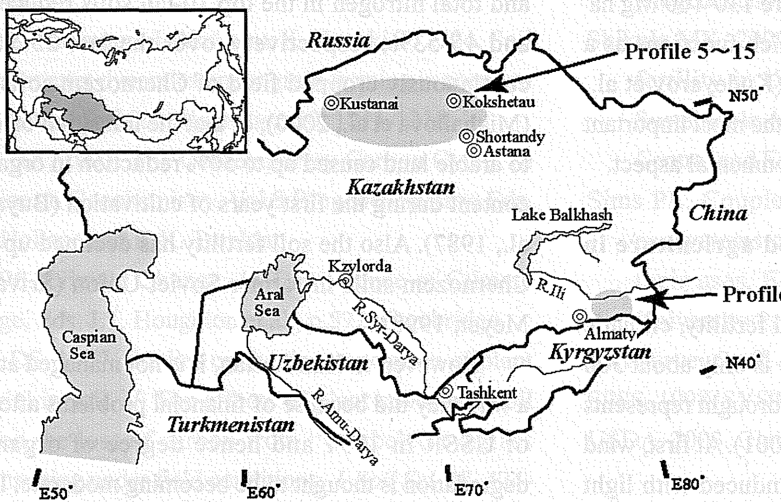


Figure 7.1. Study sites.

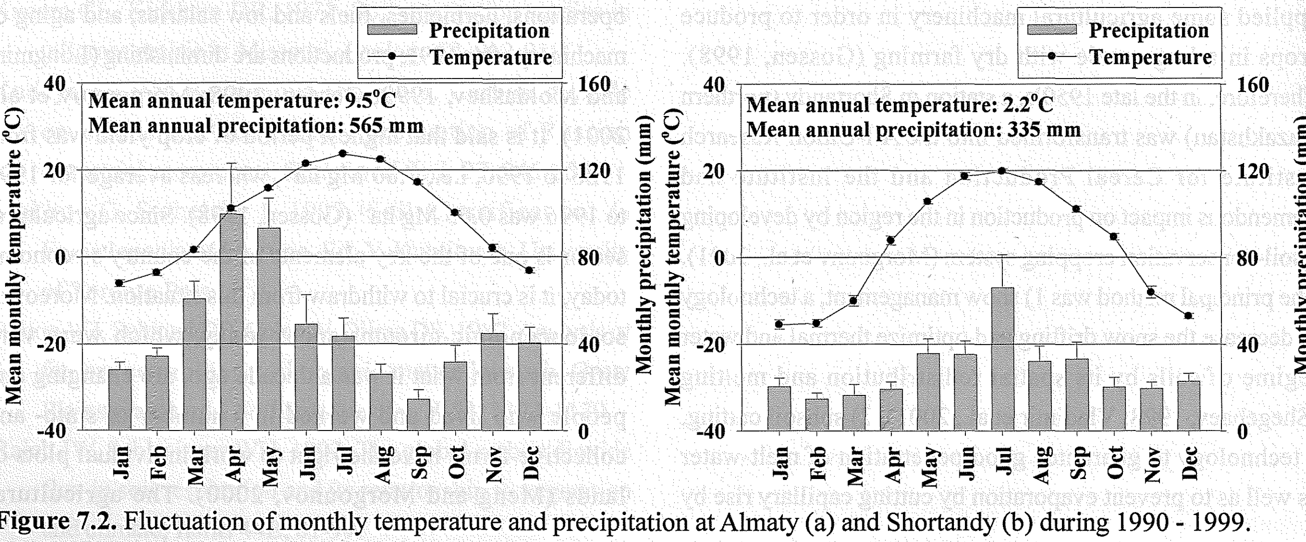


Figure 7.2. Fluctuation of monthly temperature and precipitation at Almaty (a) and Shortandy (b) during 1990 - 1999.

Profile 2 (Typic Calciudolls) **Profile 5 (Typic Haplustolls)** **Profile 7 (Typic Haplustolls)**

Profile 8 (Lithic Haplustolls) **Profile 9 (Lithic Dystrustepts)** **Profile 13 (Typic Haplosalids)**

Profile 14 (Typic Natrustalfs) **Profile 15 (Typic Haplustalfs)**

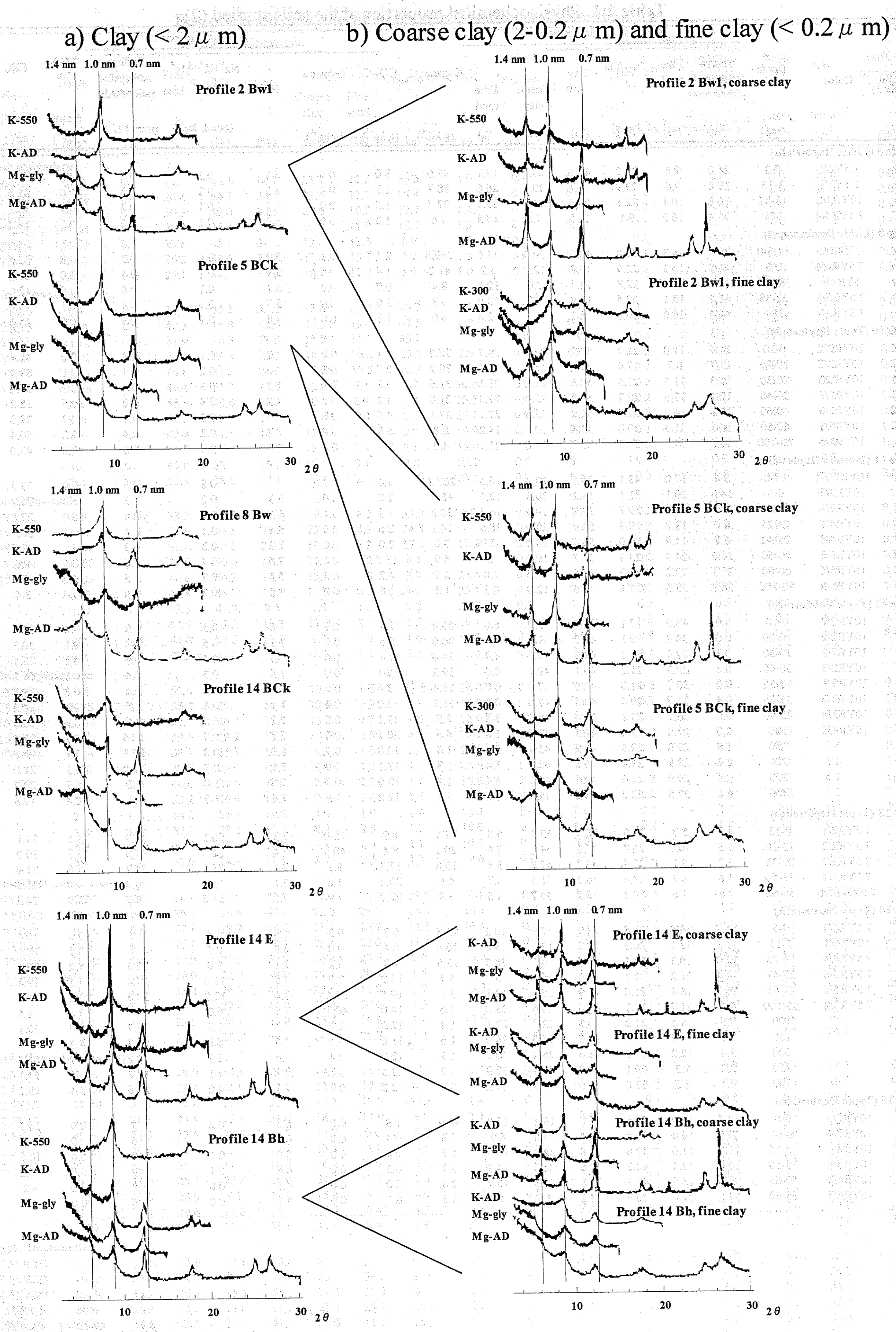
Figure 7.3. Representative soil profiles in Kazakhstan steppe.

Table 7.1. Physicochemical properties of the soils studied (1).

			Particle size distribution									Saturation extract					
Horizon	Color	Depth (cm)	Coarse sand (%)	Fine sand (%)	Silt (%)	Clay (%)	Coarse clay (%)	Fine sand (%)	Organic C (g kg^{-1})	CO$_3$-C (g kg^{-1})	Gypsum (g kg^{-1})	pH	Na$^+$+K$^+$+Mg^{2+} +Ca^{2+} (cmol$_c$ kg^{-1})	Sodium adsorption ratio (SAR) (mmol L^{-1})$^{1/2}$	Exch. Na (cmol$_c$ kg^{-1})	CEC (cmol$_c$ kg^{-1})	Exch. Na percentage (ESP) (%)
Profile 1 (Pachic Hapludolls)																	
A1	10YR2/2	0-10	0.0	19.5	46.3	34.2	22.3	11.8	66.6	3.9	0.1	6.5	2.4	0.7	0.0	33.0	0.0
A2	10YR2/3	10-26	0.1	20.4	44.7	34.7	23.6	11.1	55.4	3.1	0.1	6.0	2.4	0.7	0.0	31.3	0.0
BA	10YR3/3	26-41	0.1	20.3	49.0	30.6	20.5	10.2	17.7	2.2	0.0	6.8	0.2	0.2	0.0	19.0	0.1
Bw	10YR3/4	41-55	0.0	22.7	46.4	30.8	19.0	11.9	13.3	1.8	0.0	6.4	0.1	0.3	0.0	17.2	0.1
BC	10YR4/4	55-70	0.0	23.8	45.1	31.1	17.6	13.5	6.9	1.6	0.0	6.4	0.1	0.3	0.0	16.1	0.2
C	10YR5/3	70-120	0.1	25.2	41.6	33.1	17.4	15.7	4.2	1.8	0.0	6.2	0.1	0.4	0.1	16.0	0.3
		120+	0.0	25.1	44.2	30.6	18.2	12.4	5.9	1.0	0.0	7.3	0.2	0.4	0.0	15.3	0.3
Profile 2 (Typic Calciudolls)																	
A1	10YR2/3	0-9	0.2	32.4	35.5	32.0	15.6	16.4	49.7	3.1	0.0	6.9	0.4	0.5	0.0	31.1	0.0
A2	10YR3/3	9-18	0.0	40.3	16.8	42.9	23.3	19.6	42.5	2.8	0.0	6.7	0.6	0.1	0.0	28.0	0.1
Bw1	10YR3/3	18-32	0.2	31.9	36.3	31.6	15.9	15.7	33.2	3.2	0.0	7.0	0.3	0.1	0.1	27.1	0.2
Bw2	10YR4/3	32-42	0.2	43.1	31.6	25.1	14.8	10.3	25.5	2.9	0.0	6.8	0.2	0.2	0.1	22.6	0.3
BC	10YR4/4	42-61	0.0	44.8	31.2	24.0	13.5	10.5	16.3	2.3	0.0	6.9	0.2	0.2	0.1	21.2	0.3
Ck	10YR6/3	61-90+	0.0	49.4	31.3	19.3	12.2	7.1	5.7	30.0	0.0	7.4	0.2	0.2	0.0	10.5	0.4
		150	0.0	48.9	32.4	18.7	10.5	8.2	2.7	26.3	0.0	7.8	0.2	0.2	0.1	9.1	0.6
		200	0.0	46.2	38.7	15.2	12.8	2.3	2.1	25.1	0.0	7.8	0.2	0.3	0.1	8.6	0.7
		250	0.0	42.4	41.5	16.2	13.9	2.3	2.2	19.9	0.0	8.0	0.2	0.3	0.1	6.3	1.2
		300	0.0	45.2	35.4	19.3	13.9	5.4	2.8	15.0	0.0	8.0	0.3	0.4	0.1	8.6	1.2
		400	0.0	45.0	38.8	16.2	13.1	3.1	3.2	16.2	0.0	8.1	0.3	0.8	0.1	9.3	1.4
		500	0.0	58.3	28.6	13.1	10.8	2.3	1.7	20.2	0.0	8.1	0.3	1.8	0.2	6.8	2.6
Profile 3 (Typic Calciustolls)																	
A1	10YR3/2	0-8	2.0	33.2	36.7	28.0	19.8	8.2	33.0	2.9	0.0	7.7	0.3	0.1	0.0	21.3	0.1
A2	10YR3/3	8-18	1.3	31.9	39.5	27.2	22.9	4.3	24.3	3.1	0.0	7.7	0.3	0.1	0.0	17.1	0.2
Bw	10YR3/4	18-40	1.3	36.8	40.6	21.3	19.0	2.3	17.8	12.3	0.0	7.7	0.3	0.1	0.0	14.1	0.2
BCk	10YR5/4	40-60	0.4	33.9	50.0	15.7	15.5	0.2	6.8	31.9	0.0	7.7	0.2	0.2	0.0	8.9	0.3
C	10YR6/4	60-90+	0.4	40.6	44.2	14.8	13.3	1.5	3.9	27.6	0.0	7.8	0.2	0.3	0.1	8.7	0.6
		100	0.3	41.8	45.7	12.2	11.4	0.9	3.1	25.1	0.0	7.8	0.2	0.6	0.1	6.3	1.1
		150	0.2	43.3	47.9	8.5	7.5	1.0	2.2	22.8	0.0	7.9	0.2	0.5	0.1	6.5	1.1
		200	0.0	44.4	42.2	13.3	11.2	2.1	1.5	19.1	0.0	8.1	0.3	1.2	0.1	6.1	2.1
		250	0.0	45.0	43.5	11.5	9.7	1.8	1.6	18.9	0.1	8.0	0.9	4.9	0.5	6.0	8.4
		300	0.9	47.3	42.6	9.2	7.8	1.4	1.5	17.5	4.5	7.6	5.3	7.1	0.7	6.2	11.0
Profile 4 (Calcic Haploxerepts)																	
A1	2.5Y6/3	0-8	1.3	55.6	28.6	14.6	13.0	1.6	11.8	16.0	0.0	7.7	0.6	0.2	0.0	8.5	0.1
A2	2.5Y6/3	8-18	1.2	55.2	29.1	14.4	12.6	1.9	8.1	18.3	0.0	7.8	0.3	0.2	0.0	8.0	0.1
Bw	2.5Y6/4	18-38	1.2	50.6	26.9	21.4	15.7	5.7	6.6	18.9	0.0	7.7	0.3	0.4	0.0	7.9	0.3
BCk	2.5Y6/4	38-47	0.1	59.1	28.7	12.1	10.0	2.0	4.7	23.2	0.0	7.8	0.2	0.5	0.0	7.1	0.5
C	2.5Y6.5/4	47-90	0.0	63.7	25.5	10.8	9.2	1.6	2.5	23.5	0.0	7.9	0.2	0.7	0.0	7.4	0.6
		100	0.0	59.7	29.5	10.8	8.6	2.2	2.2	20.0	0.0	7.9	0.3	0.9	0.1	6.6	1.0
		150	0.0	60.6	29.6	9.8	7.6	2.2	1.7	18.8	0.0	7.9	0.3	0.9	0.1	6.2	1.4
		200	0.0	62.2	26.4	11.3	9.0	2.4	1.4	18.8	0.0	8.0	0.2	3.0	0.2	7.2	2.7
		250	0.0	64.2	25.4	10.5	8.6	1.9	1.4	18.3	0.0	8.0	0.2	2.3	0.1	6.3	2.1
		300	0.0	62.1	27.2	10.7	8.2	2.5	1.2	19.0	0.0	8.0	0.2	1.9	0.1	6.3	2.0
		400	0.0	62.9	25.1	12.0	9.6	2.4	1.2	19.9	0.0	8.0	0.2	3.1	0.2	6.2	3.0
		500	0.0	63.9	24.9	11.1	8.7	2.5	1.5	19.6	0.0	7.9	0.2	2.6	0.2	5.8	2.7
Profile 5 (Typic Haplustolls, clayey)																	
A1	10YR3/1	0-20	0.0	24.9	25.8	49.2	27.9	21.3	29.6	7.0	0.0	8.0	0.4	0.1	0.1	29.7	0.2
A2	7.5YR4/2	20-40	0.0	25.2	26.8	48.0	22.0	26.0	14.3	14.1	0.0	7.3	0.4	1.2	0.3	26.3	1.3
Bw	7.5YR4/2	40-50	0.0	27.1	28.9	44.0	23.1	20.9	14.1	14.4	0.0	7.8	0.4	4.5	1.6	24.7	6.4
BCk	7.5YR5/4	50-75	0.0	26.1	25.8	48.1	26.1	22.0	11.3	17.1	0.0	7.9	0.6	12.5	4.2	24.2	17.3
C1	7.5YR5/4	75-92	0.0	27.9	21.9	50.2	26.8	23.5	2.0	15.2	0.0	7.6	2.6	14.8	4.1	20.5	20.2
C2	7.5YR5/6	92-100+	0.0	29.0	22.9	48.0	27.7	20.4	1.5	12.7	121.8	7.3	4.0	10.0	2.1	16.6	12.8
		150	0.0	33.2	24.9	41.9	25.1	16.8	1.7	13.7	10.3	7.3	9.9	21.2	3.5	13.6	26.1
		200	0.0	32.4	22.6	45.0	24.4	20.6	1.5	13.5	8.8	7.4	11.2	21.3	3.7	18.0	20.6
		250	0.0	33.9	24.1	42.0	25.2	16.8	1.4	11.6	0.7	7.5	11.4	22.6	2.6	20.1	13.0
		300	0.0	30.4	25.2	44.4	24.2	20.2	1.3	11.0	0.0	7.5	10.2	26.3	2.5	24.7	10.0
Profile 6 (Typic Haplustolls, sandy)																	
Ap1	2.5Y3/2	0-10	27.6	28.9	14.1	29.5	14.0	15.5	17.9	1.4	0.0	6.5	0.1	0.3	0.1	18.2	0.3
Ap2	2.5Y3/2	10-20	28.9	28.1	11.9	31.1	13.9	17.2	18.4	1.5	0.0	6.2	0.1	0.4	0.1	18.2	0.4
A	2.5Y3/2	20-30	30.4	26.1	12.7	30.8	13.2	17.5	14.8	1.4	0.0	6.7	0.1	0.6	0.1	20.6	0.6
AB	2.5Y3/2	30-40	28.8	23.5	13.8	34.0	16.1	17.9	9.8	1.8	0.0	6.8	0.3	1.1	0.2	20.4	1.1
Bk	2.5Y4/6	40-60	27.3	33.6	23.8	15.3	14.7	0.6	6.2	15.4	0.4	7.0	1.7	5.2	0.6	13.7	4.6
BC	2.5Y5/4	60-80	29.8	32.9	23.2	14.2	13.4	0.7	4.6	16.6	0.4	7.2	2.5	9.3	1.1	13.6	8.1
C	2.5Y5/6	80-100	43.9	25.1	14.3	16.8	16.2	0.6	2.4	12.6	0.0	7.5	2.4	14.7	1.6	10.6	15.0
		125	23.0	25.2	25.8	26.0	24.1	1.8	1.8	16.2	0.0	7.5	3.9	20.1	3.1	16.0	19.1
		150	42.0	28.0	9.1	21.0	15.8	5.1	0.9	5.3	0.6	7.6	3.2	20.2	1.8	10.7	17.1
		175	33.4	29.6	21.8	15.3	14.9	0.4	1.2	7.8	19.2	7.4	4.5	20.7	2.6	14.9	17.2
		200	16.6	22.4	21.4	39.6	30.8	8.8	1.6	11.1	2.5	7.5	5.1	23.9	4.0	19.6	20.4
Profile 7 (Typic Haplustolls)																	
A1	7.5YR2/3	0-10	15.5	13.8	18.1	52.6	27.1	25.5	49.2	2.7	0.0	7.0	0.3	0.2	0.0	35.9	0.1
A2	7.5YR2/3	10-20	15.6	12.9	17.1	54.4	20.2	34.2	29.6	1.9	0.0	6.1	0.1	0.2	0.1	36.3	0.2
A3	7.5YR2/3	20-30	14.3	15.3	18.5	51.9	19.4	32.5	24.1	2.0	0.0	6.5	0.1	0.2	0.1	35.2	0.2
AB	5YR4/4	30-65	15.3	15.5	18.0	51.2	21.2	29.9	25.8	2.5	0.0	6.8	0.2	0.2	0.1	36.8	0.1
Bw	5YR4/6	65-90	14.8	16.7	17.2	51.3	39.6	11.7	15.1	7.3	0.0	7.3	0.2	0.2	0.1	30.6	0.2
BCk	5YR4/6	90-110+	14.6	17.4	18.8	49.3	43.7	5.5	5.4	12.1	0.0	7.3	0.2	0.2	0.1	26.1	0.3

Table 7.1. Physicochemical properties of the soils studied (2).

			Particle size distribution									Saturation extract					
Horizon	Color	Depth (cm)	Coarse sand (%)	Fine sand (%)	Silt (%)	Clay (%)	Coarse clay (%)	Fine sand (%)	Organic C (g kg^{-1})	CO_3-C (g kg^{-1})	Gypsum (g kg^{-1})	pH	Na^++K^++Mg^{2+} +Ca^{2+} (cmol$_c$ kg^{-1})	Sodium adsorption ratio (SAR) (mmol L^{-1})$^{1/2}$	Exch. Na (cmol$_c$ kg^{-1})	CEC (cmol$_c$ kg^{-1})	Exch. Na percentage (ESP) (%)
Profile 8 (Lithic Haplustolls)																	
A1	2.5Y2/1	0-3	21.2	9.6	27.0	42.1	23.0	19.1	97.6	3.0	0.0	6.1	0.1	0.3	0.0	42.2	0.1
A2	2.5Y2/1	3-13	19.8	9.6	23.9	46.7	20.1	26.6	58.7	1.3	0.0	6.1	0.2	0.3	0.0	38.6	0.1
Bw	10YR3/2	13-32	16.8	10.1	22.8	50.4	14.9	35.5	22.7	1.5	0.0	6.2	0.1	0.7	0.1	32.1	0.4
BC	7.5YR4/4	32+	51.4	16.5	9.1	23.1	7.6	15.5	7.6	1.3	0.0	6.2	0.1	0.9	0.1	14.7	0.6
Profile 9 (Lithic Dystrustepts)																	
Oa	5YR3/2	+1.5-0	20.3	14.3	21.8	43.6	30.0	13.6	269.5	2.1	0.1	5.9	0.4	0.3	0.0	31.5	0.0
A	7.5YR4/4	0-8	44.8	16.3	22.9	15.9	12.7	3.2	41.2	1.4	0.0	5.9	0.1	0.4	0.0	21.2	0.2
Bw	5YR4/6	8-23	45.6	17.1	22.8	14.5	2.0	12.5	8.4	0.7	0.0	6.1	0.1	0.4	0.0	12.1	0.3
BC	7.5YR5/8	23-38	41.7	18.1	22.4	17.9	4.9	13.0	6.3	1.0	0.0	5.7	0.1	0.5	0.1	15.4	0.4
C	7.5YR5/8	38+	44.4	16.8	20.0	18.7	6.3	12.4	6.0	1.3	0.0	4.8	0.1	0.5	0.0	15.6	0.3
Profile 10 (Typic Haplustolls)																	
Ap1	10YR2/2	0-10	11.5	11.0	26.7	50.9	22.2	28.7	35.3	2.4	0.0	7.0	0.1	0.3	0.0	38.3	0.1
Ap2	10YR2/3	10-20	11.7	8.7	27.4	52.1	18.7	33.4	30.2	2.7	0.0	7.0	0.2	0.3	0.1	39.1	0.2
AB	10YR2/3	20-30	10.3	11.5	23.5	54.8	21.7	33.1	31.6	2.2	0.0	7.3	0.3	0.4	0.1	35.2	0.3
Bw1	10YR2/3	30-40	10.7	13.5	22.7	53.1	25.8	27.3	21.0	4.2	0.0	7.5	0.4	2.0	0.5	38.2	1.4
Bw2	10YR2/3	40-60	10.8	14.2	22.2	52.8	25.6	27.1	27.1	4.5	0.0	6.9	0.2	1.1	0.3	39.8	0.8
BC	10YR4/3	60-80	16.3	21.3	29.0	33.4	19.2	14.2	8.8	5.8	0.0	7.7	0.3	2.4	1.2	40.4	2.9
	10YR4/6	80-100	16.5	24.5	23.3	35.7	14.6	21.1	4.2	2.6	0.0	7.6	0.4	3.0	1.6	43.0	3.6
Profile 11 (Inceptic Haplustalfs)																	
Oa	10YR1.7/1	+7-0	3.4	17.0	43.1	36.5	20.3	16.3	267.3	4.6	0.1		0.8	0.5	0.0	37.3	0.0
Ae	10YR2/3	0-3	14.6	20.1	31.1	34.2	20.6	13.6	48.3	2.0	0.0	5.3	0.3	0.3	0.0	26.9	0.2
E	10YR3/4	3-13	14.0	20.4	29.7	35.9	19.5	16.4	30.8	1.3	0.1	6.1	0.2	0.3	0.0	22.3	0.2
Bt1	10YR4/6	13-25	8.1	13.2	19.9	58.9	20.4	38.5	14.1	2.6	0.0	6.4	0.1	0.4	0.1	30.8	0.2
Bt2	10YR4/6	25-40	6.7	14.9	22.0	56.4	20.5	35.9	9.0	3.0	0.0	7.2	0.3	0.3	0.1	27.8	0.3
BCk	10YR5/6	40-60	24.6	24.9	23.3	27.2	19.3	7.9	6.9	13.5	0.1	7.6	0.4	1.6	0.1	9.6	1.1
C	10YR5/6	60-80	25.1	29.2	27.2	18.5	16.5	2.0	2.9	4.2	0.0	7.8	0.3	1.6	0.0	4.4	1.0
	10YR5/8	80-100	28.7	33.6	25.1	12.6	12.3	0.3	1.5	1.8	0.0	7.8	0.3	2.0	0.0	3.4	0.3
Profile 12 (Typic Calciustolls)																	
A1	10YR2/2	0-10	0.0	44.9	17.1	38.0	32.0	6.0	25.4	7.4	0.1	7.6	0.5	0.3	0.0	22.4	0.2
A2	10YR2/2	10-20	0.0	34.8	19.1	46.0	39.9	6.1	36.0	5.6	0.0	7.7	0.5	0.3	0.1	30.3	0.2
A3	10YR2/2	20-30	0.3	29.4	21.3	49.0	44.6	4.4	24.8	9.4	0.0	7.5	0.4	0.3	0.1	28.1	0.3
AB	10YR2/3	30-40	0.4	29.3	21.2	49.1	49.1	0.0	19.2	12.1	0.0	7.5	0.3	0.4	0.1	26.2	0.3
Bw1	10YR3/3	40-55	0.4	30.7	21.9	47.0	47.2	0.0	13.8	13.6	0.1	7.3	0.2	0.6	0.2	24.6	0.6
Bw2	10YR3/3	55-75	0.4	31.7	20.4	47.5	47.0	0.5	11.3	13.2	0.0	7.6	0.3	1.5	0.3	24.2	1.3
BC	10YR3/4	75-90	0.0	26.7	23.3	50.0	46.2	3.8	8.9	13.1	0.0	7.7	0.5	8.7	0.9	24.3	3.8
Ck	10YR4/3	100	0.0	27.8	23.4	48.9	47.0	1.8	4.6	20.1	0.0	7.7	0.7	17.4	2.7	21.6	12.3
		150	1.8	29.8	22.5	45.9	43.4	2.6	1.4	14.0	0.1	8.1	0.8	22.3	3.9	20.5	19.2
		200	2.3	28.1	23.4	46.1	42.7	3.4	1.3	13.1	0.0	7.8	0.7	23.9	3.1	21.0	14.6
		250	2.9	29.9	22.6	44.6	40.3	4.4	1.2	13.0	0.3	7.6	1.0	7.0	0.7	20.2	3.7
		300	4.1	27.5	22.2	46.2	43.5	2.8	1.3	12.2	1.5	7.4	1.7	4.3	0.4	19.8	2.0
Profile 13 (Typic Haplosalids)																	
A	7.5YR2/1	0-13	4.8	5.7	31.2	58.2	52.7	5.5	34.9	8.9	15.0	7.3	66.1	38.9	8.1	34.1	23.8
AB1	7.5YR2/2	13-20	5.5	10.7	26.3	57.5	54.7	2.8	20.7	8.4	40.5	7.4	32.2	27.8	6.7	30.9	21.6
AB2	7.5YR2/2	20-33	5.1	8.1	23.6	63.2	57.8	5.4	15.8	17.3	8.1	7.1	23.1	25.7	5.8	31.9	18.1
BA	7.5YR4/4	33-50	5.8	8.7	29.4	56.2	51.5	4.7	6.6	20.6	1.6	7.1	16.2	20.3	4.0	27.5	14.6
Bw	7.5YR4.5/6	50-60	7.0	7.6	30.3	55.2	50.7	4.5	3.9	22.7	1.9	7.1	14.6	18.2	3.9	24.3	16.2
Profile 14 (Typic Natrustalfs)																	
A	7.5YR4/4	0-5	14.7	34.4	22.8	28.0	17.9	10.2	25.8	0.7	0.3	6.8	0.4	2.7	0.0	16.4	0.0
E	10YR6/3	5-13	19.3	33.1	20.3	27.3	13.7	13.6	10.4	0.4	0.0	6.9	0.7	8.7	0.7	12.0	6.2
Bth	7.5YR4/4	13-23	12.0	19.3	14.1	54.5	16.1	38.5	13.5	1.8	2.2	7.1	8.0	22.5	5.2	29.6	17.5
Bw	7.5YR5/6	23-47	14.4	21.2	22.8	41.6	25.9	15.7	5.7	14.2	7.9	7.5	13.6	23.4	3.3	19.4	16.9
BCk	7.5YR5/4	47-65	16.7	18.4	21.0	43.9	25.8	18.1	3.1	19.5	31.5	7.4	12.2	23.8	2.8	15.0	18.8
C	7.5YR5/4	65-100	9.8	21.7	20.9	47.6	24.6	23.0	1.6	14.0	40.1	7.5	6.0	17.4	3.1	18.5	16.8
		100	9.5	19.5	21.2	49.8	22.7	27.1	1.4	12.0	2.2	7.7	1.9	17.7	4.7	20.1	23.1
		150	9.8	19.2	21.5	49.5	25.5	24.0	1.6	11.6	0.5	7.5	6.8	27.7	4.8	21.3	22.6
		200	3.4	12.2	27.8	56.6	26.4	30.2	1.3	12.0	0.4	7.6	5.7	29.2	5.9	22.7	25.7
		250	2.3	9.3	29.1	59.3	26.4	32.9	1.2	13.5	0.1	7.7	4.1	30.2	6.0	23.1	26.0
		300	7.1	8.2	32.0	52.6	33.5	19.2	0.9	12.2	0.2	7.7	4.0	27.5	3.4	13.1	25.7
Profile 15 (Typic Haplustalfs)																	
A	10YR2/3	0-8	17.7	16.9	29.6	35.8	18.1	17.8	43.9	1.9	0.0	6.5	0.2	0.3	0.0	24.1	0.1
E	10YR3/4	8-18	23.5	16.0	39.0	21.5	13.5	8.0	7.3	0.4	0.0	6.1	0.0	0.6	0.0	10.3	0.3
Bt1	10YR4/6	18-35	11.7	11.0	37.6	39.8	22.8	16.9	5.7	0.4	0.0	5.0	0.1	0.9	0.0	16.0	0.3
Bt2	10YR5/4	35-50	10.6	12.4	40.2	36.8	22.5	14.3	3.7	0.3	0.0	4.4	0.1	0.9	0.0	14.2	0.2
BC	10YR6/4	50-65	6.7	13.5	44.1	35.8	25.5	10.4	2.8	0.0	0.0	4.3	0.0	1.1	0.0	9.2	0.2
C	10YR6/3	65-80	37.3	29.0	20.6	13.2	8.5	4.7	3.5	0.1	0.0	4.7	0.0	0.8	0.0	3.6	0.1



a) Clay (< 2 μ m)

b) Coarse clay (2-0.2 μ m) and fine clay (< 0.2 μ m)

Figure 7.4. X-ray diffractograms of clay specimen collected from soils in Kazakhstan steppe.

The southern foothill steppes are widely covered by loess deposits. In order to analyze general soil characteristics, we collected four soil profiles in the area, including three steppe soils with different moisture regimes (Profiles 2 to 4) and one adjacent forest soil (Profile 1). On the other hand, distribution of soil parent materials in the northern steppe is more complicated; larger areas are covered by quaternary lacustrine and fluvial deposits and some are by granite and metamorphic rocks.

We collected three representative soils in this area; Profile 5 (clayey) and Profile 6 (sandy) from dry steppe zone and Profile 7 from northern forest steppe zone. In addition, in order to compare characteristics of steppe and forest soils pedologically, four soils are collected, i.e., Profile 8 (steppe soil on granite), Profile 9 (forest soil on granite), Profile 10 (steppe soil on quaternary deposit), and Profile 11 (forest soil on quaternary deposit). Another three soils, which have been developed on different sedimental as well as pedological environments are also collected, i.e., Profile 12 (meadow-type Chernozem soil), Profile 13 (Solonchak), Profile 14 (Solonetz), and Profile 15 (Solod).

The soil samples were air-dried and passed through a 2 mm mesh sieve for physicochemical and mineralogical analyses.

1) Soil texture was determined by a pipette method with pretreatment with acetate buffer at pH 5.0 to remove the carbonates (Soil Survey Laboratory Staff, 1992).
2) Clay mineral species were identified by X-ray diffraction using Cu-Ka radiation for both the whole and separated (coarse and fine) clay fractions.
3) The content of organic carbon was determined by wet combustion method.
4) The content of carbonate C was determined by back titration with 1 M NaOH after the addition of a known amount of HCl solution (Soil Survey Laboratory Staff, 1992).
5) Gypsum content was estimated based on the concentrations of SO_4^{2-} and Ca^{2+} in the saturated and diluted water extracts (Lagerwerff et al., 1965).
6) Saturation paste was prepared according to the method 8A in Soil Survey Laboratory Methods Manual (Soil Survey Laboratory Staff 1992). Saturation extract thus collected was analyzed for determination of the concentration of Na^+, K^+ (flame photometry) Mg^{2+}, Ca^{2+} (atomic absorption spectrophotometry (Shimadzu, AA640-01)), Cl^-, NO_3^-, SO_4^{2-} (high performance liquid chromatography (Shimadzu, LC3A)), and carbonaceous species (by a total organic carbon analyzer (Shimadzu, TOC-5000) and solution pH).
7) The content of exchangeable Na and cation exchange capacity (CEC) was determined with successive extraction/substitution using 1 M NH_4OAc, methanol for washing, and 10% NaCl solution, followed by NH_3 determination (for CEC) by steam distillation and Na determination by flame photometry.

7.4. Characteristics of the loess-derived soils on the foothill of Mt. Alatau in the south (Profiles 1 to 4)

Our sampling sites are given on the map (Fig. 7.1). Physicochemical properties of the soils are shown in Table 7.1. For representative profiles, photo and description are given in Fig. 7.3 and Appendix at the end of this chapter, respectively.

Loess-derived soils distribute east-to-west along the foothills of Mt. Alatau, between inner desert and mountain forest zones. In all the soils studied including Profile 4 next to desert, contents of soluble salts in the saturation extract, exchangeable Na, and gypsum were appreciably low throughout the profiles. The coarser fraction such as fine sand and/or silt were generally higher in these soils than in the soils in northern steppe (described later) and there was a trend that coarser soils distributed near the desert rather than mountain-side, suggesting that risk of soil salinization is limited, if any, in this area. Major components of clay minerals were 1.4 nm-smectite, mica minerals and kaolin minerals.

Profile 2, as shown in Fig. 7.3, is located in tall grass steppe that was scattered in deciduous forest zone. Since organic matter penetrated to deep (> 50 cm) and the depth of carbonates-accumulated layer was also below 60 cm in the profile (Table 7.1), the soil is supposed to have been formed under a relatively wet condition, i.e., annual precipitation exceeding 600 mm. Figure 7.5 describes vertical distribution of organic C and carbonates C in the four profiles in this region. Profile 1 locates under forest, at which the climate is more humid than at Profile 2, whereas Profiles 3 and 4 are situated under drier steppes compared to Profile 2. Since the depth of organic layer decreases in the forest soil (Profile 1) compared to the steppe soil (Profile 2), the amount of the SOM accumulated was highest in Profile 2 among the profiles and it achieved to 250 Mg C ha^{-1}. At the same time, it is obvious that the amount of SOM is decreasing and the depth of carbonates-accumulated layer is also decreasing toward drier climate.

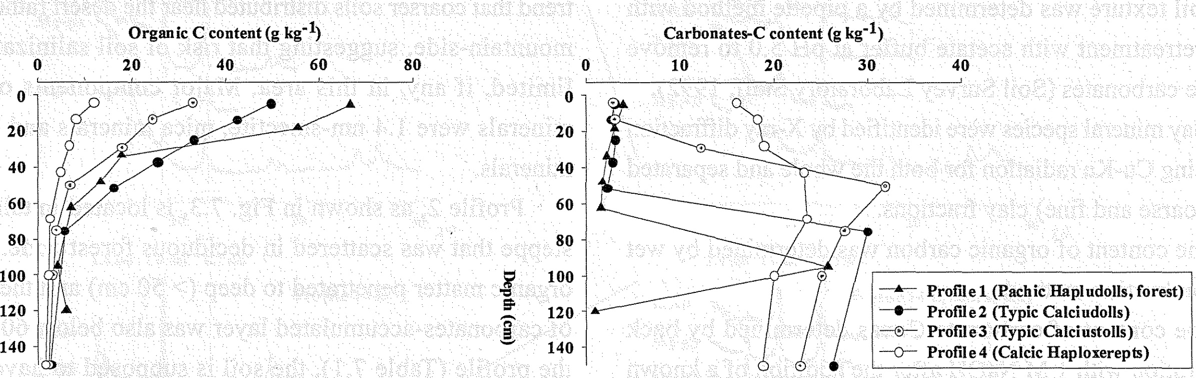
7.5. Characteristics of the Chernozem soils in northern steppe (Profiles 5 to 8)

In the northern steppe of Kazakhstan, relatively fine-textured soil distribute in the areas of Astana, a present capital, to Kokchetau from south-to-north, whereas coarser soils are often found along with R. Iritish (Pavlodar region) in the northeast and in the Kustanai region in the northwest. The southern limit of Mollisols occurrence is Astana, in which climate is drier than the upper north. In contrast, in the forest steppe zone north of Kokchetau, the soil color is getting darker presumably due to decreasing temperature. Most of the soils found here are classified as Ustolls in U.S. Soil Taxonomy (Soil Survey Staff 2003). According to the soil classification system in former Soviet Union, on the other hand, the former soils are classified as Southern Chernozem or Dark chestnut soils, while the latters as Ordinary Chernozem.

Profiles 5 and 6 are the representatives among the soils found in dry steppe zone, the former being clayey and the latter sandy. Profile 7, clayey, is, in contrast, typical for the forest steppe zone. As discussed later in detail, a larger part of the soils in the northern steppe, which have been derived from quaternary lacustrine and fluvial deposits, are rich in expandable 2:1 minerals and, hence, the soils are subjected to repeated shrinkage/expansion, resulting in a clear tongued-penetration of SOM into deep layer (see Profile 7 in Fig. 7.3). Judging from the amount of SOM accumulated in the soils, Profile 5 is comparable with Profile 3 in the southern mountain foothills and its SOM content amounted to 150 Mg ha^{-1}. A difference in the amount of annual precipitation between both the areas resulted in the difference in the depths of carbonates-washing in these profiles, that is, a larger part of the carbonates were washed out form top 30 cm layers in Profile 3, whereas it still remained even at 10 cm depth in Profile 5. The initial concentration of carbonates seems to be higher in the loess-derived soils in the south than those in the northern steppe (Fig. 5.5; Table 7.1). Main characteristics of the soils in the northern steppe are described as below:

1) The soils derived from quaternary deposits in the northern steppe were characterized by dominated 1.4 nm-clay minerals that had a higher expandability after Mg saturation and glycerol solvation (Profiles 5 and 14 in Fig. 7.4a). According to Fig. 7.4b, in which X-ray diffractograms were given separately for coarse (2-0.2

a) Soils in southern mountain foothills



b) Soils in northern steppe

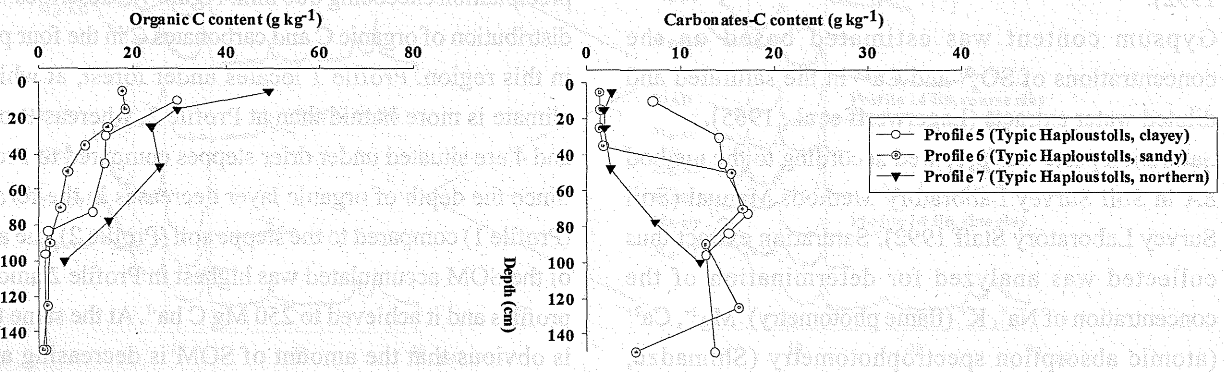


Figure 7.5. Vertical distribution of organic C and carbonates-C in soil profiles in southern mountain foothills and northern steppe of Kazakhstan.

mm) and fine (< 0.2 mm) clay fractions, the coarse clay fraction was generally composed of relatively highly-crystalline minerals with sharp peaks in the diffractogram and, hence, was considered to be mainly derived from parent materials, whereas the fine clay fraction was mainly secondary judging from the apparent low crystallinity with relatively broad peaks in the diffractograms. Since there was no significant difference among the soils studied in the diffraction patterns of the coarse clay fraction, major difference was assumed to be derived from properties of the fine clay fraction. Namely, 1.4 nm-clay minerals in the fine clay fraction had a higher expandability in Profile 5 than in Profile 2, judging from the XRD patterns of the fine clay from Profile 5 that showed a easier expansion after Mg saturation and glycerol solvation as well as a more incomplete collapse after K saturation (suggesting low charge density). It is concluded that the 1.4 nm-clay minerals in the fine clay fraction of the soils derived from quaternary deposits in the northern steppe have a more montmorillonitic properties.

2) This clay mineralogical characteristics of the soils is considered to reflect directly to the expansion and shrinkage of the soils during fluctuation of soil moisture. For example, in the wet springtime, expanded soil can reduce permeability of water derived from snowmelt, resulting in excessive water loss through accelerated evaporation and/or surface runoff. This may be one of constrains for the agriculture here.

3) There were huge amounts of soluble salts and/or gypsum in deeper layers of the soils on the quaternary deposits (Table 7.1; Profiles 5, 6, 13, and 14). The salts may have derived from the parent materials and is considered to cause a potential risk of secondary salinization if irrigation agriculture were introduced in this area.

4) There are scattered areas of granite intrusion in the northern steppe. Profiles 8 and 9 are situated on the granite and have quite different properties with the soils derived from quaternary deposits. The development of soil layer is generally limited on the granite, mostly less than 50 cm. The clay mineralogy was characterized by almost complete collapse of 1.4 nm minerals after K saturation (Fig. 7.4; Profile 8) and was rather similar to the soils from loess deposits in the south.

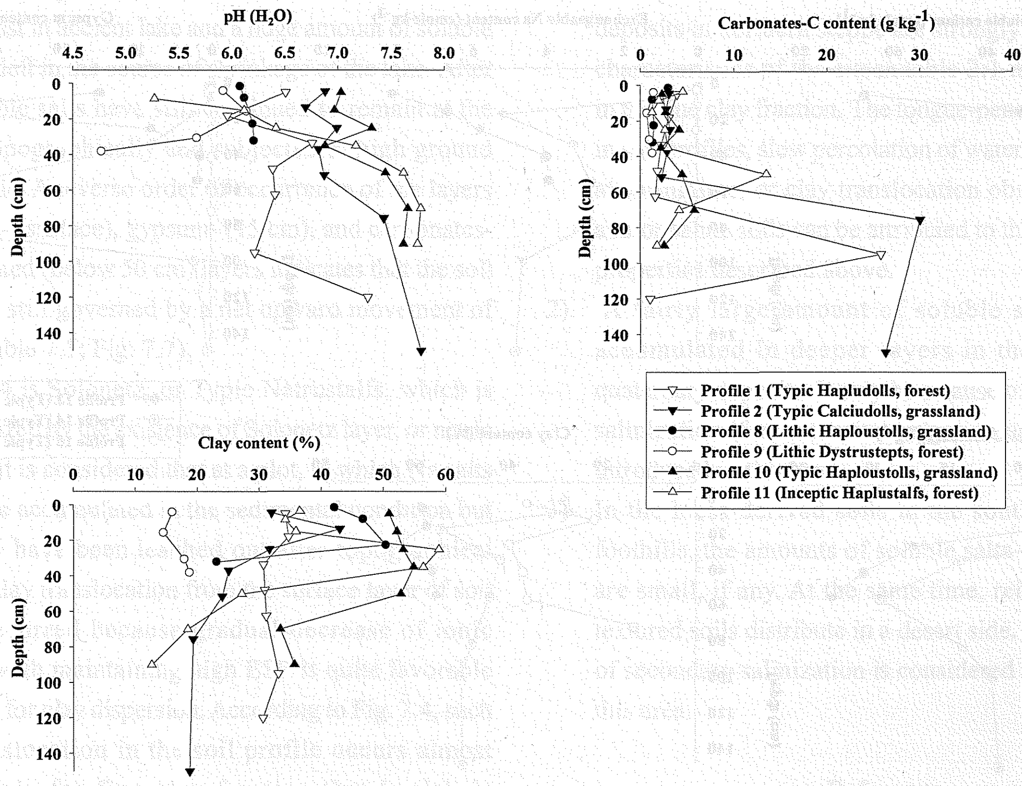


Figure 7.6. Vertical distribution of soil pH, content of carbonates-C, and clay content in soil profiles under grassland and adjacent forest in the forest steppe.

7.6. Comparison of properties of soils formed under grassland and forest in northern forest steppe zone (Profiles 8 to 11)

Since northern Kazakhstan is situated in inner continent and subjected to severe drought, a north-to-south extension of the Chernozem belt is limited to within 400 km. Southern half of the belt is covered exclusively by grass forb steppes, whereas the northern part is characterized by forest-mixed steppes. Major locations of such forest are hilly landscape on the granite intrusion and microdepression of the steppes. We compared soil properties of the soils that formed under either grassland or forest on granite (Profiles 8 (grassland) and 9 (forest)) or that on quaternary deposits (Profiles 10 (grassland) and 11 (forest)).

According to the photos in Fig. 7.3, there is a clear difference in appearance between the dark-colored steppe soil (Profile 8) and the brown-colored forest soil (Profile 9). Figure 7.6 plots vertical distribution of soil pH, carbonates-C, and clay content throughout the profiles of both the grassland (Profiles 2 (in the south), 8, and 10) and the adjacent forest (Profiles 1 (in the south), 9, and 11). The forest soils exhibited lower pHs below 6, not like as the steppe soils. The carbonates-C contents in the surface soil layers in the forest soil were not, however, different significantly from the steppe soils and in both the cases most of the carbonates seemed to be leached out from the surface soils. Among the soils studied, clay translocation in soil profile was obvious only in Profile 11 under forest on quaternary deposits, in which a fairly large amount of expandable 2:1 clay minerals originally existed. It is considered that, in the soils with a high amount of expandable minerals in the fine clay fraction, clay translocation in the profile sometimes occurred after establishment of forest stand and possibly leaching of exchangeable divalent cations as well as carbonates.

7.7. Characteristics of soils developed under different hydrological conditions in the northern steppe (Profile 12 to 15)

In the past, the area was once largely covered by lakes and/or marshes and was then transformed to upland environment today. By this reason, the soils derived from the deposits in that period are originally rich in soluble salts and, therefore, different kinds of salt-affected soils are observed in relation to different topographic conditions.

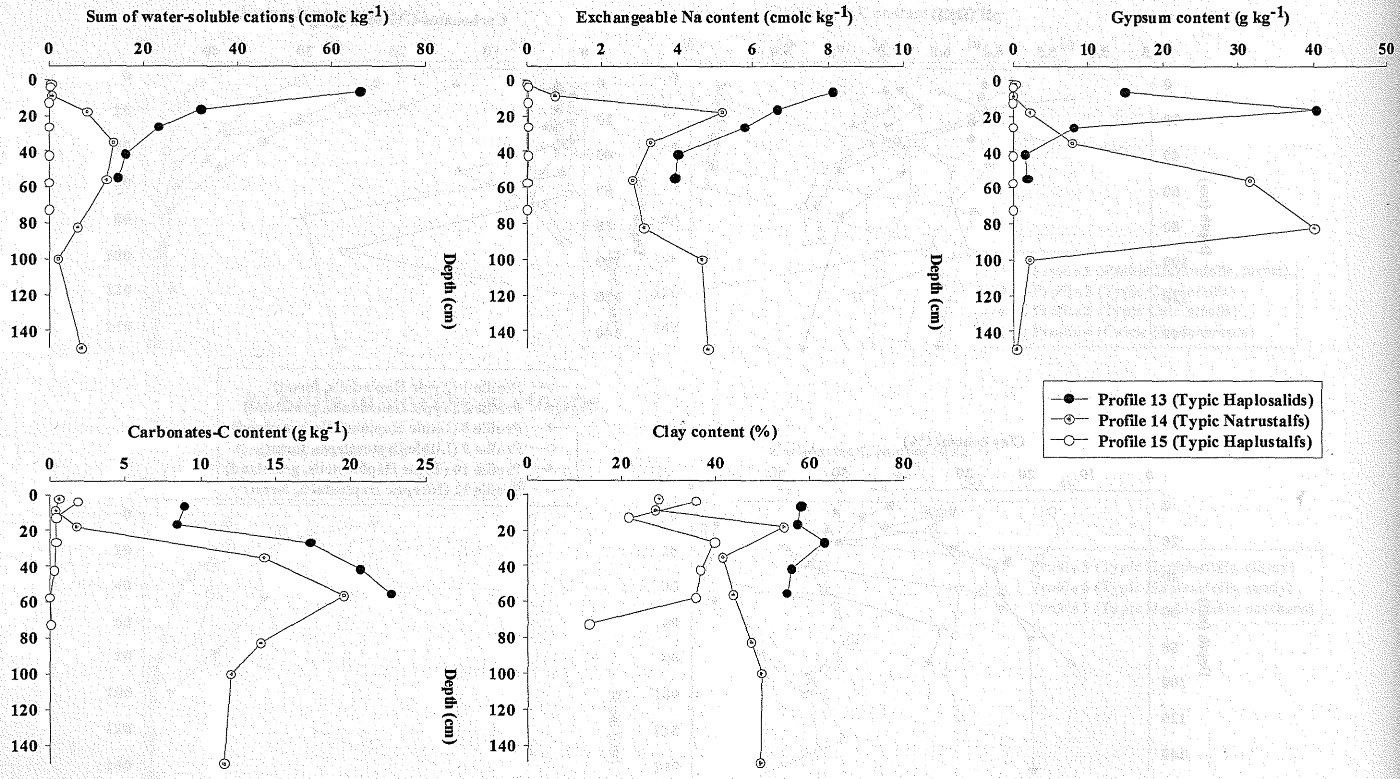


Figure 7.7. Vertical distribution of contents of soluble Na, exchangeable Na, gypsum, carbonates, and clay in soil profiles affected by salinization.

1) Profile 5 is considered to be a typical profile (Typic Haploustolls or Southern Chernozem) that occurs on gentle slopes (1/100 to 1/1000) in the area. The profile has been affected by consecutive leaching, resulting in a sequential occurrence of carbonates-accumulated (70 cm), gypsum-accumulated (100 cm), and salts-accumulated (below 150 cm) layers (Table 7.1).
2) Profile 12 is affected by higher amount of water percolated because it has been developed on microdepression on the top of plateau, at which maximum snow depth is usually recorded during early spring. It is called as "meadow subtype" of Chernozems, i.e., Meadow Southern Chernozem in the classification of former Soviet Union. Due to higher amount of water percolated in the springtime, the carbonates-accumulated layer is deeper than the typical one (Profile 5; see Table 7.1) and a gypsum- or salts-accumulated layer is no more observable within 300 cm in the soil profile. The maximum value of exchangeable Na content, exchangeable Na percentage (ESP), and sodium adsorption ratio (SAR) at the 100-200 cm depth is considered to be a relict of the Na that had been once rich in the deposits.
3) Profile 13 is Solonchak, or Typic Haplosalids in U.S. Soil Taxonomy. It is considered that the location was once lowest in ancient lake and a huge amount of soluble salts was left in the course of shrinkage of the lake. After that soluble salts have still continued to remain at the lowest topographically and subjected to high ground water table. A reverse order of occurrence of the layers with salts- (surface), gypsum- (15 cm), and carbonates-accumulated (below 50 cm) layers indicates that the soil profile is still governed by a net upward movement of water (Table 7.1; Fig. 7.7).
4) Profile 14 is Solonetz, or Typic Natrustalfs, which is characterized by the existence of Solonetz layer, or natric horizon. It is considered that at a plot, at which Na salts were once accumulated in the sedimental condition but then they have been leached out after topographical change, clay translocation from the surface layer of soil easily occurred because gradual decrease of ionic strength with maintaining high ESP is quite favorable condition for clay dispersion. According to Fig. 7.4, such clay translocation in the soil profile occurs almost exclusively for fine clay fraction that is rich in expandable 2:1 minerals. As a result, a clear contrast of a loosen and sandy surface horizon (E horizon) and a dense heavy-textured horizon with clay and humus accumulation (Bth or natric horizon) is formed. Since the latter horizon is too dense and firm for penetration of crop roots, it has been historically amended through gypsum application for agricultural use.
5) Profile 15 is Solod, which is considered to be a last stage of development of solonetz soils (Szabolcs, 1971). There is no more Na-affected layers. The natric layer has also disappeared; only a clear contrast of eluvial and illuvial horizons of clays is obvious.

A clay translocation, which was introduced previously for forest soils and saline soils, is observed almost exclusively among the soils derived from the quaternary deposits in the northern steppe/forest. It is scarcely observed among soils from loess deposits in the south and/or granite-derived soils in the north. The existence of the montmorillonitic fine clay, which might have been formed either under aquatic sedimental or pedogenetic condition, is considered to be a key factor that results in development of soil profiles with clay translocation, although more extensive survey is required for generalizing this consideration.

7.8. Conclusion for characteristics of steppe soils in Kazakhstan

1) The soils that have been developed on quaternary deposits in northern steppe are strongly affected by the characteristics of the expandable 2:1 minerals mainly in the fine clay fraction. The tongue-penetration of SOM in soil profiles, slow percolation of water from snowmelt at springtime, or clay translocation observed in forest and/or saline soils can be attributed to the mineralogical properties described above.
2) A fairly large amount of soluble salts are often accumulated in deeper layers in the soils on the quaternary deposits. It may be a cause of secondary soil salinization if an intensive irrigation agriculture were introduced in this area.
3) In the loess-derived soils in the southern mountain foothills, the amounts of soluble salts in deeper layer are small, if any. At the same time, relatively coarse-textured soils distribute in a desert side. A potential risk of secondary salinization is considered to be limited in this area.

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Appendix - profile description

Profile 2 (Typic Calciudolls)
Location: N 43° 18' 14.2", E 79° 30' 38.8"
Annual precipitation: 600 mm
Vegetation: tall grasses
Topography: gentle convex slope
Parent material: loess

Hor.	Depth (cm)	Description
A1	0-9	Brownish black (10YR2/3); moderately dry; clay loam; moderate medium granular structure; very friable; many fine roots; no gravel; clear smooth boundary to
A2	9-18	Dark brown (10YR3/3); moderately dry; light clay; moderate medium subangular blocky structure; friable common fine roots; no gravel; clear smooth boundary to
Bw1	18-32	Dark brown (10YR3/3); moderately dry; light clay; moderate medium subangular blocky structure; friable common fine roots; no gravel; clear smooth boundary to
Bw2	32-42	Dull yellowish brown (10YR4/3); moderately dry; light clay; moderate medium subangular blocky structure; friable; few fine roots; no gravel; clear smooth boundary to
BC	42-61	Brown (10YR4/4); moist; light clay; weak medium subangular blocky structure; friable; few fine roots; no gravel; gradual smooth boundary to
Ck	61-90+	Dull yellow orange (10YR6/3); moist; light clay; massive; no root; no gravel

Profile 5 (Typic Haploustolls)
Location: N 51° 34' 35.0", E 71° 15' 46.8"
Annual precipitation: 300 mm
Vegetation: natural grassland
Topography: flat
Parent material: quaternary sediments

Hor.	Depth (cm)	Description
A1	0-20	Brownish black (10YR3/1); moderately dry; light clay; sticky, plastic; moderate medium subangular blocky structure; friable; abundant fine roots; no gravel; clear smooth boundary to
A2	20-40	Grayish brown (7.5YR4/2) and brownish black (10YR3/2); moderately dry; light clay; sticky, plastic; moderate fine angular blocky structure; friable; many fine roots; no gravel; clear smooth boundary to
Bw	40-50	Grayish brown (7.5YR4/2) and dull brown (7.5YR5/3); moderately dry; heavy clay; very sticky, very plastic; moderate medium angular blocky structure; slightly firm; common fine roots; no gravel; clear smooth boundary to
BCk	50-75	Dull brown (7.5YR5/4 and 6/3) and grayish brown (7.5YR4/2) (penetration of organic matter); moderately dry; heavy clay; very sticky, very plastic; strong very coarse prismatic structure; slightly firm; few fine roots; no gravel; clear smooth boundary to
C1	75-92	Dull brown (7.5YR5/4); moist; heavy clay; very sticky, very plastic; weak coarse subangular blocky structure; friable; few fine roots; no gravel; abrupt smooth boundary to
C2	92-100+	Bright brown (7.5YR5/6); moist; heavy clay; very sticky, very plastic; weak medium subangular blocky structure; very friable; no root; no gravel

Profile 7 (Typic Haploustolls)
Location: N 53° 09' 21.1", E 69° 08' 17.8"
Annual precipitation: 300 mm
Vegetation: pasture
Topography: flat
Parent material: quaternary sediments

Hor.	Depth (cm)	Description
A	0-30	Very dark brown (7.5YR2/3); moderately dry; heavy clay; sticky, very plastic; moderate medium angular blocky structure; friable; abundant fine roots; no gravel; clear wavy boundary to
AB	30-65	Dull reddish brown (5YR4/3) with tongued penetration of organic matter (7.5YR2/2); moderately dry; heavy clay; sticky, very plastic; thin clay cutan on ped surface; moderate medium to coarse angular blocky structure; slightly firm; many fine roots; no gravel; clear smooth boundary to
Bw	65-90	Reddish brown (5YR4/6); moderately dry; heavy clay; very sticky, very plastic; thin clay cutan on ped surface; moderate medium to coarse angular blocky structure; slightly firm; common fine roots; no gravel; clear smooth boundary to
BCk	90-110+	Reddish brown (5YR4/6); moderately dry; heavy clay; very sticky, very plastic; moderate medium to coarse angular blocky structure; slightly firm; few fine roots; no gravels

Profile 8 (Lithic Haploustolls)
Location: N 52° 56' 28.9", E 70° 20' 18.5"
Annual precipitation: 350 mm
Vegetation: secondary forest (pine and birch)
Topography: flat
Parent material: granite

Hor.	Depth (cm)	Description
A	0-13	Black (2.5YR2/1); moderately dry; light clay; slightly sticky, plastic; weak medium subangular blocky structure; friable; abundant fine roots; few slightly weathered gravels; clear smooth boundary to
Bw	13-32	Brownish black (10YR3/2); moderately dry; light clay; sticky, plastic; moderate fine subangular blocky structure; slightly firm; common fine roots; many slightly weathered gravels; clear smooth boundary to
BC	32+	Brown (7.5YR4/4); moderately dry; sandy clay; slightly sticky, slightly plastic; few fine roots; abundant slightly weathered gravels

Profile 9 (Lithic Dystrustepts)
Location: N 52° 56' 50.6", E 70° 20' 25.2"
Annual precipitation: 350 mm
Vegetation: natural grassland
Topography: flat
Parent material: granite

Hor.	Depth (cm)	Description
Oa	+1.5-0	Dark reddish brown (5YR3/2)
A	0-8	Brown (7.5YR4/4); moderately dry; sandy clay loam; slightly sticky, plastic; weak medium platy structure breaking into weak fine subangular blocky structure; friable; many fine roots; few slightly weathered gravels; clear smooth boundary to
Bw	8-23	Reddish brown (5YR4/6); moderately dry; sandy clay loam; slightly sticky, plastic; weak fine

		subangular blocky structure; very friable; common medium and fine roots; many slightly weathered gravels; clear smooth boundary to
BC	23-38	Bright brown (7.5YR5/8); single grain; common fine roots; abundant slightly weathered gravels; clear smooth boundary to
C	38+	Composed of weathered rocks

Profile 13 (Typic Haplosalids)

Location: N 52° 48' 08.2", E 69° 22' 48.8"
Annual precipitation: 350 mm
Vegetation: few vegetation due to strong salinity
Topography: flat
Parent material: quaternary sediments

Hor.	Depth (cm)	Description
A	0-13	Black (7.5YR2/1); moist; heavy clay; very sticky, very plastic; moderate medium angular blocky structure; friable; common fine roots; no gravel; clear wavy boundary to
AB	13-33	Brownish black (7.5YR2/2 and 10YR3/2); moist; heavy clay; vary sticky, very plastic; moderate fine angular blocky structure; friable; few fine roots; no gravel; gradual wavy boundary to
BA	33-50	Brown (7.5YR4/4) and dark brown (7.5YR3/3); moist; heavy clay; very sticky, very plastic; weak coarse subangular blocky structure; friable; no root; no gravel; clear smooth boundary to
Bw	50-60	Bright brown (7.5YR5/6); moist; heavy clay; very sticky, very plastic; friable; no root, no gravel

Profile 14 (Typic Natrustalfs)

Location: N 51° 44' 12.2", E 71° 04' 32.5"
Annual precipitation: 350 mm
Vegetation: natural grassland
Topography: flat
Parent material: quaternary sediments

Hor.	Depth (cm)	Description
A1	0-5	Brown (8.75YR4/4); moderately dry; clay loam; slightly sticky, plastic; weak fine subangular blocky structure; very friable; many fine roots; few strongly weathered gravels; clear smooth boundary to
A2	5-13	Dull yellow orange (10YR6/3); moderately dry; sandy clay loam; slightly sticky; plastic; weak fine subangular blocky structure; very friable; many fine roots; few strongly weathered gravels; abrupt smooth boundary to
Bth	13-23	Brown (7.5YR4/4) and dull orange (7.5YR6/4) (carbonates); moderately dry; light clay; very sticky, very plastic; thick humus cutan (7.5YR3/3) on ped surface; strong medium columnar structure; firm; common fine roots on ped surface; few strongly weathered gravels; abrupt smooth boundary to
Bw	23-47	Bright brown (7.5YR5/6); moderately dry; light clay; very sticky, very plastic; weak medium prismatic structure; firm; few fine roots; few strongly weathered gravels; gradual smooth boundary to
BCk	47-65	Dull brown (7.5YR5/4) with light yellow orange (7.5YR8/2) (gypsum); moderately dry; heavy clay; very sticky, very plastic; weak coarse prismatic structure; friable; few fine roots; no gravel; clear smooth boundary to
C	65-100	Dull brown (7.5YR5/4) with light yellow orange (7.5YR8/2) (gypsum); moist; heavy clay; very sticky, very plastic; weak medium subangular blocky structure; very friable; no root; no gravel

Profile 15 (Typic Haplustalfs)

Location: N 53° 18' 39.2", E 69° 39' 07.2"
Annual precipitation: 350 mm
Vegetation: pine and birch
Topography: flat
Parent material: quaternary sediments

Hor.	Depth (cm)	Description
A	0-8	Brownish black (10YR2/3); moderately dry; clay loam; sticky, plastic; weak fine subangular blocky structure; friable; common fine roots; no gravel; clear wavy boundary to
E	8-18	Dark brown (10YR3/4); moderately dry; clay loam; sticky, plastic; weak to moderate medium platy structure; friable; few fine roots; no gravel; clear smooth boundary to
Bt1	18-35	Brown (10YR4/6); moderately dry; light clay; sticky, very plastic; weak fine angular blocky structure; friable; many medium to coarse roots; no gravel; clear smooth boundary to
Bt2	35-50	Yellowish brown (10YR5/4); moderately dry; light clay; sticky, very plastic; moderate medium subangular blocky structure; thin clay cutan on ped surface; friable; many medium to coarse roots; no gravel; gradual smooth boundary to
BC	50-65	Dull yellowish orange (10YR6/4); moderately dry; light clay; sticky, very plastic; moderate medium subangular blocky structure; friable; few coarse roots; no gravel; clear smooth boundary to
C	65-80	Dull yellowish orange (10YR6/3); moderately dry; sandy clay loam; slightly sticky, slightly plastic; mainly composed of weathered rocks

Chapter 8

Soil organic matter status of Chernozem soil in North Kazakhstan: effects of summer fallow

Elmira Karbozova-Saljnikov and Takashi Kosaki

8.1. Background

Chernozem soils in North Kazakhstan occupy 25.3×10^6 ha (Borovski and Uspanov, 1971) and are the most productive soils of the country. An area of approximately 11×10^6 ha of Chernozem soil was planted annually with spring wheat (*Triticum aestivum* L) during the Soviet period when the political aim of a rapid increase in grain production was achieved by indiscriminate plowing of as large an area of virgin lands as possible. Under nearly 50 years of monoculture of wheat, summer fallows has been practiced in crop rotation in order to retain moisture, to accumulate nutrients through mineralization and to control weed infestation. Fallowed fields are usually cultivated many times to keep the land bare during the whole cropping season. Of great concern is, however, the adverse effect of fallow, that is, the changes in soil organic matter (SOM) quality and quantity in the context of degradation of the fertility of chernozem soils and subsequent agricultural sustainability.

Ferguson and Gorby (1971), Clarke and Russell (1977) and Dormar (1983) have demonstrated that fallowing significantly exacerbates the depletion of SOM. Janzen (1987) noted that the organic C and N content of soil after 33 years of cropping decreased with increasing frequency of fallow in a rotation on Canadian soils. According to Rubinstein (1959), the Southern Chernozem (Kazakh soil classification; Redkov, 1964) of North Kazakhstan had lost 11% of its SOM compared with its initial amount. Further, Dzhalankuzov and Redkov (1993) reported 28-30% losses of humus in the surface horizon of arable Chernozems of North Kazakhstan from their initial amount before cultivation.

Different type of crop rotation results in significant differences in the mineralization rate of SOM. K. A. Akhmetov (unpublished Ph.D thesis, Kazakh Research Institute of Grain Production, 1999) reported that inclusion of summer fallow in a rotation hastens decomposition of SOM and that differences in SOM among various crop rotations are mainly due to different amount of plant residues returned to the soil.

SOM is highly heterogeneous, consisting of fractions varying in turnover time from days to many centuries. Gregorich (1994) reported that more than 75% of SOM exists as compounds that are only slowly decomposable and the remainder is readily decomposable or "mineralizable" compounds. The amount of organic C contained in a particular soil is a function of the balance between the rate of deposition of plant residues in or on soil and the rate of mineralization of the residue C by soil biota (Baldock and Nelson, 2000). Operationally defined fractions such as C and N mineralized under controlled conditions and "light" fraction organic matter proved to be good indicators of labile SOM because it affects nutrient dynamics within single growing seasons, organic matter content in soils under contrasting management regimes, and C sequestration over extended periods. Quality of SOM may also be characterized by estimates of kinetically defined pools obtained by fitting of simulation models to data on C and N mineralization (e.g. Elliott et al. 1996).

With increasing cultivation intensity, the SOM of the less stable pools is decomposed, as indicated by decreasing portions of sand-sized SOM (2-0.05 mm) (Bird et al., 1996; Christensen, 1996; Amelung et al, 1998), or light fraction C (Christensen, 1992; Trumbore et al., 1996). Organic compounds adsorbed to surfaces of clay particles might become exposed to microbial attack after disruption of aggregates due to tillage.

Although there are numerous reports regarding the effects of wheat-fallow rotations on total SOM content, the influence of summer fallow on mineralizable fractions has not been studied in semiarid regions of North Kazakhstan. Our objectives were to examine the effects of summer fallow on the characteristics of SOM on a long-term basis (type of crop rotation with a variety of frequencies of fallow) as well as on a short-term basis (pre- and post-fallow phases) with special reference to readily decomposable fractions. Our final goal was to define the most appropriate cropping system for sustainable agriculture in the area studied.

8.2. Materials and methods

8.2.1. Site description and crop rotation

The crop rotation experiment including different frequencies of fallow was conducted at the Kazakh Research

Institute of Grain Production in Shortandy, Astana (51°35'36,54N; 71°10'15,40E). The climate of the experimental site is continental and dry with large daily and monthly fluctuation in air temperatures. Mean annual temperature is around 0°C and the average yearly precipitation (1976-1998) was 324 mm (Table 8.1). The experimental site was initially cultivated in 1933 and a variety of wheat-fallow crop rotation systems have been practiced since 1961. The local cultivars of spring wheat "Tselinnaya 3C" were seeded at the rate of 125 kg ha^{-1}.

The rotations were set in a randomized complete block design in three replicates with all phases of each rotation present every year. Plot size was 220 X 10 m^2. The soil is classified as, Southern Chernozem, clayey calcareous, in the Kazakh Soil Classification System (Redkov, 1964) or as Typic Haplustolls in Soil Taxonomy (USDA, 1999) with surface soil pH of 8.2 and a clay content of 43%.

Among various cropping systems five representatives were selected. They are spring wheat rotations with different frequencies of fallow; 6-y (6R), 4-y (4R), 2-y (2R) rotations, continuous wheat (CW) and continuous fallow (CF) systems. Soil samples were collected from pre- (2R-pre, 4R-pre and 6R-pre) and post-fallow (2R-post, 4R-post and 6R-post) phases in each rotation. Selected treatments did not receive mineral or organic fertilizers except CW, which was fertilized with 60 kg N ha^{-1} of NH_4NO_3 until 1996. At harvest the wheat straw was chopped and spread onto the field. No pesticides were added to the studied fields. In semi-arid regions of Northern Kazakhstan subsoil cutting of 0-40 cm is practiced to overcome the problems associated with wind erosion, and toward preservation of soil moisture through decreased evaporation.

8.2.2. Soil sampling and analysis

In spring 1999, before fieldwork began, five topsoil samples (0-10 cm) were collected from each plot to make a composite sample, from which crop residues were removed with sieving (<2mm). Half of each composite sample was air-dried. The remainder was stored in field-moisture condition at 4°C for subsequent biological analysis.

The air-dried soils were ground and analyzed for total N concentration using a full automatic analyzer (Shimadzu NC-800-13N). Organic C was determined by dichromate oxidation method (Nelson and Sommers, 1996). Soil mineral N (min-N) as NO_3^- and NH_4^+ ions was analyzed after extraction with 2 M KCl solution. Nitrate N was analyzed after reduction of NO_3^- ion to NO_2^- by passing the extract through a Cd column. Ammonium N was analyzed by salicylate nitroprusside method (Keeny and Nelson, 1982). Mineral N was measured colorimetrically using Shimadzu Spectra MAX-190. Because at the time of sampling soil was almost air-dried the amount of NH_4^+ was negligible for all the treatments, we plotted soil mineral N as a sum of NO_3^- and NH_4^+.

The soils were assayed for labile OM content using laboratory incubation techniques with a constant temperature of 30°C and moisture of 50% of WHC for 70 days. C_{min} was measured every 14 days after incubating soil in square-plastic jar (500-mL). The evolved CO_2 was trapped in an alkali solution (10 mL 1 M NaOH) and measured by titration (0.5 M HCl). The alkali trap was replaced every 14 days. Potentially mineralizable C (PMC) was estimated from the rate of CO_2-C evolution during 70 days of incubation using non-linear regression according to the following equation (SPSS Inc., 1998a):

$$C_{min} = C_0(1 - e^{-kt}) \tag{1}$$

where, C_{min} is the quantity of mineralized C (mg kg^{-1} dry soil) at time t (d), C_0 is PMC (mg kg^{-1} dry soil), and k is a non-linear mineralization constant, i.e. fraction mineralized d^{-1}.

N_{min} was determined after incubation of soils for 14-, 28-, 42-, 56- and 70-d and analyzed for NO_3^-- and NH_4^+ - N. Non-linear regression was used to describe N mineralization potential (PMN) according to the following equation (SPSS Inc., 1998a):

$$N_{min} = N_0(1 - e^{-k(t-c)}) \tag{2}$$

where, N_{min} is the quantity of mineralized N (mg kg^{-1} dry soil) at time t (d), N_0 is PMN (mg kg^{-1} dry soil), k is a non-linear mineralization constant, i.e. fraction mineralized d^{-1}, and c is an initial delay in mineralization (mg kg^{-1} dry soil). Because mineralization of N in the first 2 weeks was delayed for all the treatments the initial delay factor c was introduced in the

Table 8.1. Average (1976-1998) monthly air temperatures and precipitation at the Shortandy experimental site.

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Average	Total
Temperature (°C)	-17.0	-16.5	-10.0	4.0	12.5	18.5	20.5	17.5	12.0	3.5	-7.0	-14.0	-0.3	-
Precipitation (mm)	17	16	12	26	37	36	52	32	23	32	23	18	-	324

first order kinetic model for the best fit of the model.

"Light fraction" organic matter (LF-OM) was separated by density separation using reagent-grade NaI solution adjusted to 1.8 g cm^{-3} (Spycher et al., 1981; Sollins et al., 1984; Janzen, 1992; Elliot and Cambardella, 1991). After centrifugation, the floating material, i.e., the "light fraction", was transferred directly to a vacuum filtration unit. The LF-OM was then washed (three aliquots of 10 ml 0.01M $CaCl_2$ followed by three aliquots of distilled water), dried at 70°C for 15 h and weighed. The residue was resuspended and the procedure was repeated to ensure complete collection of the LF. The composite LF was finely ground and analyzed for total N and C concentrations.

A quantitative- weighing method was applied to measure weed biomass (Lykov and Tulikov, 1976). Every plot was diagonally divided into 10 small subplots, each of 0.25 m^2. Weeds were pulled out and sorted by biological group. Then they were counted, weighed and determined for fresh and dry weight. Dry weight was determined after drying the weeds in oven at 80°C for 48 h.

Grain yield of wheat was determined by using combine harvester "SAMPO" (Finland), where every plot was harvested separately and the grain yield was weighed.

8.2.3. Statistics

All variables were subjected to a one-way analysis of variance using SYSTAT software (SPSS Inc., 1998b). Where significant treatment effects were observed (P=0.001), LSD analyses were performed to permit separation of means.

Table 8.2. Effects of fallow (F) frequency and rotation phase on soil organic C (SOC) and total N (TN) in surface soil of Southern Chernozem.

Rotation phase	Rotation phase, sampled[2]	SOC (kg Mg^{-1} soil)	TN (kg Mg^{-1} soil)	C-to-N ratio
CF	Cont. Fallow	21.9a[1]	1.97a	11
2R-pre	(F)-W	25.4b	2.26b	11
2R-post	F-(W)	25.1b	2.16b	12
4R-pre	(F)-W-W-W	26.1b	2.26b	12
4R-post	F-(W)-W-W	24.9b	2.19b	11
6R-pre	(F)-W-W-W-W-W	31.0c	2.57c	12
6R-post	F-(W)-W-W-W-W	30.6c	2.50c	12
CW	Cont. Wheat	27.2c	2.38c	13

[1] a-c: values within columns followed by the same letter are not significantly different (p=0.05) as determined by LSD analysis.

[2] ( ) denotes rotation phase sampled.

8.3. Results

8.3.1. Soil organic carbon and total nitrogen

Soil organic carbon (SOC) content was significantly affected by long-term fallowing. The CF system maintained the least SOC (21.9 kg Mg^{-1}), while 6R (31.0 kg Mg^{-1}) and CW (27.2 kg Mg^{-1}) stored the most SOC (Table 8.2). SOC was inversely proportional to fallow frequency, indicating the negative effect of fallow on long-term accumulation of SOM.

The effect of the rotations on total nitrogen (TN) paralleled that described for SOC (Table 8.2). The highest TN concentrations were observed in the 6R (2.54 kg Mg^{-1}) and CW (2.38 kg Mg^{-1}) systems and lowest concentrations in the CF system (1.97 kg Mg^{-1}).

8.3.2. Potentially mineralizable carbon

Differences in PMC among the rotation systems (p<0.001) were more clearly shown than for SOC (Table 8.3). PMC ranged from 3.6 (CF) to 5.8% (CW) of the SOC. The amount of PMC was more affected by the long-term effect of fallow than by the short-term effect and was inversely proportional to fallow frequency.

8.3.3. Soil mineral nitrogen

On a long-term basis, the CF system accumulated the highest amount of soil mineral nitrogen (min-N). But min-N was strongly affected by summer fallow on a short-term basis as well. Pre- and post-fallow phases showed significant differences with min-N accumulating in post-fallow than in pre-fallow phase (Table 8.3). Post-fallow phases accumulated

Table 8.3. Effects of fallow frequency and rotation phase on labile fractions of SOM in surface soil of Southern Chernozem.

Rotation phase	Mineralizable C and N			"Light fraction" OM		
	PMC (mg kg^{-1} soil)	min-N (mg kg^{-1} soil)	PMN (mg kg^{-1} soil)	LF-DM (g kg^{-1} soil)	LF-C (mg kg^{-1} soil)	LF-N (mg kg^{-1} soil)
CF	794b[1]	46a	69a	0.9	240a	15a
2R-pre	1194ab	14b	166b	3.6	810b	51b
2R-post	1012b	42a	69a	2.5	660b	38bc
4R-pre	1224a	13b	86c	5.7	1330c	81d
4R-post	1215a	24c	67a	5.3	1250c	73d
6R-pre	1524c	16b	124b	6.4	1560d	74d
6R-post	1300ac	30c	82c	6	1500d	75d
CW	1581c	14b	93c	7.4	1730e	103e

[1] a-e: values within columns followed by the same letter are not significantly different (p<0.001) as determined by *LSD* analysis.

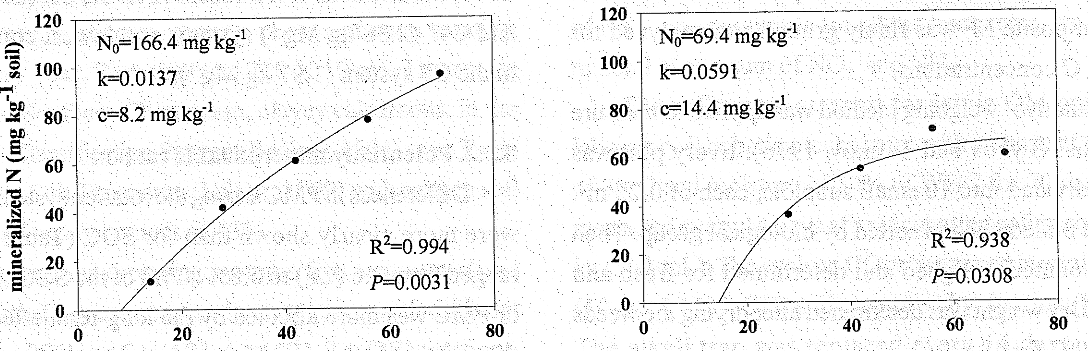
3.0-, 1.9- and 1.9-fold amounts of min-N of pre-fallow phases in 2R, 4R and 6R, respectively.

8.3.4. Potentially mineralizable nitrogen

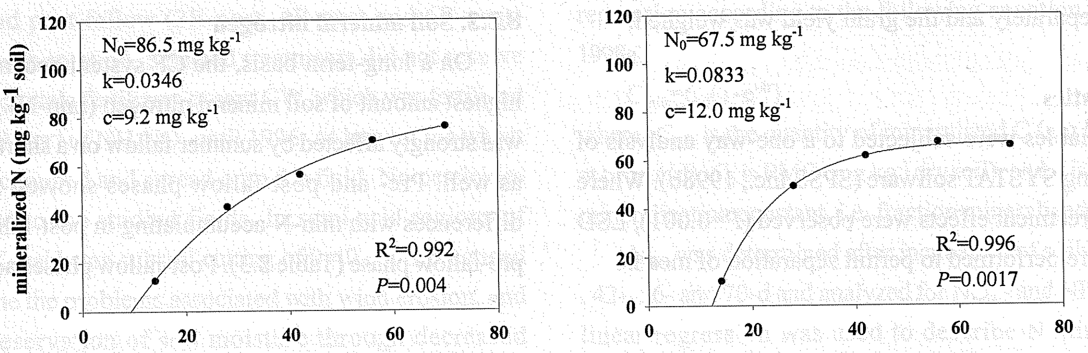
The pattern of N mineralization showed a different trend between pre- and post-fallow phases in all rotations (Fig. 8.1). Pre-fallow phases (Fig. 8.1. a, c and e) were characterized by a larger value of PMN (N_0), a smaller mineralization rate constant (*k*), and a shorter initial delay of mineralization (*c*) than in the post-fallow phases (Fig. 8.1. b, d, and f).

Fallow influenced accumulation of PMN on short-term basis, that is, pre-fallow phases (2R-pre, 4R-pre and 6R-pre) accumulated more PMN than post-fallow (2R-post, 4R-post and 6R-post) phases (Table 8.3). The lowest PMN was observed under the CF system (69 mg kg^{-1}) and the highest under 6R-pre (124 mg kg^{-1}). Pre-fallow phases accumulated

(a) Pre-fallow phase in 2-y rotation (2R-pre) **(b) Post-fallow phase in 2-y rotation (2R-post)**



(c) Pre-fallow phase in 4-y rotation (4R-pre) **(d) Post-fallow phase in 4-y rotation (4R-post)**



(e) Pre-fallow phase in 6-y rotation (6R-pre) **(f) Post-fallow phase in 6-y rotation (6R-post)**

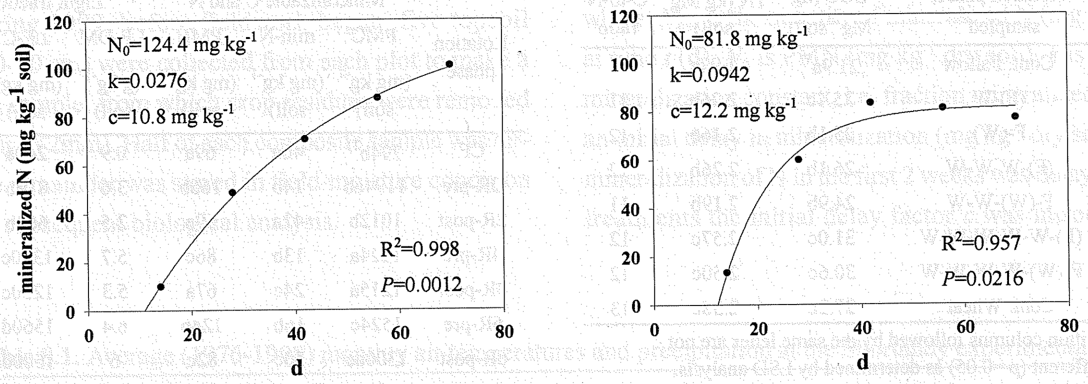


Figure 8.1. Fitting curves of N mineralization of surface soils from pre- and post-fallow phases of the 2-, 4-, and 6-y wheat-fallow rotations in Southern Chernozem, as described by the first order kinetic model with an initial delay of mineralization ($N_{min} = N_0(1-e^{-k(t-c)})$, where Nmin is mineralized N at time *t*, N_0 is potentially mineralizable N (PMN), *k* is a mineralization rate constant, and *c* is an initial delay in mineralization).

2.4, 1.3 and 1.5 fold amount of PMN of post-fallow phases in 2R, 4R and 6R, respectively.

8.3.5. "Light fraction" organic matter

The amount LF-OM was highly responsive to fallow frequency, accounting for 1.1(CF)-6.3(CW)% of the SOC and 0.8(CF)-4.3(CW)% of the TN (Table 8.4). LF-OM, as expressed on the basis of dry matter (LF-DM), C (LF-C) or N (LF-N), was inversely related to fallow frequency. For example, the LF-C content of the CW system was 7.2 times higher than that in the CF system. These results agree with those of other studies (e.g. Janzen et al., 1992; Haynes, 2000;), where LF content was highest under continuous cropping and lowest in those with a high frequency of summer fallow. Additionally, LF-C was affected by the rotation phase, showing larger amounts in pre- than in post-fallow phases in 4R and 6R rotations.

8.3.6. Grain yields and weed biomass

Weed biomass was linearly proportional to the duration of a rotation (Table 8.4). Average yearly inputs of weed biomass were 132 in 2-y, 155 in 4-y, 162 in 6-y and 869 kg ha^{-1} per cropping year in CW plots in 1997. Whereas, the grain yields were negatively proportional to the weed biomass and to the duration of rotation. The largest weed contamination was observed in the CW system, where weed biomass as a dry matter exceeded grain yield by 1.8-fold.

Grain yield of the studied 1998 year was very low in all the rotations (510, 520, 540 and 490 kg ha^{-1} y^{-1} for 2-y, 4-y, 6-y and CW plots, respectively (Table 8.4, K.A. Akhmetov, loc.cit), although low grain yield is common for the area studied, where lack of water is a main limiting factor for wheat growth, the year 1998 was extremely dry. Fertilizer and herbicide free management also affected grain yields. This was undertaken to exclude all other factors but the effects of summer fallows.

Table 8.4. Grain yield (1986 - 1998) and weed biomass (1986 - 1996 and 1997) in wheat-based rotation systems with different frequency of fallow in Southern Chernozem.

Rotation	Grain yield (Mg ha^{-1})		Weeds' biomass (dry matter) (Mg ha^{-1})	
	1986-1996	1998	1986-1996	1997
Two-year (2R)				
Fallow	-	-	-	-
Wheat after fallow	1.85	1.02	0.12	0.13
Average of rotation	0.93	0.51	0.06	n/a
Four-year (4R)				
Fallow	-	-	-	-
Wheat 1st year	1.84	1.16	0.14	n/a
Wheat 2nd year	1.78	0.48	0.26	n/a
Wheat 3rd year	1.56	0.45	0.12	n/a
Average of cropping years	1.73	0.70	0.17	0.16
Average of rotation	1.30	0.52	0.13	n/a
Six-year (6R)				
Fallow	-	-	-	-
Wheat 1st year	2.09	1.16	0.09	n/a
Wheat 2nd year	1.66	0.55	0.22	n/a
Wheat 3rd year	1.61	0.56	0.20	n/a
Wheat 4th year	1.58	0.65	0.18	n/a
Wheat 5th year	1.55	0.31	0.15	n/a
Average of cropping years	1.70	0.65	0.17	0.16
Average of rotation	1.41	0.54	0.14	n/a
Continuous wheat cropping (CW)				
CW	1.00	0.49	1.13	0.87

8.4. Discussion

8.4.1. Soil organic carbon and total nitrogen

To protect the field against weeds and to store more moisture and nutrients in the soil, fallowed field are cultivated 4 to 5 times during the vegetative season. Such intensive mechanical disturbance causes enhanced mineralization of SOM in fallow, firstly, due to better aeration of surface soil, and secondly, particular organic matter occluded within aggregates might become exposed to microbial attack after disruption of aggregates. Additionally, bare fallow does not contribute plant residues for the replenishment of SOM.

In general, distributions of SOC and TN among rotations with different fallow frequencies were comparable to those reported by Collins et al. (1992), Campbell and Zentner (1993) and Biederbeck et al. (1994) for Chernozem soils. Frequently fallowing systems such as 2R showed less SOM than less frequently fallowing systems, such as 6R. Our results confirmed the findings from North American arable systems that frequently fallowing system accelerates mineralization of SOM (e.g. Janzen, 1987; Campbell and Zentner, 1993; Biederbeck et al., 1994).

8.4.2. Potentially mineralizable carbon

Continuous wheat (CW) and 6-y systems (6R) had higher amount of PMC that was inversely proportional to fallow frequency and indicated the long-term effect of fallow. These results corroborate the study of Campbell et al. (1999) who found for a silt-loam in southwestern Saskatchewan that mineralized C (measured after 30 days at 21°C) represented 1.06 and 1.45% of SOC in a 2-y fallow-wheat rotation and continuous growing of wheat, respectively. Campbell et al. (1992) found that C mineralization was not related to the amount of crop residue from the previous year. In our study PMC was a little higher in the pre-fallow (2R-pre, 4R-pre and 6R-pre) than in the post-fallow (2R-post, 4R-post and 6R-post) phases, probably reflecting the input of crop and weed residues in the preceding year (Table 8.3).

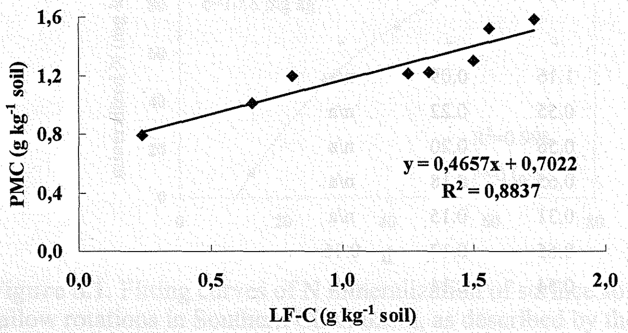


Figure 8.2. Correlation of potential mineralizable C (PMC) with "light fraction" C (LF-C).

8.4.3. Soil mineral nitrogen

As expected, the CF system maintained the highest amount of soil min-N that was due to enhanced mineralization of SOM compared to the other systems. The short-term effect of fallow on the accumulation of min-N is clearly observed as well. During fallow phase min-N is not subjected to either plant uptake or leaching, thus resulting in a greater accumulation of soil min-N in post-fallow (2R-post, 4R-post and 6R-post) than in pre-fallow phases (2R-pre, 4R-pre and 6R-pre).

8.4.4. Potentially mineralizable nitrogen

Larger amounts of mineralized nitrogen (N_0) in the pre-fallow phases indicate larger storage of PMN in these soils than in post-fallow soils. Differences in the rate constant (k) between pre- and post-fallow phases indicate that fallowing has caused changes in the quality of the PMN.

Due to multiple cultivations of fallows the soil is subjected to alternating wet-dry cycles. The wet period provided better moisture condition microorganism activity and produced greater biomass than in cropped fields. Then in the subsequent dry period the greater biomass turned into necromass due to drought. This cycle may be repeated several times in a cropping season. And later, during incubation in the laboratory, this microbial necromass as well as living biomass was rapidly mineralized showing a higher mineralization rate constant in the post fallow than in the pre-fallow phases (Fig. 8.1).

The soils from the post-fallow phase showed a longer initial delay of mineralization, suggesting that higher concentration of min-N compared to pre-fallow phase probably stimulated microbial activity and resulted in immobilization of mineralized N during the initial stages of incubation (Mamilov et al., 1985).

The long-term effect of fallow was not observed for soil min-N or PMN suggesting that N mineralization is only affected by the substrate added during the previous year or the latest cycle of rotation. Nitrogen in the forms of NO_3^- and NH_4^+ is assimilated by plants and returned into soil whereas C originates from CO_2 in the air and plowed as organic residue into soil. Nitrogen transformations are closely related to the processes of mineralization of its organic forms in plant-soil system.

Therefore, in plant-soil systems N cycling is affected over shorter period than C cycling.

8.4.5. "Light fraction" organic matter

"Light fraction" of SOM (LF-OM) consists mainly of plant residues, small animals and microorganisms adhering to plant-derived particulate matter at various stages of decomposition that serves as a readily decomposable substrate for soil microorganisms and also as a short-term reservoir of plant nutrients (Gregorich et al., 1994).

The "light fraction' C (LF-C) was positively correlated with PMC (Fig. 8.2), and confirm the hypothesis that the reduced fallowing system has more potential to supply soil with easily mineralizable C. However, there was no linear correlation between LF-N and PMN (Fig. 8.3), presumably because the high C-to-N ratio of the LF-OM temporary induced N immobilization (Janzen et al., 1992).

The content of labile OM, which is closely related to LF-OM, may be governed by the degree to which temperature and moisture conditions constrain decomposition of accumulated residues (Beiderbeck et al, 1994). Under the CW system decomposition of residues during periods of favorable soil temperature was retarded by the depleted soil moisture (Shields and Paul, 1973; Douglas et al., 1992; Akhmetov, loc.cit.). Then, when moisture and temperature constraints were removed during laboratory incubations, soil showed a high respiration rate (Janzen et al., 1992). On the contrary, residues in the 2R system during the fallow phase were always exposed to an extended period with favorable moisture and temperature. Therefore, labile organic matter was rapidly depleted in the field, and in the laboratory respiration rates were much lower in 2R than in CW (Biederbeck et al., 1994).

8.4.6. Grain yields and weed biomass

The first year after fallow gave the highest grain yield and the lowest amount of weeds. But in the second and successive years after fallow the yield fell considerably (Table 8.4, Fig. 8.4). This is, firstly, because plants in a post-fallow phase take advantage of higher soil min-N. Secondly, because when a field is in fallow provides the only break for weed infestation, the amount of weeds was generally least in the first year after fallow and reduced competition for nutrients.

In contrast to the grain yield, weed infestation reached its maximum in the second years after fallow in 4R and 6R. probably, some of the weeds were not destroyed during the fallow and their seeds remained dormant but germinated in the second year after fallow (Akhmetov, 1999, loc.cit.).

Correlation between the grain yield and weed infestation average for 1986-1996 is presented by the following equation of multiple linear regression:

$Y = 20.82 - 0.189X$,

where X total amount of weeds, pieces/m^{-2}.

The coefficient of determination was also high ($R^2 = 0.78$) or 78% of changes of the yield depend on weed infestation.

The highest grain output, counting per whole rotation, was obtained by 6R (540 kg ha^{-1}) that parallels the distribution of soil labile OM (PMC and LF-C) and supports the hypothesis that the longer rotations with fewer fallows contribute more to the accumulation of SOM than shorter rotations with greater fallow frequencies.

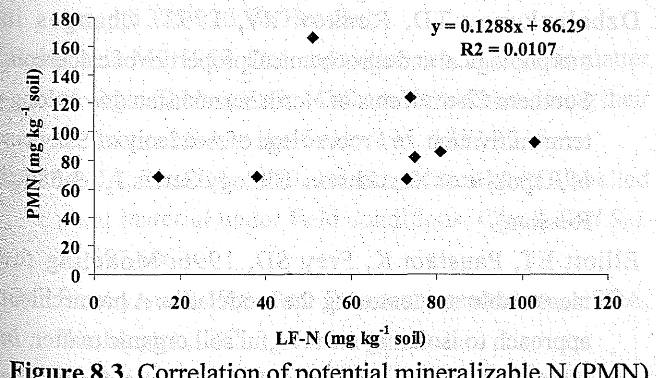


Figure 8.3. Correlation of potential mineralizable N (PMN) with "light fraction" N (LF-N).

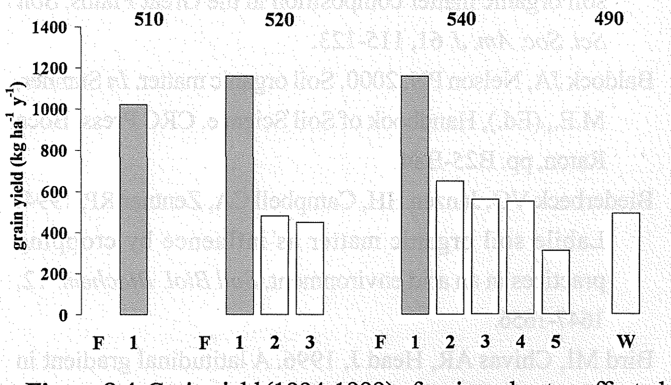


Figure 8.4. Grain yield (1994-1999) of spring wheat as affected by years after fallow.
F is a fallow; 1,2,3,4,5 are succession of crops after fallow. The values above bars are average yield per rotation including the fallow year.

8.5. Conclusions

Our results on a Southern Chernozem in North Kazakhstan suggested that N dynamics were closely related to the recent input of substrate added as plant residue while C dynamics were more related to long-term substrate addition.

Yearly input of plant residue in a 6-y wheat-fallow rotation system built up more labile OM, especially LF-C or readily decomposable C, whereas 2-y rotation system with a high frequency of fallow depleted SOM via accelerated mineralization. Therefore, with no fertilizer or pesticides application, in the semiarid regions of northern Kazakhstan, the inclusion of fallow in wheat monoculture every 6 years is the most appropriate farming system in terms of sustainability in both grain production and soil fertility.

The relatively high SOM content under CW system may be due to (a) high nutrient content in this soil due to former fertilization, (b) the high input of nutrients from the weed biomass, and (c) the low output of nutrients with the crops. Losses of labile OM as a result of cultivation tend to be disproportional higher than total OM losses. Therefore, labile fractions of soil OM such as PMC, PMN and LF-OM are good indices for detecting subtle changes of SOM quality due to the effects of summer fallow in semiarid regions.

To some extent our results may provide prediction of SOM response to fallow frequency in wheat-based rotation systems in Chernozem soils of semiarid regions: the susceptibility of labile fractions of OM and their relationship to fallow frequency suggest the possibility of managing labile OM through controlling the length of wheat-fallow rotation systems.

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Chapter 9

Soil organic matter dynamics under grain farming in northern Kazakhstan

Shinya Funakawa, Iwao Nakamura and Kanat Akshalov

9.1. Background

The natural grass forb steppes of northern Kazakhstan have largely been replaced by arable land mainly for the cultivation of spring wheat due to the implementation of Khrushchev's Virgin Lands Agricultural Program from 1954 to 1960 when Kazakhstan was ruled by the former Soviet Union (Medvedev, 1987). Chernozem soil (Mollisols), which is a typical soil found in this region, is considered to be one of most productive soils in the world. In Kazakhstan, Chernozem soil covers 32.1×10^6 ha or 11.8% of the country territory (GUGK, 1982). It is stated that an area of 26.5×10^6 (GUGK, 1982; Morgounov and Zuidema, 2001) or 24.6×10^6 ha (Gossen, 1998) of Chernozem soil in Kazakhstan had already been converted to arable land. Presently, the significance of food production in this area is widely recognized. On the other hand, the characteristics of the Chernozem soils which can store a large amount of soil organic matter (SOM) have recently drawn considerable attention in terms of both the large source and sink of carbon dioxide in relation to the problem of "global warming". In this sense, Chernozem soils are one of the most important resources from both agricultural and environmental viewpoints (Paustian et al., 1997).

This area is strongly affected by the continental climate, being typically cold and dry. For example, at our study site, mean annual precipitation and average year temperature were 323 mm and 1.6°C (1936-2000), respectively (Barayev Kazakh Research and Production Center of Grain Farming; unpublished data). Because of the harsh conditions during the winter period, only spring cereals such as wheat, barley, and/or oats have become adapted, except for a few crops such as sunflower, maize for silage, etc. Additionally, very dry conditions during the summer period are also one of the main constraints on crop yields there, e.g. the average grain yield is generally as low as 1.0 Mg ha^{-1} (in 1986-90 for whole Kazakhstan) (Gossen, 1998).

Therefore, since the primary concern of agriculture in this area has been to ensure water resources for crop production, several water management practices have been developed for this purpose. They include 1) snow management, which is conducted mainly in February, in order to accumulate additional snowfall by making parallel snow-rows at certain intervals, 2) summer fallow to store rainfall water for the next cropping, and 3) subsoil cutting in autumn to reduce the loss of water through evaporation by decreasing capillary rise (Shegebaev, 1998). Among them, summer fallow is usually practiced in the rotation systems once in five years in order to store moisture in soils, to decrease weed hazard, and to accumulate mineral nitrogen through mineralization of soil organic matter. Fields under fallow are usually mechanically harrowed several times to keep the land bare and to minimize evapotranspiration during the cropping season. This practice is also commonly applied in the steppe area of North America, in which the annual precipitation is below 500 mm (e.g. Farahani et al., 1998). Unfortunately, it has often been reported that such agricultural practices on Chernozem soils had accelerated organic matter decomposition (Buyanovsky et al., 1987; Srivastava and Meyer, 1998; Mikhailova et al., 2000; Karbozova-Saljnikov et al., 2004).

Given the vast acreage of cereal production in northern Kazakhstan, it is important to maintain SOM there from both environmental and agricultural viewpoints. This study was carried out to provide information on SOM budget under cereal production in the Chernozem soil of northern Kazakhstan. Dynamics of *in situ* soil respiration and microbial biomass, as well as soil environmental factors such as soil temperature and moisture, were analyzed in order to determine the SOM budget and the factors that affect the SOM decomposition rate.

9.2. Study methods

This experiment was conducted in 2000 at the experimental farm of Barayev Kazakh Research and Production Center of Grain Farming, Shortandy, northern Kazakhstan (51°35'N, 71°03'E). According to the long-term meteorological monitoring at the Center, mean annual precipitation and average year temperature (1936-2000) were 323 mm and 1.6°C, respectively, as previously mentioned. The soil characteristics are briefly described below; pH determined in water was neutral to slightly alkaline, usually ranging from 7.5 to 9, texture was typically clayey with more than 40% of clay, organic carbon content ranged between 20 and 25 g kg^{-1} in the plow layer (surface 30 cm), carbonates were detected near the soil surface, and the depth of the layer with organic matter-accumulation was approximately 50 cm. According to the USDA soil classification system, the soils are classified into Typic Haplustolls, which corresponds to the Southern Chernozem soils in the classification system of the former Soviet Union.

For the present study, five plots (F0-C, O0-C, F1-C, O1-C, and F4-C) were established in the experimental farm. These plots were included in an experimental block in which long-term experiments had been conducted since 1983 for improving farming technology. The size of each plot was 6 m × 60 m and crop species and land use stages of the experimental plots are summarized in Table 9.1. The F0-C plot was left fallow in 2000. The O0-C and O1-C were included in the rotation system in which oat cropping was substituted for summer fallow. Spring wheat was planted in the F1-C, O1-C and F4-C plots, whereas oats were planted in the O0-C plot. It should be noted that since F1-C was the field just after fallow, it had not received any residue input in the preceding year. The climatic conditions during the experiment in 2000 are summarized in Fig. 9.1. Monthly data on precipitation and air temperature both in 2000 and the average in 1990-1999 are listed in Table 9.2. The mean annual precipitation and average year temperature in 2000 were 362 mm and 2.4°C, respectively. Precipitation which was recorded at the early stage of crop growth, i.e. in May and June in 2000 was higher than the 10-year average, which may account for the higher crop yield in that year than the average one indicated in Table 9.1. On the other hand, the temperature during summer time (June, July, and August) in 2000 was similar to the average one. In these plots, CO_2 emissions from the soil surface were measured in triplicate 14 times with approximately two-week intervals during the period of April to September, 2000. In order to mitigate the effect of possibly high daily fluctuations of CO_2 emissions due to temperature fluctuations, the alkali-trap method for one-day

Table 9.1. Description of study plots.

Plot	Crop rotation system$^{1) 2)}$	Overall crop yield at the same stage of rotation 2000 (Mg ha^{-1})	average in 1990-99 (Mg ha^{-1})	Remarks
F0-C	**F**-W-W-B-W	0	0	Summer fallow
O0-C	**O**-W-W-B-W	3.01	1.82	Fallow in conventional rotation was substituted by oat cultivation
F1-C	F-**W**-W-B-W	1.52	1.63	1st year after fallow
O1-C	O-**W**-W-B-W	1.90	1.34	1st year after oats in the modified rotation
F4-C	F-W-W-B-**W**	2.09	1.29	4th year after fallow

1) F: fallow, W: wheat, B: barley, O: oats
2) Bold letters denote the cropping stage of each plot.

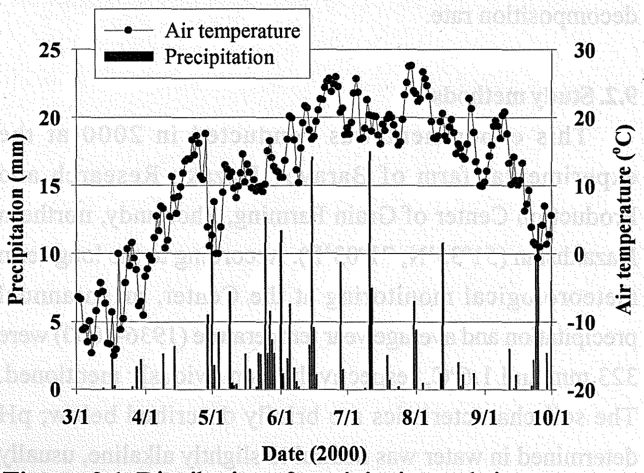

Figure 9.1. Distribution of precipitation and air temperature during the experiment.

Table 9.2. Comparison of monthly meteorological data in 2000 with the 10-year average.

Month	Temperature (°C) average in 1990-1999	Temperature (°C) 2000	Precipitation (mm) average in 1990-1999	Precipitation (mm) 2000
Jan-Mar	-13.7	-13.6	54.0	53.0
Apr	3.9	7.7	20.0	11.3
May	12.9	10.6	35.7	64.1
Jun	18.7	19.4	30.4	60.9
Jul	19.9	20.2	62.8	35.0
Aug	17.4	18.4	35.8	21.5
Sep	11.2	10.5	33.1	31.4
Oct-Dec	-5.8	-5.6	66.0	84.4

respiration was used in the present study. The procedure basically followed the guidelines of Anderson (1982). On each measurement, after removal of the plants in the surroundings to minimize the influence of root respiration, steel cans with a diameter of 10 cm were installed on the ground surface upside-down, in which 1 mol L^{-1} NaOH solution was placed in an evaporation dish. After 24 hours, the amount of CO_2 absorbed in the alkali solution was determined by a second-step titration (from pH 8.3 to pH 4.3 using phenolphthalein and bromocresol green as indicators) with a standardized HCl solution. At the same time, the contents of microbial biomass C and N were determined for fresh soils from the surface 15-cm depth using the chloroform fumigation-extraction method (Brookes et al. 1985; Vance et al. 1987). The soil temperature at the 5 cm depth and soil moisture at the surface 0-30 cm depth were continuously monitored for each plot using a datalogger system (CR-10X, Campbell Scientific, Inc.). At the time of harvest, plant biomass and grain yield were measured in a 1 m2 subplot in triplicate.

9.3. Fluctuations of soil temperature, soil moisture content, and soil respiration rate

Figure 9.2 shows the fluctuations of the soil temperature and soil moisture content during the experiment, which were monitored by the datalogger. During a certain period, data were missing due to mechanical treatment of the field at the time of seeding (May 25- June 7 in all the plots) and malfunction of the datalogger (July 4 - 19 in F4-C).

Mean daily soil temperature increased to above 0°C in early April and remained at above 20°C from mid-June to mid-August. Then it sharply decreased to below 5°C at the end of September. Most of the biological activities were considered to be limited during this period, i.e. April to September. On the other hand, the soil moisture content in the surface layers remained high after thawing until mid-June. Then in the cropped plots, it continuously decreased except during the rainfall events. In contrast, the fallow plot (F0-C) could maintain a certain level of soil moisture after July because of the lack of transpiration by plants. The soil

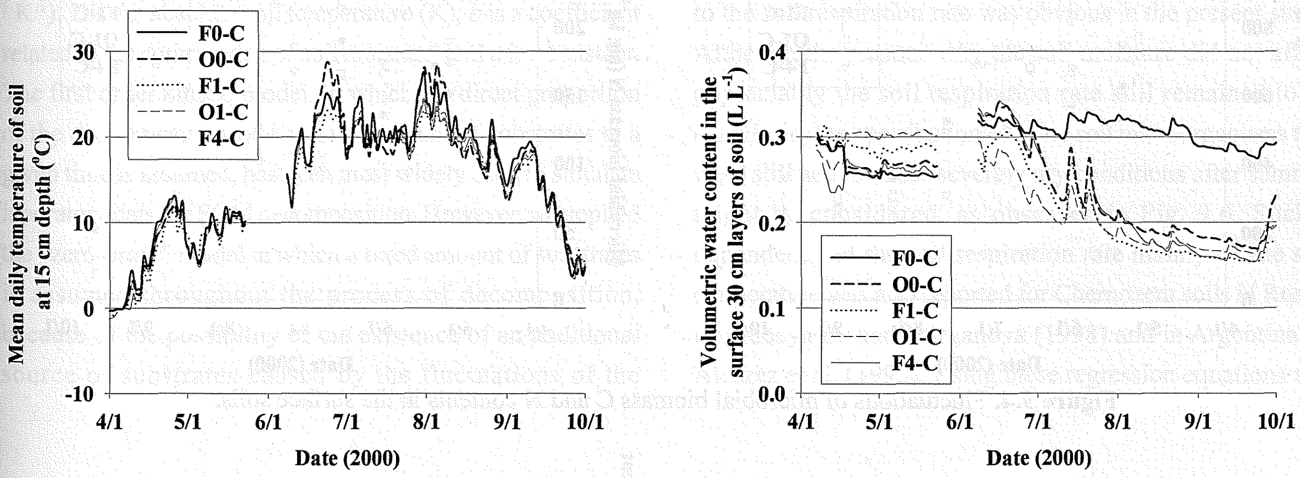

Figure 9.2. Fluctuations of soil temperature and soil moisture content during the experiment, measured by datalogger.

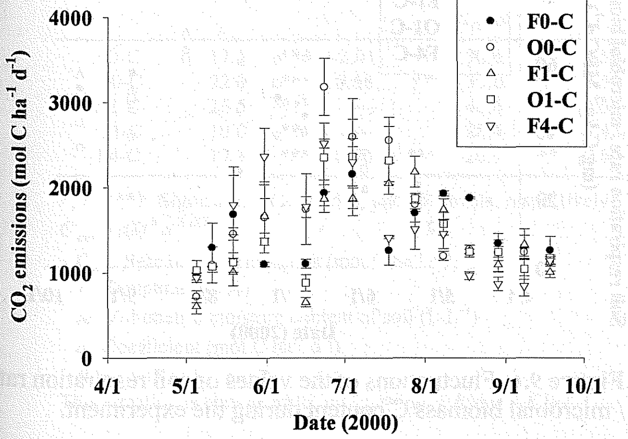

Figure 9.3. CO_2 emissions from the soil surface of the experimental plots.

moisture content at 0.18 L L^{-1} was equivalent to the permanent wilting point (-1.5 MPa) of the soils, based on the moisture retention curves (unpublished data). Hence, the cropped soils here were subjected to very dry conditions during late summer (late June to August), with a remarkable increase of the soil temperature. These data were later used for the calculation of annual CO_2 emissions after interpolated correction of the missing data.

Figure 9.3 shows *in situ* CO_2 emissions, i.e. the soil respiration rates, during the cropping period in 2000. Maximum values were recorded on June 24 or July 4, during which soil was still moist in spite of the high temperature of above 20 °C, and then the values decreased, as soil was getting drier. The overall profile of CO_2 fluctuations, however, still seemed to be similar to that of the soil temperature.

9.4. Dynamics of soil microbial biomass

According to Fig. 9.4, the amounts of microbial C and N in the soils were high in early summer and then drastically decreased, indicating similar trends to those of the soil moisture content. Actually, there was a highly positive correlation between the soil moisture content and microbial biomass except for the fallow plot (F0-C), in which repeated plowing during the summer may have interfered with such a clear relationship (Fig. 9.5).

The difference in the fluctuation patterns between the soil respiration rate and the amount of soil microbial biomass brought a unique dynamics in the values of the soil respiration rate / microbial biomass C content, which showed an apparent increase in late summer (Fig. 9.6). This implied that, in spite of the decrease in the amount of soil microbial biomass due to the very dry conditions, some microorganisms

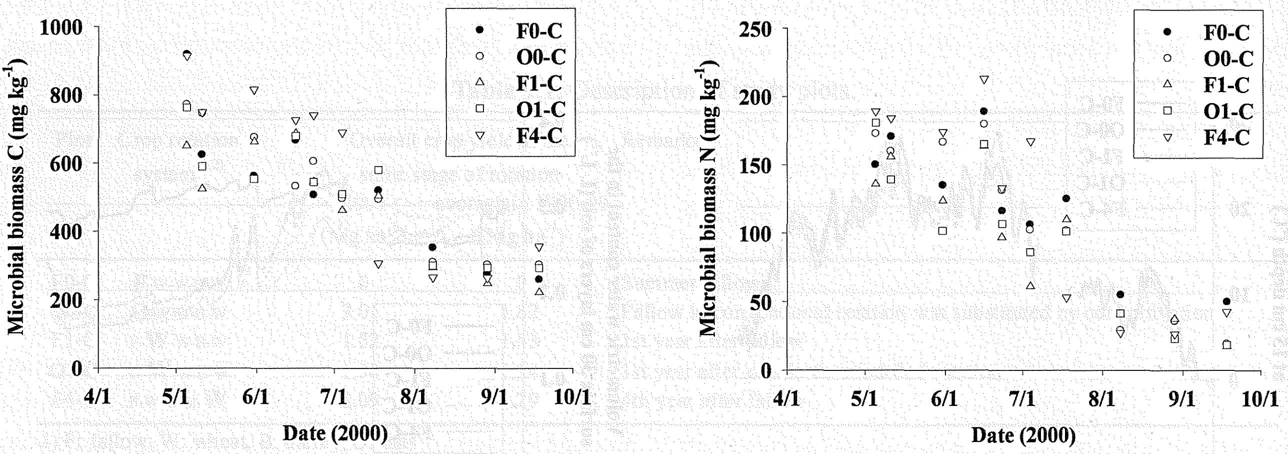

Figure 9.4. Fluctuations of microbial biomass C and N contents in the surface soils.

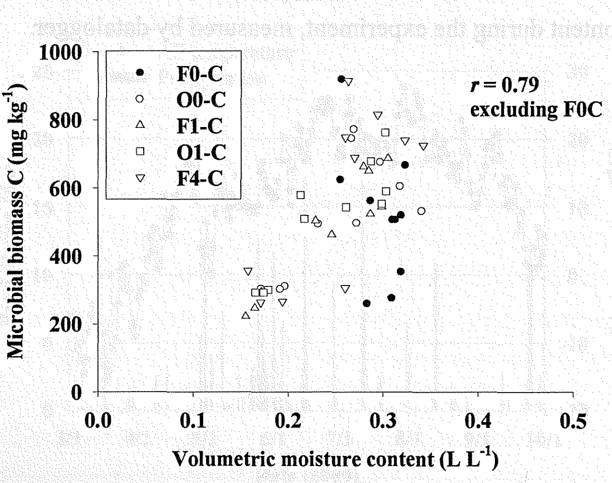

Figure 9.5. Relationship between the volumetric water content of soils and the microbial biomass C content.

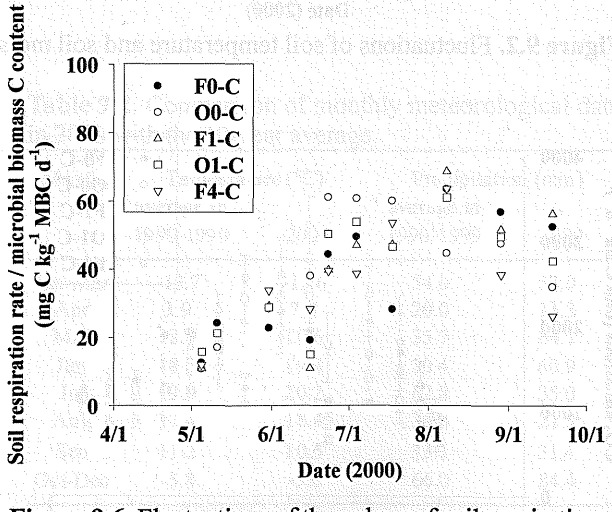

Figure 9.6. Fluctuations of the values of soil respiration rate / microbial biomass C content during the experiment.

were still active and contributed to soil respiration, by possibly using dead microbial debris as additional substrates.

9.5. Estimation of CO_2 emissions throughout the cropping period using the measured data of soil temperature, moisture content, and soil respiration rate

For estimating the total soil respiration rate throughout the cropping period, we first derived an equation that represented the relationship between the *in situ* daily soil respiration rate and climatic factors such as soil temperature and moisture content by multiple regression analysis. Then we calculated the daily soil respiration rate by substituting each parameter of the equation using monitored data, and summed up the daily soil respiration rates for a given period. In the first step, we assumed that the Arrhenius relationship between the soil temperature and respiration rate was as follows:

$$C_{em} = aM^b e^{-E/RT}$$

where C_{em} is the daily soil respiration rate (mol C ha^{-1} d^{-1}), M is the volumetric soil moisture content (L L^{-1}), E is the activation energy (J mol^{-1}), R is the gas constant (8.31 J mol^{-1} K^{-1}), T is the absolute soil temperature (K), b is a coefficient related to the contribution of soil moisture, and a is a constant. The first order kinetic model, in which the direct proportion of the decomposition rate and the amount of substrates at a given time is assumed, has been most widely used to simulate laboratory data for SOM decomposition. However, we applied the "zero-order" model in which a fixed amount of substrates is assumed throughout the process of decomposition, because of the possibility of the existence of an additional source of substrates caused by the fluctuations of the temperature and moisture content during the field experiment. The equation was then rewritten in the logarithm form:

$$\ln C_{em} = \ln a + b\ln M - E/RT$$

Then a series of coefficients, a, b, and E were calculated by stepwise multiple regression analysis (p=0.25) using the measured data, C_{em}, M, and T (SPSS, 1998).

The results are given in Table 9.3. Generally a significant relationship at 1 or 5% level was obtained between the soil respiration rate and the activation energy, E, indicating a significant dependency of the soil respiration rate on the soil temperature. Based on the value of E, we could estimate that the Q_{10} values from 10 to 20°C ranged between 1.3 and 2.0. In contrast, the contribution of moisture was somewhat uncertain, except for the O0-C and F4-C plots, based on the fact that the moisture parameter was rejected even at the level of p=0.25 in the stepwise regression. In some cases (especially O1-C), the r^2 value was unexpectedly low, presumably because short-term effects of surface soil disturbance on seeding and harrowing, occasional rainfall events during the dry summer, etc may have been neglected.

Thus the positive contribution of the soil temperature to the soil respiration rate was obvious in the present study. Although the reasons why the soil moisture did not affect appreciably the soil respiration rate still remained to be elucidated, the contribution of some soil microorganisms that were still active under severely dry conditions after summer might be considered, as observed in Fig. 9.6. Such a dependency of the soil respiration rate mainly on the soil temperature was also reported for Chernozem soils in Russia by Kudeyarov and Kurganova (1998) and in Argentina by Alvarez et al. (1995). Using these regression equations and

Table 9.3. Coefficients determined by stepwise multiple regression analysis.

Site	------------------- Coefficients				-----------------		R^2		n	$C_{em} = aM^b \exp(-E/RT)$	Cumulative CO_2
	ln$a$		b		E (kJ mol^{-1})					(at T = 298K, M = 0.2 L L^{-1}) (mol C ha^{-1} d^{-1})	emission from Apr. 10 to Oct. 3 (Mg C ha^{-1})
F0-C	17.5	***	-2.01	*	30.6	***	0.53	***	13	4485	2.92
O0-C	22.0	***	0.68	**	33.0	***	0.59	***	13	2014	3.19
F1-C	26.5	***	-----		46.6	***	0.65	***	12	2197	2.52
O1-C	19.0	***	-----		28.4	**	0.42	**	13	1927	2.76
F4-C	17.3	***	0.90	***	20.9	**	0.69	***	10	1634	3.06

*, **, ***: Significant at 25%, 5%, and 1% levels, respectively.

$C_{em} = aM^b e^{-E/RT}$

C_{em}: Rate of CO2 emissions (mol C ha^{-1} d^{-1})
T: Temperature (K)
M: Volumetric moisture content of soil (L L^{-1})
a: Coefficient (mol C ha^{-1} d^{-1})
R = 8.315 (J K^{-1} mol^{-1})

This equation is converted to; $\ln C_{em} = \ln a + b\ln M - E/RT$

the data monitored by the dataloggers, the fluctuations of the soil respiration rate during the cropping season were simulated as indicated in Fig. 9.7 and cumulative soil respiration throughout the period of Apr. 10 to Oct. 3 was calculated to be 2.9 (F0-C), 3.2 (O0-C), 2.5 (F1-C), 2.8 (O1-C), and 3.1 (F4-C) Mg C ha^{-1}, respectively. Since the monthly trend of air temperature during summer time in this year was similar to the 10-year average (Table 9.2), the calculated values here can represent the conditions in normal years. The lower value of the soil respiration rate estimated in the F1-C plot, just after summer fallow, than the others suggested the possible depletion of readily decomposable SOM due to the absence of crop residues in the preceding year. Excluding further the fallow plot, F0-C, the average value of the remaining three cropped plots (O0-C, O1-C, and F4-C), which received crop residues at least in the preceding year, was 3.0 Mg ha^{-1} during the cropping phase.

9.6. Soil carbon budget under rain-fed grain farming in northern Kazakhstan

Although the soil respiration was generally considered to be associated with both SOM decomposition by the soil microorganisms and plant root respiration, the results obtained in the present study were considered to have practically excluded a large part of root respiration due to the removal of nearby plant materials during the measurements. Table 9.4 gives summarized data on SOM budget in the experimental plots. The crop yields in the experimental plots, which were primarily determined by the amounts of available water during the cropping season (Funakawa et al., 2004), were 3.2 (O0-C, oat), 1.9 (F1-C), 1.4 (O1-C), 2.0 (F4-C) Mg ha^{-1}, respectively. After harvest, 4.5 (O0-C), 2.3 (F1-C), 1.6 (O1-C), and 2.6 (F4-C) Mg C ha^{-1}, respectively, were expected to be returned to the soils as plant residues. Assuming that all the soil respiration determined here was caused by the SOM decomposition, the budget of the SOM pool was estimated to be -2.9 (F0-C), 1.3 (O0-C), -0.2 (F1-C), -1.2 (O1-C), and -0.5 (F4-C) Mg C ha^{-1}, respectively. Except for the plot planted with oats (O0-C), in which the exceptionally higher residue biomass of oats than that of wheat contributed positively to the budget, the SOM budget in the cropped plots was slightly negative in this year, that is, the soils lost their organic matter stock. This trend might be more conspicuous in an average year since the crop yield of 2000 was considerably higher than the 10-year average, as indicated in Table 9.1. In the fallow plot, F0-C, such SOM loss was much higher than that in the cropped plots because of the lack of residue input.

In the same plots, a significant relationship was observed between the amount of available water and wheat production (Funakawa et al. 2004). Using the same data, the following relationship can be established between the amount of evapotranspiration (*ET* in mm) and content of organic C of the wheat residues (*CR* in Mg C ha^{-1}):

$$CR = 0.0201\,ET - 2.43 \qquad r^2 = 0.48,\ n = 9$$

In order to obtain the wheat residues that could compensate for the CO_2 emissions, namely 3.0 Mg C ha^{-1} in the corrected average of the present study or 2.0 Mg C ha^{-1} under the assumption that one third of the CO_2 emissions in the present study was derived from root respiration, approximately 270 or 220 mm of water would be required for evapotranspiration, respectively, according to the equation listed above. However, since even in the experimental farm,

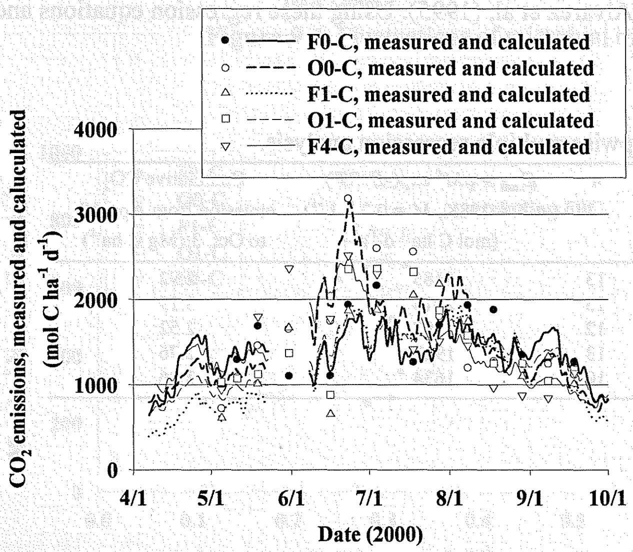

Figure 9.7. Estimation of CO_2 emissions throughout the cropping season using the regression equations obtained in Table 9.1.

Table 9.4. Budget of soil organic carbon in the period of April 10 to October 3, 2000, in the experimental field of Shortandy.

Site	Cummulative CO_2 emission from Apr. 10 to Oct. 3 (Mg C ha^{-1})	Crop yield (Mg ha^{-1})	Plant residue (Mg C ha^{-1})	Budget of SOM (Mg C ha^{-1})
F0-C	2.92	--------	--------	-2.92
O0-C	3.19	3.20 (0.19)	4.46 (0.27)	1.27
F1-C	2.52	1.86 (0.07)	2.28 (0.15)	-0.24
O1-C	2.76	1.36 (0.12)	1.60 (0.08)	-1.16
F4-C	3.06	2.03 (0.03)	2.61 (0.04)	-0.45

* Parrensis denotes standard error.

in which land and water management was ideally practiced, the maximum value of evapotranspiration was 259 mm under intensive snow management in 1999/2000 (Funakawa et al., 2004), it would be very difficult for individual farmers to secure 220 to 270 mm of available water for wheat production. In addition, burning of cereal husks in springtime and/or cattle grazing, which were sometimes actually practiced in farmers' fields, would further reduce the crop residue input into soils. Since the amount of potentially mineralizable carbon of the surface 15-cm soils in our field, which was determined by application of the first order kinetic model for the dataset of the laboratory incubation experiment of fresh soils for 133 d under constant conditions (temperature and gravimetric soil moisture fixed to 30°C and 60%, respectively), was 5.44 ± 0.14 (S.E.) Mg C ha^{-1} soil ($n = 4$) and was significantly higher than that in the nearest farm in Shortandy (2.72 ± 0.13 (S.E.) Mg C ha^{-1}, $n = 70$), both the C input and output as well as mineralizable pool of SOM in farmers' fields were expected to be lower than those in the present study. Although it is difficult to generalize the C budget in different years because of the large variations in crop growth due to the fluctuations of annual precipitation, the disadvantage of summer fallow is obvious from the viewpoint of SOM budget. The annual loss of SOM in the fallow plot (F0-C), 2.9 Mg C ha^{-1}, was approximately equivalent to 4% of the total SOM stock in the plow layer (30 cm) (70 to 80 Mg C ha^{-1}).

To reduce further loss of SOM, at least evenly extensive use of summer fallow should be reconsidered. Intensive snow management would be an alternative approach to improve the soil moisture conditions at some topographical locations (Funakawa et al., 2004). Since the results of the present study were associated with unique condition, i.e. strictly managed experimental farm, it is still necessary to determine the actual relationship between the topographical characteristics and the possible water management or carbon dynamics. A general conclusion from this study, namely that the soil respiration was mostly controlled by the soil temperature while residue input was a function of moisture conditions, would give an insight into the development of an appropriate land use system in accordance to the topographical characteristics that would enable to obtain yields at a reasonable level and decrease the net C release at the same time.

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Chapter 10

Water dynamics in soil-plant systems under grain farming in northern Kazakhstan

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10.1. Background

Since the 1950s when Kazakhstan was ruled by the former Soviet Union, large-scale grain farming has been developed in the steppe region of northern Kazakhstan. Approximately 11×10^6 ha of land covered with Chernozem soil (mostly Typic Haplustolls or Typic Calciustolls) are planted with spring wheat (*Triticum aestivum* L.). This area is strongly affected by the continental climate, being typically cold and dry. Because of such extremely dry conditions for wheat growth, the average grain yield was generally as low as 1.0 Mg ha^{-1} (during the period of 1986-90 for whole Kazakhstan) (Gossen, 1998) and water management is one of the major concerns for sustainable production. Main water management practices here include 1) snow management, which is conducted mainly in February, in order to accumulate additional snowfall by making parallel snow-rows at certain intervals (see Fig. 10.1a), 2) summer fallow to store rainfall water for the next cropping (Fig. 10.1b), and 3) subsoil cutting (conservation tillage) in autumn to reduce the loss of water through evaporation by decreasing capillary rise (Fig. 10.1c) (Shegebaev, 1998). Among them, summer fallow is usually practiced in the rotation systems once in five years in order to store moisture in soils, to decrease weed hazard, and to accumulate mineral nitrogen through mineralization of soil organic matter. Surface soils under fallow are usually mechanically harrowed several times to keep the land bare and to minimize evapotranspiration during the cropping season. This practice is also commonly applied in the steppe area of North America, in which the annual precipitation is below 500 mm (e.g. Farahani et al., 1998). The sustainability

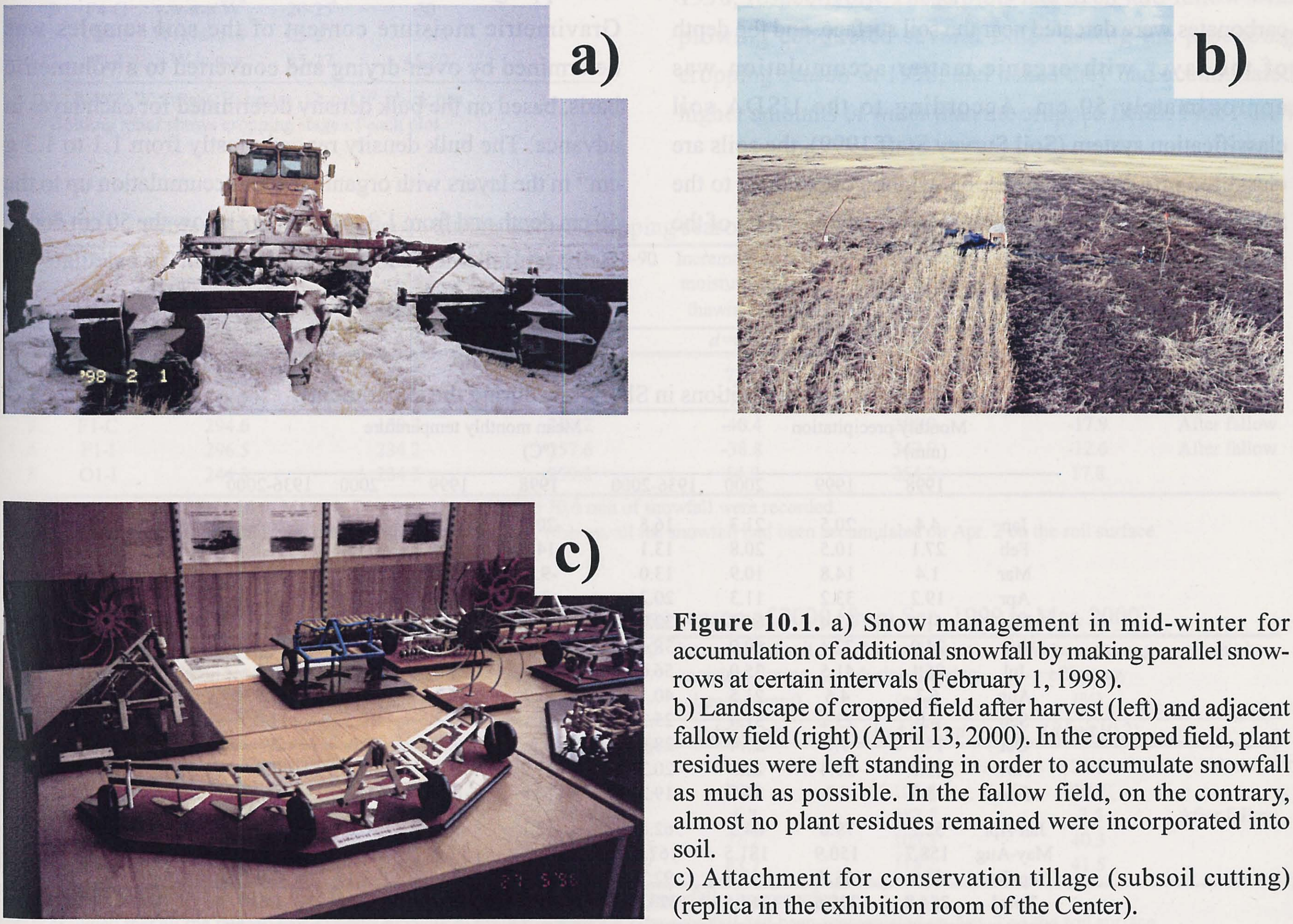

Figure 10.1. a) Snow management in mid-winter for accumulation of additional snowfall by making parallel snow-rows at certain intervals (February 1, 1998).
b) Landscape of cropped field after harvest (left) and adjacent fallow field (right) (April 13, 2000). In the cropped field, plant residues were left standing in order to accumulate snowfall as much as possible. In the fallow field, on the contrary, almost no plant residues remained were incorporated into soil.
c) Attachment for conservation tillage (subsoil cutting) (replica in the exhibition room of the Center).

of such management including summer fallow is, however, one of the most controversial subjects because the very low water storage efficiency or possible effect on the acceleration of decomposition of soil organic matter through repeated disturbance of soils (Janzen, 1987; Mikhailova et al., 2000; Karbozova-Saljnikov et al., 2004). The objectives of the present study were to compare water budgets in fallow and cropped fields and to specify the conditions under which a particular type of water management is more effective.

10.2. Study methods

This experiment was conducted over a period of two years from autumn, 1998 to autumn, 2000 at the experimental farm of Barayev Kazakh Research and Production Center of Grain Farming, Shortandy, northern Kazakhstan (51°35'N, 71°03'E). According to the long-term meteorological monitoring at the Center, the mean annual temperature was 1.6°C and the mean annual precipitation was 323 mm (Table 10.1). The soil characteristics are briefly described below; pH determined in water was neutral to slightly alkaline, usually ranging from 7.5 to 9, texture was typically clayey with more than 40% of clay, organic carbon content ranged between 20 and 25 g kg^{-1} in the plow layer (surface 30 cm), carbonates were detected near the soil surface, and the depth of the layer with organic matter accumulation was approximately 50 cm. According to the USDA soil classification system (Soil Survey Staff 1999), the soils are classified into Typic Haplustolls, which corresponds to the Southern Chernozem soils in the classification system of the former Soviet Union.

For the present study, five plots in 1998-1999 and seven plots in 1999-2000, respectively, were established in the experimental farm. These plots were included in an experimental block in which long-term experiments had been conducted since 1983 for improving farming technology. The size of each plot was 6 m × 60 m and the plots were managed under different farming methods. Crop species and field management of the experimental plots for the present study are given in Table 10.2. They included plots with crop rotation at different stages as well as mechanical management at different intensities such as depth of main tillage or degree of snow capturing. The meteorological data recorded during the experiments are presented in Table 10.1 with long-term data collected at the Center. While the precipitation during the winter time (January to April) and cropping period (May to August) in 1999 and 2000 was almost similar to the long-term averaged data, the precipitation after the harvest season (September to December) in 1998 and 1999 was lower than the average.

In these 12 plots, soil samples were collected in duplicate from every 15 cm depth up to 90 cm by augering on September 16, 1998 and thereafter at 10 to 20-day intervals throughout the cropping seasons from April to September 1999 and 2000. Gravimetric moisture content of the soil samples was determined by oven-drying and converted to a volumetric basis, based on the bulk density determined for each layer in advance. The bulk density ranged mostly from 1.1 to 1.3 g cm^{-3} in the layers with organic matter accumulation up to the 50 cm depth and from 1.3 to 1.5 g cm^{-3} below the 50 cm depth. Daily rainfall was recorded at the Center. To calculate the

Table 10.1. Climatic conditions in Shortandy during the experiments.

	Monthly precipitation (mm)				Mean monthly temperature (°C)			
	1998	1999	2000	1936-2000	1998	1999	2000	1936-2000
Jan	4.4	20.5	21.3	16.5	-20.7	-13.2	-15.2	-16.9
Feb	27.1	10.5	20.8	13.1	-14.6	-11.4	-11.4	-16.8
Mar	1.4	14.8	10.9	13.0	-9.8	-17.0	-8.3	-10.5
Apr	19.2	33.2	11.3	20.2	-3.3	3.5	7.7	3.2
May	41.4	32.4	64.1	32.8	12.2	14.1	10.6	12.3
Jun	24.9	72.4	60.9	38.4	21.0	14.0	19.4	18.3
Jul	86.1	41.5	35.0	56.6	23.0	20.5	20.2	20.0
Aug	6.3	4.6	21.5	40.1	20.9	19.3	18.4	17.3
Sep	4.0	23.2	31.4	25.3	10.5	14.3	10.5	11.2
Oct	14.7	7.9	27.4	28.0	4.5	6.6	0.0	2.7
Nov	12.0	30.4	22.3	20.2	-11.2	-9.8	-11.8	-7.8
Dec	13.3	4.2	34.7	19.2	-10.8	-10.0	-11.1	-14.1
Jan-Apr	52.1	79.0	64.3	62.8	-12.1	-9.5	-6.8	-10.3
May-Aug	158.7	150.9	181.5	167.9	19.3	17.0	17.2	17.0
Sep-Dec	44.0	65.7	115.8	92.7	-1.7	0.3	-3.1	-2.0
Total	**254.8**	**295.6**	**361.6**	**323.3**	**1.8**	**2.6**	**2.4**	**1.6**

water supply derived from thawing, maximum depths of snow coverage and snow density were measured on April 2, 1999 and March 17, 2000, except for Plot 11 and Plot 12. In the representative plots, including both the fallow and cropped plots in the preceding year, fluctuations of the soil temperature during springtime were recorded using dataloggers (CR-10X, Campbell Scientific, Inc). During the cropping period, plant biomass was measured several times in a 1 m^2 subplot in triplicate. Grain yield was also measured at the time of harvest.

Table 10.2. Description of study plots.

Plot No.	Plot	Crop rotation system1) 2)	Depth of main tillage in autumn (cm)	Maxmum depth of snow coverage (cm)	Remareks
1998-1999					
1	F0-C	**F**-W-W-B-W	20-25	30	Fallow
2	F1-S	F-**W**-W-B-W			After fallow
3	F1-C	F-**W**-W-B-W	20-25	30	After fallow
4	F1-I	F-**W**-W-B-W	25-27	45-50	After fallow
5	O1-I	O-**W**-W-B-W	25-27	45-50	
1999-2000					
6	F0-C	**F**-W-W-B-W	20-25	30	Fallow
7	O0-C	**O**-W-W-B-W	20-25	30	
8	F1-C	F-**W**-W-B-W	20-25	30	After fallow
9	O1-C	O-**W**-W-B-W	20-25	30	
10	F4-C	F-W-W-B-**W**	20-25	30	
11	CW-I	**W**-W-W-W-W	25-27	45-50	
12	P1-I	P-**W**-W-B-W	25-27	45-50	

1) F: fallow, W: wheat, B: barley, O: oat, P: chick pea
2) Bolding letter shows cropping stage of each plot.

10.3. Water dynamics in the pre-cropping seasons of 1998/1999 and 1999/2000 under different land use stages and types of field management

The soil profiles here displayed a layer with gypsum accumulation at around 1 m depth with a drastic increase in the amounts of soluble salts below 1 m, suggesting that the water movement was almost equilibrated around that depth. Based on the assumption that the water budget was balanced at the depth of 90 cm, we calculated the amount of evapotranspiration as the difference between precipitation and soil moisture increment in a given period. Downward or upward movement of water beyond this depth may, therefore, result in possible error by over- or under-estimation of evapotranspiration.

Figure 10.2 shows the dynamics of the soil moisture content and cumulative precipitation, including water derived from thawing and cumulative evapotranspiration estimated throughout both the pre-cropping and cropping phases. Table 10.3 summarizes the water budget during the pre-cropping seasons of 1998/1999 and of 1999/2000. According to Table 10.3-1, total water contents up to 90 cm depth (*a*) were 295 and 297 mm in Plot 3 and Plot 4 on September 16, 1998, respectively. These plots had been laid fallow with plowing conducted several times during the preceding cropping season in 1998, and hence they had accumulated higher amounts of water than the cropped fields, Plot 1 (144

Table 10.3.1. Water balance during the pre-cropping season of 1999 (from Sep. 1998 to Apr. 1999).

Plot No.	Plot	Soil moisture in 0-90 cm on Sep. 16 (mm)	†Accumulation of snow on Apr. 2 (mm)	Soil moisture in 0-90 cm on May 11 (mm)	Increment of soil moisture during thawing (mm)	Loss of water during thawing (mm)	Water capturing efficiency (%)	Remarks
		a	*b*	*c*	*d*=(*c*-*a*)	(*b*+†74.9)-*d*	*d*/(*b*+†74.9)	
1	F0-C	144.1	116.7	217.8	73.7	117.9	38.5	Fallow
2	F1-S	218.2	102.7	206.2	-12.0	189.6	-6.8	After fallow
3	F1-C	294.6	150.7	254.2	-40.4	266.0	-17.9	After fallow
4	F1-I	296.5	234.2	257.6	-38.8	347.9	-12.6	After fallow
5	O1-I	244.3	234.2	299.2	54.9	254.2	17.8	

†During the period of Sep. 16 to May 10, 74.9 mm of rainfall and 70.6 mm of snowfall were recorded.
It is assumed that all the rainfall was directly supplied to the soil, whereas all the snowfall had been accumulated on Apr. 2 on the soil surface.

Table 10.3.2. Water balance during the pre-cropping season of 2000 (from Sep. 1999 to Mar. 2000).

Plot No.	Plot	Soil moisture in 0-90 cm on Nov. 11 (mm)	†Accumulation of snow on Mar. 17 (mm)	Soil moisture in 0-90 cm on Apr. 25 (mm)	Increment of soil moisture during thawing (mm)	Loss of water during thawing (mm)	Water capturing efficiency (%)	Remarks
		a	*b*	*c*	*d*=(*c*-*a*)	(*b*+†10.2)-*d*	*d*/(*b*+†10.2)	
6	F0-C	174.3	165.5	221.1	46.8	128.9	26.6	Fallow
7	O0-C	175.4	165.5	246.2	70.9	104.8	40.3	
8	F1-C	232.1	166.3	225.9	-6.2	182.7	-3.5	After fallow
9	O1-C	170.7	166.3	241.9	71.2	105.3	40.3	
10	F4-C	170.2	191.6	253.9	83.7	118.2	41.5	

†During the period of Nov. 11 to Apr. 24, 10.2 mm of rainfall and 86.9 mm of snowfall were recorded.
It is assumed that all the rainfall was directly supplied to the soil, whereas all the snowfall had been accumulated on Apr. 2 on the soil surface.

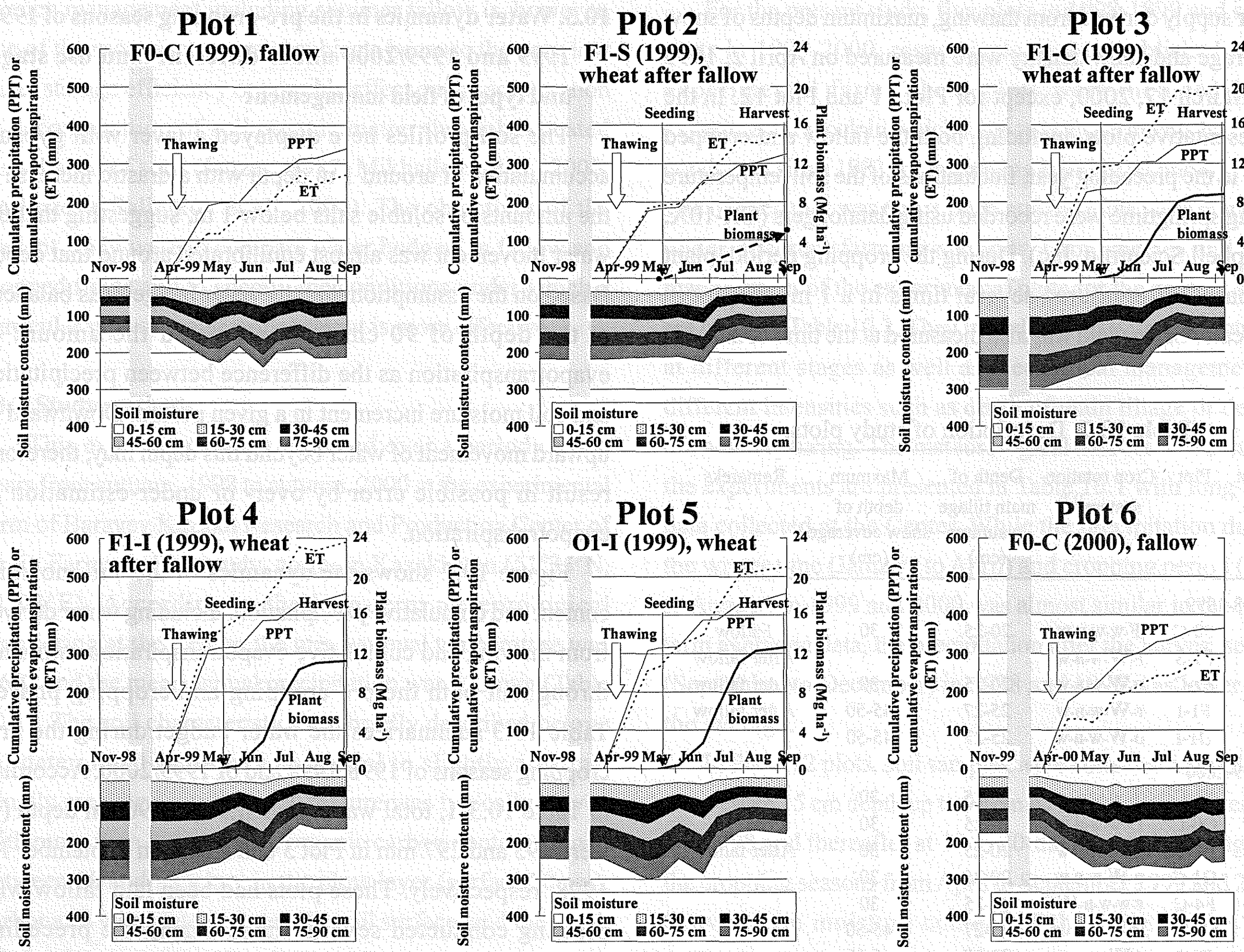

Figure 10.2.1. Dynamics of soil moisture and cumulative precipitation, including water derived from thawing and estimated cumulative evapotranspiration. *For Plot 11, the amount of accumulated snow was estimated from the values in the plots with the same level of snow management (Plots 4 and 5 in 1999). **For Plots 11 and 12, the amount of moisture content in autumn, 1999 was estimated based on the average values determined in autumn, 1999 for cropped plots, i.e. Plots 2, 3, 4, and 5. ***For Plots 1 and 6, negligible amounts of weed biomass were detected.

mm) and Plot 5 (244 mm). Since Plot 2 had also been laid fallow but had been more extensively managed (Table 10.2), the soil did not accumulate an appreciable amount of water. A similar trend was also observed for the plots in 1999/2000 (Table 10.3-2), in which the fallow plot in the preceding summer (Plot 8) had accumulated appreciably higher amounts of soil water (232 mm) than the cropped plots (Plot 6: 174 mm, Plot 7: 175 mm, Plot 9: 171 mm, and Plot 10: 170 mm).

During the wintertime, 70.6 mm and 86.9 mm of snowfall were recorded in 1998/1999 and 1999/2000, respectively. From late January to early February, during which the snow depth reached 20 to 30 cm, snow management was carried out at different intensities (i.e. different heights of snow-rows) in order to accumulate the snow-cover by making parallel snow-rows at certain intervals (Fig. 10.1a). Total amount of snow-cover, which was expected to be added to the soils at the time of thawing in the springtime, ranged from 102 to 234 mm of water on April 2, 1999 and March 17, 2000 (*b* in Table 10.3).

After thawing, soils accumulated 206 to 299 mm of water in 1999 and 221 to 254 mm of water in 2000, respectively (*c* in Table 10.5.3). The increase in the soil water content since autumn of the preceding year was, however, quite variable, namely ranging from -40 mm (Plot 3) to 74 mm (Plot 1) in 1999 and -6 mm (Plot 8) to 84 mm (Plot 10) in 2000, respectively (*d* in Table 10.3), and the difference between the highest and lowest water catchment amounted to 114 mm in 1999 and 90 mm in 2000, respectively. In spite of snow management during winter, the amount of soil water decreased in some cases. Figure 10.3 shows that, during thawing, the increment of soil moisture decreased (Fig. 10.3a) and the loss of water increased (Fig. 10.3b), as the soil moisture storage in the preceding autumn increased.

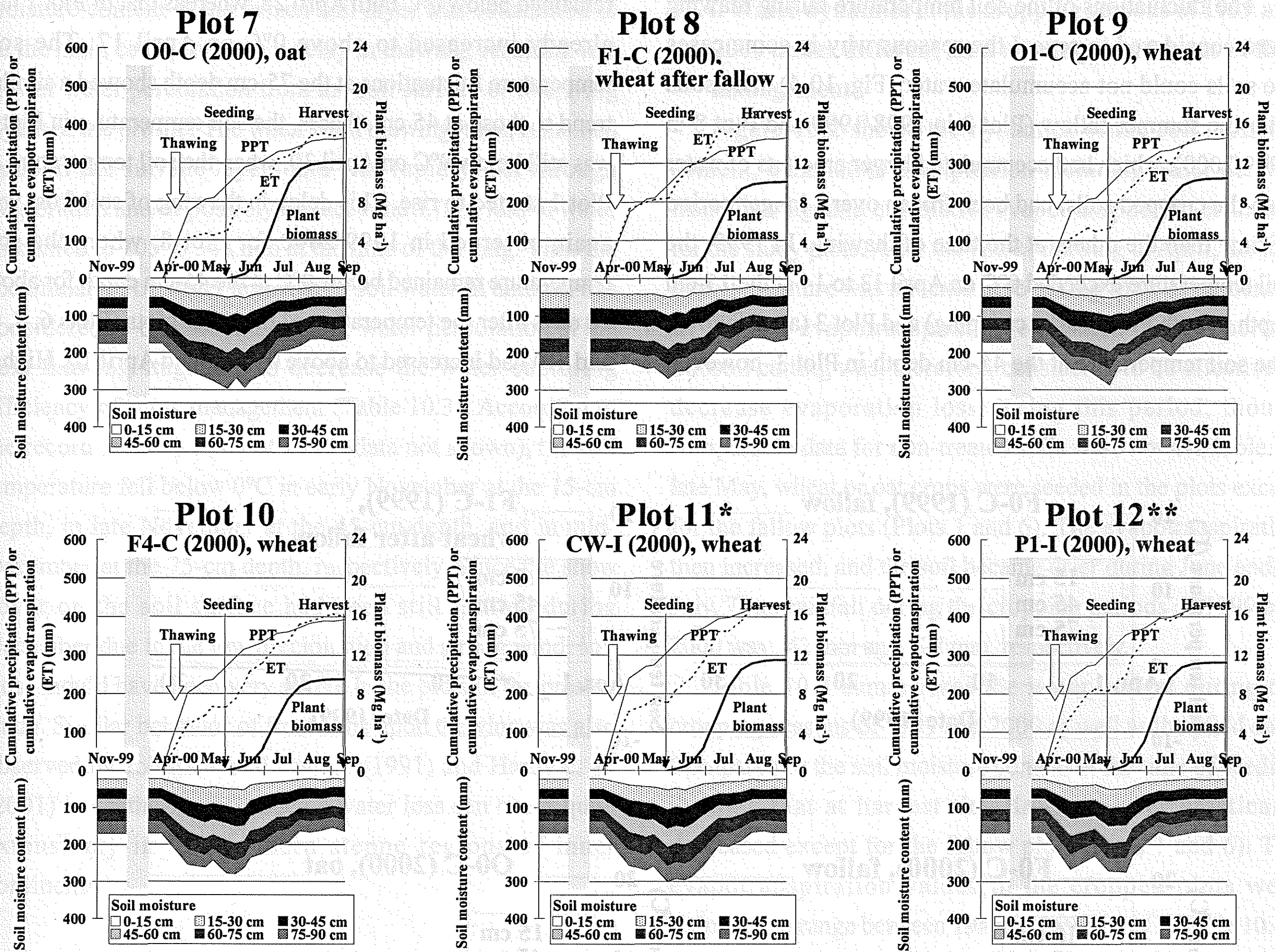

Figure 10.2.2. Dynamics of soil moisture and cumulative precipitation, including water derived from thawing and estimated cumulative evapotranspiration. *For Plot 11, the amount of accumulated snow was estimated from the values in the plots with the same level of snow management (Plots 4 and 5 in 1999). **For Plots 11 and 12, the amount of moisture content in autumn, 1999 was estimated based on the average values determined in autumn, 1999 for cropped plots, i.e. Plots 2, 3, 4, and 5. ***For Plots 1 and 6, negligible amounts of weed biomass were detected.

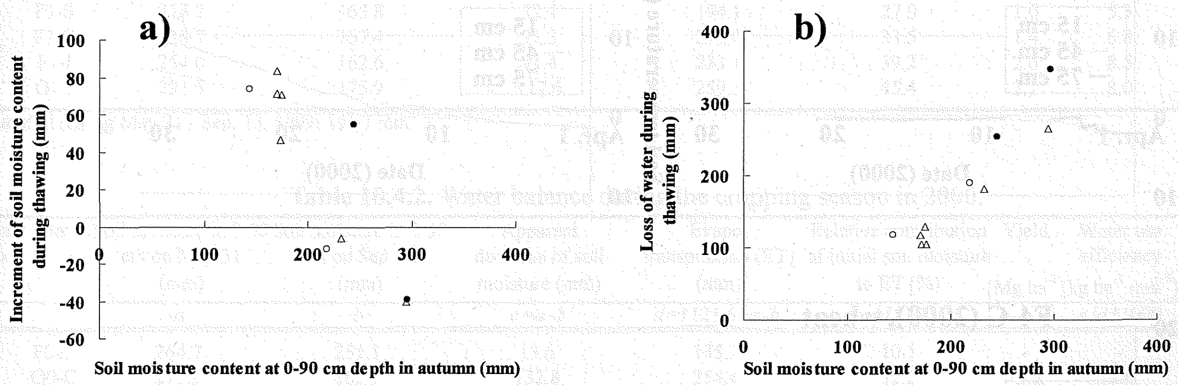

Figure 10.3. Relationships between soil moisture content in autumn and a) increment of soil moisture or b) loss of water by evaporation and/or surface runoff during thawing. Accumulation of snow: ○ 100-150 mm, △ 150-200 mm, and ● >200 mm, respectively.

The fluctuations of the soil temperature during thawing were considered to reveal the reasons why in some cases the soils could not accumulate water (Fig. 10.4). The soils after the summer fallow (Plot 3 in 1998/1999 and Plot 8 in 1999/2000), which had accumulated larger amounts of water than the cropped soils, had been frozen over a longer period of time than the others at the time of thawing. In 1999, the soil temperature exceeded 0°C on April 13 to 14 at the 15-cm depth in both Plot 1 (after cropping) and Plot 3 (after fallow). The soil temperature at the 45-cm depth in Plot 3, however, remained below 0°C until April 28, whereas that of Plot 1 had already increased to above 0°C on April 17. The soil temperature fluctuations at the 75-cm depth showed a similar trend to those at 45 cm, that is, the soil temperature in Plot 3 was still below 0°C on April 30, when the soil temperature in Plot 1 started to rise. This delay in thawing of soil frost was again observed in 1999/2000 for Plot 8, where the soil temperature remained below 0°C at the 45-cm depth for about 10 days after the temperature of the other plots (Plots 6, 7, 9, and 10) had increased to above 0°C around April 10. Higher

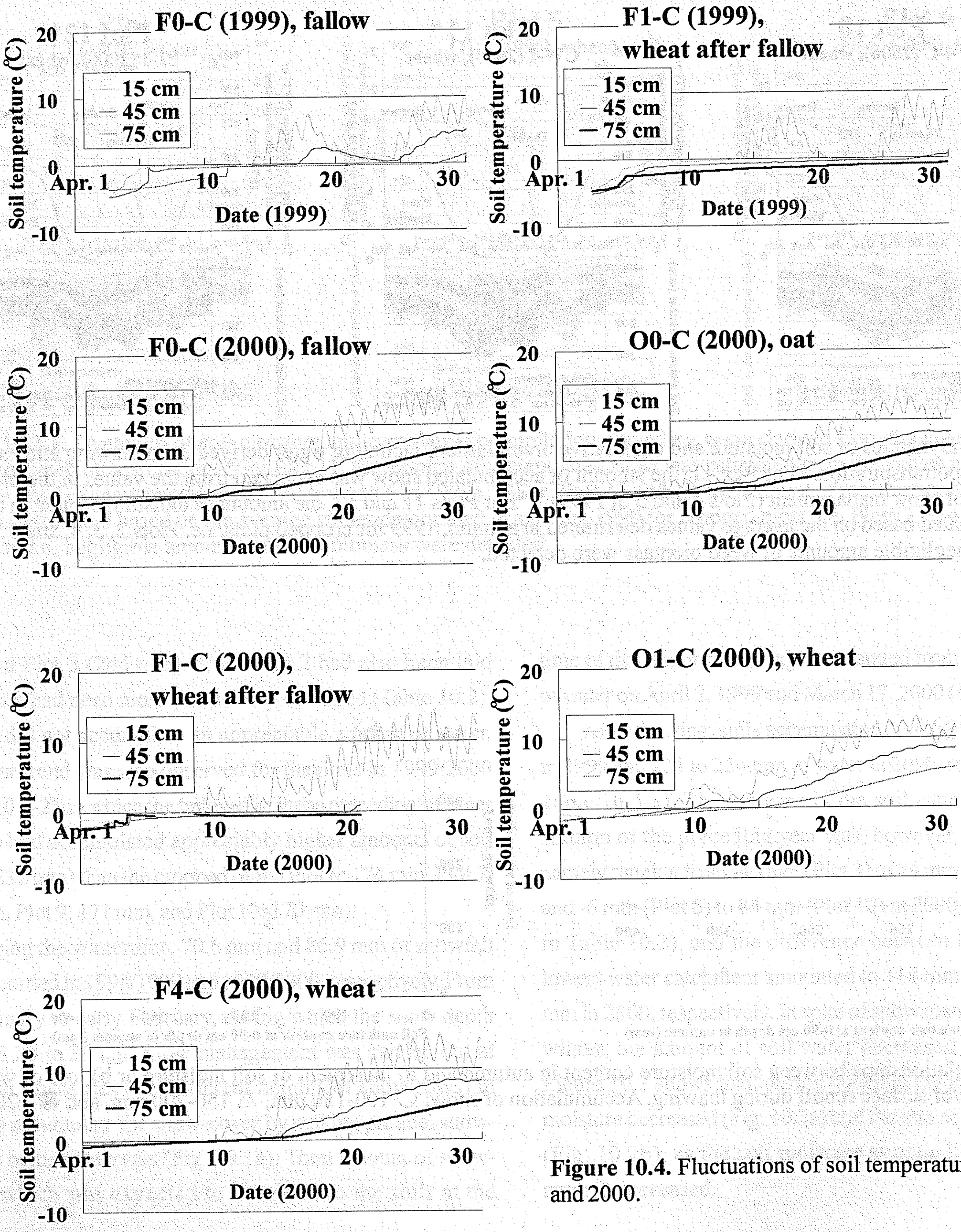

Figure 10.4. Fluctuations of soil temperature in April 1999 and 2000.

moisture content in the frozen soil layer was considered to be the main cause for such a delay in thawing, resulting in a slower water percolation from the soil surface or overlying layers of the profile. The water from thawing, then, remained in/upon the surface layers and was rapidly lost through evaporation and/or possibly surface runoff. The loss of water amounted to 105 to 348 mm at the time of thawing. Thus the accumulation of larger amounts of soil water in autumn was considered to occasionally hinder water percolation at the next thawing stage and to decrease the water-capturing efficiency of snow management (Table 10.3). According to the record in the autumn of 1999 (data not shown), the soil temperature fell below 0°C in early November at the 15-cm depth, in late November at the 45-cm depth, and in mid-December at the 75-cm depth, respectively. Since the snow cover on the soil surface had been still limited during December due to the low precipitation and strong wind, soil frost should have been very severe in the plots in the present study. Similar behavior of frost soils upon thawing was also observed by Johnsson and Lundin (1991) and Hardy et al. (2001) in northern USA. Such a water loss can occur quite extensively in the northern steppe regions of inner continents.

10.4. Water dynamics in the cropping seasons of 1999 and 2000 under different land use stages and types of field management

Figure 10.2 shows the dynamics of the soil moisture content, cumulative precipitation including water derived from thawing, and cumulative evapotranspiration estimated for the study plots. After the end of thawing in April, the loss of soil moisture was not extensive during May, as evidenced by the low evapotranspiration estimated for this period. Subsoil cutting was, therefore, considered to be effective to decrease evaporation loss during this period, though comparable data for non-treated soils were not available. In late May, wheat or oat crops were seeded in the plots except for the fallow plots (Plots 1 and 6). The evapotranspiration then increased, and the soil became drier during June and/or July. Total rainfall during the cropping periods of 1999 and 2000 was 142 mm and 122 mm, respectively.

Table 10.4 summarizes the water budget during the cropping seasons of 1999 and 2000 as well as the yield data. Compared to the soil moisture content at the time of seeding in May, that at harvest time in September drastically decreased except for the fallow plots (Plots 1 and 6). The evapotranspiration values in the cropped plots were estimated to range between 194 and 259 mm (*d* in Table 10.4), being equivalent to 1.67 and 2.31 mm as daily average,

Table 10.4.1. Water balance during the cropping season in 1999.

Plot No.	Plot	Soil moisture in 0-90 cm on May 21 (mm)	Soil moisture in 0-90 cm on Sep. 14 (mm)	Apparent decrease of soil moisture (mm)	Evapo-transpiration (ET) (mm)	Relative contribution of initial soil moisture to ET (%)	Yield (Mg ha^{-1})	Water use efficiency (kg ha^{-1} mm^{-1})	Remarks
		a	*b*	*c=a-b*	*d*=†141.7+*a-b*	*c/d**100	*e*	*e/d**1000	
1	F0-C	225.7	212.3	13.3	155.0	8.6	-	-	Fallow
2	F1-S	218.2	165.8	52.4	194.1	27.0	1.0	5.3	After fallow
3	F1-C	238.7	167.4	71.3	213.0	33.5	1.4	6.8	After fallow
4	F1-I	254.0	162.6	91.4	233.1	39.2	2.0	8.5	After fallow
5	O1-I	293.5	175.9	117.6	259.3	45.4	2.1	8.0	

†Rainfall during May 21 - Sep. 13, 1999: 141.7 mm

Table 10.4.2. Water balance during the cropping season in 2000.

Plot No.	Plot	Soil moisture in 0-90 cm on May 31 (mm)	Soil moisture in 0-90 cm on Sep. 18 (mm)	Apparent decrease of soil moisture (mm)	Evapo-transpiration (ET) (mm)	Relative contribution of initial soil moisture to ET (%)	Yield (Mg ha^{-1})	Water use efficiency (kg ha^{-1} mm^{-1})	Remarks
		a	*b*	*c=a-b*	*d*=†121.6+*a-b*	*c/d**100	*e*	*e/d**1000	
6	F0-C	264.7	251.1	13.6	135.2	10.1	-	-	Fallow
7	O0-C	295.5	162.7	132.8	254.4	52.2	*3.2	12.6	
8	F1-C	268.6	162.8	105.9	227.5	46.5	1.4	6.0	After fallow
9	O1-C	284.5	164.5	120.0	241.6	49.7	1.9	7.7	
10	F4-C	277.0	163.4	113.6	235.2	48.3	2.0	8.6	
11	CW-I	300.4	167.9	132.5	254.1	52.2	2.3	9.0	
12	P1-I	271.1	165.7	105.4	227.0	46.4	1.7	7.5	

†Rainfall during May 31 - Sep. 18, 2000: 121.6 mm

*Yield of oat

respectively. These values were considered to correspond to the upper limit of the amount of water that crops could use during the period. Although the yield data recorded here was somewhat higher than those reported in farmers' fields in whole Kazakhstan, i.e. 1.00 Mg ha^{-1} during 1986-90 and 0.65 Mg ha^{-1} during 1994-1996 after the financial crisis, respectively (Gossen 1998), presumably because of better management in the experimental field, a positive correlation between the evapotranspiration and the biomass or yield of wheat at the harvest time was obvious, indicating that crop production here was mostly determined by the amount of available water. The yield increase for every 1 mm of water supply (i.e. estimated evapotranspiration) in the present study, which was calculated to be 0.017 Mg ha^{-1} (Fig. 10.5a), was similar to the reported values for winter cereals, i.e. 0.015 or 0.019 Mg ha^{-1} (Leggett 1986; Cook and Veseth 1991). The relative contribution of the initial soil moisture to whole evapotranspiration was calculated to range from 27 to 52%. Since the amount of precipitation in both cropping periods of 1999 and 2000 was not appreciably different, there was also a positive correlation between the soil moisture content just before seeding and crop yield or biomass (Fig. 10.5b).

According to Fig. 10.2 and Table 10.4, the relative benefit of summer fallow for the accumulation of soil moisture was obvious, because the fallow plots (Plots 1 and 6) retained approximately 50 and 90 mm more water than the cropped plots at harvest time (*b* in Table 10.4), respectively. But it was remarkable that, even under fallow, 155 and 135 mm of water were already lost through evaporation in Plots 1 and 6, respectively, (*d* in Table 10.4), which exceeded the precipitation during that period (142 and 122 mm). The difference in the evapotranspiration indicated that the fallow plots accumulated 39 to 104 mm more water in 1999 and 100 to 119 mm in 2000 than the cropped plots, respectively (*d* in Table 10.4). These values were almost comparable to the difference in moisture acquisition upon thawing under different conditions, that is, 114 mm in 1999 and 90 mm in 2000, respectively, which was considerably affected by the soil moisture content in the preceding autumn.

10.5. Conclusion

Comparison of the water budgets during the pre-cropping and cropping seasons in the plots under fallow and cropping revealed that both summer fallow and snow management could increase the soil moisture content up to approximately 100 mm, but that the benefit of snow management would be occasionally canceled by the effect of the summer fallow, since the moisture increment in autumn could decrease the water-capturing efficiency in the next spring through severe soil frost. Taking into account the possibly negative effect of the summer fallow on enhanced decomposition of soil organic matter (e.g. Karbozova-Saljnikov et al., 2004; Funakawa et al., 2004), we recommend that snow management should be the main approach for capturing water in the studied plots rather than the summer fallow practice, at least from the viewpoint of water management. However, the possible benefit of snow management could largely vary in fields depending on the topographical characteristics, soil properties such as texture and/or organic matter contents, etc. At the same time, such an emphasis on snow treatment over the summer fallow practice would inevitably require the development of alternative technologies for N management and weed control that have been traditionally involved in the function of fallow. It is very important to determine

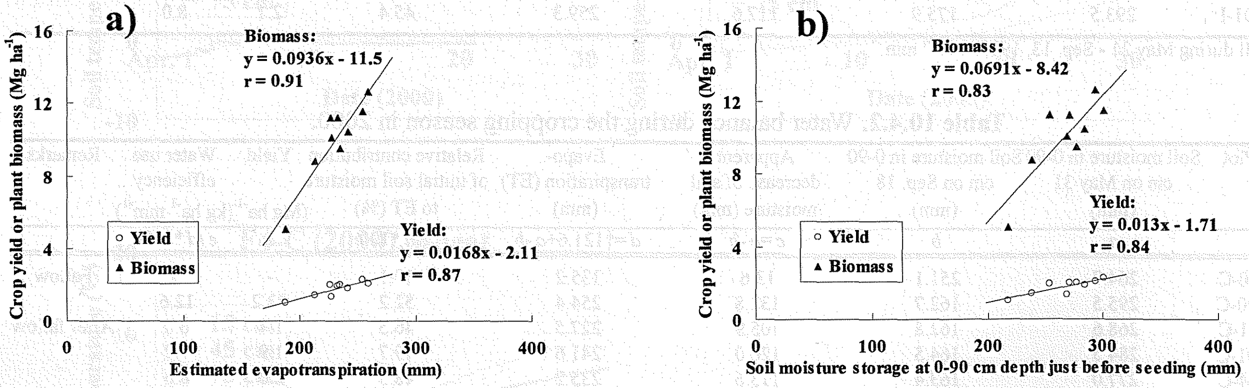

Figure 10.3. Relationships between soil moisture content in autumn and a) increment of soil moisture or b) loss of water by evaporation and/or surface runoff during thawing. Accumulation of snow: ○ 100-150 mm, △ 150-200 mm, and ● >200 mm, respectively.

whether soil and/or topographical conditions are more effective for individual water-capturing management and also are more suitable from economic and environmental viewpoints, together with the possibility of developing an alternative technological package.

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Chapter 11

Spatial variability of organic matter dynamics in the semi-arid croplands of northern Kazakhstan: analysis on distribution patterns of organic matter-related properties of soils in agro-landscape using geostatistics

Junta Yanai, Azusa Mishima and Kanat Akshalov

11.1. Background

Chernozems, derived from the Russian term "black soil", are typical soils mainly found in the mid-latitude steppe or prairie zone of Eurasia, North America with an abundant vegetation and high natural fertility (Boul et al., 1989). The soils cover 230 million ha in the world (ISSS Working Group RB, 1998) and approximately 8% of the area of the former Soviet Union (Gerasimov and Grazovskaya, 1964). These have been, therefore, one of the most important areas for food production and also for the sink of organic matter on a global scale.

In Kazakhstan, a country belonging to the former Soviet Union in central Asia, Chernozem soils cover 32.1×10^6 ha or 11.8% of the country territory (GUGK, 1982). Because of political reasons, the natural grass forb steppes of the area have disappeared over the last decades and have largely been replaced by arable land, mainly for the cultivation of spring wheat, due to Khrushchev's Virgin Lands Agricultural Program implemented from 1954 to 1960 (Medvedev, 1987). Accordingly, 26.5×10^6 (GUGK, 1982; Morgounov and Zuidema, 2001) or 24.6×10^6 (Gossen, 1998) of the Chernozem soils in Kazakhstan were converted to arable land and these areas are one of the main agricultural regions of Kazakhstan. Chernozem soils in northern Kazakhstan are also considered to store a substantial amount of organic matter, which functions as a huge source and sink of carbon dioxide. In this sense, Chernozem soils are one of the most important resources from both agricultural and environmental viewpoints (Paustian et al., 1997).

Even though these areas show high soil fertility, the climatic conditions are generally harsh, with an annual precipitation of about 300 mm. Accordingly, drought has become a major abiotic stress (Morgounov et al., 2001). A new cropping system with the following types of management was therefore introduced (Morgounov et al., 2001); 1) summer fallow to protect weeds, to capture the soil moisture and to accumulate nutrients due to the increased mineralization of organic matter by skipping cultivation for one year, 2) subsoil cutting to reduce evaporation by interrupting the capillary flow of water from the subsoil and 3) snow management to decrease snow drifting and optimize the water regime of soils due to spatial redistribution and melting of snow (Shegebaev, 1998).

Introduction of this kind of technology uniformly and intensively during the former Soviet Union era was successful in terms of crop production. However, the increased yield was achieved at the expense of sustainability, as soil degradation or accelerated organic matter decomposition has been reported recently (Srivastava and Meyer, 1998). For example, transition of virgin soils to arable status led to a reduction of up to 50% in the organic matter content during the first years of cultivation (Buyanovsky et al., 1987), the contents of soil organic carbon and soil total nitrogen in the top 10 cm layers decreased in the ranges of 38-43% and 45-53%, respectively, during the past 25-30 years in the continuously cropped fields of Chernozem soils in Russia (Mikhailova et al., 2000) or the overall budget of soil organic matter under conventional cropping systems became slightly negative, which led to soil degradation (Funakawa et al., 2004a). Also the amount of potentially mineralizable carbon in soil was inversely proportional to the frequency of fallow, suggesting that a frequent fallow system would lead to the depletion of soil organic matter via accelerated mineralization (Karbozova-Saljinikov et al., 2004). This tendency was in contrast to the recent general requirement from the environmental viewpoint, according to which organic matter decomposition or CO_2 emission from soil should be reduced.

Furthermore, after the collapse of the USSR in 1991, the intensity of agricultural markedly decreased due to financial problems. The drastic changes in the socio-economic conditions resulted in a reduced use of fertilizers and herbicides and a lower dependency on agricultural machinery in agricultural management. As a consequence, the average yield of wheat also decreased after 1991 from 1.00 Mg ha^{-1} during the period of 1986-1990 to 0.65 Mg ha^{-1} during the period of 1994-1996 (Gossen, 1998). In this context, an alternative approach for the promotion of sustainable agriculture is now urgently required, which would enable to harmonize agricultural production with environmental conservation.

Against this background, the current situation of organic matter dynamics in large-scale upland fields in northern Kazakhstan was investigated to develop a rational system of management for the promotion of sustainable agriculture in this region. The objectives of the current study were 1) to evaluate the carbon-related properties of soil and plant in relation to the topography and amount of available water, 2) to analyze their spatial variability using geostatistics and 3) to propose a rational system of management for the control of organic matter dynamics in upland fields.

11.2. Materials and methods

Location of the study site: The present study was carried out in large-scale upland fields located near the Barayev Kazakh Research and Production Centre of Grain Farming in Shortandy, Akmolinsk Oblast, northern part of the Republic of Kazakhstan (Fig. 11.1). The latitude and longitude of the site were N51° 30-37' and E71° 08-17', respectively. The area was characterized by a continental climate with hot summers and cold winters and abrupt changes of temperature and rainfall. Mean annual precipitation was 323 mm with large variations among years, suggesting the existence of harsh conditions for crop growth. Average annual air temperature was 1.6°C. Average monthly temperature was below zero from November to March, causing frost damage that did not enable to cultivate winter wheat in this region. In addition, there were some risks of frost damage in April and May, and early frost in late August. The cultivation season was, therefore, fixed from the end of May to mid-September for about 110 days, during which the average temperature was 18.5°C.

Soil: Chernozem soils are characterized by a thick and black topsoil, a neutral pH, a large amount of humus and a high natural fertility. Chernozem soils are fine-grained and easily cultivated but also highly susceptible to wind erosion. As a result of the natural fertility, the areas covered with these soils are rated among the world best zones for growing wheat, sugar beets and other crops. The Chernozem soil of this site occurred in a relatively dry region, reflecting the relatively low precipitation. Accordingly, calcium carbonate was observed from the surface soil and a gypsum accumulation layer was found at the 110-120 cm depth. A preliminary study showed that the general properties of the surface soil in this area were as follows: pH (H_2O), 7.9-8.1; electrical conductivity, 0.15-0.24 dS m^{-1}; texture, light clay to silty clay; cation exchange capacity, 27.8 $cmol_c$ kg^{-1}. The soil of the study site was, therefore, classified as Typic Haplustolls (Soil Survey Staff, 1998), Haplic Chernozem (FAO, ISRIC and ISSS, 1998) or Southern Chernozem based on the classification system of the former USSR.

Land use of the study site: The original vegetation of the study site was represented by grassland or a semiarid grass-forb steppe dominated by *Stipa capillata, Stipa lessingiana, Agropyron cristatum, Kochia prostrata, Medicago falcata, Festuca valesiaca, Salvia stepposa, Artemisia marshalliana,* and *Artemisia glauca* (Johnson et al., 1999). Grasslands cover nearly one-fifth of the world's land surface or approximately 2.4×10^7 km^2. These ecosystems are large reservoirs of carbon globally, containing approximately 30% of global soil C stocks (Anderson, 1991; Eswaran et al., 1993) and the soil component is the main C reservoir in these ecosystems. Under Khrushchev's Virgin Lands Program, people were encouraged

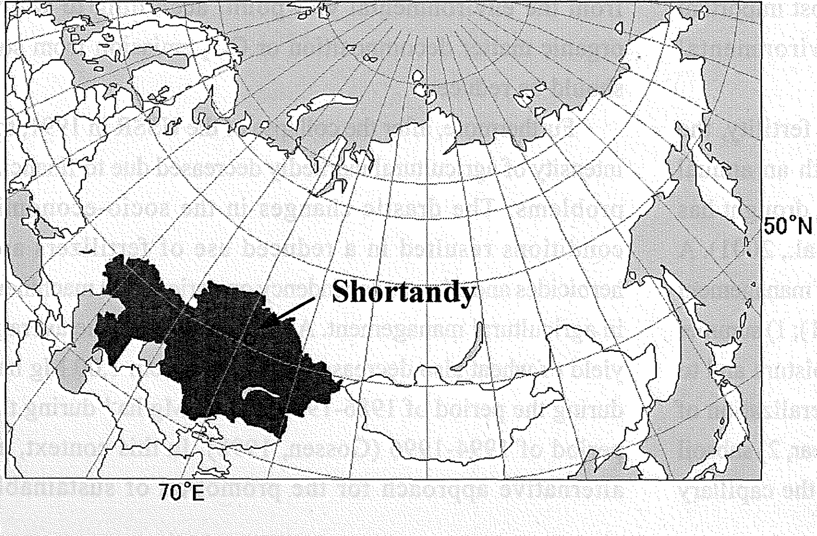

Figure 11.1. Location of the study site.

to cultivate Kazakhstan's northern pastures to increase grain production, by the application of agricultural technology to produce crops on a large scale, including deep cultivation, snow management, and summer fallow to store soil moisture levels for use during the cropping season. However, the application of this technology, in particular repeated cultivation or soil disturbance during summer fallow uniformly and intensively, led to the acceleration of soil organic matter degradation (Karbozova-Saljinikov et al., 2004). After the collapse of the USSR in 1991, Kazakhstan's agriculture became much less intensive because of the lack of equipment, herbicides, fuel and labour. Tractors, harvesters and other items of farm equipment had been subjected to minimal maintenance. Due to limited investment, farm machinery was generally old and in poor condition. At present, most of the farms are managed without the use of fertilizers and herbicides. The land use of the study sites consisted mostly of arable land with the cultivation of spring wheat as major crop and barley and oats as minor crops. The other types of land use included fallow, grassland, and abandoned land. The crop rotation system at this study site consisted of a four-year rotation, i.e. fallow-wheat-wheat-wheat/barley.

Soil and plant sampling and measurement of micro-topography: The study field (14 km×5 km) was divided into 70 plots (1 km×1 km each), as shown in Fig. 11.2(A) and the organic matter dynamics was investigated at the center of each plot. Namely, soils were sampled to a depth of 90 cm at 15 cm intervals in June 2001, i.e. at the beginning of the growing season. Samples of surface soil (0-15 cm) were collected at three points within 1 m around the center of each plot using a hand auger, mixed and used as a soil sample. Subsoil samples (15-90 cm) were collected every 15 cm at the center of each plot using a hand auger. Plant sampling was carried out from late August to September 2001. From each plot, above- and belowground plants in 1 m×0.92 m quadrates were harvested at the planted sites. In addition to soil and plant sampling, the elevation of the center point of each plot was measured using a differential Global Positioning System (GPS) (Magellan ProMARK X) in May 2001 to investigate the micro-topography of the study field. Accordingly, it was found that the elevation ranged from 402 m to 437 m with an average value of 427 m. The central plateau showed the highest elevation and the north-facing slope and south-facing slope stretched very gently from the plateau, as shown in Fig. 11.2(B). Furthermore, the snow depth was measured at each sampling site in March 2002 to investigate the distribution of snow accumulation.

Analytical methods for soil and plant samples: For the overall soil samples (0-90 cm), the organic carbon content, total nitrogen content and C/N ratio were measured to investigate the organic matter status of the soils; the water content was measured to obtain an index of the amount of available water stored in the soil profile at the beginning of the growing season and the bulk density was calculated. For the surface soil samples (0-15 cm), the amount of potentially mineralizable carbon (PMC) was also measured. That is, the amount of soil organic carbon was measured by the Tyurin method; the total nitrogen content was measured by the dry combustion method (Sumika NC-800-13N); the soil water content and bulk density were determined by drying the soil samples at 105°C for 24 h. PMC was determined by the incubation of 15 g of fresh soil samples for 19 weeks, controlling the water content at 60% of the maximum water-holding capacity at 30°C. CO$_2$ emitted during the incubation period was repeatedly collected using an alkaline trap (10 mL

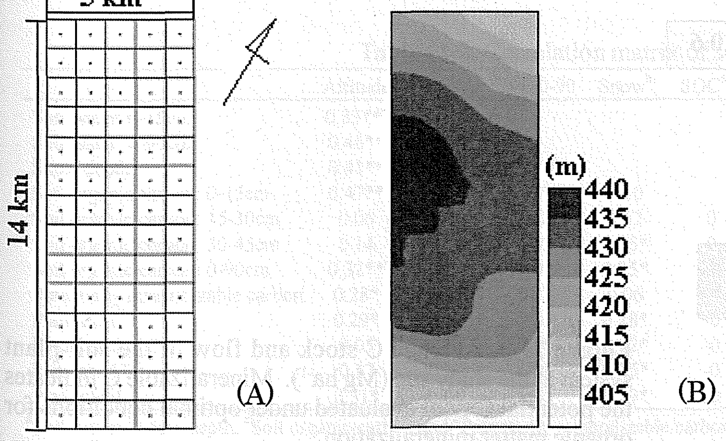

Figure 11.2. (A) Schematic diagram of the sampling sites indicated as dots in the field and (B) topography of the study site.

of 1 M NaOH) and the amount was measured by titrating with 0.1 M HCl. The amount of PMC was then calculated using a first order kinetic model, on the assumption that the rate of carbon mineralization was proportional to the amount of mineralizable carbon present with the following equation: PMC = Ct / (1 - e^{-kt}), where Ct is the amount of carbon mineralized in time t and k is the mineralization rate constant.

Plant samples were separated into ears, stems and leaves, dried at 70°C for 24 h and then weighed as plant biomass. For the ear samples, grains were threshed with a thresher and weighed to represent the yield. Total carbon and nitrogen contents were measured for the dried samples by the dry combustion method (Sumika NC-800-13N).

Statistical analysis: The mean, maximum and minimum values and the coefficient of variation of each property were calculated as descriptive statistics. Correlation analysis was also carried out for all the datasets to investigate their relationship. A statistical software SYSTAT 8.0 (SPSS Inc., 1998) was used for the analysis.

Geostatistical analysis: In this analysis, a semivariogram was first used to evaluate the spatial variability of the properties (i.e., to describe the average variances of pairs of points at a given distance apart) (Oliver, 1987; Webster and Oliver, 2001; Yanai et al., 2001). This mirrors the similarity of pairs separated by an equal distance. Often, it is found that the semivariance increases with the increasing distance between sampling points to a maximum (the sill), at a moderate distance (the range). Points closer together than the range are autocorrelated, whereas points further apart are not related to one another. The variation below the scale of investigation and/or due to experimental errors, the nugget variance, is determined as the ordinate intercept. In the analysis, two indices of spatial dependency were employed. One is the *Q* value [calculated as (sill-nugget)/sill], which indicates spatial structure or the degree of development of spatial dependence at the sampling scale, and the other is the range, which indicates the limit of spatial dependence. In the analysis, the semivariogram model with the smallest residual sum of squares was used for the estimation of the semivariogram parameters. Maps were computed subsequently using block kriging to evaluate the regional patterns of variation rather than local details. The geostatistical software, GS$^+$ Version 5.3 for Windows (Gamma Design Software), was used for the analysis (Robertson, 1998).

11.3. General trend of organic matter dynamics

Table 11.1 shows the descriptive statistics of the field properties measured. The average content of soil organic carbon which was 25.6 g kg^{-1} for the surface soil, decreased with depth until 6.1 g kg^{-1} at the depth of 75-90 cm. Reflecting the trend of the organic matter content in soil, the bulk density increased with depth; 1.04, 1.21, 1.22, 1.32, 1.43 and 1.60 Mg m^{-3} from 0-15 cm to 75-90 cm. Accordingly, the total amount of C stored in soil which was 39.8 Mg ha^{-1} for the surface soil, gradually decreased with depth, i.e. 37.0, 31.1, 26.7, 21.7 and 14.6 Mg ha^{-1} for 15-30, 30-45, 45-60, 60-75 and 75-90 cm, respectively. Even though there was a decreasing trend with depth, the subsoil also contained a considerable amount of C, which cannot be ignored from the environmental viewpoint, i.e. the total amount of organic C stored within the 90 cm depth was 170.9 Mg ha^{-1}, with a coefficient of variation of 17.4%. Potentially mineralizable C of the surface soil amounted to 2.7 Mg ha^{-1} or was equivalent to 6.8% of

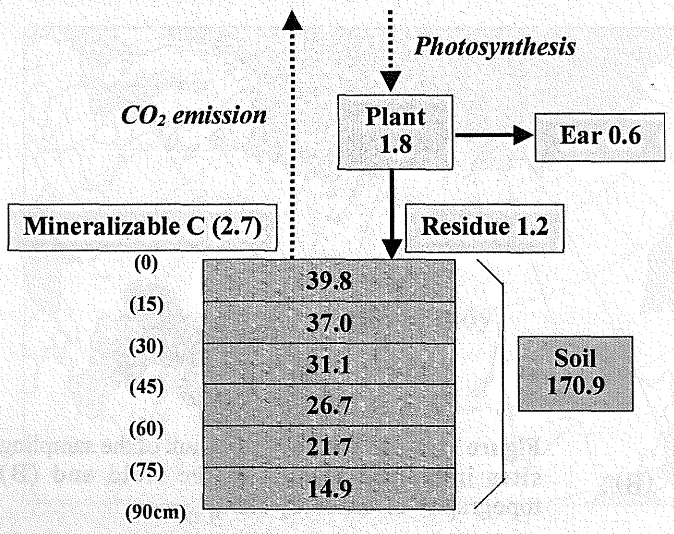

Figure 11.3. Average C stock and flow of the soil-plant system at the study site (Mg ha^{-1}). Mineralizable C indicates the potential C pool evaluated under optimal conditions for organic matter mineralization.

the amount of organic C, suggesting that a considerable part of the C in soil could be released as CO_2 under favourable conditions for organic matter decomposition. The coefficient of variation exceeded 40%, suggesting the existence of a higher variation compared to the total C stock (17.1%), presumably because the amount of potentially mineralizable C depends on both the amount of chemically mineralizable C and the microbiological activity for mineralization.

Plant biomass contained 1.8 Mg ha^{-1} of C, of which 1.2 Mg ha^{-1} was returned to the field as plant residues and 0.6 Mg ha^{-1} was removed as crop (ear). Average crop yield, calculated based on 54 data with crop cover, amounted to 1.38 Mg ha^{-1} on a dry weight basis, which was almost similar to the average crop yield in this area. It was also noted that the coefficients of variation of all the plant properties exceeded 40%, suggesting the existence of a large variation in the field. Based on these results, the average C stock and flow of this soil-plant system are presented in Fig. 11.3.

Table 11.1. Descriptive statistics of the soil, plant and water properties.

Field properties	Mean	Maximum	Minimum	CV (%)[a]
Soil				
Organic carbon: 0-15cm (g kg^{-1})	25.6	36.1	16.3	17.1
Organic carbon: 15-30cm (g kg^{-1})	20.4	31.1	6.3	21.6
Organic carbon: 30-45cm (g kg^{-1})	17.0	34.9	3.9	27.5
Organic carbon: 45-60cm (g kg^{-1})	13.5	21.5	4.3	27.5
Organic carbon: 60-75cm (g kg^{-1})	10.1	18.5	1.4	41.4
Organic carbon: 75-90cm (g kg^{-1})	6.1	13.4	0.5	55.2
Organic carbon: 0-15cm (Mg ha^{-1})	39.8	65.1	22.7	19.4
Organic carbon: 15-30cm (Mg ha^{-1})	37.0	56.9	11.2	21.0
Organic carbon: 30-45cm (Mg ha^{-1})	31.1	63.3	7.0	27.1
Organic carbon: 45-60cm (Mg ha^{-1})	26.7	41.4	8.2	27.6
Organic carbon: 60-75cm (Mg ha^{-1})	21.7	41.1	3.2	41.6
Organic carbon: 75-90cm (Mg ha^{-1})	14.6	32.2	1.2	55.2
Organic carbon: 0-90cm (Mg ha^{-1})	170.9	250.3	108.1	17.4
Potentially mineralizable carbon: 0-15cm (Mg ha^{-1})	2.72	6.87	0.69	40.4
Plant				
Yield (Mg ha^{-1})[b]	1.38	3.52	0.00	56.4
Ear C: output C (Mg ha^{-1})	0.61	1.51	0.00	56.6
Residue C: input C (Mg ha^{-1})	1.22	2.33	0.27	42.5
Total C (Mg ha^{-1})	1.82	3.72	0.41	42.2
Soil water				
Soil water: 0-15cm (mm)	32	52	15	18.1
Soil water: 15-30cm (mm)	39	50	22	15.1
Soil water: 30-45cm (mm)	40	49	27	11.4
Soil water: 45-60cm (mm)	41	54	21	14.2
Soil water: 60-75cm (mm)	42	60	25	18.2
Soil water: 75-90cm (mm)	43	57	27	17.7
Soil water: 0-90cm (mm)	237	293	158	12.0
Snow depth (mm)	302	462	135	21.8
Topography				
Altitude (m)	427	437	402	2.1

[a]Coefficient of variation. [b]On a dry weight basis.

Table 11.2. Correlation matrix of selected field properties.

	Altitude	SW[a] 0-15	SW[a] 0-90	Snow[b]	SOC[c] 0-15	SOC[c] 15-30	SOC[c] 30-45	SOC[c] 0-90	PMC[d]
Soil water: 0-15cm	0.33**[e]								
Soil water: 0-90cm	0.46**	0.59**							
Snow depth	0.41**	0.12	0.30*						
Soil organic carbon: 0-15cm	0.47**	0.44**	0.33**	0.10					
Soil organic carbon: 15-30cm	0.06	-0.14	-0.03	0.12	0.19				
Soil organic carbon: 30-45cm	0.14	-0.14	0.02	0.25*	0.16	0.72**			
Soil organic carbon: 0-90cm	0.32**	0.17	0.40**	0.25*	0.47**	0.61**	0.66**		
Potentially mineralizable carbon	0.28*	0.19	0.12	0.06	0.43**	-0.14	-0.04	0.11	
Plant ear C	0.29*	0.07	0.05	0.28*	-0.03	0.15	0.06	-0.03	-0.06
Plant residue C	0.05	0.15	0.09	0.32*	-0.04	0.06	-0.01	-0.02	-0.12
Plant total C	0.17	0.14	0.08	0.35*	-0.04	0.10	0.02	-0.03	-0.11
Plant yield	0.31*	0.08	0.05	0.29*	-0.01	0.16	0.08	-0.01	-0.04

[a]Soil water, [b]Snow depth, [c]Soil organic carbon and [d]Potentially mineralizable carbon. [e]* and ** indicate significant level of 0.05 and 0.01, res

The amount of soil water stored at the beginning of the growing season was about 30-40 mm at each 15 cm depth with a tendency for a slight increase with depth. Soil water at the 0-90 cm depth amounted to 237 mm, which was more than one and a half the amount of the average precipitation during the growing season (about 160 mm). This suggests the importance of stored soil water in springtime for sound growth of wheat/barley in this region, even though not all the soil water would be available to plants. Furthermore the snow depth measured in the winter of 2002 was 302 mm on the average, which would correspond to 75 mm of water based on the assumption of 0.25 Mg m^{-3} for the snow density. Management of snow during the wintertime would, therefore, contribute considerably to the storage of available water in the soil profile, as suggested by Funakawa et al., (2004b).

11.4. Correlation of the field properties

Table 11.2 shows the correlation matrix of selected field properties. Elevation showed a positive relationship with the amount of soil water in both surface layer (0-15 cm) and whole profile (0-90 cm), snow depth, soil organic C content, in both surface layer (0-15 cm) and whole profile (0-90 cm) ($p<0.01$), potentially mineralizable C content, plant ear C content and plant yield ($p<0.05$). The amount of soil water (0-15 cm, 0-90 cm) showed a positive relationship with the soil organic C content, but did not show a significant relationship with the plant properties, even though the soil water content (0-30 cm) showed a moderately positive relationship with the yield and ear C content ($p<0.10$). Snow depth showed a positive relationship with the soil organic C content at the 30-45 cm and 0-90 cm depths ($p<0.01$) and all the plant properties ($p<0.05$). The amount of potentially mineralizable C was positively correlated with the organic C content at the same depth ($p<0.01$), indicating the presence of a strong link between the C source and the amount of CO_2 emission. As a result, topography, available water content, soil C stock, plant C content and yield were all interrelated, as N.K. Azarov, Kazakh Research Institute of Grain Farming in Shortandy, suggested that the geographical characteristics were correlated with the snow depth, humus content, moisture content and cereal productivity.

11.5. Spatial variability of organic matter dynamics

Geostatistical parameters of the field properties are shown in Table 11.3. The Q values of soil organic C ranged between 0.7 and 1.0, suggesting the existence of a highly developed spatial structure, whereas those of the potentially mineralizable C and soil water were about 0.5-0.7, suggesting a considerable development of the spatial structure. For the plant properties, total and residue C displayed a well-developed spatial structure, whereas yield and ear C displayed a poorly developed one. As the spatial structures

Table 11.3. Geostatistical parameters of the soil, plant and water properties.

Field properties	Nugget	Sill	Range (km)	Q value	Model[a]
Soil					
Organic carbon: 0-15cm (Mg ha^{-1})	24.7	79.2	6.9	0.69	S
Organic carbon: 15-30cm (Mg ha^{-1})	4.3	63.6	1.6	0.93	S
Organic carbon: 30-45cm (Mg ha^{-1})	13.9	77.4	1.6	0.82	E
Organic carbon: 45-60cm (Mg ha^{-1})	1.9	54.4	1.0	0.97	S
Organic carbon: 60-75cm (Mg ha^{-1})	10.6	83.3	1.6	0.87	E
Organic carbon: 75-90cm (Mg ha^{-1})	1.4	64.7	1.3	0.98	S
Organic carbon: 0-90cm (Mg ha^{-1})	115	901	2.6	0.87	E
Potentially mineralizable carbon: 0-15cm (Mg ha^{-1})	1.02	2.04	9.0+	0.50	E
Plant					
Yield (Mg ha^{-1})[b]	0.40	1.04	9.0+	0.38	S
Ear C: output C (Mg ha^{-1})	0.08	0.22	9.0+	0.34	S
Residue C: input C (Mg ha^{-1})	0.24	0.26	1.7	0.95	L
Total C (Mg ha^{-1})	0.5	0.62	9.0+	0.81	L
Soil water					
Soil water: 0-15cm (mm)	20	37	3.5	0.46	E
Soil water: 15-30cm (mm)	5	36	2.6	0.85	E
Soil water: 30-45cm (mm)	10	29	9.0+	0.65	S
Soil water: 45-60cm (mm)	5	36	1.4	0.86	E
Soil water: 60-75cm (mm)	35	69	7.7	0.50	S
Soil water: 75-90cm (mm)	43	98	9.0+	0.56	E
Soil water: 0-90cm (mm)	575	1259	9.0+	0.54	E
Snow depth (mm)	1512	4021	3.0	0.62	S

[a] S: Spherical, E: Exponential and L: Linear.

were moderately to well-developed, the ranges could be interpreted as the limit distances of spatial dependency. The ranges of the soil water content (0-15 cm), snow depth and plant residue C were 3.5,3.0 and 1.7 km, respectively, suggesting a relatively short spatial dependency. On the contrary, the soil organic C content (0-15 cm), potentially mineralizable C and plant yield showed relatively long ranges of 6.9 or well-developed spatial structure and hence had the potential to be managed spatially or more than 9 km. These results suggest that most of the field properties displayed a site-specifically based on this spatial dependency.

Figure 11.4 shows the isarithmic maps or spatial patterns of the selected properties in the field, which were obtained based on the data of spatial dependency described above. Spatial pattern of elevation is also shown for comparison and contour lines in other maps indicate the isarithm of elevation. Soil water content (0-15 cm) was relatively high in the central plateau and relatively low in the north-facing and south-facing slope areas, confirming the strong correlation between the elevation and soil water content ($p<0.01$), presumably because soil water is retained more stably in the central flat plateau than in other slope areas. Soil organic C content and the amount of potentially mineralizable C showed a similar trend to that of the soil water content (0-15 cm), indicating that the value in the central plateau was the highest, followed by the north-facing slope and then the south-facing slope areas. These results suggest that the central plateau had the greatest sink of organic matter and accordingly became the largest source of CO_2 as well. The lowest soil organic C level in the south-facing slope area may be due to the lower plant C input mentioned below, reflecting the lower soil water content due to the larger amount of sunshine and hence evaporation. It should also be noted that the spatial pattern of the amount of potentially mineralizable C showed only a general trend of CO_2 emission under optimal conditions for organic matter decomposition and further studies should be carried out to estimate actual values of CO_2 emission in the field *in situ* under field conditions. The C budget of the field would be properly evaluated, therefore, if the amount of CO_2 emission could be estimated based on the amount of potentially mineralizable C in soil and annual data of the field conditions such as soil temperature and moisture content.

On the contrary, plant properties showed slightly different spatial patterns, i.e. plant residue C was higher in the north-facing slope area, slightly north compared with the content of soil C. This tendency was more pronounced for the plant yield; the yield was the highest in the north-facing slope area followed by the central plateau and south-facing slope area. Ear C content, an index of C output from the system, showed an almost similar pattern to that of yield. These patterns would be mainly ascribed to those of the

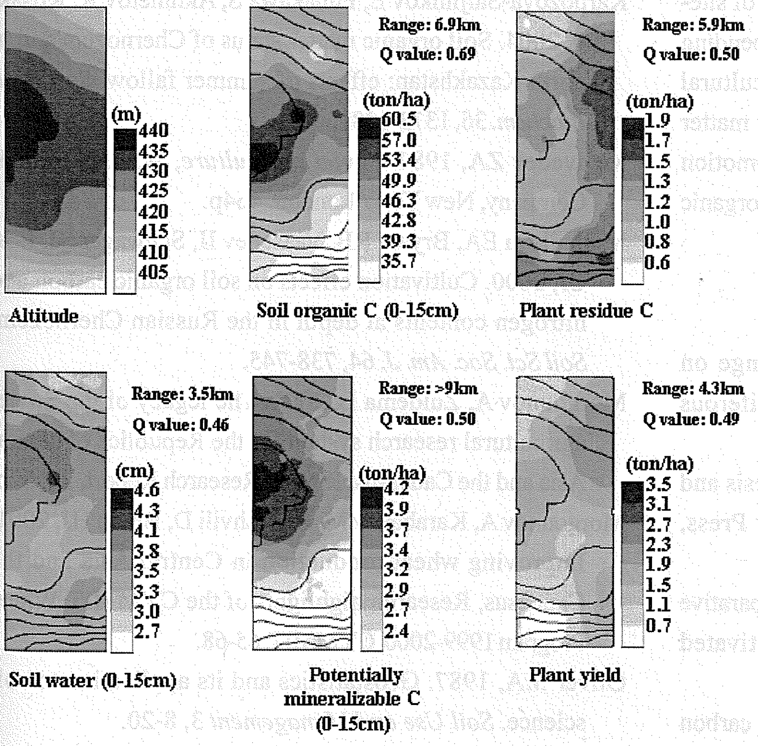

Figure 11.4. Spatial variability of selected field properties related to organic matter dynamics.

content of soil water and of available or mineralizable organic matter because water and available nitrogen are generally considered to be the two major determining factors for plant growth in this region.

11.6. Site-specific management for sustainable agriculture

Spatial patterns of the field properties strongly suggest that the organic matter dynamics in the field was markedly affected by the topography and that the most favourable area for the storage of organic matter was slightly different from that for food production. Namely, in the north-facing slope area, the yield was relatively high and the soil C stock was moderate, in the central plateau, the yield was moderate and the soil C stock and release of CO_2 from soil were the highest, whereas in the south-facing slope area, the yield and soil C dynamics were relatively low. Judging from these results, it would be reasonable to propose a site-specific management as an alternative for sustainable agriculture in this region. For example, one possibility would be to intensify management in the north-facing slope area to maximize crop yield without accelerating organic matter decomposition. This could be achieved by the intensification of fertilizer use and/or seed spreading in this area. Another possibility would be to reduce or even discontinue agricultural management in the south-facing slope area because crop yield was expected to be considerably low under current management. Obviously, since the most appropriate management would vary regionally depending on both environmental and socio-economic conditions (Paustian et al., 1997), the type of site-specific management should be carefully selected depending on the conditions. In conclusion, site-specific agricultural management based on the spatial patterns of organic matter dynamics could become a suitable option for the promotion of sustainable agricultural production and for limiting organic matter decomposition or soil degradation.

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Chapter 12

Spatial variation of carbon budget in agro-landscape in northern Kazakhstan

Yusuke Takata, Azusa Mishima and Kanat Akshalov

12.1. Background

Organic carbon in soils plays a key role in the carbon cycle and has a potentially large impact on the greenhouse effect (Lal et al., 1998). World soil carbon content is estimated 1.5×10^{18} g, which is twice as much as the atmosphere and three times the level held in terrestrial vegetation (Post, 1998). Annual net release of carbon from agricultural land has been estimated at 2.5×10^{15} g, which is about 15% of current global fossil fuel emission (Smith, 1999). The increase in atmospheric CO_2 can be slowed by retaining the carbon captured by plant photosynthesis. Soil organic matter is a natural reservoir of organic carbon. The amount of carbon that could potentially be stored in soils in the U.S. has been estimated to be between 5 and 10% of the current annual emission of U.S. (Lal et al., 1998).

In Kazakhstan, a country of former Soviet Union in central Asia, Chernozem occupy 32.1×10^{6} hectares or 11.8% of the country (GUGK, 1982), and it store 65-80 Mg ha^{-1} of organic carbon in the top 20 cm (Kudeyarov et al., 1995). Historical land-use changes that converted grass to cropland as well as many conventional agricultural practices in this area have caused much loss of natural reservoir of soil organic carbon. For example, summer fallow, which is a generally adopted practice in the northern Kazakhstan, has been amounted to 5 million hectares, taking about 15% of cropland (Suleimenov et al., 2001). It is justified by its advantages in increase of water accumulation and soil nitrogen availability prior to spring wheat planting, in weed control, and more stable crop yields (Morgounov et al., 2001). Even though it was a strategy for increase in crop production efficiency. Uniform of intensive application of such technologies during the period of former Soviet Union was rather focused on production, which often came at the expense of sustainability (Srivastava and Meyer, 1998). In fact, soil organic carbon in top 10 cm reduced 38-43% over the last 25-30 years in continuously cropped field of Chernozem in Russia (Mikhailova et al., 2000). Carbon loss can be linked to soil production, soil quality, carbon sequestration, and, ultimately, crop production (Paustian et al., 1997). This tendency is in contrast to the recent general requirement from both environmental and agricultural viewpoint that organic matter decomposition or CO_2 emission from soil should be reduced. Therefore, there is a need for a tool that will estimate how management system will affect organic matter storage in soils at the site-specific level. These estimates could be provided by a field-level carbon sequestration model sensitive to local soils, climate, crop rotation system, and yields.

In the northern Kazakhstan, Yanai et al. (2005) evaluated soil organic matter dynamics in relation to topography. They showed that organic matter dynamics, which estimated under laboratory condition, was highly affected by topography, and they also mentioned that there is need to estimate absolute values of CO_2 emission under the field condition. Therefore, the objective of this research is 1) to make the mineralization model of soil organic matter based on an estimation of CO_2 emissions *in situ*, 2) to clarify the spatial variability of carbon budget, and 3) to evaluate the influence of crop rotation phase and topography on carbon budget in the field, with the final goal of this research being an establishment of agricultural system that enable a proper management of organic matter in the northern Kazakhstan steppe zone.

12.2. Materials and methods

Study area: This study was carried out at the Barayev Kazakh Research and Production Centre of Grain Farming, which is situated in Shortandy, Akmolinsk Oblast, in the northern part of the republic of Kazakhstan. The crop rotation system is fallow-wheat-wheat-wheat (barley) in this study area. A study field (14 km×5 km) was divided into 70 plots of dimensions 1 km×1 km (Fig. 12.1). The altitude of the study field was measured using a differential global positioning system at the each plot. The altitude of the study field was highest in the middle-eastern part, and gradually decreased to the north and south direction. The entire field was separated into a north-facing slope, a south-facing slope, and a plateau at the altitude of 430 m.

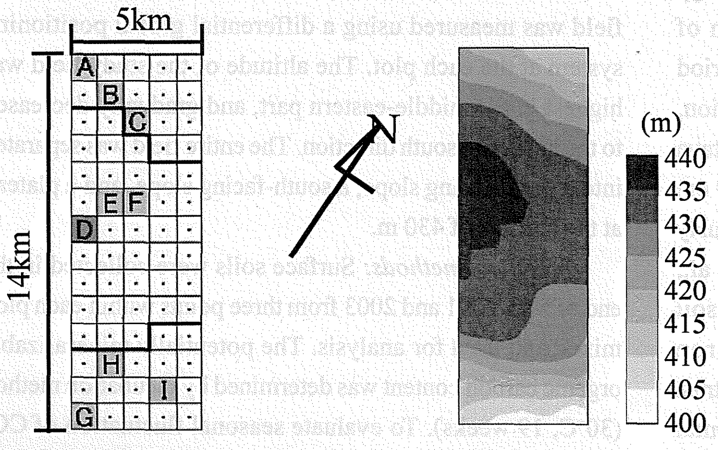
Analytical methods: Surface soils were collected in the end of May 2001 and 2003 from three points within each plot, mixed and used for analysis. The potentially mineralizable organic carbon content was determined by incubation method (30°C, 19 weeks). To evaluate seasonal fluctuation of CO_2 emission *in situ*, CO_2 emission was measured once a week from the end of May 2002 to mid September 2002, during the cropping season. Three typical points in each section were selected considering the organic carbon and potentially mineralizable carbon distribution data. They are A, B, C, D, E, F, G, H, and I (Fig. 12.1). An alkaline absorption method was used for the determination of CO_2 emission. Chambers were installed at the soil surface and CO_2 respired within 24 h was measured by 0.1 M HCl. A root-impermeable mesh was buried at a 15 cm depth to limit the influence of root respiration. At the time of measurement, maximum and minimum temperature at 5 cm depth was recorded using maximum minimum thermometer (AD-5625, AND, Inc.) installed at each plot; volumetric water content (%) at 0-15 cm depth using a soil moisture sensor (Hydro Sense, Campbell Scientific, Inc.) was also recorded. Air temperature, soil temperature (5 cm, 15 cm), soil moisture (0-15 cm), and precipitation was monitored from 26th May to 10th September, 2002 using a micro logger (Campbell Scientific, Inc.) at 30 minute intervals at the D plateau plot (Fig. 12.1). Plant sampling was carried out from late August to September 2001, 2002 and 2003. From each plot, above and below ground plants in 1 m×0.92 m quadrates were harvested in non-fallow plots (2001: 55 plots, 2002: 57 plots, 2003: 45 plots). Harvested plant samples were dried at 70°C for 24 h and weighed. Total carbon content was measured for the dried sample by dry combustion method (SumikaNC-800-13N).

Statistical analysis: Stepwise multiple regression analysis using soil temperature, soil water content, precipitation and potentially mineralizable carbon using Arrhenius model was carried out to explain main factor of CO_2 emission. Daily CO_2 emission was estimated by inputting daily monitoring data of soil temperature and precipitation, and potentially mineralizable carbon to the equation obtained.

Geostatisitical analysis: Geostatistics is a branch of applied statistics that quantifies the spatial dependence and spatial structure of a measured property and, uses the spatial structure to predict values of the property at unsampled locations. These two steps typically involve spatial modeling (variography) and spatial interpolation (kriging) (Mulla and McBratney 2000). Spatial dependence can be quantified and modeled using the semivarigram (Burgess and Webster, 1980). The semivariogram γ (h) is calculated using the equation:

$$\gamma\,(h) = \frac{1}{2n(h)} \sum_{i=1}^{n(h)} [z_i - z_{i+1}]^2$$

where h is the distance between locations x_i and x_{i+h}, z_i and z_{i+h} are the measured values for the regionalized variable at locations x_i or x_{i+h}, and $n(h)$ is the number of pairs at any separation distance h. The semivariogram model and its parameters provide a quantitative expression of spatial structure for the measured property. The nugget parameter is a measure of the amount of variance due to errors in sampling, measurement, and other unexplained source of variance. The sill is theoretically equal to the variance of the sampled population at large separation distances if the data have no trend. The Q value;[(sill-nugget)/sill], which indicates the spatial structure at the sampling scale. The range indicates the limit of spatial dependence. Kriging is a general term describing a geostatistical approach for interpolation at unsampled locations. There are several types of univariate kriging method including punctual, indicator, disjunctive, universal, and block kriging. In this study, block kriging was used to evaluate regional patterns of variations. The geostatistical software, GS^+ Version 5.3 for Windows (Gamma Design Software), was used in the analysis.



(A) Sampling points (B) Altitude

Figure 12.1. (A) Schematic diagram of the sampling plots indicated as dots in the field and (B) topography of the study site.

12.3. Land use history

Land-use history from 2001 to 2003 in this study site is shown in Fig. 12.2. The crop rotation phase were divided into following 6 groups; two years of summer fallow and one year of wheat (Two years of fallow), continuous wheat cropped without summer fallow (Continuous wheat), continuous barley without fallow (Continuous barley), two years of barley and one year of wheat (Two years of barley), one year fallow and two years of cereal (One year of fallow), and continuous grassland or continuous abandoned. It should be noted that plant sampling was conducted only in the wheat and barley plots, and continuous grassland and abandoned plots are omitted from following discussions.

12.4. Potentially mineralizable organic carbon

The isarithm map of potentially mineralizable organic carbon content, which collected in 2001 and 2003 is shown in Fig. 12.3. Potentially mineralizable organic carbon in 2001 and 2003 had average values of 2.72 and 2.56 Mg C ha^{-1}, and ranged from 0.7 to 6.9 Mg C ha^{-1} and from 1.4 to 5.1 Mg C ha^{-1}, respectively. In geostatistical analysis, the ranges of 2001 and 2003 sampling sets were 8.5 km and 6.2 km, respectively. This difference of range might be influenced by the carbon input as plant residue in 2001 and 2002. The *Q* value of 2001 and 2003 sampling set were 0.50 and 0.53, respectively, suggesting a considerable degree of spatial structure. In both years, potentially mineralizable organic carbon was highest in the plateau, and it was higher in the north-facing slope than south-facing slope. This result indicated that the potential contribution as a source of carbon dioxide was highest in the plateau followed by north-facing slope and then south-facing slope.

12.5. Seasonal change of soil

Dynamics of CO_2 emission in 2002 are shown in Fig. 12.4. The measurement started from the end of May and finished in September. Total of 15 measurements were accomplished. CO_2 emission rose toward summer, attained maximum in summer, and declined toward autumn. It is possible that the period of high CO_2 emission maybe due to climatic factor, but it could also be due to the release of plant derived C as indicated by Stoyan et al. (2000). There were high CO_2

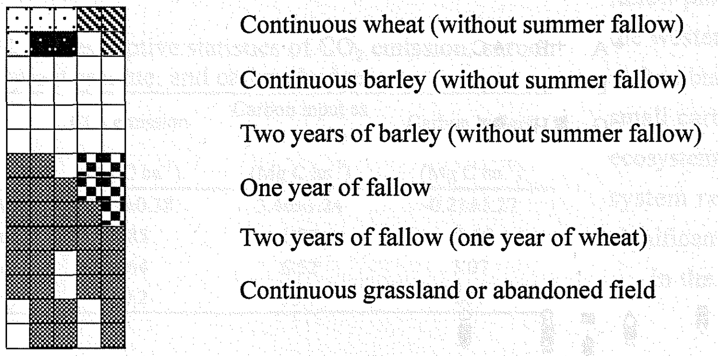
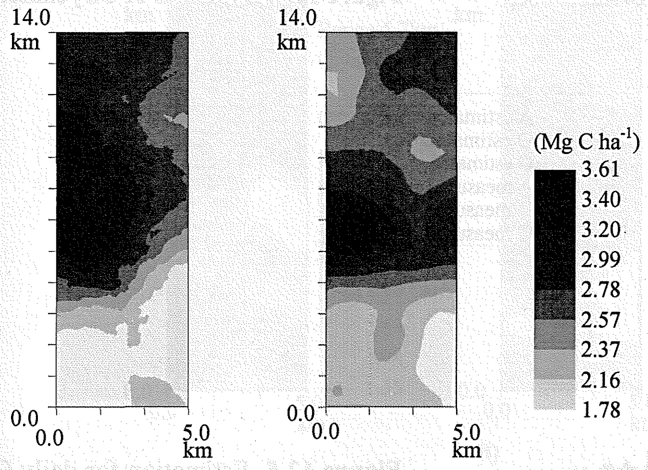


Figure 12.2. Land-use history.



A) 2001 **B) 2003**

Figure 12.3. Spatial variability of potentially mineralizable organic carbon.

emission at plateau plots, especially F plot. The result coincide well with pattern of potentially mineralizable organic carbon.

To estimate daily CO_2 emission and to comprehend main factor of CO_2 emission fluctuation, relationship of CO_2 emission to soil temperature, water content, precipitation, and potentially mineralizable carbon was examined by multiple regression by all plots using Arrhenius model. Arrhenius model is often used to determine the activation energy for a reaction based on how the rate constant changes with temperature. Arrhenius equation together with extensive form of estimating CO_2 emission can be stated as follows:

$$C_{em}=aP^{b}C_0^{c}W^{d}e^{-E/RK}$$

$$\ln C_{em} = \ln a + b\ln P + c\ln C_0 + d\ln W - E/RK$$

where C_{em} is CO_2 emission (kg C ha^{-1} d^{-1}), a is rate constant, T is minimum temperature, P is precipitation for a week, C_0 is potentially mineralizable organic carbon (Mg C ha^{-1}), W is volumetric water content (L L^{-1}), b is order of reaction with respect to P, c is order of reaction respect to C, d is order of reaction respect to W, E is activation energy, R is gas constant; 0.082, and K is Kelvin temperature. The following regression model was obtained,

$$C_{em} = e^{47.72} \times P^{0.137} \times C_0^{0.34} \times e^{-1089.65/RK} \qquad (n=130, R^2=0.49)$$

Soil moisture factor in the multiple regression for CO_2 emission were excluded by stepwise estimation with probability 0.15. Kudeyarov and Kurganova (1998) found that correlation between soil respiration rates and soil moisture was weaker than that between soil respiration rates and soil temperature in Russian Chernozems. The study of Alvarez et al. (1995) indicated soil respiration had no relationship with soil moisture, and was regulated only by the temperature in the wheat-soybean field in Argentina pampas. These studies were similar with this study. But precipitation factor, which show drastic change of soil moisture and obtained high correlation coefficient (data was not shown). From the study of Rochette et al. (1991), it indicates precipitation factor strongly contributed than soil moisture content factor to CO_2 emission, particularly rainfall occurred after a dry period.

Estimated daily CO_2 emissions at plots A, D, and G are shown in Fig. 12.5. The CO_2 emission was small from January to April, rose up from May and reached its peak in July, then

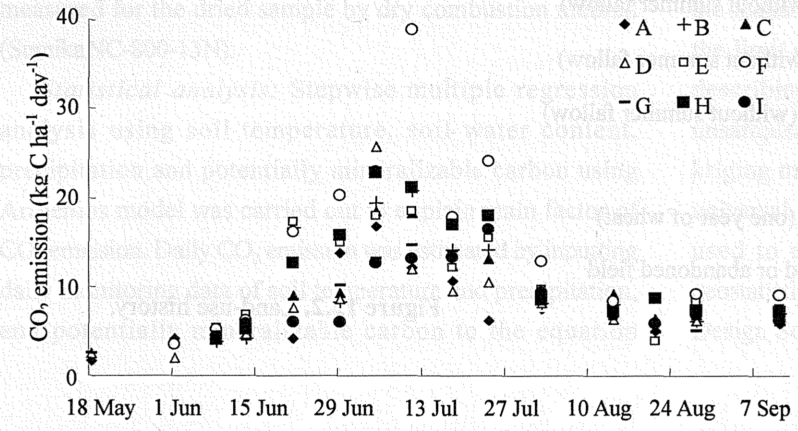


Figure 12.4. Dynamics of CO_2 emission.

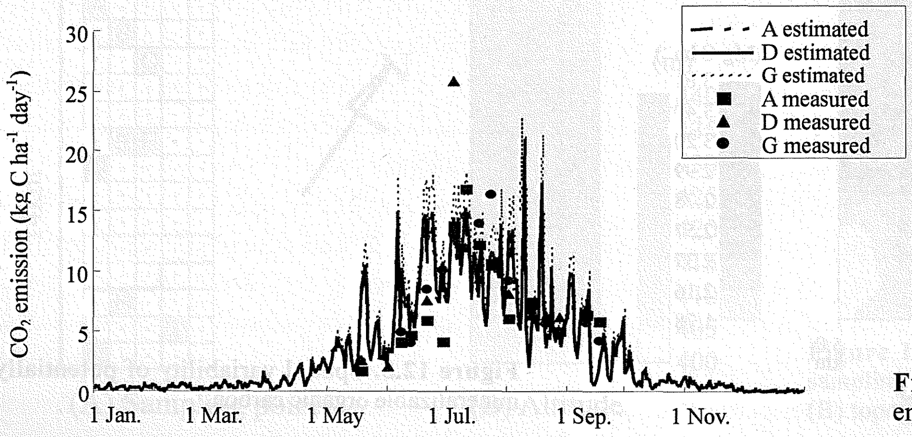


Figure 12.5. Estimation for daily CO_2 emission.

decreased progressively, and became nearly zero from October. In fact, soil temperature of January to mid of March and from November to December was below zero. Regarding that there is practically naught CO_2 emission when soil temperature is below zero (Frank et al., 2002).

12.6. Carbon budget from 2001 to 2003

Descriptive statistics of CO_2 emission and carbon input as plant residue is listed in Table 12.1. Carbon input of summer fallow was calculated 0 Mg C ha^{-1}. Total CO_2 emission and total carbon input as plant residue had average values of 3.71 and 3.46 Mg C ha^{-1}, and ranged from 2.85 to 4.64 Mg C ha^{-1} and 1.07 to 6.52 Mg C ha^{-1}, respectively. The mean carbon budget was -0.21 Mg C ha^{-1}, implying that soil degradation is progressing under the current conditions.

Figure 12.6 show isarithmic maps of the total carbon input as plant residue, total CO_2 emission, and carbon budget, each of them show the data set from 2001 to 2003. In the geostatistical study, the range of total carbon input and carbon budget was about 5.0 km, and the Q value of was about 0.9, and this result show that the spatial pattern of total carbon input and carbon budget is similar. The range of total CO_2 emission was 7.4 km, and the Q value was 0.5. The total carbon input was highest in the eastern part of north-facing slope which was continuous wheat zone. Contrary, in summer fallow plots, especially two years fallow plots, carbon input was small. And, the carbon input of barley plots, which were situated in the western part of north-facing slope, was relatively small than in the continuous wheat plots. These results indicate that total carbon input as plant residue is strongly related to crop rotation phase. The total CO_2 emission was highest in the plateau followed by north-facing slope then south-facing slope. The distribution pattern of soils respiration showed similar trend with potentially mineralizable organic carbon, and these results suggest that the loss of soil organic carbon is related to topography. The carbon budget was highest in the eastern part of north-facing slope where total carbon input was highest, and their total CO_2 emission was small. The carbon budget was positive in the eastern part of north-facing slope, northern part of plateau, and western part of south-facing slope, and it is indicated that these zones contributed to carbon accumulation. Contrary, the carbon budget was negative in the all of summer fallow plots. Most of the barley plots which were situated in the western part of north-facing slope, also were negative carbon budget. There was relatively large CO_2 emission and small carbon input in the barley plots. In this agricultural ecosystem, the summer fallow management and crop rotation system regardless of local condition is resulting in the significant decrease of soil organic carbon.

In the semiarid croplands of northern Kazakhstan, the

Table 12.1. Descriptive statistics of CO_2 emission, carbon input as plant residue, and carbon budget.

	CO_2 emission (Mg C ha^{-1})	Carbon input as plant residue (Mg C ha^{-1})	Carbon budget (Mg C ha^{-1})
Mean ± S.D.	3.71±0.38	3.46±1.24	-0.21±1.27
Minimum	2.85	1.07	-2.66
Maximum	4.64	6.52	3.07
C.V. (%)	10.2	35.7	601

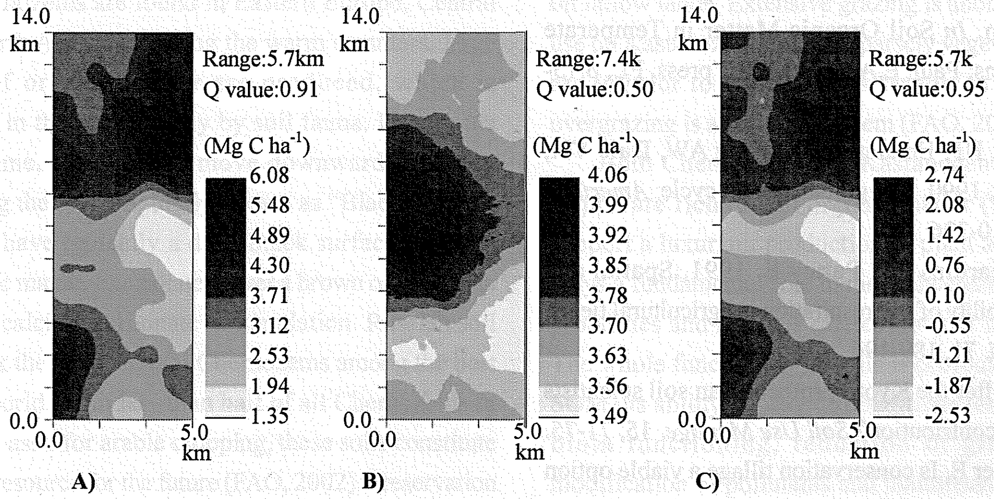


Figure 12.6. Spatial variability of A) total carbon input as plant residue, B) total CO_2 emission, and C) carbon budget.

fate of soil organic carbon is related to landscape and crop rotation phase. To establish an agricultural system that properly manages organic matter, site-specific management should be paid more attention.

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Chapter 13

Features and properties of chernozemic soils and humic substances in the Eurasian steppe

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13.1. Background

The climatic conditions are one of the most critical factors to determine the soil formation processes and distribution in the Eurasian steppe area. Steppe and steppic regions receive between 250 and 500 mm of precipitation annually, i.e. more than twice the quantity that falls in true desert areas where rainfall is insufficient to support vegetation that could protect the land from erosion, degradation, and desertification (FAO, 2002). These areas are usually covered with 'loess' materials carried by strong winds during the Ice Age, or either covered with tills, deglaciation sediments, or lacustrine sediments. These materials are usually calcareous, unstratified, and yellowish-grey. The vast loess and till plains are now colonized by grass and/or forest as natural vegetation. They are the home of some of the best soils of the world: the 'black earths'. Deep, black Chernozems occupy the central parts of the Eurasian steppe zone. Brown Kastanozems are typical of the drier parts of the steppe zone and border on arid and semi-arid lands.

The steppe and steppic regions in Eurasia are extensively covered by loess materials, from which Chernozems and Kastanozems in WRB classification (FAO, 1998) are commonly formed and developed. Chernozems are soils of the tall grass or steppe plains and hills in region with a continental climate (warm summers and cold winters). Vast areas of Chernozems are found in Eastern Europe, Central Asia, and North America. During the warm summers, large quantities of organic matter are produced, which is incorporated in the soils mainly by soil fauna. During the cold wintertime, soil animals move downwards, thereby homogenizing the soil. Popularly known as "Black Earths", Chernozems have typically a deep black surface horizon, high in organic matter, immediately over a brown or yellowish horizon with calcium carbonate accumulation. Russian soil scientists rank the deep, central Chernozems among the best soils in the world. With less than half of all Chernozems in Eurasia being used for arable cropping, these soils constitute a formidable resource for the future (FAO, 2002). Preservation of the favorable soil structure thoroughly timely cultivation and careful irrigation at low water rates prevents ablation and erosion. Application of P-fertilizers is required for high yields. Wheat, barley and maize are the principal crops grown, alongside other food crops and vegetables. Part of the Chernozem area is used for livestock rearing. In the northern temperate climatic belt, the possible growing period is short and principal crops grown are wheat and barley, in places in rotation with vegetables. Maize is widely grown in the warm temperate belt. Maize production tends to stagnate in drier years unless the crop is adequately irrigated.

Kastanozems occur adjacent to Chernozems on the drier side of the Chernozem belt (FAO, 2002). The climax vegetation consists of short grasses. The name of Kastanozems refers to the chestnut color of many of these soils. Organic matter production on Kastanozems is less than in the Chernozem belt but enough to form a dark mollic surface horizon. Accumulation of calcium carbonate or gypsum in the solum is a characteristic of Kastanozems. The vast, almost level plains of the Central Asian Kastanozem belt are suitable for large-scale mechanized agricultural enterprises. Kastanozems are potentially rich soils; periodic lack of soil moisture is the main obstacle to high yields. Irrigation is nearly always necessary for high yields; care must be taken to avoid secondary salinization of the surface soil. Small grains and (irrigated) food and vegetable crops are the principal crops grown. Wind erosion is a problem of Kastanozems, especially on fallow lands. Extensive grazing is another important land use on Kastanozems but the sparsely vegetated grazing lands are inferior to the tall grass steppe on Chernozems and overgrazing is a serious problem (FAO, 2002).

Both Chernozems and Kastanozems in the Eurasian steppe are rich in soil organic matter (SOM), which can support a luxuriant production of plant and biomass. SOM plays a fundamental role in the maintenance of the main soil properties and regimes related not just to the soil fertility. The whole functioning of soils is profoundly influenced by SOM, its ability to provide conditions for plant growth, soil biota functioning, reduction of greenhouse gases, modification of pollutants and maintenance of soil physical condition (Shevtsova *et al.*, 2003). In the respective soils, carbon sequestration in SOM through agricultural practices is of great importance, and a steady state between the C input and mineralization of SOM should be optimum (Rasmussen *et al.*, 1998; Filip and Kubát, 2003). SOM quality parameters as well as SOM quantitative level are common indicators of the effect of agricultural management practices on SOM change. Shevtsova *et al.* (2003) investigated the changes in topsoil C content and quality measured in 60 experiments on soddy-podzolic soils in the Russian Federation, Belarus, Ukraine, Lithuania, and Latvia with different management characteristics, reporting that the management practices lead to changes not only in total SOM but also in SOM quality parameters. Especially, the influences of long-term cultivation and organic cropping on SOM dynamics of humic substances had been paid much attention (Aoyama and Kumakura, 2001; Klimowicz and Uziak, 2001; Doane *et al.*, 2003; Filip and Kubát, 2003).

Humic acids are the mixture of continuum of HA molecules with different degree of humification and their chemical characteristics vary depending on their degree of humification (Maie *et al.*, 2002). Therefore, indexes of humification are useful to evaluate the effects of agricultural management practices on SOM dynamics and qualities of humic substances. Most humified HAs (Type A HAs), of which solution shows very dark color per unit carbon, have been commonly in the surface layer of grassland soils developed on volcanic ash in Japan and in Chernozemic soil in Europe (Kumada, 1987). Vast areas of Chernozems are found in the Eurasian steppe, mostly being used for arable cropping, however, little was known on features and properties of Chernozemic soils and their SOM dynamics of humic substances in the Eurasian Steppe. Especially, the SOM qualities of humic fractions should be critical to understand the fate of soil organic carbon in the Eurasian steppe, which would affect the soil fertility and the environmental impact.

In the present study, Chernozemic and related soil samples under natural grasslands and arable lands were collected from nine profiles in Ukraine and Hungary to investigate the properties and characteristics of the SOM dynamics of humic substances in the Eurasian Steppe. Chernozemic soils collected from three profiles in Canada were also used to compare with the Eurasian soils and distinguish their features. Some physico-chemical properties of soil samples were analyzed to clarify the soil development and features of the Chernozemic profiles. Humification indexes ("└ log *K* and *RF*) were used to classify the Chernozemic humic acids and to examine the influences of natural and artificial impacts on degree of humification. ^{13}C NMR spectroscopy was also applied to characterize the structure and composition of humic acids in the Eurasian Chernozems. The objectives of this study are to investigate 1) the effects of climate and moisture regimes on soil development and SOM dynamics of four Chernozemic subtypes in Ukraine, 2) the effects of agricultural impacts on changes in soil features and humic fractions of Chernozems under intensive management practices in Hungary and Canada, 3) the relationship between soil carbon degradation and expense of humic acids in the Eurasian steppe.

13.2. Materials and methods

13.2.1. Soil survey and sample collection

The soil survey was carried out from October to November in 2001; where soil samples were collected horizon-wise form four profiles in Ukraine and five profiles in Hungary (Table 13.1). Popularly known as "Black Soil Belts", Chernozemic zones are composed of one of the most fertile and rich black-soils in the world, distributing in Eastern Europe, Central Asia including South Russia, North America (known as 'prairie') and South America (known as 'pampas'). In particular, the greater part of lands is covered by Chernozems and related soils (Kastanozems) in Ukraine, where must be the central and representative Chernozemic zones in the Eurasian steppe. Four sites, where the soils had been covered by natural steppe vegetation except for one site (Ordinary Chernozem), were selected to assess the relationship between moisture regimes and soil development in Ukraine (Table 13.1). The eastern part of Hungary boarders on Ukraine, being covered by vast plains of Chernozems called as 'puszta'. Since the intensive wheat and maize productions have been conducted in such areas of Hungary, lands under the natural steppe vegetation are almost scarce (Table 13.1). Canadian soil samples were also used in the present study to contrast the soils in the Eurasian steppe with those in the Great Plains. These soils were collected in 1999 by Tani and Fujitake (data was not published), from three profiles of wheat fields in Saskatchewan, Canada (Table 13.1). The collected soil samples were air-dried and passed through a 2 mm pore-size sieve. Finely ground soil samples were also prepared for the analysis of soil organic carbon, inorganic carbon, total carbon and nitrogen, and humic substances.

Several statistical data of agricultural production, which are yields of total crops, wheat, and ,maize, from 1998 to 2000

Table 13.1. Location and land use of study sites and soil classification of the profiles.

No.	Country	Site and land use	Location	Soil classification		
				Russian	WRB	Others
U1	Ukraine	Grakovo Natural grassland	—	Typical Chernozem	Chernic-Siltic Chernozems	—
U2	Ukraine	Krasnograd Arable land (wheat)	—	Ordinary Chernozem	Calcic-Siltic Chernozems	—
U3	Ukraine	Askania-Nova Natural grassland	N 46° 28' E 33° 54'	Southern Chernozem	Hypocalcic-Siltic Chernozems	—
U4	Ukraine	Askania-Nova Natural grassland	N 46° 30' E 34° 2'	Dark Chestnut	Calcic-Siltic Chernozems	—
H1	Hungary	Valence Lake, near Budapest Arable land	N 47° 15' E 18° 40'	—	Calcic-Siltic Chernozems	Typic Calcisutolls (USDA)
H2	Hungary	Valence Lake, near Budapest Arable land	N 47° 15' E 18° 40'	—	Calcic Chernozems	Typic Calciudolls (USDA)
H3	Hungary	University of Gödöllő Arable land (wheat)	N 47° 42' E 19° 37'	Leached Chernozem	Haplic Chernozems (Chernic?)	—
H4	Hungary	Karcag, University of Debrecen Arable land (wheat and maize)	N 47° 17' E 20° 54'	—	Vertic-Siltic Chernozems (Luvic?)	—
H5	Hungary	Latokép, University of Debrecen Arable land	N 47° 34' E 21° 27'	—	Haplic Chernozems (Chernic?)	—
C1	Canada	Wakaw, Saskatchewan Arable land (wheat)	N 52° 60' W 105° 75'	—	Calcic-Siltic Chernozems	Black Chernozemic soil (Canada)
C2	Canada	Kenaston, Saskatchewan Arable land (wheat)	N 51° 50' W 106° 22'	—	—	Dark Brown Chernozemic soil (Canada)
C3	Canada	Swift Current, Saskatchewan Arable land (wheat)	N 50° 42' W 105° 5'	—	Calcic-Anthric Kastanozems	Brown Chernozemic soil (Canada)

Table 13.2. Statistical data of agricultural production from 1998 to 2000 in Ukraine, Hungary, and Canada (FAO, 2003).

	Yield of total crops				Yield of wheat				Yield of maize			
	1998	1999	2000	Avg.	1998	1999	2000	Avg.	1998	1999	2000	Avg.
	(kg ha^{-1})				(kg ha^{-1})				(kg ha^{-1})			
World	3059	3094	3034	3062	2694	2758	2698	2717	4433	4363	4230	4342
Ukraine	2106	2003	1949	2019 (66)	2648	2290	1972	2303 (85)	2534	2522	3002	2686 (62)
Hungary	4555	4695	3623	4291 (140)	4139	3595	3622	3785 (139)	6008	6413	4145	5522 (127)
Canada	2783	3088	2801	2891 (94)	2255	2595	2445	2432 (90)	8007	8030	6273	7437 (171)

Values in the parentheses are the percentage to the averaged values in the World.

in the World, Ukraine, Hungary, and Canada are shown in Table 13.2 (FAO, 2003). The yields of total crops, wheat, and maize in Hungary are considerably higher than those in the World and Ukraine, indicating that extremely intensive agricultural practices have been enforced. The area of total arable land in Hungary is about 4.8 million ha in 1999 (FAO, 2003), which is similar to that in Japan (4.5 million ha) and obviously smaller than that in Canada (46 million ha) and Ukraine (34 million ha). The intensive managements and practices to increase agricultural productivity per unit land area would lead to serious soil degradation and erosion in Hungary (Gábris *et al.*, 2003; Birkás *et al.*, 2004). The yield of total crops in Canada is one-and-a-half times as high as that in Ukraine, and especially the yield of maize is almost three times as high as that in Ukraine. From these data, it can be supposed that the Chernozems in arable lands of Hungary and Canada should be strongly affected by agricultural impacts, such as mineral fertilization, tillage, irrigation, and long-term cultivation, than those of Ukraine. However, Ukraine traditionally has been a major agricultural region of Europe, resulting in soil degradation and decrease in soil fertility. After the independence in 1991, Ukraine is growing into sizeable agriculture and steps are underway to improve soils and restore them to their former levels of fertility and productivity (Medvedev, 2004).

13.2.2. Analytical methods for physico-chemical properties

Selected physico-chemical properties of the soil samples were analyzed by following methods. The particle distribution was determined by a sedimentation method. Soil pH in a suspension of air-dried soil / distilled water in the ratio of 1 : 2.5 was measured with a glass electrode, and was designated as pH(H_2O). The organic carbon content was determined by a dichromate oxidation method (modified Tyurin method). The inorganic carbon content was determined by a weight-loss method (Blakemore *et al.*, 1987). The cation-exchange-capacity (CEC) was measured by a Schollenberger method combined with a steam distillation method to determine an ammonium ion, which was retained by soil colloids and percolated with potassium chloride solution. The exchangeable cations in the ammonium acetate percolate, obtained in the Schollenberger method for CEC determination, were measured by an atomic adsorption spectrophotometry (Z-5010, Hitachi, Japan).

13.2.3. Analytical methods for humic substances

13.2.3.1. Extraction of humic substances and humification index

Two grams of air-dried samples were placed into 50 mL plastic centrifuge tubes and once washed by using 30 mL of 0.05 mol L^{-1} H_2SO_4 solution and shaking for 1 h before the extraction to remove free calcium carbonate, which might occlude organic matter. After centrifugation of the suspension at 10,000 × *g* for 15 min, the supernatant was decanted. The humic fraction was then extracted by using 30 mL of 0.1 mol L^{-1} NaOH solution and shaking for 16 h at an ambient temperature. The extract was separated from the soil residue by centrifugation at 10,000 × *g* for 15 min. The supernatant was transferred into a 100 mL volumetric flask and the residue was extracted twice with 20 mL of 0.1 mol L^{-1} NaOH solution containing 3 % of Na_2SO_4 by shaking for 20 min and centrifugation at 10,000 × *g* for 15 min. The supernatants were collected together in the volumetric flask, then added with 1 mL of concentrated H_2SO_4, diluted to 100 mL and allowed to stand for overnight. The extract was filtered using No. 6 Filter Paper (Advantec Toyo, Japan), collecting the filtrate into a 100 mL volumetric flask. The precipitate retained on the filter paper was then washed with 1 % H_2SO_4, and the filtrates were combined in the volumetric flask and diluted to 100 mL (fulvic acid fraction, FA). The precipitate was dissolved with 0.1 mol L^{-1} NaOH solution and diluted to 100 or 200 mL in a volumetric flask (humic acid fraction, HA).

The absorbances of the HAs from 220 to 700 nm were recorded on a spectrophotometer (UV-2200, Shimadzu, Japan) within 2 h after the dissolution. Organic carbon contents in the HA (Ch) and FA (Cf) solutions were determined by a colorimetric method using a potassium dichromate-sulfuric acid solution as a reagent (Tatsukawa, 1966).

In the classification of HAs, ”└ log *K* and *RF* based on the spectrophotometric properties of the HAs are used as indexes of degree of humification of the HAs, which are defined as follows: ”└ log K = log E_{400} – log E_{600}, where E_{400} and E_{600} are the absorbances at 400 and 600 nm, respectively, and $RF = E_{600} / c \times 15$, where *c* is mg C / mL of the HA solutions (Kumada *et al.*, 1967; Kumada, 1987). By using these indexes, the HAs are categorized into four groups (Types A, B, P, and Rp), and Type A HAs are the most humified HAs of which ”└ log $K < 0.7$ and $RF > 80$ (Kumada *et al.*, 1967; Kumada, 1987; Maie *et al.*, 2002).

13.2.3.2. ^{13}C NMR spectroscopy of humic acids

The preparation of HA samples and procedures for solution ^{13}C NMR spectroscopy were described by Kawahigashi *et al.* (1995) and Fujitake and Kawahigashi (1999). Solution ^{13}C NMR spectra were recorded at 62.896 MHz on a Bruker DPX 250 spectrometer (Bruker GmbH, Karlsruhe) using sample tubes 10 mm in diameter. Solutions of the humic acid samples were prepared by suspending 50-120 mg in 1 mL of 0.5 mol L^{-1} NaOH. The solution was then filtered through a glass column filled with absorbent cotton, which was then washed with 1 mL of D_2O (for a deuterium NMR lock signal). The filtrates were combined in a final volume of 2.2 mL. For the chemical shifts, an external TMS capillary was used as reference. To obtain quantitative conditions for the integration of the spectra, ^{13}C signals were proton-decoupled by the inverse gated decoupling technique as follows: pulse width 45°, acquisition time 0.2 s. A total repetition time of 2.5 s was applied to permit complete relaxation of all the spins. To improve the signal-to-noise ratio, a line broadening of 40 Hz was used. Scans numbering 18,000 to 48,000 were accumulated.

13.3. Climate and soils in the Eurasian steppe

13.3.1. Moisture regime and soil development in Ukraine

The distribution of each subtype of Chernozems in Ukraine is controlled by mostly climatic conditions, especially the soil moisture regime, and the soil zonality is quite distinct. In the northern part of Ukraine, the mean temperature, annual precipitation, and evaporation is relatively cool, high, and low, respectively, compared to the southern part. As a result, the soil moisture regime is drier in the southern part than the northern part. The more moist conditions can stimulate the accumulation of plant residues and their humification processes, resulting in a deep black surface horizon, high in organic matter. The leaching of calcium carbonate from surface horizons to lower parts of the profile and the consecutive 'mycelium'-type accumulation of calcium carbonate in the deeper horizons can be also observed. In the meantime, the more droughty conditions can build up a profile with a relatively thin dark-brown or brown surface horizon and a 'white eye'-type calcium carbonate accumulation at the shallower depth of the profile.

As an instance, four subtypes of Chernozems and the related soils, which can be found in the eastern part of Ukraine; 'Typical Chernozems', 'Ordinary Chernozems', 'Southern Chernozems', and 'Dark Chestnuts' according to Russian classification system (Stolbovoi, 2000) are described here (Table 13.3). The illustrative profile of Typical Chernozems under natural steppe vegetation was found in Grakovo, close to Kharkiv where the second largest cities in Ukraine, distinguished by a thick black A horizons (0-70 cm). On the way from Kharkiv to the south, the representative profile of Ordinary Chernozems was found in wheat filed of Krasnograd, which had a thick black to dark-brown A horizons (0-65 cm). Askania-Nova, the southeastern part of Ukraine, is the vast 'UNESCO Natural Reserved' area of natural virgin-steppe vegetation. The most dominant soils in Askania-Nova were Dark Chestnuts and Southern Chernozems, characterized by thin dark-brown A horizons (38 and 55 cm, respectively) and 'white-eye' type calcium carbonate accumulation in Bk horizons at the shallower depths.

13.3.2. Physico-chemical properties of Chernozems in Ukraine

Some general physico-chemical properties of the soil samples in Ukraine were shown in Table 13.4. Chernozemic soil samples in Ukraine were high in silt and clay fractions, exhibiting fine texture. Most soil texture was classified into silty clay loam (SiCL) or silty clay (SiC) except for some surface and subsurface soil samples, of which soil texture was classified into light clay (LiC) or heavy clay (HC). The soil pHs were neutral to slightly alkaline, reflecting high exchangeable calcium contents. The pH(H_2O) of Typical Chernozem (U1), Southern Chernozem (U3), and Dark Chestnut (U4), which were under natural steppe vegetation, increased with increase in soil depth. Organic carbon contents were high in surface horizons of each profile, decreasing with increase in soil depth. Cation-exchange-capacity (CEC) were also high in topsoils and highly correlated with organic carbon contents ($r = 0.881, p < 0.001$). Inorganic carbon contents, which mainly originated from calcium carbonate, were highest in the Bk horizons of U1, U3, and U4, and in the BA horizon of Ordinary Chernozem

Table 13.3. Brief description of the soil profiles in Ukraine.

Sample	Horizon	Depth (cm)	Soil color (Wet and field condition)	Accumulation
Typical Chernozem in Grakovo, Ukraine (U1)				
U1-1	A1	0-30	black (2.5Y 2/1)	humus
U1-2	A2	30-46	black (10YR 2/1)	humus
U1-3	A3	46-70	brownish black (7.5YR 3/1)	humus
U1-4	AB	70-105	dull yellowish brown (10YR 5/3)	mycelium-type $CaCO_3$
U1-5	Bk	105-120+	dull brown (7.5YR 5/4)	mycelium-type $CaCO_3$
Ordinary Chernozem in Krasnograd, Ukraine (U2)				
U2-1	Ap	0-23	brownish black (10YR 3/1)	humus
U2-2	A1	23-48	black (7.5YR 2/1)	humus
U2-3	A2	48-65	brownish black (7.5YR 3/1)	humus
U2-4	BA	65-88	dull yellowish brown (10YR 5/3)	mycelium-type $CaCO_3$
U2-5	BC	88-100+	dull yellowish brown (10YR 5/4)	white eye-type $CaCO_3$
Southern Chernozem in Askania-Nova, Ukraine (U3)				
U3-1	A1	0-25	brownish black (7.5YR 3/1)	humus
U3-2	A2	25-55	brownish black (7.5YR 3/1)	humus
U3-3	BA	55-70	brownish black & dull yellowish brown(10YR 3/2 & 10YR 5/4)	
U3-4	Bk	70-92	dull brown (7.5YR 5/4)	white eye-type $CaCO_3$
U3-5	BC	92-103+	dull yellowish brown (10YR 5/4)	
Dark Chestnut in Askania-Nova, Ukraine (U4)				
U4-1	A1	0-25	brownish black (7.5YR 3/2)	humus
U4-2	A2	25-38	grayish brown (7.5YR 4/2)	humus
U4-3	BA	38-64	dull yellowish brown(10YR 4/3)	
U4-4	Bk	64-90	dull brown (7.5YR 5/4)	white eye-type $CaCO_3$
U4-5	C	90-108+	dull yellowish brown (10YR 5/4)	

(U2), where distinct mycelium-type and/or white eye-type $CaCO_3$ accumulations were observed in the profiles (Table 13.3). Distribution of total carbon contents in each profile of Chernozems was shown in Fig. 13.1. The total carbon contents were more than 2 % for all horizons of U1 and U2, even in the lower horizons. The total carbon contents were higher in the A1 and Bk horizons of U3 and U4, where humus and calcium carbonate accumulations were found in the profiles, respectively, and lowest in the A2 horizons of both profiles.

The profiles of Typical Chernozem (U1), Southern Chernozem (U3), and Dark Chestnut (U4) investigated in the present study were under natural steppe vegetation, never affected by cultivation and agricultural practices. However, the profile of Ordinary Chernozem (U2) was under wheat cultivation. Strongly-developed angular blocky and/or subangular blocky structures with fine to medium sizes were distinctly observed in all horizons of the U1, U3, and U4 profiles. Moderately-developed fine subangular blocky structure was found in the Ap horizon of the U2 profile, and moderately- to strongly-developed subangular blocky structures were also observed in other horizons of the U2 profile. Although the soil color of the A2 horizon of the U2 profile was slightly darker than that of the Ap horizon (Table 13.3), the organic carbon content of the Ap horizon was slightly higher than that of the A2 horizon (Table 13.4). Judging from well-developed structures, soil dark colors, and organic carbon contents of the surface and subsurface soils of the arable U2 profile, it was supposed that agricultural management practices in this area were relatively extensive compared with those in Hungary and Canada described in the later section.

13.3.3. Characteristics of humic substances of Chernozems in Ukraine

Properties of humic substances and humification indexes in the surface and subsurface horizons of the Ukrainian profiles were presented in Table 13.5. The extracted carbon

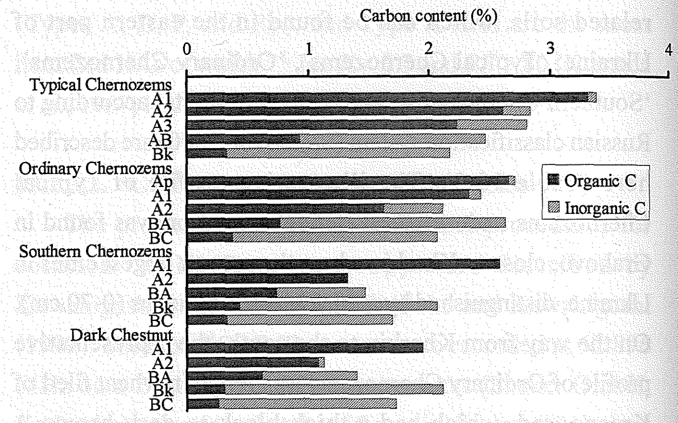

Figure 13.1. Organic and inorganic carbon contents of the soil samples in Ukraine.

Table 13.4. General physico-chemical properties of the soil samples in Ukraine.

Sample	horizon	Particle size distribution			Soil texture	pH (H_2O)	Carbon contents		CEC	Exchangeable cations			
		Clay	Silt	Sand			Organic	Inorganic		Mg	Ca	Na	K
			(%)				(%)		($cmol_c$ kg^{-1})		($cmol_c$ kg^{-1})		
Typical Chernozem in Grakovo, Ukraine (U1)													
U1-1	A1	43.4	37.7	18.9	LiC	7.52	3.32	0.06	35.0	3.80	68.9	0.16	2.17
U1-2	A2	23.9	57.6	18.5	SiCL	8.15	2.61	0.23	32.4	3.28	113	0.28	1.69
U1-3	A3	21.6	59.9	18.5	SiCL	8.32	2.23	0.58	25.3	4.26	118	1.34	1.65
U1-4	AB	19.2	62.5	18.3	SiCL	8.68	0.94	1.53	17.8	5.51	107	0.94	1.29
U1-5	Bk	27.8	54.7	17.5	SiC	8.79	0.33	1.84	16.3	6.40	103	0.79	1.29
Ordinary Chernozem in Krasnograd, Ukraine (U2)													
U2-1	Ap	37.9	40.5	21.6	LiC	8.34	2.67	0.06	31.1	3.07	75.2	0.13	2.45
U2-2	A1	32.6	45.5	21.9	SiC	8.25	2.33	0.09	30.3	3.02	83.8	0.21	1.84
U2-3	A2	19.6	59.9	20.4	SiCL	8.38	1.63	0.48	21.8	3.24	111	0.24	1.62
U2-4	BA	17.6	60.7	21.7	SiCL	8.51	0.77	1.86	11.5	3.63	104	0.28	1.14
U2-5	BC	19.2	58.5	22.3	SiCL	8.66	0.38	1.68	15.4	5.77	104	0.44	1.31
Southern Chernozem in Askania-Nova, Ukraine (U3)													
U3-1	A1	39.0	36.1	24.9	LiC	6.76	2.59	N.D.	23.9	5.29	38.5	0.16	5.13
U3-2	A2	45.5	36.1	18.3	HC	7.75	1.33	N.D.	26.0	7.71	38.6	0.36	2.76
U3-3	BA	22.6	58.4	19.0	SiCL	8.53	0.75	0.73	20.7	9.52	94.1	0.78	2.23
U3-4	Bk	28.5	53.1	18.4	SiC	9.15	0.44	1.64	15.9	10.6	91.3	2.55	1.41
U3-5	BC	26.7	56.3	17.0	SiC	9.28	0.33	1.37	16.8	12.2	121	4.67	1.46
Dark Chestnut in Askania-Nova, Ukraine (U4)													
U4-1	A1	35.1	38.3	26.6	LiC	7.11	1.95	N.D.	19.4	4.82	28.5	0.09	3.83
U4-2	A2	46.4	32.8	20.8	HC	7.58	1.08	0.06	25.0	5.95	27.9	0.15	2.23
U4-3	BA	21.2	57.1	21.7	SiCL	8.57	0.63	0.78	18.4	8.22	90.5	0.25	1.91
U4-4	Bk	22.7	55.0	22.3	SiCL	8.83	0.31	1.81	15.1	11.3	91.5	0.54	1.53
U4-5	C	23.8	53.2	23.0	SiCL	8.99	0.26	1.47	15.0	13.3	88.7	1.32	1.61

N.D., Not detected.

contents were higher in the surface soils than in the subsurface soils of each profile. The extracted carbon contents in fulvic acids (Cf) decreased in the order of *climosequence* of the soils from the northern wetter zone to the southern drier zone. The total extracted carbon content (Cf + Ch) was highest in the A1 horizon of the Typical Chernozem (U1-1) and lowest in the A2 horizon of the Southern Chernozem (U3-1). The Ch to Cf ratio (Ch/Cf) and the humic acid ratio in extracted humus (*PQ*) of the Southern Chernozem (U3) and Dark Chestnut (U4) were higher than those of the Typical Chernozem (U1) and Ordinary Chernozem (U2). Especially, the *PQ* values of the subsurface horizons of the U3 and U4 profiles were more than 95 %, probably due to strong affinity of soil mineral colloids to the FAs, microbial depletion of the FAs, and/or other factors.

The humification indexes (Δ log *K* and *RF*) and classification diagram of HAs in the surface and subsurface horizons of the soil profiles in Ukraine were shown in Table 13.5 and Fig. 13.2, respectively. The averaged value of Δ log *K* was 0.56, which was slightly higher than those of HAs (0.52) in Japanese Andisols (Maie *et al.*, 2002), and a distinct difference between the HAs of the Chernozems in Ukraine were not observed. On the other hand, the *RF* values were remarkably higher in the surface and subsurface horizons of the Typical Chernozem (U1-1 and U1-2) and Ordinary Chernozem (U2-1 and U2-2) than those of the Southern Chernozem (U3-1 and U3-2) and Dark Chestnut (U4-1 and U4-2). The *RF* values increase as the humification of highly humified HAs progresses (Kumada, 1987). The humification degree of HAs of the Chernozems developed in the wetter zone of Ukraine was higher than those in the drier zone. Most of HAs in the surface and subsurface horizons of the Chernozems in Ukraine were classified into Type A except for U4-2 (Fig. 13.2).

^{13}C NMR spectra obtained for the six HAs extracted and purified from the surface and subsurface horizons of the Chernozems in Ukraine were shown in Fig. 13.3. The patterns and peak strength of all the spectra were much the same. Two resonances, due to aromatic and C=C carbon around 130 ppm and C=O in the carboxylic groups around 175 ppm, predominated in the spectra of all the HAs. Especially, the

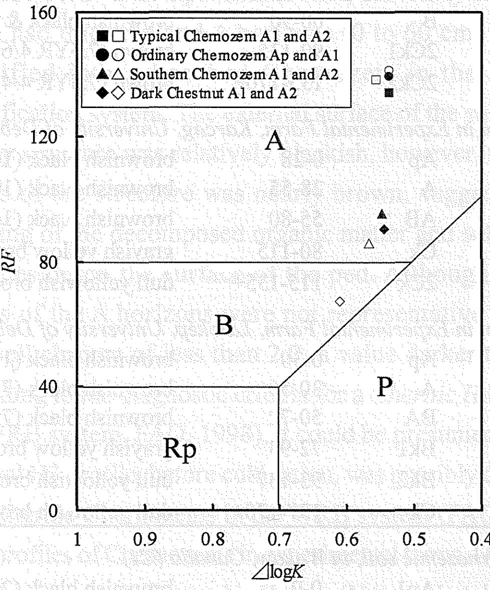

Figure 13.2. Classification diagram of humic acids in the surface and subsurface horizons of the soil profiles in Ukraine.

Table 13.5. Properties of humic substances in the surface and subsurface horizons.

Sample	horizon	Extracted carbon Cf (mg g^{-1})	Extracted carbon Ch (mg g^{-1})	Ch/Cf	*PQ*	Humic acid ⊿log*K*	Humic acid *RF*	Humic acid Type
Typical Chernozem in Grakovo								
U1-1	A1	3.8	17.4	4.6	82	0.54	134	A
U2-1	A2	3.8	11.4	3.0	75	0.56	138	A
Ordinary Chernozem in Krasnograd								
U2-1	Ap	2.9	14.5	5.0	83	0.54	139	A
U2-2	A1	2.3	13.4	5.8	85	0.54	142	A
Southern Chernozem in Askania-Nova								
U3-1	A1	1.9	17.2	9.1	90	0.55	95	A
U3-2	A2	0.5	9.6	19.2	95	0.57	86	A
Dark Chestnut in Askania-Nova								
U4-1	A1	1.4	13.9	9.9	91	0.55	90	A
U4-2	A2	0.4	11.4	28.5	97	0.61	67	B

Cf: extracted carbon contents in fulvic acids (FA)
Ch: extracted carbon contents in humic acids (HA)

Table 13.6. Brief description of the soil profiles in Hungary and Canada.

Sample	Horizon	Depth (cm)	Soil color (Wet and field condition)	Accumulation
Chernozem (Ustolls) in Valence Lake, near Budapest, Hungary (H1)				
H1-1	Ap	0-25	brownish black (7.5YR 3/2)	
H1-2	BA	25-60	dark brown (10YR 3/3)	mycelium-type $CaCO_3$
H1-3	Ck	60-100	dull yellow (2.5Y 6/4)	mycelium-type $CaCO_3$
H1-4	2Ck	100-150+	yellowish brown (2.5Y 5/4)	mycelium-type $CaCO_3$
Chernozem (Udolls) in Valence Lake, near Budapest, Hungary (H2)				
H2-1	Ap	0-32	brownish black (10YR 2/2)	
H2-2	BA	32-75	brownish black & grayish yellow brown (10YR 3/1 & 10YR 6/2)	mycelium-type $CaCO_3$
H2-3	Ck	75-100	yellowish brown (2.5Y 5/4)	mycelium-type $CaCO_3$
H2-4	2Ck	100-150+	yellowish brown & grayish yellow brown (2.5Y 5/4 & 10YR 5/2)	
Leached Chernozem in Experimental Farm, University of Gödöllõ, Hungary(H3)				
H3-1	Ap	0-32	dark brown (10YR 3/3)	
H3-2	A	32-60	brownish black (7.5YR 3/2)	
H3-3	B	60-90	brownish black & dull yellowish brown (7.5YR 3/2 & 10YR 5/4)	
H3-4	2Ck1	90-135	brown (7.5YR 4/6)	mycelium-type $CaCO_3$
H3-5	2Ck2	135-170+	brown (7.5YR 4/4)	mycelium-type $CaCO_3$
Chernozem in Experimental Farm, Karcag, University of Debrecen, Hungary (H4)				
H4-1	Ap	0-28	brownish black (10YR 3/1 & 10YR 3/2)	humus
H4-2	A	28-55	brownish black (10YR 3/1)	humus
H4-3	AB	55-80	brownish black (10YR 3/2)	mycelium-type $CaCO_3$
H4-4	Ck	80-115	grayish yellow brown & dull yellowish brown (10YR 4/2 & 10YR 5/4)	mycelium-type $CaCO_3$
H4-5	2Ck	115-135+	dull yellowish brown (10YR 5/4)	mycelium-type $CaCO_3$
Chernozem in Experimental Farm, Latokép, University of Debrecen, Hungary (H5)				
H5-1	Ap	0-30	brownish black (10YR 3/1)	humus
H5-2	A	30-50	brownish black (7.5YR 3/1)	humus
H5-3	BA	50-72	brownish black (7.5YR 3/2)	
H5-4	Bk1	72-93	grayish yellow brown (10YR 4/2)	mycelium-type $CaCO_3$
H5-5	Bk2	93-137	dull yellowish brown (10YR 5/3)	mycelium-type $CaCO_3$
H5-6	Ck	137-170+	dull yellowish brown (10YR 5/4)	white eye-type $CaCO_3$
Black Chernozemic soil, in Wakaw, Canada (C1)				
C1-1	Ap1	0-9	brownish black (2.5Y 3/1)	humus
C1-2	Ap2	9-18	brownish black (2.5Y 3/1)	humus
C1-3	A/B	18-23	brownish black & olive brown (2.5Y 3/1 & 2.5Y 4/3)	
C1-4	Bk1	23-43	yellowish brown (2.5Y 5/3)	white eye-type $CaCO_3$
C1-5	Bk2	43-56	yellowish brown (2.5Y 5/3)	white eye-type $CaCO_3$
C1-6	BC	56-70+	yellowish brown (2.5Y 5/3)	
Dark Brown Chernozemic soil in Kenaston, Canada (C2)				
C2-1	Ap1	0-9	brownish black (2.5Y 3/2.5)	
C2-2	Ap2	9-20	olive brown (2.5Y 3.5/3)	
Brown Chernozemic soil in Swift Current, Canada (C3)				
C3-1	Ap	0-12	olive brown (2.5Y 4/3)	
C3-2	Bk	12-24	dull yellow (2.5Y 6/3)	white eye-type $CaCO_3$
C3-3	BC	24-37		
C3-4	2C	37-48+		

peak strength of aromatic C around 130 ppm was higher than that of carboxylic C around 175 ppm. Apparently, these spectra were characterized by the presence of highly aromatic HAs with a high content of aromatic C and carboxylic C (Fujitake and Kawahigashi, 1999). The spectra of the HAs extracted from the Chernozems in Ukraine were remarkably similar to those of Type A HAs extracted from Japanese Andisols (Fujitake, 2003). Three resonances, due to aliphatic C around 30 ppm, methoxyl C around 57 ppm, and carbohydrate around 80 ppm, were extremely weak in all the spectra. These distinctive features were most obvious in the spectrum of the HA extracted from Ap horizon of the Ordinary Chernozem (U2-1), being similar to those of HAs extracted buried Andisols (Fujitake, 2003).

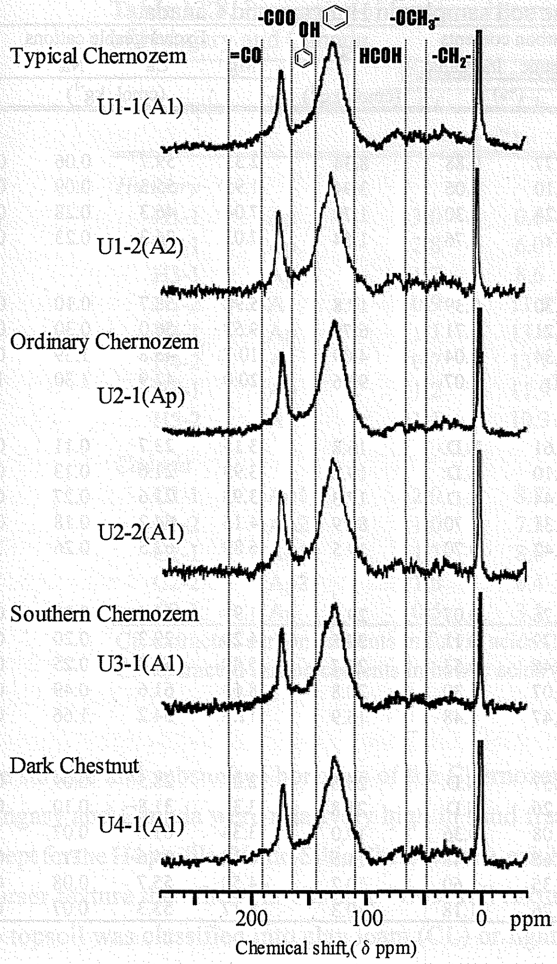

Figure 13.3. Solution ^{13}C NMR spectra of humic acids extracted and purified from surface and subsurface horizons of Chernozems and Chestnut soils in Ukraine.

13.4. Agricultural use and soils in the Eurasian steppe

13.4.1. Chernozemic soils in Hungary and Canada

Chernozemic soils are one of the most fertile soils in the world, rich in both organic matter and plant nutrients. During the warm summer, large quantities of organic matter are produced under natural steppe and mixed vegetation, which can assure the everlasting fertility of Chernozemic soils. However, the lands covered by Chernozemic soils and the climatic conditions in such areas are suitable for wheat, barley and maize production, alongside other food crops and vegetables. The intensive agricultural practice would induce soil carbon degradation, due to low input of plant residues and high microbial decomposition of organic matter accompanied by plowing, resulting in irreversible decrease in the soil fertility.

Chernozemic soils are widely distributing in Hungary, especially in the vast areas of the eastern plain called as 'puszta'. Since the intensive wheat and maize productions have been conducted in such areas, lands under the natural steppe vegetation are almost scarce. The soil colors of the surface horizons in these areas are brownish black to dark brown, not real black, probably reflecting the soil carbon degradation through agricultural practices (Table 13.6). Two profiles of Chernozems in Valence Lake, near Budapest (H1 and H2), had relatively thin humic A horizons. Weakly-developed fine granular and/or subangular blocky structures were observed in surface and subsurface horizons of the H1 and H2 profiles, and the hardness of these horizons was compact, probably due to intensive agricultural management practices. These profiles were classified into Calcic-Siltic Chernozems or Calcic Chernozems in the WRB system (FAO, 1998). A profile in an experimental farm, University of Gödöllõ (H3), had thick Ap and A horizons (0 to 60 cm) and was classified into a Leached Chernozem in the Russian classification system. The external surface of the subangular blocky structure was relatively blackish, however, the inner colors of the structure was nearly brown, suggesting the leaching of the decomposed organic matter and subsequent re-adhesion on the surface of the ped. Although the soil colors of the A horizons were not representative black (a Munsell chroma of less than 2.0, a value darker than 2.0, according to the diagnostic criteria for a *Chernic Horizon*, in the WRB system, FAO, 1998), it could be presumed that the original H3 profile, before cultivation, was possibly classified into Chernic Chernozems in the WRB system (FAO, 1998). Two profiles of Chernozems in experimental farms, University of Debrecen, were observed in Karcag (H4) and Latokép (H5). The soil colors of A horizons in the H4 and H5 profiles were relatively darker than those in the H1, H2, and H3 profiles, of which Munsell chromas were mostly 1.0. Since the 'slickensides' were observed on the structural surfaces of the Ap and A horizons, and fine fractions of clay and silt were dominated in the A horizons, the H4 profile was classified into Vertic-Siltic Chernozems in the WRB system (FAO, 1998). Strongly-developed fine to medium subangular blocky structures were found in the A horizon of the H4 profile. The H5 profile had thick A horizons (0 to 50 cm) and their hardness was medium, not compact. It could be assumed that the virgin H5 profile was possibly classified into Chernic Chernozems in the WRB system (FAO, 1998) as same as the H3 profile. Moderately-developed fine subangular block structures were observed even in the Ap horizon, suggesting that the impacts of agricultural practices on the soil carbon depletion and soil degradation could be less critical in the H4 and H5 profiles.

Chernozemic soils are widely distributing in the central and south part of Canada, which support the intensive wheat,

Table 13.7. General physico-chemical properties of the soil samples in Hungary and Canada.

		Particle size distribution			Soil	pH	Carbon contents		CEC	Exchangeable cations			
Sample	horizon	Clay	Silt	Sand	texture	(H_2O)	Organic	Inorganic		Mg	Ca	Na	K
			(%)				(%)		(cmol$_c$ kg^{-1})		(cmol$_c$ kg^{-1})		
Chernozem (Ustolls) in Valence Lake, near Budapest, Hungary (H1)													
H1-1	Ap	19.7	30.2	50.1	CL	8.24	1.77	0.88	8.34	2.33	59.7	0.06	0.40
H1-2	BA	5.2	46.4	48.3	SiL	8.36	1.10	2.06	3.94	1.95	55.3	0.09	0.20
H1-3	Ck	12.3	27.4	60.4	L	8.86	0.24	3.30	1.70	7.04	46.3	0.28	0.11
H1-4	2Ck	3.9	32.9	63.2	SL	9.30	Tr.	2.76	1.84	7.03	36.3	0.23	0.12
Chernozem (Udolls) in Valence Lake, near Budapest, Hungary (H2)													
H2-1	Ap	24.6	37.2	38.1	CL	8.41	2.30	0.39	17.8	5.90	58.7	0.10	0.56
H2-2	BA	21.8	37.9	40.2	CL	8.67	1.21	1.71	6.79	9.53	56.0	0.30	0.29
H2-3	Ck	16.6	46.7	36.7	SiCL	9.31	0.34	3.04	4.09	10.7	48.8	1.39	0.68
H2-4	2Ck	32.7	45.1	22.2	SiC	9.31	Tr.	2.07	9.96	20.0	42.9	1.30	1.71
Leached Chernozem in Experimental Farm, University of Gödöllõ, Hungary(H3)													
H3-1	Ap	30.7	34.4	34.9	LiC	6.62	1.61	N.D.	16.8	3.15	23.7	0.11	0.49
H3-2	A	36.3	29.2	34.5	LiC	6.82	1.10	N.D.	19.2	3.93	21.6	0.13	0.42
H3-3	B	35.9	25.8	38.3	LiC	7.09	0.44	N.D.	17.3	3.93	21.6	0.27	0.46
H3-4	2Ck1	17.1	38.5	44.4	CL	8.40	0.31	1.70	8.79	4.15	64.2	0.18	0.29
H3-5	2Ck2	18.3	38.4	43.3	CL	8.21	0.42	0.70	19.5	6.89	62.5	0.26	1.28
Chernozem in Experimental Farm, Karcag, University of Debrecen, Hungary （H4)													
H4-1	Ap	38.0	45.2	16.7	SiC	6.73	1.76	0.07	29.3	1.97	11.4	0.08	0.40
H4-2	A	42.1	39.8	18.2	LiC	7.82	1.79	0.11	27.5	4.28	29.3	0.20	0.67
H4-3	AB	7.4	76.1	16.5	SiL	8.29	1.46	0.53	25.7	5.49	65.3	0.25	0.55
H4-4	Ck	29.2	52.3	18.4	SiC	8.45	1.07	1.30	20.8	8.63	61.6	0.49	0.43
H4-5	2Ck	29.2	52.3	18.5	SiC	8.88	0.47	1.48	15.9	11.3	54.2	1.66	0.41
Chernozem in Experimental Farm, Latokép, University of Debrecen, Hungary （H5)													
H5-1	Ap	29.8	28.0	42.2	LiC	7.79	1.57	N.D.	25.6	2.27	28.5	0.09	0.88
H5-2	A	29.3	27.8	42.9	LiC	7.90	1.26	N.D.	21.8	3.31	31.8	0.10	0.76
H5-3	BA	22.1	35.9	42.0	CL	8.39	1.08	0.36	19.0	3.34	61.3	0.07	1.30
H5-4	Bk1	20.0	38.9	41.1	CL	8.53	0.65	1.48	11.5	0.19	14.6	Tr.	0.04
H5-5	Bk2	20.2	36.8	43.0	CL	8.55	0.35	1.60	10.2	4.59	55.7	0.08	0.30
H5-6	Ck	17.7	34.7	47.6	CL	8.83	0.26	1.18	10.3	8.17	53.3	0.07	0.29
Black Chernozemic soil, in Wakaw, Canada (C1)													
C1-1	Ap1	23.2	27.6	49.2	CL	8.22	2.22	0.36	17.0	8.14	51.4	0.17	2.80
C1-2	Ap2	23.0	27.0	50.0	CL	8.32	1.90	0.45	16.6	10.7	54.6	0.28	1.50
C1-3	A/B	20.2	29.6	50.2	CL	8.30	1.01	0.52	15.0	14.0	48.1	0.39	1.24
C1-4	Bk1	21.1	29.1	49.8	CL	8.55	0.43	2.15	5.81	16.7	81.9	0.55	0.76
C1-5	Bk2	18.1	50.9	31.1	SiCL	8.56	0.28	2.62	6.87	22.4	78.8	0.86	0.91
C1-6	BC	17.2	50.7	32.1	SiCL	8.55	Tr.	2.06	7.88	20.6	74.6	0.90	1.03
Dark Brown Chernozemic soil in Kenaston, Canada (C2)													
C2-1	Ap1	23.6	20.1	56.2	CL	7.76	1.79	0.27	14.3	4.72	28.5	0.12	4.14
C2-2	Ap2	24.3	22.8	52.9	CL	7.43	0.98	0.31	13.0	5.38	20.4	0.16	1.11
Brown Chernozemic soil in Swift Current, Canada (C3)													
C3-1	Ap	28.0	20.3	51.7	LiC	8.23	0.88	0.27	17.4	6.60	30.9	0.23	2.60
C3-2	Bk	35.0	33.6	31.4	LiC	8.71	0.69	3.06	8.89	10.1	91.6	0.28	0.80
C3-3	BC	26.7	28.5	44.8	LiC	8.85	0.56	2.54	6.37	13.8	85.9	0.40	0.83
C3-4	2C	20.9	15.4	63.7	SCL	9.02	Tr.	1.84	6.23	16.2	74.3	0.43	0.86

Tr., Trace amount; N.D., Not detected.

barley, and canola productions. Three profiles of Chernozemic soils derived from lacustrine deposits, not from loess materials, in Saskatchewan, where must be a center for the crop production in Canada, were classified into a Black Chernozemic soil (C1), a Dark Brown Chernozemic soil (C2), and a Brown Chernozemic soil (C3) according to the Canadian system of soil classification (Agriculture and Agri-Food Canada, 1998). Although the C1 profile was classified into Chernozems in the WRB classification system, the C3 profile was classified into Calcic-Anthric Kastanozems (Table 13.1), of which soil color of the surface horizon was olive brown and not black. Weakly-developed fine granular and/or subangular blocky structures were observed in Ap horizons of the C1 and C3 profiles as observed in those of the H1 and H2 profiles, suggesting that the intensive agricultural management practices and heavy tillage would lead to soil compaction and structural degradation (Birkás *et al.*, 2004).

13.4.2. Intensive agriculture and soil physico-chemical properties

Some general physico-chemical properties of the soil samples in Hungary and Canada were shown in Table 13.7.

Table 13.8. Properties of humic substances in the surface and subsurface horizons of the profiles of Hungary and Canada.

Sample	Horizon	Extracted carbon Cf (mg g^{-1})	Extracted carbon Ch (mg g^{-1})	Ch/Cf	*PQ*	Humic acid ⊿log*K*	Humic acid *RF*	Humic acid Type
Hungary								
H1-1	Ap	3.0	0.6	0.2	17	0.78	45.7	B
H2-1	Ap	2.8	6.0	2.1	68	0.59	90.1	A
H3-1	Ap	1.7	8.6	5.1	83	0.59	98.5	A
H3-2	A	0.9	11.5	12.8	93	0.60	79.9	B
H4-1	Ap	1.1	13.4	12.2	92	0.58	100.5	A
H4-2	A	0.7	13.7	19.6	95	0.57	107.7	A
H5-1	Ap	1.2	11.9	9.9	91	0.55	110.8	A
H5-2	A	1.1	10.3	9.4	90	0.56	118.7	A
Canada								
C1-1	Ap1	2.0	8.7	4.4	81	0.65	99.5	A
C1-2	Ap2	1.0	7.3	7.3	88	0.60	98.5	A
C2-1	Ap1	1.1	8.0	7.3	88	0.55	85.5	A
C2-2	Ap2	1.8	8.4	4.7	82	0.57	75.8	B
C3-1	Ap	0.5	3.1	6.2	86	0.66	57.7	B

Cf: extracted carbon contents in fulvic acids (FA)
Ch: extracted carbon contents in humic acids (HA)

The surface and subsurface horizons of the Chernozems in Hungary and Canada were relatively high in sand fraction except for the H4 profile (Vertic-Siltic Chernozems), exhibiting coarser texture than those in Ukraine. Most soil texture of the topsoil was classified into clay loam (CL) or light clay (LiC), probably due to erosion in some cases (Mezosi and Szatmari, 1998; Gábris *et al.*, 2003), while silty texture was predominated in Ukraine. The soil pHs were mostly neutral to slightly alkaline, reflecting high exchangeable calcium contents. However, the pH(H_2O) of the surface soils of the H3 and H4 profiles were below 7, probably due to high application of mineral N fertilizers and consequent nitrification of residual N (Nemeth, 1995). Organic carbon contents were high in surface and subsurface horizons of each profile, decreasing with increase in soil depth. Inorganic carbon contents were higher in the Bk and Ck horizons, where distinct mycelium-type and/or white eye-type $CaCO_3$ accumulations were observed in the profiles (Table 13.6).

The weighted-average values of organic carbon contents (%) in the surface layers (0 to 30 cm) of Chernozems and Kastanozem were shown in Fig. 13.4. The organic carbon content was highest in the Typical Chernozem of Ukraine (U1), followed by the Ordinary Chernozem (U2), and the Southern Chernozem (U3) of Ukraine. The organic carbon contents in arable soils of Hungary and Canada were generally lower than the soils in Ukraine, mostly less than 2 %. The soil carbon degradation would cause a global warming through carbon dioxide emission and also a desertification of semi-arid and/or steppic zones. The balance of SOM should be critical to preserve the vast areas of the fertile soils in the Eurasian Steppe, which could assure a luxuriant production of crops and grasses.

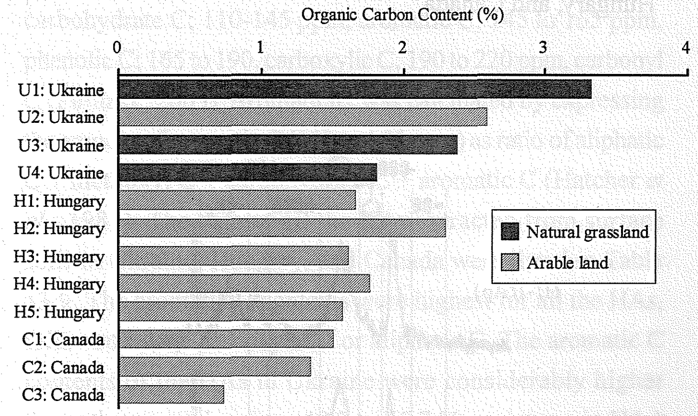

Figure 13.4. Weighted-average of organic carbon contents in topsoils (0-30 cm) of Chernozems.

13.4.3. Intensive agriculture and SOM dynamics of humic acids

Properties of humic substances and humification indexes in the surface and subsurface horizons of the Hungarian and Canadian profiles were listed in Table 13.8. The extracted carbon contents (Cf + Ch) in the surface soils of Hungary and Canada ranging from 3.6 to 14.5 mg g^{-1}, being less than those of Ukraine ranging from 15.3 to 21.2 mg g^{-1}. However, those in the subsurface soils were much the same. Although the extracted carbon contents in humic acids (Ch) were higher

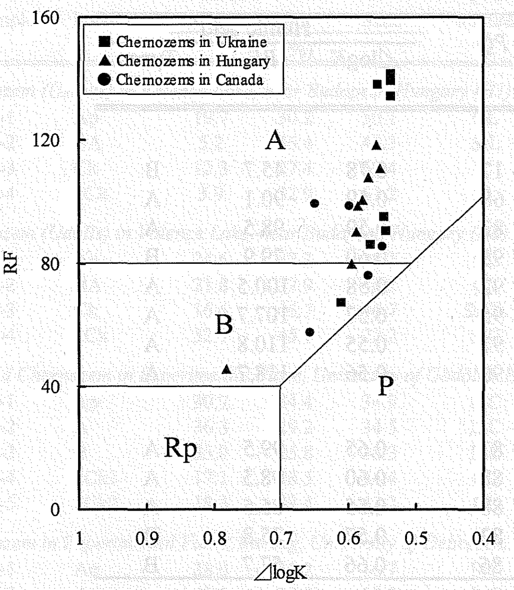

Figure 13.5. Classification diagram of humic acids in surface and subsurface horizons of the Chernozems in Ukraine, Hungary, and Canada.

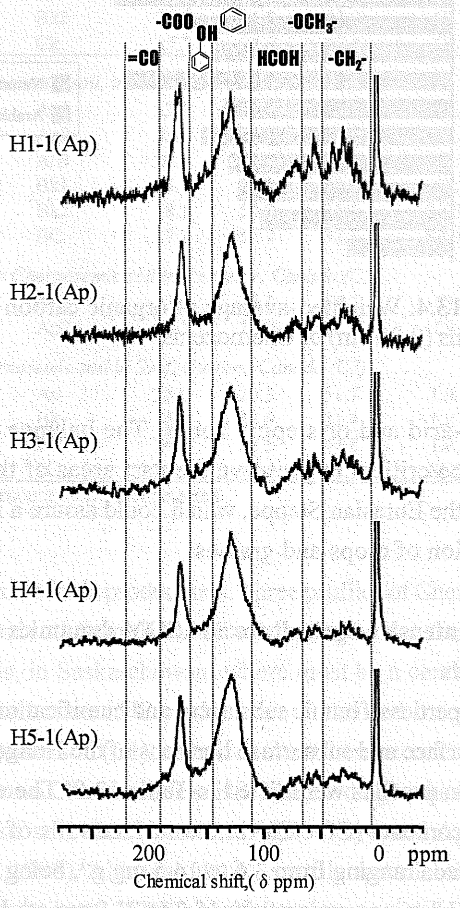

Figure 13.6. Solution ^{13}C NMR spectra of humic acids extracted and purified from surface horizons of Chernozems in Hungary.

in the surface soils than in the subsurface soils of each profile in Ukraine, the inverse results were observed in the H3, H4, and C2 profiles. The *PQ* values were mostly more than 80 % except for the H1 and H2 profiles. Klimowicz and Uziak (2001) reported that the long-term cultivation on silty soils developed from loess materials in Poland had induced no further change in humus content, but increase in the portion of FAs at the expense of HAs. Their results were consistent with those of the H1 and H2 profiles, however, contradictory to those of the H4 and H5 profiles, where the *PQ* values were high and more than 90 %.

The classification diagram of HAs in the surface and subsurface horizons of all the soil profiles were shown in Fig. 13.5. The $\Delta \log K$ values of the HAs of Hungary ranged from 0.55 to 0.78, and the mean value was 0.60, which was higher than that of Ukraine (0.56). The mean value was 0.58 without the H1-1, of which the $\Delta \log K$ value was exceptionally higher than others (Table 13.8). The mean $\Delta \log K$ value of the HAs of Canada was 0.60, which was also higher than that of Ukraine. The *RF* values of the HAs of Hungary and Canada were mostly more than 80, while those of the H1-1 and C3-1 were remarkably lower than others (Table 13.8). Most of the HAs in the surface and subsurface horizons of the Chernozems in Hungary and Canada were classified into Type A HAs except for H1-1, H3-2, C2-2, and C3-1, which were classified into Type B HAs (Fig. 13.5). The *RF* values of the HAs of the H4 and H5 profiles were more than 100, and higher in the subsurface horizons than in the surface horizons, as same as the case of the U1 and U2 profiles (Table 13.5). In the previous section (4-1), it was suggested

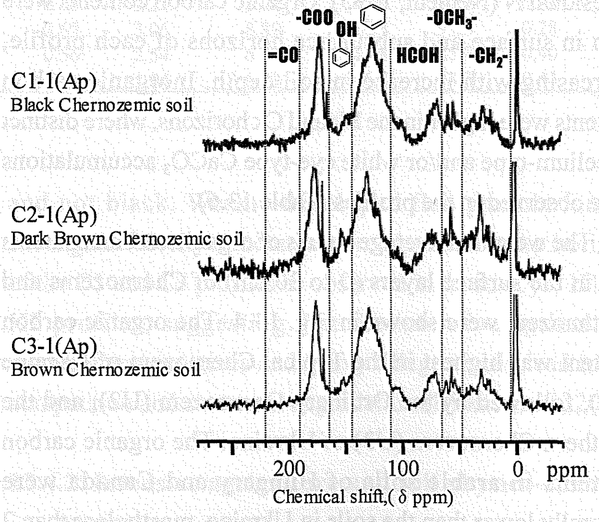

Figure 13.7. Solution ^{13}C NMR spectra of humic acids extracted and purified from surface horizons of Chernozems in Canada.

that the impacts of agricultural practices on the soil carbon depletion and soil degradation could be less critical in the H4 and H5 profiles than other profiles in Hungary and Canada, judging from well-developed soil structures and blackish soil colors. The relatively high humification degree of the H4 and H5 profiles also supported the above interpretation. However, the *RF* values of the H3 and H5 profiles, of which original soil types before cultivation in the WRB classification system (FAO, 1998) were presumed to be Chernic Chernozems, were lower than the values of the U1 profile corresponding to Chernic Chernozems, suggesting the *RF* values would decrease by the agricultural impacts to greater and lesser degrees.

^{13}C NMR spectra obtained for the HAs extracted and purified from the surface horizons of the Chernozems in Hungary and Canada were shown in Fig. 13.6 and Fig. 13.7, respectively. The patterns and peak strength of the spectra of the HAs extracted from H4-1 and H5-1 were much the same with those of the HAs in Ukraine (Figs. 13.3 and 13.6), where two resonances, due to aromatic and C=C carbon around 130 ppm and C=O in the carboxylic groups around 175 ppm, predominated in the spectra of all the HAs. Although these two peaks were distinct even in the HAs extracted from H1-1, H2-1, and H3-1, three resonances, due to aliphatic C around 30 ppm, methoxyl C around 57 ppm, and carbohydrate around 80 ppm, were stronger to a certain extent than the HAs in the H4-1, H5-1, and Ukrainian samples. Especially, the peak strength of aromatic C around 130 ppm was lower than that of carboxylic C around 175 ppm in the spectrum of the HA of H1-1, and the resonances of aliphatic C and methoxyl C of the HA of H1-1 were more obvious than other spectra. The spectra of the HAs of C1-1, C2-1, and C3-1 were comparatively similar to that of H1-1 (Fig. 13.7). The peak strength of carbohydrate around 80 ppm of the HAs in Canada was slightly stronger than the HAs in Hungary and Ukraine. Fujitake and Kawahigashi (1999) reported that the peak strength around 30 ppm assigned to chains of methylene group had increased remarkably with the increase of the particle size in the ^{13}C NMR spectra of fractions with different particle sizes from an Andosol humic acids. The spectra of the larger particle size fraction (more than 100 K) shown by Fujitake and Kawahigashi (1999) were resembling with those of H1-1, H3-1, C1-1, C2-1, and C3-1, suggesting that depletion of the smaller particle size fractions of highly aromatic HA would occur due to the intensive agricultural managements and insufficient conservation.

To compare the carbon species distribution, the spectra were divided into the following seven areas: 10 to 48 ppm, aliphatic C; 48 to 65 ppm, methoxyl C; 65 to 110 ppm, carbohydrate C; 110-145 ppm, aromatic C; 145 to 165 ppm, phenolic C; 165 to 190, carboxylic C; 190 to 220 ppm, carbonyl C (Fujitake, 2003). Aromaticity was calculated by expressing the amount of aromatic C (110 to 165 ppm) as ratio of aliphatic C + methoxyl C + carbohydrate C + aromatic C (Hatcher *et al.*, 1981). The data of all the HAs extracted from surface soils in Ukraine, Hungary, and Canada were listed in Table 13.9. The aromatic C contents were highest for all the HAs, followed by the carboxylic C or aliphatic C. The aromatic C contents of the HAs in Ukraine were considerably higher than others, ranging from 48.2 to 55.7 %, and those in H4-1 (51.7 %) and H5-1 (47.1 %) were also high. Although the aromatic, carboxylic, and phenolic C were the highest three

Table 13.9. Distribution of carbon species of humic acids in the surface horizons of each profile in Ukraine, Hungary, and Canada.

Sample	Horizon	Chemical shift (δ, ppm)							Aromaticity
		10-48 (aliphatic)	48-65 (methoxyl)	65-110 (carbohydrate)	110-145 (aromatic)	145-165 (phenolic)	165-190 (carboxylic)	190-220 (carbonyl)	
Ukraine									
U1-1	A1	8.63	4.24	8.78	48.23	9.95	16.70	3.46	0.73
U2-1	Ap	6.57	2.51	5.87	55.70	9.37	17.48	2.51	0.81
U3-1	A1	7.52	3.78	8.52	50.50	9.69	16.79	3.21	0.75
U4-1	A1	5.60	3.54	6.69	53.79	10.18	17.28	2.92	0.80
Hungary									
H1-1	Ap	19.68	10.74	11.70	30.94	5.99	18.10	2.84	0.47
H2-1	Ap	12.60	6.15	8.57	44.61	7.95	18.49	1.64	0.66
H3-1	Ap	15.96	7.79	11.15	38.60	7.93	15.68	2.90	0.57
H4-1	Ap	8.86	4.69	7.81	51.69	8.10	17.44	1.41	0.74
H5-1	Ap	10.84	5.08	6.05	47.13	9.64	18.83	2.43	0.72
Canada									
C1-1	Ap	12.10	7.68	14.41	38.17	7.18	17.37	3.10	0.57
C2-1	Ap	17.97	10.06	13.33	31.39	6.97	17.72	2.55	0.48
C3-1	Ap	11.54	7.17	12.34	40.73	7.60	18.74	1.88	0.61

carbon species in the HAs of Ukraine, the aromatic, carboxylic, and aliphatic C were predominated three carbon species in the HAs of H4-1 and H5-1. The mean contents of aliphatic C of Hungary and Canada were 13.6 and 13.9 %, respectively, twice as high as that of Ukraine (7.1 %). The carbohydrate C contents of Canada were slightly higher than those of Ukraine and Hungary. The aromaticity of U1-1, U2-1, U3-1, U4-1, H4-1, and H5-1 was more than 0.7, and higher than those of others. Fujitake and Kawahigashi (1999) indicated that the aromaticity of the HA in an Andosol decreased from 0.73 to 0.51 with the increase in the particle size from 3 K to 500 K, where the aromaticity of the whole HA was 0.63. From the results, it was inferred that the intensive agricultural impacts could lead to changes in the SOM quality of humic acids, especially the decrease in the aromatic HAs of smaller particle size.

13.5. Conclusion

The greater part of lands is covered by Chernozems and the related soils in Ukraine, where must be the central and representative Chernozemic zones in the Eurasian steppe. In the eastern part of Ukraine, the *climosequence* of the soils from the northern wetter zones to the southern drier zones can be distinctly observed. Under the moist conditions in the north, Typical Chernozems and Ordinary Chernozems, which can be distinguished by a deep black surface horizon with strongly-developed structures and the highly humified Type A humic acids, of which the *RF* value and aromaticity are remarkably high. Southern Chernozems and Dark Chestnuts are the common subtypes under the relatively dry moisture regime, the profiles of which can be characterized by a relatively thin dark-brown or brownish black surface horizon. These soils are also characterized by the Type A humic acids, however, the *RF* value is less than Typical Chernozems and Ordinary Chernozems. The carbon stock as organic carbon and/or inorganic carbon through the profile is extremely high in either case, can support and assure a luxuriant production of plant and biomass, and can reduce greenhouse gases.

The lands covered by Chernozemic soils and the climatic conditions in such areas are suitable for wheat, barley and maize production, alongside other food crops and vegetables. The intensive agricultural practice would induce soil carbon degradation, due to low input of plant residues and high microbial decomposition of organic matter accompanied by plowing, resulting in irreversible decrease in the soil fertility. The soil colors of the surface horizons in the arable soils of Hungary and Canada are brownish black to dark brown, not real black, and the organic carbon contents in the topsoils are relatively lower than those of Ukraine, probably reflecting the soil carbon degradation through agricultural impacts. They are characterized by the Type A or B humic acids, of which ” └ log *K* value is higher, the *RF* value is lower, and aromaticity is remarkably lower than those of the typical Type A humic acids observed in Ukraine.

From the results, it was inferred that the intensive agricultural impacts can lead to changes not only in the SOM quantity but also in the SOM quality of humic acids, especially the decrease in the aromatic and highly-humified HAs of smaller particle size. The long-term cultivation and fertilization may contribute to the formation of labile (not stable) humic substances (larger particle size) at the expense of highly aromatic HAs (smaller particle size), which are more resistant to microbial decomposition and act as the binding agents of aggregate stability, resulting in deterioration of soil structure and depletion of soil fertility.

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Chapter 14

Characterization of soil organic matter status of Chernozem soils from different climatic regions of former Soviet Union

Elmira Karbozova-Saljnikov and Takashi Kosaki

14.1. Background

Climate impacts the soil organic carbon (organic C) content primarily through the effects of temperature, moisture, and solar radiation on the array and growth rate of plant species, and on the rate of soil organic C mineralization. Post et al. (1982) have found that amounts of soil organic C were positively correlated with precipitation and, at a given level of precipitation, negatively correlated with temperature.

Soil maintenance can have a varying influence on the total, microbial, and readily mineralizable pools of soil organic carbon (SOC) depending on inherent site characteristics, including soil texture and climate (Collins et al., 1992; Gupta et al., 1994; Franzluebbers et al., 1994; Franzlueberrs and Arshad, 1996). Climatic influences on biologically active fractions of SOM are not well understood. This limits environmental assessment system that is based on the mechanisms of transformations and storage of organic matter (Franzluebbers et al., 2001). Number of studies reported that stock of SOC is generally greater in both colder and wetter climates compared with hotter and drier climates (e.g., Jenkinson, 1988).

Van Veen et al. (1985), Ladd and Amato (1988), and Voroney et al. (1989) have reported stabilizing effect of clay particles on SOM and microbial biomass. West et al. (1988a) have found that soil texture affects the rate of decline of microbial biomass C in air-dried soils; and Marshall (1975) has stated that clay particles may protect cells from the effects of desiccation and predation.

Many studies have demonstrated a relationship between decomposition and plant residue characteristics thought to be indicative of residue quality (Edmonds and Thomas, 1995; Hobbie, 1996; Cortez et al., 1996; Agren and Bosatta, 1996).

14.2. Description of study soils

Four experimental sites all located within the Chernozem Belt of former Soviet Union were examined during spring-summer of 1999 and 2000. They are: Kharkov (dry forest-steppe, east Ukraine), Uman (moist forest-steppe, central Ukraine), Kherson (dry steppe, south Ukraine) and Shortandy (dry steppe, north Kazakhstan). The sites are located in different soil-ecological zones and differ in the amount of precipitation, temperature, soil type and vegetation. General site descriptions are given in Table 14.1. The four selected geographical regions are characterized as follows: wet-frigid (Kharkov; mean annual temperature 6.5°C, mean annual precipitation 542 mm), wet-mesic (Uman; 8.5°C, 660 mm), dry-thermic (Kherson; 11°C, 332 mm) and dry-frigid (Shortandy; 1°C, 325 mm).

Table 14.1. General characteristics of study sites.

Site location	Precipitation (mm)	Mean air temperature (°C)		Ecological and climatic region	Soil classification		Cropping plants and land management
		winter	summer		USDA	Local	
Kharkov, east Ukraine 50°N, 36oE	515-570	-10	18	South forest-steppe; Wet-frigid	Hapludolls	Typical chernozem	Sugar beet (*Beta vulgaris*), winter wheat, barley (*Hordeum vulgare*) corn, pea (*Pisum sativum*), sunflower (*Helianthus*); conventional tillage
Uman, central Ukraine 48.8°N, 30.2oE	550-770	-5	17	North forest-steppe; Wet-mesic	Argiudolls	Podzolized charnozem	Winter wheat, sugar beet, corn, pea, clover (*Trifolium incarnatum*); conventional tillage
Kherson, south Ukraine 46.6°N, 32.6oE	315-350	0	22	South steppe Dry-thermic	Calciustolls	Southern chernozem	Alfalfa (*Medicago sativa*), winter wheat, corn (*Zea mays*), conventional tillage
Shortandy, north Kazakhstan 51°N, 70oE	300-350	-18	19	North steppe; Dry-frigid	Haplustolls	Southern chernozem	Spring wheat (*Triticum aestivum*) monoculture; sub-soil cutting

14.2.1. Ukraine experimental sites

Kharkov: Experimental site in Kharkov is located at the border of forest-steppe and steppe zones with mean annual precipitation of 542 mm, mean annual air temperature of –7 to + 20°C. Soil of the site is classified as ***Typical Chernozem***, in Dokuchaev Soil Classification System (Soil Classification and Diagnosis 1967) or as ***Typic Hapludolls*** in Soil Taxonomy (Soil Survey Staff, 2003). Profile of the soil is presented in Fig. 14.1a. The soil is characterized with thick humified horizon (*A*+*B* is 85-120 cm) and high humus content in the upper layer (in natural land 80-120 g kg^{-1} that is about 600 to 750 Mg ha^{-1}). Texture is homogeneous throughout the profile. Carbonates are presented mainly as mycelium and nodules ($CaCO_3$; 45-180 g kg^{-1}) at 85-120 cm depth. Soil pH is near to neutral (6.5-7.0) in the upper layer and weakly alkaline in the carbonate accumulation horizon. There are no soluble salts in the profile of Typical Chernozems of the area studied. CEC of the upper layer is about 35-60 cmol$_c$ kg^{-1} soil. The soil is insufficiently supplied with available phosphorus (3 to 10 mg 100 g^{-1} soil).

Uman: Uman experimental site is located in forest-steppe zone with the highest amount of precipitation among the study sites and is most affected by forest vegetation. The mean annual precipitation is 550-770 mm; mean air temperature in winter is –4°C, in summer +21°C. The soil is classified as ***Podzolized Chernozem*** in Dokuchaev Soil

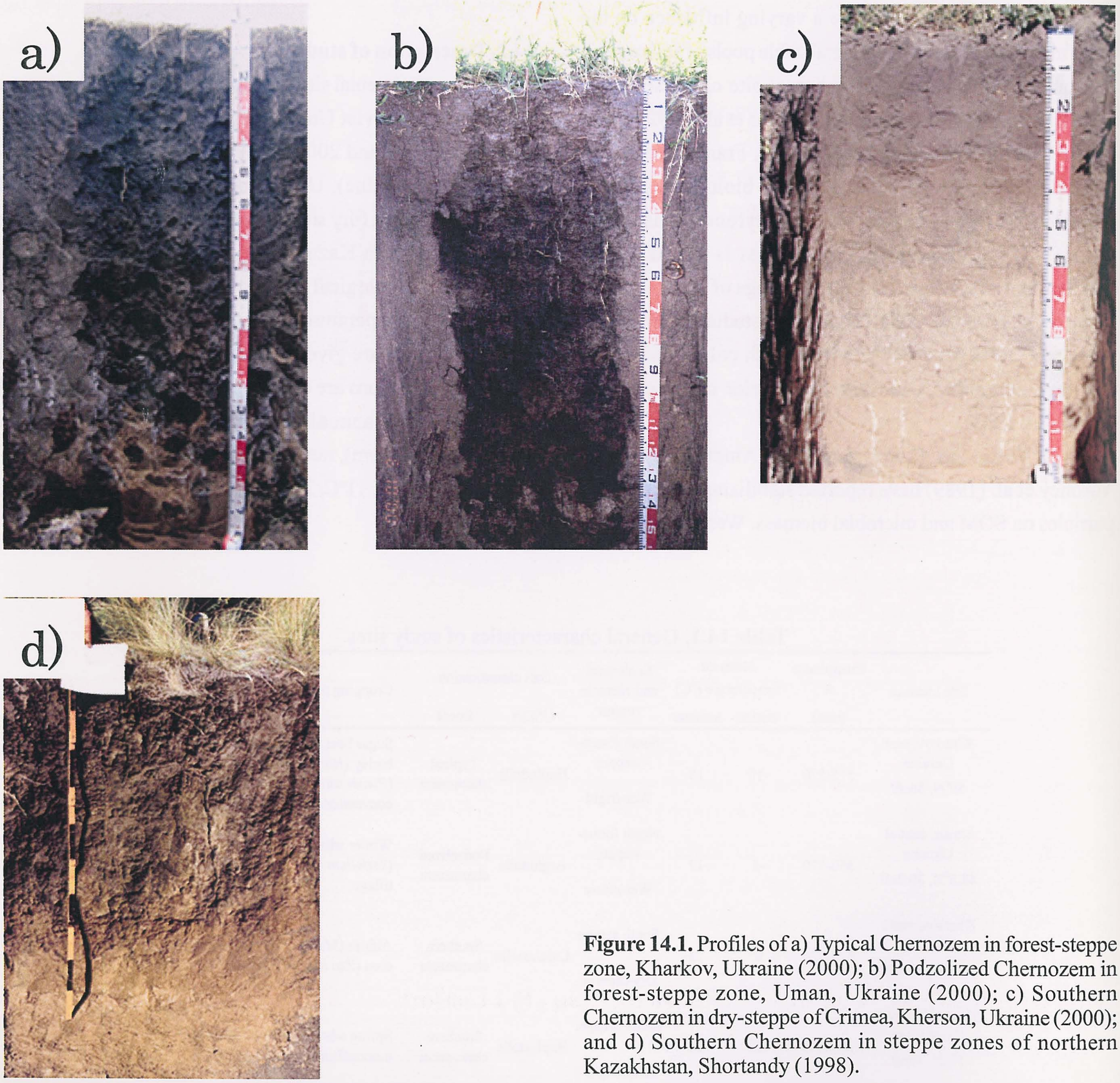

Figure 14.1. Profiles of a) Typical Chernozem in forest-steppe zone, Kharkov, Ukraine (2000); b) Podzolized Chernozem in forest-steppe zone, Uman, Ukraine (2000); c) Southern Chernozem in dry-steppe of Crimea, Kherson, Ukraine (2000); and d) Southern Chernozem in steppe zones of northern Kazakhstan, Shortandy (1998).

Classification System (Soil Classification and Diagnosis, 1967) that corresponds to ***Argiudolls*** in Soil Taxonomy (Soil Survey Staff, 2003). Profile of this soil is shown in Fig. 14.1b. Thickness of humus horizon (*A*+*B*) is 50 to 70 cm. Humus content of native land is 50-80 g kg^{-1}. *A* horizon is slightly bleached. In the humus layer there is a silica powdering. The soil is characterized with absence of carbonates in a humus layer. There are no water-soluble salts in the profile of Podzolized Chernozem. In the upper layer of the profile, formation of new organo-mineral complexes with high CEC (30-45 $cmol_c$ kg^{-1} soil) is taking place. Clay illuviation horizon is present in the profile.

Kherson: Kherson experimental site is located in dry steppe zone in south Ukraine (north of Crimea) with the least amount of precipitation among the study sites. Mean annual precipitation is 315-350 mm; mean air temperature in winter is 0°C, in summer +22°C. The soil of the site is classified as Southern Chernozem in Dokuchaev Soil Classification System (Soil Classification and Diagnosis, 1967) that corresponds to Calciustolls in Soil Taxonomy (Soil Survey Staff, 2003). The profile of the soil is presented in Fig. 14.1c. The *A* horizon is dark-gray colored. Thickness of the humus horizon is 30-50 cm. Humus content of natural land is 40-60 g kg^{-1}. Carbonate accumulation horizon is very distinct and carbonates are presented at 40-60 cm depths as concretions (white eye, $CaCO_3$; 90-160 g kg^{-1}). pH of the surface soil is 7.0-8.0. Water-soluble salts and gypsum is present at 200-300 cm depth. CEC of the humus layer is around 35-40 $cmol_c$ kg^{-1} soil.

14.2.2. Northern Kazakhstan experimental site

Shortandy: Shortandy experimental site is situated in dry steppe area of northern Kazakhstan, Astana province, between 51° and 52° latitude and 70° and 72° longitude that is mid-continent region situated in the central part of Eurasia. The landscape is characterized as plain to undulating, with average altitude of 370 m above sea level. The climate is very continental with long-lasting cold winter and short dry summer. The mean annual precipitation is 340 mm; mean air temperature in winter is –17, in summer +19°C. The soil of the *Shortandy* experimental site is classified as, Southern Chernozem, clayey, calcareous, in Kazakh Soil Classification System (Redkov, 1964) or as Typic Haplustolls in Soil Taxonomy (Soil Survey Staff, 2003). The soil profile is shown in Fig. 14.1d. The soil of the experimental field was formed on a heavy-clay textured parent material and contains up to 60% of silt + clay fraction (< 50 μm), including 40-45% of clay. The depth of *A* horizon is 15-20 cm; humus content in natural steppe is 55-60 g kg^{-1}. CEC in *A* horizon reaches 30 to 35 $cmol_c$ kg^{-1} soil. Soluble salts are at 20-40 cm in natural land, and in arable land might be present from the surface. Carbonate accumulation layer is located at 35-45 cm, with carbonates presented as "white eyes" (white soft spots). Gypsum horizon is present at 150-200 cm depth.

14.3. Analytical methods

Soil pH: Soil pH was measured with a glass electrode pH meter using a soil to solution (H_2O) ratio of 1 to 5 after being shaken for one hour (Methods of soil analysis 1996).

Soil electrical conductivity: Soil electrical conductivity (EC) was measured with EC meter (TOA CM-5B) after being shaken for one hour. Soil to water ratio was 1 to 5 (Methods of soil analysis 1996).

Total carbon and nitrogen: Total C and N were determined by a dry combustion method using NC-auto analyzer (Sumika NC-800-13N) after the soil samples were ground to powder state and oven dried (Methods of soil analysis, 1996).

Organic carbon: Organic C was measured by acidification of organic C of the soil by excess amount of potassium dichromate: $3C + 4Cr^{6+} = 4Cr^{3+} + 3C^{4+}$. Acidification took place in a strongly acidic environment so it was accompanied by reduction of Cr^{6+} into Cr^{3+}. Excess dichromate in the solution after acidification of organic C was titrated by Mohr's Salt. By subtracting the volume of dichromate before and after acidification the amount of organic C was calculated (Methods of soil analysis, 1996).

Labile organic matter (biological analysis): The soils were assayed for labile OM content using laboratory incubation techniques with constant temperature of 30°C and moisture of 50% of WHC for 10 weeks. After the soils were removed from the refrigerator, they were left for several days for conditioning of the samples to avoid flash of CO_2

Carbon mineralization potentials: Mineralized C was measured by placing 20 g of soil in incubation jar along with 10-mL of alkali trap (1 M NaOH). The jar was sealed and placed for 10-weeks incubation. Each sample was duplicated to avoid any experimental error. Alkali trap was to be replaced every two weeks. CO_2 emissions trapped in the alkali was precipitated as carbonate by addition of $BaCl_2$ solution and titrated with 1 M HCl solution a presence of phenolphthalein indicator. PMC was calculated by summing up 2-, 4-, 6-, 8-, and 10-week CO_2 emissions. Potentially mineralizable carbon (PMC) was obtained after fitting the data of mineralized C to the first order kinetic model using non-linear regression model (SPSS Inc., 1998b):

$C_{\min}=C_0(1\text{-}e^{-kt})$, (1)

where, $C_{\min}$ is the experimental data of mineralized C at a given time (t), that was plotted to fit the equation 1, C_0 is a value of PMC that was calculated after fitting the curve and $_k$ is a mineralization rate constant.

Nitrogen mineralization potentials: Mineralized N was determined after incubation of soils for 2-, 4-, 6-, 8-, 10-weeks and analyzed for nitrate and ammonium N content by colorimetric method following extraction with 2 M KCl solution. Nitrate N was analyzed after reduction of NO_3 ions to NO_2 by passing the extraction through cadmium column. Ammonium N was analyzed by salicylate nitroprusside method (Keeny and Nelson, 1982). Potentially mineralizable nitrogen (PMN) for Ukraine soils was obtained after fitting the data of mineralized N to the first order kinetic model (SPSS Inc., 1998b):

$N_{\min}=N_0(1\text{-}e^{-kt})$ (2)

where, $N_{\min}$ is an experimental value of mineralized N at a given time (t) that was plotted to fit the equation 2, N_0 is a value of PMN that was calculated after fitting the curve, k is the mineralization rate constant.

N mineralization of Shortandy soil was delayed first two weeks. Therefore PMN of this soil was calculated using the first order kinetic model with initial delay (SPSS Inc. 1998b):

$N_{\min}=N_0(1\text{-}e^{-k(t-d)})$ (3)

where, $N_{\min}$ is an experimental value of mineralized N at a given time (t) that was plotted to fit the equation 2, N_0 is a value of PMN that was calculated after fitting the curve, k is the mineralization rate constant, and d is initial delay of mineralization.

Microbial biomass carbon and nitrogen: Microbial biomass was retrieved by fumigation-extraction method and calculated by subtraction of values before and after fumigation and dividing by coefficient k_{ec} - 0.68 (Jenkinson and Powlson, 1976). Extracting reagent was 1 M K_2SO_4 solution in the ratio 1 to 5. Content of organic C in the K_2SO_4 extract was determined with a total organic carbon analyzer (Shimadzu, TOC-5000), whereas the content of total N in the extract was determined photometrically at 220 nm after potassium peroxodisulfate oxidation treatment (Japanese Industrial Standards Committee 1991).

"Light fraction" organic matter: "Light fraction" organic matter (LFOM) is the organic debris with recognizable cellular structure. LF may be derived from different sources, but is usually dominated by pieces of plant structures. This fraction of soil organic C serves as a source of both energy and nutrients for soil organisms, and as a source of nutrients for plants. LFOM fills an intermediate position between fresh non-decomposed plant materials and more decomposed humus fraction (Baldock and Nelson , 2000).

"Light fraction" OM was analyzed by densitometry method. It has been applied to isolate "light fraction" of soil (Spycher et al., 1981; Sollins et al., 1984; Janzen, 1992; Elliot and Cambardella, 1991), which has been defined as a fraction with density of 2.0 g cm^{-3} or less. Reagent-grade NaI solution was used as the separation medium after adjusting its density to 1.8 g cm^{-3}. Ten grams of air-dry soil was suspended in 40-mL of NaI solution. After centrifugation the suspended material, "light fraction" (LF), was transferred directly to a filtration unit by vacuum. The LF was then washed (three aliquots of 10-mL $CaCl_2$ followed by three aliquots of distilled water), dried at 70°C for 15 h and weighed. The residue was resuspended and the procedure was repeated to ensure complete collection of LF. The composite LF was finely ground and analyzed for total N and C concentrations.

Exchangeable cations and cation exchange capacity (CEC): Exchangeable cations (Ca, Mg, K, Na) were extracted from the soils by 1M ammonium acetate solution (pH = 7) after being shaken for one hour. Soil to solution ratio was 1:5. Exchangeable Ca and Mg were determined by atomic absorption analyzer, and exchangeable K and Na by flame emission spectrophotometer (Shimadzu AA-640-12). CEC was determined after replacement of exchangeable cations in residual soils and after the soils was washed with deionized water and ethanol solution successively to remove the excess ammonium. Absorbed NH_4-N was then extracted with 10% NaCl solution, and measured by the Kjeldahl distillation method (Methods of soil analysis, 1996).

Soil texture: The soil texture was analyzed by pipette method (Methods of soil analysis, 1986). Subsamples were taken by a pipet at a depth ***h***, at time ***t***. Using Stokes' Law, settling times for the clay fraction (< 2 μm) was calculated for sampling at a given depth for a given temperature. Firstly, carbonates were removed by sodium acetate under 60-70°C for several hours on hot plate. Secondly, organic matter was removed by adding deionized water and heating samples at 90°C on hot plate. Then soluble salts were removed by ultrasonication with addition of water. After sampling sand fraction, silt and clay fractions were sampled.

Statistical analysis: All variables were subjected to a one-way analysis of variance to determine the significance of treatment effects (SPSS, 1998a). Where significant treatment effects were observed (p<0.05), *LSD* analysis was

Table 14.2. Soil organic C and N and some chemical characteristics of Chernozem soils from different climatic regions.

Region	TN	SOC	C/N ratio	pH	EC
	(g kg^{-1} soil)				(μS cm-1)
Kharkov (n=24)	2.5	26.8	11	6.3	152
Uman (n=18)	1.7	20.5	12	5.6	63
Kherson (n=12)	1.24	15.3	12	6.1	75
Shortandy (n=24)	2.29	20	9	8.2	148

performed to permit separation of means. The relationships between selected soil properties among treatments were defined by regression analysis. Non-linear regression model was used for C and N mineralization to fit a first order kinetic model to obtain their potentials and corresponding rate constants (SPSS Inc., 1998b).

14.4. Soil organic carbon and total nitrogen

In Table 14.2 selected soil characteristics are shown. The highest content of soil organic carbon (SOC) and total nitrogen (TN) was observed in wet-frigid (Kharkov) region, 25.4 and 3.07 g kg^{-1}, respectively and the lowest in dry-thermic (Kherson) region, 15.3 and 1.24 g kg^{-1}, respectively. These results agree with the previously reported ones where the stock of SOC was generally greater in both colder and wetter climates compared to hotter and drier climates (e.g., Jenkinson, 1988). Franzluebbers et al., (2001) reported that soils of colder regions contain more SOC than soils of hotter regions. They found no significant effect of precipitation on SOC, while other authors have reported general increase in SOC with increasing precipitation (e.g, Sparling, 1992).

In the extensive study of Jenny (1930), nitrogen content of the soil was two to three times lower for each rise of 10°C in mean annual temperature. In this study TN content was also significantly higher in frigid (3.07 and 2.29 g kg^{-1} in Kharkov and Shortandy, respectively) than in mesic (Uman and Kherson) (1.70 and 1.24 g kg^{-1}, respectively) regions.

Lower temperature and higher precipitation in wet-frigid region (Kharkov) maintained the highest SOM, probably because of lower temperature in winter when it falls below the threshold for biological activity, limits decomposition of SOM resulting in its accumulation with time (Franzluebbers et al., 2001). Also, higher amount of precipitation would potentially lead to higher plant biomass production and organic C input (Sparling 1992). Dry-thermic (Kherson) region maintained the least concentrations of SOC and TN because limited rainfall produces less plant biomass that could contribute to accumulation of SOM.

Dry-frigid (Shortandy) and wet-mesic region (Uman) maintained approximately equal concentrations of SOC (20.0 and 20.5 g kg^{-1} soil, respectively). In Shortandy the plant biomass production was lower due to less precipitation and shorter vegetative season, but the decomposition of SOM was retarded due to moisture deficiency and low temperatures in winter and dry summer. Higher precipitation in Uman produced greater plant biomass that was subjected to faster decomposition due to favorable moisture and temperature conditions.

14.5. Labile soil organic matter

Labile organic matter is derived partially from the death of the portion of soil biota, and partially from non-living SOM (Jenkinson, 1966; Sorensen, 1974). A number of studies reported that soil microbial biomass carbon (MBC) and potential mineralizable carbon (PMC) are often highly related to the level of SOC (Woods and Schuman, 1986; Insam, 1990; Franzluebbers et al., 1994, 1996), therefore separating these total and active fractions from that of climate can only be achieved with expression of active fractions per unit of SOC (Franzluebbers et al., 2001). However, in this study all variables were not correlated to the amount of SOC. Moreover, high correlation coefficients were observed between the pools of labile fraction and their proportions in total SOM (Table 14.3).

Table 13.3. Pearson correlation coefficients between fractions of SOM.

	SOC	PMC	MBC	LFC	LFN
SOC	1				
PMC	-0.599	1			
MBC	-0.288	0.642	1		
LFC	-0.04	0.619	0.617	1	
LFN	-0.269	0.55	0.657	0.909	1
PMC/SOC		**0.92**	0.553	0.423	0.587
MBC/SOC		0.71	**0.846**	0.538	0.67
LFC/SOC		0.592	0.637	**0.861**	0.918
LFN/SOC		0.611	0.605	0.782	**0.913**

SOC – soil organic C; PMC – potentially mineralizable C; MBC – microbial biomass C; LFC – "light fraction" C; LFN – "light fraction" N.

14.6. Carbon mineralization potentials

Carbon mineralization patterns are shown in Fig. 14.2 (first order kinetic model) and Fig. 14.3 (scatter plot of site variations). The amount of potentially mineralizable carbon (PMC) was higher in drier (Kherson and Shortandy, 1189 and 1219 mg kg^{-1}, respectively) than in wetter (Kharkov and Uman, 741 and 1039 mg kg^{-1}, respectively) regions. Mineralization rate constant (*k*) generally paralleled PMC values, being the least in Kharkov (0.013) and the highest in Kherson (0.031). Dalias et al. (2001), Ellert and Bettany (1992) and Zogg et al. (1997) found that temperature increased the pool size of substrate C and N available for microbial mineralization with little effect on the first order rate constant. Franzluebbers et al. (2001) suggested that temperature increased the pool size of labile fractions due to longer time for plant production. In the present study temperature didn't affect PMC and the first rate constant. But greater amount of PMC was observed in drier than in wetter regions, which indicates effect of precipitation.

There are several possible explanations of these results. In wetter regions (Kharkov and Uman) microbial respiration is always higher (Orchard et al. 1983), and more organic substrate was utilized than in drier regions (Shortandy and Kherson). In contrary, the soils from drier regions experienced moisture deficiency and were unable to use the existing available organic substrate. Consequently, when microbial activity was not limited by moisture during the laboratory incubation there was enough energy substrate to promote

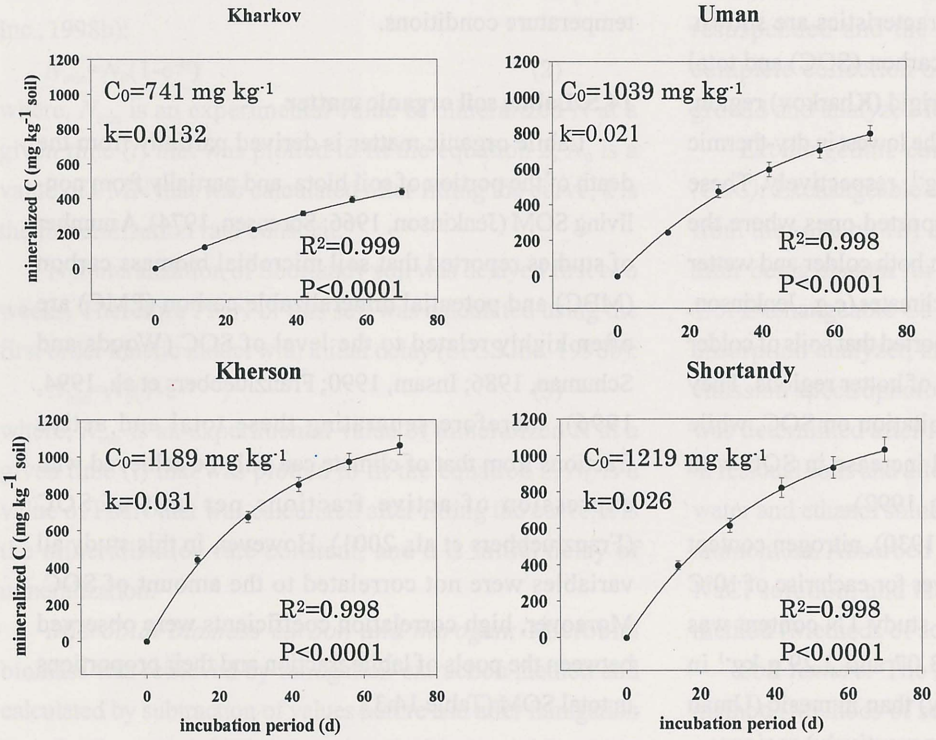

Figure 14.2. Carbon mineralization pattern and rate constant (*k*).

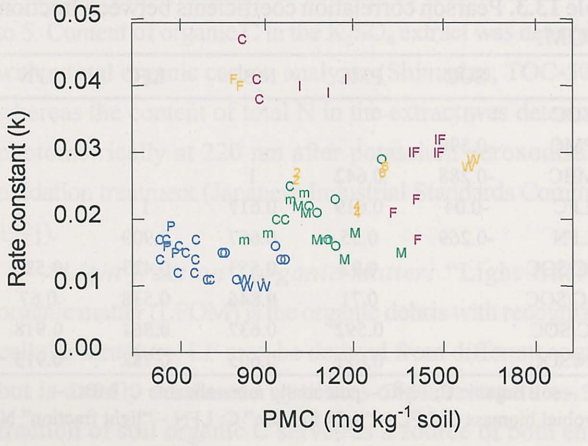

Figure 14.3. Relationship between mineralized C and mineralization rate constant (*k*) in Chernozem soils from different climatic regions.

Kharkov: C - control; P - pea; O - manure; W - wheat;
Uman: C - control; m - low rate mineral fertilizer; M - high rate mineral fertilizer; O - manure;
Shortandy: F - continuous fallow; 2-two year fallow-wheat rotation; 4- four year fallow-wheat rotation; 6 - six year fallow wheat rotation; W - continuous wheat;
Kherson: C - control; I - irrigated; F - fertilized; IF - irrigated and fertilized.

the high respiration rate. Additionally, in dry conditions potential lethal effect could contribute "dead biomass" to the organic substrate pool (Orchard et al., 1983; Jager and Bruins, 1975). And since mineral soils are typically C-limited environment (Dommergues et al., 1978), these readily decomposable organic substrate should be rapidly taken up and utilized by surviving soil microorganisms, thus contributing to the increased soil respiration observed when soils from dry regions were moistened (Orchard and Cook, 1983; Kieft et al., 1987). Lundquist et al. (1999) suggested that severe wet-dry cycles, present in Shortandy and Kherson, enhance turnover of MB and condensation of microbial products, thus increasing the amount of soluble C. They also reported that wet-dry cycles disrupt soil structure thereby making previously protected C more available as dissolved organic carbon. Therefore, since Kherson and Shortandy experience more severe dry-wet regime than Kharkov and Uman, higher amount of PMC in these regions might be partially due to disruption of soil aggregates that exposed insoluble soil organic matter to microbial attack.

Another possibility that Kharkov maintained less PMC is derived from the effect of crop rotation implemented in this site. In Kharkov the crop rotation includes fallow phase and sugar beet phase. Both fallow and sugar beet fields are cultivated many times during the vegetation season to prevent weed infestation. Such intensive cultivation makes favorable conditions for accelerated mineralization of total SOM, thus contributing to higher accumulation of mineral N and less PMC (this aspect is discussed in details in Chapter 5).

14.7. Site variation in potentially mineralizable carbon and mineralization rate constant (*k*)

The largest variations in the amount of potentially mineralizable carbon (PMC) and corresponding first order rate constant (*k*) within the sites were observed in dry regions that are Kherson and Shortandy as shown in Fig. 14.3.

In Kherson, the highest rate constant (*k*) and the lowest PMC was found in control (C), and irrigated only (I) treatments, and in Shortandy in continuous fallow (F) indicating that these treatments accumulated smaller amount of easily decomposable substrate, which was subjected to faster decomposition compared to other treatments of the related site. The reasons are different for the two sites. In the case of Kherson, control (C) didn't receive any fertilizer or irrigation treatment, therefore producing the least plant biomass production, which is one of the main sources for labile C. Irrigation only (I) makes favorable conditions for microbial activity that promotes mineralization of easily available organic substrate in the field. Therefore, this soil showed low PMC in the laboratory incubation experiment. F treatment in Shortandy implies firstly no cropping (no substrate addition), and secondly, repeated cultivation of the fallow field (accelerated mineralization of SOM). Therefore, absence of organic substrate added with plants and intensive mineralization of SOM in the field caused the lowest amount of PMC obtained in laboratory incubation.

Variations of PMC and the rate constant *k* in the other two regions were generally less than variations between the sites. In Uman, however, PMC value was significantly smaller in control treatment (C) that was not receiving any fertilization and in treatment with low-rate mineral fertilization (M). These treatments maintained smaller biomass production that was reflected in the amount of PMC. Treatments where manure and high rates of mineral fertilizer were applied in Uman showed the highest amount of PMC. Manure itself contains easily mineralizable organic compounds that contribute to the PMC, while high rates of mineral fertilization maintain high plant biomass production that serves as organic substrate. Broadbent (1968), Kharin (1993), Ilyaletdinov (1988) and Mamilov et al. (1998) suggested that prolonged application of organic fertilizers contributes to both humification and mineralization processes.

In Kharkov generally, control (C) and continuous growing of pea (P) maintained higher mineralization rate constant and lower PMC, while manured (O) treatment and continuous growing of wheat (W) have higher PMC. As discussed earlier, application of manure contributes to the amount of PMC. Probably, continuous growing of wheat contributes to the accumulation of plant residues that serves as a readily decomposable C when soil is placed under favorable laboratory conditions.

14.8. Microbial biomass carbon

Microbial biomass carbon (MBC) was significantly higher in dry (281 and 309 mg kg^{-1} in Kherson and Shortandy, respectively) than in wet (203 and 206 mg kg^{-1} in Kharkov and Uman, respectively) regions (Table 14.4). Most probable reason for this is that soils from Shortandy and Kherson were undisturbed for at least several months by the time of sampling: Shortandy soil was sampled early in May, before initiation of any fieldwork; Kherson soil was sampled from the second-year stand of alfalfa that was not cultivated for more than one year. Whereas soils from Kharkov and Uman

Table 14.4. Microbial biomass carbon (MBC), "light fraction" carbon (LFC) and nitrogen (LFN) of Chernozem soils from different climatic regions.

Region	MBC	LFN	LFC	SOC as %	
	mg kg^{-1} soil			MBC	LFC
Kharkov (wet-frigid, n=24)	203±15	60±8	1180±96	0.8	4.65
Uman (wet-mesic, n=18)	206±14	66±5	1106±95	1	5.39
Kherson (dry-thermic, n=12)	281±32	110±4	1687±69	1.84	11.03
Shortandy (dry-frigid, n=24)	309±24	64±10	1436±182	1.54	7.18

Table 14.5. Soil organic carbon and clay content.

Region	SOC (g kg^{-1} soil)	Sand 200-20μm	Silt 20-2μm	Clay <2μm
Kharkov (n=24)	25.4	20.4	37.5	42.1
Uman (n=18)	20.5	22.9	37.7	39.4
Kherson (n=12)	15.3	43.4	26.9	29.7
Shortandy (n=24)	20	25.6	30.6	43.8

were sampled soon after planting crops, therefore tillage of soil evidently induced destruction of microorganisms thus decreasing their population (Calderon et al., 2000) and diversity (Lupwayi et al., 1998). Giller (1996) reported that disturbance by tillage may result in reductions in diversity of soil organisms due to desiccation, mechanical destruction, soil compaction, reduced pore volume and disruption of access to food resources.

Van Gestel (1993a,b) reported that after remoistening of soils, microbial cells killed by drying, and other sources of SOM which had become available during drying, were rapidly metabolized, leading to increases in biomass C. Because of abundant organic substrate in Kherson and Shortandy soils, addition of water to these soils reasoned quick increase of microbial population during the three days when moisture and temperature were favorable.

Changes in the relative contribution of bacteria and fungi to soil respiration occur as soil dries (Orchard and Cook, 1983). Kharkov and Uman soils normally undergo less severe fluctuations in water potential than Shortandy and Kherson soils. Wong and Griffin (1976a,b) have shown that bacterial activity is largely restricted to water films in soil in contrast to fungi activity. Hyphae extension occurs at much lower water potentials allowing fungi to bridge air-filled pores and actively explore for nutrients (Griffin, 1969). West et al. (1988b) have demonstrated with soils from a climosequence that the biomass in the soil from the lowest rainfall region was the most resistant to imposed gradual drying treatment. It is possible that in this study microbial community of drier regions might be of different composition than of wetter regions.

14.9. "Light fraction" organic matter

In this study the highest amount of "light fraction" carbon (LFC) was observed in dry-thermic region (1687 mg kg^{-1} soil, Kherson), followed by dry-frigid region (1436 mg kg^{-1}, Shortandy), and the least was observed in wet regions (1180 and 1105 mg kg^{-1} in Kharkov and Uman, respectively) (Table 14.4). Generally, distribution of LFC among sites was well correlated with PMC (r= 0.79). Amount of "light fraction" organic matter (LFOM) was more affected by precipitation rather than by temperature: decomposition processes during the period of favorable soil temperature were inhibited by lack of water (Shields and Paul, 1973; Douglas and Rickman, 1992).

Because LFOM is largely influenced by the amount of plant residues (Gregorich et al., 1994) it was important to consider the cropping practices implemented in the study sites. Crop rotation in Kharkov includes summer fallow and sugar beet. Summer fallow accelerates mineralization of SOM (detailed discussion in Chapter 8). Sugar beet is a row crop and the technology of its growing makes field conditions similar to summer fallow, in that way increasing mineralization of SOM. Soil from Kherson was sampled at alfalfa (second-year stand) phase, which produces considerably higher amount of plant residues than other crops used in the experiments (Kharin, 1993). Besides, alfalfa second year stand was not cultivated for two cropping seasons that also reduced mineralization rate in the field. Greater amount of plant residues in Shortandy is also explained by monoculture of wheat that greatly contributes to organic substrate due to addition of wheat straw (Kharin, 1993; Akhmetov, 1999).

Rodionov et al. (2001) reported that microbial residues in ELF (enriched labile fraction, 2.07-2.22 g cm^{-3}) were enriched with fungal debris compared to other fractions. Therefore, as it was discussed in section 14.8, it might be possible that fungi contributed to the amount of "light fraction" C and N in dry regions more than in wet regions.

14.10. Relationship between soil organic matter and clay content

The inert carbon is strongly correlated with clay content, while most changes in both carbon and nitrogen occur in the readily decomposable fraction (Körschens et al., 1998). Firstly, clay minerals can adsorb large organic molecules directly, reducing their availability to decomposition. Secondly, organic material may be located in pores too small for microorganisms to enter (Juma, 1993; Elliott, 1986; Gupta and Germida, 1988; Amelung and Zech, 1996; Young and Spycher, 1979; Kyuma et al., 1969; McGill et al., 1974).

In this study, clay content was highest in Kharkov and Shortandy regions (43.1% and 48.8%, respectively) versus Uman and Kherson (39.4% and 29.7%, respectively) (Table 14.5). It is reasonable to conclude that higher clay content and plant biomass production in Kharkov maintained higher SOM. Körschens et al. (1998) reported that inert carbon was strongly correlated with clay content, while most changes in both carbon and nitrogen occur in the readily decomposable fraction. Turchenek and Oades (1979) determined that "light fraction" (LF) of fine silt and coarse clay was more humified and more aromatic than other LF, concluding that LF represents a continuum of undecomposed to highly humified materials. Applying this concept to authors' data it can be assumed that sites with higher silt fraction (2-0.2 μm) that are Kharkov and Uman (37.5% and 37.7%, respectively) might form organo-mineral complexes with large molecules of LF. Therefore, those mineral-associated LF probably were not retrieved from these soils during the separation procedure, whereas, Kherson and Shortandy contained less silt fraction (26.9% and 26.6%, respectively) that could entrap LF, resulting in higher LFOM in these soils.

However, although Shortandy possesses the highest clay content the SOM was less than in Kharkov soil. This is explained by the climatic conditions in this region. Lack of water produces less plant biomass, and inhibits mineralization processes contributing to the accumulation of labile OM, which explains higher PMC content in this soil. Also, organic compounds adsorbed to surfaces of clay particles become exposed to microbial attack after disruption of aggregates due to severe dry-wet conditions on soil in Shortandy (Birch, 1960; Jenkinson and Powlson, 1976). The lowest clay content (29.7%) and lack of water in Kherson can explain the lowest SOM content in this soil.

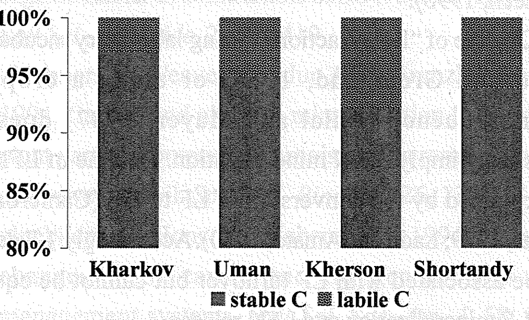

Figure 14.4. Distribution of labile and stable C among the study sites.

14.11. Distribution of labile and stable carbon

In Fig. 14.4 the distribution of labile and stable carbon among the four climatic regions is presented. The highest amount of stable C and the least amount of labile C was found in wet-frigid (Kharkov) region, while the least amount of stable and the greatest amount of labile C was found in dry-thermic (Kherson) region. Because wet-frigid (Kharkov) region maintained the highest amount of total SOC and the least amount of easily mineralizable organic matter (PMC), the suggestion is: in wet-frigid region transformation of organic substrates into more stable humified forms of OM has taken place more actively.

14.12. General discussion

Organic matter in soil can be divided into pools of different SOM release and turnover time (van Veen et al., 1984; Parton et al., 1987). The partitioning of organic C and N among such pools depends on several factors, such as cultivation history (Tiessen and Stewart, 1983; Dalal and Mayer, 1986), fertilization (Christensen, 1988) or climate (Bird et al., 1996; Trumbore et al., 1996; Amelung et al., 1998). With increasing cultivation intensity, but also as soil temperature increases, SOM of the less stable pools is decomposed, as indicated by decreasing portions of sand-sized SOM (2-0.05 mm) (Bird et al., 1996; Christensen, 1996; Amelung et al., 1998), or "light fraction" carbon (Christensen, 1992; Trumbore et al., 1996). However, parts of the soil organic matter are not accessible for microbial degradation, because they are physically protected from microbial attack in clay particles (Elliott, 1986; Gupta and Germida, 1988; Amelung and Zech, 1996).

Decline of "light fraction" during laboratory incubations (Ford and Greenland, 1968) or along a cropping chronosequence (Dalal and Mayer, 1987) does not necessarily imply the N mineralization. Decline of LFN can be explained by the conversion of LF to HF (Cameron and Posner, 1979; Ladd and Amato, 1980). Accordingly, LF decline can be associated with LF turnover but cannot be equated with LF mineralization and LFN release.

Readily decomposable substrates were also found to originate partially from nonliving SOM (van Gestel et al., 1993a,b). This source of non-biomass substrate may become available by aggregate disruption, litter defragmentation and substrate desorption, and redistribution of water, oxygen, substrate and microorganisms resulting from drying and rewetting of soil (Lund and Goksoyr, 1980; Sommers et al., 1981; Kieft et al., 1987; van Gestel et al., 1993a,b). Soil drying and rewetting promotes the turnover of carbon derived from added plant material (Gestel et al., 1993). Drier condition causes more disruptions of entrapped or stabilized organic matter when the soil is rewetted. Also, higher respiration in the soils exposed to wet-dry cycles may have been due to utilization of organic substrates that was gradually built up due to limited microbial activity when the soil was air-dried (Orchard and Cook, 1983).

14.13. Conclusions

Summarizing the results of this study the author made the following conclusions:

Total SOM among the four agro-ecological regions was distributed as follows:

Kherson (dry-thermic) < Shortandy (dry-frigid) <= Uman (wet-mesic) < Kharkov (wet-frigid)

Labile OM among the four agro-ecological regions was distributed as follows:

Kherson (dry-thermic) >= Shortandy (dry-frigid) > Uman (wet-mesic) > Kharkov (wet-frigid)

The above comparison suggests that wet-frigid zone is the most favorable for accumulation and stabilization of SOM.

Higher precipitation produced higher plant biomass contributing to the amount of SOM with further decomposition upon temperatures and soil texture. While less plant biomass production in drier regions in a lesser degree was subjected to decomposition due to moisture deficiency, thus contributing to the amount of labile SOM. Because wet-frigid (Kharkov) region maintained the highest amount of total organic carbon and the least amount of easily mineralizable organic matter (PMC), transformation of organic substrates into more stable humified forms of organic matter might have taken place more actively in this region.

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Chapter 15

Factors controlling mineralization of soil organic matter in Eurasian steppe

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15.1. Background

In global terrestrial ecosystems, dynamics of soil organic carbon has been widely studied because of its vast stock in soil (1550×10^{15}g C: Eswaran et al., 1995; Schlesinger, 1991), i.e. almost double of atmospheric carbon (780×10^{15}g C: Houghton, 2003) and triple of carbon in terrestrial plants (560×10^{15}g C). Under aerobic condition, soil organic matter (SOM) decomposes to CO_2 and nutritional elements such as nitrogen in the forms of NH_4^+ and/or NO_3^-. Therefore degradation of SOM causes the lowering fertility and adverse impact of N to environment as well as emission of the greenhouse gas. Despite the complex process of decomposition of SOM, relatively simple models have successfully described the long-term dynamics of SOM. Smith et al. (1997) tested 9 models to evaluate 12 datasets from 7 long-term field experiments and identified models suitable for a given environment. Since most of the models assume SOM fractions defined by their rate of decomposition, however, this approach does not guarantee accurate prediction at process level, in terms of simulation of short- to medium-term dynamics (De Wiligen, 1991). In addition, it may be more expedient to model the measurable components than to measure the modelable components because separation of all SOM fractions by reactivity is impossible (Christensen, 1996; Elliott et al., 1996; Magid et al.,1996).

SOM is composed of fractions with different turnover rates, which range from hours to thousands of years (Jenkinson and Rayner, 1977; Van Veen and Paul, 1981; Parton et al., 1987). Among these fractions, readily mineralizable organic matter—as determined by incubation experiments—has been studied in the most detail, because it varies widely depending on land use or cultivation practices (El-Harris et al., 1983; Hades et al., 1986; Bonde et al., 1988; Boyle and Paul, 1989). Stanford and Smith (1972) measured inorganic N accumulation during 8 weeks incubation and introduced first order kinetics to estimate the size of readily mineralizable nitrogen pool. The concept has been applied to carbon mineralization, then developed to describe several organic pool (Molina et al., 1980; Lindemann and Cardenas, 1984; Murayama et al., 1990), zero-order kinetics (Seyfried and Rao, 1988), initial flush of mineralization (Jones 1984) or delay in mineralization (Bonde and Lindberg, 1988).

The content of readily mineralizable organic matter in soils has been related to many other soil properties such as total SOM (Zak et al., 1993), water-soluble OM (Stanford and Smith, 1972; Curtin and Wen, 1999), and light fraction OM (Sollins et al., 1984; Curtin and Wen, 1999); microbial biomass (Van Veen et al., 1984); clay content (Saunder and Grant, 1962; Simard and N'dayegamiye, 1993), pH or CEC (Van Veen and Kuikman, 1990; Schrawat 1983).

Because of the complex interactions amongst these factors, however, regional and macroclimatic influences on readily mineralizable organic matter are not yet well understood (Franzluebbers et al., 2001).

The final goal of this study is 1) to determine the factors controlling the readily mineralizable organic matter and 2) to offer a simple process-based model with measurable SOM pools that describe dynamics of SOM. In this paper, we tested soil samples from Eurasia steppe area with respect to the relationship between readily mineralizable OM and soil properties as well as climatic indices.

15.2. Materials and methods

Sample soils: A total of 41 surface soil samples (0-10 cm) was collected from Ukraine in May 2000 and from Kazakhstan in September-October 2000 covering a range of climatic condition and land use (Fig. 15.1). Table 15.1 shows the location of each site and estimated annual precipitation and temperature from their adjacent meteorological stations. According to the US Soil Taxonomy (Soil Survey Staff 1998), soil temperature regime (STR) and soil moisture regime (SMR) were determined for each site. In short, annual mean soil temperature less than 8°C was referred to as frigid, 8-15°C as mesic, 15-22°C as thermic and >22°C as hyperthermic. Continuously moist soil was referred to as udic, soils of moist in winter and dry in summer as xeric, soil of dry for more than 3 months as ustic and soils of dry for more than half of a year as aridic. The sites in Ukraine were classified as mesic temperature regime and ustic or xeric moisture regime. In Kazakhstan, most of the sites in northern region belong to frigid STR whereas the other regions were mostly mesic. Though several xeric and udic sites were included in southern mountain area, major parts of our sites fall into aridic SMR.

All the sites were classified to 4 land use categories, i.e.

grassland, forest, cropland and desert. In grassland sites, pasture, rangeland or natural grassland were included.

Each soil sample was sieved to 2 mm. A portion was stored in the refrigerator for the analysis of readily mineralizable organic carbon (C_0) and nitrogen (N_0), and the remainder air-dried for chemical analysis.

Readily mineralizable organic carbon: Twenty grams aliquots of fresh soil, adjusted to a moisture content of 60% water holding capacity (Tanaka et al., 1998), were incubated at 30°C in sealed plastic bottles with 1M NaOH (Anderson, 1982) in duplicate. The amount of CO_2 trapped in the alkali solution was measured by titration after 7, 35, 63 and 133 days. Readily mineralizable organic carbon (C_0) was calculated by fitting the amounts of CO_2 released to the best equation of the following 3 equations:

$$C = C_0(1\text{-}e^{-k_C t})$$

$$C = a(1\text{-}e^{-k_{C1} t})+b(1\text{-}e^{-k_{C2} t}),\quad C_0=a+b$$

$$C = C_0\exp(\text{-}e^{-k_C (t-t_0)})$$

where C (mg C kg^{-1}) is cumulative CO_2 released at time t (d), k_C, k_{C1} and k_{C2} (d^{-1}) are rate constants, t_0 (d) is calculated time when C equals to C_0/e. The first equation was simple first order kinetic model, the second was double first order model with different rate constants and the third was known as Gompertz equation.

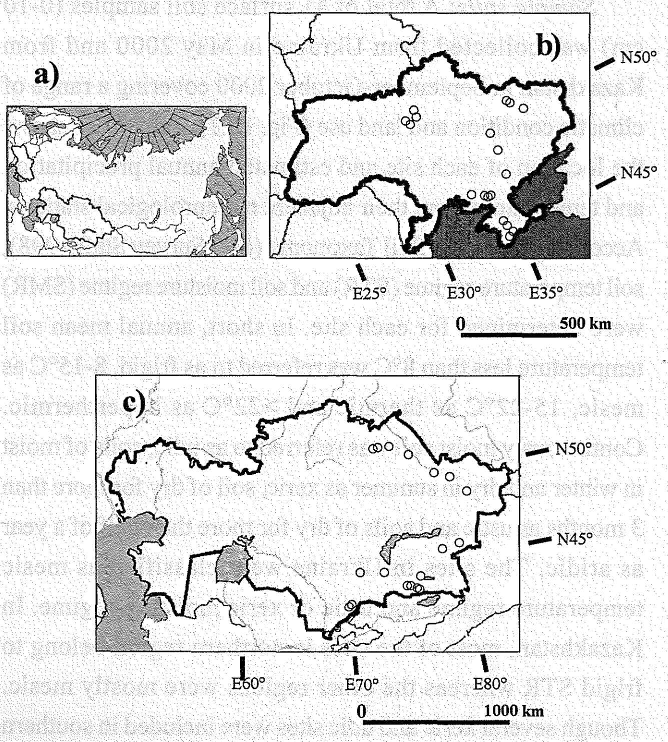

Figure 15.1. Location of Ukraine and Kazakhstan (a), and sampling sites (○) in Ukraine (b) and Kazakhstan (c).

Readily mineralizable organic nitrogen: Aliquots of fresh soil equivalent to 10 g in dry weight were weighed into glass bottles and adjusted to 60% water holding capacity (Tanaka et al., 1998). The bottles were sealed with aluminum foil and incubated at 30°C for 7, 35, 63 and 133 d in duplicate. Ammonium and nitrate ions mineralized were extracted from each soil with 50 mL of 2 M KCl solution by shaking for 1 h. The contents of NH_4^+ and NO_3^- were determined after steam distillation with successive addition of MgO and Devalda's alloy (Bremner, 1965). The amount of nitrogen released in each time was calculated by summation of ammonium and nitrate-N and fitted to the best equation of the following 3 equations:

$$N = N_0(1\text{-}e^{-k_N t})$$

$$N=N_{max}/(1+(N_{max}/N_{int}\text{-}1)e^{-k_N t}),\quad N_0=N_{max}\text{-}N_{int}$$

$$N=N_0\exp(\text{-}e^{-k_N(t-t_0)})$$

where N (mg N kg^{-1}) is cumulative N released at time t (d), N_0 (mg N kg^{-1}) is readily mineralizable organic N, k_N (d^{-1}) is rate constant, N_{max} (mg N kg^{-1}) is calculated maximum amount of

Table 15.1. Location, land use and meteorological data for sampling sites.

Site	Land use	Latitude	Longitude	Mean annual precipitation	Mean annual temperature	SMR	STR
		--- degree ---		mm	°C		
Ukraine							
U01	Forest	50.26	30.50	598	8	ustic	mesic
U02	Cropland	50.26	30.50	598	8	ustic	mesic
U03	Cropland	50.23	30.51	598	8	ustic	mesic
U04	Cropland	50.09	30.21	598	8	ustic	mesic
U05	Forest	50.08	30.24	598	8	ustic	mesic
U06	Cropland	50.08	30.24	598	8	ustic	mesic
U07	Grassland	49.93	36.63	537	7	xeric	mesic
U08	Cropland	49.93	36.63	537	7	xeric	mesic
U09	Forest	49.92	36.65	537	7	xeric	mesic
U10	Grassland	49.32	37.24	537	7	xeric	mesic
U11	Cropland	49.32	37.24	537	7	xeric	mesic
U12	Cropland	48.95	35.33	513	9	xeric	mesic
U13	Cropland	48.22	35.35	513	9	xeric	mesic
U14	Cropland	46.86	35.39	513	9	xeric	mesic
U15	Grassland	46.48	33.85	386	10	xeric	mesic
U16	Grassland	46.48	33.82	386	10	xeric	mesic
U17	Grassland	46.46	33.90	386	10	xeric	mesic
U18	Cropland	45.35	33.92	405	11	xeric	mesic
U19	Forest	44.51	34.25	622	13	xeric	mesic
U20	Forest	44.51	34.24	622	13	xeric	mesic
U21	Forest	44.75	34.35	622	13	xeric	mesic
U22	Grassland	45.15	34.00	405	11	xeric	mesic
U23	Cropland	46.74	32.71	450	10	xeric	mesic
Kazakhstan							
K01	Grassland	43.15	76.88	587	6	xeric	frigid
K02	Grassland	43.05	76.96	800	-2	udic	frigid
K04	Grassland	43.17	76.54	587	9	xeric	mesic
K05	Grassland	43.32	76.07	453	9	xeric	mesic
K06	Desert	-		50	10	aridic	mesic
K08	Desert	44.92	71.47	50	10	aridic	mesic
K10	Grassland	42.35	70.37	673	9	xeric	mesic
K11	Grassland	42.45	70.43	528	11	xeric	mesic
K12	Grassland	43.96	77.26	135	6	aridic	frigid
K13	Grassland	45.35	78.63	135	6	aridic	frigid
K14	Grassland	45.85	80.61	250	5	aridic	frigid
K15	Grassland	49.05	81.97	400	4	aridic	frigid
K16	Grassland	50.23	80.45	264	3	aridic	frigid
K18	Grassland	50.63	79.94	264	3	aridic	frigid
K19	Grassland	51.41	77.84	325	2	aridic	frigid
K20	Grassland	51.70	74.27	325	2	aridic	frigid
K21	Grassland	51.72	72.84	325	2	aridic	frigid
K22	Cropland	51.74	72.71	325	2	aridic	frigid

SMR: Soil moisture regime; STR: Soil temperature regime inorganic N in soil, N_{int} (mg N kg^{-1}) is calculated initial amount of N in soil, t_0 (days) is calculated time when N equals to N_0/e. The first model was simple first order kinetic model, the second was known as logistic equation and the third was Gompertz equation.

Physico-chemical analysis: Soil pH and electrical conductivity (EC) were measured with a pH meter (Iwaki glass, pH /ion meter 225) and an EC meter (TOA, CM-30S) using a soil to water ratio of 1:5, and shaking for 1 h. Contents of sand (>0.02 mm), silt (0.02- 0.002 mm) and clay (< 0.002 mm) were measured by sieving and the pipette method after carbonate removal by HCl, organic matter removal by H_2O_2, preparation of pH and ultrasonic dispersion.

Contents of light fraction (LF) and heavy fraction (HF) were determined as follows: 10 g aliquots of air-dried soil were dispersed in sodium iodide solution (1.6 g cm^{-3}) and then centrifuged at 3000 rpm (Strickland and Sollins, 1987). Material in the supernatant was considered to be LF (mostly partially decomposed plant residues), whereas that in the sediment was HF (more fully-decomposed residues and mineral material). Carbon and nitrogen contents in LF (LFC and LFN) were measured by dry combustion with an NC analyzer (Sumika, NC-800-13N). Carbon and nitrogen contents in HF (HFC and HFN) were determined by subtraction of LFC and N from total C and N.

Statistical analysis: Data were analyzed using analysis of variance (ANOVA) for the comparison of land use, except for 2 desert sites. Principal component analysis (PCA) was performed with varimax rotation using the soil properties and meteorological variables (mean annual precipitation and mean annual temperature). Tested soil properties included soil pH, EC, sand, silt and clay content, carbon and nitrogen content of LF and HF, C/N ratio of LF and HF. Then factors controlling C_0 and N_0 were determined by linear regression with the stepwise method, using the extracted factor scores. Statistical analysis was performed with SYSTAT 8.0 (SPSS, 1998).

Table 15.2. General properties of sample soils.

Site	Land use	TN	TC	C/N	EC	pH	Sand	Silt	Clay	LFw	LFN/LFw	LFC/LFw	LF C/N	LFN	LFC	HFN	HFC	HF C/N	LFN/TN	LFC/TC
		--- g kg^{-1} soil ---			µS cm^{-1}		-------- % ---------			------------ % ------------				---------------- g kg^{-1} soil ----------------					--------- % ---------	
Ukraine																				
U01	Forest	0.75	9.4	12.5	127	4.5	72	12	16	0.23	0.7	18	24.6	0.02	0.42	0.73	9.0	12.2	2.3	4.5
U02	Cropland	0.77	8.4	10.9	82	5.0	72	11	16	0.22	0.9	17	18.8	0.02	0.37	0.75	8.0	10.7	2.6	4.4
U03	Cropland	1.32	14.9	11.3	97	6.5	67	16	17	0.08	1.1	21	19.2	0.01	0.17	1.31	14.7	11.2	0.7	1.1
U04	Cropland	2.98	34.0	11.4	148	6.1	60	19	21	0.41	1.4	18	13.3	0.06	0.75	2.92	33.3	11.4	1.9	2.2
U05	Forest	2.63	31.5	12.0	200	4.8	64	18	18	1.31	1.4	22	15.7	0.18	2.83	2.45	28.6	11.7	6.8	9.0
U06	Cropland	2.18	25.2	11.6	104	5.7	60	16	24	0.26	1.0	17	17.8	0.02	0.44	2.16	24.8	11.5	1.1	1.8
U07	Grassland	4.26	51.4	12.1	125	6.6	19	38	42	1.29	1.5	25	17.1	0.19	3.21	4.07	48.1	11.8	4.4	6.2
U08	Cropland	2.62	32.0	12.2	174	7.8	20	36	44	0.31	1.1	18	16.7	0.03	0.57	2.59	31.4	12.2	1.3	1.8
U09	Forest	3.69	44.1	12.0	168	5.5	26	40	34	0.84	1.2	25	21.2	0.10	2.15	3.59	42.0	11.7	2.7	4.9
U10	Grassland	4.55	57.5	12.6	115	6.0	31	30	38	1.99	1.3	23	18.5	0.25	4.65	4.30	52.8	12.3	5.5	8.1
U11	Cropland	2.55	31.3	12.3	133	7.7	30	34	36	0.28	1.4	22	15.8	0.04	0.61	2.51	30.6	12.2	1.5	2.0
U12	Cropland	2.60	32.2	12.4	152	7.7	25	34	41	0.20	1.1	19	17.9	0.02	0.40	2.58	31.8	12.3	0.9	1.2
U13	Cropland	1.57	20.0	12.7	77	7.0	41	27	32	0.50	1.1	21	18.7	0.06	1.04	1.51	18.9	12.5	3.5	5.2
U14	Cropland	0.53	7.7	14.5	116	7.1	94	0	5	0.24	1.7	29	16.5	0.04	0.67	0.49	7.0	14.3	7.7	8.8
U15	Grassland	4.63	52.1	11.3	240	5.6	21	36	43	3.73	1.4	23	16.1	0.53	8.52	4.10	43.6	10.6	11.4	16.4
U16	Grassland	1.54	18.3	11.9	73	5.9	36	40	24	0.91	1.1	18	16.9	0.10	1.67	1.44	16.6	11.5	6.4	9.1
U17	Grassland	2.96	36.0	12.2	135	6.7	29	37	34	2.42	1.2	20	16.1	0.30	4.77	2.66	31.3	11.7	10.0	13.2
U18	Cropland	2.17	24.9	11.5	204	7.9	17	31	52	0.34	1.2	19	16.2	0.04	0.66	2.13	24.2	11.4	1.9	2.7
U19	Forest	5.83	90.7	15.6	283	6.9	12	28	60	4.61	1.4	33	24.0	0.63	15.11	5.20	75.6	14.5	10.8	16.7
U20	Forest	2.04	68.6	33.6	190	8.0	55	23	22	3.04	1.1	30	27.3	0.34	9.26	1.70	59.4	34.9	16.6	13.5
U21	Forest	5.88	81.7	13.9	268	6.3	19	40	41	3.40	1.3	27	20.7	0.44	9.09	5.44	72.6	13.3	7.5	11.1
U22	Grassland	1.85	26.7	14.5	149	8.1	18	26	56	0.76	1.0	23	22.4	0.08	1.73	1.77	25.0	14.1	4.2	6.5
U23	Cropland	1.32	15.6	11.8	188	6.2	45	27	29	0.47	1.2	17	14.9	0.05	0.81	1.27	14.7	11.7	4.1	5.2
Kazakhstan																				
K01	Grassland	6.53	73.6	11.3	356	5.9	25	44	31	1.70	1.4	25	18.4	0.23	4.27	6.30	69.3	11.0	3.6	5.8
K02	Grassland	5.73	61.0	10.7	230	5.7	24	43	33	1.63	1.4	23	16.6	0.23	3.82	5.50	57.2	10.4	4.0	6.3
K04	Grassland	3.66	41.8	11.4	137	8.2	27	45	28	2.72	1.5	22	14.4	0.41	5.91	3.25	35.9	11.0	11.2	14.1
K05	Grassland	1.14	22.5	19.8	110	8.6	48	35	17	1.73	1.3	19	14.7	0.22	3.21	0.92	19.3	21.0	19.1	14.2
K06	Desert	0.12	5.2	43.0	54	8.7	97	0	3	0.28	2.0	30	14.8	0.06	0.83	0.07	4.4	67.1	46.1	15.9
K08	Desert	0.33	15.4	47.3	150	8.7	77	13	10	0.30	1.1	17	14.7	0.03	0.51	0.29	14.9	51.2	10.6	3.3
K10	Grassland	2.45	28.8	11.8	401	5.6	23	44	34	2.11	1.5	25	17.2	0.31	5.34	2.14	23.5	11.0	12.7	18.5
K11	Grassland	2.95	36.7	12.4	170	8.2	33	40	28	1.73	1.5	24	15.5	0.27	4.15	2.68	32.5	12.1	9.1	11.3
K12	Grassland	0.34	10.9	31.7	69	8.7	96	1	3	0.61	1.2	19	15.6	0.07	1.17	0.27	9.7	36.2	21.8	10.7
K13	Grassland	0.53	12.0	22.6	84	8.5	89	5	6	0.76	1.3	20	15.2	0.10	1.53	0.43	10.5	24.4	19.0	12.7
K14	Grassland	0.87	16.5	18.9	125	8.1	66	20	14	1.27	1.5	22	15.2	0.19	2.86	0.68	13.6	19.9	21.5	17.3
K15	Grassland	1.79	32.2	18.0	137	8.4	42	21	37	0.71	1.3	17	13.4	0.09	1.22	1.70	30.9	18.2	5.1	3.8
K16	Grassland	1.73	17.1	9.9	51	6.8	64	22	14	3.50	1.0	13	13.1	0.34	4.53	1.38	12.6	9.1	20.0	26.5
K18	Grassland	0.70	8.9	12.6	27	6.1	88	6	5	0.95	1.4	22	15.4	0.13	2.06	0.57	6.9	12.0	18.9	23.1
K19	Grassland	0.43	5.6	12.8	24	6.5	91	4	5	0.46	1.4	19	14.2	0.06	0.88	0.37	4.7	12.6	14.4	15.9
K20	Grassland	2.68	32.8	12.2	72	6.1	24	37	39	3.17	1.2	18	15.4	0.37	5.61	2.32	27.2	11.7	13.6	17.1
K21	Grassland	1.21	14.6	12.1	66	6.8	57	20	23	0.80	1.1	17	15.0	0.09	1.37	1.12	13.2	11.8	7.6	9.4
K22	Cropland	1.15	13.2	11.5	53	6.4	59	15	25	0.59	1.2	18	15.3	0.07	1.06	1.08	12.1	11.2	6.0	8.0

TN, TC: Total nitrogen and carbon; LFw: LF content of the soil weight; LF N/LFw or LFC/LFw (%): C and N concentration in LF

15.3. Soil properties and the comparison in land use

Table 15.2 shows soil properties for each site. The average of soil properties for all sites and each land use were shown in Table 15.3.

Though total N was not significantly different among the land use, total C in the forest sites was higher than the others, i.e. total C in the cropland sites showed about 40 % of the forest sites. Saviozzi et al. (2001) reported continuous corn cropland had organic C of 14.7 g C kg^{-1}, which is equivalent with 30 % of adjacent grassland site and 40 % of adjacent forest site in Italy. They also reported total N had a similar trend, but the difference between the value in the cropland and in the forest (or grassland) was smaller than the case for total C. Hajabbasi et al. (1997) showed deforestation caused 50 % degradation of soil organic carbon. Rodionov et al. (2000) compared total organic C and N in native steppe and cultivated land, i.e. C and N in the cropland was 39-64 % and 45-61 % relative to native steppe, respectively. In this paper, the cropland sites had 69 % of TC and 72 % of TN compared to the grassland sites.

Soil EC, pH and soil texture were not significantly different among the land uses, except for the desert sites.

Though light fraction (LF) occupied only 1.3 % of the whole soil by weight, LF carbon (LFC) and nitrogen (LFN) accounted for 9.5 % of total C and 9.3 % of total N. Those values were generally consistent to previous reports. Janzen et al. (1992) reported LF (< 1.7 g cm^{-3}) of 0.2-2.4 % in whole soil accounted for 2-17 % of total organic C from cropland soils in Canada. Khanna et al. (2001) summarized 9 articles reporting LF in forest soils and showed mean LFC of 17.9 g C kg^{-1} ranging from 0.5 to 77.2 g C kg^{-1}. Alvarez et al. (1998) reported on Typic Argiudolls in Argentina that pasture (15 y) soil had 8.2% of LFC in total C. In this study, LFC in the forest sites (6.5 g C kg^{-1}) and the grassland sites (3.5 g C kg^{-1}) were 10.8 and 5.8 times higher than the cropland sites (0.6 g C kg^{-1}), respectively. LFC/TC in the cropland sites (3.7 %) was significantly lower than the forest sites (9.9 %) and grassland sites (12.7 %). Saviozzi et al. (2001) reported LFC (<1.7 g cm^{-3}) in cropland, forest and grassland sites were 0.16, 2.4, 2.2 g C kg^{-1}, respectively.

Several articles reported similar LF C/N values in spite of the difference in methodology and land use (Christensen, 1992). Greenland and Ford (1963) reported the LF C/N ranging from 12 to 30 in Australian soils. In this study, LF C/N ranged from 13.1 to 27.3 with the higher values in the forest sites. It might be due to the higher net primary production in the forests.

15.4. Amounts of C_0 and N_0 under different land use

Calculated amounts of C_0 and N_0, their rate constants, their proportion in total carbon and nitrogen and their best-fitted models for all soils were shown in Table 15.4. In most cases, the amounts of carbon mineralization were fitted to first order kinetic model, whilst models for nitrogen mineralization were varied in several equations. It might be due to delay in net mineralization of N in early stage. Ellert and Bettany (1988) reported lagged mineralization patterns, which were observed in soils from a long-term cultivated field, a recently clear cut field or an organic layer of native forest, were best described by Gompertz models.

Average value of C_0 and N_0, their proportions of total C and N for all the soils and each land use were shown in Table

Table 15.3. Average and SD values of soil properties in each land use.

		Total (N=41)		Cropland (N=12)		Forest (N=6)		Grassland (N=21)		Desert (N=2)	
		AVR	CV (%)	AVR	SD	AVR	SD	AVR	SD	AVR	SD
TN	(gN kg^{-1} soil)	**2.3**	72	**1.8** a	0.8	**3.5** a	2.1	**2.5** a	1.8	**0.2**	0.1
TC	(gC kg^{-1} soil)	**30.8**	70	**21.6** b	9.6	**54.3** a	31.4	**31.3** b	19.1	**10.3**	7.2
C/N		**15.5**	54	**12.0** a	0.9	**16.6** a	8.5	**14.4** a	5.2	**45.2**	3.1
EC	(μS cm^{-1})	**143**	58	**127** a	47	**206** a	60	**138** a	98	**102**	68
pH		**6.9**	17	**6.7** a	0.9	**6.0** a	1.3	**7.0** a	1.1	**8.7**	0.04
Sand	(%)	**48**	55	**49** a	24	**41** a	26	**45** a	27	**87**	14
Silt	(%)	**25**	53	**22** a	11	**27** a	11	**28** a	15	**6**	9
Clay	(%)	**27**	55	**28** a	13	**32** a	17	**26** a	15	**7**	4
LFw	(%)	**1.3**	91	**0.3** b	0.1	**2.2** a	1.7	**1.7** a	1.0	**0.3**	0.01
LFN/LFw	(%)	**1.3**	18	**1.2** a	0.2	**1.2** a	0.2	**1.3** a	0.2	**1.6**	0.6
LFC/LFw	(%)	**21.4**	20	**19.8** b	3.2	**25.9** a	5.4	**20.8** b	3.2	**23.3**	9.0
LFN	(gN kg^{-1} soil)	**0.17**	93	**0.04** b	0.02	**0.28** a	0.23	**0.22** a	0.13	**0.05**	0.02
LFC	(gC kg^{-1} soil)	**2.9**	107	**0.6** c	0.3	**6.5** a	5.6	**3.5** b	2.0	**0.7**	0.2
LF C/N		**17.1**	18	**16.8** b	1.8	**22.2** a	4.0	**16.0** b	2.0	**14.8**	0.1
HFN	(gN kg^{-1} soil)	**2.2**	74	**1.8** a	0.8	**3.2** a	1.9	**2.3** a	1.7	**0.2**	0.2
HFC	(gC kg^{-1} soil)	**27.9**	69	**21.0** b	9.6	**47.9** a	26.2	**27.8** b	18.0	**9.7**	7.4
HF C/N		**16.2**	71	**11.9** a	0.9	**16.4** a	9.1	**14.5** a	6.4	**59.2**	11.3
LFN/TN	(%)	**9.3**	93	**2.8** b	2.2	**7.8** ab	5.4	**11.6** a	6.4	**28.4**	25.1
LFC/TC	(%)	**9.5**	66	**3.7** b	2.6	**9.9** a	4.8	**12.7** a	5.9	**9.6**	8.9

TN, TC: Total nitrogen and carbon;
LF N/LFw or LFC/LFw (%): C and N concentration in LF;
LFw: LF content of the soil weight
For each variables in land use, different letter indicates significant difference ($p<0.05$)

15.5. According to analysis of variance, average C_0 value was increasing in the order of the cropland sites (1115 mg C kg^{-1}), grassland sites (2824 mg C kg^{-1}) and forest sites (5630 mg C kg^{-1}), whilst C_0/TC in forest (10.0%) and grassland (10.1%) sites were not significantly different. Similar values have been reported elsewhere. Khanna et al. (2001) measured C_0 of 56 forest soils from Australia and reported that C_0/TC was lower than 10% in most cases. Ajwa et al. (1998) reported that, in the surface layer under tallgrass prairie, C_0 of 2561 mg C kg^{-1} and C_0 proportion in organic C of 11.6%, whereas for adjacent agricultural land 1655 mg C kg^{-1} and 21.0%, respectively. In our study, N_0/TN in the cropland (8.7%), the forest (8.8%) and the grassland sites (11.6%) were not significantly different, whilst N_0 in the cropland sites (141 mg N kg^{-1}) was lower than the forest sites (291 mg N kg^{-1}). These values were consistent to previous reports. Zak et al. (1993) reported N_0/TN of soils under several tree species near Great Lakes ranging from 5.4-14.9%. Ajwa et al. (1998) showed N_0 of 291.2 mg N kg^{-1} and N_0/TN of 12.2% for prairie, whilst 93.3 mg N kg^{-1} and 10.2% for agricultural land, respectively.

15.5. Principal component analysis (PCA) on soil and meteorological properties

Soil and meteorological properties were summarized into 4 factors by PCA, and correlation coefficients between factor scores and each soil property are shown in Table 15.6. Though all the factors were independent each other, HFC was correlated with 2 factors. This relationship may suggest HFC can be affected by possible two different components, i.e. that closely associating with clay content and that just processed from LF. Since HF C/N was correlated with pH (r = 0.57**) and mean annual precipitation (r = -0.60**), these 3 variables were summarized to one factor. The low precipitation

Table 15.4. Readily mineralizable C and N of the soils.

Site	land use	C_0	C model	k_C	C_0/TC	N_0	N model	k_N	N_0/TN
		mgC kg^{-1} soil		day^{-1}	(%)	mgN kg^{-1} soil		day^{-1}	(%)
U01	Forest	1223	Fi	0.006	13.0	91	Fi	0.008	12.1
U02	Cropland	874	G	0.021	10.4	183	G	0.008	23.7
U03	Cropland	1082	Fi	0.003	7.3	77	G	0.017	5.8
U04	Cropland	1224	Fi	0.008	3.6	195	Fi	0.007	6.5
U05	Forest	2379	Fi	0.009	7.6	195	Fi	0.012	7.4
U06	Cropland	1138	Fi	0.007	4.5	208	Fi	0.005	9.5
U07	Grassland	3248	Fi	0.011	6.3	301	G	0.029	7.1
U08	Cropland	1184	Fi	0.013	3.7	169	G	0.011	6.5
U09	Forest	2687	Fi	0.009	6.1	208	Fi	0.013	5.6
U10	Grassland	3976	Fi	0.013	6.9	230	Lo	0.045	5.1
U11	Cropland	1008	Fi	0.015	3.2	111	Lo	0.045	4.3
U12	Cropland	969	Fi	0.014	3.0	186	G	0.010	7.2
U13	Cropland	1022	Fi	0.016	5.1	114	Fi	0.015	7.2
U14	Cropland	653	Fi	0.010	8.5	47	G	0.052	8.8
U15	Grassland	4038	Fi	0.013	7.8	388	G	0.036	8.4
U16	Grassland	2097	Fi	0.007	11.5	164	Fi	0.013	10.6
U17	Grassland	3122	Fi	0.014	8.7	296	Fi	0.009	10.0
U18	Cropland	1737	Fi	0.011	7.0	211	Fi	0.008	9.7
U19	Forest	14787	Fi	0.007	16.3	687	G	0.006	11.8
U20	Forest	5399	Fi	0.010	7.9	199	G	0.034	9.7
U21	Forest	7307	Fi	0.007	8.9	366	Lo	0.021	6.2
U22	Grassland	3081	Fi	0.011	11.5	165	G	0.031	8.9
U23	Cropland	1167	Fi	0.013	7.5	113	Fi	0.014	8.6
K01	Grassland	3487	Fi	0.014	4.7	278	G	0.027	4.3
K02	Grassland	5610	Fi	0.007	9.2	220	G	0.037	3.8
K04	Grassland	5114	Fi	0.012	12.2	437	Fi	0.008	11.9
K05	Grassland	2752	Fi	0.012	12.2	239	G	0.020	21.0
K06	Desert	459	Fi	0.016	8.8	23	Fi	0.017	18.5
K08	Desert	581	Fi	0.021	3.8	35	G	0.042	10.9
K10	Grassland	3135	Fi	0.023	10.9	211	Fi	0.022	8.6
K11	Grassland	5419	Fi	0.012	14.8	438	Fi	0.007	14.9
K12	Grassland	760	Fi	0.020	7.0	51	Lo	0.045	15.0
K13	Grassland	1557	Fi+Fi		12.9	135	Fi	0.014	25.5
K14	Grassland	2379	Fi	0.014	14.4	192	G	0.026	22.1
K15	Grassland	1543	Fi	0.009	4.8	109	G	0.055	6.1
K16	Grassland	1793	Fi	0.017	10.5	168	Fi	0.015	9.7
K18	Grassland	1263	Fi	0.013	14.2	95	G	0.045	13.4
K19	Grassland	762	Fi	0.014	13.7	67	Lo	0.047	15.4
K20	Grassland	2679	Fi	0.020	8.2	288	Fi	0.016	10.8
K21	Grassland	1486	Fi	0.015	10.2	146	Fi	0.011	12.1
K22	Cropland	1322	Fi	0.014	10.0	79	Lo	0.039	6.9

Fi: First order kinetics, G: Gompertz equation, Lo: Logistic equation

Table 15.5. Average and SD values of C_0 and N_0 and their proportions in each land use.

	Total (N=41)		Cropland (N=12)		Forest (N=6)		Grassland (N=21)		Desert (N=2)	
	AVR	CV(%)	AVR	SD	AVR	SD	AVR	SD	AVR	SD
C_0 (mgC kg^{-1})	**2622**	97	**1115** c	264	**5630** a	5008	**2824** b	1435.5	**520**	86
C_0/TC (%)	**8.8**	40	**6.2** b	3	**10.0** a	4	**10.1** a	3	**6.3**	4
N_0 (mgN kg^{-1})	**198**	65	**141** b	57	**291** a	213	**220** ab	111	**29**	9
N_0/TN (%)	**10.5**	51	**8.7** a	5	**8.8** a	3	**11.6** a	6	**14.7**	5

For each variables in land use, different letter indicates significant difference ($p<0.05$)
TC and TN: Total C and N contents in soil

Table 15.6. Correlation matrix between factors and soil properties.

variable	Clay-HF	LF	pH-HF C/N	LF C/N
EC	0.53 **	0.40 **	-0.15	0.40 **
pH	0.04	-0.09	0.91 **	-0.03
Sand	-0.94 **	-0.23	0.11	-0.11
Silt	0.88 **	0.27	-0.14	-0.05
Clay	0.87 **	0.16	-0.07	0.20
LFC	0.22	0.92 **	-0.01	0.23
LFN	0.25	0.93 **	-0.00	0.02
LF C/N	0.04	0.18	-0.26	0.84 **
HFC	0.58 **	0.62 **	-0.16	0.31 *
HFN	0.67 **	0.53 **	-0.32 *	0.11
HF C/N	-0.46 **	0.05	0.73 **	0.21
MAP	0.46 **	0.10	-0.67 **	0.38 *
MAT	0.21	0.09	0.33 *	0.78 **
exprained (%)	31	21	16	14

(Factor Name spans the columns Clay-HF, LF, pH-HF C/N, LF C/N.)

MAP: mean annual precipitation, MAT: mean annual temperature, TN, TC: Total nitrogen and carbon; LFw: LF content of the soil weight; LF N/LFw or LFC/LFw Significant correlation coefficient was attatched by (*: $p<0.05$) and (**: $p<0.01$)

tend to accumulate carbonates in surface soil. Mean annual temperature (MAT) correlated with LF C/N ($r = 0.46$**). Scatter plot between LF C/N and MAT (Fig. 15.2) suggested forest sites in high MAT area contributed the higher LF C/N. Judging from the correlation between factors and variables, these factors were named "Clay-HF", "LF", "pH-HF C/N" and "LF C/N" factors.

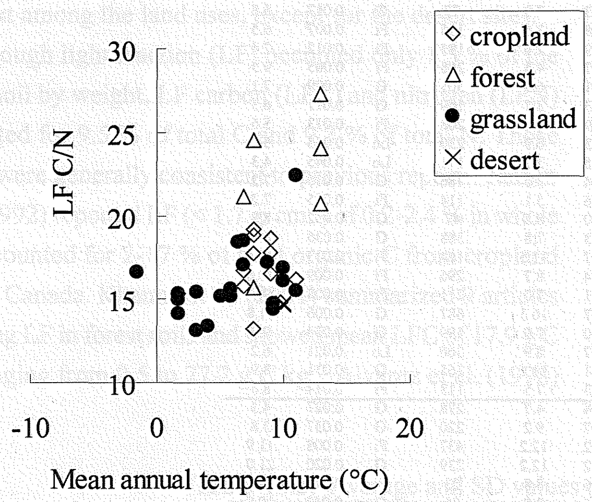

Figure 15.2. Scatter plot between LF C/N and mean annual temperature for each land use.

15.6. Relationship between factors and land use

Factor scores of each soil were plotted separately in terms of land use (Fig. 15.3). The clay-HF factor showed no difference in land use, whilst LF factor in cropland sites was lower than the others. It would be due to the more labile nature of LF than HF associating with clay minerals and/or relatively low amount of organic matter input in the cropland caused low accumulation of LF. The pH-HF C/N factor in desert sites was relatively higher than the others. This could be explained by the higher evapotranspiration in the desert sites. The LF C/N factor in the forest sites showed the highest of all. It might be due to high accumulation of C in the residues in the forest sites.

15.7. Determination of factors controlling readily mineralizable C and N by linear regression with the stepwise method

Linear regression analysis was conducted to simulate C_0 or N_0 as dependent variables by using the clay-HF, LF, pH-HF C/N and LF C/N factors as independent variables. The following two equations were obtained:

C_0 (mg C kg^{-1}) = 2622 + 1976 (LF factor) + 837(clay-HF factor) + 778 (LF C/N factor) ($R^2 = 0.81$**)

N_0 (mg N kg^{-1}) = 198 + 88 (LF factor) + 66 (clay-HF factor) +18 (LF C/N factor) ($R^2 = 0.75$**)

Since each factor was standardized by PCA, each coefficient in equation indicates its relative contribution.

Though average LF content in soils was 1.3% in whole soil by weight and 9.5% in total carbon, the contribution of LF to C_0 was much higher than that of HF associating with clay content. This probably reflects the relatively labile nature of LFC, which is more easily decomposed than HFC. There

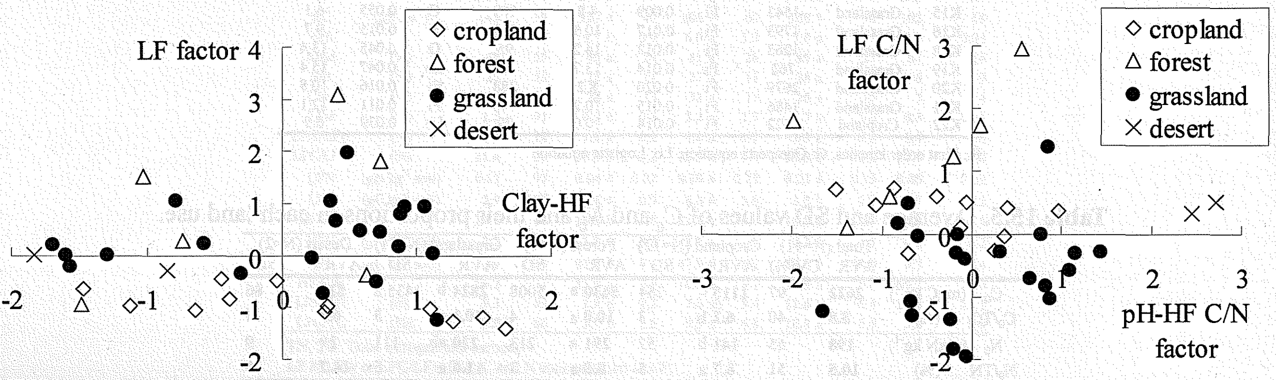

Figure 15.3. Scatter plots among factors: (a) clay-HF factor and LF factor and (b) LF C/N factor and pH-HF C/N factor.

are several reports that LF is enriched in carbohydrates relative to both the whole soil and HF (Oades, 1972; Whitehead et al., 1975; Murayama et al., 1979; Dalal and Henry, 1988). Alvarez et al. (1998) reported that 58, 37 and 10 % of the LF (<1.13 g cm^{-3}), MF (1.13-1.37 g cm^{-3}) and HF carbon, respectively, was mineralized during 160-day incubation experiment.

The contribution of LF to N_0, however, was not conspicuous as C_0. Using an anaerobic incubation technique, Boone (1994) showed that LFN was less available than HFN. Later Wharlen et al. (2000) reported that addition of LF to soil decreased net N mineralization due to N immobilization. Such a function of LF both as possible sink and source for N mineralization could explain the relatively small contribution of LF to N_0, compared to the case of C_0.

LF C/N contributed positively both to C_0 and N_0. Though higher C/N of organic matter generally causes net immobilization of N by soil microbes, relatively low LF C/N (17.1, N=41) might not prevent mineralization in the present study.

15.8. Conclusion

In this study, the factors controlling readily mineralizable carbon (C_0) and nitrogen (N_0) content were LF, HF associating with clay mineral and LF C/N. The contribution of LF to C_0 was much higher than that of HF. The contribution of LF to N_0, however, was not conspicuous as C_0. The higher C_0 values in the forest sites were considered to be contributed by the higher amount of LFC and LF C/N in the forest sites. In tern, the lowest amounts of C_0 and N_0 in the cropland sites were caused by low LF content in these soils.

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Chapter 16

Comparison of *in situ* soil respiration in different regions of Eurasian steppe

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16.1. Background

There are a huge number of studies on *in situ* soil respiration under different ecosystems (Kucera and Kirkham, 1971; de Jong et al., 1974; Coleman et al., 1976; Warembourg and Paul, 1977; Buyanovsky et al., 1987; Raich and Tufekcioglu, 2000). It generally increases along with temperature/moisture increases and positively correlates net primary production of ecosystems (Raich and Schlesinger, 1992). In the present research, soil respiration in Ukraine and northern Kazakhstan was investigated in Chapters 4, 6 and 9. In this chapter, results from Hungary and southern Kazakhstan are additionally reported and comparatively discussed in order to clarify possible factors that regulate *in situ* soil respiration.

16.2. Materials and methods

Study sites: Information about the study sites is given in Table 16.1. Steppe landscapes are spread in northern foothill of Mt. Alatau as a belt between desert and mountains. Climatic conditions are somewhat similar to Mediterranean, with dry summer and wet winter. Annual precipitation is drastically increasing from 200 to 800 mm from north to south due to the influence of the mountain. Soil temperature regime is mostly mesic below elevation of 1500 m. The ecological zones in this area are roughly separated into two regions by the presence of Mt. Kalatau, which extends from south to north as a branch of Mt. Alatau. The eastern half (Almaty State) is relatively cold and western half (South Kazakhstan State including Shimkent city) is hotter than the east. In this territory, within several km intervals, Sierozem (Cambids; Soil Survey Staff, 1998), Chetnut (east) or Gray cinnamonic (west) soils (mostly Ustolls) and Chenozems (east) or Cinnamonic soils (west) (corresponding to Ustolls/Udolls and Udalfs) are distributed from the desert to mountain in this order. The parent materials of soils in are mostly loess deposit. We measured field soil respiration rate at semi-natural pastures in this region, i.e. CH and DC near Almaty city and CN and GC in east of Shimkent city.

The Great Hungarian Plain is the western end of Mollisols' distribution in Eurasian steppe. The climate in the area is situated in the border of Continental, Mediterranean and of West Europe's. Mean annual temperature is about 10°C, and annual precipitation is about 500 mm. Parent materials of soils are loess and its secondary deposits. Since most of the area has already been cultivated unless being affected by salinization, we selected three agricultural fields for the present study; i.e. VC (Velence) at southwest of Budapest city, KC (Karcag) and KH (Kunhegeyes) at west of Debrecen city. At VC, two plots were installed, one of which was planted with spring barley (VC-BY) and the other with winter wheat (VC-WT). At KC, similarly two plots were installed on the no-fertilized block (KC-CL) and on fertilized block (200-0-100 kg ha^{-1} in N-P-K). These plots were planted with spring barley. At KH, winter wheat was planted. The soils of the Hungarian sites were Ustolls.

Measurements: In these 9 plots, CO_2 emissions from the

Table 16.1. Outline and general physicochemical properties of the soils studied.

Sites	Classification	Location	Annual precipitation (mm)	Mean annual temperature (°C)	Altitude (m)	Land use	Particle size distribution sand (%)	silt (%)	clay (%)	pH (H_2O)	Organic C (g kg^{-1})	Total N (g kg^{-1})	CN ratio
Southern Kazakhstan													
CH	Pachic Hapludolls	N43°20' E77°37'	730	7.6	1200	pasture	34	39	28	7.5	49.1	5.4	9.1
DC	Typic Calciustolls	N43°13' E76°26'	approx. 350	approx. 9	900	pasture	30	45	25	8.1	24.3	2.4	10.1
CN	Typic Hapludalfs	N42°28' E70°35'	650	9.5	1300	pasture	23	41	36	6.5	24.8	2.5	9.9
GC	Udic Argiustolls	N42°28' E70°05'	approx. 350	approx. 11.5	900	pasture	18	44	37	7.1	28.0	2.5	11.2
Hungary													
VC-BY	Typic Calciustolls	N47°15' E18°40'	520	10.4	125	cropland	24	47	29	7.9	19.0	n.d.	n.d.
KC-CL	Typic Haplustolls	N47°17' E20°54'	530	10.9	90	cropland	25	33	42	6.7	23.0	2.1	11.1
KH	Typic Haplustolls	N47°22' E20°40'	530	10.9	80	cropland	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Ukraine													
GK	Pachic Haploxerolls	N49°56' E36°12'	540	6.9	150	pasture	17	35	48	6.2	40.0	3.6	11.1
AN	Calcic Haploxerolls	N46°27' E33°47'	390	9.5	30	natural grassland	24	39	38	6.5	33.2	2.9	11.4
Northern Kazakhstan													
Shortandy[1]	Typic Haplustolls	N51°35' E71°03"	320	1.6	390	cropland	30	34	36	8.0	21.4	2.4	9.1

[1] Including 5 plots; F0-C, O0-C, F1-C, O1-C and F4-C.

soil surface were measured using a closed chamber method in five replications for more than ten times, in which temperature and moisture conditions considerably fluctuated. At the plots in southern Kazakhstan, the measurement was conducted over two consecutive years from May 2001 to April 2003, whereas in Hungary during one year from April 2002 to May 2003. The experimental procedure was the same as that presented in Chapter 6. The concentration of CO_2 was measured with a portable Infrared CO_2 analyzer (Anagas CD98; Environmental Instruments, Leamington Spa, UK). While both the whole and microbial soil respirations were measured at the Hungarian plots, only whole soil respiration was measured in southern Kazakhstan since to eliminate plant roots was somewhat unrealistic on the developing of root-mat in semi-natural grassland. At the same time, the soil temperature at the 5 cm depth and soil moisture at the surface 0-15 cm depth were measured. The datalogger systems (CR-10X, Campbell Scientific, Inc.) were installed in CH, CN. VC-BY and VC-WT during the experiment to continuously monitor the soil temperature, moisture and rainfall. Plant biomass was measured at the time of harvest in the cropped plots in Hungary or in early spring in semi-natural grassland in southern Kazakhstan.

Data analysis: Same approach as in Chapter 6 was employed: For estimating the total soil respiration rate throughout the cropping period, we firstly derived an equation that represented the relationship between the *in situ* hourly soil respiration rate and climatic factors such as soil temperature and moisture content by multiple regression analysis. Then we calculated the hourly soil respiration rate

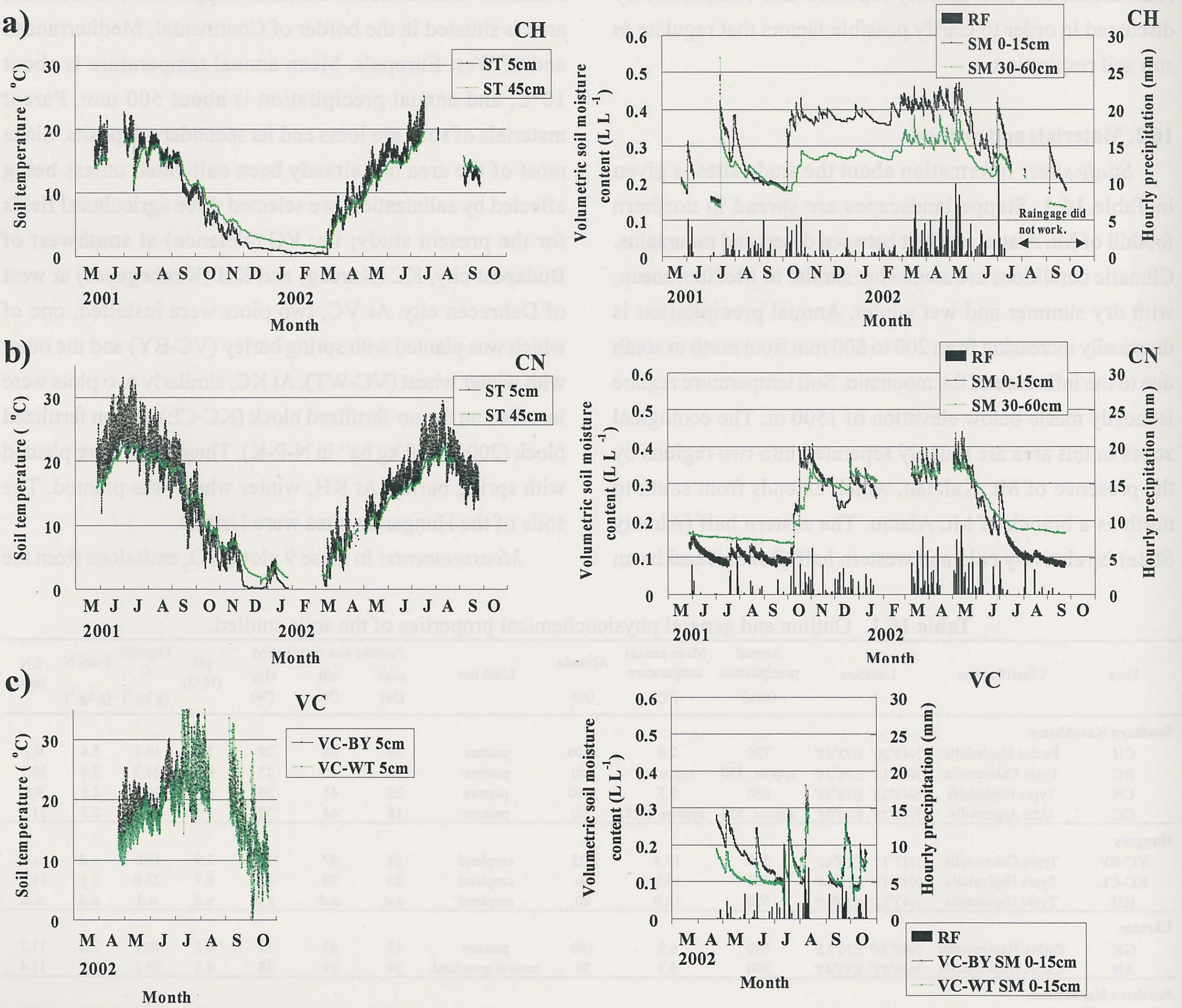

Figure 16.1. Fluctuation of soil temperature and moisture and precipitation recorded datalogger stations at CH (a), CN (b) and VC(c).

by substituting each parameter of the equation using monitored data, and summed up the hourly soil respiration rates for a given period. In the first step, we assumed that the Arrhenius relationship between the soil temperature and respiration rate was as follows:

$$C_{\mathrm{em}} = aM^{b}\mathrm{e}^{-E/RT}$$

where C_{em} is the hourly soil respiration rate (mol C $\mathrm{ha}^{-1}\ \mathrm{h}^{-1}$), M is the volumetric soil moisture content (L L^{-1}), E is the activation energy (J mol^{-1}), R is the gas constant (8.31 J $\mathrm{mol}^{-1}\ \mathrm{K}^{-1}$), T is the absolute soil temperature (K), b is a coefficient related to the contribution of soil moisture, and a is a constant. The equation was then rewritten in the logarithm form:

$$\ln C_{\mathrm{em}} = \ln a + b\ln M - E/RT$$

Then a series of coefficients, a, b, and E were calculated by stepwise multiple regression analysis (p=0.15) using the measured data, C_{em}, M, and T (SPSS, 1998). Using these regression equations and the data monitored by the dataloggers, the fluctuations of the soil respiration rate under a given period were calculated. Since good correlations were always obtained between actual soil temperature/moisture determined in the plots at the CO_2 measurement and those monitored at the nearby datalogger stations (station at CH for CH and DC plots, that at CN for CN and GC plots, VC-BY station for VC-BY, KC-CL and KC-200 plots, VC-WT station for VC-WT and KH plots, respectively), these monitored data were used for the estimation of continuous soil respiration after conversion using their correlation.

16.3. Fluctuation of soil temperature and moisture and *in situ* soil respiration rate at the experimental plots

The monitored data at the datalogger stations (CH, CN and VC) are given in Fig. 16.1. During a certain period, data were missing due to mechanical treatment of the field at the time of harvest and malfunction of the datalogger. Both the soil temperature and moisture fluctuated appreciably during the periods. In the southern Kazakhstan (CH and CN), a clear contrast of dry summer and wet winter was observed. For the datasets of the field CO_2 measurement, a negative correlation between soil temperature and moisture was also observed in the plots of southern Kazakhstan. Although such a trend was week in Hungarian plots, it might bring some uncertainty to analysis of temperature/moisture dependence of soil respiration caused by the interactive of soil temperature and moisture.

The fluctuation of soil respiration as well as soil temperature and moisture measured in Kazakhstan plots is given in Fig. 16.2. It is much higher than the values in the Hungarian cropland (data were later shown in Fig. 16. 3 together with estimated values), suggesting active dynamics of SOM as well as high plant-root respiration in the semi-natural grassland.

16.4. Parameters for simulating *in situ* soil respiration rates

Using the datasets obtained, parameters in the equations given above were calculated (Table 16.2). The data from

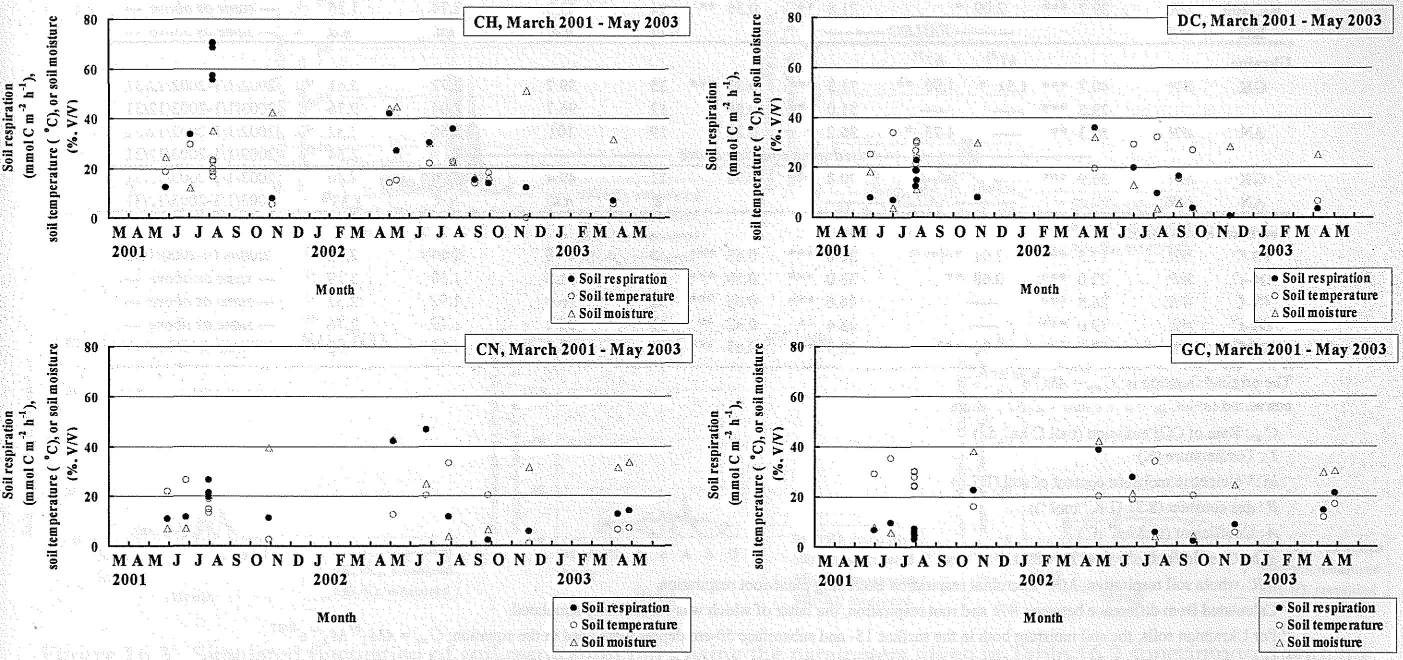

Figure 16.2. Measured values of soil temperature, moisture and respiration rates inthe plots of southern Kazakhstan.

Chapters 6 (Ukraine) and 9 (Kazakhstan) are also cited for comparison after correction of the unit of soil respiration into mol C ha^{-1} d^{-1}. GK and AN in this chapter represent the plots of Grakovo and Askania Nova in Chapter 6, respectively. In some cases, the stepwise analysis and calculation of parameters failed to be established, or was unexpectedly in low confidence level. It would be caused by agricultural practices in cropland and/or irregular rainfall during dry summer, which might bring a flush of SOM mineralization.

The parameter relating to temperature-dependence of SOM decomposition, namely activation energy E, was usually significant, while the contribution of moisture dependence (b) was somewhat uncertain especially in the East European plots (Ukraine and Hungary) compared to the southern Kazakhstan plots. Several interpretations are possible for the difference. Firstly, the former ecosystems were often experienced dry summer in normal years, resulting in an establishment of drought tolerance of soil microbes, and possibly of plant activity, in terms of soil respiration. It may cause a continuous mineralization of SOM even under severely dry conditions. Additionally it is possible to assume the effect of mineralization flush during dry summer in the datasets. They may cease apparent moisture-dependence of soil respiration. Another aspect is that there is a clear negative correlation between soil temperature and moisture among the datasets of southern Kazakhstan. The high contribution of soil moisture in the soils was possible to be statistically emphasized by the uniqueness of the datasets.

Compared to the uncertainty involved in the moisture-dependence, the contribution of temperature is obvious. It

Table 16.2. Comparison of parameters for *in situ* soil respiration rate and estimated amounts of annual soil respiration in different steppe soils.

Sites	Type[1]	Parameters determining for in situ soil respiration rates a	b		E (kJ mol^{-1})	R^2	n	C_{em} (at T=25°C, M=0.3 L L^{-1}) (kg C ha^{-1} d^{-1})	Q_{10} (15-25°C)	Annual soil respiration (Mg C ha^{-1} y^{-1})	Period for estimation
Southern Kazakhstan											
CH	*WR*	39.1 ***	1.21 ***		69.5 ***	0.66 ***	15	184	2.65	22.6 [4]	2001/7/2-2002/7/1
DC	*WR*	49.4 ***	1.22 ***		96.0 ***	0.70 ***	13	114	3.84	9.37 [4]	--- *same as above* ---
CN	*WR*	46.3 ***	1.64 ***		84.7 ***	0.82 ***	12	303	3.28	10.6 [4]	2001/5/29-2002/5/28
GC	*WR*	28.6 ***	1.26 ***		44.5 ***	0.89 ***	13	106	1.87	13.2 [4]	--- *same as above* ---
Hungary											
VC-BY	*WR*	24.8 **	------		43.6 *	0.19 *	15	16.7	1.84	3.60 [4]	2002/4/23-2002/10/20
VC-WH	*WR*		---------- *FAILED* ----------				15	*n.d.*	*n.d.*	*n.d.*	--- *same as above* ---
KC-CL	*WR*		---------- *FAILED* ----------				14	*n.d.*	*n.d.*	*n.d.*	--- *same as above* ---
KC-200	*WR*	14.9 ***	------		18.5 *	0.20 *	14	20.9	1.30	3.31 [4]	--- *same as above* ---
KH	*WR*	11.1 ***	------		8.7 *	0.14 *	11	23.1	1.13	3.78	--- *same as above* ---
VC-BY	*MR*	54.7 ***	1.83 ***		109.9 ***	0.67 ***	12	41.9	4.67	1.35	2002/4/23-2002/10/20
VC-WH	*MR*	39.9 ***	1.87 **		73.6 ***	0.58 **	12	35.4	2.80	2.01	--- *same as above* ---
KC-CNTL	*MR*	39.5 ***	1.55 **		73.8 ***	0.59 ***	14	30.4	2.81	1.27	--- *same as above* ---
KC-200	*MR*	39.7 ***	2.09 *		71.8 **	0.36 **	14	43.3	2.74	1.35	--- *same as above* ---
KH	*MR*		---------- *FAILED* ----------				11	*n.d.*	*n.d.*	*n.d.*	--- *same as above* ---
Ukraine			$b1$[3]	$b2$[3]							
GK	*WR*	40.7 ***	1.31 *	1.90 **	71.3 ***	0.33 ***	35	39.7	2.72	3.61 [4]	2002/1/1-2002/12/31
		29.6 ***	-----	-----	51.0 ***	0.86	12	96.7	2.04	9.76 [4]	2003/1/1-2003/12/31
AN	*WR*	29.3 **	-----	4.73 *	36.2 *	0.20 *	19	101	1.66	2.52 [4]	2002/1/1-2002/12/31
			---------- *used same equation above* ----------							2.54 [4]	2003/1/1-2003/12/31
GK	*MR*	36.9 ***	-----	-----	70.8 ***	0.75	11	49.4	2.70	4.80	2003/1/1-2003/12/31
AN	*MR*		---------- *FAILED* ----------				8	*n.d.*	*n.d.*	1.35[2]	2003/1/1-2003/12/31
Northern Kazakhstan											
F0-C	*WR*	17.5 ***	-2.01 *		30.6 ***	0.53 ***	13	23.8	1.54	2.92 [4]	2000/4/10-2000/10/3
O0-C	*WR*	22.0 ***	0.68 **		33.0 ***	0.59 ***	13	31.8	1.59	3.19 [4]	--- *same as above* ---
F1-C	*WR*	26.5 ***	-----		46.6 ***	0.65 ***	12	26.4	1.92	2.52 [4]	--- *same as above* ---
O1-C	*WR*	19.0 ***	-----		28.4 **	0.42 **	13	23.1	1.49	2.76 [4]	--- *same as above* ---
F4-C	*WR*	17.3 ***	0.90 ***		20.9 **	0.69 ***	10	28.2	1.34	3.06 [4]	--- *same as above* ---

The original function is: $C_{em} = AM^{b} e^{-E/RT}$,
converted to: $\ln C_{em} = a + b \ln M - E/RT$, where
C_{em}: Rate of CO2 emission (mol C ha^{-1} d^{-1})
T: Temperature (K)
M: Volumetric moisture content of soil (L L^{-1})
R: gas constant (8.31 (J K^{-1} mol^{-1}))
A: Coefficient (mol ha^{-1} d^{-1})
a, b: Coefficients; $a = \ln A$, R = 8.31 (J K^{-1} mol^{-1})

[1] *WR:* whole soil respiration; *MR:* microbial respiration excluding plant-root respiration.

[2] Calculated from difference between *WR* and root respiration, the latter of which was successfully simulated.

[3] For Ukrainian soils, the soil moisture both in the surface 15- and subsurface 50-cm depths were used in the equation: $C_{em} = AM_1^{b1} M_2^{b2} e^{-E/RT}$.

[4] These data were included in the statistical analysis using PCA and stepwise regression to reveal factors affecting annual soil respiration in section 16.6.

*, **, ***: Significant at 25%, 5%, and 1% levels, respectively.

is one of the main characteristics of SOM decomposition in temperate regions, not like as the case in the tropical countries such as Thailand or Indonesia, where annual fluctuation of soil temperature is limited (Funakawa et al., unpublished data). The values of E or Q_{10}, which was related to temperature-dependence of the soil respiration, mostly ranges between 30 and 80 kJ mol^{-1} and 1.5 and 3, respectively. Since the datasets covered a relatively wide-range of temperature fluctuation, the obtained values relating to temperature-dependence were mostly consistent with the range determined by laboratory-incubation experiment (Katterer et al.,1998; Chapter 17 in this volume).

When comparing soil respiration rate under a fixed condition, namely C_{em} was calculated at the condition of $T = M = 0.3$ L L^{-1}, it was the highest in the southern Kazakhstan plots (grassland), followed by Ukrainian plots (grassland); and that in the Hungary or northern Kazakhstan (cropland) was the lowest. A higher contribution of root respiration under grassland is supposed.

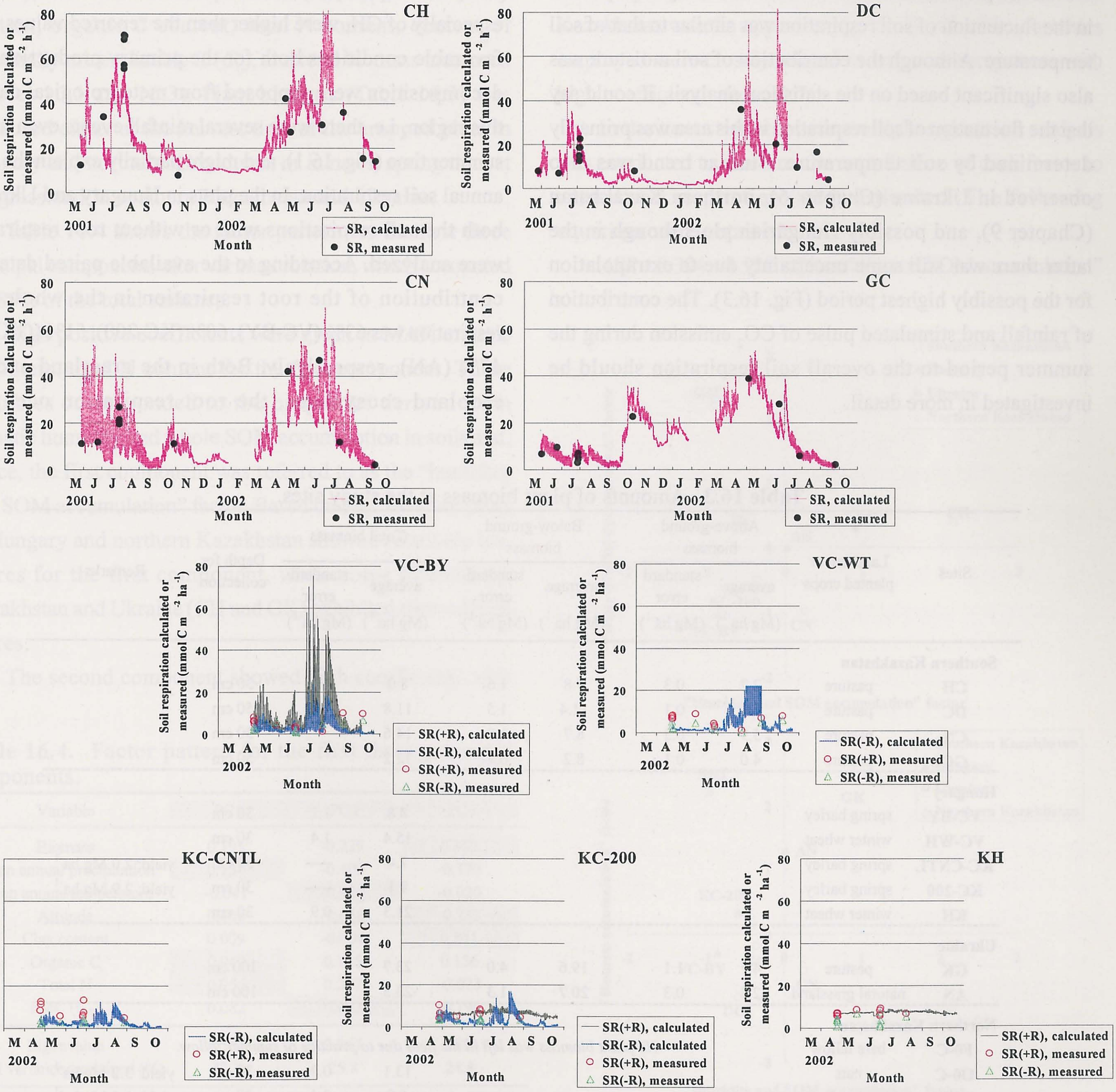

Figure 16.3. Simulated fluctuation of soil respiration rates using the parameters given in Table 16.2 superimposed with the measured values.

16.5. Simulation of annual fluctuation of soil respiration using the parameters

Using the parameters obtained and soil-climatic data monitored by the datalogger at the nearest sites, annual fluctuation of soil respiration was calculated and plotted together with the measured data in Fig. 16.3. Generally the data in southern Kazakhstan plots were comfortably simulated (high R^2 in Table 16.2). Although some of the Hungarian datasets were poorly simulated, it would be possible to use later in the comparison of the amounts of annual respiration in different regions because the values at Hungarian plots were mostly kept low.

In the plots of southern Kazakhstan, the overall pattern in the fluctuation of soil respiration was similar to that of soil temperature. Although the contribution of soil moisture was also significant based on the statistical analysis, it could say that the fluctuation of soil respiration in this area was primarily determined by soil temperature. Similar trend was also observed in Ukraine (Chapter 6), northern Kazakhstan (Chapter 9), and possibly Hungarian plots though in the latter there was still some uncertainty due to extrapolation for the possibly highest period (Fig. 16.3). The contribution of rainfall and stimulated pulse of CO_2 emission during the summer period to the overall soil respiration should be investigated in more detail.

The simulated values of the soil respiration were summed up for a given period, usually for one year, and the annual soil respiration calculated was also given in Table 16.2. Although the monitoring data did not cover the winter period in Hungary and northern Kazakhstan, the estimated values were considered to be very close to the annual amounts because the winter temperature in these regions was too low to expect high soil respiration.

According to Table 16.2, it is obvious that the amount of annual soil respiration was higher in the southern Kazakhstan plots than in the others. Although most of them were within the range of previous reports introduced in Chapter 6 (p.92), the values in southern Kazakhstan, especially of CH, were higher than the reported values. The favorable conditions both for the primary production and decomposition were supposed from meteorological data in this region, i.e. there were several rainfall events even in dry summer time (Fig. 16.1), and might partially explain the high annual soil respiration. In the plots in Hungary and Ukraine, both the soil respirations with or without root respiration were analyzed. According to the available paired data, the contribution of the root respiration in the whole soil respiration was 63% (VC-BY), 60% (KC-200), 51% (GK) and 47% (AN), respectively. Both in the grassland and the cropland ecosystems, the root respiration occupied

Table 16.3. Amounts of plant biomass at the study sites.

Sites	Land use or planted crops	Above-ground biomass		Below-ground biomass		Total biomass		Depth for collection	Remarks
		average (Mg ha^{-1})	standard error (Mg ha^{-1})	average (Mg ha^{-1})	standard error (Mg ha^{-1})	average (Mg ha^{-1})	standard error (Mg ha^{-1})		
Southern Kazakhstan									
CH	pasture	2.2	0.3	5.8	1.6	8.0		30 cm	
DC	pasture	0.4	0.1	11.4	1.5	11.8		50 cm	
CN	pasture	5.9	0.3	8.7	1.0	14.6		30 cm	
GC	pasture	4.0	0.1	8.2	0.7	12.2		50 cm	
Hungary									
VC-BY	spring barley					8.8	1.1	30 cm	
VC-WH	winter wheat					15.4	1.4	30 cm	
KC-CNTL	spring barley					7.4	-----	30 cm	yield: 2.0 Mg ha^{-1}
KC-200	spring barley					9.1	-----	30 cm	yield: 2.9 Mg ha^{-1}
KH	winter wheat					21.3	0.9	30 cm	
Ukraine									
GK	pasture	4.1	1.1	19.6	4.0	23.7		100 cm	
AN	natural grassland	2.8	0.3	20.7	1.3	23.5		100 cm	
Northern Kazakhstan									
F0-C	bare fallow	*No plant biomass was left in the field due to practice of summer fallow.*							
O0-C	oats					13.1	0.8	30 cm	yield: 3.2 Mg ha^{-1}
F1-C	spring wheat					6.9	0.4	30 cm	yield: 1.9 Mg ha^{-1}
O1-C	spring wheat					4.9	0.3	30 cm	yield: 1.4 Mg ha^{-1}
F4-C	spring wheat					7.8	0.1	30 cm	yield: 2.0 Mg ha^{-1}

approximately a half of the whole soil respiration.

16.6. Factors affecting the amounts of annual soil respiration in the study plots

In order to analyze the factors affecting the amounts of annual soil respiration in the study plots, principal component analysis followed by stepwise multiple linear regression was conducted for the datasets. The datasets used for the analysis were of CH, DC, CN, GC, VC-BY, KC-200, GK (average of 2002 and 2003), AN, and SHT (average of the 5 plots in northern Kazakhstan), as indicated in Table 16.2. Variables employed includd mean annual precipitation (MAP), mean annual temperature (MAT), altitude, clay content, organic C content, total N content, content of potentially mineralizable C (C_0), and total biomass measured (Tables 16.1 and 16.3). Plant biomass (Table 16.3) was measured either at the harvest time at the cropped plots in Hangary and northern Kazakhstan or in moist spring time at the grassland in southern Kazakhstan and Ukraine.

Table 16.4 shows the factor pattern for the first three principal components after varimax rotation, which accounted for 83% of the total variance.

High positive coefficients were given to MAP, organic C content, total N content for the first component. These variables corresponded to the properties derived from climatic humidity and whole SOM accumulation in soils and, hence, the first component was referred to as the "humidity and SOM accumulation" factor. Based on Fig. 16.4, our plots in Hungary and northern Kazakhstan showed relatively low scores for the first component, while some of southern Kazakhstan and Ukraine (CH and GK) exhibited showed high scores.

The second component showed high coefficients with MAT (negative) and the C_0 content and was considered to be a "delay of SOM decomposition" factor. The plot of northern Kazakhstan, referred as SHT, showed a very high score in this factor.

Table 16.4. Factor pattern for the first three principal components.

Variable	PC1	PC2	PC3
Biomass	0.195	-0.229	0.802
Mean annual precipitation	0.734	-0.400	-0.170
Mean annual temperature	-0.041	-0.920	-0.020
Altitude	0.408	-0.068	-0.733
Clay content	0.009	-0.004	0.841
Organic C	0.949	0.145	0.156
Total N	0.955	0.237	-0.073
PMC (C_0)	0.082	0.962	-0.196
Eigenvalue	2.566	2.367	1.984
Total variance explained (%)	32.1	25.8	24.8
	Humidity and SOM accumulation	Delay of SOM decomposition	Biomass accumulation

The third component exhibited high coefficients, positive or negative, with biomass, clay content (positive) and altitude (negative), indicating a close relation with biomass accumulation on clayey soils. Higher moisture retention in clayey soil may serve a favorable condition for accumulation of production into plant biomass, and hence, the third component was referred to as the "biomass accumulation" factor. Our study plots in Ukraine showed relatively high scores in this factor, while those in southern Kazakhstan was the opposite (Fig. 16.4). All of the variables employed were closely related to only one component with high coefficients above 0.7.

In the next step, stepwise multiple regression analysis was conducted to examine the contribution of each factor to annual soil respiration (ASR) estimated. The following equations were obtained:

$ASR = 8.304 + 4.928 \times$ ("humidity and SOM accumulation"

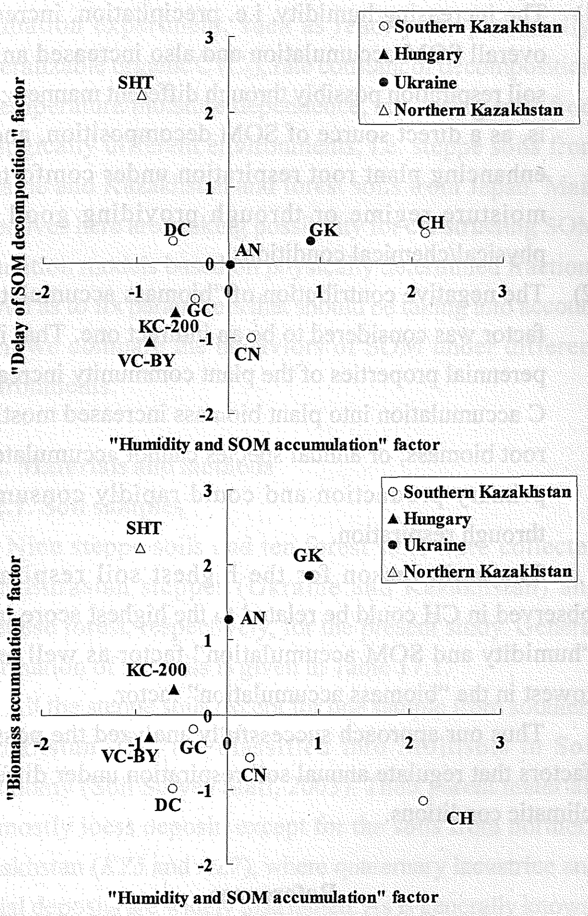

Figure 16.4. Scattergram between the first and second or third principal component scores determined for each plot.

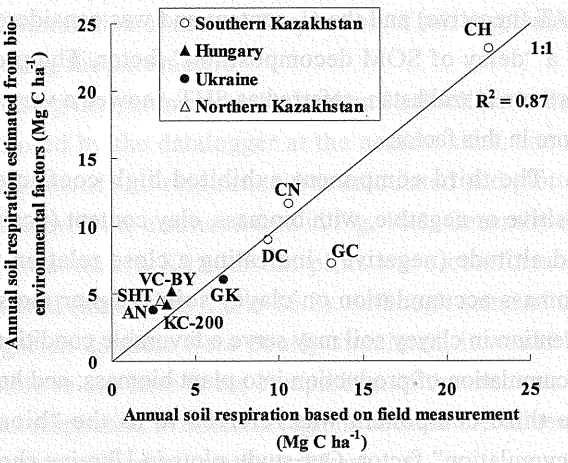

Figure 16.5. Relationship between the annual soil respiration based on the field-measured data and that from bio-environmental factors.

factor) - 3.658 × ("biomass accumulation" factor);

$R^2 = 0.87^{**}$ ($n = 9$)

The relationship between the annual soil respiration based on the field-measured data and that from bio-environmental factors are shown in Fig. 16.5. This equation indicated that:

1) The increasing humidity, i.e. precipitation, increased overall SOM accumulation and also increased annual soil respiration possibly through different manners; that is, as a direct source of SOM decomposition, and by enhancing plant root respiration under comfortable moisture regime or through providing good soil physical/chemical conditions.
2) The negative contribution of "biomass accumulation" factor was considered to be an indirect one. That is, as perennial properties of the plant community increased, C accumulation into plant biomass increased mostly as root biomass; or annual species cannot accumulate the primary production and could rapidly consume it through respiration.

The main reason for the highest soil respiration observed in CH could be related to the highest score in the "humidity and SOM accumulation" factor as well as the lowest in the "biomass accumulation" factor.

Thus our approach successfully analyzed the possible factors that regulate annual soil respiration under different climatic conditions.

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Chapter 17

Temperature/moisture dependence of organic matter decomposition in soils from different environments with special reference to contribution of light- and heavy-fraction C

Shinya Funakawa, Yuko Nishiyama and Ayako Kato

17.1. Background

Dynamics of soil organic matter (SOM) is recently drawn considerable attention in terms of both the large source and sink of carbon dioxide in relation to the problem of "global warming". There are several attempts to simulate quantitatively SOM dynamics in models such as NCSOIL (Molina et al., 1983), CENTURY (Parton et al., 1987), RothC (Jenkinson, 1990), DAYSY (Hansen et al., 1991), etc., which have succeeded under given environments. The models listed are usually multi-compartments models, in which several pools of organic materials are supposed to be decomposed according to first order kinetics with given decomposition rate constants. To fix the parameters, a huge numbers of investigation have been conducted using different methodologies; i.e. laboratory incubation for determination of readily decomposable SOM pools and their decomposition rate constants (e.g. summarized by Katterer et al., 1998), radiocarbon-dating technique associated with acid hydrolysis for determination of resistant pool of SOM (Paul et al., 1997), so on. It was suggested, however, that generally better simulation by each model tends to be limited within a respective ecosystem, i.e. either forest or grassland soils (Smith et al., 1997).

Another problem relating to simulation of SOM dynamics lies in the fact that one of most serious problems is drastic changes in land uses and soil environments in tropical countries. They are still straggling to overcome the problems for sufficient food supply - it means that additional reclamation of forest is necessary for agricultural use, being required to conserve forest as a CO_2 sink at the same time. Most of the models established for simulating SOM dynamics are, however, developed in temperate countries. It is still questionable whether they can appropriately simulate such situations as changes from forest to cropland or the reverse under extremely humid and/or warm conditions in tropical countries.

The authors consider that main difficulty in validating the fitness of these models under different environments are partially coming from their "hypothesized" fractionation of SOM, which restricted us to trace only changes in total amount of SOM when we try to compare actual and simulated changes in SOM. In this context, models having more fractions of SOM that are experimentally measurable are more desirable (Paul et al., 2001; Six, et al., 2002). The approach for investigating dynamics of SOM based on its physical fractionation into light- and heavy-fractions (LF and HF, respectively) has been tried repeatedly (Spycher et al., 1983; Sollins et al., 1984; Dalal and Meyer, 1986; Strickland and Sollins, 1987; Kogel-Knabner and Ziegler, 1993; Boone, 1994; Golchin et al. 1994; Kadono et al., 2002; Karbozova-Saljnikov, 2004) and possibly overcomes the limitation mentioned above; but the information are not integrated in a single model yet.

In the present study, we comparatively analyze possible relationships between the physical fractions of SOM (LF and HF) and parameters biologically determined by incubation experiment, such as readily (or potentially) mineralizable organic C (C_0), rate constant of decomposition, its temperature/moisture dependence, etc., using soils from ecologically different environments, i.e. steppe soils from Ukraine and Kazakhstan and forest soils from Japan. Main objectives here are seeking possibility for constructing SOM simulation models based on physically determined fractions as well as to fix parameters that should be taking into account when we compare the behaviors of SOM under different environments.

17.2. Materials and methods

17.2.1. Soil samples

Nine steppe soils and ten forest soils were collected from Eurasian steppes (Ukraine and Kazakhstan) and Japanese forest, respectively, for the present study. General information of the soils is given in Table 17.1.

All the steppe soils except for one sample from southern Kazakhstan, *CN*, are classified into Mollisols in Soil Taxonomy (Soil Survey Staff, 2003). Their parent materials are mostly loess deposit, except for the soils from northern Kazakhstan (*KZ5* and *KZ7*), where quaternary lacustrine and fluvial deposits are widely distributed. As is generally known, such dark-colored steppe soils are formed under a relatively dry climate with annual precipitation of less than 500 mm. The values of soil pH are, consequently, close to neutral among the soils. *AN1* and *AN2* were collected in different years, i.e. 1997 and 2002, from natural steppe of Askania-Nova Biosphere Reserve, which was located in southern dry steppe of Ukraine. *GK* was collected from pasture of Grakovo Experimental field of Institute for Soil Science and Agrochemistry Research, Kharkov, in northeastern Ukraine. These soils are classified into Xerolls. *KZ5* and *KZ7* were collected from cropland and pasture in northern Kazakhstan, respectively. They have been formed under continental and hence cold and dry climate and classified into Haplustolls. The remaining four steppe soils, i.e. *CH*, *DC*, *CN*, and *GC* were collected from pasture under different climatic conditions in the foothill of Tien Shan Mountains in southern Kazakhstan. *CH* and *DC* are located near Almaty city and *CN* and *GC* are west of Shimkent. They are classified into different taxonomic groups as shown in Table 17.1. All the steppe soils were collected from surface 15 cm for the present study.

On the other hand, the forest soils in Japan are largely affected by volcanic ejecta as is classified into Andisols or termed by "andic" in Soil Taxonomy. Such an andic nature of soil is especially conspicuous in the soils of *Y*, which were collected from the foothill of Mt. Yatsugatake and strongly affected by volcanic ash (acid-ammonium-oxalate-extractable Al (Alo) and Fe (Feo) amounted 44 g kg^{-1} in Alo+1/2Feo). The soils of *B*, *S* and *N* were situated under cool temperate forest with different vegetation, i.e. beech (*Fagus crenata*), Japanese cedar (*Criptomeria japonica*) and deciduous oak (*Quercus mongolica*), respectively, and were also affected by the andic nature to some degrees with certain amounts of Alo+1/2Feo, i.e. 15-34, 16-20 and 15-18 g kg^{-1}, respectively, for the studied soil layers. *K* was collected from the deciduous evergreen forest of Kyoto city and situated in warm temperate zone. The Japanese forest soils exhibit low pH values between 3.9 and 4.7 (Table 17.1) and hence the contents of exchangeable Al were high as ranging from 2.4 to 15.1 cmol_c kg^{-1} (data are not shown). The chemical properties and possible soil-forming factors of the Japanese forest soils were presented by Mori et al. (2005). All the forest soils were collected from different two surface layers as given in Table 17.1.

All the sample soils exhibit medium to fine texture with relatively high SOM contents, i.e. greater than 20 g kg^{-1} in total organic C (C_{org}). According to Table 17.1, main differences in soil properties between the steppe and forest soils are: 1) the values of pH are significantly lower in the Japanese forest soils than in the Eurasian steppe soils, and 2) the contents of organic matter are higher in the forest soils

Table 17.1. Outline and general physicochemical properties of the soils studied.

Soil samples	Sampling depth (cm)	Classification	Location	Annual precipitation (mm)	Mean annual temperature (°C)	Altitude (m)	Land use	Particle size distribution sand (%)	silt (%)	clay (%)	pH (H_2O)	Organic C (g kg^{-1})	Total N (g kg^{-1})	CN ratio
Eurasian steppe soils														
AN1	0-15	Calcic Haploxerolls	N46°27' E33°47'	390	9.5	30	natural grassland	22.1	37.8	40.0	5.9	27.3	2.6	10.5
AN2	0-15							23.8	38.5	37.7	6.5	33.2	2.9	11.4
GK	0-15	Pachic Haploxerolls	N49°56' E36°12'	540	6.9	150	pasture	17.3	35.2	47.5	6.2	40.0	3.6	11.1
KZ5	0-15	Typic Haplustolls	N54°32' E69°34'	320	0.5	120	cropland	19.3	25.4	55.3	7.0	40.2	3.5	11.5
KZ7	0-15	Typic Haplustolls	N54°32' E69°31'	320	0.5	130	pasture	20.3	26.1	53.6	8.0	38.7	3.7	10.5
CH	0-15	Pachic Hapludolls	N43°20' E77°37'	730	7.6	1200	pasture	33.7	38.8	27.6	7.5	49.1	5.4	9.1
DC	0-15	Typic Calciustolls	N43°13' E76°26'	approx. 350	approx. 9	900	pasture	30.0	44.7	25.3	8.1	24.3	2.4	10.1
CN	0-15	Typic Hapludalfs	N42°28' E70°35'	650	9.5	1300	pasture	23.2	41.1	35.7	6.5	24.8	2.5	9.9
GC	0-15	Udic Argiustolls	N42°28' E70°05'	approx. 350	approx. 11.5	900	pasture	18.4	44.2	37.4	7.1	28.0	2.5	11.2
Average								23.1	36.9	40.0	7.0	34.0	3.2	10.6
CV (%)								22	18	25		24	28	7
Japanese forest soils														
K1	0-5	Typic Dystrudepts	N35°01' E135°47'	1510	15.7	80	natural forest	47.1	24.8	28.1	3.9	41.6	2.4	17.3
K2	5-15							43.2	26.0	30.8	4.1	16.8	0.9	18.7
Y1	0-10	Acrudoxic Melanudands	N35°58' E138°28'	1430	6.8	1450	secondary forest	25.0	31.2	43.8	4.7	173.8	11.3	15.4
Y2	10-20							26.2	30.7	43.1	4.6	178.3	11.1	16.1
B1	0-10	Andic Haplohumods	N35°37' E135°11'	1750	10.7	680	narural forest	11.6	39.7	48.7	4.0	86.5	5.0	17.3
B2	10-20							13.6	41.7	44.7	4.2	60.6	3.5	17.3
S1	0-10	Andic Dystrudepts	N35°37' E135°11'	1750	10.7	640	natural forest	19.6	34.4	46.0	4.0	97.1	5.8	16.7
S2	10-20							17.6	34.2	48.2	4.3	74.8	4.3	17.4
N1	0-10	Alic Hapludands	N35°38' E135°10'	1750	10.7	650	artificial forest	13.7	45.2	41.1	4.0	97.0	5.9	16.4
N2	10-20							11.7	44.0	44.3	4.2	58.4	3.4	17.2
Average								22.9	35.2	41.9	4.2	88.5	5.4	17.0
CV (%)								53	19	16		56	61	5
Difference between the two groups[1)]											**	**		**

[1)] Significantly different at: *5% level, **1% level.

than in the steppe soils with higher CN ratios. At the same time, the values of CV (coefficient of variation; in %) indicates that the clay content of the steppe soils is more variable than that of the forest soils while organic matter-related properties (C_{org} and total N) exhibits the reverse tendency.

17.2.2. Analytical methods

Aerobic incubation under different conditions. The fresh soils collected were passed through a 2 mm mesh sieve and preserved in a refrigerator without drying until analyses. Before the incubation experiment, moisture content of each sample soil was adjusted to 0.1, 0.25 and 0.4 L L^{-1} on volumetric basis (θ) (the bulk density was already determined elsewhere) for the steppe soils and to 0.2, 0.4 and 0.6 L L^{-1} for the forest soils, respectively, by drying slowly in the refrigerator. These moisture contents were selected based on the frequency that the soils have been actually experienced in the respective field conditions. Then the steppe soils were incubated in duplicate under different nine conditions (three temperature levels at 10, 20 and 30°C×three moisture levels described above) and forest soils under seven conditions (10°C×0.2(θ), 10°C×0.6(θ), 20°C×0.2(θ), 20°C×0.4(θ), 25°C×0.2(θ), 25°C×0.4(θ) and 25°C×0.6(θ)), respectively. The soil prepared was put in a 50 mL of vial and then placed in a plastic bottle (500 mL) together with a 10 mL of 1 M NaOH solution for CO_2 absorption in a separate vial. In the bottom of the plastic bottle, few mL of weakly acidified water was added to prevent for drying during the incubation. Then the lid of the bottle was closed tightly. Mineralized C, or CO_2 emitted, which was absorbed in a NaOH solution, was determined by second-step titration by HCl solution (from pH 8-9 to pH 4) using phenolphthalein and bromocresol green as indicators. On each measurement, a new alkali solution was placed for next term of measurement.

Measurement of organic matter in light and heavy fractions. The LF and HF were separated based on the difference in specific gravity. Each 10 g aliquot of soils (air-dried) were dispersed in NaI solution (1.6 g cm^{-3}) and then centrifuged at 3000 rpm (Strickland and Sollins, 1987). Materials remaining in the supernatant were collected and regarded as LF (mostly partially decomposed plant residues), whereas those included in the sediment were as HF (more decomposed organic materials possibly fixed by soil mineral parts). The contents of C and N in LF were determined by dry combustion with an NC analyzer (Sumika, NC-800-13N). Those in HF were determined by subtracting the contents of C and N in LF from C_{org} and total N.

17.3. Results

The C mineralization patterns under different conditions are presented in Fig. 17.1 for each sample soil. As is well known, increasing temperature and/or moisture resulted in an apparent increase of C mineralization. In both the series of soils, no initial flush was observed during the incubation experiment, suggesting that the soil-drying effect during the pretreatment was practically avoided.

Soil properties relating to the physical fractionation into the LF and HF are presented in Table 17.2. Both the C contents in LF and HF (LFC and HFC, respectively) are significantly higher in the Japanese forest soils than in the Eurasian steppe soils. The relative proportion of the two fractions is, however, not significantly different; LFC occupies approximately 7% of C_{org}. Rather higher CN ratios of LF in the forest soils indicate a possible difference in their quality, presumably due to vegetation. The obtained values of LFC/C_{org} as well as CN ratio in the present study are still lower than many cases of forest soils reported (28% and 37.9 in average; Khanna et al., 2001). Thus the forest soils and their organic components are characterized by lower pH, higher LFC and HFC, and higher CN ratio of LF compared to the steppe soils.

Table 17.2. Soil properties relating to physical fractionation.

	Organic C content	C content in light fraction (LFC)		CN ratio of light fraction	C content in heavy fraction (HFC)
	(g kg^{-1})	(g kg^{-1} soil)	(% in SOM)		(g kg^{-1} soil)
Eurasian steppe soils					
AN1	27.3	1.57	5.73	18.0	25.7
AN2	33.2	5.80	17.5	16.4	27.4
GK	40.0	0.896	2.24	21.4	39.1
KZ5	40.2	0.543	1.35	18.6	39.7
KZ7	38.7	1.40	3.61	16.9	37.3
CH	49.1	1.25	2.55	16.9	47.9
DC	24.3	4.26	17.5	13.0	20.0
CN	24.8	1.28	5.17	16.3	23.5
GC	28.0	2.07	7.40	18.2	25.9
Average	34.0	2.12	7.00	17.3	31.8
CV (%)	24	78	84	12	28
Japanese forest soils					
K1	41.6	6.32	15.2	17.5	35.3
K2	16.8	0.860	5.12	22.5	15.9
Y1	174	11.7	6.73	17.5	162
Y2	178	5.87	3.29	21.2	172
B1	86.5	4.17	4.82	20.6	82.3
B2	60.6	1.64	2.71	28.1	59.0
S1	97.1	11.5	11.9	25.1	85.6
S2	74.8	5.47	7.31	30.3	69.3
N1	97.0	8.86	9.13	19.4	88.1
N2	58.4	1.33	2.28	25.5	57.1
Average	88.5	5.78	6.85	22.8	82.7
CV (%)	56	65	58	18	57
Difference between the two groups[1]	**	*		**	**

[1] Significantly different at: *5% level, **1% level.

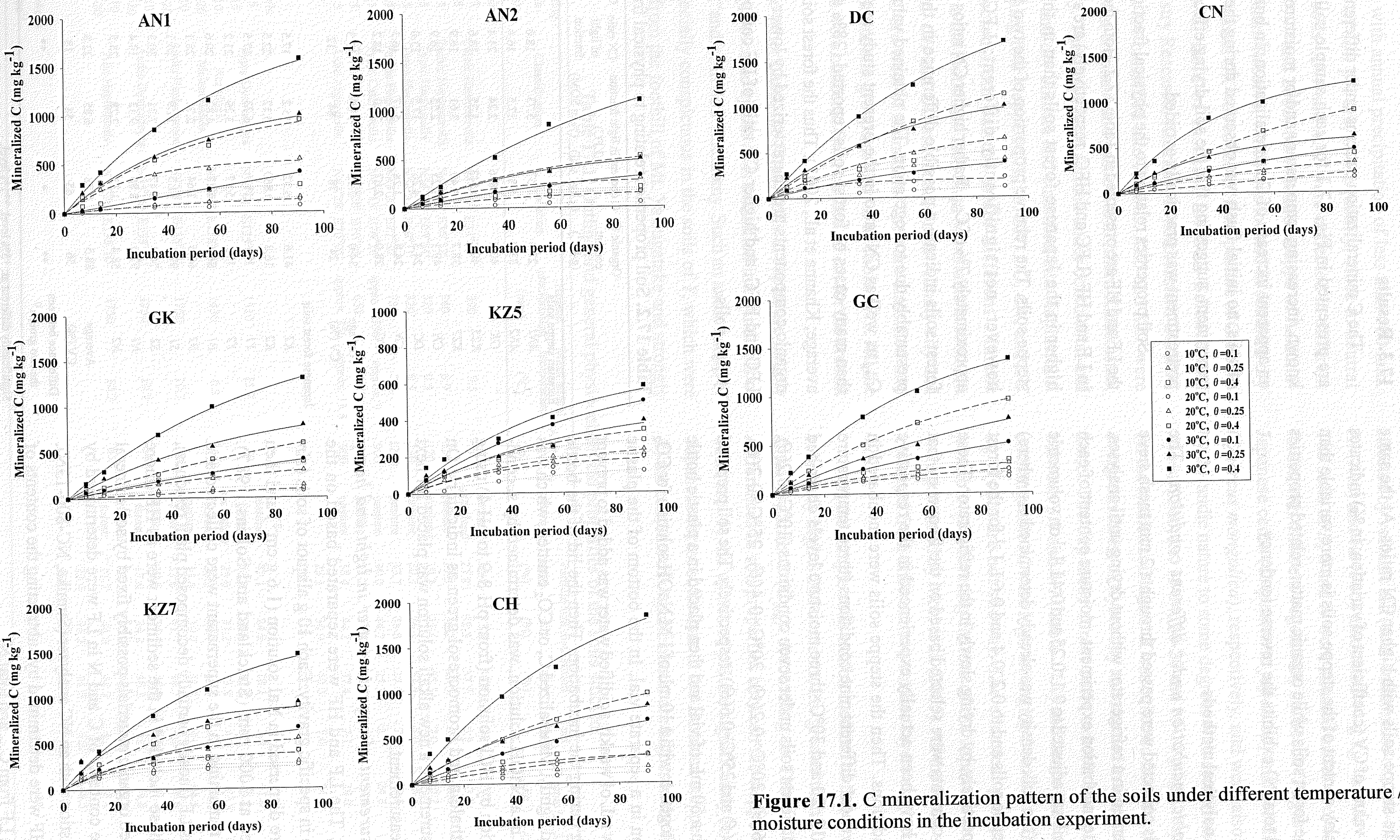

Figure 17.1. C mineralization pattern of the soils under different temperature / moisture conditions in the incubation experiment.

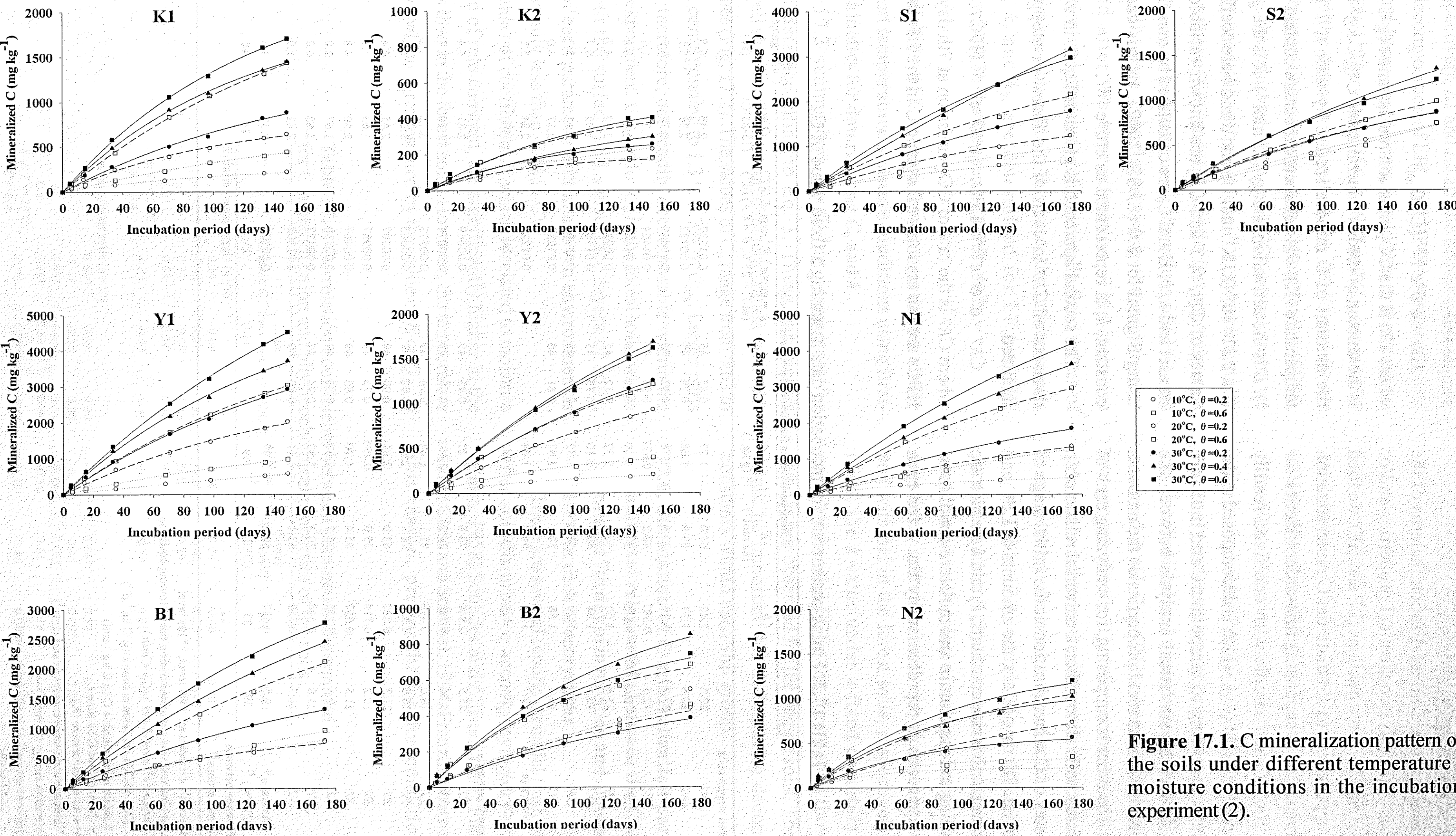

Figure 17.1. C mineralization pattern of the soils under different temperature / moisture conditions in the incubation experiment (2).

17.4. Outline of data analysis

In order to assess the C mineralization patterns of the soils in relation to the physicochemical properties and/or physically determined organic fractions (LF and HF), we tried different two approaches to simulate the C mineralization patterns observed. One is supposing first-order kinetics for C mineralization of each sample with one fixed readily mineralizable pool of SOM (C_0), which is decomposed under varying k values according to temperature and moisture conditions, followed by statistical analysis between the parameters and physicochemical properties or the amounts of LF and HF. The other is supposing, for analyzing each of the steppe or forest soils all together, a universal relationship between the rates of C mineralization at the initial stage of the incubation, i.e. 7th day, ($CR7$), the amounts of LFC and HFC and their respective rate constants, k_1 and k_2, which are variable according to temperature and moisture conditions.

The first approach is represented by Eq. 1 for each sample soil.

$$CRt = e^{a}\theta^{b}e^{-E/RT}\,(C_0\text{-}C_{\min}) \qquad \text{(Eq. 1)}$$

where CRt is the CO_2 emission rate at time t (g C kg^{-1} d^{-1}), C_0 is the amount of readily mineralizable C (g C kg^{-1} soil), $C_{\min}$ is the amount of C mineralized C by time t, T is absolute temperature (K), θ is volumetric moisture content of soil (L L^{-1}), E is the activation energy (kJ mol^{-1}), R is the gas constant (i.e. 8.31×10^{-3} (kJ K^{-1} mol^{-1})), and a and b are coefficients. The values of CRt, θ, T and $C_{\min}$ are known variables from the dataset and a, b, E and C_0 are calculated by non-linear fitting using SigmaPlot 8.0 (SPSS, 2002). In this case, the rate constant, k, is represented as $e^{a}\theta^{b}e^{-E/RT}$.

The second approach is given in Eq. 2, in which all the datasets of $CR7$ in each of the forest or steppe soils are included.

$$CR7 = e^{a_1}\theta^{b_1}e^{-E_1/RT}\,\mathrm{LFC7} + e^{a_2}\theta^{b_2}e^{-E_2/RT}\,\mathrm{HFC7} \qquad \text{(Eq. 2)}$$

where $CR7$ is the rate of CO_2 emission at 7th day, LFC7 and HFC7 are the amounts of organic C in the LF and HF at the

Table 17.3. Fitting parameters for incubation data assuming a fixed value of C_0.

	Fitting parameters for first order kinetic model2)								C_0/Organic C
	a	b	E (kJ mol^{-1})	C_0 (g kg^{-1})	R^2	n	$k = \exp(a)\,\theta^{b}\exp(-E/RT)$ (at T = 25°C, θ = 0.4) (d^{-1})	Q_{10} (15-25°C)	(%)
Eurasian steppe soils									
AN1	22.8	1.40	64.0	1.77	0.85	45	0.01337	2.45	6.5
AN2	20.5	1.37	59.9	1.68	0.78	45	0.00722	2.31	5.1
GK	25.7	1.28	72.6	1.78	0.92	45	0.00849	2.77	4.5
KZ5	12.3	0.387	40.2	0.627	0.53	45	0.01424	1.76	1.6
KZ7	18.4	0.832	54.0	1.49	0.68	45	0.01642	2.13	3.8
CH	23.4	1.50	66.0	2.32	0.82	45	0.00971	2.52	4.7
DC	15.5	1.34	46.5	2.10	0.75	45	0.01183	1.92	8.7
CN	19.0	1.70	53.4	1.32	0.79	45	0.01690	2.11	5.3
GC	19.3	1.58	55.1	1.67	0.81	45	0.01239	2.17	6.0
Average	19.7	1.26	56.9	1.64			0.01229	2.24	5.1
CV (%)	20	30	17	28			26	13	36
Japanese forest soils									
K1	25.5	0.846	73.8	2.27	0.93	49	0.00669	2.81	5.4
K2	5.56	0.587	24.2	0.462	0.60	49	0.00874	1.40	2.7
Y1	28.0	0.498	81.1	6.64	0.94	49	0.00573	3.12	3.8
Y2	26.8	0.325	78.3	2.58	0.92	49	0.00605	3.00	1.4
B1	21.3	0.832	63.9	3.81	0.90	49	0.00507	2.45	4.4
B2	10.2	0.714	35.0	0.795	0.75	49	0.00987	1.63	1.3
S1	21.5	0.557	65.4	4.70	0.86	49	0.00467	2.50	4.8
S2	10.1	0.258	36.7	1.50	0.86	49	0.00730	1.67	2.0
N1	23.8	0.884	70.3	5.80	0.94	49	0.00477	2.68	6.0
N2	21.7	0.763	63.1	1.11	0.80	49	0.01202	2.42	1.9
Average3)	19.5	0.627	59.2	2.97			0.00709	2.37	3.4
CV (%) 3)	39	33	32	69			33	24	48
Difference between the two groups1)		**					**		

1) Significantly different at: *5% level, **1% level.

2) Dataset obtained was simulated usaing the following equation:

C_{R_t}: = exp(a) θ^{b} exp($-E/RT$) (C_0-$Cmin$)

C_{R_t}: Rate of CO2 emission at time t (g C kg^{-1} d^{-1})

C_0: Readily mineralizable C (g C kg^{-1} soil)

$Cmin$: Mineralized C by time t

T: Absolute temperature (K)

θ : Volumetric moisture content of soil (L L^{-1})

E: activation energy (kJ mol^{-1})

R: Gas constant (= 8.31×10^{-3} (kJ K^{-1} mol^{-1}))

a, b, c : Coefficients

7th day, respectively, *E1* and *E2* are the activation energy (kJ mol^{-1}) for decomposition of LFC and HFC, respectively, and *a1*, *a2*, *b1* and *b2* are coefficients, in addition to the variables defined in Eq. 1. The values of *CR7*, θ, T and $C_{\min}$ are initially known from the datasets and *a1*, *a2*, *b1*, *b2*, *E1* and *E2* are calculated by non-linear fitting using SigmaPlot 8.0 (SPSS, 2002). Since the values of LFC7 and HFC7 are unknown, we temporarily used the initial values (i.e. experimentally determined values of LFC and HFC) for the first approximation and then repeated the fitting using the values of LFC7 and HFC7, which were calculated using the parameters determined after the approximation. This stepwise approximation was repeated until practically fixed values of parameters were obtained. In this case, the universal rate constants, k_1 and k_2, are determined for LF and HF, respectively, both in the steppe and forest soils.

17.5. Simulation of C mineralization patterns under different temperature/moisture conditions using first-order kinetics for determining C_0 and k

Table 17.3 summarizes the fitting parameters for incubation data according to Eq. 1. These parameters generally well simulate the measured mineralization rates with high R^2 values (Fig. 17.2). The values of C_0 range from 0.63 to 6.64 g kg^{-1}, corresponding to 1.3 to 8.7% of C_{org}. Larger parts of C_{org} are, therefore, not readily decomposable within the incubation experiment. Except for C_0 in the forest soils, which include both the surface and subsurface layers of soils, variation of each parameter within a given environment is not large, usually less than 40% in CV.

The values of coefficient b, which is related to moisture dependence of rate constant, are significantly higher in the steppe soils than in the forest soils. However, the temperature dependence, which is represented by the value of E or Q_{10}, is not significantly different between the two groups of soils, i.e. in the steppe soils the Q_{10} values (15-25°C) varies from 1.76 to 2.52 (average: 2.24) and in forest soils from 1.40 to 3.12 (average: 2.37). The values of k under a fixed condition (at $T = 25$°C, $\theta = 0.4$) in the steppe soils range from 0.0072 to 0.0169 d^{-1} - mean resident times (MRT) are approximately from 60 to 140 d - are also higher than those in the forest soils, i.e. from 0.0047 to 0.0120 d^{-1} or from 80 to 210 d in MRT. As analyzed earlier, significant differences in the physicochemical and organic matter-related properties are observed in pH, C_{org}, CN ratio and LFC content between the two groups of soils. Therefore some of these parameters are assumed to influence the difference in the values of parameter b or k between the two groups of soils.

In Table 17.4, correlation coefficients between the parameters and soil physicochemical or organic matter-related properties in each group of soils are listed. The value of b is negatively correlated with clay content in the steppe soils and with pH in the forest soils, respectively. On the other hand, the k value under a fixed condition is negatively correlated with LFC in the forest soils though such clear trend is not observed for the steppe soils. These parameters might be important for determining decomposition-rate constants within each soil group.

17.6. Simulation of C mineralization patterns using a universal relationship between the C mineralization rates at 7th day of incubation and amounts of LFC and HFC in each of ecosystems

There are several reports on initial flush of CO_2 emission after soil disturbance accompanying dry-rewet treatment (Birch, 1958; Soulides and Allison, 1961; Funke and Harris, 1968; Clein and Schimel, 1994; Franzluebbers et al., 2000). By this reason, pre-incubation for conditioning is often

Table 17.4. Correlation coefficients between parameters determined for C mineralization and physicochemical properties of the soils.

	Organic C	Light fraction-C (LFC)	LFC/OC	C/N ratio of LF	Heavy fraction-C (HFC)	pH	Clay
Eurasian steppe soils (n=9)							
a	0.24	-0.09	-0.18	0.46	0.24	-0.48	-0.20
b	-0.41	0.27	0.31	-0.20	-0.42	-0.25	-0.76*
E	0.31	-0.08	-0.19	0.50	0.29	-0.48	-0.15
C_0	0.04	0.34	0.34	-0.29	-0.02	0.19	-0.76*
k at T = 25°C, θ = 0.4	-0.31	-0.50	-0.38	-0.18	-0.19	0.21	0.31
Japanese forest soils (n=10)							
a	0.66*	0.63	0.30	-0.68*	0.64*	0.22	0.07
b	-0.44	-0.16	0.20	-0.39	-0.45	-0.69*	-0.29
E	0.68*	0.65*	0.31	-0.68*	0.66*	0.23	0.08
C_0	0.65*	0.89**	0.36	-0.58	0.61	0.18	0.26
k at T = 25°C, θ = 0.4	-0.50	-0.78**	-0.54	0.49	-0.46	0.04	-0.12

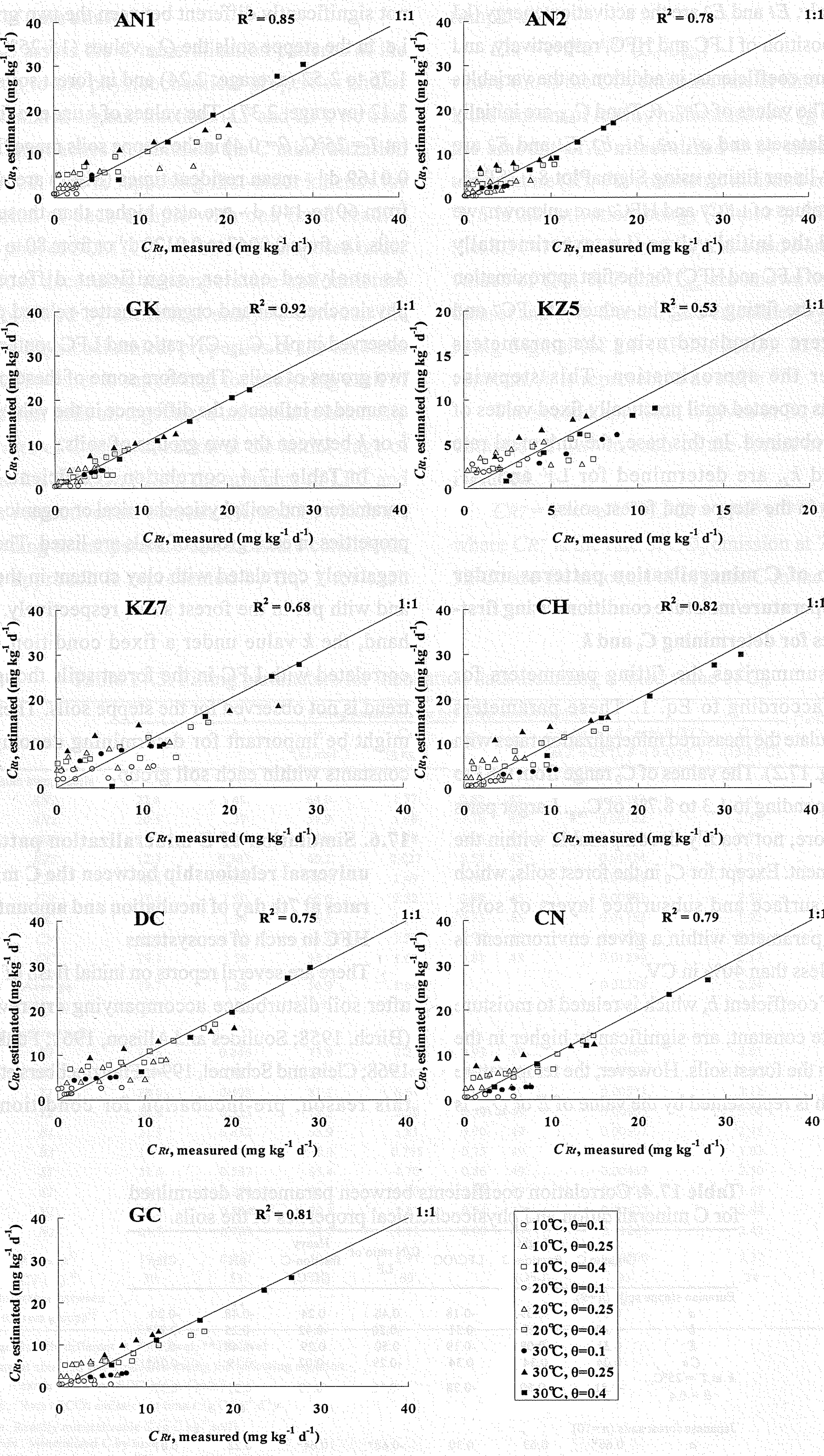

Figure 17.2. Fitting parameters for incubation data assuming a fixed value of C_0.

Table 17.5. Fitting parameters for determining CO_2 emission rate at 7th day of incubation using LFC and HFC contents for separately all the steppe and forest soils.

	Parameters on LF			Parameters on HF					$k = \exp(a)\ \theta^{b} \exp(-E/RT)$ (at T = 25°C, θ = 0.4)		Q_{10} (15-25°C)	
	a_1	b_1	E_1 (kJ mol^{-1})	a_2	b_2	E_2 (kJ mol^{-1})	R^2	n	LF (d^{-1})	HF (d^{-1})	LF	HF
Urasian steppe soils (9 samples)	10.6	1.26	37.5	7.92	0.696	37.6	0.72	81	0.00322	0.00037	1.69	1.69
Japanese forest soils (8 samples)	23.6	0.642	74.2	6.99	0.496	37.8	0.81	56	0.00100	0.00016	2.83	1.70

$C_{R7} = \exp(a_1)\ \theta^{b_1} \exp(-E_1/RT)$ LFC + $\exp(a_2)\ \theta^{b_2} \exp(-E_2/RT)$ HFC
C_{R7}: Rate of CO_2 emission at 7th day (g C kg^{-1} d^{-1})
LFC: Organic C content in light fraction (g C kg^{-1} soil)
HFC: Organic C content in heavy fraction (g C kg^{-1} soil)
T: Absolute temperature (K)
θ : Volumetric moisture content of soil (L L^{-1})
E_1 and E_2: activation energy for LF and HF decomposition, respectively (kJ mol^{-1})
R: Gas constant (= 8.31×10^{-3} (kJ K^{-1} mol^{-1}))
a_1, a_2, b_1, b_2: Coefficients

recommended. Although such an initial flush was not clearly observed in the present study, we use the CO_2 emission rate at 7th day, which is comparable with the data after conditional incubation in another studies.

Using Eq. 2, fitting parameters for determining CO_2 emission rate at 7th day of the incubation are calculated and listed in Table 17.5. Generally the CO_2 emission rates are well simulated by the parameters with high R^2 values (Fig. 17.3). It should be noted, however, that the soils with strong amorphic property, i.e. *Y1* and *Y2*, are excluded from this calculation because our first trial including them failed because extremely high HFC in these samples was not reflected in the CO_2 emission.

General trend of the parameters determined here is similar to the first approach in that coefficient *b* and the rate constant *k* at a given condition are higher in the steppe soils than in the forest soils (see the average values in Table 17.3). The rate constants for LF are approximately ten-times higher than those for HF whereas the amounts of LF are only 1/13 of HF in average, resulting in almost similar contribution of LF and HF on soil respiration rate at the time. This estimation is well consistent with the results of statistical analysis in Chapter 15 in this volume, in which the C_0 values are contributed both by the amounts of LF and HF similarly.

According to Table 17.5, the moisture/temperature dependence of HF is similar in both the soils. Main differences in the parameters are observed for LF; i.e. coefficient b_1 of the steppe soils is higher and E_1 of the forest soils is also higher than those for the other cases. This implies that under humid temperate zone in Japan the major constraint of SOM decomposition is low temperature during wintertime and therefore temperature-susceptible LF - which can be decomposable if suitable temperature were given - is remaining in soils, while in Eurasian steppes severely dry condition during summertime retards decomposition of SOM and hence more moisture-susceptible LF is left in soils. Thus the properties of LF are variable in different ecosystems while those of HF are rather similar.

The values of *k* under a given condition (at T = 25°C, θ = 0.4) are considerably different; that in the steppe soils is much higher than in the forest soils. As discussed before, main differences of the two groups of soils are pH, C_{org}, CN ratio, and LFC content. Most of the differences are still significant if the soils of *Y* are excluded from the analysis. Therefore factors relating to higher LFC content with increasing CN ratio of whole the soils, or lower pH of the forest soils are considered to be responsible for lowering *k*

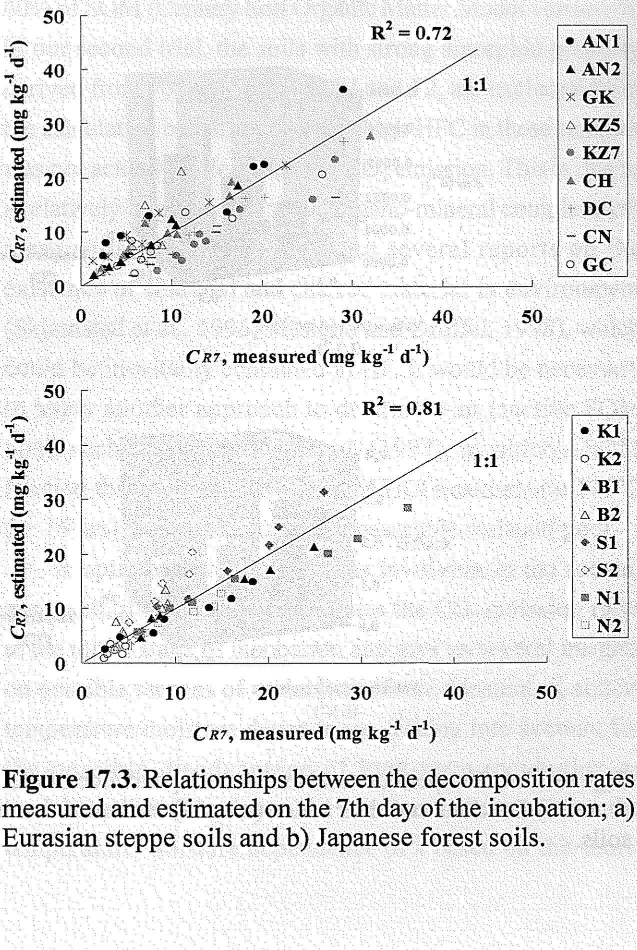

Figure 17.3. Relationships between the decomposition rates measured and estimated on the 7th day of the incubation; a) Eurasian steppe soils and b) Japanese forest soils.

value of LF for the forest soil; presumably through suppressing microbial activity or giving selection for survival among soil microbes, resulting domination of those with higher tolerance against acidity. These factors retard active decomposition of LF in forest soils and may contribute to its accumulation in the ecosystems. On the other hand, the k value of HF is also possibly influenced by the content of inactive SOM pools in HF; namely if such inactive SOM is larger, k value is assessed to be lower than actual. Most of the Japanese forest soils are affected by volcanic activity more or less and the inactive pool of SOM is expected to be high. This may cause, in addition to the effect of low pH, the apparent lower rate constant of the soils. In any cases, the values of k under a fixed condition (at $T = 25$°C, $\theta = 0.4$) are much lower in the second approach, i.e. 0.0032 and 0.0010 d^{-1} for LF and 0.00037 and 0.00016 d^{-1} for HF, respectively, corresponding approximately 310, 1000, 2700 and 6300 d in MRT. This is due to the fact that the amount of the mineralizable pool of SOM is hypothesized to be large as total SOM (LF plus HF) in the second approach though in the first approach the values of C_0 occupy only 1.3 to 8.7% of C_{org}.

Another aspect is, as shown in Fig. 17.4, that the decomposition of LF is more pronounced than that of HF under more favorable conditions, that is, the values of k_{HF}/k_{LF} is decreasing along with increase of temperature and/or moisture. In turn, there is a possibility that small changes in climatic factors can substantially affect the amounts and properties of LF.

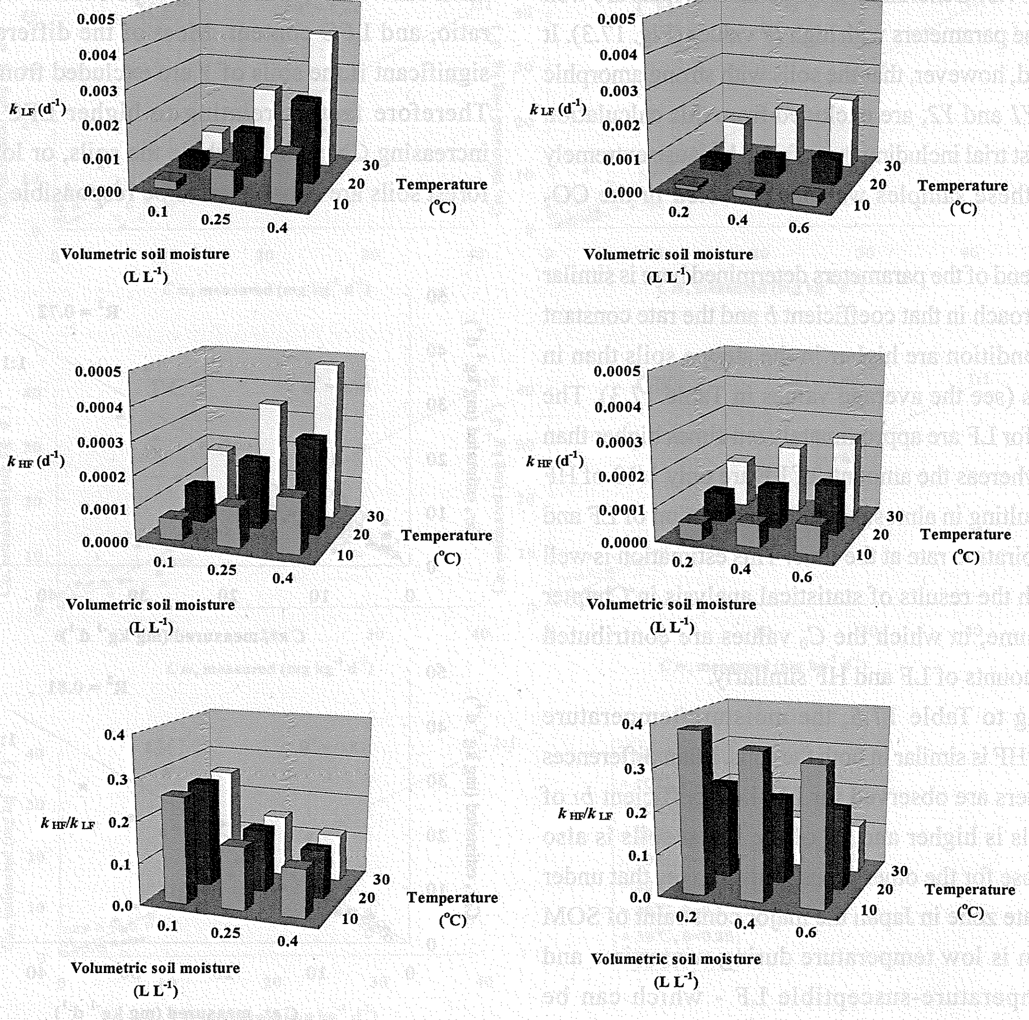

Figure 17.4. Temperature and moisture dependence of the rate constants of decomposition both for light (a and d) and heavy (b and e) fractions and their ratios (c and f) estimated for the Eurasian steppe (a, b and c) and the Japanese forest (d, e and f) soils.

17.7. General discussion on the possibility of inclusion of physical fractionation into SOM dynamic models

In the first approach, a fixed C_0 with varying k values according to temperature/moisture conditions is supposed; but the actual figure of mineralization suggest the existence of different values of maximum mineralization under different conditions (Fig. 17.1). It is, therefore, questionable to suppose only one fixed C_0 as a SOM pool with rather homogeneous characteristics in terms of temperature/moisture dependence of decomposition. The varying sizes of pools are, however, not practical in handling in models and would not be actually used in simulation. Even so, we should note the possibility of variable pool sizes under varying environments; e.g. in case we apply established models to different environments, such as humid tropics, with its original condition in temperate regions.

In addition, there might be another difficulties for supposing a fixed C_0 value based on long-term incubation data. When simulating *in situ* mineralization process, the initial mineralization rates would be one of the most important parameters since under field conditions additional substrates are usually supplied to soils continuously, indicating that the decomposition rate in later stage of the incubation becomes somewhat meaningless. Moreover, there is some uncertainty in the respiration rates in the later stage of incubation, as well as the values of C_0, because after long-term incubation microbial composition and soil properties such as pH and/or available nutrients (e.g. N or P) might be changed. By these reasons, the authors would like to seek the possibility of the second approach, in which a universal relationship is supposed between the rates of C mineralization at the initial stage of the incubation, i.e. 7th day, (*CR7*), the amounts of LFC and HFC and their respective rate constants, k_1 and k_2, which are variable according to temperature and moisture conditions.

As mentioned earlier, the overall trend of the parameters obtained is similar in both the approach tested in the present study. But there are several differences among the values obtained. As for temperature dependence, the E or Q_{10} values determined in the first approach are consistent with the summary report on temperature dependence by Katterer et al. (1998), in which the average parameter values of E and Q_{10} are determined to be 52.7 to 54.8 kJ mol^{-1} and 2.02 to 2.13, respectively, using 25 datasets published. On the other hand, in the second approach of the present study, the parameters on temperature dependence are lower (approximately 38 kJ mol^{-1} corresponding to a Q_{10} value of 1.7 except for LF in the forest soils) when we focus on the initial stage of decomposition. This is much lower than widely believed. Such difference is considered to be derived from datasets used; that is, in the first approach using a long-term incubation data, maximum decomposition under more favorable conditions has the highest loading in non-linear fitting and, therefore, the value of C_0 is inevitably set to high whereas quite low decomposition rates under lower temperature are optimized by lowering k, i.e. increasing E or Q_{10}. Although the analysis of Katterer et al. (1998) was a little different from the first approach of our study in that they firstly determined parameters at the highest temperature using the single or double sets of first order kinetic model and then optimized the datasets at lower temperature by temperature-correction parameters of rate constant such as E or Q_{10}, the situation of highest loading of the datasets under highest temperature is similar as far as all datasets are optimized into a single equation. It is necessary to analyze whether such low E values as determined in the second approach are commonly found in the SOM decomposition, especially among HF.

Additionally, there is another serious problem in the second approach, that is, how to fix SOM pools that are actually inactive under a given environmental condition. For example, in the CECTURY model, a passive SOM pool with MRT of several thousand years is supposed to amount 30-40% of SOM (Century Soil Organic Matter Model version 5). In our second trial, the soils with strong amorphic property derived from volcanic ash, i.e. *Y1* and *Y2*, are excluded from the calculation because extremely high HFC in these samples was not actually reflected in the CO_2 emission. This is due to a relatively large pool of stable organo-mineral complexes of these soils. Moreover, there are several reports on the existence of charcoal and charred material in environment (Skjemstad et al., 1996; Masiello and Druffel, 1998), which could be inevitably contained in HF. It would be necessary to apply another approach to determine an inactive SOM pool, such as trial by Paul et al. (1997), in which a SOM fraction that still remains after 6 M HCl treatment (at 115°C for 16 hrs) is proposed to be a measurable resistant pool.

In spite of several questions involving in the second approach, it successfully simulates the CO_2 emission rates at the initial stage of incubation and give us several insights on possible reasons of variability of rate constant, k, and its temperature/moisture dependence. Taking into account for the possible disadvantage of long-term incubation as mentioned earlier, it would be worthwhile to test the temperature/moisture dependence of k based on the short-term basis. This approach would, however, require us such a condition that time-step of possible simulation models is shortened, in which decomposition rates could be practically regarded as a function of a fixed pool of SOM.

17.8. Conclusion

1) Using the physical fractions of SOM (i.e. LFC and HFC) as measurable pools, the SOM decomposition rate at early stage of incubation (7th day) was successfully simulated for each of different ecosystems. In this approach, possible disadvantages involved in the analysis of long-term incubation were avoided.
2) The amounts and properties of LF also influenced on the decomposing properties of SOM such as rate constant and its temperature/moisture dependence. These parameters were rather similar within a given ecosystem but substantially different between the ecosystems.
3) Such an analysis enabled us to fix possible factors that should be taken into account when we constructed global SOM dynamics models over different ecosystems. In the present study, a possible effect of pH on SOM decomposition as well as different nature of LF from the respective environments was supposed.
4) However some problems still remained in this approach, i.e. low temperature dependence of rate constant, difficulty to fix a resistant pool of SOM, etc.
5) The integration of the measurable fractions into SOM-simulation models would increase the possibility of validation of the models when we compare actual and simulated changes of SOM in different ecosystems.

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Chapter 18

Conclusion

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18.1. SOM dynamics in Ukrainian steppe (Chapters 2 to 6)

Eurasian steppe in central Europe is distributed insularly and occupies the river valleys of Morava, Vltava and Laba, as well as the vast plains of Mid-German low hills. In the southeastern part it lays as a large continuous massive within Lower-Danube lowland and in the west - within the system of Middle Danube lowlands. Eurasian steppes continuously spread from the western border of Ukraine, including Moldova, through Northern Caucasus, Lower Volga, southern Ural, Kazakhstan, Mongolia, and southern Siberia to northern China. Total surface area of Eurasian steppe is about 700×10^6 ha. Formation of steppe landscapes in the Typical steppe zone is conditioned mainly by climate and first of all by water insufficiency, whereas in the Forest-steppe zone, which receives more water, it is conditioned by a geomorphologic factor, namely by the poor drainage of the territory **(Chapter 2)**.

Large extension of European steppe zone from west to east and from north to south conditions variability of climatic characteristics, which has influenced the characteristics of distribution of vegetation cover. Meadow steppes and steppened meadows as the most water-resistant type of steppe landscapes are spread over the territory of the Forest-steppe zone. Motley-tipchak-feathergrass typical steppe is extended in northern part of the Typical steppe zone. Tipchak-feathergrass steppe extends only in Eastern Europe over three regions: Black Sea coast, Caucasus-Lower Don and eastern bank of Volga, and was characterized with domination of xerophile dense-turf cereals. Wormwood-tipchak-feathergrass steppe is typical for the Dry steppe zone. In southern part of tipchak-feathergrass and especially in wormwood-tipchak-feathergrass steppe, steppened-desert and desert vegetation cover, which was conditioned by solonetz and solonchak spots, could be found.

Existence of the steppe as a natural phenomenon is primarily determined by water condition. The most complete reflectors of water supply and energy for soil formation are hydrothermal coefficient ($HTC_{V\text{-}IX}$) for the period with air temperature above 10°C, amount of precipitation during the cold period and its assimilation by soil. Therefore, they can be used for mapping of Eurasian steppes into moisture-homogeneous territories. Results of the researches done in Ukraine indicate that there is a close correlation between these indices and humus contents in soils ($R>0.9$). Based on the indices, Typical steppe zone of Ukraine is clearly differentiated into 4 soil-ecological zones, where each of them is characterized by inherent hydrothermal parameters, type of soil formation and quantitative indices of humus accumulation. In total 11 classes are detected in terms of humus accumulation: i.e. <80, 80-140, 140-180, 180-230, 230-280, 280-340, 340-400, 400-480, 480-540, 540-650 Mg ha^{-1} and higher. However, within these provincial standards, certain deviations are observed, which are caused by the difference in supply of water resources due to additional water feed by surface flow or contrary increase of drought by water loss due to expositional effect of slopes. It is established that deviations of total humus content against background soils within each soil-ecological province are, depending on water supply: 130±10% for Meadow chernozems (or Meadow chestnut soils) with semi-hydromorphic, 115±5% for soils with increased humidity, 100±10% for the background, 74±15% for weakly-xeromorphics, 50±10% for moderately-xeromorphics, and 30±10% for strongly-xeromorphics **(Chapter 3)**.

Steppe biosphere, natural reserve of Askania Nova, southern Ukraine, is situated within north part of the Dry Steppe zone. In grass stand composition of the steppe, zonal turf-cereal vegetation is dominant in placor conditions. Researches relating to soil temperature and moisture regimes, dynamics of SOM as well as plant production, and soil microbial activity both under natural steppe and cultivated land were conducted in 1967-1974. Following results were obtained.

1) In zones of the Southern and Dry steppes under natural vegetation, non-percolative water regime was established. The cultivated soils were characterized with more favorable water conditions. In some years positive yearly water balance was formed in them that makes possible sporadically deep (> 500 cm) percolation of soil depth in the cold periods.
2) Natural and agro-ecosystems without irrigation were characterized by the almost same bio-productivity. On the virgin and the cultivated soils without irrigation,

practically the same amount of biomass took place in the annual energy-mass-exchange. Capacity of cycles for nitrogen and mineral elements on the cultivated system was higher than those on the virgin soil. However, partial removal of biomass along with harvest on the cultivated soils led to a decrease of the energy reserves and materials accumulated in the soils during the virgin soil formation period.

3) Biological activity in the soils of the studied zone was determined by the water regime. Under the virgin vegetation, due to fast consumption of water for evapotranspiration, the biological activity concentrates in spring and early summer time. In cultivated soils with no irrigation, the biological activity including the activity of cellulose decomposition increased by almost 2 times, which was determined by the improved water regime.
4) CO_2 regime in the soil air and the intensity of gas exchange varied during the vegetative period depending upon the hydrothermal conditions and plant development. Maximum concentrations of CO_2 and intensity of its emission rate were achieved in the first half of the warm period as a result of intensive plant growth and high biological activity of the soils. In the second half of vegetation period, CO_2 concentration in the soil air as well as intensity of soil respiration significantly decreased. The pattern of CO_2 concentration curves in the soil air and intensity of soil respiration rate complied with the same pattern as those of the biological activity and plant growth that were determined by the dynamics of water regime fluctuation.
5) Soils of Askania steppe were characterized by spatial heterogeneity of the humus content. Based on the humified layer of soil, both on the virgin and the cultivated soils, two soil groups were separated: i.e. 55-65 cm and 70-80 cm; and within both the groups, on the virgin land there were 5 and on the cultivated land there are 6 groups were divided based on their particle size distribution.
6) In cultivated soils amounts of humus decreased by 10-20% relative to the virgin, herewith decrease occurred due to decrease of the least stable form - detritus. Fundamental changes in humus formation in the cultivated soils of different level of intensity relative to virgin analogues were not found. The amount of plant biomass incoming into the cycle on the non-irrigated cultivated soil is close to the virgin. Processes of humification on the studied treatments practically did not differ, that was confirmed by the same characteristics on seasonal dynamics of total and labile humus. Results of fractional composition of both the total and the labile forms of humus indicated the same characteristics of humus formation both in the cultivated and the virgin soils **(Chapter 4)**.

Since fertilizer application is determinative for obtaining contented yield of agricultural crops, its proper use with the aim to conserve and restore the fertility of Chernozem soils is a most important responsibility both of scientists and practicing farmers. The agronomic impact via fertilization, manure application and irrigation on SOM changes, both total and labile, of Chernozems in Ukraine were investigated through analyzing dynamics of labile organic matter. As a result, it was concluded that application of high rates of manure tended to increase labile forms of SOM, such as potentially mineralizable C and N, as well as soil microbial biomass, due to higher input of humic materials applied with manure. Also, application of manure tended to activate biochemical processes due to addition of large number of microorganisms that resided in manure, hence increasing the possibilities for organic matter transformations, both, mineralization and immobilization **(Chapter 5)**.

Soil respiration, i.e. carbon dioxide (CO_2) emission from soils both under Forest steppe zone in Kharkov, northeastern Ukraine and Dry steppe zone in Askania Nova was measured in order to determine a dependence of *in situ* carbon flux on soil temperature and moisture as well as to estimate annual carbon flux from Chernozem and Kastanozem soils in Ukraine. Two experimental plots were selected; i.e. Grakovo Experimental Field (N49° 44’, E36° 56’, Alt: 154 m) and Askania Nova Biosphere Reserve (N46° 27’, E33° 53’, Alt: 27 m). At these plots soil respiration with ($C_{\mathrm{em+R}}$) or without ($C_{\mathrm{em-R}}$) plant roots-respiration was measured several times during growing season in 2002 and 2003 by a closed-chamber method. It should be noted that the annual precipitation in 2003 was much higher than in normal years. As a result, in Grakovo, inter-annual variation of soil respiration was much higher than in Askania Nova. Despite the difference in the amount of the respiration, the maximum value for each year was recorded in May in Grakovo. The seasonal pattern of soil respiration was not clear in Askania Nova. Based on the measured data, the amounts of $C_{\mathrm{em+R}}$, $C_{\mathrm{em-R}}$ and plant root respiration ($C_{\mathrm{em+R}}$-$C_{\mathrm{em-R}}$) are calculated;. in Grakovo, the average proportion of root respiration in whole soil respiration was 53.2%, with ranging from 30.8 to 73.4%, whereas in Askania Nova, the average was 37.2% except for one negative value. For determining the total annual soil respiration, we firstly derived an equation that describes the relationship between the *in situ* soil respiration rate and/or soil temperature and moisture by multiple regression analysis using Arrhenius type model. The total soil respiration was then calculated by the equation with application of the monitored soil temperature and moisture data. As a result, in both the sites, positive correlation between soil respiration and soil temperature as well as soil moisture was observed. The Q_{10} value for Grakovo was 2.8, whilst for Askania Nova was 1.7. In conclusion, in Grakovo (Chernozem) annual whole soil respiration in 2002 and 2003 was 3.61 and 9.76 Mg C ha^{-1}, respectively, whilst in Askania Nova (Kastanozem) 2.52 and 2.54 Mg C ha^{-1}, respectively. The root respiration contributed about half of the whole soil respiration in each site. The soil microbial respiration in Grakovo was equivalent to the belowground biomass in the surface 10 cm, whilst that in Askania Nova was about 30% of the belowground biomass in 10 cm **(Chapter 6).**

18.2. SOM dynamics in northern Kazakhstan steppe (Chapters 7 to 10)

General soil characteristics in Kazakhstan steppe were investigated. The soils that had been developed on quaternary deposits in northern steppe were strongly affected by the characteristics of the expandable 2:1 minerals mainly in the fine clay fraction. The tongue-penetration of SOM in soil profiles, slow percolation of water from snowmelt at springtime, or clay translocation observed in forest and/or saline soils can be attributed to the mineralogical properties described above. A fairly large amount of soluble salts were often accumulated in deeper layers in the soils on the quaternary deposits in the northern steppe. It may be a cause of secondary soil salinization if an intensive irrigation agriculture were introduced in this area. On the other hand, in the loess-derived soils in the southern mountain foothills, the amounts of soluble salts in deeper layer were small, if any. At the same time, relatively coarse-textured soils distributed in a desert side. A potential risk of secondary salinization is considered to be limited in this area **(Chapter 7).**

In order to examine the effects of summer fallow on the characteristics of SOM on a long-term basis (type of crop rotation with a variety of frequencies of fallow) as well as on a short-term basis (pre- and post-fallow phases), dynamics of labile SOM such as readily mineralizable and "light fraction" SOM were investigated on Southern chernozem in northern Kazakhstan. Our results suggested that N dynamics were closely related to the recent input of substrate added as plant residue while C dynamics were more related to long-term substrate addition. Yearly input of plant residue in a 6-y wheat-fallow rotation system built up more labile OM, especially LF-C or readily decomposable C, whereas 2-y rotation system with a high frequency of fallow depleted SOM via accelerated mineralization. The relatively high SOM content under continuous-wheat system may be due to (a) high nutrient content in this soil due to former fertilization, (b) the high input of nutrients from the weed biomass, and (c) the low output of nutrients with the crops. Losses of labile OM as a result of cultivation tend to be disproportional higher than total OM losses. Therefore, labile fractions of SOM such as PMC, PMN and LF-OM are good indices for detecting subtle changes of SOM quality due to the effects of summer fallow in semi-arid regions **(Chapter 8).**

In order to determine the SOM budget under grain farming in the Chernozem soil of northern Kazakhstan, *in situ* soil respiration and soil environmental factors such as soil temperature as well as moisture content were investigated. Five experimental plots including one fallow field were established at the experimental farm of Barayev Kazakh Research and Production Center of Grain Farming, Shortandy, northern Kazakhstan (mean annual precipitation and average year temperature are 323 mm and 1.6°C, respectively). Mean daily soil temperature increased to above 0°C in early April, remaining at above 20°C from mid-June to mid-August, and then sharply decreased to below 5°C at the end of September. Most of the biological activities were considered to be limited from April to September. On the other hand, the soil moisture content remained high after thawing until mid-June and then continuously decreased in the cropped plots except during the rainfall events. The soil respiration rate recorded the highest values from late June to early July and overall fluctuations were similar to those of the soil temperature, unlike the fluctuations of soil microbial C and N contents, which exhibited similar patterns to those of the soil moisture content. In order to represent the daily soil respiration rates using the soil environmental factors, the following relationship was introduced as a model function: $C_{\mathrm{em}} = aM^{b}\mathrm{e}^{-E/RT}$. The coefficients, a, b, and E (activation energy in Arrhenius equation), were determined by stepwise multiple regression after logarithm transformation using the measured data, C_{em} (daily soil respiration rate), M (volumetric soil moisture content), and T (absolute soil temperature). As a result, a significant relationship was always obtained between the soil respiration rate and the activation energy, *E*, while the contribution of the soil moisture content to the soil respiration rate was uncertain. Using the regression equations and monitored data of soil temperature and moisture content, cumulative soil respiration throughout the cropping period was calculated to be in the range of 2.5 to 3.2 Mg C ha^{-1}. On the other hand, the amounts of crop residues in the cropped plots that were expected to be incorporated into the soils ranged from 1.6 to 4.4 Mg C ha^{-1}. Except for the plot planted with oats (higher amounts of residues than for wheat), the SOM budget was slightly negative in this year, that is, the soils lost their organic matter stock. Although it is difficult to generalize the C budget in different years because of the large variations in crop growth due to fluctuating water resources, the disadvantage of summer fallow (no residues) was obvious in terms of SOM budget. The net soil respiration rate in the fallow plot, 2.9 Mg C ha^{-1}, was approximately equivalent to 4% of the total SOM stock in the plow layer (30 cm) (70 to 80 Mg C ha^{-1}). To reduce further loss of SOM, at least evenly extensive use of summer fallow should be reconsidered **(Chapter 9)**.

The water dynamics and budget in soil-plant ecosystems under dry farming in northern Kazakhstan were investigated for two consecutive years from autumn in 1998 to the end of the cropping season in 2000. In total, 12 plots were established at the experimental farm of Barayev Kazakh Research and Production Center of Grain Farming, Shortandy, and the soil moisture content up to the 90 cm depth was measured several times throughout the period. In spite of snow management during the winter time, in which parallel snow rows were developed in order to accumulate additional snowfall between the rows, the increase in the soil moisture content at the time of thawing widely ranged from -40 to 74 mm in 1999 and from -6 to 84 mm in 2000, respectively. Monitoring of the soil temperature revealed that, in the plots after fallow, a higher moisture content in the frozen subsurface soil layer was responsible for the slow thawing there, resulting in slower water percolation from the overlying layers of the profile and in water loss through enhanced evaporation and possible surface runoff. After thawing, the soil moisture content decreased throughout the cropping season, except during several rainfall events. The evapotranspiration was estimated to range between 194 and 259 mm during the cropping season. The biomass and yield of wheat at harvest time were linearly correlated with the estimated evapotranspiration, indicating that crop production here was mostly determined by the amounts of available water. The initial soil moisture content accounted for 27 to 52% of the total evapotranspiration. In the summer fallow plots, 39 to 104 mm more water accumulated in 1999 and 100 to 119 mm in 2000 than in the cropped plots, respectively. Comparison of the water budgets during the pre-cropping and cropping seasons in the plots under fallow and cropping revealed that both summer fallow and snow management could increase the soil moisture content up to approximately 100 mm, but that the benefit of snow management would be occasionally canceled by the effect of the summer fallow. Given the possibly adverse effects of the summer fallow on enhanced decomposition of SOM, we recommend that snow management should be the main approach for capturing water in the studied plots rather than the summer fallow practice. Further studies should be carried out to determine whether soil and/or topographical conditions are more effective for individual water-capturing management and also are more suitable from economic and environmental viewpoints **(Chapter 10)**.

18.3. Comparison of properties of SOM in steppe ecosystems in different environments (Chapters 13 and 14)

The climatic conditions are one of the most critical factors to determine the soil formation processes and distribution in the Eurasian steppe area. Both Chernozems and Kastanozems in the Eurasian steppe are rich in SOM, which can support a luxuriant production of plant and biomass. Humic acids are the mixture of continuum of HA molecules with different degree of humification and their chemical characteristics vary depending on their degree of humification. Therefore, indexes of humification are useful to evaluate the effects of agricultural management practices on SOM dynamics and qualities of humic substances. In the present study, Chernozemic and related soil samples under natural grasslands and arable lands were collected from Ukraine, Hungary and Canada to investigate the properties and characteristics of the SOM dynamics of humic substances in the steppes.

The greater part of lands is covered by Chernozems and the related soils in Ukraine, where must be the central and representative Chernozemic zones in the Eurasian steppe. In the eastern part of Ukraine, the *climosequence* of the soils from the northern wetter zones to the southern drier zones can be distinctly observed. Under the moist conditions in the north, Typical Chernozems and Ordinary Chernozems, which can be distinguished by a deep black surface horizon with strongly-developed structures and the highly humified Type A humic acids, of which the *RF* value and aromaticity are remarkably high. Southern Chernozems and Dark Chestnuts are the common subtypes under the relatively dry moisture regime, the profiles of which can be characterized by a relatively thin dark-brown or brownish black surface horizon. These soils are also characterized by the Type A humic acids, however, the *RF* value is less than Typical Chernozems and Ordinary Chernozems. The carbon stock as organic carbon and/or inorganic carbon through the profile is extremely high in either case, can support and assure a luxuriant production of plant and biomass, and can reduce greenhouse gases.

The lands covered by Chernozemic soils and the climatic conditions in such areas are suitable for wheat, barley and maize production, alongside other food crops and vegetables. The intensive agricultural practice would induce soil carbon degradation, due to low input of plant residues and high microbial decomposition of organic matter accompanied by plowing, resulting in irreversible decrease in the soil fertility. The soil colors of the surface horizons in the arable soils of Hungary and Canada are brownish black to dark brown, not real black, and the organic carbon contents in the topsoils are relatively lower than those of Ukraine, probably reflecting the soil carbon degradation through agricultural impacts. They are characterized by the Type A or B humic acids, of which $\Delta \log K$ value is higher, the *RF* value is lower, and aromaticity is remarkably lower than those of the typical Type A humic acids observed in Ukraine.

From the results, it was inferred that the intensive agricultural impacts can lead to changes not only in the SOM quantity but also in the SOM quality of humic acids, especially the decrease in the aromatic and highly-humified HAs of smaller particle size. The long-term cultivation and fertilization may contribute to the formation of labile (not stable) humic substances (larger particle size) at the expense of highly aromatic HAs (smaller particle size), which are more resistant to microbial decomposition and act as the binding agents of aggregate stability, resulting in deterioration of soil structure and depletion of soil fertility **(Chapter 13)**.

Climate impacts the soil organic C content primarily through the effects of temperature, moisture, and solar radiation on the array and growth rate of plant species, and on the rate of soil organic C mineralization. In this chapter, properties of SOM from different climatic conditions, i.e. Kharkov (dry forest-steppe, east Ukraine; wet-frigid (mean annual temperature 6.5°C, mean annual precipitation 542 mm)), Uman (moist forest-steppe, central Ukraine; wet-mesic (8.5°C, 660 mm)), Kherson (dry steppe, south Ukraine; dry-thermic (11°C, 332 mm)) and Shortandy (dry steppe, north Kazakhstan; dry-frigid (1°C, 325 mm)), were analyzed with special reference to its labile fractions. Following results were obtained: Total SOM among the four agro-ecological regions was distributed as follows:

Kherson (dry-thermic) < Shortandy (dry-frigid) <= Uman (wet-mesic) < Kharkov (wet-frigid)

Labile OM among the four agro-ecological regions was distributed as follows:

Kherson (dry-thermic) >= Shortandy (dry-frigid) > Uman (wet-mesic) > Kharkov (wet-frigid)

The above comparison suggests that wet-frigid zone is the most favorable for accumulation and stabilization of SOM. Higher precipitation produced higher plant biomass contributing to the amount of SOM with further decomposition upon temperatures and soil texture. While less plant biomass production in drier regions in a lesser degree was subjected to decomposition due to moisture deficiency, thus contributing to the amount of labile SOM. Because wet-frigid (Kharkov) region maintained the highest amount of total organic carbon and the least amount of easily mineralizable organic matter (PMC), transformation of organic substrates into more stable humified forms of organic matter might have taken place more actively in this region **(Chapter 14)**.

18.4. Geostatistic approach to realize SOM study for regional scale agriculture (Chapters 11 and 12)

Soil degradation or accelerated organic matter decomposition has been reported recently in northern Kazakhstan due to specific agricultural management such as summer fallow to increase the soil moisture for the cropping season. The objectives of this study were 1) to evaluate the carbon-related properties of soil and plant in relation to the topography and amount of available water in upland fields, 2) to analyze their spatial variability using geostatistics and 3) to propose a rational system of management for the promotion of sustainable agriculture in this region. Field investigations were carried out in large-scale upland fields in Shortandy, northern Kazakhstan, where a crop rotation system had been developed on Typic Haplustolls or Southern Chernozem soils. The study field (14 km×5 km) was divided into 70 plots (1 km×1 km each) and, at the center of each plot, organic carbon (C) content (0-90cm) and potentially mineralizable C content (0-15cm) in soil, total, ear and shoot

C contents in plant, and crop yield were investigated in addition to the elevation and soil water content at the beginning of the growing season. The total amount of C stored in soil (0-90cm) was 170.9 Mg ha^{-1} with the highest C content of 39.8 Mg ha^{-1} being recorded in the surface soil (0-15cm). Potentially mineralizable C in soil (0-15cm) amounted to 2.72 Mg ha^{-1}, equivalent to 6.8% of the total C in the surface soil, suggesting that a considerable part of C in soil could be released as CO_2 under favorable conditions for organic matter decomposition. Plant aboveground biomass C amounted to 1.8 Mg ha^{-1}, of which 1.2 Mg ha^{-1} was returned to the field as plant residues and 0.6 Mg ha^{-1} was removed as crop (ear). Coefficients of variation in the amount of soil mineralizable C and plant properties exceeded 40%, suggesting a considerable variation in the field. Correlation analysis indicated that the elevation showed a positive relationship with the water content, soil organic C content ($p<0.01$), content of potentially mineralizable C and plant yield ($p<0.05$). The spatial patterns of the measured properties in the isoarithmic maps showed that the content of soil organic C was the highest in the top plateau; water content, plant C content and yield were the highest in the north-facing slope area; whereas the values of all of these parameters were relatively low in the south-facing slope area. These results strongly suggest that the organic matter dynamics in the field was considerably affected by the topography and that the most favourable area for the storage of organic matter was different from that for food production **(Chapter 11)**.

In this chapter, *in situ* CO_2 emission was measured in order to evaluate the influence of crop rotation phase and topography on carbon budget in the field, with the final goal of this research being an establishment of agricultural system that enable a proper management of organic matter in the northern Kazakhstan steppe zone. Potentially mineralizable organic carbon in 2001 and 2003 had average values of 2.72 and 2.56 Mg C ha^{-1}, and ranged from 0.7 to 6.9 Mg C ha^{-1} and from 1.4 to 5.1 Mg C ha^{-1}, respectively. In geostatistical analysis, the ranges and Q values of 2001 and 2003 sampling sets were 8.5 km and 6.2 km, and 0.50 and 0.53, respectively, suggesting a considerable degree of spatial structure. In both years, potentially mineralizable organic carbon was highest in the plateau, and it was higher in the north-facing slope than south-facing slope. This result indicated that the potential contribution as a source of CO_2 was highest in the plateau followed by north-facing slope and then south-facing slope. In nine representative plots in terms of topography and the SOM stock above analyzed, *in situ* CO_2 emission was measured in 2002. Total of 15 measurements were accomplished during May to September. CO_2 emission rose toward summer, attained maximum in summer, and declined toward autumn. There were high CO_2 emission at plateau plots. The result coincide well with pattern of potentially mineralizable organic carbon. To estimate daily CO_2 emission and to comprehend main factor of CO_2 emission fluctuation, relationship of CO_2 emission to soil temperature, water content, precipitation, and potentially mineralizable carbon was examined by multiple regression by all plots using Arrhenius model and the following equation was obtained:

$$C_{em} = e^{47.72} \times P^{0.137} \times C_0^{0.34} \times e^{-1089.65/RT} \quad (n=130, R^2=0.49)$$

where C_{em} is CO_2 emission, P is precipitation for a week, C_0 is potentially mineralizable organic carbon, R is gas constant; 0.082, and T is Kelvin temperature. It is notable that soil moisture factor in the multiple regression for CO_2 emission were excluded by stepwise estimation with probability 0.15. Total CO_2 emission estimated by the equation above and total carbon input as plant residue had average values of 3.71 and 3.46 Mg C ha^{-1}, and ranged from 2.85 to 4.64 Mg C ha^{-1} and 1.07 to 6.52 Mg C ha^{-1}, respectively. The mean carbon budget was -0.21 Mg C ha^{-1}, implying that soil degradation is progressing under the current conditions. In the geostatistical study, the range of total carbon input and carbon budget was about 5.0 km, and the Q value of was about 0.9, and this result show that the spatial pattern of total carbon input and carbon budget is similar. The range of total CO_2 emission was 7.4 km, and the Q value was 0.5. The total CO_2 emission was highest in the plateau followed by north-facing slope then south-facing slope. The distribution pattern of soils respiration showed similar trend with potentially mineralizable organic carbon, and these results suggest that the loss of soil organic carbon is related to topography. The carbon budget was highest in the eastern part of north-facing slope where total carbon input was highest, and their total CO_2 emission was small. The carbon budget was positive in the eastern part of north-facing slope, northern part of plateau, and western part of south-facing slope, and it is indicated that these zones contributed to carbon accumulation. Contrary, the carbon budget was negative in the all of summer fallow plots. Most of the barley plots which were situated in the western part of north-facing slope, also were negative carbon budget. There was relatively large CO_2 emission and small carbon input in the barley plots. In this agricultural ecosystem, the summer fallow management and crop rotation system regardless of local condition is resulting in the significant decrease of soil organic carbon. In the semi-arid croplands of northern Kazakhstan, the fate of soil organic carbon is related to landscape and crop rotation phase. To establish an agricultural system that properly manages organic matter, site-specific management should be paid more attention **(Chapter 12)**.

18.5. Toward the establishment of SOM dynamics model under different bio-climatic conditions (Chapters 15 to 17)

Because of the complex interactions amongst several factors, regional and macroclimatic influences on readily mineralizable organic matter are not yet well understood. In this chapter, we analyzed factors controlling mineralization of SOM in different regions of Eurasian steppe using a total of 41 surface soil samples (0-10 cm) from Ukraine and Kazakhstan. All the sites were classified into 4 land use categories, i.e. grassland, forest, cropland and desert. The amount of C and N (NH_4^+ and NO_3^-) mineralized was measured by titration after 7, 35, 63 and 133 days and simulated by the simple first order kinetic model, the double first order model with different rate constants (for C), logistic model (for N) and Gompertz equation. The contents of light fraction (LF) and heavy fraction (HF) were determined using sodium iodide solution (1.6 g cm^{-3}). Though light fraction (LF) occupied only 1.3 % of the whole soil by weight, LF carbon (LFC) and nitrogen (LFN) accounted for 9.5% of total C and 9.3% of total N. The amount of LFC in the forest sites (6.5 g C kg^{-1}) and the grassland sites (3.5 g C kg^{-1}) were 10.8 and 5.8 times higher than the cropland sites (0.6 g C kg^{-1}), respectively. The LF C/N ranged from 13.1 to 27.3 with the higher values in the forest sites. The average C_0 value was increasing in the order of the cropland sites (1115 mg C kg^{-1}), grassland sites (2824 mg C kg^{-1}) and forest sites (5630 mg C kg^{-1}), whilst C_0/TC in forest (10.0%) and grassland (10.1%) sites were not significantly different.

Soil and meteorological properties were summarized into 4 factors by PCA, namely, "Clay-HF", "LF", "pH-HF C/N" and "LF C/N" factors. The clay-HF factor showed no difference among land uses, whilst LF factor in cropland sites was lower than the others. It would be due to more labile nature of LF against decomposition than HF associating with clay and/or relatively low input of plant residues into the cropland soils. The pH-HF C/N factor in desert sites was higher than the others. The LF C/N factor in the forest sites showed the highest of all. It might be due to high accumulation of C from litterfall in the forest sites. Using the four factors as independent variables, stepwise regression analysis was conducted to simulate C_0 or N_0 as dependent variables. The following two equations were obtained:

C_0 (mg C kg^{-1}) = 2622 + 1976 (LF factor) + 837 (clay-HF factor) + 778 (LF C/N factor) ($R^2 = 0.81^{**}$)

N_0 (mg N kg^{-1}) = 198 + 88 (LF factor) + 66 (clay-HF factor) +18 (LF C/N factor) ($R^2 = 0.75^{**}$)

Though average LF content in soils was 1.3% in whole soil by weight and 9.5% in total carbon, the contribution of LF to C_0 was much higher than that of HF associating with clay. This probably reflects the relatively labile nature of LFC, which is more easily decomposed than HFC. The contribution of LF to N_0 was, however, not conspicuous as C_0. LF C/N contributed positively both to C_0 and N_0. In conclusion, the factors controlling readily mineralizable carbon (C_0) and nitrogen (N_0) content were LF, HF associating with clay and LF C/N. The higher C_0 values in the forest sites were considered to be contributed by the higher LFC or higher LF C/N in the forest sites. In tern, the lowest amounts of C_0 and N_0 in the cropland sites were caused by low LF content in these soils **(Chapter 15)**.

In the present research, soil respiration in Ukraine and northern Kazakhstan was investigated in Chapters 4, 6 and 9. In this chapter, results from Hungary and southern Kazakhstan are additionally reported and comparatively discussed in order to clarify possible factors that regulate *in situ* soil respiration. As was conducted in the previous chapters, *in situ* soil respiration was simulated using an Arrhenius-type equations: $C_{em} = aM^be^{-E/RT}$ and corresponding parameters were obtained. As a result, the parameter relating to temperature-dependence of SOM decomposition, namely activation energy E, was usually significant, while the contribution of moisture dependence (b) was somewhat uncertain especially in the East European plots (Ukraine and Hungary) compared to the southern Kazakhstan plots. Such a clear temperature-dependence of *in situ* soil respiration would be one of the main characteristics of SOM decomposition in temperate regions, not like as the case in the tropical countries, where annual fluctuation of soil temperature is limited. The values of E or Q_{10} mostly ranges between 30 and 80 kJ mol^{-1} and 1.5 and 3, respectively, and were consistent with the range determined by laboratory-incubation experiment. Using the parameters obtained and soil-climatic data monitored by the datalogger at the nearest sites, fluctuation of soil respiration rates was calculated and then summed up for determining total annual soil respiration. It was obvious that the amount of annual soil respiration was higher in the southern Kazakhstan plots than in the others.

According to the available paired data, the contribution of the root respiration was calculated to be approximately a half of the whole soil respiration.

In order to analyze the factors affecting the amounts of annual soil respiration in the study plots (four from southern Kazakhstan, 2 from Hungary, 2 from Ukraine and 1 from northern Kazakhstan), principal component analysis followed by stepwise multiple linear regression was conducted for the datasets. Variables employed included mean annual precipitation (MAP), mean annual temperature (MAT), altitude, clay content, organic C, total N, potentially mineralizable C (C_0), and total biomass measured. As a results, three principal components were obtained; i.e. "humidity and SOM accumulation", "delay of SOM decomposition", and "biomass accumulation" factors. The annual amount of soil respiration (*ASR*) was well explained with the following equation:

ASR = 8.304 + 4.928 × ("humidity and SOM accumulation" factor) - 3.658 × ("biomass accumulation" factor); and $R^2 = 0.87^{**}$ ($n = 9$).

This equation indicated that:

1) The increasing humidity, i.e. precipitation, increased overall SOM accumulation and also increased annual soil respiration possibly through different manners; that is, as a direct source of SOM decomposition, and by enhancing plant root respiration under comfortable moisture regime or through providing good soil physical/chemical conditions.
2) The negative contribution of "biomass accumulation" factor was considered to be an indirect one. That is, as perennial properties of the plant community increased, C accumulation into plant biomass increased mostly as root biomass; or annual species cannot accumulate the primary production and could rapidly consume it through respiration.

Thus our approach successfully analyzed the possible factors that regulate annual soil respiration under different climatic conditions **(Chapter 16)**.

In this chapter, we comparatively analyze possible relationships between the physical fractions of SOM (LF and HF) and parameters biologically determined by incubation experiment, such as readily (or potentially) mineralizable organic C (C_0), rate constant of decomposition, its temperature/moisture dependence, etc., using soils from ecologically different environments, i.e. steppe soils from Ukraine and Kazakhstan and forest soils from Japan. Main objectives here are seeking possibility for constructing SOM simulation models based on physically determined fractions as well as to fix parameters that should be taking into account when we compare the behaviors of SOM under different environments. In order to assess the C mineralization patterns of the soils in relation to the physicochemical properties and/or physically determined organic fractions (LF and HF), we tried different two approaches to simulate the C mineralization patterns observed. One is supposing first-order kinetics for C mineralization of each sample with one fixed pool of readily mineralizable SOM (C_0), which is decomposed under varying *k* values according to temperature and moisture conditions: $CRt = e^{a}\theta^{b}e^{-E/RT}(C_0\text{-}C_{\min})$. The other is supposing, for analyzing each of the steppe or forest soils all together, a universal relationship between the rates of C mineralization at the initial stage of the incubation, i.e. 7th day, ($CR7$), the amounts of LFC and HFC and their respective rate constants, k_1 and k_2, which are variable according to temperature and moisture conditions: $CR7 = e^{a_1}\theta^{b_1}e^{-E_1/RT}\,\mathrm{LFC7} + e^{a_2}\theta^{b_2}e^{-E_2/RT}\,\mathrm{HFC7}$. In this case, the universal rate constants, k_1 and k_2, are determined for LF and HF, respectively, both in the steppe and forest soils.

In the first approach, the values of coefficient *b*, which is related to moisture dependence of rate constant, are significantly higher in the steppe soils than in the forest soils. However, the temperature dependence, which is represented by the value of *E* or Q_{10}, is not significantly different between the two groups of soils. The values of *k* under a fixed condition (at $T = 25$°C, $\theta = 0.4$) in the steppe soils range from 0.0072 to 0.0169 d^{-1} - mean resident times (MRT) are approximately from 60 to 140 d - are also higher than those in the forest soils, i.e. from 0.0047 to 0.0120 d^{-1} or from 80 to 210 d in MRT. In the second approach, the CO_2 emission rates were also well simulated by the parameters with high R^2 values. It should be noted, however, that the soils with strong amorphic property were excluded from this calculation because our first trial including them failed because extremely high HFC in these samples was not reflected in the CO_2 emission. General trend of the parameters determined is similar to the first approach in that coefficient *b* and the rate constant *k* at a given condition (at $T = 25$°C, $\theta = 0.4$) are higher in the steppe soils than in the forest soils. The rate constants for LF are approximately ten-times higher than those for HF whereas the amounts of LF are only 1/13 of HF in average, resulting in almost similar contribution of LF and HF on soil respiration rate. The properties of LF are variable in different ecosystems while those of HF are rather similar. The values of *k* under a given condition are much higher than in the forest soils. Since main differences of the two groups of soils are pH, C_{org}, CN ratio, and LFC content, factors relating to higher LFC content with increasing CN ratio of whole the soils, or lower pH of the forest soils are considered to be responsible for lowering k value of LF for the forest soil; presumably through suppressing microbial activity or giving selection for survival among soil microbes, resulting domination of those with higher tolerance against acidity. These factors retard active decomposition of LF in forest soils and may contribute to its accumulation in the forest ecosystems. The decomposition of LF is more pronounced than that of HF under more favorable conditions, that is, the values of k_{HF}/k_{LF} is decreasing along with increase of temperature and/or moisture. In turn, there is a possibility that small changes in climatic factors can substantially affect the amounts and properties of LF. Thus using the physical fractions of SOM (i.e. LFC and HFC) as measurable pools, the SOM decomposition rate at early stage of incubation (7th day) was successfully simulated for each of different ecosystems. In this approach, possible disadvantages involved in the analysis of long-term incubation were avoided. The integration of the measurable fractions into SOM-simulation models would increase the possibility of validation of the models when we compare actual and simulated changes of SOM in different ecosystems **(Chapter 17)**.

18.6. General conclusion

As summarized in Chapter 16, CO_2 flux from soil surfaces varied widely; it was higher in some grassland ecosystems (southern Kazakhstan) than in most of the cropland. Nonetheless a rather simple relationship was obtained between the *in situ* annual soil respiration and bio-environmental factors (namely “humidity and SOM accumulation” and “biomass accumulation” factors). At the same time, in spite of apparent large difference in the CO_2 fluxes under the field conditions, the laboratory approach to fix decomposition rates of SOM showed an overall similarity of the rate constants within each respective ecosystem such as steppe or forest (Chapter 17). This might be one of main reasons for an apparent success of simulation models ever established, in which several pools of organic materials are supposed primarily based on the difference in the order of decomposition rate constants.

Lowering soil respiration under cropped ecosystems tended to alleviate an active degradation of SOM-related properties of soils, which was initially observed. A significant change after reclamation of natural grassland mostly appeared in the decrease of more labile fractions of SOM, such as light fraction C or C_0 (Chapters 4, 5, 8 and 15). In the regional scale, the value of C_0 was useful for predicting CO_2 emission (Chapter 12). Chernozem soils seemed to be, relatively speaking, stable against changes in environmental conditions and/or land use, not like as forest ecosystems, in which accelerated decomposition of SOM was often observed after reclamation. In this case, to simulate a drastic change of decomposition rate constants with response to environmental factors including soil acidity and/or C/N ratio, using measurable pools such as LFC, would be more important.

The geostatistical analysis in Chapters 11 and 12 suggested that the overall accumulation of SOM in agro-landscape in northern Kazakhstan was primarily affected by the cumulative primary production as a result of soil moisture regime and land use/management. Such a variation caused by topography and water regime was also pointed out in Chapter 3 for Ukrainian steppe soils. The most important determinant for primary production is water availability, whereas that of decomposition is usually temperature in the steppe ecosystems investigated (Chapters 6, 9, 10 and 16). Agricultural practices usually modifies soil water regime for achieving maximum crop production, followed by removal of primary production as harvest, but it does not essentially change the dynamics of SOM and/or nutrients (Chapter 4). If the adverse effect of agricultural practices on SOM regime under steppe environment is actually limited, as suggested in Chapters 4, 15, 16 and 17 from different approaches, a site-specific agricultural management based on the spatial patterns of organic matter dynamics would be a suitable option in reality for harmonizing sustainable agricultural production with environmental conservation by reducing organic matter decomposition.