Studies on the Circulation of Carbon and Nitrogen in Forest ecosystems

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森林生態系における炭素およびチッ素の循環について

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RÉSUMÉ

This paper deales with studies on comparing the carbon-cycle with the nitrogen-cycle from the studies of amounts stored in various forest ecosystems and on presuming the interaction of these materials.

Amounts of carbon and nitrogen stored in forest ecosystems did not clearly related with temperature, but the rates of input and of output tended to increase with the increasing temperature, that is, the cycling rates of carbon and of nitrogen in forest ecosystems were presumed to be higher in higher temperature.

Carbon and nitrogen were closely related quantitatively, and the ratios of C–N were about 10, 15 and 20, in tropical forests, warm-temperate forests and subarctic forests respectively. The difference of C/N between climatic zones would be attributed that the relationship between input and temperature was different between carbon and nitrogen.

The relationship between C/N and C_m/N_m in soils was expressed by the formula;

$$C_m/N_m=\frac{16\cdot C/N}{33-1.1C/N}$$

Contributions from JIBP–PT No. 157.

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The larger was C/N ratio, the more was the propotional rate of mineralized carbon to mineralized nitrogen. So that the large value of C/N ratio in soils would become smaller gradually.

要　　旨

本報告では各種の森林の物質現存量を求め，それらの蓄積を支配する要因についての考察を通して，炭素とチッ素の循環のパターンを比較し，それぞれの特性とその相互関係について考察を加えた。

生態系内に蓄積された炭素量およびチッ素量と温度との間にははっきりした関係はみとめられなかった。しかし，両物質とも供給量および分解量は気温の高い地域など大きくなる傾向がみられた。すなわち，炭素およびチッ素の循環速度は高温地域ほど大きくなると考えられた。

林地の炭素とチッ素は量的に密接な関係にあり，その比 (C/N) は気候帯によって異なり，熱帯林で 10, 暖温帯林で 15, 亜寒帯林で 20 となり，高温地域ほど小さくなる傾向がみられた。気候帯による C/N の違いは炭素とチッ素とで供給量と温度との関係が異なるためであろう。

林地の C/N と C_m/N_m との間に

$$C_m/N_m=\frac{16C/N}{33-1.1C/N}$$

の関係があることが認められ，C/N が大きくなると C_m/N_m の値が大きくなり，チッ素の分解量に対し炭素の分解量の割合が大きくなる。この結果として C/N がしだいに小さくなると考えられた。

INTRODUCTION

It is well-known that carbon, nitrogen and minerals are cycling between plants, soils and atmosphere in forest ecosytems.[(1)(2)(3)(4)(5)(6)] That is, the greenplants produce the organic matters with carbon dioxide, water, sun-light energy, and minerals which are uptaken from soil by roots. The produced organic matters are accumulated in leaves, branches, stems and roots. Only parts of organic matters produced by woodland plants are retained within plants and the rest are returned to soil as litter fall and to atmosphere as CO_2.

The dead organic matters accumulated on the surface of mineral soil are decomposed by micro-organisms (bacteria, fungi, et.) and soil animals. Some of carbon and nitrogen are released into the atmosphere as gaseous forms, and most of carbon and nitrogen and nutrients are transferred into soils. These nutrients are mineralized and utilized by plants. However, our present knowledges of the quantitative aspects of the processes concerned in forest dynamics are unfortunately far too scanty. Ovington[(4)] and Rodin et. al.[(7)] had shown the masses of organic matter and nutrients in various woodland ecosystems and discussed about the forest ecosystem dynamics. But little has been done to establish the roles of weathering, erosion and nitrogen-fixation played in the systems.

The two primary objectives of this study are to compare the carbon-cycle with the nitrogen cycle from the studies of amounts stored in various forest ecosystems and to presume the interaction of these materials from mineralization of nitrogen.

EXPERIMENTAL AREAS

The investigated forests were chosen including Japanese main tree-species in warm-temperate forests to subarctic forests; *Abies mayriana*[8] (nature), *Cryptomeria japonica*[9] (plantation), *Pinus densiflora*[10] (plantation), *Chamaecyparis obtusa*[11] (plantation), *Larix letolepis*[21] (plantation), *Metasequeoia*[13] (plantation), *Castanopsis cuspidata*[14] (nature), *Camelia japonica*[15] (nature), *Fagus crenata*[16] (nature) *and Betula japonica*[17] (nature). Besides, the tropical forests in Thailand[18] were added to compare with Japanese forests.

METHOD OF ANALYSIS

For the measurement of carbon and nitrogen in soils, soil samples were took from six layers by depth, down to 70 cm.

A_0 horizens were sampled from seven quadrats ($1\times1\ m^2$) and about ten trees in order to obtain a respective sample were selected for falling in each plots.

Carbon was determined by the Tiurin method and total nitrogen by the Kjeldahl technique.

RESULT AND DISCUSSION

1. Cycle of carbon and of nitrogen in woodland ecosystems

To understant the cycles of carbon and of nitrogen quntitatively, it is necessary to measure the masses of these materials in forest ecosystems, since the biomass in ecosystem is accumulated as the result of the cycling.

1) Cycle of carbon

(1) Amount of carbon in trees

Amounts of carbon in trees are mesured by multipling dry matters into carbon concentration. In this study the concentrations of carbon were not analyzed. But the carbon concentration was calculated as 55–65 percent by Ovington,[19] Kawata[20][21] and so on. These values were not greatly influenced by the difference of tree-parts, species and site conditions. Consequently, the amounts of carbon in the trees are approximately in propotion to that of dry matters, being independent on species, ages and site conditions. This may show that the movement of corbon in the trees is the same as that of plant biomasses.

Table 1 gives the amount of plant biomass present in woodlands. Plant biomass figures are ranged 30 to 310 ton per ha. The differrence are influenced by the age of stand, tree-species and environments.

The relationship between plant biomass and temperature is shown in Fig. 1. There is not obvious trend in this relationship, but the plant biomasses in stable and mature forests are fairly ranging between 300 and 400 ton per ha (dry weight) irrespective of climatic zones,[22] for instance, 350, 310, 320 ton per ha in tropical,[23] warm-temperate and subpolar zone forests respectively. Other data reported previously are of this ranges, too. The trend does not mean that there is the same relation in the gross primary productivity.

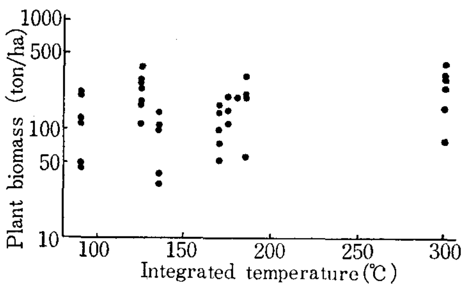

Fig. 1. Relationship between plant biomass and the integrated temperature

The plant biomass is determined by the balance of input and putput. The input is photosynthate and output is litter fall and respiration (excluding of grazing). In generaly, associated with the higher temperature, the greater are the photosynthate and respiration and the more is the amount of litter fall. Consequently, the gross primary production may be greater in the higher temperate regions.

Rodin[7] suggested that the amounts of dry matter as fallen litter and the net stemwood production are 2.5–35 ton per ha and 4.5–13 ton per ha in tropical rain and warm-temperate forests respectively. According to Kira[24], the gross production (net production+litter fall+respiration) are 120, 40–80 and 10–30 ton per ha in tropical rain, warm-temperate and deciduous forests respectively. As the result of both reports, the cycling rate of carbon in plants is larger in higher temperate regions, though the plant biomasses are fairly uniform irrespective of climatic zone.

(2) Amount of carbon in forest soils

In studied Japanese forest soils, the greatest amount of accumulated carbon was 191

Table 1. Amounts of organic matter in forest ecosystems

Tree	*Cryptomeria japonica*										*Abies mayriana*	
Location	Nara			Akita							Hokkaido	
Ages of trees	11	24	30	34	33	37	70	53	51	25	—	
Leaves	26.2	19.9	18.5	30.5	24.3	31.9	28.8	21.7	20.5	27.4	19.3	12.9
Branches	7.9	7.6	9.2	15.4	9.7	16.0	21.8	10.4	7.6	10.6	25.1	6.4
Stems	65.6	117	142	22.6	143	236	320	207	152	76.0	180	27.5
Roots	—	—	—	—	—	—	—	—	—	—	—	—
total	99.7	145	170	272	177	284	371	239	180	114	224	46.8
Ao	7.5	12.1	11.5	11.1	12.5	9.2	12.4	29.1	16.4	24.5	37.7	59.4
Soil*	75.9	135	222	138	203	229	178	267	195	305	219	153
Total	183	292	404	421	393	522	561	535	391	444	491	259

Tree	*Pinus densiflora*			*Chamaecyparis*	*Larix*					*Metasequeoia*
Location	Nagano		Ibaragi	Shiga	Nagano					Yamaguchi
Ages of trees				40	48	28	9	43	18	9
Leaves	9.1	8.4	4.9	18.8	2.7	4.5	4.2	3.6	3.7	5.1
Branches	19.3	15.5	13.0	24.8	23.0	13.6	11.0	12.9	11.0	7.5
Stems	131	93.7	104	218	118	82.1	17.1	91.5	25.0	40.4
Roots	—	—	—	74.1	—	—	—	—	—	8.9
total	159	118	121	336	144	100	32.3	108	39.7	61.9
Ao	3.6	8.2	11.1	17.1	14.4	12.8	3.6	10.4	12.4	—
Soil*	328	89.8	121	245	398	285	424	350	292	—
Total	491	214	253	598	557	398	460	468	344	—

Tree	*Camelia japonica*			*Castanopsis cuspidata*				*Betula*	*Fugus*
Location	Mie			Kagoshima				Hokkaido	Kyoto
Ages of trees									
Leaves	6.1	5.0	6.4	8.6	11.9	5.0	4.4	2.1	3.0
Branches	37.1	23.0	36.5	80	30.4	8.8	24.8	13.9	95.1
Stems	107	86.0	161	219	157	429	133	97.8	194
Roots	—	—	—	—	—	—	39.7	—	45.2
tatol	150	114	205	308	199	56.8	202	114	338
Ao	5.5	3.9	5.8	11.2	27.9	6.3	12.6	14.1	11.6
Soil*	148	151	152	120	127	126	157	207	162
Total	3.3	269	363	439	354	189	371	335	511

* Carbon ×1.724

ton per ha for *Cryptomeria japonica*, except brack soils, and the least 41 ton per ha for *Pinus densiflora* stand (Table 1). In tropical evergreen forests[18] there were noteworth ranged from 24 to 56 ton per ha, but these contents tend to less than in Japan. The differences of the amount of carbon accumulated in soils between tropical forests and temperate forests may be greatly influenced by the temperature.

The relationship between temperature and carbon content is shown in Fig. 2. The amounts of carbon accumulated in forest soils tend to decrease exponentially with temperature, as described by Jenny et. al.[25]. This relation is expressed by the formula;

$$\log C = -0.005\,T + 1.898$$

where C represents the carbon content (ton/ha) and T mean integrated temperature (°C).

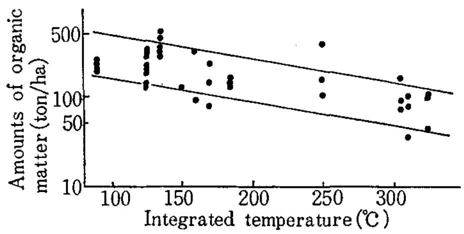

Fig. 2. Relationship between the amount of organic matter in soils and the integruted temperature

The accumulation of carbon in forest soils is decided by the balance of income (addition) and loss (decomposition).

Parts of photosynthate producted by woodland plants are added to soils as litter fall. The litter above the mineral soils are gradually decomposed, transfered into soils and accumulated there. Crocker et. al.[26] had investigated the annual rate of accumulation of carbon in the extensive recently deglaciated area, the result of which carbon increased according to maturity of the forest. The same trend was recognized for the afforestation for erosion control.[27] Forther, there are many studies on this problem with the method of mathematical models.[28][29][30][31][32][33][34] That is to say, the rate of accumulation of carbon was expressed by the formula;

$$dC/dt = L - kC$$

where L represents the income, k the decomposition rate and C accumulation of carbon in soils.

This model shows if and when the accumulation reaches to a steady-state level, the rate of change in the equation is zero. So income=loss

$$L = kC$$

This equation expresses that the accumulation of carbon in steady-state forest is estimated from income and decomposition rate.

The rate of addition is given by the annual falls of leaves, twigs and other parts of trees and dead roots. The litter fall productions measured in many woodlands were of a wide range. This differente may be dependent on age, species, dencity of stands and site conditions.

Bray[35] and Robin et. al.[7] have reported the relationship between the environments and litter production in forest of the world; 8–15 ton/ha in tropical forests, 3–8 ton/ha in warm-temperate forests and 1.5–3 ton/ha in subarctic forests. This shows the trend that in higher latitude is the higher litter production. That is, associated with the higher temperature is the greater addition of carbon.

The amounts of litter fall which we measured in some forests[36] do not so greatly differ from the values found by Bray and et. al..

It is impossible to measure directly the amount of addition of dead roots, so it is not identified now. Greenland et. al.[29] have given 0.5×litter fall for average annual dead roots under published data.

As mentioned above, the amounts of addition of carbon into forest soils increase with the increase of mean annual temperature. But as shown in Fig. 2, the carbon accumulated in soils have a tendency to decrease in higher temperature. This is because of the larger decomposition rate, as shown $L=kC$. That is, the carbon tends to be decomposed earlier in higher temperature regions.

Assumed that the forest soils studied here may approximately be in a steady-state, the decay parameter k can be made from the rate of annual litter production and carbon accumulation of forest soils. Since the annual litter productions were not measured in the investigated forests, the annual leaf increment was used in place of it.

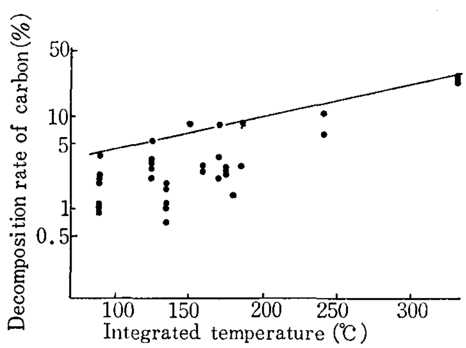

Fig. 3. Relationship between the decomposition rate of carbon in soils and the integrated temperature

The relationship between the decomposition rate and the temperature is shown in Fig. 3. The rate of decomposition tends to increase exponentially in higher temperature; 1–4% in *Abies mayruana* of subarctic forests, 3–9% in laurel-leaved forests and about 25% in tropical forests.[18] The scatters in Fig. 3 may be because of difference of the locations and tree species.

This tendency may be understood from the fact that the activities of soil-fauna and -flora which decomposed the soil organic matters primarily depend on environmental factors such as temperature and moisture.

Both the litter fall and the rate of decomposition increase with increasing temperature. This fact implies that the input and output of carbon in soils, that, is, carbon cycling is larger in higher temperature.

On the contrary, the accumulation of soil organic carbon tends to be less in higher temperature. This may be attributed to the difference of influence of temperature between the input and output; namely, the litter fall- temperature relation is linear and the decomposition-temperature relation is exponential.

(3) Carbon content in woodland ecosystem

The amounts of carbon in woodland ecosystems are obtained the amount of carbon accumulated in plants, A_0 horizon and soils.

These values are great different ranging from 104 to 347 ton per ha in Table 1.

Presuming from the plant biomasses and soil organic matters, total carbon content in woodland ecosystems may be influenced by temperature. So the relationship between temperature and total amounts of carbon is shown in Fig, 4. The data in Fig. 4 show that the amount of carbon in forest ecosystem is fairly uniform (about 290 ton per ha) for upperlimit irrespective of climatic zones. It may be due to the great difference for plant biomass which occupy normally much of the organic matters present in woodland ecosystems.

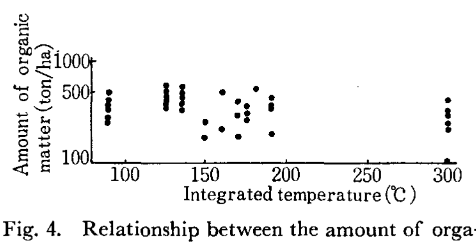

Fig. 4. Relationship between the amount of organic matter in forest ecosystems and the integrated temperature

However, the tendency of proportionate distribution of soil carbon in forest ecosystems is smaller in regions of higher temperature; 30% in warm-temperate forests and 50% in subarctic forests.

Although the relationship between the accumulated amount of carbon in woodland ecosystems and temperature is not particularly clear, the input and output of carbon in woodland ecosystems tend to increase with the increasing temperature. Consequently, the carbon cycle in woodland ecosystem would be larger in the regions of higher temperature.

2) Cycle of nitrogen

(1) Amount of nitrogen in trees

The greatest amount of nitrogen among stands studied was 860 kg per ha for laurel-leved forest at Kyushu, and the less was the 170 kg per ha for *Larix* stand (Table 2).

As for the amount accumulated in trees, there is a fairly close relationship between the amounts of organic matter present and the amounts of nitrogen it contains (Fig. 5). The regression formula is;

Table 2. Amounts of nitrogen in forest ecosystems

Tree	*Cryptomeria japonica*										*Abies mayriana*	
Location	Nara			Akita							Hokkaido	
Leaves	278	243	189	270	324	399	291	256	189	282	212	148
Branches	18.2	22.0	22.1	20.4	30.8	25.3	32.7	27.0	13.7	20.1	95.9	29.4
Stems	78.8	117	99.4	172	203	283	352	228	152	83.6	217	38.5
Roots	—	—	—	—	—	—	—	—	—	—	—	—
total	375	382	311	462	558	717	676	551	355	386	525	216
Ao	55.9	79.9	96.3	83.8	70.0	86.9	80.6	28.2	139	184	455	701
Soil	5230	4810	11100	8810	6350	10100	7630	11490	7710	11600	5570	4830
Total	5661	5272	11517	9356	6978	10904	8387	12324	8204	12170	6550	5747

Tree	*Pinus densiflora*			*Chamaecyparis*	*Larix*					*Metasequeoia*
Location	Nagano		Ibaragi	Shiga	Nagano					Yamaguchi
Leaves	96.5	85.7	50.8	184	65.7	88.6	96.6	81.6	105	119
Branches	59.8	48.1	49.2	49.6	34.1	43.2	41.9	8.5	16.3	33.1
Stems	105	65.6	76.7	175	153	98.5	31.5	101	69.9	89.0
Roots	—	—	—	111	—	—	—	—	—	38.3
total	258	199	187	520	253	230	170	191	191	280
Ao	31.7	96.2	87.0	99.5	255	200	66.0	84.4	165	—
Soil	17859	4227	5187	10640	16770	12100	17270	17029	13870	—
Total	18149	4522	5461	11259	17278	12530	17506	17304	14226	—

Tree	*Camelia japonica*			*Castanopsis cuspidata*				*Betula*	*Fagus*
Location	Mie			Kagoshima				Hokkaido	Kyoto
Leaves	74.1	121	96.4	128	211	93.9	53.7	48.9	57.6
Branches	193	177	127	384	141	41.8	84.3	5.8	390
Stems	127	183	298	394	299	101	186	15.6	350
Roots	—	—	—	—	—	—	87.1	—	109
total	394	482	521	906	651	237	411	70.3	907
Ao	125	85.7	71.5	126	438	92.9	114	168	105
Soil	7389	7177	5967	8430	5450	5840	7500	4937	13050
Total	7908	7745	6560	9462	6539	6170	8025	5175	14062

$$\log N = 0.886 \log w + 0.643$$

where N is the amount of nitrogen in trees and w is weight of organic matter. This regression shows that nitrogen content increases with the increasing total weight of organic matter, and the fact that the tangent of this regression is smalley than 1 means that the ratio of nitrogen-organic matter (average nitrogen concentration) become smaller with increasing organic matters.

The large scatters in Fig. 5 may be separated with tree-species; namely, the amounts of nitrogen tend to decrease in order of *Abies mayrinana*, *Larix*, broad leaved forest and *Cyriptmeria japonica*. This difference is attributed to that of average nitrogen concentration, that is, because of the difference of the nitrogen concentration and of the distribution of dry matter for tree parts.

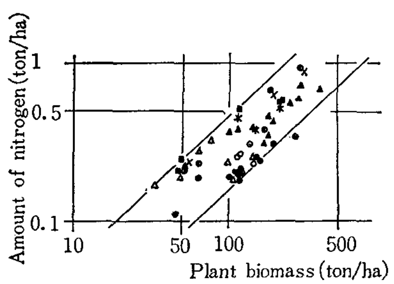

Fig. 5. Relationship between the plant biomass and the amount of nitrogen it contains

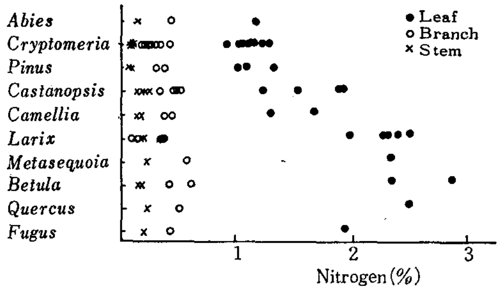

Fig. 6. The nitrogen concentration of leaves, branches and stems of different tree species

The relationship between forest type and nitrogen concentration is shown in Fig. 6.[37] Leaf nitrogen concentrations differ with forest types; 0.3–1.33%, 1.3–1.9% and 2.0–2.9% for evergreen needle-leaved trees, evergreen broad-leaved trees and deciduous trees respectively.

The leaf biomasses are also change with forest types as same as nitrogen concentration; thus Pinus 5 ton, evergreen needle leaved trees 10–20 ton, evergreen broad leaved trees 8–13 ton and deciduous trees 3–5 ton per ha.[38] The smaller is the leaf biomass, the larger is nitrogen concentration. So that differences for the nitrogen contents of leaf organic mass of woodland are not so great as might be excected from differences for the nitrogen concentration.

The concentration of nitrogen in the branches and stems differed considerably for tree species, site conditions and stand age, but there were also wide variation within same species and same stands. Consequently, there was no distinct relationship between these nitrogen concetrations and the forest type, tree spcies, site conditions and forest age.

The proportionate distribution fo above ground parts of woodland ecosystems is related with plant biomass and tree species. The distribution of the amount of nitrogen is also affected by the trend above mentioned.

This relation pertaining to Sugi and *Larix* stands are shown in Fig. 7.

Increasing with the dry matter of the above gorund parts, the proportion fo leaves having much greater nitrogen concentration decreases and that of branches and stems having the smaller nitrogen increase. This result may produce that the tangent of regression between dry matter and the nitrogen amount is less than one (Fig. 5).

As indicated priviously, there is a fairly close relationship between the amount of organic matter and total amount of nitrogen it contains, although this relation is affected by

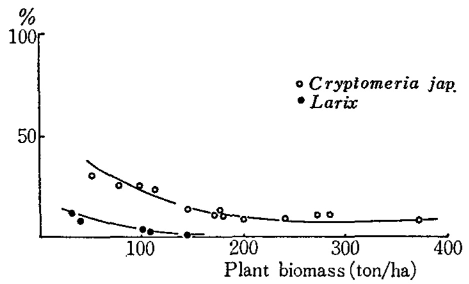

Fig. 7-a. Proposition of leaves to total plant biomass

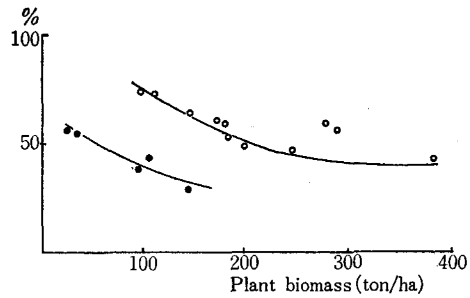

Fig. 7-b. Proportion of nitrogen in leaves to total mitrogen in plant biomass

the nitrogen concentration and the proportionate distribution of tree parts. That is to say, the nitrogen within plant organic matters is accumulated to keep a fairly fixed relation quantitatively with the carbon of which the intaking way into plants differs from nitrogen.

(2) Amount of nitrogen in forest soil.

The amounts of nitrogen in soils of forest stands studied (included A_0 layer) in Japan ranged from 2 to 15 ton per ha. Nitrogen does not consist in parent materials, but begins to accumulate in soils according to the growing of forests by the action of micro-organisms. The increase of nitrogen in forest soils has been reported in the extensive recently deglaciated area[26] and the afforestation for the errosion control.[27]

The nitrogen cycle in the woodland ecosystems is opened system as same as carbon. But there are various differences in the pathway between cabon and nitrogen; Soil carbon originates from the litter of green plants and goes out to atmosphere by microbial decomposition, and nitrogen is fixed by soil micro-organisms from air to soils and mineralized nitrogen is absorbed by plants and returns to soil as litter. A part of mineralized nitrogen is leached out from soil.

Since the rate of accumulation for discrete interval of time shows the same trend for carbon and nitrogen, it is presumed that nitrogen may be closely related with carbon quntitatively.[39][40]

As shown in Fig. 8, nitrogen contents in soils increase with increasing carbon contents. The ratio of carbon to nitrogen are about 10, 15 and 20 in tropical forests, warmtemperate forests and subarctic forests respectively. This fact shows that the both substances are closely regulated mutually, though the cycling pathways of these are quite different. Consequently, the simular rules found in carbon may be applicable to nitrogen.

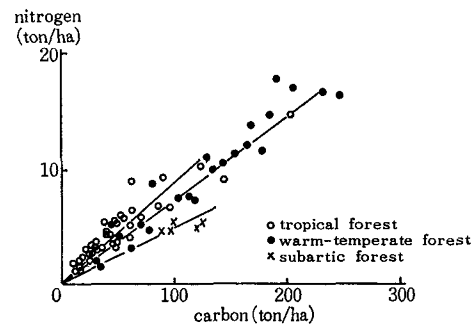

Fig. 8. Amounts of carbon and of nitrogen in soils.

When the carbon in soils reaches to a dynamic steady level, the nitrogen gets an equilibration, too. That is, the accumulation of nitrogen under the condition of steady-state are influenced by the temperature.

The relationship between nitrogen and temperature is shown in Fig. 9. The equation has the form;

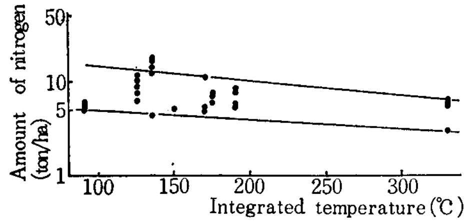

Fig. 9. Relationship between the amount of nitorogen in forest ecosystems and the integrated temperture

$$\log N = -0.032T + 0.591$$

where N represents nitrogen content in soils (kg/ha), T is temperature (°C).

This equation shows that the nitrogen contents decrease exponentially with increasing temperature, although there are wide fluctuation in the graph. This relationship is apploximately the same as the results of Harradine[4] and Jenny et. al.[42].

The quantitative difference of the amount of nitrogen in soils between tropical forests and subarctic forests was indistinct as compared with that of the carbon and the value of tangent was smaller (C: 0.052, N: 0.032).

As the result, the ratio of C/N in soils may vary with the climatic zones; The values decrease with increasing temperature. That fact may be revealed that the factors and the effects which influence the input and output differ essentially between nitrogen and carbon.

The input of nitrogen to soils are derived from litter fall, microbial fixation and precipitation. As reported earlier, the microbial fixations were in the range of 2–70 kg/ha/yr which were measured indirectly.[29][31][43] The values are variable due to climate, tree species, soil conditions and method of presumption.

The microbial fixations of atmospheric nitrogen are affected by climate, especially temperature.[44] That is, nitrogen fixation may increase with increasing temperature. Greeland[29] found that nitrogen fixations were 20–55 kg/ha, 5–14 kg/ha and 11 kg/ha, in tropical forests, in sabanna and in temperate forests respectively at 75% level of equiliblium.

On the other hand, in forest ecosystem, the input of nitrogen to soils as litter is an important pathway. The nitrogen concentrations of litter are different depending on tree species and site conditions, but the amount of dry matter is also the effective factor in deciding the amount of nitrogen added to soil. As indicated previously, the amounts of litter fall increase with increasing temperature. Consequently, the input of nitrogen as litter may show the same tendency as dry matters; Rodin et. al.[7] has reported that the additions of nitrogen by litter were 250–325 kg/ha in tropical forests and 50–70 kg/ha warm-temperate forests. The amounts which we measured in some forests did not so greatly differ from these values.[36]

The output of nitrogen from soils is more complex than that of carbon. Nitrogen in organic compounds is decomposed by soil micro-organisms and is transferred to mineral nitrogen (NH_4 or NO_3). These mineral nitrogens are absorbed by plants, leached by precipitation and released to atomosphere as gasous form.

Considering earlier data, it is comsumed that the output from soils is influenced by temperature. So that the relationship between the rate of decomposition and temperature was estimated. Under the assumption that the forest soils may apploximately be in a steady state level, the decomposition rate is estimated from input/accumulation. Since there are no data of the amount of nitrogen input by fixation and precipitation, only the amount of nitrogen as litter was estimated as input, here. The result showed that the rate of decomposition of nitrogen in soils tended to increase exponetially with increasing temperature, although this relation was not so clear as carbon; for example, 6.0–9.8% in tropical forests, 0.6–1.7% in warm-temperate forests and 0.5–1.0%in subarctic forests.

From the above results, it may be recognized that in higher temperature is the greater rate of nitrogen cycling in soils, although the differences for the amount of the accumulated nitrogen in soils are not so distinct.

(3) Nitrogen in woodland ecosystem

The amounts of nitrogen in woodland ecosystems ranged from 2 to 17 ton per ha.

As indicated previously, there was a fairly close relationship between the amounts of plant organic matter present and of nitrogen contained. As mentioned previously, the weights of organic matter in nature stands are apploximately equal, regardless with the differences of tree species and climate, so that nitrogen of woodland ecosystems may be not so great different for the climate. On one hand, soil nitrogen indistinctly tends to decrease with higher temperature.

Consequently, it would be assumed that the amounts of nitrogen in woodland ecosystems decrease and the proportionate distributions of plant nitrogen increase with increasing temperature. But these relations were not so distinct in the present studies, as shown in Fig, 10.

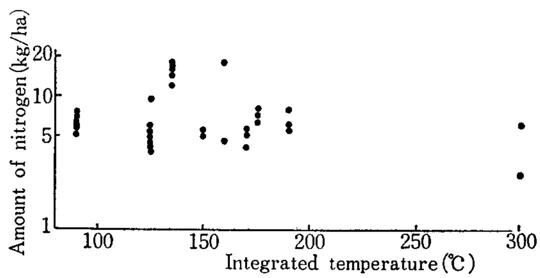

Fig. 10. Relationship between the amount of nitrogen in forest ecosystems and the integrated temperature

The distributions of nitrogen in woodland ecosystems were following; about 10% in trees, about 2% in A_0 horizon and the remaining in soils.

Although the amounts and the distributions of nitrogen are not distinct in relation with the climate, this fact does not indicate that the cycling rate of nitrogen in woodland ecosystems have no relation with climate.

The input and output of nitrogen in soils which occupy most of total nitrogen tend to increase with higher temperature. Consequently, the rate of nitrogen cycle in woodland ecosystems is larger in the temperate regions.

2. The relationship between carbon and nitrogen in soils

Carbon and nitrogen in woodland ecosystems are taken in from atmosphere by the synthsis of greenplants and fixation by soil micro-organisms.

Both substances are open cycles and the amounts of these elements in crease with the progress of development of forests. Carbon and nitrogen have the close relation with each other in the amounts that are accumulated in trees and soils.

On one hand, there may be some differences in the accumulation of these elements, because of the difference of cycling pathway between carbon and nitrogen.

There is the difference of the tangents of regression lines between the accumulation in soils and temperature. This would be attributed to the difference for the relationship between temperature and the rate of input or output of both carbon and nitrogen.

So whether this assumption was right was studied from the relationship between mineralization of nitrogen and temperature.

In general, the ratios of C/N of organic matters added to forest soils show very large values of 50 to 100.[19][20][21] It has been reported that the ratio of C/N decreases with increasing the decomposition and generally falles within a fairly narrow range, usually a mean value of about 10 which is nearly equal to the C/N ratio of soil micro-organismsm.[45] However, the forest soils investigated in the present studies and Anderson et. al.[4] had C/N ratios considerably higher than 10.

Two different explanations could be assumed for these results.

One is that, the amount of carbon and nitrogen reach to the dynamic steady state, when the *C/N* ratio of soil falles to around 10. This is impling that the soils having higher *C/N* ratio than 10 does not be in steady state.

The other is that, the amounts of carbon and nitrogen are able to reach dynamic steady state at various *C/N* ratio, usually between 10–25. The value of *C/N* varies depending upon many factors, such as climate, tree species and soil conditions.

The reliability of the assumptions should be examinened by measuring the input, output and turnover of carbon and nitrogen through soils. Unfortunately, it is more difficult to measure the input and output of nitrogen than that of carbon. So this problem was studies in the present paper by the experiment of mineralization of nitrogen and carbon.

1) Relationship between the mineralization of nitrogen and temperature

The much large parts of nitrogen stored in soils are in organic forms and the mineralized forms are usually very scanty.

It is well known prosses that organic nitrogen converes into the inorganic ammonum and nitrate ions. The transformation can probably only take place through the following prosses

organic nitrogen → ammonum → nitrite → nitrtate

These transformation are predominantly brought about in soils by micro-organisms. The biological activities concerning to nitrogen transformation are largely influenced by the abiotic environments, e. q. soil moisture, temperature et..

Generally, the biological activity would change with the season.[47] As the result, the mineralization of nitrogen in soils would vary with the season, too.[48]

The majority of earlier investigations pertaining to the seasonal variation of mineralization of nitrogen in soils were carried out at nurseries and little in forest soils.

The seasonal variation of total mineral nitrogen (NH_4+NO_3-N) showed that the maximum was in summer and the minimum was in winter, as shown in Fig. 11. The trend

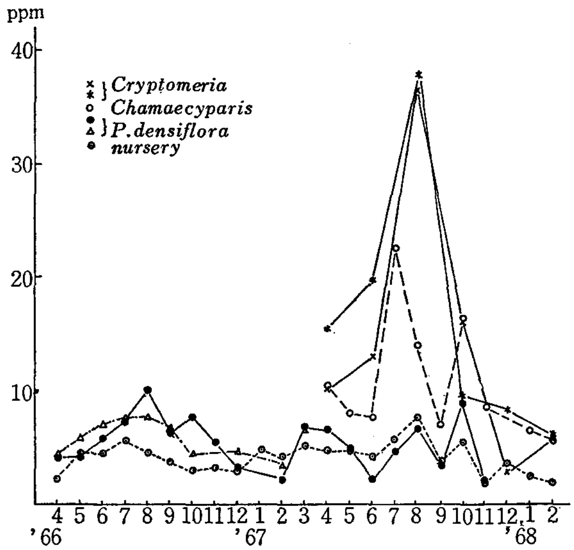

Fig. 11. Seasonal variations of mineral nitrogen (NH_4+NO_3-N) in soils

was approximately similar to that of NH_4-N, because the amount of NH_4^-N covered the larger parts of mienral nitrogen. It would mean that mineral nitrogen has a close relation with temperature. When the concentration of total mineral nitrogen was plotted against mean temperature (Fig. 12), the following equation was obtained

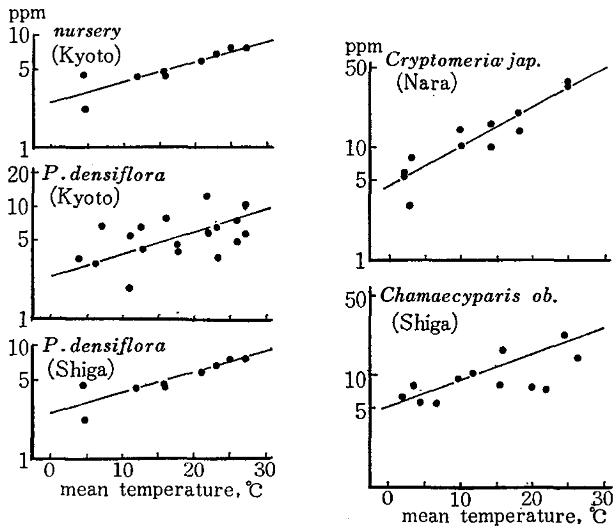

Fig. 12. Relationship between mineral nitrogen content and the mean temperature

$$\log N = aT + b$$

where N represents mineral nitrogen, T mean temperature and a and b constant.

The mineral nitrogen content increased exponentially with increasing temperature. Constants a and b concerning to forest soils studies were calculated and shown in Table 3.

Table 3. Values of constant a and b of the formula showing the relationship between mineral N and temperature.

	Total-N (%)	a	b
Cryptomeria	0.82	0.0313	0.643
Chamaecyparis	0.52	0.0242	0.691
P. densifloral (Kyoto)	0.20	0.0198	0.380
〃 (Shiga)	0.11	0.0125	0.415
Nursery	0.08	0.0179	0.398

Accoding to Table 3, these values were closely correlative with total nitrogen and the formulas

$$a = 0.036N + 0.012$$

$$b = 0.79N + 0.31$$

where N represents total nitrogen content in soils.

The same tendency was recognized in incubation tests.[48]

The results revealed that the mineralization of nitrogen in soils was predominantly influenced by temperature and total nitrogen.

Similar relationship between soil respiration and temperature have been reported,[49][50][51] that is, the mineralization of carbon increased exponentially with increasing temperature, too.

This fact seems to indicate the common phenomenon that both carbon and nitrogen are mineralized by the action of mico-organisms. Consequently, the amounts of both substances in soils are closely related with each other quantitatively.

The results above mentioned would be able to applied to climatic zones, that is, in latitude is the higher rate of mineralization of carbon and nitrogen.

The input of carbon as litter relates linearly with temperature and the input of nitrogen fixed by same microbial-organisms as the output of nitrogen would increase exponetially with temperature. The difference of input between carbon and nitrogen may lead to the difference of tangent of regression lines between the accumulation in soils and temperature.

2) The relationship between mineralization of nitrogen and carbon and nitrogen contents

A consequence of the relative constancy of the *C/N* ratio in soils is that the added organic matters decomposed to leave a residue having the *C/N* ratio in narrow range, that is around 10–25. Hence, if organic matters low in nitrogen are added to soils, soil population will remove all the available ammonium and nitrates present in the soil to help lower the ratio, whilst it is high in nitrogen, the decomposition will be releasing ammonium or nitrates into the soils.[52]

This is, in fact, shown that there is a strong conection between the addition and decomposition of carbon and those of nitrogen.[39]

The amounts of addition and decomposition of carbon can be measured with litter fall and soil respiration. However, those of nitrogen can not be easily measured owing to be more complicated than carbon.

So that this relation was determined from the incubation experiments.

Twenty-five soils (0–5 cm topsoil) sampled from the forests of different tree species, regions and soil types were incubated at 30°C for 30 days. Loss of moisture due to evaporation was made up periodically by addition water.

Results are shown in detail in earlier report.[48] Total mineral nitrogen accumulated ranging from 3 to 21 ppm. The amount of mineral nitrogen seemed to be correlated with total nitrogen. But the relationship was not clear because of including widely different soil types.

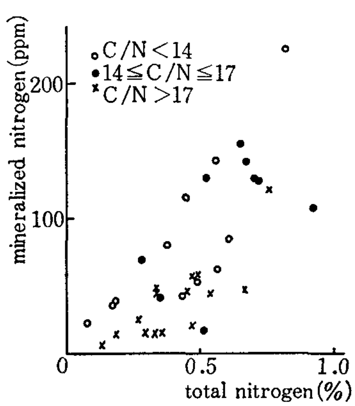

Fig. 13. Relationship between total nitrogen and mineralized nitrogen during 30 days' incubation

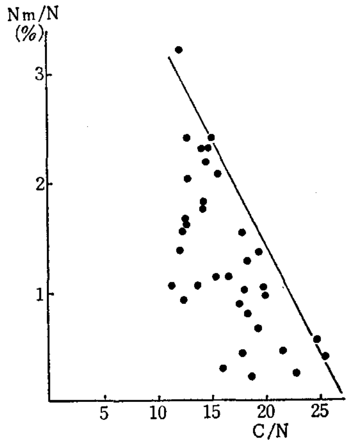

Fig. 14. Relationship between C/N and the rate of decomposition of nitrogen (Nm/N)

When soils having nearly the same C/N ratio were selected, the correlation between mineral nitrogen accumulated and total nitrogen became much distinct (Fig. 13).

This fact showed that the rate of mineralization of nitrogen (N_m/N) was significantly correlated with C/N ratio (Fig. 14). The equation had the form;

$$N/N_m = A + B \cdot C/N$$

The rate of mineralization of nitogen decreased linearly with increasing C/N ratio. The similar relation has already been reported in the experiment of the litter decomposition.[54] Though Harmsen et. al.[55] mentioned that no mineralization of nitrogen may be expected in the C/N ratio of 20 to 25, there existed the low mineral nitrogen accumulation in studied soils with high C/N ratio. And Jones et. al.[56] found that the C/N ratio was not significantly correlated with incubation mineral nitrogen production. This was presumably because that there is a difference of soil micro-organisms between forest soil and nursery soil.

It has been recognized that the higher is the carbon in soils, the more mineralization of carbon is provided for incubation experiments and under field conditions. The similar tendency was found in the present studies. The fact shows that the decomposition of carbon in soils depends primarily on the amount of carbon, but the rate of decomposition (C_m/C) is constant independently on the amount of carbon and C/N ratio. As the results, the relationship between C_m or N_m and C/N could be expressed by the formulas;

$$N/N_m = A + B \cdot C/N$$

$$C/C_m = k$$

From those equations, the following regression equation is obtained

$$C_m/N_m = \frac{k \cdot C/N}{A - B \cdot C/N}$$

This relation shows that the decomposition of nitrgen against that of carbon decreases with increasing C/N ratio (Fig. 15).

In order to make this relation more clear, the soils treated with pure cellulose and lignin were incubated at 20°C for 30 days. And the results were shown in Table 4.

As shown in Table 4, the mineral nitrogen accumulated were accounted for 32ppm after 2 weeks and 73 ppm after 4 weeks in the control soils, and the mineralization of nitrogen in soils which were treated with cellulose and lignin were smaller than the control. On the contarary, the mineralization of carbon were more accounted in treated soils.

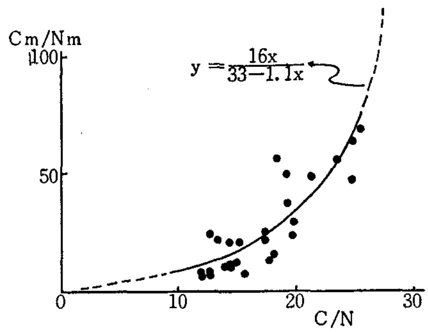

Fig. 15. Relationship between C/N and Cm/Nm

In soils that carbon was applied and the C/N ratio became larger, accumulation of mineral nitrogen reduced. It would mean that mineral nitrogen produced was used as the nutrition of soil micro-organisms, or that the mineralization of nitrogen was supressed.

If the result could be applied to the field, the loss of nitrogen of soils with larger C/N ratio would be infinitely small or only the carbon content would be reduced.

It is not so well inform that the input of nitrogen in soils is significantly correlately with the C/N ratio. However, if only the output of nitrogen is controled, nitrogen would be

Table 4–a. Mineralized–N in soils treated with pure cellulose and lignin (ppm)

		control	Cellulose				lignin			
			1 (g)	2 (g)	4 (g)	6 (g)	1 (g)	2 (g)	4 (g)	6 (g)
after 2 weeks	NH_4–N	5.2	2.7	4.6	2.3	1.3	2.7	2.1	3.4	2.7
	NO_3–N	26.7	0.6	0.7	0.8	0.5	24.3	22.7	18.3	14.3
	total	31.9	3.3	5.3	3.3	1.8	27.0	24.8	21.7	17.0
after 4 weeks	NH_4–N	15.4	4.3	—	—	2.3	3.9	3.0	3.1	6.4
	NO_3–N	57.2	0.8	—	—	0.6	52.8	54.3	42.0	33.4
	total	72.6	5.1	—	—	2.9	56.7	57.3	45.1	39.8

Table 4–b. Mineralized C in soils treated with cellulose (ppm)

control	cellulose		
	1 (g)	2 (g)	3 (g)
64.1	168.2	266.5	250.8

continued to accumulate in soils and the C/N ratio become to small gradually. At the end, all soils should have the C/N ratio of about 10.

In fact, the C/N ratio of every matured forest soil is not always about 10 and the investigated forest soils had the higher C/N ratio ranging from 20 to 25.

The input of nitrogen are taken place by soil micro-organisms. And it would be also to assume that the higher is the C/N ratio the less is the input of nitrogen, too.

If both input and output are controlled by the C/N ratio, it would be assumed that the final value of C/N ratio is not always limited to about 10, but have somewhat a wide range. And soils with the C/N ratio higher than 20 are not on the way of falling to 10, but are stable in such values.

The result obtained in this study was apparent that the carbon and nitrogen in soils had a different cycling pathway one from another, but both substances had close relation through the living things (plants and micro-organisms) quantitatively.

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