

Evaluation of intensive multiple cropping
and its control in the southeast coastal
area of Lake Dianchi, Yunnan Province,
China

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Chapter 1

Background: Change from paddy-broad bean fields to vegetable fields under vinyl houses in the coastal area of southeast Lake Dianchi, Yunnan province, China

1-1 Introduction

China has made great progress in economic, increasing demands for agricultural products (Chen et al., 2006; Inamura et al., 2009). To obtain greater annual yields and higher profits, farmers have changed land use type and kind of crop, and increased cropping intensity. For instance, traditional double cropping system of rice-wheat and rice-broad bean have been converted to a intensive cropping system of vegetables (Li and Wang, 2003; Min et al., 2011). A significant increasing in multiple-cropping index was observed in eastern China after 1985 (Li and Wang, 2003). The change happened not only in cultivated way but also in cultivated area. A large area of farmland has been lost to non-agricultural use in the progress of industrialization and urbanization, and cultivated area decreased more severely in the more developed and faster growing coastal provinces, where was particularly fertile and suitable for annual multiple cropping (Lin and Ho, 2003).

Intensive multiple cropping system demands high application of chemical fertilizer. Chinese agriculture had consumed 52 million tons fertilizer in 2008 on a limited land area, that was, over one-third of word consumption (Sun et

al., 2012). The input of nitrogen (N) fertilizer in China reached 32.6 million tons in 2007, increasing by 191% over 1981 (Guo et al. 2010). Since 1980s, fertilizer use efficiency of inorganic N fertilizer has been decreasing, recovery ratio of N in the harvest crop decreased from 57% in 1979 to 43% in 1998. The low N use efficiency has continued since 1998 and now is an issue for almost all cereal and vegetable crops (Sun et al., 2012). Decreasing N use efficiency indicates that more N fertilizer is being lost to the environment, causing further negative environmental impacts (Xing and Zhu, 2002).

A similar agricultural change was observed in the coastal area of southeast Lake Dianchi, Yunnan Province, China, but few studies have focused on the change in this area. The objective of this chapter was to investigate the converting from traditional cropping of rice-broad bean to intensive multiple cropping of vegetables in this area, a background of whole study.

1-2. Materials and methods

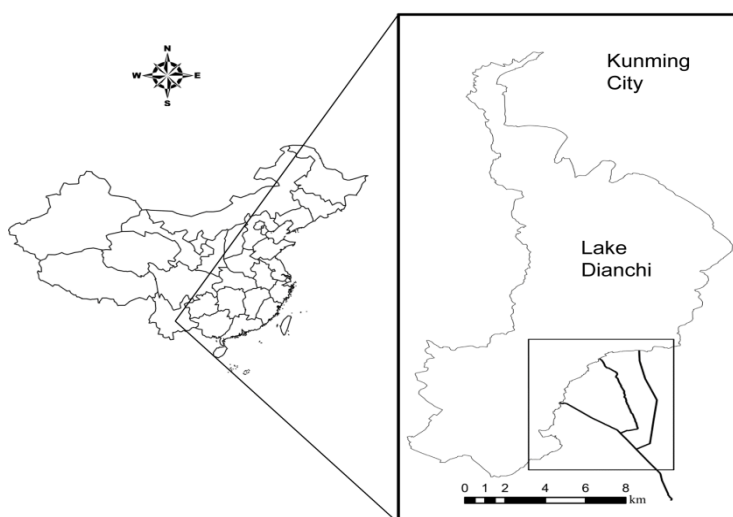


Fig. 1-1. Location of the study area



Fig. 1-2. Top view of the study area

Site of study

This study was conducted from March 2011 to February 2012 in the coastal area of southeast Lake Dianchi, located southwest of Kunming City, the provincial capital of Yunnan Province, in southwest China ($24^{\circ}42' \text{ N}$, $102^{\circ}42' \text{ E}$) (Fig. 1-1). The study area is a suburban area near the Kunming city where the residential population is 6280,000 (Statistical Bureau of Yunnan province and Survey Office of the National Bureau of Statistics in Yunnan, 2010). It is a supply base of vegetable, flower, meat and milk and includes three townships, Jincheng, Shangsuan, and Xinjie. Before 2000, a paddy rice-broad bean cropping system was dominant in this area, but from 2001 to 2009, most of the paddy fields were changed to multiple cropping of vegetable and continuous cropping of flower under vinyl house (Fig. 1-2). Moreover, the breeding number of livestock increased sharply, for instance, from 2001 to 2009, the number of cow increased from 362 to 770 in Jincheng town and from 525 to 1191 Shangsuan town respectively. The cropping system in my research area is

multiple cropping which consists of several kinds of leaf vegetables. Since the kind of leaf vegetables cultivated changes depending on the prices of crops, the cropping system changes with farmers and years. An amount of input of fertilizer and manure increases for getting large early growth of vegetables and high commodity value (vegetable with deep green leaf). In such various cropping systems, the annual amount of input is very high with high cropping intensity and high amount of input of fertilizer and manure per crop. Although this annually high amount of input of chemical fertilizer and livestock manure is a cause of eutrophication, it is not clear which input is a more important factor for controlling of eutrophication.

The climate is of the monsoon type. The annual precipitation is 980 mm, the rainy season extends from May to October, and 79% of annual precipitation occurs in this period. The annual transpiration is larger than the annual precipitation, and is 1876 mm. The annual mean temperature is 15°C (National Astronomical Observatory of Japan, 2013). Soils in this area have a clayey texture and a dull brown or dull reddish brown color, and the coefficients of variation of sand, silt, and clay properties were not high. The soils are classified as Eutric Cambisol (WRB soil classification) or Dystric Eutrochrept (USDA Soil Taxonomy) (Moritsuka et al., 2013).

There are three rivers with complicated situation in the area. There are many water-gates along these rivers. In rainy season, the main water source of the three rivers is precipitation and upstream reservoir, and in dry season, local government pumped water from Lake Dianchi to these rivers to replenish water deficiency (Tanaka et al., 2013).

Basically agricultural information

The data of total area of farmland, application of chemical fertilizer, population of agricultural labor, and cultivated area of each crop of three townships in 2001, 2006, and 2009 were obtained from local governments. Data of Xinjie in 2001 was absent. The data of cultivated areas of different crops in China mainland were cited from the statistics division of the Food and Agriculture Organization of the United Nations (FAO).

1-3. Results

Temporal variation of farmland area, application of compound fertilizer, and population of agricultural labor in the study area

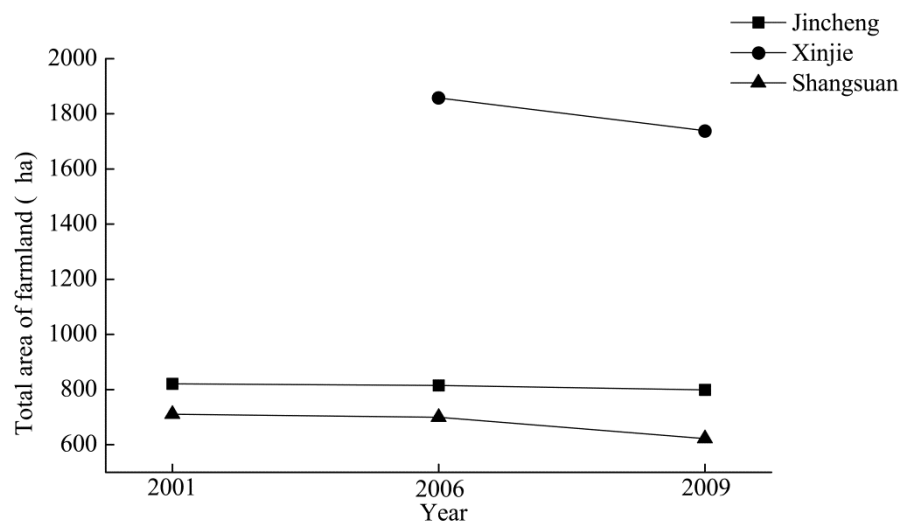


Fig. 1-3. Temporal variation of farmland area in the coastal area of southeast Lake Dianchi, southwest of Kunming city, Yunnan province, China.

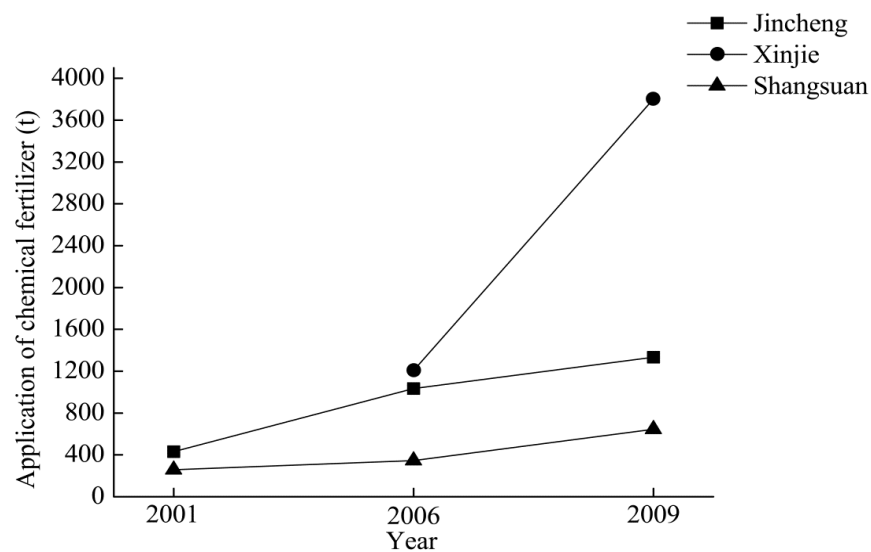


Fig. 1-4. Temporal variation of application of chemical fertilizer in the coastal area of southeast Lake Dianchi, southwest of Kunming city, Yunnan province, China.

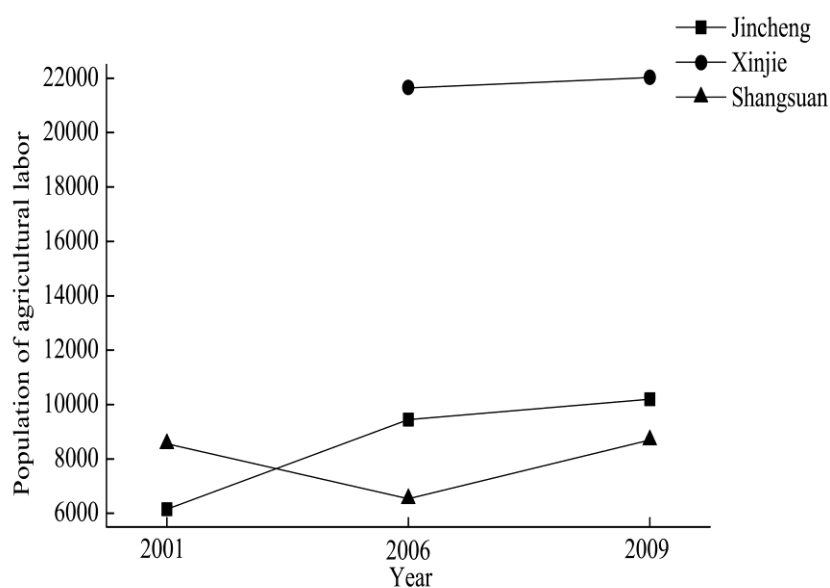


Fig. 1-5. Temporal variation of population of agriculture labor in the coastal area of southeast Lake Dianchi, southwest of Kunming city, Yunnan province, China.

Total areas of farmlands in the three townships had slightly decreased (Fig. 1-3). Application of chemical fertilizer in Jincheng and Shangsuan in 2001 was low, but it had increased from 2001 to 2009 (Fig. 1-4). Application of chemical

fertilizer in Xinije sharply increased from 2006 to 2009. In general, population of agriculture labor in the three townships had slightly increased (Fig. 1-5).

Temporal variation of cultivated areas of different crops in China and in the study area

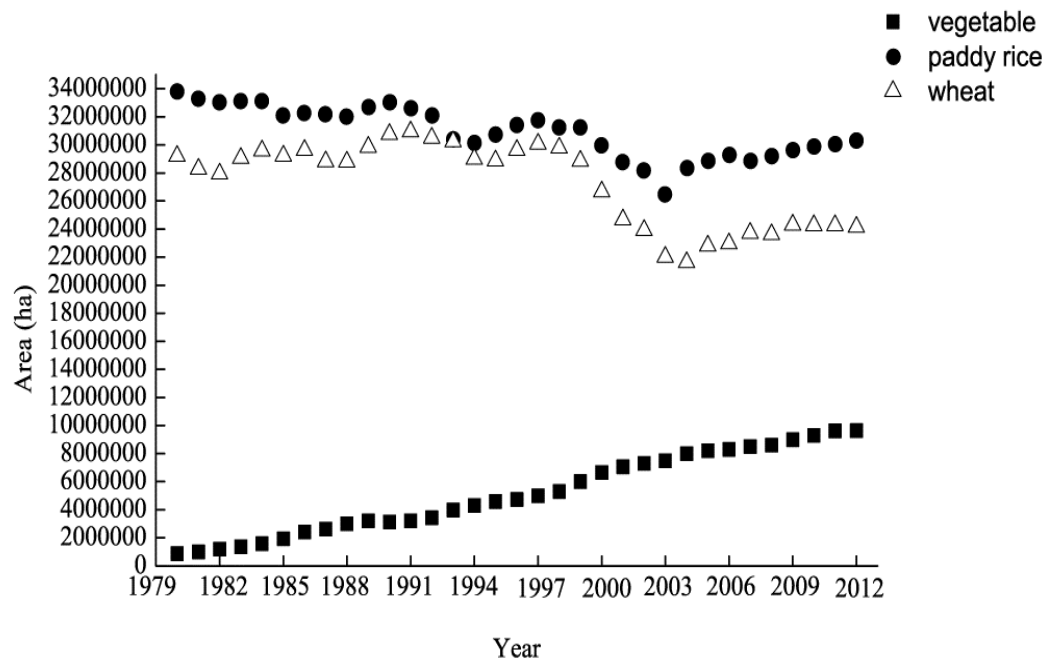


Fig. 1-6. Temporal variation of cultivated areas of different crops in China mainland. The data are cited from the statistics division of the Food and Agriculture Organization of the United Nations (FAO).

Figure 1-6 indicates the temporal variation of cultivated vegetable, paddy rice, and wheat in China mainland. The cultivated area of paddy rice and wheat had decreased from 1980 to 2003, and reached the lowest value in 2003 and 2004, respectively, then increased slightly. In general, the cultivated area of paddy rice and wheat had trended to decrease from 1980 to 2012. The cultivated area of vegetable had increased year by year from 1980 to 2012.

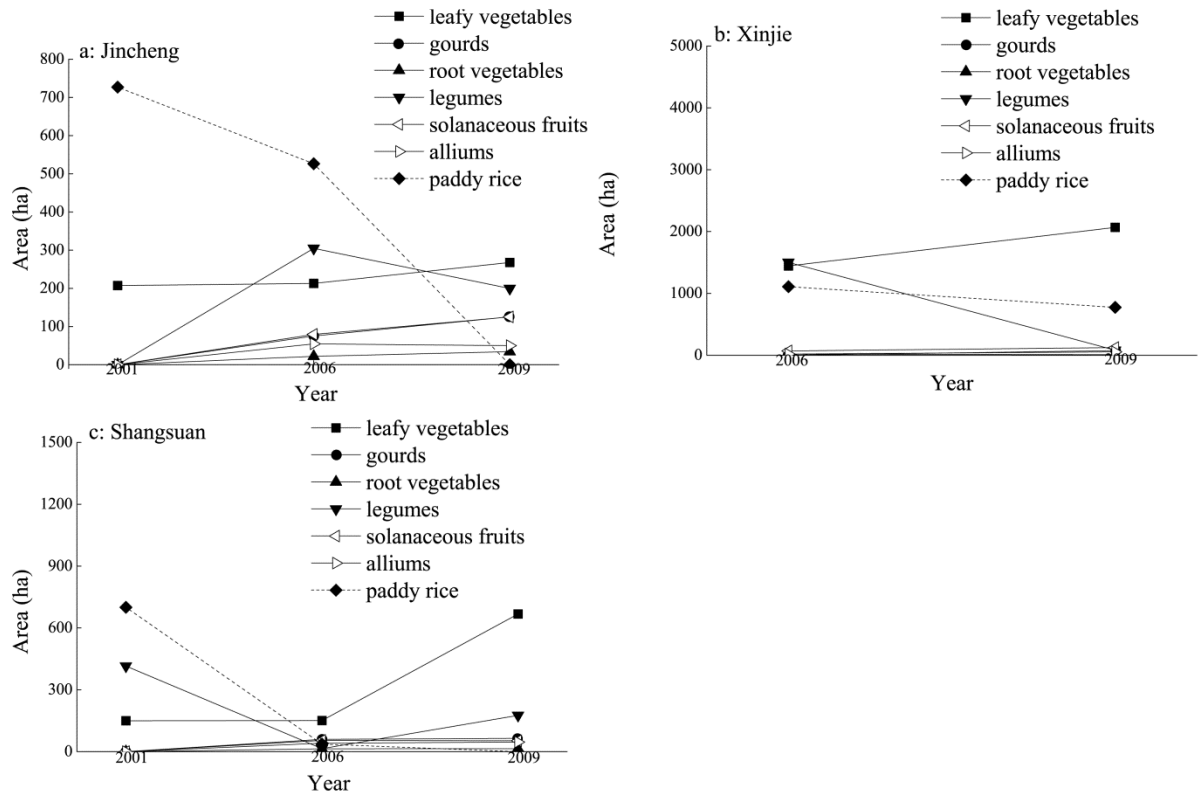


Fig. 1-7. Temporal variation of cultivated areas with different crops in the coastal area of southeast Lake Dianchi, southwest of Kunming city, Yunnan province, China.

In Jincheng, cultivated areas of paddy rice decreased from 727 to 526 ha in the duration 2001 to 2006, then decreased to zero in 2009 (Fig. 1-7a). Cultivated areas of legumes increased in 2006, and then decreased in 2009. Cultivated areas of leafy vegetables increased slightly before 2009, but according to my survey, those should obviously increase after 2009. In Xinjie and Shangsuan, cultivated areas of paddy rice and legumes decreased sharply, cultivated areas of leafy vegetables had obviously increased until 2009 (Fig. 1-7b, fig. 1-7c). Compared with data in 2006, total cultivated areas of paddy rice and legumes in three townships in 2009 decreased to 46% and 25%, respectively, and those of leafy vegetables increased to 166%. Cultivated areas of other crops in the study area kept at very low levels.

1-4. Discussion

A paddy rice-broad bean cropping system was dominant in this area before 2001. Cropping intensity in this system was two per year, paddy rice had been cultivated from April to October, and broad bean was cultivated in winter. After 2012, most of the paddy fields were changed to vegetable fields under vinyl house, coinciding with the general change in China (Fig. 1-6, fig. 1-7). Application of chemical fertilizer in 2001 was very low, indicating that paddy rice-broad bean system depended on low application of chemical fertilizer (Fig. 1-4). The chemical fertilizer used to this system was mainly N fertilizer (e.g., urea and ammonium bicarbonate). For instance, N fertilizer accounted for 67% of chemical fertilizer in Jincheng in 2001. Meanwhile, little or no manure was applied.

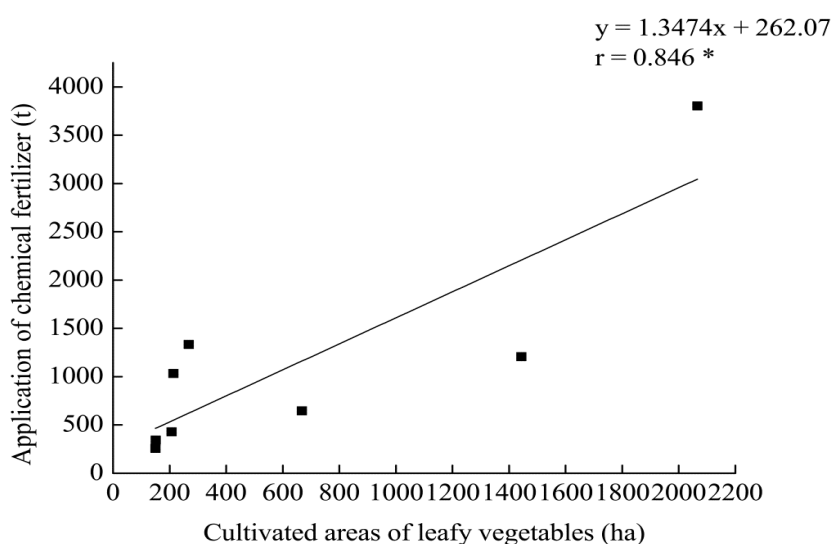


Fig. 1-8. Relationship between cultivated areas of leafy vegetables and application of chemical fertilizer in the coastal area of southeast Lake Dianchi, southwest of Kunming city, Yunnan province, China. * denote significant at $P < 0.05$

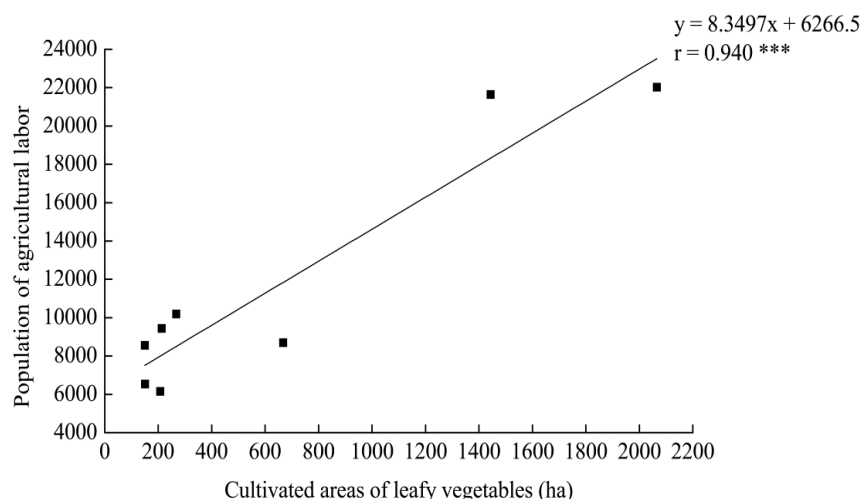


Fig. 1-9. Relationship between cultivated areas of leafy vegetables and population of agricultural labor in the coastal area of southeast Lake Dianchi, southwest of Kunming city, Yunnan province, China. *** denote significant at $P < 0.001$

The rise of leafy vegetables areas significantly increased application of chemical fertilizer and population of agricultural labor, meanwhile total area of farmland decreased, indicating that such system was intensive (Fig. 1-3, 1-8, and 1-9). In vegetable fields, chemical fertilizer mainly included urea and compound fertilizer, and 30 to 300 t ha⁻¹ manure (mainly cow manure) was used as basal fertilizer. Application of fertilizer in vegetable fields will be discussed in Chapter 2. After several years' development, irrigation facilities were popularized in this area, and massive ground and surface water were irrigated (Tanaka et al., 2013).

The study area is a supply base of vegetable: The total yield of leafy vegetable in Kunming city was 1,095,936 t in 2009 (Statistical Bureau of Yunnan province and Survey Office of the National Bureau of Statistics in Yunnan, 2010), and that in this area was 109,500 t, accounting for 10%. Furthermore, the total area of farmland, the consuming of chemical fertilizer and compound fertilizer in Kunming city were 246,258 km², 166,604 t and

31,078 t, respectively (Statistical Bureau of Yunnan province and Survey Office of the National Bureau of Statistics in Yunnan, 2010). Although farmland in this area accounted for 0.013%, consuming of chemical fertilizer and compound fertilizer in this area accounted for 3.47 and 3.29%.

Objectives of this study

In this study, the agricultural technique of intensive multiple cropping in the vegetable fields in research area was investigated, and the result was compared with them of other areas of China and neighboring countries (Chapter 2). Then, the N, P, and K balances were calculated to determine the amounts of N, P, and K which were not absorbed by vegetables. The soil chemical properties in vegetable fields and paddy fields were analyzed, and the effects of the agricultural technique of intensive cropping on soil were discussed based on the analysis results. Furthermore, some methods which should be effective to decrease nutrient input–output balance and to reduce nutrient surplus in soil were proposed (Chapter 3). Then, existence of nitrate leaching in the study area was clarified based on the relationship between nitrate concentration in soil and groundwater (Chapter 4). Then, pot experiment was conducted to decrease N, P, and K balances by reducing application of chemical fertilizer without yield loss. To extend the application of this result, the model was developed for predicting the N balance and dry matter production after reducing half input of N chemical fertilizer without a pot experiment (Chapter 5). Finally, the study was concluded (Chapter 6).

Chapter 2

Intensive multiple cropping of vegetable in the study area

2-1. Introduction

In intensive agriculture, the amount of input (chemical fertilizer and livestock manure) per year increases to maintain productivity and get high commodity value, which is unsustainable crop production system. Soil physicochemical and biological properties may change dramatically after several years of continually high annual inputs, and one prominent characteristic of intensive agriculture is nutrient accumulation in soil (Du et al., 2011; Lv et al., 2011; Phupaibul et al., 2004; Fang et al., 2006). In addition, the surplus nutrients in soil continuously leak into the ground and surface water through a year, leading to nonpoint source (NPS) pollution, a principal factor in water eutrophication in China (Sun et al., 2012; Ongley et al., 2010). Moreover, intensive agriculture plays a major role in the global fluxes of the greenhouse gases, such as carbon dioxide, nitrous oxide, and methane (Robertsan et al., 2000).

The previous investigation (Chapter 1) indicated that the converting from paddy cropping to intensive vegetable cropping sharply increased application of fertilizer in the coastal area of southeast Lake Dianchi, might resulting negative impacts to local environment. Study in chapter 1 was based on the

basically agricultural data obtained from local governments. However, the concrete data of agricultural management, such as duration of intensive cropping, cropping sequence, cropping intensity, and input of fertilizer to each crop, were thought to be necessary to evaluate the intensive cropping in the area.

2-2. Materials and methods

Weather data collecting

A weather station (Weather Hawk Station, Campbell Scientific, USA) was installed in Xiaozhai village (24°41'29.90" N, 102°43'51.07" E). Reading for hourly air temperature, solar radiation, and precipitation were obtained from the station.

Crop management survey

On the basis of uniform distribution of sampling sites and different cultivation characteristics, 36 fields were selected (Fig. 2-1), and farmers were interviewed on April 30, May 1–3, July 14–16, September 26–28, December 9–11, 2011 and February 20–22, 2012. Four fields were cultivated with paddy rice, for farmers' own consumption. The other 32 fields were cultivated with vegetable under vinyl houses, and therefore nutrient dynamics in crop-soil system should not be affected by rainfall. The questions focused on the varieties of crops, the year in which multiple cropping was started, cultivation calendar, and the inputs (amount of chemical fertilizer and manure) in the selected fields.

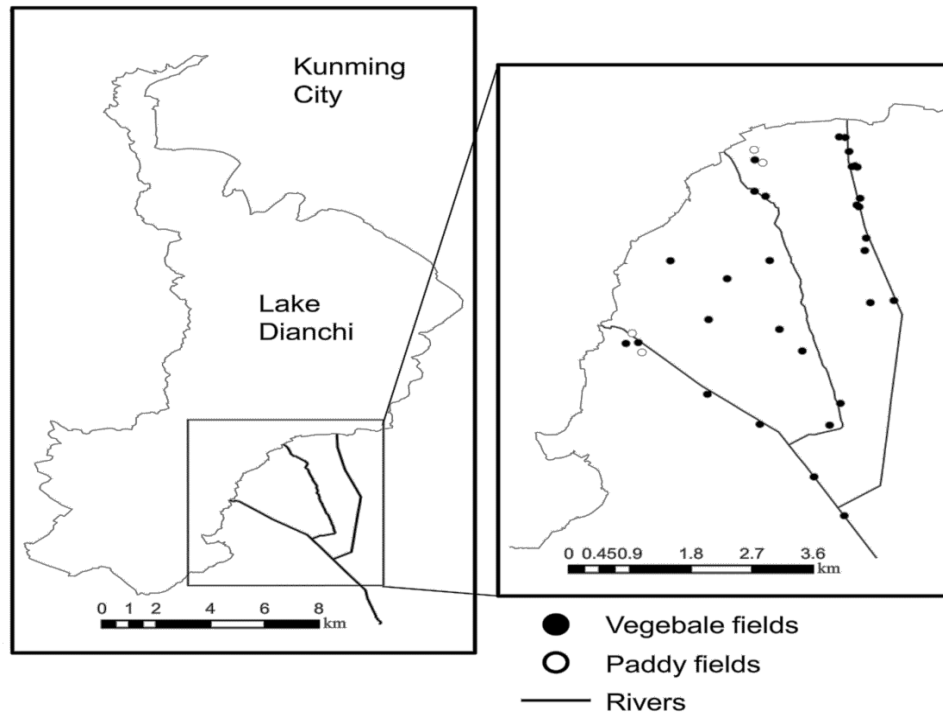


Fig. 2-1. Location of the studied fields

2-3. Results

Weather conditions

Figure 2-2 shows the meteorological conditions from February 2011 to March 2012 at the study site. Daily solar radiation ranged from 4.4 to 18.5 MJ m⁻². The mean daily temperature ranged from 7 to 23.6°C, and the yearly temperature change coincided with the data observed by the National Astronomical Observatory of Japan from 1981 to 2010. The rainy season extended from May 2011 to September 2011, and the dry seasons were from February 2011 to April 2011 and from October 2011 to March 2012. The rainfall from February 2011 to January 2012 was 466 mm, and it was less than

the mean value from 1981 to 2010. A drought occurred in 2011.

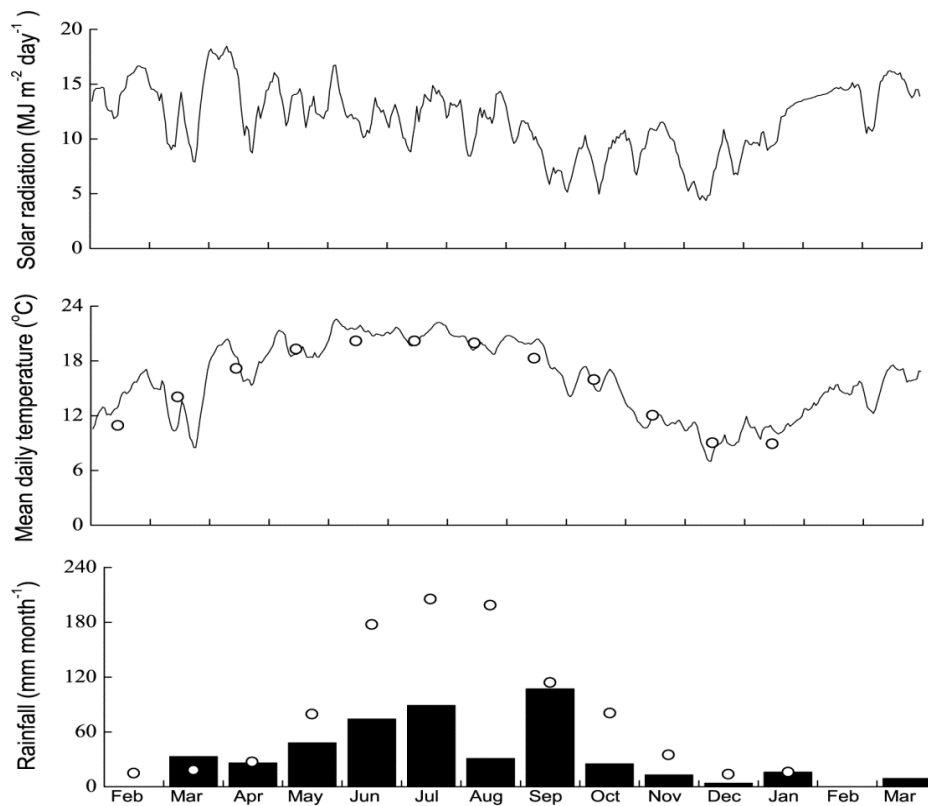


Fig. 2-2. Climatic conditions in the coastal area of southeast Lake Dianchi, southwest of Kunming city, Yunnan province, China. Mean daily temperature and solar radiation are 7-day moving averages, whereas rainfall data are presented as monthly totals. Data with circles represent average values in Kunming city from 1981 to 2010, cited from National Astronomical Observatory of Japan.

Cultivation in the study area

The vegetables grown were mainly leafy and divided into two types: short-term varieties (growth duration in a field is 30 to 50 days), such as bok choy (*Brassica rapa* L. var. *chinensis*), stem lettuce (*Lactuca sativa* L.), and long-term varieties (growth duration in a field is more than 50 days), such as celery (*Apium graveolens* L. var. *dulce*) (Fig. 2-3). These vegetables were transplanted in many cases and this is also one of the reasons of the short

growing duration in a field. Some farmers chose to cultivate short-term varieties throughout the year, whereas others cultivated one or two long-term varieties in winter and several short-term varieties at the other times. After harvesting, there were several days (5-10 days) of break, during which the underground parts of vegetable were returned to the deeper soil layer, and the residue was composted nearby and returned to the field. Cultivation activities were performed year round by most farmers. Chemical fertilizer used in this area is mainly compound fertilizer with different N–Phosphorus (P)–Potassium (K) ratio and urea, and it is applied as basal fertilizer and/or topdressing for each crop. The manure is mainly cow manure and is applied once or twice in a year as basal fertilizer.

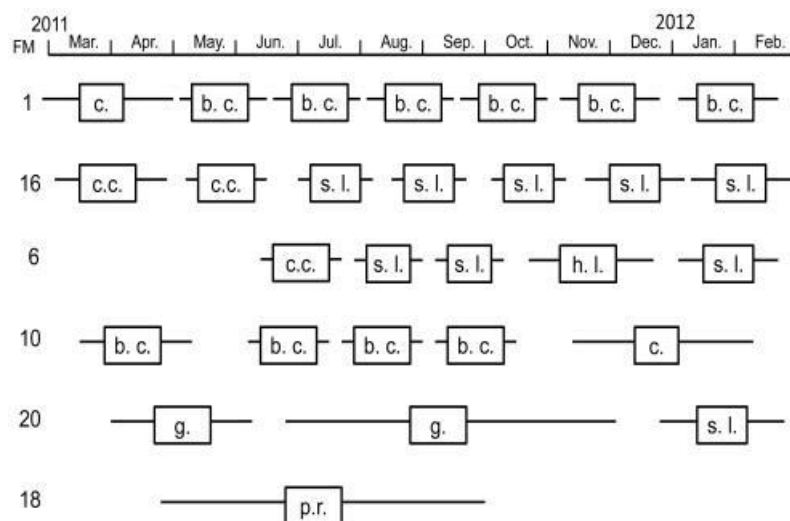


Fig. 2-3. Cropping sequence in representative fields in the coastal area of southeast Lake Dianchi, southwest of Kunming city, Yunnan province, China from March 2011 to February 2012, c: celery; b.c.: bok choy; c.c.: Chinese cabbage; s.l.: stem lettuce; h.l.: head lettuce; g.: garlic; p.r.: paddy rice. The line indicates the growth duration of each crop.

Table 2-1. Descriptive statistics of farmland area; years of multiple cropping; cropping intensity; N, P, and K input from chemical fertilizer per year; N, P, and K input from manure per year in 32 vegetable fields and four paddy fields.

Variable	Unit	Mean	Maximum	Minimum	C.V.(%)
Farmland area	m ²	3185	13333	53	91
Years of vinyl house cultivation	year	4.7	9	0	54
Cropping intensity per year	crops year ⁻¹	5.9 (1)	7 (1)	1 (1)	25 (0)
Input of chemical fertilizer per year	g m ⁻² year ⁻¹				
N		137 (30)	297 (40)	17 (21)	45 (25)
P		31 (1.4)	97 (5.6)	7 (0)	65 (200)
K		86 (0)	187 (10.6)	10 (0)	57(200)
Input of manure per year	g m ⁻² year ⁻¹				
N		40 (0.8)	165 (3.3)	5 (0)	87 (200)
P		12 (0.4)	75 (1.5)	2 (0)	120 (200)
K		24 (0.4)	87 (1.7)	3 (0)	82 (200)

Data of paddy fields are in brackets.

Table 2-1 shows descriptive statistics of cultivation. Farmland area per farmer household ranged from 53 to 13,333 m². There were great differences in years of multiple cropping, ranging from 0 to 9 (0 years imply that single cropping of paddy rice had just been converted to multiple cropping of vegetable). Thus, this situation was helpful for estimating the influence of multiple intensive cropping in the area. Among the 32 vegetable farmers, five farmers cultivated five crops per year, 23 farmers cultivated six or seven crops per year. The four paddy rice farmers cultivated one crop per year.

High application of chemical fertilizer and manure were observed in vegetable fields. In contrast, limited application of chemical fertilizer was needed for paddy rice fields, and little or no manure was used.

Table 2-2. Correlation coefficients of years of multiple cropping and cropping intensity with N, P, and K inputs from chemical fertilizer and manure per year in 32 vegetable fields.

	Years of multiple cropping	Cropping intensity
Years of multiple cropping	1	
Cropping intensity	0.357*	1
N input from chemical fertilizer and manure	0.489**(0.383*)	0.504**(0.404*)
P input from chemical fertilizer and manure	0.423*(0.319)	0.434*(0.335)
K input from chemical fertilizer and manure	0.544**(0.441*)	0.603**(0.521**)

** and * denote significant at 0.01 and 0.05 level, respectively. Data in brackets represent the partial correlation coefficients of corresponding variable in the row and variables in the column, controlling factor is another variable in the row.

Years of multiple cropping and cropping intensity were significantly correlated with N, P, and K input from chemical fertilizer and manure. Meanwhile, there was a significant correlation between years of multiple cropping and cropping intensity, thus, I calculated partial correlation coefficients of multiple cropping and cropping intensity with N, P, and K inputs from chemical fertilizer and manure per year. N and K inputs from chemical fertilizer and manure partially correlated with years of multiple cropping and cropping intensity, respectively.

2-4. Discussion

The significant correlation between years of multiple cropping and cropping intensity suggested that the farmers who cultivated with a long duration had abundant experiences and great abilities to increase cropping intensity (Table 2-2).

For other multiple cropping systems in China, Shi et al. (2009) found that

vegetable producers in south-Eastern China usually grew three crops per year in the same field. In the Yangtze River delta region, two or three crops per year were recorded in greenhouse fields (Huang et al., 2006). The northern plain is the main vegetable-producing area in China and two or three crops were grown in this area (Ju et al., 2007). But in my research area, most farmers cultivated six or seven crops per year. This very high cropping intensity is based on the combination of vegetables with a short growing duration and transplanting culture. Kunming city is famous in China as “Spring City” with solar radiation and temperature suitable for vegetable cultivation year round (Fig. 2-2), and this area is adjacent to Lake Dianchi providing abundant water. Moreover, the multiple cropping was carried out within the vinyl house which promotes growth of vegetables. In my research area with high annual transpiration, the vinyl house aims at keeping humidity in addition to keeping warm. The greatest reason for high intensity is for fulfilling the huge demand, for instance, the winter demand in southern China, where vegetable cultivation is limited by low temperatures.

In south-eastern China, total inputs of N, P, and K were 126, 46, and 52 g m⁻² y⁻¹ and the inputs of N, P, and K to each crop were 42, 15, and 17 g m⁻² (Shi et al., 2009). In the Yangtze River delta region, total inputs of N, P, and K were 142, 44, and 60 g m⁻² y⁻¹, and the inputs of N, P, and K to each crop were 55, 20, and 25 g m⁻² (Huang et al., 2006). In northern China, total inputs of N, P, and K were 282, 93, and 93 g m⁻² y⁻¹ and inputs of N, P, and K to each crop were 110, 37, and 37 g m⁻² (Ju et al., 2007). By contrast, total inputs of N, P, and K were 177, 44, and 110 g m⁻² y⁻¹ in my research area, and inputs of N, P, and K to each crop were 30, 7, and 18 g m⁻² (Table 2-1). In comparing with

these areas, the high total input per year in my research area appeared to depend on high cropping intensity, which is the reason why cropping intensity partially correlated with N and K input from chemical fertilizer and manure (Table 2-2). Considering neighboring countries, in Hanoi city, Vietnam, six to nine crops were recorded in intensively cultivated vegetable fields. Total inputs of N, P, and K were 92, 23, and 54 g m⁻² y⁻¹ on average, and inputs of N, P, and K to each crop were 10-15, 0.4-4, and 2-9 g m⁻² (Nguyen et al., 2007). In Suphan Buri-Nakhon Pathom provinces, Thailand, intensities in some vegetable fields ranged from five to seven, and total inputs of N and P to each crop were 6 and 0.2 g m⁻² (Phupaibul et al., 2002). In comparing with these areas, the high total input per year in my research area depended on high inputs to each crop.

Chapter 3

Annual nutrient balance and soil chemical properties in the intensive cropping system

3-1. Introduction

In China, there are three highly eutrophic freshwater lakes, Lake Dianchi, Taihu, and Chaohu, where the above intensive agriculture is performed in the coastal area. Overuse of fertilizers is a main source of water eutrophication of the three lakes (Liu and Qiu, 2007). Current countermeasures against eutrophication of the three lakes can be divided to three types: (1) External nutrient loading control, for example, a pollution interception project has been performed in the region of Lake Dianchi and Lake Taihu; (2) Internal source control, such countermeasures focus on reducing the released nutrient from sediment, for example, sediment dredging project has been used widely in eutrophic lakes in China; and (3) ecosystem recovery technology, for example, a constructed wetland was operated for agricultural runoff treatment in the Dianchi valley (Liu and Qiu, 2007; Lu et al., 2009). These countermeasures are not against the main source of pollution, abusive use of fertilizer in agriculture.

Agricultural fundamental information for sustainable agriculture which can reduce environmental pollution without profit loss of a farmhouse is required in such intensive agriculture. Most of previous studies have focused on fertilization and quality of soil, water, and sediment (Lv et al., 2011; Mao et al.,

2011; Shi et al., 2011; Yang et al., 2010). For the key pollution source, agricultural pollution, many studies have used models to estimate the actual circumstances of NPS pollution (Wu et al., 2012; Li et al., 2012; Shi et al., 2005).

More intensive cropping and the increasing in breeding number of livestock are indispensable in China, particularly in the suburban area near a big city where cultivated area declines more severely although the demands of fresh vegetable and milk severely increase with the faster economic development (Lin and Ho, 2003). It is supposed that the increasing excreta of livestock might have impact on environmental pollution directly in intensive agriculture because the excreta is used in own cropland or sold for the neighbor farmers to be applied as manure in their cropland. Very few studies have determined which of chemical fertilizer and livestock manure is the principal source of residual nutrients in soil.

This chapter aimed to (1) calculate N, P, and K input–output balances; (2) determine the response of crops to high annual application of N, P, and K; (3) extract the principle factor resulting residual N, P, and K in soil and propose efficient methods in reducing soil nutrients.

3-2. Materials and methods

Plant sampling and analyses

The growths of vegetables at different sites in a vinyl house might be different, for instance, the vegetables beside the entrance of vinyl house might be a bit smaller than those in the center. Thus, I chose an area for vegetable

sampling with average growth status. Aboveground biomass of vegetables that was mature enough to be harvested was sampled from three subsample points in each vegetable field. The area of a subsample point was about 0.5-m^2 , and the three subsample points uniformly distributed on the diagonal line of average growth area. Then, sampling area was measured accurately. The indica/indica F_1 hybrid varieties of paddy rice used in the study site were Chugeng and Li251. Aboveground biomass of paddy rice was sampled from three subsample points in each paddy field at physiological maturity stage (September 26-28, 2011). The area of a subsample point was about 4-m^2 . Then, sampling area was measured accurately. Plant samples were oven-dried at 70°C to a constant weight and ground until they were fine enough to pass through a 2-mm sieve. The plant sample was digested by the Kjeldahl method. NH_4^+ was determined using the cresol red method (cresol red dissolved in sodium hydroxide solution, and then mixed with Hepes, the final solution was used as an indicator) (Schulze et al., 1988) and flow-injection spectrophotometer (WIS-2000, HIRANUMA, Japan); P was determined using the vanadomolybdate method (Stuffins, 1967) and spectrophotometer (U-1500, HITACHI, Japan); and K was determined using atomic absorption spectrophotometer (AA-7000, SHIMADZU, Japan). The concentration of nitrate (NO_3^-) was determined using the Cataldo method (Cataldo et al., 1975) and spectrophotometer (U-1500, HITACHI, Japan).

Soil sampling and analyses

Just after plant sampling, surface soil (0–15 cm) samples were collected at biomass sampling points from each field. These were air-dried and ground to

pass through a 2-mm sieve. Drying soil might increase N mineralization, but this change was significant linear. Thus, it is thought that NO_3^- after drying can reflect NO_3^- levels in moist soils (Birch, 1959, 1960). Electrical conductivity (EC) and pH (H_2O) were measured using a glass electrode after the soil was mixed with distilled water (1:5, w/v). The extraction was used to determine NO_3^- and P by the Cataldo method (Cataldo et al., 1975) and sulfuric acid-molybdenum method (Martin and Doty, 1949) respectively, using a spectrophotometer (U-1500, HITACHI, Japan). The concentration of K was determined with an atomic absorption spectrophotometer. Total nitrogen (TN) and total carbon (TC) were determined using a mass spectrometer (Delta S, Finnigan MAT, Bremen, Germany) coupled with an elemental analyzer (EA1108, Fisons, Rodano, Milan, Italy) in the Center for Ecological Research, Kyoto University (Kyoto, Japan). The annual average value was used in the analysis of data.

Manure data

N, P and K concentrations in manure were cited from *Fertilization Guidance for Main Crops in China* (Zhang et al., 2009).

Statistical analysis

Pearson correlations were calculated. Analysis of covariance (ANCOVA) was performed to identify differences among regression coefficients and regression constants.

To extract the principal components of input, output, and balance properties of N, P, and K, principal component analysis with varimax rotation

was performed with eigenvalues higher than 1.0. To obtain the optimum models for predicting soil performance, stepwise multiple regression analysis was performed. Each soil component was used as a dependent variable and standardized scores of the two principal components of the 32 vegetable fields were used as independent variables. The standardized score of a principal component of a vegetable field was the total sum of products of each measured value of 32 variables on the field and with the component loading of the principal component of each of the 32 variables. Principal components and multiple regression analysis were performed with SPSS software.

3-3. Results

Descriptive statistics of collected data

In vegetable fields, the input–output balance (input included chemical fertilizer and manure) showed that 58.2% of N, 72.1% of P and 20% of K were not absorbed by vegetable (Table 3-1). The C.V. values of K balance were high, and K balance in some fields was negative. In paddy fields, little N remained and input–output balances of P and K were negative.

NO_3^- , water-soluble P, and water-soluble K in vegetable fields were higher than those in paddy fields, and pH in vegetable fields were slightly lower than those in paddy fields.

Years of multiple cropping was significantly correlated with the four variables of output and N input–out balance (chemical fertilizer + manure) (Table 3-2). After excluding the influence of cropping intensity, years of multiple cropping was partially correlated with N, P, and K outputs.

Table 3-1. Descriptive statistics of dry matter and N, P, and K output per year; N, P, and K input–output balance; and seven properties of soil after harvesting in 32 vegetable fields and four paddy fields.

Variable	Unit	Mean	Maximum	Minimum	C.V.(%)
Output per year					
Dry matter	$\text{g m}^{-2} \text{ year}^{-1}$	1692 (1216)	3272 (1609)	954 (742)	33 (38)
N		74 (9.6)	141 (11.1)	16 (8.2)	35 (18)
P		13 (2.4)	29 (3.8)	2 (1.0)	41 (67)
K		88 (10.7)	174 (12.2)	11 (8.2)	36 (18)
Input–output balance(chemical fertilizer)					
	$\text{g m}^{-2} \text{ year}^{-1}$				
N		62 (20.4)	196 (31.6)	1 (12.7)	74 (39)
P		19 (–1)	87 (1.8)	–10 (–3.8)	113 (230)
K		–1 (–8.1)	125 (–1.6)	–122 (– 12.2)	33 (57)
Input–output balance(chemical fertilizer + manure)					
	$\text{g m}^{-2} \text{ year}^{-1}$				
N		103 (21.2)	332 (31.6)	17 (16)	62 (33)
P		31 (–0.6)	112 (1.8)	4 (–3.8)	91 (390)
K		22 (–7.6)	141 (–1.6)	–70 (12.2)	224 (61)
Soil properties after harvesting					
Total N	g kg^{-1}	3.0 (2.8)	4.1 (3.1)	1.9 (2.5)	19 (15)
Total C	g kg^{-1}	18.4 (24.3)	31.0 (25.5)	11.3 (23.1)	26 (7)
Soil NO_3^-	mg kg^{-1}	163 (44)	320 (60)	48 (28)	34 (51)
water-soluble P	mg kg^{-1}	13 (2)	50 (3)	0 (1)	107 (53)
water-soluble K	mg kg^{-1}	97 (77)	399 (94)	32 (60)	76 (32)
pH		6.9 (7.3)	7.5 (7.4)	6 (7.3)	5 (1)
EC	ms m^{-1}	81 (93)	200 (131)	22 (56)	49 (57)

Data of paddy fields are in brackets. Input–output balance (chemical fertilizer) = N, P, or K input from chemical fertilizer – N, P, or K output by vegetable. Input–output balance (chemical fertilizer + manure) = N, P, or K input from chemical fertilizer and manure – N, P, or K output by vegetable.

Table 3-2. Correlation coefficients of years of multiple cropping and cropping intensity with input from chemical fertilizer and manure per year, output per year, input–output balance (chemical fertilizer + manure) per year, and seven properties of soil after harvesting in 32 vegetable fields.

	Years of multiple cropping	Cropping intensity
Dry matter output	0.388*(0.327)	0.370*(0.304)
N output	0.472**(0.356*)	0.532**(0.441*)
P output	0.503**(0.424*)	0.384*(0.253)
K output	0.520**(0.418*)	0.523**(0.422*)
N input–out balance (chemical fertilizer + manure)	0.420*(0.320)	0.414*(0.312)
P input–out balance (chemical fertilizer + manure)	0.335(0.234)	0.368*(0.282)
K input–out balance (chemical fertilizer + manure)	0.289(0.186)	0.354*(0.281)
Soil total N after harvesting	–0.068(–0.018)	–0.145(–0.130)
Soil total C after harvesting	–0.241(–0.118)	–0.390*(–0.335)
Soil NO ₃ [–] after harvesting	–0.315(–0.303)	–0.092(0.023)
Soil water-soluble P after harvesting	0.076(0.099)	–0.046(–0.079)
Soil water-soluble K after harvesting	–0.027(–0.073)	0.115(0.133)
Soil pH after harvesting	–0.041(–0.084)	0.104(0.127)
Soil EC after harvesting	0.207(0.146)	0.207(0.146)

** and * denote significant at 0.01 and 0.05 level, respectively. Data in brackets represent the partial correlation coefficients of corresponding variable in the row and variables in the column, controlling factor is another variable in the row.

Cropping intensity was significantly correlated with the four variables of output, N, P, and K input–out balances (chemical fertilizer + manure), and soil total C. After excluding the influence of years of multiple cropping, cropping intensity was partially correlated with N and K outputs.

Table 3-3 shows the effects of input from chemical fertilizer and manure per year, output, and input–output balance (chemical fertilizer + manure) per year on seven properties of soil after harvesting. P input from chemical fertilizer and manure per year and P input–output balance (chemical fertilizer + manure) per year were significantly correlated with soil water-soluble P after harvesting.

Crop absorptive response to input of N, P, and K

Vegetable fields were divided to three types depending on different cultivation duration under multiple cropping (0–2, 3–5, and 6–9 years). Significant correlations were observed between input N from chemical fertilizer and N absorbed by vegetable in the three types of fields (Fig. 3-1a). According to the result of ANCOVA, there were no significant differences among the three regression coefficients. The regression constant for 0–2 years under multiple cropping was significantly lower than the others.

Figure 3-1b and 3-1c indicated that the correlations between input of P, K from chemical fertilizer and P, K absorbed by vegetable were not significant, except for K in 3–5 years under multiple cropping.

Compared with vegetable fields, the N, P, and K of input and absorption in paddy fields were low.

Table 3-3. Correlation coefficients of input from chemical fertilizer and manure per year, output, input–output balance (chemical fertilizer + manure) per year with seven properties of soil after harvesting in 32 vegetable fields.

	Input from chemical fertilizer and manure			dry matter	Output			Input–out balance (chemical fertilizer + manure)		
	N	P	K		N	P	K	N	P	K
Soil total N after harvesting	0.029	0.151	0.086	0.301	0.085	0.303	0.323	0.003	0.097	–0.108
Soil total C after harvesting	–0.125	–0.026	–0.029	0.302	–0.091	0.151	0.128	–0.120	–0.054	–0.115
Soil NO ₃ [–] after harvesting	–0.272	–0.076	–0.128	–0.105	–0.271	–0.191	–0.117	–0.230	–0.040	–0.070
Soil water-soluble P after harvesting	–0.024	0.422*	–0.083	0.050	–0.190	–0.080	–0.066	0.047	0.439*	–0.052
Soil water-soluble K after harvesting	–0.111	0.370*	0.018	–0.235	–0.254	–0.233	–0.076	–0.036	0.415*	0.069
Soil pH after harvesting	0.234	–0.083	–0.001	0.310	0.357*	0.328	0.225	0.148	–0.144	–0.146
Soil EC after harvesting	0.147	0.088	0.303	0.357*	0.155	0.179	0.268	0.121	0.057	0.175

* denote significant at 0.05 level.

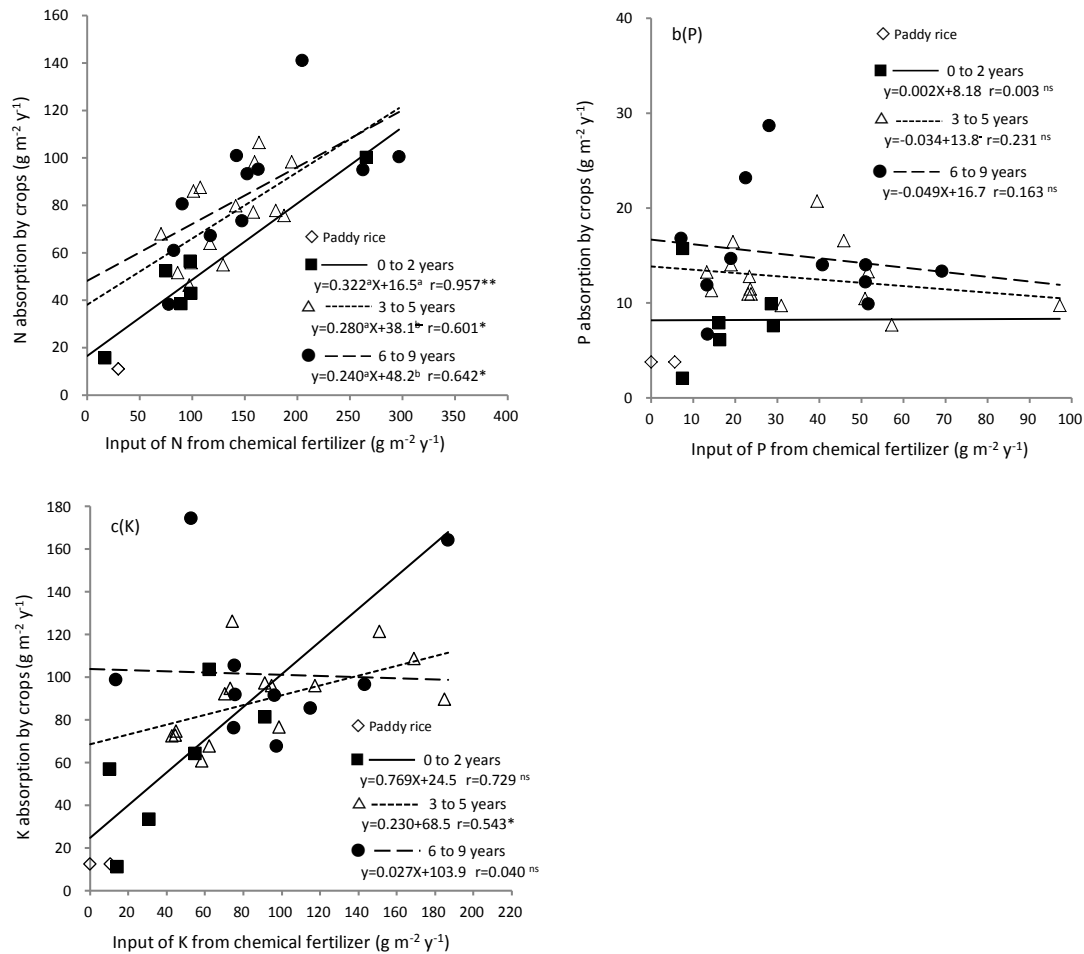


Fig. 3-1. Relationship between input amounts of N, P, and K from chemical fertilizer and N, P, and K absorption by crops in paddy fields and vegetable fields under multiple cropping (0–2, 3–5, and 6–9 years) from March 2011 to February 2012. **, * and n.s denote significant at $P < 0.01$, significant at $P < 0.05$ and not significant, respectively. Different letters of the right shoulder of regression coefficients and regression constants indicate significant differences ($P < 0.05$).

Crop biomass response to input of N, P, and K

The result of nonlinear regression analysis (Fig. 3-2a) showed that the dry matter production increased when the input of N increased to approximately $200 \text{ g m}^{-2} \text{y}^{-1}$. Above this level there was no obvious increase in dry matter production. Vegetable fields were accordingly divided into two types, those fertilized with more or less than $200 \text{ g m}^{-2} \text{y}^{-1}$. Figure 3-2b indicates that the correlations between dry matter production and input of P from chemical

fertilizer were not significant in the two types of fields. For K, a significant correlation was observed only in the fields supplied with more than $200 \text{ g m}^{-2} \text{ y}^{-1}$ (Fig. 3-2c).

Compared to vegetable fields, little or no input of N, P, and K supported a certain amount of dry matter production in paddy fields.

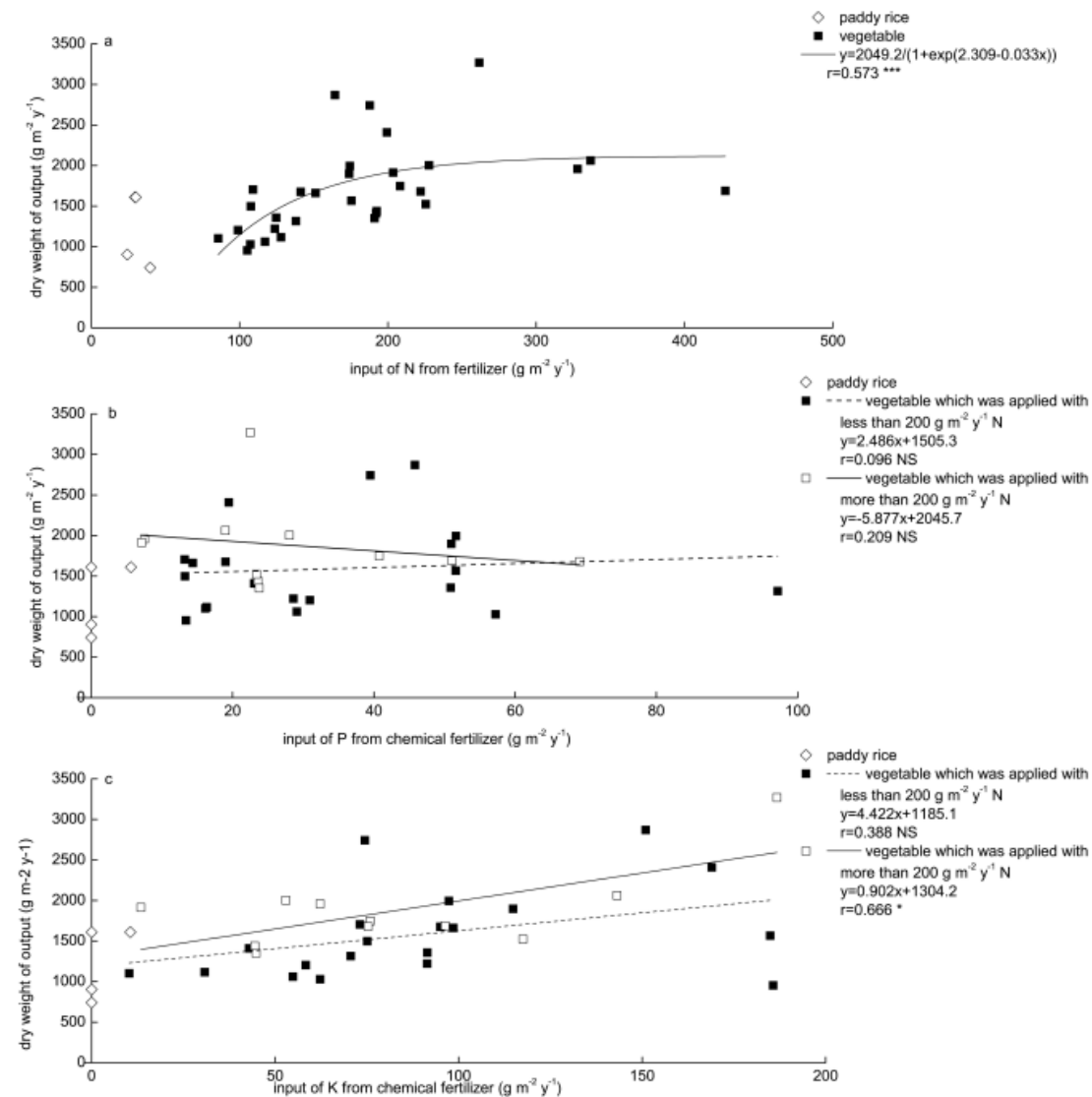


Fig. 3-2. Relationship between the input of N from fertilizer (including chemical fertilizer and manure) and dry matter production, and between input of P and K from chemical fertilizer and dry matter production in the vegetable fields fertilized with less and more than $200 \text{ g m}^{-2} \text{ y}^{-1}$ N. ***, * and n.s denote significant at $P < 0.001$, significant at $P < 0.05$ and not significant, respectively.

Principal component analysis

The result of Pearson correlation analysis showed significant correlations among input property, output property, and input–output balance properties. For example, input of N from chemical fertilizer was significantly correlated with N output (Fig. 3-1a). Significantly correlated variables cannot be used as independent variables in a multiple regression analysis. For this reason, principal component analysis was used to integrate the input, output, and input–output balance properties independently (Table 3-4, table 3-5, and table 3-6).

By varimax rotation, principal component analysis extracted 2 components (PC1 and PC2) with eigenvalues greater than 1.0 for each of N, P, and K, and these accounted for 77.2, 82.9, and 81.8% of the total variance. The first component (PC1) showed a high loading with input from chemical fertilizer, input–output balance (chemical fertilizer), and input–output balance (chemical fertilizer + manure). The component loadings of N,P, and K input from manure were lower than those from chemical fertilizer, and after adding the component loadings of N, P, and K input–output balances from manure, the component loadings of N, P, and K input–output balances from chemical fertilizer and manure did not become as high as those from chemical fertilizer. The second component (PC2) showed high loading with the output property for each of N, P, and K.

Table 3-4. Component loading, eigenvalue and percentage of total variance explained for the first two principal components of N.

Variable	PC1	PC2
Nitrogen input property		
Chemical fertilizer	0.897	0.31
Manure	0.55	0.13
Nitrogen output property		
Nitrogen output	0.452	0.848
Dry matter output	0.277	0.804
Absorption rate	-0.291	0.812
Nitrogen input–output balance property		
Chemical fertilizer	0.92	-0.046
Chemical fertilizer + manure	0.971	0.04
Eigenvalue	3.261	2.143
Ratio of cumulative contribution	0.466	0.772

Table 3-5. Component loading, eigenvalue and percentage of total variance explained for the first two principal components of P.

Variable	PC1	PC2
Phosphorus input property		
Chemical fertilizer	0.938	-0.074
Manure	0.577	0.418
Phosphorus output property		
Nitrogen output	-0.092	0.938
Dry matter output	-0.050	0.894
Absorption rate		
Phosphorus input–output balance property		
Chemical fertilizer	0.914	-0.283
Chemical fertilizer + manure	0.989	0.005
Eigenvalue	3.036	1.940
Ratio of cumulative contribution	0.506	0.829

Table 3-6. Component loading, eigenvalue and percentage of total variance explained for the first two principal components of K.

Variable	PC1	PC2
Potassium input property		
Chemical fertilizer	0.885	0.398
Manure	0.135	0.558
Potassium output property		
Nitrogen output	-0.127	0.945
Dry matter output	0.082	0.883
Absorption rate		
Potassium input–output balance property		
Chemical fertilizer	0.978	-0.168
Chemical fertilizer + manure	0.978	0.057
Eigenvalue	2.735	2.173
Ratio of cumulative contribution	0.456	0.818

Multiple regression analysis for predicting soil components

The following equations showed the most appropriate models for the performance of each soil component.

$$N_{\text{soil}} = 149.48 + 0.858 \times \text{PC1} - 0.383 \times \text{PC2}$$

$$P_{\text{soil}} = 12.79 + 0.074 \times \text{PC1}$$

$$K_{\text{soil}} = 107.19 + 0.136 \times \text{PC1} - 0.032 \times \text{PC2}$$

In Table 3-7, the magnitude of each standardized score of principal component in its contribution to the performance of soil components was determined by the regression coefficients in the above equations. R^2 indicates the proportion of the variation explained by each model with respect to the total variation in soil components.

For soil N and K, PC1 and PC2 explained 27.2 and 19.8% of the total variance, PC1 contributed to soil N and K in larger magnitude than PC2, and PC2 showed negative contributions to soil N and K. For soil P, the contribution of PC2 to soil P was not significant, and PC1 explained 15.9% of the total variance.

Table 3-7. Contribution of each principal component to N, P and K in soil and R^2 and P -value of models.

Soil component	PC1	PC2	R^2	P
N	0.691	0.309	0.272	0.013
P	1.000	—	0.159	0.027
K	0.808	0.192	0.198	0.063

3-4. Discussion

Effect of intensive cropping on soil

In the study area, NO_3^- , water-soluble P and K in vegetable fields were higher than those in paddy fields. A similar accumulation of nutrients in soil occurred in China. In south-eastern China, soil TN, extractable NO_3^- , available P, and exchangeable K concentrations increased from 1.63 to 2.01, 0.1 to 0.25, 0.16 to 0.3, and 0.22 to 0.25 g kg^{-1} in a two years plot experiment (Shi et al., 2009). In the Yangtze River delta, TN, extractable NO_3^- , available P, and exchangeable K concentrations in vegetable fields were 1.6, 0.19, 0.14, and 0.15 g kg^{-1} , but those in barren were 1.0, 0.11, 0.05, and 0.08 g kg^{-1} , respectively (Huang et al., 2006). In northern China, TN, extractable NO_3^- , available P, and exchangeable K concentrations in the vegetable fields under multiple cropping were significantly more than those in the wheat-maize rotation fields (Ju et al., 2007).

Table 3-2 shows that soil total C tended to decrease with increasing intensity of cropping. In my research area, local farmers do not apply extraneous C sources to vegetable fields, meanwhile, the mainly applied livestock manure is cow manure, and the main feeding to cow is locally unused leaf of vegetable. The input of C is limited, and the output of C increases with increasing intensity of cropping. Moreover, the decomposition of organic matter is enhanced under more aerobic and warmer conditions in vinyl houses. These should be the reason why total C tended to decrease with increasing intensity of cropping (Moritsuka et al., 2013).

Guo et al. (2010) reported that intensive cropping management with large input of chemical fertilizer induced declines of 0.3-0.8 in soil pH in high-input fields, such as vegetable, fruit, and tea fields, and decreased soil pH below 6.0 in major Chinese croplands, inhibiting growth of crop root and affecting nutritional absorption. In my study area, the mean pH value of the four paddy fields was 7.3, the mean pH value of vegetable fields was 6.9, and the lowest value was 6, which was comparatively high and might be due to the conventional application of alkaline materials for controlling clubroot disease.

Crop response to intensive cropping

Figure 3-1a shows significant correlations between input of N from chemical fertilizer and N absorbed by vegetables in 0-2, 3-5, and 6-9 years under multiple cropping. The regression coefficient reflects the N absorption ratio, and the absence of significant differences among the three regression coefficients indicates that N absorption ratios in the three types of fields were not significantly different. The N absorption ratios of vegetables in greenhouse

in Japan ranged from 0.31 to 0.46 (Nishio et al., 2001), those in my research area were lower, ranging from 0.24 to 0.32 (Fig. 3-1a). Improvement of N absorption ratio can reduce the demand of N fertilizer and residual N in soil. Previous studies proved that application of slow-release fertilizer and utilization of split application could improve N absorption ratio (Shaviv and Mikkelsen, 1993; Sowers et al. 1994). The regression constant reflects N absorption from sources other than chemical fertilizer, namely, from soil, manure, or irrigation water. The regression constant of 3-9 years under multiple cropping was significantly higher than 0-2 years, indicating vegetable absorbed massive N absorption from the sources other than chemical fertilizer in 3-9 years fields.

The correlations between input P from chemical fertilizer and P absorbed by vegetable were not significant (Fig. 3-1b). This result may be accounted for by the abundant P in soil or manure, affecting the response of vegetables to inputs of P from chemical fertilizer.

The amount of applied nutrient exceeds crops demand in many intensive cropping fields (Zhu et al., 2005). Inputs in some fields in my research area were excessive, according to the local government's advice card, whose recommended standard application of N from chemical fertilizer to spinach and celery were 13.1 g m^{-2} and 27.9 g m^{-2} per crop, respectively. The actual mean inputs of N from chemical fertilizer to spinach and celery were 28.8 g m^{-2} and 75.6 g m^{-2} per crop. The result suggested that N application was excessive in some fields (Fig. 3-2a). Figure 3-2b indicates that vegetable yields could not be increased by increasing the input of P from fertilizer. Figure 3-2c indicates that, under sufficient input of N, vegetable productivity might be raised by

increasing inputs of K from chemical fertilizer. In my survey, some farmers used compound fertilizer with equal N-P-K ratio, such as 17-17-17, which was shown by the results to be unsuitable.

Efficient method in reducing soil N, P, and K

It is thought that elucidating the relations among annual input, annual output, annual input–output balance, and chemical properties of soil in such various cropping systems are important to obtain the underlying data for improvement of cultivation. However, there are few reports for these various systems. I used statistical methods to elucidate these relations which are useful for mitigation of eutrophication.

In PC1, the component loading of N, P, and K inputs from chemical fertilizer were higher than those from manure, implying that higher inputs from chemical fertilizer simultaneously increased the value of input–output balance (chemical fertilizer) and input–output balance (chemical fertilizer + manure), and that inputs of N, P, and K from chemical fertilizer increased N, P, and K concentrations in soil to a larger extent than did inputs of N, P, and K from manure (Tables 3-4, 3-5, and 3-6). It was thought that the relative lowness of the effect of manure resulted from the low amount of application as compared with chemical fertilizer. If the ammonia vaporization of the manure in a field is taken into consideration, an actual contribution of manure may be still lower. The second component (PC2) showed high loading with output properties other than absorption ratio for each of P and K, and with absorption ratio for N. A large dry matter output corresponded to a large N output. It also corresponded to large aboveground part, indicating crops had abundant underground

organization, which could enhance the absorption ratio.

Except PC1 and PC2, other elements might contribute to soil N, P, and K, such as nutrients leaching and nitrogen loss by gaseous forms through denitrification, which was the reason why the components only explained 27.2, 15.9, and 19.8% of the total variance of soil N, P, and K, respectively. In terms of the elements used in multiple regression analysis, PC1 contributed to the N and K concentrations in soil with a larger magnitude than PC2 (Table 3-7), and the contribution of PC2 to soil P was not significant, indicating that it would be more efficient to reduce the N, P, and K in soil by reducing input than by enhancing output. As mentioned above, N, P, and K from chemical fertilizer played a more important role than those elements from manure, but local government has sometimes taken the policy which controls the contamination from manure by building the area which restricts breeding of livestock and poultry (Li et al., 2011). This effect is considered to be low in view of the results, except inhibition of direct inflow of manure to river. Probably, control of the application of chemical fertilizer should also be promoted simultaneously. PC2 showed a negative contribution to N and K in soil, suggesting that increasing N and K output would reduce soil N and K. However, it is contradictory to reduce the amount of input and to increase the amount of output. As the effective management method, it will be available to increase the vegetable productivity by increasing inputs of K from chemical fertilizer under sufficient input of N. Feike et al. (2010) reported that intercropping used environmental resources more efficiently and generated high and stable output. This cropping method has seldom popularized in my study area, because the transplantation and harvest work are complicated, but it would be worthwhile

to be introduced. In large areas, cruciferous vegetables were observed to suffer from clubroot disease, probably caused by fungi. N output would be improved by controlling the disease with application of alkaline materials and fungicide, while, application of alkaline materials would also increase soil pH, improving the output. Although the local government has established a standard for using chemical fertilizer, extension work is lacking, leaving most farmers to depend on personal experience to apply fertilizer. In addition, only one standard was established for the whole area, it is essential to formulate several more detailed standards which consider different soil fertilities of different sites.

As mentioned above, the cultivation in farmers' fields were consisted by several kinds of leaf vegetables, thus it is difficult to analyze the relations among annual input, annual output, annual input–output balance, and the chemical properties of soil for each kind of vegetable. The above-mentioned relations which covered several kinds of leaf vegetables should be clarified by a field experiment, and then the relations according to each kind of vegetable should be clarified by the pot experiment using soil of farmer's field. And a demonstration of the principle of decreasing N, P, and K in soil by controlling input N, P, and K from chemical fertilizer maintaining productivity will await a pot or local field experiment.

Chapter 4

Nitrate contamination in groundwater in the study area

4-1. Introduction

Rapid economic development in China has increased demands for high economic crops such as vegetables and fruits since the early 1980s. The cultivation of vegetables and fruits depended on high application of chemical fertilizer. The N fertilizer consumption in China reached 32.6 million tons in 2007, increasing 191% compared with 1981 (Guo et al., 2010). Nitrate cannot be absorbed by soil colloid, thus high application of N fertilizer might lead to nitrate contamination of groundwater under excessive irrigation and precipitation (Li et al., 2007).

In Japan, nitrate concentration in groundwater has steadily increased due to the development of intensive agriculture during the last two decades. In 1999, nitrate concentration in 64 of 1,362 (4.7%) wells and 173 of 3,374 (5.1%) used as drinking water exceeded the criteria level (Kumazawa, 2002). Nitrate pollution of groundwater from intensive agriculture was a common fact in Europe. The European standard for the maximum concentration of nitrate in potable water is 50 mg L⁻¹. At present, this concentration is often exceeded in potable extracted from aquifers recharged by water from areas of agricultural activity (Smolders A.J.P. et al., 2010). Chinese Academy of Agricultural

Science conducted a survey of groundwater nitrate concentration in China in 2004, and the results indicated that 45% of 600 groundwater samples exceeded the WHO and European limit for nitrate in drinking water, and the proportion of samples exceeded the limit in intensive vegetable fields was much higher than that in other cropping fields (Zhang et al., 2004).

Many methods were used to investigate nitrate contamination of groundwater from agricultural activity, such as using ^{15}N techniques (Zhu et al., 2005), using drainable lysimeter (Song et al., 2009), or comparing nitrate concentration in groundwater in different cropping systems (Ju et al., 2006). Besides them, it might be a useful method to determining the risk of nitrate leaching by discussing the relationship between nitrate concentration in soil and groundwater, but related researches were limited. This study aimed to ascertain it by collecting a large number of soil and groundwater samples.

4-2. Materials and methods

Soil sampling and analyses

Soil samples were collected from 22 vegetable fields, one was upland field and the others cultivated in vinyl houses with different cultivation durations (zero to two, three to five, and six to nine years). Surface soil (0-10 cm) samples were collected from three sites in each field after harvesting, and then the three subsamples were thoroughly mixed. Soil was mixed with distilled water (1:5, W/V). The extraction was used to determined nitrate concentration by Cataldo method (Cataldo et al., 1975)

Groundwater sampling and analyses

After soil sampling, groundwater was sampled from the adjacent well of each field, then frozen at -35°C until further use. Samples were filtered through $45\mu\text{m}$ filter (670-12540-12, SHIMADZU, Japan), concentration of nitrate was determined by ion chromatography (PIA-1000, SHIMADZU, Japan).

4-3. Result

In the vegetable fields under vinyl houses, groundwater nitrate was significantly correlated with soil nitrate. Basically, soil nitrate and groundwater nitrate in the fields with six to nine cultivations were higher than those with zero to five years.

In the upland field, soil nitrate was 320 mg kg^{-1} , the groundwater nitrate was 84 mg L^{-1} and was higher than those in the fields under vinyl houses.

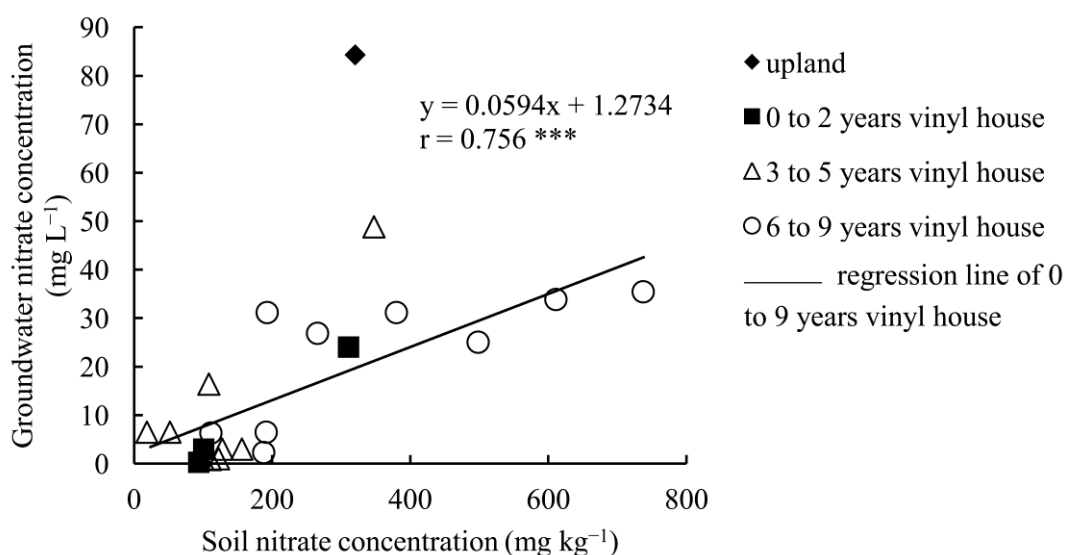


Fig. 4-1. Relationship between soil nitrate concentration and groundwater nitrate concentration. *** denote significant at $P < 0.001$.

4-4. Discussion

Local farmers ploughed soils deeply after each harvesting, thus nitrate in surface layer could reflect nitrate in deep layer. The significant correlation between soil nitrate and groundwater nitrate in the fields under vinyl houses suggested that nitrate leaching occurs in the vinyl houses fields in the study area. Furthermore, it was suggested that, in the fields cultivated with longer duration, the soil nitrate was high and groundwater contamination was severe.

The evapotranspiration in upland field is high without covering of vinyl house, so more irrigating water is needed in the upland field than that in the field under vinyl house, that is, the water use efficiency should be low in the upland field. High amount of irrigation might increase nitrate leaching in the upland field. Tanaka et al. (2013) studied the impact of land use on river quality in this area, and indicated that greenhouse covered the soil from precipitation and nitrate load of greenhouse could be less than that of open field cultivation while the rainfall event. Consequently, precipitation should be another factor increasing nitrate leaching in the upland field.

Some farmers in this area use the groundwater to cook meal and drink after boil. The nitrate limit of drinking water in China is 10 mg L^{-1} (Ministry of Health of the People's Republic of China, 2006). Nitrate in ten wells exceeded the level and was harmful, which should be paid attention to. According to the formula in Figure 4-1, nitrate in ground water exceeded 10 mg L^{-1} when soil nitrate exceeded 147 mg kg^{-1} , suggesting that reducing soil nitrate lower than this level might result ground water safely in nitrate.

The principle for managing nitrate leaching need to be considered to

synchronize N application with N sinks (Meisinger and Delgado, 2002). I discussed several methods to decrease N application and N absorption ratio in Chapter 3, which was thought to be efficient to decrease nitrate leaching. In addition, improve water use efficiency might be another approach (Dole et al., 1994). Local irrigation belongs to sprinkler irrigation, introducing root-zone drip irrigation can improve water use efficiency and reduce nitrate leaching, which had been adopted in other areas in China (Deng et al. 2006).

Chapter 5

Decreasing input–output balance by reducing input from chemical fertilizer without yield loss

5-1. Introduction

Over the past three decades, multiple cropping has played a very important role in meeting the rising need for food in China (Yan et al., 2014); however, chemical fertilizer consumption has increased greatly in this intensive cropping system (Ju et al., 2007). Runoff and drainage of excess fertilizers in agriculture is a main source of water eutrophication in China, called non-point source pollution (Sun et al., 2012). Numerous studies have focused on the various nutrient surpluses from agriculture in China, especially in conjunction with intensive vegetable cultivation. For instance, Ju et al. (2006) reported that nitrogen (N), phosphorus (P), and potassium (K) surpluses to greenhouses were more those to wheat-maize fields and apple orchards on the north China plain; Chen et al. (2004) evaluated the effect of fertilizer practices on nutrients accumulation in vegetable fields in the Beijing region; Min et al. (2011) determined the N balance and loss in greenhouse in southeastern China; and Moritsuka et al. (2013) reported that accumulation of soluble nutrients in soil was due to over-application of fertilizers in the southeastern basin of Lake Dianchi, China. Few studies, however introduced practical measures to reduce

this environmental risk by decreasing the input–output balance in vegetable fields under intensive cropping.

I conducted a study in the coastal area of southeast Lake Dianchi, Yunnan province, China (Chapters 2 and 3). Heavy multiple vegetable cropping in vinyl-covered greenhouse is dominant in this area, with large inputs of chemical fertilizer and livestock manure. About 58.2, 72.1, and 20% of N, P, and K were unused by vegetables, inducing nutrient accumulation in soil. By statistical analysis, I found that it would be more efficient to decrease the input–output balance by reducing input from chemical fertilizer than by reducing input from manure, which was also more efficient than by increasing output.

However, reducing application of chemical fertilizer might cause reduction of crop yields, damaging farmers' gross income. This study aimed to decrease agricultural pollution by reducing input from chemical fertilizer according to soil characteristics and while maintaining vegetable yield. The methods and results of this study should be useful in decreasing environmental risks from intensive vegetable cropping in China.

5-2. Materials and methods

Soil selecting

In previous study (Chapters 2 and 3), soils were collected from 32 vegetable fields. Six fields were selected from the 32 fields and took soils for pot experiment (Fig. 5-1). Field 1 had been converted from a paddy field and was awaiting for vegetable cultivation just before soil collection for the pot

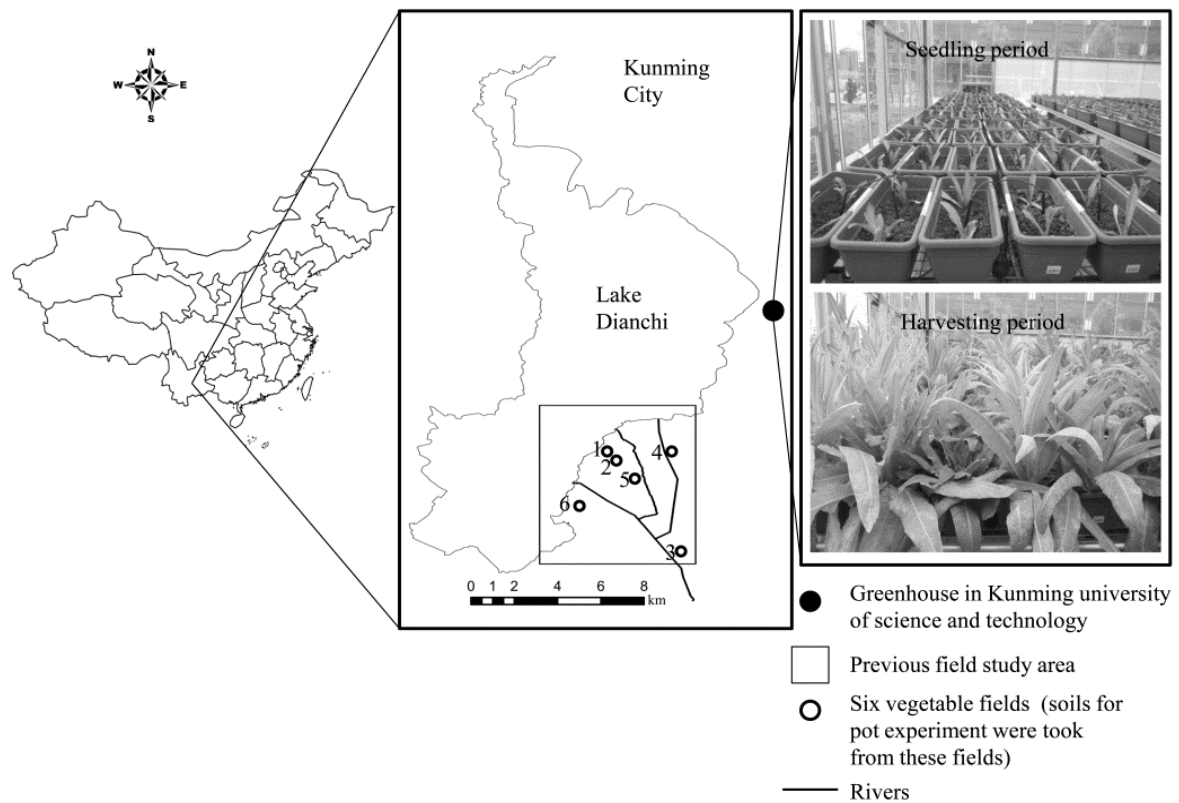


Fig. 5-1. Locations of vegetable fields where the soils for pot experiment were taken from.

experiment, and field 2 was similar but had been cultivated with one crop of vegetables (Table 5-1). Fields 3 and 6 had been cultivated with vegetables under vinyl houses for five and three years, respectively, representing medium-length vegetable-growing periods. Fields 4 and 5 represented relatively long-length vegetable-growing periods. The cropping intensities of vegetables in fields 3 to 6 ranged from four to seven crops per year, representing the cropping intensities of most vegetable fields in this area. In addition, the variation of soil properties of the six fields reflects fairly well those of the 32 previously surveyed vegetable fields. For instance, soil nitrate in the six fields ranged from 60.2 to 274.1 mg kg⁻¹ with an average of 170.8 mg kg⁻¹, and those in the 32 fields ranged from 40 to 320 mg kg⁻¹ with an average of 163 mg kg⁻¹. In summary, the six fields from which soils were taken for pot experiments were representative of the study area.

Table 5-1. Descriptive statistics of cultivation in vinyl house fields and properties of soils used for pot experiment.

Variable	Unite	Field 1	Field 2	Field 3	Field 4	Field 5	Field 6
Years of vinyl house cultivation	year	0	0(1crop)	5	8	8	3
Cropping intensities of vegetable per year	crop year ⁻¹	-	-	4	5	7	7
Input of chemical fertilizer per year							
N	g m ⁻² y ⁻¹	29.85	17.00	74.79	142.21	262.49	107.62
P	g m ⁻² y ⁻¹	5.61	7.48	16.15	28.05	51.05	18.99
K	g m ⁻² y ⁻¹	10.58	14.11	10.26	52.91	96.30	94.99
Input of manure per year							
N	g m ⁻² y ⁻¹	0.00	0.00	10.67	85.50	164.99	33.54
P	g m ⁻² y ⁻¹	0.00	0.00	4.25	22.50	75.00	9.66
K	g m ⁻² y ⁻¹	0.00	0.00	7.46	51.75	87.00	20.88
Input-output balance (chemical fertilizer + manure)							
N	g m ⁻² y ⁻¹	18.77	1.33	33.15	113.88	332.50	53.61
P	g m ⁻² y ⁻¹	1.83	5.43	12.51	31.25	112.03	14.62
K	g m ⁻² y ⁻¹	-1.59	3.08	-39.05	1.22	91.98	20.05
Properties of soils used for pot experiment							
Total N	g kg ⁻¹	2.52	3.06	1.19	2.11	1.52	2.61
Total C	g kg ⁻¹	25.46	27.76	8.15	16.16	12.03	24.40
Nitrate	mg kg ⁻¹	60.20	185.80	288.70	94.20	121.50	274.10
Water-soluble P	mg kg ⁻¹	3.06	18.76	29.40	18.80	21.64	15.30
Water-soluble K	mg kg ⁻¹	94.40	122.00	112.40	89.10	51.40	145.80
EC	ms m ⁻¹	130.90	154.20	69.20	98.90	39.80	57.40
pH		7.41	7.48	7.45	7.11	7.41	7.34

Content in brackets means only one crop of vegetable had been cultivated before soil collecting for pot experiment. Input of chemical fertilizer per year, input of manure per year, and input-output balance in field one indicate cultivation of paddy rice, and those in other fields indicate cultivation of vegetable.

Experimental design

This experiment was conducted from June 1 to July 15, 2012 at a greenhouse in Kunming University of Science and Technology, about 20 km from the previously studied fields. Just after vegetable harvesting by farmers, the surface soil (0–15 cm) was collected from three sites in each field, then uniformly mixed, and 6 kg (dry weight) of soil was loaded into plastic pots (39 cm long, 15 wide, and 13 cm high).

The experimental design is shown in Table 5-2, and there were three replications of each treatment. The inputs of N, P, and K from chemical fertilizer for stem lettuce in the control plot were averages from the 32 vegetable fields reported in a previous study (Wang et al., 2014). Urea ($\text{N} \geq 46.4\%$), calcium superphosphate ($\text{P}_2\text{O}_5 \geq 16.0\%$), and potassium chloride ($\text{K}_2\text{O} \geq 60.0\%$) were applied as N, P, and K fertilizer, respectively.

Two seedlings of stem lettuce, a representative vegetable in the study area, were planted in each pot. To avoid the effects from external factors, the positions of the pots were arranged at random. To control irrigation for each pot as equally as possible, I set a main irrigating pipe with hermetically separated small pipes leading to each pot, and irrigated soils until they reached about pF 2.0 humidity (DIK-8343, DAIKI, Japan) (Peijnenburg et al., 2000). Forty-five days after seedling transplantation, the stem lettuce was harvested. The growth duration was based on the local farmers' typical management practices.

Table 5-2. Different application amounts of N, P, and K chemical fertilizer.

Treatment	Amount of application (N-P-K mg pot ⁻¹)
Control (N100-P100-K100)	879-386-727
Half-N (N50-P100-K100)	440-386-727
No-N (N0-P100-K100)	0-386-727
Half-P (N100-P50-K100)	879-193-727
No-P (N100-P0-K100)	879-0-727
Half-K (N100-P100-K50)	879-386-364
No-K (N100-P100-K0)	879-386-0

Vegetable and soil analyses

The aboveground biomass of vegetables was harvested. Vegetable samples were oven-dried at 70°C to a constant weight and ground until they were fine enough to pass through a 2-mm sieve. The plant sample was digested by the Kjeldahl method, then the concentrations of NH_4^+ , P, and K were determined, respectively, by the cresol red method (cresol red dissolved in sodium hydroxide solution, then mixed with Hepes; the final solution was used as an indicator per Schulze et al., 1988) with a flow-injection spectrophotometer (WIS-2000, HIRANUMA, Japan); the vanadomolybdate method (Stuffins, 1967) with a spectrophotometer (U-1500, HITACHI, Japan); and an atomic absorption spectrophotometer alone (AA-7000, SHIMADZU, Japan). The concentration of nitrate (NO_3^-) was determined using the Cataldo method (Cataldo et al., 1975) and a spectrophotometer (U-1500, HITACHI, Japan).

The soils used for analysis were extracted from the soils prepared for the pot experiment. Soils were air-dried and ground to pass through a 2-mm sieve. Electrical conductivity (EC) and $\text{pH}(\text{H}_2\text{O})$ were measured using a glass electrode after the soil was mixed with distilled water(1:5, w/v). Extraction was used to determine the nitrate and P contents by the Cataldo method (Cataldo et al., 1975) and sulfuric acid-molybdenum method (Martin and Doty, 1949),

respectively, using a spectrophotometer (U-1500, HITACHI, Japan). The concentration of K was determined with an atomic absorption spectrophotometer. Total nitrogen (TN) and total carbon (TC) were determined using a mass spectrometer (Delta S, Finnigan MAT, Bremen, Germany) coupled with an elemental analyzer (EA1108, Fisons, Rodano, Milan, Italy) at the Center for Ecological Research, Kyoto University (Kyoto, Japan). The annual average value was used in the analysis of data.

Data analyses

N, P, or K balance was calculated as:

$$\text{N, P, or K balance} = \text{N, P, or K input from chemical fertilizer} - \text{N, P, or K output by vegetable}$$

The N, P, and K absorbed from sources other than chemical fertilizer was defined as N, P, and K outputs under application by N0-P100-K100, N100-P0-K100, and N100-P100-K0, respectively.

The slope of the linear correlation between input of N chemical fertilizer and output of N reflects the N recovery efficiency. Consequently, N recovery efficiency of chemical fertilizer was calculated as:

$$\text{N recovery efficiency of chemical fertilizer} = \frac{\frac{N_{out_{N100-P100-K100}} - N_{out_{N0-P100-K100}}}{N_{100}} + \frac{N_{out_{N50-P100-K100}} - N_{out_{N0-P100-K100}}}{N_{50}}}{2}$$

where $N_{out_{N100-P100-K100}}$, $N_{out_{N50-P100-K100}}$, and $N_{out_{N0-P100-K100}}$ are N outputs under applications by N100-P100-K100, N50-P100-K100, and N0-P100-K100, respectively. P and K recovery efficiencies of chemical fertilizer were calculated by the same methods.

Response of dry matter production to N absorbed from chemical fertilizer was calculated as:

$$\triangle DM / \triangle N_{out} = \frac{\frac{DM_{N100-P100-K100} - DM_{N0-P100-K100}}{N_{out_{N100-P100-K100}} - N_{out_{N0-P100-K100}}} + \frac{DM_{N50-P100-K100} - DM_{N0-P100-K100}}{N_{out_{N50-P100-K100}} - N_{out_{N0-P100-K100}}}}{2}$$

where $\triangle DM / \triangle N_{out}$ stands for variation of dry matter production per unit N absorbed from chemical fertilizer, and $DM_{N100-P100-K100}$, $DM_{N50-P100-K100}$, and $DM_{N0-P100-K100}$ are dry matter production of vegetable under application by N100-P100-K100, N50-P100-K100, and N0-P100-K100, respectively. Responses of dry matter production to P and K absorbed from chemical fertilizer were calculated by the same methods.

5-3. Results

The effects of different application of chemical fertilizer on dry matter production of stem lettuce

Table 5-3 shows the effects of different applications of chemical fertilizer on dry matter production of stem lettuce. In the case of soil 1, dry matter production of stem lettuce under application of N50-P100-K100, N100-P50-K100, N100-P100-K50, and N100-P100-K0 were not significantly lower than that of N100-P100-K100, respectively. These results indicated that the application of N and P from chemical fertilizer, and the application of K from chemical fertilizer to soil 1 could be reduced to one half and zero, respectively, without yield loss. In the case of soil 4, although the difference did not reach statistical significance, dry matter production under application of N0-P100-K100 was somewhat lower than those under N50-P100-K100 and N100-P100-K100. In the case of soil 5, dry matter productions under

application of N50-P100-K100, N100-P50-K100, N100-P0-K100, and

Table 5-3. Dry matter production of stem lettuce under different application of chemical fertilizer.

Treatment	Dry matter production (g pot ⁻¹)					
	1	2	3	4	5	6
N100-P100-K100	27.0 ^a	15.6 ^a	22.9 ^a	36.4 ^a	22.3 ^a	16.9 ^a
N50-P100-K100	21.9 ^{ab}	19.2 ^a	29.8 ^a	41.5 ^a	19.2 ^a	13.4 ^a
N0-P100-K100	13.5 ^b	18.5 ^a	31.3 ^a	21.5 ^a	12.1 ^b	15.7 ^a
N100-P100-K100	27.0 ^a	15.6 ^a	22.9 ^a	36.4 ^a	22.3 ^a	16.9 ^a
N100-P50-K100	19.9 ^a	19.4 ^a	19.3 ^a	34.0 ^a	20.6 ^a	15.5 ^a
N100-P0-K100	4.4 ^b	11.3 ^a	29.5 ^a	37.7 ^a	18.4 ^a	19.6 ^a
N100-P100-K100	27.0 ^a	15.6 ^a	22.9 ^a	36.4 ^a	22.3 ^a	16.9 ^a
N100-P100-K50	19.5 ^a	20.4 ^a	25.9 ^a	32.1 ^a	17.9 ^{ab}	13.2 ^a
N100-P100-K0	17.5 ^a	18.2 ^a	22.2 ^a	32.8 ^a	15.1 ^b	19.4 ^a

Different letters within a column indicate significant differences ($P < 0.05$) by Tukey's honestly significant difference test.

N100-P100-K50 were not significantly lower than that of N100-P100-K100, respectively. These results indicated that the application to soil 5 of N and K from chemical fertilizer could be halved while that of P could be eliminated without yield loss. In the cases of soils 2, 3, and 6, there were no significant differences among the dry matter productions under different application of N, P, and K chemical fertilizer, indicating that the application of N, P, and K from chemical fertilizer could all be reduced to zero without yield loss.

The effects of different application of chemical fertilizer on N, P, and K outputs

Decreasing application of N, P, and K chemical fertilizer induced a significant decrease of N absorbed by vegetables in soils 1, 4, and 5. Decreasing application of P chemical fertilizer induced a significant decrease of P absorbed by stem lettuce grown in soil 1. Decreasing application of K

chemical fertilizer induced a significant decrease of K absorbed by stem lettuce grown in soils 1 and 5 (Tables 5-4, 5-5, and 5-6). For other soils, there were no significant differences in the nutrient absorptions under different applications of chemical fertilizer.

Table 5-4. N outputs under different application of chemical fertilizer.

Treatment	N output by vegetable (mg pot ⁻¹)					
	1	2	3	4	5	6
N100-P100-K100	402.3 ^a	427.5 ^a	666.5 ^a	732.0 ^a	506.5 ^a	778.1 ^a
N50-P100-K100	299.0 ^{ab}	524.6 ^a	767.0 ^a	559.4 ^{ab}	476.0 ^a	595.8 ^a
N0-P100-K100	172.1 ^b	478.3 ^a	776.0 ^a	268.2 ^b	299.0 ^b	523.9 ^a
N100-P100-K100	402.3 ^a	427.5 ^a	666.5 ^a	732.0 ^a	506.5 ^a	778.1 ^a
N100-P50-K100	400.3 ^a	611.9 ^a	379.6 ^{ab}	269.2 ^b	226.0 ^{ab}	527.0 ^a
N100-P0-K100	118.6 ^b	236.0 ^a	292.2 ^b	506.7 ^{ab}	153.6 ^b	612.0 ^a
N100-P100-K100	402.3 ^a	427.5 ^a	666.5 ^a	732.0 ^a	506.5 ^a	778.1 ^a
N100-P100-K50	413.2 ^a	586.0 ^a	756.4 ^a	520.8 ^a	318.0 ^b	426.2 ^a
N100-P100-K0	364.2 ^a	533.7 ^a	971.0 ^a	534.2 ^a	305.8 ^b	665.1 ^a

Different letters within a column indicate significant differences ($P < 0.05$) by Tukey's honestly significant difference test.

Table 5-5. P outputs under different application of chemical fertilizer.

Treatment	P output by vegetable (mg pot ⁻¹)					
	1	2	3	4	5	6
N100-P100-K100	161.6 ^a	151.1 ^a	215.8 ^a	291.8 ^a	223.7 ^a	165.2 ^a
N50-P100-K100	104.8 ^b	105.2 ^a	168.8 ^a	244.9 ^a	148.7 ^b	104.8 ^a
N0-P100-K100	69.1 ^b	112.1 ^a	173.8 ^a	139.3 ^b	94.9 ^b	108.6 ^a
N100-P100-K100	161.6 ^a	151.1 ^a	215.8 ^a	291.8 ^a	223.7 ^a	165.2 ^a
N100-P50-K100	115.6 ^b	161.2 ^a	169.7 ^a	281.0 ^a	227.2 ^a	156.1 ^a
N100-P0-K100	29.3 ^c	99.6 ^a	254.1 ^a	303.4 ^a	186.0 ^a	147.6 ^a
N100-P100-K100	161.6 ^a	151.1 ^a	215.8 ^a	291.8 ^a	223.7 ^a	165.2 ^a
N100-P100-K50	111.9 ^b	181.8 ^a	197.4 ^a	279.4 ^a	156.4 ^a	97.1 ^a
N100-P100-K0	132.6a ^b	133.5 ^a	172.2 ^a	248.3 ^a	143.8 ^a	173.4 ^a

Different letters within a column indicate significant differences ($P < 0.05$) by Tukey's honestly significant difference test.

Table 5-6. K outputs under different application of chemical fertilizer.

Treatment	K output by vegetable (mg pot ⁻¹)					
	1	2	3	4	5	6
N100-P100-K100	1075.1 ^a	733.1 ^a	1015.8 ^a	927.9 ^a	1035.3 ^a	1335.4 ^a
N50-P100-K100	1157.8 ^a	1003.4 ^a	1323.5 ^a	1575.8 ^a	1216.5 ^a	1266.7 ^a
N0-P100-K100	877.4 ^a	1085.8 ^a	1427.6 ^a	1377.9 ^a	984.4 ^a	1601.6 ^a
N100-P100-K100	1075.1 ^a	733.1 ^a	1015.8 ^a	927.9 ^a	1035.3 ^a	1335.4 ^a
N100-P50-K100	1063.4 ^a	1019.1 ^a	925.3 ^a	1399.3 ^a	1265.2 ^a	1342.7 ^a
N100-P0-K100	404.4 ^b	853.8 ^a	1414.1 ^a	1537.1 ^a	1214.4 ^a	1577.2 ^a
N100-P100-K100	1075.1 ^a	733.1 ^a	1015.8 ^a	927.9 ^a	1035.3 ^a	1335.4 ^a
N100-P100-K50	835.1 ^b	768.6 ^a	950.3 ^a	951.8 ^a	916.6 ^{ab}	875.3 ^a
N100-P100-K0	588.8 ^c	622.4 ^a	710.6 ^a	738.4 ^a	705.6 ^b	999.3 ^a

Different letters within a column indicate significant differences ($P < 0.05$) by Tukey's honestly significant difference test.

The effects of different application of chemical fertilizer on N, P, and K balances

Tables 5-7, 5-8, and 5-9 show the N, P, and K balances under different applications of chemical fertilizer; the negative values in the tables indicate that the amounts of N, P, and K absorbed by stem lettuce were higher than the inputs of N, P, and K. Except for the cases of soils 4 and 6 under the application of N50-P100-K100, the N balances under the application of N50-P100-K100 and N0-P100-K100 were significantly lower than those of N100-P100-K100, respectively. Except for the case of soil 3 under the application of N100-P50-K100, the P balances under the application of N50-P100-K100 and N0-P100-K100 were significantly lower than that of N100-P100-K100, respectively. In the case of K, the K balances in soils 1 and 5 under N100-P100-K0, and soils 2 and 4 under the application of N100-P100-K50 and N100-P100-K0 were significantly lower than that of N100-P100-K100, respectively.

Table 5-7. N balances under different application of chemical fertilizer.

Treatment	N balance (mg pot ⁻¹)					
	1	2	3	4	5	6
N100-P100-K100	476.7 ^a	451.5 ^a	212.5 ^a	147.0 ^a	372.5 ^a	100.9 ^a
N50-P100-K100	141.0 ^b	-84.6 ^b	-327.0 ^b	-119.4 ^{ab}	-36.0 ^b	-155.8 ^a
N0-P100-K100	-172.1 ^c	-478.3 ^b	-776.0 ^c	-268.2 ^b	-299.0 ^c	-523.9 ^b
N100-P100-K100	476.7 ^a	451.5 ^a	212.5 ^a	147.0 ^a	372.5 ^a	100.9 ^a
N100-P50-K100	478.7 ^a	267.1 ^a	499.4 ^{ab}	609.8 ^b	653.0 ^{ab}	352.0 ^a
N100-P0-K100	760.4 ^b	643.0 ^a	586.8 ^b	372.3 ^{ab}	725.4 ^b	267.0 ^a
N100-P100-K100	476.7 ^a	451.5 ^a	212.5 ^a	147.0 ^a	372.5 ^a	100.9 ^a
N100-P100-K50	465.8 ^a	293.0 ^a	122.6 ^a	358.2 ^a	561.0 ^b	452.8 ^a
N100-P100-K0	514.8 ^a	345.3 ^a	-92.0 ^a	344.8 ^a	573.2 ^b	213.9 ^a

Different letters within a column indicate significant differences ($P < 0.05$) by Tukey's honestly significant difference test.

Table 5-8. P balances under different application of chemical fertilizer.

Treatment	P balance (mg pot ⁻¹)					
	1	2	3	4	5	6
N100-P100-K100	224.4 ^a	234.9 ^a	170.2 ^a	94.2 ^a	162.3 ^a	220.8 ^a
N50-P100-K100	281.2 ^b	280.8 ^a	217.2 ^a	141.1 ^a	237.3 ^b	281.2 ^a
N0-P100-K100	316.9 ^b	273.9 ^a	212.2 ^a	246.7 ^b	291.1 ^b	277.4 ^a
N100-P100-K100	224.4 ^a	234.9 ^a	170.2 ^a	94.2 ^a	162.3 ^a	220.8 ^a
N100-P50-K100	77.4 ^b	31.8 ^b	23.3 ^a	-88.0 ^b	-34.2 ^b	36.9 ^b
N100-P0-K100	-29.3 ^c	-99.6 ^b	-254.1 ^b	-303.4 ^c	-186.0 ^c	-147.6 ^c
N100-P100-K100	224.4 ^a	234.9 ^a	170.2 ^a	94.2 ^a	162.3 ^a	220.8 ^a
N100-P100-K50	274.1 ^b	204.2 ^a	188.6 ^a	106.6 ^a	229.6 ^a	288.9 ^a
N100-P100-K0	253.4 ^{ab}	252.5 ^a	213.8 ^a	137.7 ^a	242.2 ^a	212.6 ^a

Different letters within a column indicate significant differences ($P < 0.05$) by Tukey's honestly significant difference test.

Table 5-9. K balances under different application of chemical fertilizer.

Treatment	K balance (mg pot ⁻¹)					
	1	2	3	4	5	6
N100-P100-K100	-348.1 ^a	-6.1 ^a	-288.8 ^a	-200.9 ^a	-308.3 ^a	-608.4 ^a
N50-P100-K100	-430.8 ^a	-276.4 ^a	-596.5 ^a	-848.8 ^a	-489.5 ^a	-539.7 ^a
N0-P100-K100	-150.4 ^a	-358.8 ^a	-700.6 ^a	-650.9 ^a	-257.4 ^a	-874.6 ^a
N100-P100-K100	-348.1 ^a	-6.1 ^a	-288.8 ^a	-200.9 ^a	-308.3 ^a	-608.4 ^a
N100-P50-K100	-336.4 ^a	-292.1 ^a	-198.3 ^a	-672.3 ^a	-538.2 ^a	-615.7 ^a
N100-P0-K100	322.6 ^b	-126.8 ^a	-687.1 ^a	-810.1 ^b	-487.4 ^a	-850.2 ^a
N100-P100-K100	-348.1 ^a	-6.1 ^a	-288.8 ^a	-200.9 ^a	-308.3 ^a	-608.4 ^a
N100-P100-K50	-471.1 ^{ab}	-404.6 ^b	-586.3 ^a	-587.8 ^b	-552.6 ^{ab}	-511.3 ^a
N100-P100-K0	-588.8 ^b	-622.4 ^b	-710.6 ^a	-738.4 ^b	-705.6 ^b	-999.3 ^a

Different letters within a column indicate significant differences ($P < 0.05$) by Tukey's honestly significant difference test.

5-4. Discussion

Decreasing N, P, and K balances without yield loss

While reducing agricultural pollution by limiting chemical fertilizer input is important, maintaining yield is also important. Table 10 summarizes the data in Tables 5-3, 5-7, 5-8, and 5-9, reflecting the application methods in the six soils that could decrease the N, P, and K balances by reducing inputs from chemical fertilizer without resulting in yield loss. Since these would lower the soil nutrient levels, they would not be sustainable indefinitely, but would rather help reduce non-point source pollution in the short term.

Table 5-10. Percentage reduction of N, P, and K inputs without yield loss.

	1	2	3	4	5	6
N	50	100	100	50	50	100
P	50	100	100	100	100	100
K	100	100	100	100	50	100

In the case of soil 1, there was a contradiction between reducing the input of N and P from chemical fertilizer without yield loss and decreasing the input–output balances of N and P. Under N0-P100-K100 and N100-P0-K100, the input–output balances of N and P significantly decreased, but the dry matter production fell. When the N and P inputs were both reduced by half, productivity was maintained, but 141.0 mg pot⁻¹ of N and 77.4 mg pot⁻¹ of P remained (Table 5-3, 5-7, and 5-8). Yields were preferentially considered in this situation. In the case of soil 4, although the dry matter production showed no statistically significant difference had a significant difference between control and zero-treatment, absolute values of the control and zero-treatment indicated some effects (Table 5-3). On the other hand, there was a significant difference in the amount of absorbed N between the control and zero-treatment plants (Table 5-4). Such a relation was not seen in the other soils. For the above reason, I considered that reduction by half of the N input of was appropriate for decreasing the N balance in soil 4. In the case of soil 5, reduction by half of the N and K inputs, and the elimination of the P input were appropriate for decreasing the N, P, and K balances without yield loss. In the case of other soils, reduction of all the N, P, and K inputs for one season was appropriate. In addition, this result is helpful for increasing farmers' profits by saving expenses on chemical fertilizer.

The input–output balance is relevant to both of soil recharge and reducing nutrient accumulation in soil. In the case of infertile soil, decreasing the input–output balance to a negative value will make the soil more infertile, unsustainable in terms of productivity. For instance, soil 1 was not excessively

fertile in nitrate. In this situation, some soil recharge was thought to be more important, thus, the balance under application of N50-P100-K100, 141 mg pot⁻¹, was more appropriate than that under application of N0-P100-K100, – 172.1 mg pot⁻¹. For excessively fertile soil, reducing nutrient accumulation is principal, and a negative input–output balance will mitigate agricultural non-point source pollution.

The reason for different responses of nutrient absorption to reduction in chemical fertilizer input

First, the effects of soil nutrients on nutrients absorption from sources other than chemical fertilizer were considered. Figure 5-2a shows a significant correlation between nitrate in soil and N absorbed from sources other than chemical fertilizer by stem lettuce, suggesting that under the complete elimination of N chemical fertilizer, N absorbed by stem lettuce mainly originated from the nitrate in soil. The relationships between soil P and P absorbed from sources other than chemical fertilizer, and soil K and K absorbed from sources other than chemical fertilizer were not significant, however (Figure 5-2b and 5-2c). These results suggested that the absorbed P and K that did not come from fertilizer originated from sources and mechanisms other than soil P and K.

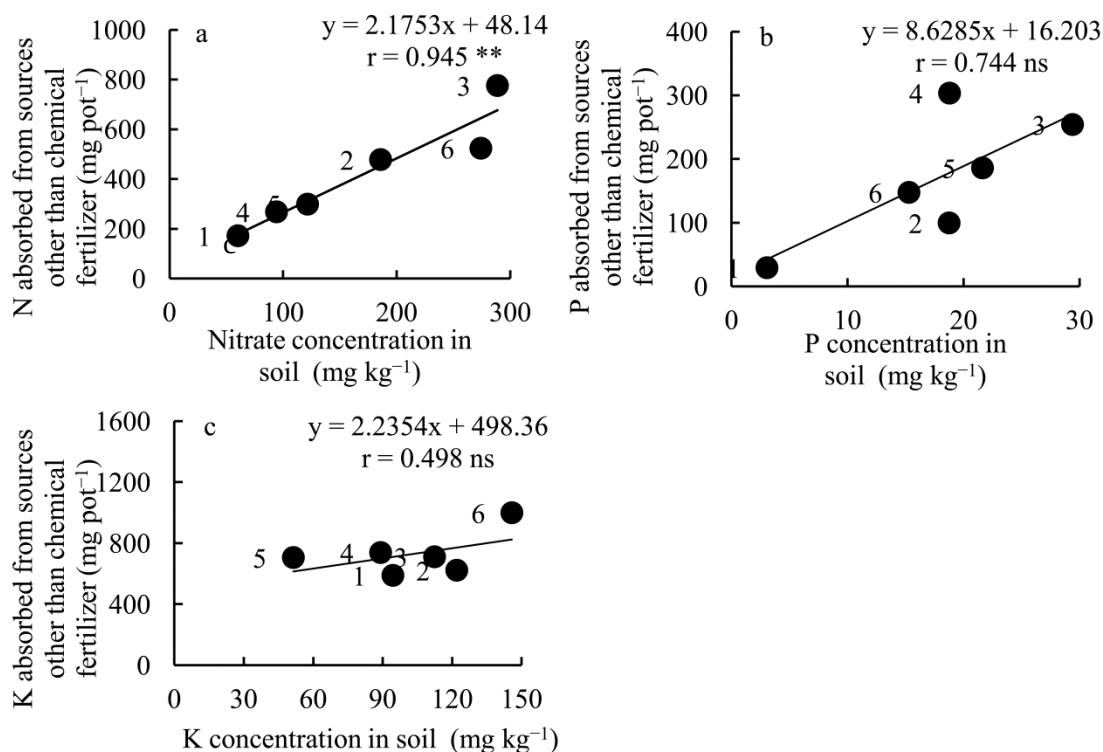


Fig. 5-2. Relationships between soil Nitrate, P, and K and N, P, and K absorbed from sources other than chemical fertilizer by lettuce. Numbers on the left of dots represent the numbers of the soils for pot experiment. **, significant at $P < 0.01$; ns, not significant.

Next, the effects of the nutrient absorption from sources other than chemical fertilizer on nutrient recovery efficiency were considered. The correlation between N absorbed from sources other than chemical fertilizer and N recovery efficiency of chemical fertilizer was not significant (Figure 5-3a), but the P value was 0.063, which is very close to 0.05. The N recovery efficiency of chemical fertilizer was negatively related with N absorbed from sources other than chemical fertilizer, which mainly originated from soil nitrate, indicating that N absorption from soil had a complementary relationship with N absorption from chemical fertilizer by vegetables (Figure 5-2a and 5-3a). It was considered that high N recovery efficiency of chemical fertilizer greatly decreased the absorption of N chemical fertilizer by reducing the amount of

input of N chemical fertilizer. N absorbed from soil was lower in soils 1, 4, and 5 than those in other fields (Figure 5-2a), owing to there being relatively less nitrate in those soils (Table 5-1). In this situation, the N recovery efficiency of chemical fertilizer by stem lettuce was higher in soils 1, 4, and 5 than those in soils 2, 3, and 6 (Figure 5-3a), indicating that if the amount of input of N chemical fertilizer was reduced in soils 1, 4, and 5, the total amount of N absorbed would easily decrease.

The correlation between P absorbed from sources other than chemical fertilizer by stem lettuce and the P recovery efficiency of chemical fertilizer was significantly negative (Figure 5-3b), indicating that P absorbed from other sources inhibited P recovery efficiency of chemical fertilizer. But P absorbed from other sources was not affected by soil P (Figure 5-2b); thus, soil P did not affected the P recovery efficiency of chemical fertilizer by stem lettuce. As in the case of P, soil K did not affected the K recovery efficiency of chemical fertilizer by stem lettuce (Figure 5-2c and 5-3c).

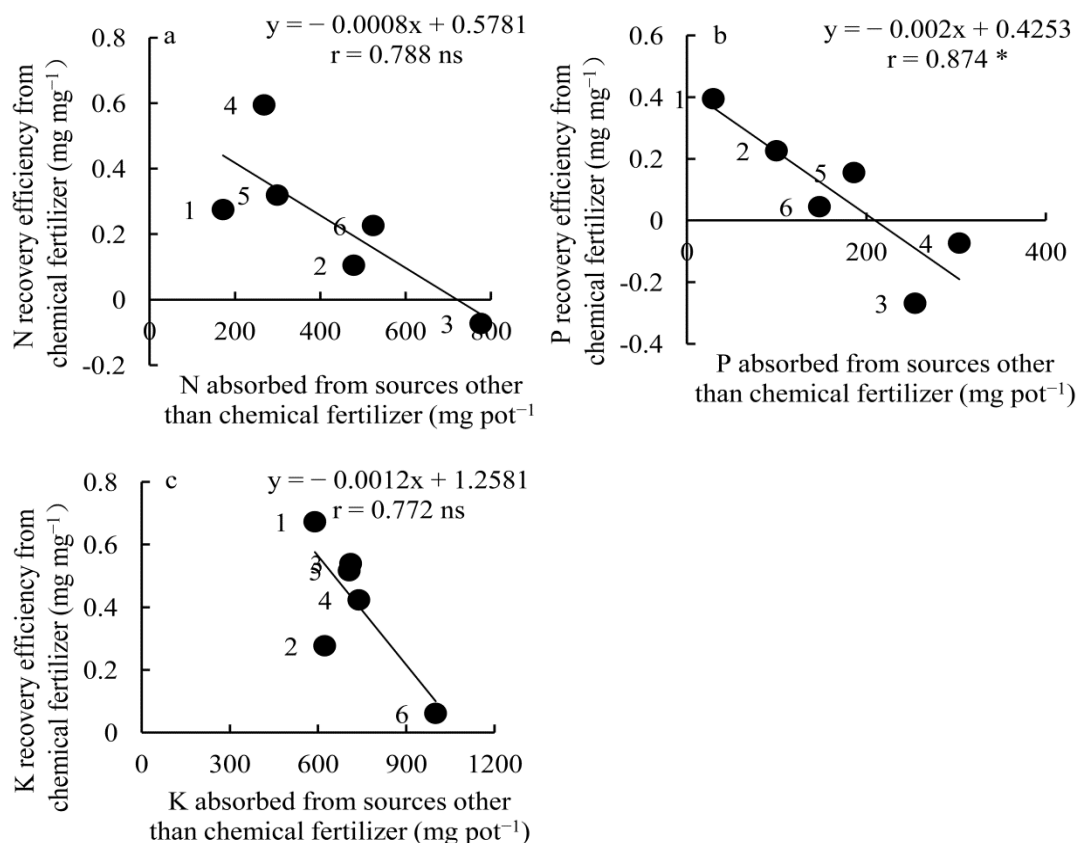


Fig. 5-3. Relationships between N, P, and K absorbed from sources other than chemical fertilizer and N, P, and K recovery efficiencies of chemical fertilizer. Numbers on the left of dots represent the numbers of the soils for pot experiment. *, significant at $P < 0.05$; ns, not significant.

The response of dry matter production to N absorbed from chemical fertilizer was negatively associated with N absorbed from sources other than chemical fertilizer, namely from soil (Figure 5-4a). The less N absorbed from soil, the more sensitively dry matter production responded to N absorbed from chemical fertilizer.

As mentioned above, reducing the amount of chemical fertilizer application should decrease N absorbed from chemical fertilizer by stem lettuce in soils 1, 4, and 5; moreover, the responses of dry matter production to N absorbed from chemical fertilizer were more sensitive in these pots. Accordingly, reducing a

certain input amount of N chemical fertilizer would more easily decrease the dry matter production in soils 1, 4, and 5. In the cases of soils 2, 3, and 6, owing to the high concentration of soil nitrate, the N input-output balance could be decreased by reducing N input from chemical fertilizer without yield loss. These soils were fertile in nitrate (Table 1), and decreasing N balance to a negative value was conducive to mitigation of eutrophication.

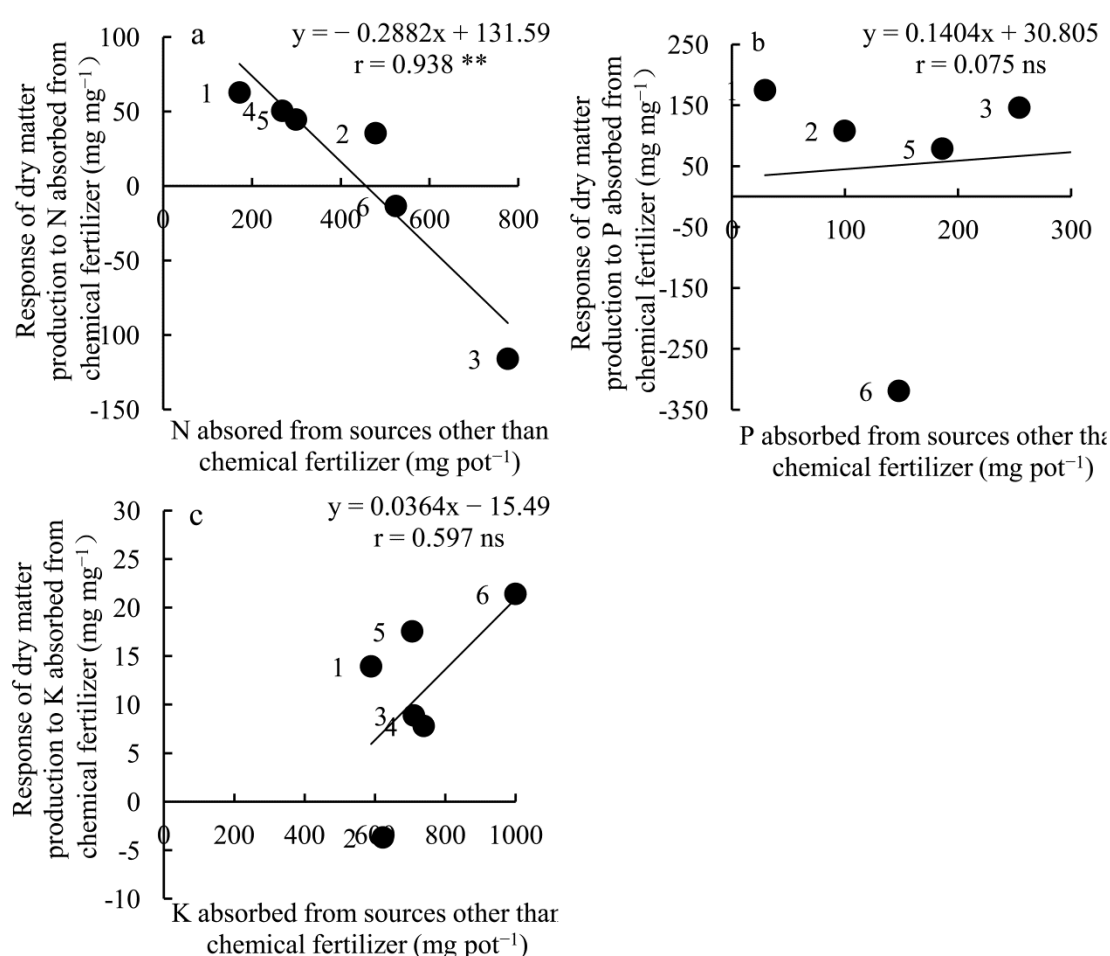


Fig. 5-4. Relationships between N, P, and K absorbed from sources other than chemical fertilizer and responses of dry matter production to N, P, and K absorbed from chemical fertilizer. Numbers on the left of dots represent the numbers of the soils for pot experiment. **, significant at $P < 0.01$; ns, not significant.

Relationships between P and K absorbed from sources other than chemical fertilizer and the responses of dry matter production to P and K absorbed from chemical fertilizer were not significant (Figure 5-4b and 5-4c). The method of analyzing the effect of reducing N fertilizer on dry matter production was not thought to be suited to P and K.

A model predicting the N balance and dry matter production after halving the input of N chemical fertilizer

The effects of reducing N chemical fertilizer on the N balance and dry matter production in six selected fields were certain through a pot experiment (Tables 5-3 and 5-7), but the pot experiment was thought to be too complicated for local farmers. Thus, I developed a model that could predict N balance and dry matter production after reducing by half, or halving, the input of N chemical fertilizer without a pot experiment (Figure 5-5).

Substituting soil nitrate in the formula of Figure 5-2a can determine the amount of N absorbed from sources other than chemical fertilizer, and then substituting N absorbed from sources other than chemical fertilizer in the formulae of Figures 5-3a and 5-4a can provide the N absorption ratio from chemical fertilizer and the response of dry matter production to N absorbed from chemical fertilizer, respectively. The dry matter production, N output, and input of N from chemical fertilizer before halving the input of N chemical fertilizer is certain, and the input of N from chemical fertilizer after halving the input of N chemical fertilizer is certain. Substituting the above-mentioned six certain factors in the model can provide the N balance and dry matter production after halving the input of N chemical fertilizer.

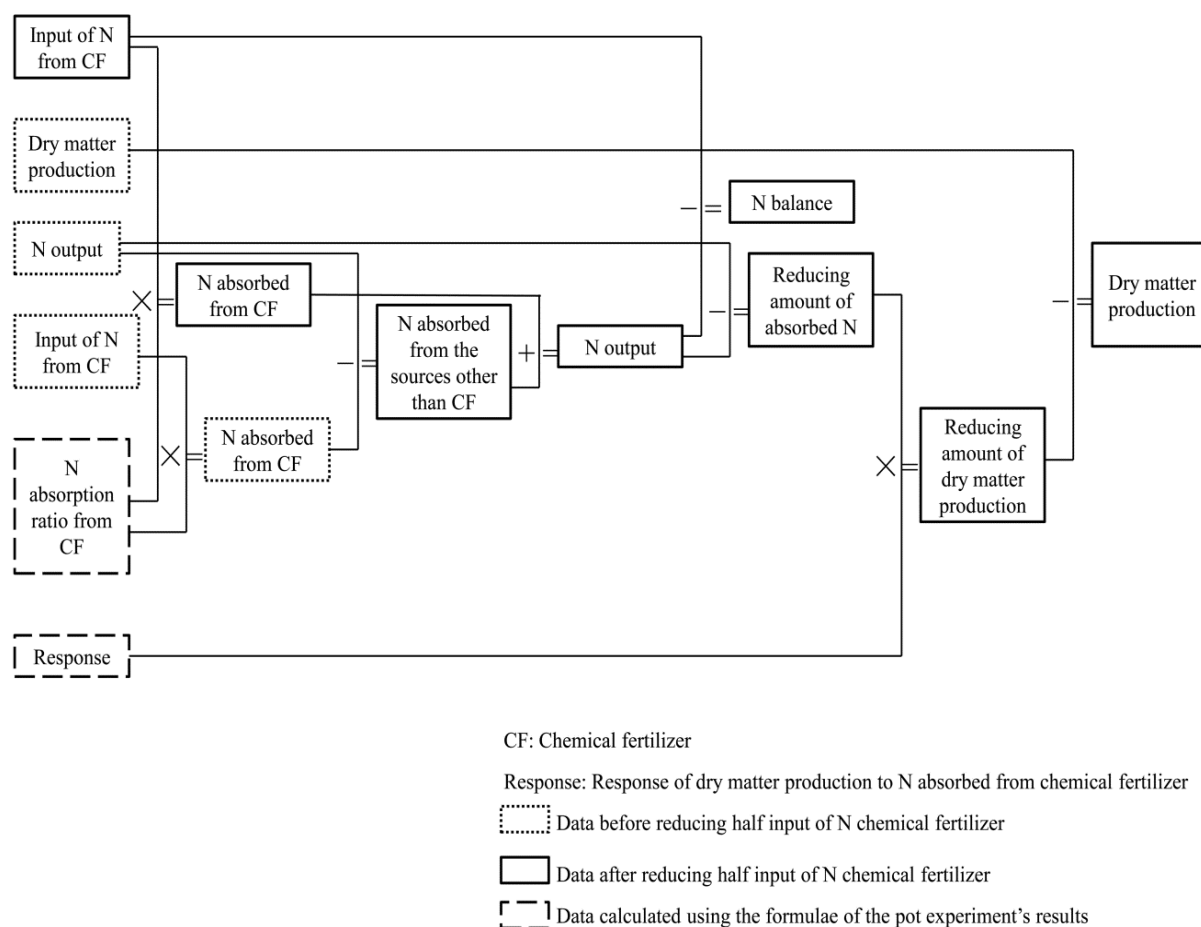


Fig. 5-5. A model predicting the N balance and dry matter production after halving the input of N chemical fertilizer.

The complicated parts of this model are determining the nitrate concentration in the soil and the N output. I surveyed 32 vegetable fields in the previous study, and 10 of these fields mainly cultivated stem lettuce. The N output through stem lettuce in the 10 fields ranged from 7.0 to $7.9 \text{ g m}^{-2} \text{ crop}^{-1}$ with a very low coefficient of variation, 4%. Thus, the N output in other fields might be considered to be around $7.5 \text{ g m}^{-2} \text{ crop}^{-1}$. Using the model to predict the N balance and dry matter production after halving the input of N chemical fertilizer, the soil nitrate at different sites in the study area can be determined.

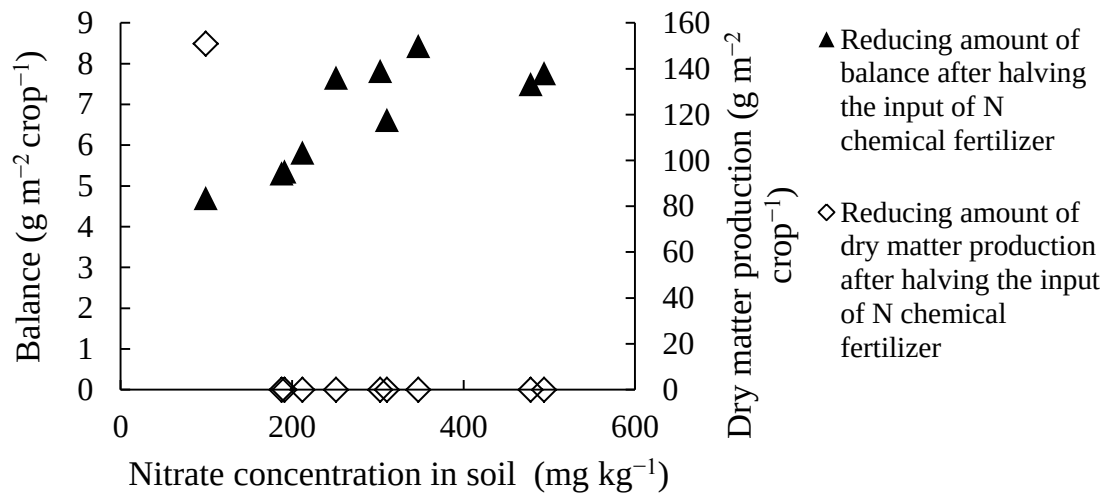


Fig. 5-6. Nutrient balances and dry matter production rates in the 10 fields after reducing by half the input of N chemical fertilizer.

I calculated the reducing amounts of balances and dry matter productions in the 10 fields after halving the input of N chemical fertilizer using the model (Figure 5-6). The reducing amounts of N balances ranged from 4.7 to 8.4 g m⁻² crop⁻¹. Dry matter production did not fall in nine fields while that in one field with a low nitrate concentration fell 151 g m⁻² crop⁻¹.

The average N absorbed from sources other than chemical fertilizer in the ten fields before halving the input of N chemical fertilizer was 5.78 g m⁻² crop⁻¹, which was calculated using the model. To verify the model, I performed a linear regression analysis between inputs of N from chemical fertilizer and N outputs in the ten fields before halving the input of N chemical fertilizer, and the regression constant that reflected N absorbed from sources other than chemical fertilizer was 5.82, which was very close to 5.78. This result suggested that the results obtained from the model should be close to reality.

Application of this study

Zhang et al. (2007) indicated that from 1999 to 2005 the P concentration in

Lake Dianchi decreased from 0.331 mg L^{-1} to 0.187 mg L^{-1} , and the contribution of N to the eutrophication was larger than that of P based on the total pollution analysis and statistical analysis from several years' water monitoring data. This pot experiment is helpful to reduce the N burden from agriculture.

Given China's trend toward intensive agriculture (Ju et al., 2009), this study should have universal application. For instance, Shouguang City of Shandong province is the largest greenhouse vegetable production base in China, and vegetable cropping is intensive with large inputs of fertilizer. As documented in 2010, the average contents of available N and available K in the soil were 248 and 486 mg kg^{-1} , respectively, and the available P was $135\text{--}377 \text{ mg kg}^{-1}$; all three are much more than vegetables require (Yu et al., 2010). Thus, the same pot experiment is thought to be suitable for reducing nutrient balance without yield loss in the area. To get a more exactly optimal amount of chemical fertilizer, greater varieties of application amounts of chemical fertilizer are needed.

Chapter 6

Conclusion

Since 1979, farmers in China have changed land use type and kind of crop, and increased cropping intensity per year. For instance, traditional double cropping system of rice-wheat and rice-broad bean has been converted to a intensive cropping system of vegetables. A similar converting was observed in the coastal area of southeast Lake Dianchi. Agricultural data was obtained basically from local governments. Paddy fields had converted to vegetable fields under vinyl houses from 2001 to 2009, resulting that application of chemical fertilizer sharply increased. The over application of fertilizer is the principal factor of water eutrophication in three highly eutrophic lakes in China, and Lake Dianchi is one of them.

The results of survey of 32 vegetable fields under vinyl houses and four paddy fields revealed that cropping intensity in most vegetable fields and input of N, P, and K to each crops was extremely high. By the synergistic effect of both factors, the annual amount of input was extremely high. Input–output balance results showed that 58.2, 72.1, and 20% of N, P, and K were not absorbed by vegetable under over-fertilization. ANCOVA results suggested that N absorption ratio in vegetable field had room for an improvement, and that the amount of mineralized N absorbed from the sources other than chemical fertilizer by vegetable under multiple cropping with longer cultivation duration

was increasing. It was thought that the fertilization method needs to be improved based on these results, for instance, slow-release fertilizer and split application might increase N absorption ratio. Regression analysis of P and K suggested that vegetables absorbed P and K independent of the input of P and K from chemical fertilizer. Dry matter production did not respond to N input when N input exceeded $200 \text{ g m}^{-2} \text{ y}^{-1}$, but the response to input of K from chemical fertilizer was significant at this N input level, suggesting that N application exceeded vegetable's demand and K limited vegetable production when N input exceeded $200 \text{ g m}^{-2} \text{ y}^{-1}$. Principal component analysis revealed that concentrations of N, P, and K in soil increased to a larger extent with input of N, P, and K from chemical fertilizers than from manure. Multiple regression analysis indicated that reducing the input of N, P, and K would be more efficient than increasing their output. From the above point of view, the following step was considered to be effective as an approach which farmer can use actually. First, dry matter production is ensured by control of soil disease damage and by the improvement of fertilizing balance. Second, the amount of applied chemical fertilizer is controlled in the range which does not decrease the agricultural income. Finally, the residual nutrient in soil is controlled by the reduction of the applied chemical fertilizer and by the effective use of soil mineralization N.

I simultaneously collected 22 soil and groundwater samples from 21 fields under vinyl houses and one upland field, and the significant correlation between soil nitrate and groundwater nitrate in the vegetable fields under vinyl houses suggested that nitrate leaching occurred in the study area. Furthermore, in the fields cultivated with longer duration, the soil nitrate was high and

groundwater contamination was severe. Soil nitrate in upland field showed a medium value, but the groundwater nitrate was high, possibly due to high evapotranspiration and precipitation without covering of vinyl house. Nitrate in ten groundwater exceeded the limit of drink water in China, 10 mg L^{-1} , and the corresponding soil nitrate was 147 mg L^{-1} , suggesting that reducing soil nitrate lower than this level possibly resulted groundwater safely in nitrate. I proposed that reducing N application and improving water use efficiency should reduce groundwater nitrate.

I collected soils from six fields representing the characteristic soil and cultivation treatments in the study area, and then performed a pot experiment applying chemical fertilizer with different amounts of N, P, and K. Reducing N, P, and K chemical fertilizer decreased the dry matter production in soils 1 and 5. Reducing inputs of N and P chemical fertilizer decreased the N and P input–output balance in all soils, and reducing the input of K chemical fertilizer decreased the K input–output balance in soils 1, 2, 4, and 5. I summarized the vegetable dry matter production and input–output balances under these treatments, and found the appropriate percentages by which N, P, and K chemical fertilizer could be reduced for each soil and still maintain yields. Decreasing the input–output balance to a negative value in infertile soil will make soil more infertile, unsustainable in terms of productivity. But for fertile soil, decreasing the input–output balance to a negative value will reduce nutrient accumulation in soil while and maintaining productivity.

Then I discussed the reasons why dry matter production decreased under lower chemical fertilizer inputs in some soils. The presence of low nitrate concentration in soils 1, 4, and 5 resulted in low N absorption from sources

other than chemical fertilizer and high N absorption from chemical fertilizer. Moreover, the responses of dry matter production to N absorbed from chemical fertilizer were more sensitive in these soils. Accordingly, dry matter production was more easily affected by reducing N chemical fertilizer in these soils. However, the method of analyzing the effect of reducing N chemical fertilizer on dry matter production was not suitable for the analysis of P and K.

To extend the application of this study, I developed a model that could predict the N balance and dry matter production after halving the input of N chemical fertilizer without a pot experiment. Using the model, reducing the amounts of balances and dry matter productions in 10 fields after halving the input of N chemical fertilizer were calculated. Results showed that in nine fields, the N balances were obviously reduced, while, dry matter production was maintained. I then calculated the results based on the model, which coincided well with the real experimental values.

Since intensive cropping is indispensable in China, decreasing the input–output balance by reducing the application of chemical fertilizer should help decrease nutrient surpluses and mitigate non-point source pollution from agriculture. The method of this study is easy to perform and should have universal application in other eutrophic agricultural areas in China.

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* In Japanese with English abstract

** In Japanese

*** In Chinese with English abstract

**** In Chinese

List of symbols and abbreviations used in the thesis

Symbol/Abbreviation	Description
ANCOVA	analysis of covariance
EC	electrical conductivity
K	potassium
N	Nitrogen
NPS pollution	nonpoint source pollution
P	phosphorus
NO_3^-	nitrate
TC	total carbon
TN	total nitrogen

Summary

Since 1979, the collective production team system has been replaced by the farm household responsibility system in China. To obtain greater annual yields and higher profits, farmers have changed land use type and increased cropping intensity. For instance, the traditional double cropping system of rice–wheat and rice–broad bean has been converted to a multiple cropping system of vegetables. Intensive multiple cropping systems demand high applications of chemical fertilizer and livestock manure. Such intensive crop production systems are unsustainable. Soil physicochemical and biological properties may dramatically change after continuous high annual inputs, and one prominent characteristic of intensive agriculture is nutrient accumulation in soil. In addition, the surplus nutrients in the soil leach into ground and surface water throughout year, leading to nonpoint source pollution, a principal factor of water eutrophication in China.

In China, there are three highly eutrophic freshwater lakes, Lake Dianchi, Taihu, and Chaohu, where the above intensive agriculture is performed in the coastal area. The present study was performed in multiple cropped vegetable fields in the coastal area of southeast Lake Dianchi, Yunnan Province, and aimed to (1) evaluate the effect of intensive multiple cropping on crop growth, soil chemical properties and groundwater, and (2) identify the effective methods for reducing the input–output balance without yield loss.

Most farmers cultivate six or seven crops per year in vegetable fields under vinyl houses in the study area. This very high cropping intensity is based on a

combination of vegetables with a short growing duration and transplant culture. Some farmers choose to cultivate short-term varieties throughout the year, whereas others cultivate one or two long-term varieties in winter and several short-term varieties at other times. Thus, cropping order is complicated. Farmers apply livestock manure one or two times per year as basal fertilizer but apply chemical fertilizer to each crop. In the study area, annual total inputs of N, P, and K were 177, 44, and 110 g m⁻² y⁻¹, respectively, and inputs of N, P, and K to each crop were 30, 7, and 18 g m⁻², respectively. In comparison with other areas of China and neighboring countries, the high annual total input in the study area appeared to depend on both high cropping intensity and high inputs to each crop.

Soil and crops were sampled in 32 vegetable fields and four paddy fields. The surveys were simultaneously conducted. In vegetable fields, cropping intensity and the input to each crop were extremely high and 58%, 72%, and 20% of N, P, and K were not absorbed by crops. The concentrations of NO₃⁻, P, and K in vegetable fields were higher than those in paddy fields, indicating that nutrient accumulation occurred in vegetable fields. ANCOVA results suggested that the N absorption ratio in vegetable field had a scope for improvement and that the amount of mineralized N absorbed from soil by vegetables increased with longer duration of cultivation. Regression analysis of P and K suggested that vegetables absorbed P and K independent of the input of P and K from chemical fertilizer. The dry matter production did not respond to N input when N input exceeded 200 g m⁻² y⁻¹, but the response to the input of K from chemical fertilizer was significant at this N input level, suggesting the importance of the method of fertilizer application according to the soil

characteristics. Furthermore, principal component analysis revealed that concentrations of N, P, and K in soil increased to a larger extent with the input of N, P, and K from chemical fertilizers than from manure. Multiple regression analysis indicated that reducing the input of N, P, and K would be more efficient than increasing their output.

I selected 22 vegetable fields, one upland field and the others cultivated in vinyl houses with different cultivation durations. Soil and groundwater were simultaneously sampled. There was a significant correlation between soil nitrate and groundwater nitrate in the fields under vinyl houses, suggesting that nitrate leaching occurs in the study area. Furthermore, in the fields cultivated with longer duration, soil nitrate was high and groundwater contamination was severe. The nitrate limit of drinking water in China is 10 mg L^{-1} , but nitrate in some wells exceeded this level and was harmful to health. Soil nitrate in the upland field showed a medium value, but the groundwater nitrate was much higher than that in vegetable fields under vinyl houses. This suggested that vinyl house cultivation is a water-saving practice.

A pot experiment was performed with the application of chemical fertilizer with different amount of N, P, and K, using the soils from six vegetable fields representing the study area. The presence of high nitrate concentration in some soils resulted high N absorption from sources other than chemical fertilizer and low N absorption from chemical fertilizer. Moreover, the responses of dry matter production to N absorbed from chemical fertilizer were less sensitive in these soils. Accordingly, reducing N input from chemical fertilizer reduced the input–output balance without a decline in dry matter production. The high concentration of nitrate in these soils did not seem to be dependent on

cultivating duration and cropping intensity. In other cases, reducing N input from chemical fertilizer reduced dry matter production, owing to low soil nitrate. Reducing N balance to a minus value could purify the soils with high nitrate, benefiting the environment and local farmers. The reducing amount of chemical fertilizer input without yield loss should depend on the soil chemical properties.

These results indicated that to reduce the input–output balance in the study area, reducing the input would be more efficient than increasing the output. For reducing the input, reducing the application of chemical fertilizer was the principal factor. The results of a pot experiment suggested the possibility of simultaneously reducing the input–output balance, removing nitrate from soil, and maintaining productivity. In conclusion, I propose that these methods would be effective in reducing nutrient surpluses and mitigating non-point source pollution from agriculture in the coastal area of southeast Lake Dianchi and other eutrophic agricultural areas in China.

List of Publications

(Chapter2, Chapter3)

Wang Y, Tanaka T, Inoue H, Li KZ, Yang D, Inamura T. 2014. Annual Nutrient Balance and Soil Chemical Properties in Heavy Multiple Cropping System in the Coastal Area of Southeast Lake Dianchi, Yunnan Province, China. *Plant Production Science* (in press).

(Chapter5)

Wang Y, Tanaka T, Li KZ, Inamura T. 2014. Decreasing Input–output Balance by Reducing Input from Chemical Fertilizer without Yield Loss in Intensive Cropping System in the Coastal Area of Southeast Lake Dianchi, Yunnan Province, China. *Plant Production Science* (under submission).