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Estimation of Balance of Nitrogen, Phosphorus and Potassium in Relation to Chemical Fertilizer Application in Japanese Orchard Fields

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Abstract

The consumption of chemical fertilizers in 1996 amounted to 511,700 t for nitrogen (N), 610,100 t for phosphorus (P2P5), 441,200 t for potassium (K2O). The area of orchard fields was 314,900 ha in 1995 and the ratio to the total cultivated area was 6.4%. If the same amount of chemical fertilizer is applied to each field, the total application to orchard fields should be 32,700 t for nitrogen, 39,000 t for phosphorus and 28,200 t for potassium. respectively. In this report, we estimated the input of chemical fertilizers to orchard fields based on the results of official surveys of orchard area and the standard application rate based on the cultivation guidelines adopted in 37 prefectures. In 1995, the input for main fruit tree species amounted to 50,600 t for nitrogen, 36,400 t for phosphorus and 40,700 t for main fruit tree species amounted to 50,600 t for nitrogen, 36,400 t for phosphorus and 40,700 t for potassium. The output of nutrients from the orchard fields was estimated based on the results of field experiments for the nutrient uptake of fruit trees as follows: 39,800 t for nitrogen, 9,100 t for phosphorus and 35,300 t for potassium for mature fruit-bearing trees. The ratio of estimated input to output was 1.3 for nitrogen, 4.5 for phosphorus and 1.2 for potassium, respectively. These results indicate that the amount of chemical fertilizer application to the orchard fields may be appropriate for nitrogen and potassium but is excessive for phosphorus. However the total nutrient balance was not calculated exactly in Japanese orchard fields because the total nutrient input could not be determined owing to the paucity of statistical data on organic matter application and also the total output could not be calculated due to the paucity of field experimental data.

Discipline: Soils. Fertilizers and plant nutrition
Additional key words: fruit tree, nutrient uptake, nutrient balance, application rate of fertilizer, sustainable agriculture

Introduction

Many temperate and some tropical fruit trees are planted in Japan because the country consists of many islands extending from the temperate to the subtropical zone. The total area of fruit trees decreased from 430,000 ha in 1975 to 308,000 ha in 1996. Especially the area of citrus fruits decreased remarkably and the area in 1995 was about half of that in the 1975s. This decrease of the area is due to the decrease in the fruit demand. The demand for citrus fruits per capita per year decreased from 25 kg in 1975 to 11 kg in 1995. This situation is attributed to the diversification of eating habits or food culture associated with the changes in the economic conditions. The increase of fruit importation is also likely to affect the decrease of area. Along with the changes in the marketing environment, the quality of fruits is becoming more important than the quantity for sales. These changes led to a decrease in the rate of fertilizer application to orchard fields because, based on many field experimental data, emphasis was placed on the production of high quality fruits under suitable low application rates. However, the surplus fertilizer that was applied previously may affect the environment around the orchard fields. As the sustainability of agriculture has become a social problem, it remains to be determined whether fertilizer or organic matter application results in a load to the surroundings of orchard fields. We attempted to estimate the nitrogen (N), phosphorus (P_2O_5) and potassium (K_2O) balance in relation to chemical fertilizer application by compiling the results of surveys and field experiments to determine the nutrient balance in Japanese orchard fields.

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Table 1. Standard application rates of fertilizer for mature fruit-bearing trees

	Nitrogen (N)	Phosphorus (P_2O_5)	Potassium (K_2O)	Yield of fruits
		(kg/ha)		(t/ha)
Pineapples	350	115	310	52
Navel orange	326	239	246	34
'Iyo' tangor	317	227	242	33
'Hassaku' pummelo mandarins	316	199	221	39
Natsudaidai	309	229	224	41
'Unshu' mandarins	219	164	160	34
Loquats	204	167	162	9
Japanese pears	204	156	164	31
Kiwifruit	179	138	158	22
Japanese persimmons	178	127	152	21
Mume apricot	166	106	152	15
Chestnuts	149	107	124	3
Peaches	141	98	127	20
Cherries	130	78	114	7
Plums	121	98	119	15
Pears (except Japanese pears)	120	80	97	15
Apples	115	63	93	36
Grapes	111	115	115	15

Input of nitrogen, phosphorus and potassium associated with chemical fertilizer application

The standard application rate of fertilizer to orchard fields was determined based on the results of field experiments in most of the prefectures. We compiled the rates from the cultivation guidelines adopted in 37 prefectures. The rates are generally determined depending on the species and age of the fruit trees. The yield of fruits and the soil type of orchard fields are also key factors to determine the rate in some prefectures.

1) Species of fruit trees

Table 1 shows the mean of standard application rates of nitrogen, phosphorus and potassium for mature fruit-bearing trees. These results indicate that much more fertilizer is applied to orchard fields with evergreen and tropical fruit trees. The means of rates ranged from 204 to 350 kg per ha for nitrogen (N), 115 to 239 kg per ha for phosphorus (P_2O_5) and 160 to 310 kg per ha for potassium (K_2O). The rates for the late maturing citrus species, Navel orange, 'Iyo' tangor, 'Hassaku' pummelo mandarin and Natsudaidai, were higher than those for the

Table 2. Standard application rates of fertilizer for fruit trees that did not bear fruits

	Nitrogen (N)	Phosphorus (P_2O_5)	Potassium (K_2O)	Age after planting
		(kg/ha)		(yr)
Pineapples	352	116	312	3
'Iyo' tangor	108	75	75	4
'Unshu' mandarins	92	62	52	4
Navel orange	83	43	67	3
Loquats	63	42	46	3
Kiwifruit	54	43	47	3
Peaches	48	36	36	3
Cherries	47	35	44	5
Chestnuts	47	38	44	4
Apples	44	31	32	3
Japanese pears	41	29	32	3
Japanese persimmons	41	29	32	3
Mume apricot	35	25	32	4
Grapes	21	20	21	3

early maturing species, 'Unshu' mandarin. But in the case of Unshu mandarin, the rates for the late maturing varieties were almost the same as those for the early maturing varieties although the late maturing varieties were harvested in the same season as the late maturing citrus species. For the deciduous fruit tree species, the rate for Japanese pears was the highest and about twice that of apple and grapevine trees for nitrogen. These differences may depend on the nutrient uptake and the characteristics of root distribution. The rates for the evergreen fruit trees that did not bear fruits were also higher than those for the deciduous fruit trees that did not bear fruits as well as mature fruit-bearing trees (Table 2).

2) Age of fruit trees

The standard application rates of fertilizer for the trees that did not bear fruits (from 3 to 5 years old) ranged from one-third to one-fifth of those of mature fruit-bearing trees (10 or more years old) (Tables 1, 2). The application rate of fertilizer to each mature fruit-bearing tree should range from 6 to 10 times that of trees that did not bear fruits because the planting density of the latter trees is about twice that of the mature fruit-bearing trees. This difference may be due to the size of the trees. The rates for bigger mature fruit-bearing trees should be higher than those for smaller trees that did not bear fruits because fertilizer is usually applied under the trees. The rates for mature fruit-bearing trees usually increase until the trees become about 15 years old. However, the rates are almost the same after 15 years in many fruit tree species, while the rate for Unshu mandarin increases until 50 years after planting.

3) Yield of fruits

As the yield increased, the application rates of fertilizer increased for each fruit tree species. The rates for the high-yielding species such as citrus fruit and pineapple trees were generally higher than those for the other fruit trees (Table 1). However the yield of apple trees was high although the application rate was low. And the yield in plastic greenhouses was about 1.5 times higher than that in orchard fields with the same fertilizer application rates in the case of Unshu mandarin. These differences may be due to the climatic conditions during the growth period of fruits. The ratio of application rate to yield was higher for chestnuts, loquats and cherry tree which gave a low yield (Table 3). But the ratio was significantly low in apple trees and half or one-third of that of the other trees.

4) Soil type

The application rates of chemical fertilizer were determined for certain soil types in some prefectures. The rate was generally higher in sand-dune regosols and lower in andosols. This difference between the soil types is usually not as conspicuous as that between fruit tree species. However this difference must affect the rates of each fruit tree species because the main area of citrus species consists of yellow soils whereas that of apple and grapevine trees consists of brown forest soils.

Table 3. Ratio of application rates of fertilizer to yield of fruits

	Nitrogen (N)	Phosphorus (P_2O_5)	Potassium (K_2O)	Yield of fruits
		(kg/t)		(t/ha)
Pineapples	6.7	2.2	6.0	52
Natsudaidai	7.6	5.6	5.5	41
'Hassaku' pummelo mandarins	8.2	5.2	5.7	39
Navel orange	9.7	7.1	7.3	34
'Iyo' tangor	9.7	6.9	7.4	33
'Unshu' mandarins	6.5	4.9	4.8	34
Apples	3.2	1.8	2.6	36
Japanese pears	6.6	5.0	5.3	31
Kiwi fruit	8.2	6.3	7.2	22
Japanese persimmons	8.5	6.1	7.3	21
Peaches	7.0	4.9	6.3	20
Grapes	7.4	7.7	7.7	15
Pears (except Japanese pears)	8.0	5.3	6.5	15
Plums	8.2	6.6	8.0	15
Mume apricot	11.4	7.3	10.5	15
Loquats	23.2	19.0	18.4	9
Cherries	18.3	11.0	16.1	7
Chestnuts	43.9	31.5	36.6	3

Table 4. Total nutrient uptake of fruit trees

	Nitrogen (N)	Phosphorus (P_2O_5)	Potassium (K_2O)	Age	Planting density	References
		(kg/ha/yr)		(yr)	(No./ha)	
'Unshu' mandarins	235	38	178	16~50	750, 1500	3, 4, 5, 6
Natsudaidai	202	35	150	14	750	
Loquats	164	40	182	15, 20	300	
Mume apricot	142	34	154	14	300	
Kiwifruit	137	77	220	4~11	320	7
Chestnuts	123	30	56	7~13	160~330	1
Peaches	115	28	97	7~11	180~480	8, 14
Japanese persimmons	115	27	99	9~25	180~400	10, 11
Apples	79	31	113	10~23	120	12
Grapes	66	26	74	3~ 5	400	2
Japanese pears	64	19	98	8~36	70~200	9

Output of nitrogen, phosphorus and potassium

The output of nutrients from the orchard fields is mainly estimated based on the nutrient uptake of fruit trees. However, there are few field experimental data because it is very difficult to determine the nutrient uptake of fruit trees in orchard fields. In one field experiment, 2 middle-sized trees were selected at first. One tree was cut in spring and the other tree in winter. The nutrient uptake was calculated by the difference in the dry weight between the 2 cut trees and the nutrient content of each section. Table 4 shows the total nutrient uptake of 11 fruit tree species that was calculated based on the results of the field experiments[1-12,14]. These results show that the nutrient uptake of evergreen fruit trees was higher than that of deciduous fruit trees, while the potassium uptake of chestnut trees was lower than that of the other trees compared to nitrogen and phosphorus[1]. On the other hand, the phosphorus and potassium uptake of kiwifruit was higher than that of the other trees[7]. However, it is difficult to determine the nutrient uptake of each fruit tree species because the age of the sample trees and yield of fruits were different and the soil type was also different in each experimental field. A larger number of experimental data should be collected to determine whether these differences are associated with the nutrient requirement of each fruit tree species.

Nitrogen, phosphorus and potassium balance in relation to chemical fertilizer application

The input of chemical fertilizer to the orchard fields was calculated by the following formula based on the orchard area determined in the official surveys[13] and the average value of the rates of chemical fertilizer application compiled from the cultivation guidelines adopted in 37 prefectures.

Input (t) = Orchard area (ha) × Chemical fertilizer application rate (kg/ha)/1000

The input of fruit-bearing trees and trees which did not bear fruits was 50,600 t for nitrogen, 36,400 t for phosphorus and 40,700 t for potassium, respectively in 1995. The output from fruit-bearing trees in the orchard fields was calculated by the following formula based on the orchard area determined in the official surveys and field experimental data of nutrient uptake.

Output (t) = Orchard area (ha) × Nutrient uptake based on field experiment (kg/ha)/1000

However, it was difficult to calculate the output because no field experimental data of nutrient uptake were available for pineapples, Navel orange, Iyo tangor, Hassaku pummelo mandarins, cherries, plums and pears. The data of other similar species were used for these species to calculate the output. The data of Natsudaidai were used for Navel orange, Iyo tangor and Hassaku pummelo mandarins. The data of peaches[8,14] were used for cherries. The data of Mume apricot were used for plums. The data of Japanese pears[9] were used for pears. However since there were no good data for pineapples, the output was estimated to be half of that of the chemical fertilizer application. The output from fruit-bearing trees in 1995 was 39,800 t for nitrogen, 9,100 t for phosphorus and 35,300 t for potassium, respectively.

The ratio of the input to output was 1.3 for nitrogen, 4.5 for phosphorus and 1.2 for potassium. The ratio of each fruit tree species ranged from 1 to 2 for nitrogen and potassium and from 2 to 6 for phosphorus, excluding Japanese pears (Table 5). These results indicate that the balance of nitrogen and potassium was adequate in 1995 while the phosphorus balance was excessive in the Japa-

Table 5. Ratio of application rates of fertilizer to nutrient uptake of fruit trees

	Nitrogen (N)	Phosphorus (P_2O_5)	Potassium (K_2O)
Japanese pears	3.0	8.0	2.0
Japanese persimmons	1.6	4.8	1.5
Natsudaidai	1.5	6.5	1.5
Apples	1.5	2.1	0.8
Kiwi fruit	1.3	1.8	0.7
Peaches	1.2	3.5	1.3
Mume apricot	1.2	3.1	1.0
Loquats	1.2	4.2	0.9
'Unshu' mandarins	0.9	4.3	0.9
Chestnuts	1.0	3.0	1.8

nese orchard fields. However about 30 years ago, the rates of nitrogen and potassium were also almost twice those of the present ones. The surplus chemical fertilizer may flow to groundwater. It was reported that the NO_3-N content of groundwater is presently above the environmental upper standard (10 mg/L) in some orchard fields. Results from the surveys in orchard fields show that phosphorus tends to accumulate in soil. In these areas, the available phosphorus content exceeds 100 (mg/100 g dry soil) although the adequate level of available phosphorus is 30 (mg/100 g dry soil) based on the official guidelines adopted for orchard fields.

In Japanese pears, the ratios were higher than in the other species. Especially the ratio of phosphorus was remarkably high with a value of 8. This difference may be due to the planting density. We used the mean of chemical fertilizer application rates and the nutrient uptake in order to estimate the nutrient balance. The planting density of mature Japanese pears is the lowest among all fruit tree species, 70 per ha (Table 4). Therefore, Japanese pear trees may not be able to absorb nutrients effectively because the root distribution is not very dense.

Organic matter application and nutrient balance

We must estimate the total input of organic matter to calculate the nutrient balance exactly in orchard fields. However, we could not estimate the input because statistical data were not available. The results of the official surveys covering 2,757 farmers show the tendency of organic matter consumption. The standard nutrient contents of 12 organic materials are also listed for nitrogen (0.6~3.6%), phosphorus (0.2~5.1%) and potassium (0.3~2.7%). If the consumption of these organic materials, nutrient contents and area data are used to estimate the input of organic matter, the input to the orchard fields should amount to 11,900 t for nitrogen, 15,600 t for phosphorus and 12,400 t for potassium. This input ranged from half to one-fourth of that from chemical fertilizer. However, organic matter application is common in only some orchard fields because it is difficult to obtain a sufficient amount of organic matter in other orchard fields. Therefore these data show that nutrient input from organic matter may be the same as or higher than that from chemical fertilizer in some orchard fields. The surplus organic matter may lead to eluviation of nutrients around the fields. The results of the soil surveys in orchard fields show that the potassium content of soils is excessive in some orchard fields to which a large amount of manure had been applied for a long time because the manure has a high potassium content. In these areas, the rate of potassium fertilizer application decreased.

Conclusion

We estimated the input of chemical fertilizer to the orchard fields based on the results of official surveys of orchard areas and the standard application rate based on the cultivation guidelines adopted in 37 prefectures in 1995. The input was 50,600 t for nitrogen, 36,400 t for phosphorus and 40,700 t for potassium for the main fruit tree species. The output of nutrients from the orchard fields was estimated from the results of field experiments for the nutrient uptake of fruit trees. The output was 39,800 t for nitrogen, 9,100 t for phosphorus and 35,300 t for potassium for mature fruit-bearing trees. Because the ratio of the input of chemical fertilizers to the output from fruit trees was 1.3 for nitrogen and 1.2 for potassium, the application of nitrogen and potassium fertilizer to the orchard fields is not considered to affect the surrounding environment presently. But about 30 years ago, the application rates were almost twice those of the present ones. The NO_3-N content of groundwater exceeds the environmental upper standard (10 mg/L) in some orchard fields. And the available phosphorus content is above 100 (mg/

100 g dry soil) in some orchard fields although the adequate level is 30 (mg/100 g dry soil) based on the guidelines for orchard fields because the ratio of input to output is still 4.5.

The total nutrient balance was not calculated exactly because the total nutrient input could not be determined due to the paucity of statistical data on organic matter applications. Moreover, the total output could not be calculated due to the paucity of field experimental data. However the results of the estimation of the nutrient balance in relation to chemical fertilizer application indicate that the total nutrient balance in some orchard fields may show an excess in nitrogen, phosphorus and potassium. The surplus nutrients must lead to the increase of the available nutrient content in soil and result in a load to the surrounding environment of the orchard fields if heavy application continues.

References

1) Aoki, A. & Wakabayashi, S. (1967): The amount of the nutrient elements absorbed by chestnut tree on the volcanic ash soil. *Bull. Tochigi Agric. Exp. Stn.*, **12**, 111–116 [In Japanese].
2) Aragaki, K. et al. (1983): Studies on diagnosis of growth and nitrogen application in Kyoho grape. *Bull. Yamagata Hortic. Exp. Stn.*, **2**, 33–58 [In Japanese].
3) Harada, Y. & Inoue, H. (1982): Investigation on seasonal change of several nutritional components absorption in Satsuma Mandarin trees in plastic greenhouse. *Bull. Kagawa. Agric. Exp. Stn.*, **34**, 16–22 [In Japanese with English summary].
4) Hirobe, M. & Ogaki, C. (1968): Experiment on the absorption of nutrient elements in Unshiu orange tree. 1. On the seasonal absorption of nutrient elements by non-bearing young tree. *Bull. Kanagawa Hortic. Exp. Stn.*, **16**, 4–11 [In Japanese with English summary].
5) Hirobe, M. & Ogaki, C. (1969): Experiment on the absorption of nutrient elements in Unshiu orange tree. 2. On the seasonal absorption of nutrient elements by mature tree. *Bull. Kanagawa Hortic. Exp. Stn.*, **17**, 18–26 [In Japanese with English summary].
6) Hirobe, M. & Ogaki, C. (1970): Experiment on the absorption of nutrient elements in Unshiu orange tree. 3. On the seasonal absorption of nutrient elements by bearing young tree. *Bull. Kanagawa Hortic. Exp. Stn.*, **18**, 10–17 [In Japanese with English summary].
7) Hirobe, M. (1992): On the distribution of root systems and the amounts of nutrient elements absorbed by Kiwifruit trees grown on volcanic ash soil. *Bull. Kanagawa Hortic. Exp. Stn.*, **42**, 1–10 [In Japanese with English summary].
8) Kimura, M., Sobajima, Y. & Osamura, Y. (1958): Studies on the amount of the nutrient elements absorbed by the peach trees. *J. Jpn. Soc. Hortic. Sci.* , **26**, 59–68 [In Japanese with English summary].
9) Sakamoto, H. & Wakabayashi, S. (1968): Studies on fertilized phosphorus on pear in Volcanic ash soil 2. On the amount of absorbed nitrogen, phosphorus, potassium, calcium, magnesium for one year and accumulated nitrogen, phosphorus, potassium in tree trunk. *Bull. Tochigi Agric. Exp. Stn.*, **13**, 104–110 [In Japanese].
10) Sato, K. & Ishihara, M. (1954): The amounts of the nutrient elements absorbed by Japanese persimmon trees. 1. *J. Jpn. Soc. Hortic. Sci.*, **22**, 1–5 [In Japanese with English summary].
11) Sato, K. & Ishihara, M. (1956): The amounts of the nutrient elements absorbed by Japanese persimmon trees. 2. *J. Jpn. Soc. Hortic. Sci.*, **24**, 217–221 [In Japanese with English summary].
12) Sato, Y., Suzuki, T. & Sasaki, I. (1976): Seasonal changes of the nutrients in newly produce top tissues of apple trees. *Bull. Fukushima Hortic. Exp. Stn.*, **6**, 1–16 [In Japanese].
13) Statistics and Information Department (1997): Fruit and Nuts. *In* The 72th statistical yearbook of Ministry of Agriculture Forestry and Fisheries. ed. MAFF, 82–88.
14) Suzuki, A., Sato, Y. & Sasaki, I. (1986): The process of production of dry matter and nutrient absorption of peach trees in ten years. *J. Jpn. Soc. Hortic. Sci.*, **54**, 431–437 [In Japanese with English summary].

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