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# Nutrient Balance in the Paddy Field of Northeast Thailand

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**Abstract**

To examine whether the prevailing rice farming in Northeast Thailand is sustainable in terms of agro-ecology, the gain and loss of plant nutrients between a paddy plot and its surroundings were studied in the village of Um Mao, Roi Et Province from 1993. The loss of major nutrients, including N, P and K, from the paddies in the form of harvested grains was well balanced by the gain from chemical fertilizers. It was judged that the present farming is fairly compatible with the environment at the current yield level of around 2 ton of unhusked grain per ha. Higher than the present dose of fertilizer would probably result in lower efficiency of application and little increase in the yield. Farmers appear to be well aware of this. For further improvement of the productivity, other means should be sought.

## I Introduction

According to FAO [1989], "sustainable" agriculture is defined as the "successful management of resources for agriculture to satisfy changing human needs, while maintaining or enhancing the quality of the environment and conserving natural resources." Every farmer as well as agricultural scientist is eager to increase the yield. For the sustainable agriculture, however, the successful management of resources is as essential as satisfying human needs.

Northeast Thailand is often quoted as an example of an area undergoing environmental deterioration: deforestation, and soil erosion and degradation caused by the expansion of arable farming. It is also true, however, that the exploitation of the environment sustained the rapid growth of population in the region. For agriculture to be sustainable in this region, the two conditions, maintenance of the quality of the environment and concurrent fulfillment of human needs, were apparently not compatible. Is this really the case? More scientific investigations on the complex interaction between crops, the environment and man are needed in order to clarify the sustainability of arable farming in the region.

In view of the above, the nutrient balance in rice cultivation was studied. The

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balance is a key to study the crop-environment interaction: the excessive supply of nutrients not only is a waste of resources but also a potential cause of eutrophication of the environment, while the reverse would eventually result in depletion of inherent nutrients in soil and irreversible deterioration of the environment.

## II Methods

*The Study Area*

Northeast Thailand covers an area of approximately 170,000 $km^2$, about one third of Thailand's area, and is located in the Khorat plateau. Its climate is classified as tropical savanna. The rainy season extends from May to October and the pattern is bimodal, with peak rainfall occurring in June and September. Annual precipitation ranges from 800 to 1,400 mm, which is marginal for paddy rice farming, and the rainfall is erratic [Kono 1991 : 506-517]. The staple food in this region is lowland rice of the glutinous type, most of which is cultivated in rain-fed fields. In proportion to the population increase, paddy fields expanded from the most suitable alluvial plains to gently sloping to undulating landforms, the latter comprising nearly 80% of the region. The Khorat plateau is mainly composed of the Mesozoic sediments called the Khorat series. The soils have several problems. One is poor fertility due to low contents of organic matter and clay, and small cation exchange capacity (CEC) of the sandy soils.

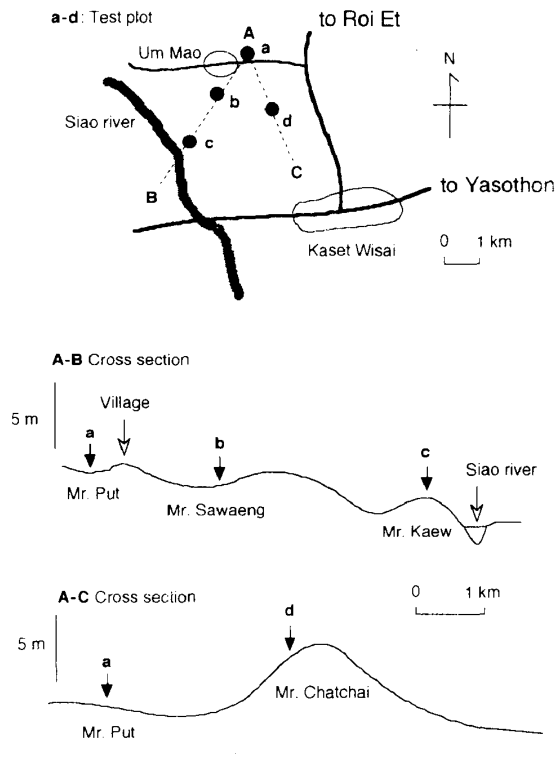


**Fig. 1** The Location of Um Mao Village and the Test Plots

We selected the village of Um Mao, Kaset Wisai District, Roi Et Province (Fig. 1). From the village, it takes about one hour by car to the provincial capital city Roi Et and about 10 minutes to Kaset Wisai. The village is located at the northern periphery of the Thun Kula area and 6 km north of the Siao River. Villagers eat glutinous rice as their staple food. The village's population in 1994 was 823 in 154 households, and of whom 73 persons were working in Bangkok and coming home once a year. A few villagers were employed by the government in Kaset Wisai and the rest engaged in rice farming. The village had 3,330 *rai*[1)] of paddy fields, 200 *rai* of fruit orchards, but no upland except for a small area of home gardens. All the paddy fields were rain-fed and there were no irrigation facilities other than a few small ponds (less than 3,000 $m^3$ each).

According to the village headman and old farmers, chemical fertilizers were first introduced to this village in 1961, but did not become popular until 1967. In that year the common rate of application was 12.5 kg/ha of 16-20-0.[2)] The rate increased year by year and became 156.25 kg/ha of 16-16-8 in 1987, showing no further increase from then till 1994. Nonglutinous rice is a cash crop and is sold to rice mills in Kaset Wisai without husking. Kao Dok Mali 105 (KDM 105, nonglutinous) and RD8 (glutinous) were the favorite varieties in 1994. Farmers apply fertilizers twice, the first time a top-dressing just after transplanting, and the second one month after transplanting when the seedlings are established. The rather late application is due to the greater risk if applied earlier. Fertilizer shops in Kaset Wisai also suffer a fall in sales by about 30% in a drought year.

*Topography, Soils and the Soil Sampling*

We requested four farmers, Messrs. Put, Sawaeng, Kaew and Chatchai, to allow us to use part of their paddy fields for the study. They are the landowners, and their main source of income is the sale of rice, except for the case of Mr. Chatchai. Fig. 1 illustrates the topography around the village. The paddies of the four farmers, indicated by the black circles **a** to **d**, are located along a slope from the village to the Siao River, a tributary of the Mun River. The two plots farther from the Siao River, Plot **a** and Plot **b**, have thick (50 to 100 cm) sandy surface layers, while Plot **c** and Plot **d** have sandy surface layers of 15 cm underlain by clayey subsoils. Plot **a** and Plot **b** are 20 m × 20 m square in the fields of Messrs. Put and Sawaeng, while Plot **c** and Plot **d** occupy the whole fields of Messrs. Kaew and Chatchai, 660 and 224 $m^2$, respectively.

Land preparation and transplanting were carried out by the landowners in their normal way. Calculated amounts of chemical fertilizer based on plot area were prepared by ourselves and applied by the farmers. Soils were sampled twice a year: before

1) 1 *rai* = 1,600 $m^2$, 1 ha = 6.25 *rai*.

2) The figures represent the content of the nutrients in percentages as N, $P_2O_5$ and $K_2O$ in this order.

transplanting in June, when the paddy fields were turned up and the stumps were plowed in; and after harvesting in December. The soils and the stumps were sampled separately. From each plot, 10 to 20 soil samples were taken from the surface using a sampling core (5 cm in diameter) and bulked into a composite sample. This was repeated three times, producing three composite samples for each plot. Rice plants were harvested, threshed and weighed by ourselves. The grain and straw samples were bulked into a composite sample for a plot. The stumps in three 2 × 2 m quadrants on the diagonal of each plot were weighed and nine representative hills were subjected to analysis.

Rainwater was collected using a rain gauge set in the village and sampled every morning. Water samples were collected from a well in the village in 1993 and 1995, and from the Siao River once a month from January 1995, and from the Chi River every 10 days at Maha Chana Chai throughout 1993. The well is located in the northern part of the village and villagers utilize the water for cooking, drinking and washing. The nearest paddy field is located 40 m from the well. The well water was sampled every 10 days from June to October 1993.

*Pot Experiment*

The soils of Plot **a** and Plot **b** were sieved through a 2-mm mesh, mixed and used for the pot experiment. The experiment was carried out in a greenhouse of the Central Laboratory, Kamphaengsaen Campus, Kasetsart University. Thirteen kilogram of the soil was placed in a 1/2,000a pot, and N, P and K were applied at 0.59, 0.25 and 0.1 g as $(NH_4)_2SO_4$, $Na_2HPO_4$, and KCl, respectively, which corresponded to N 25 kg, P 11 kg and K 10 kg per ha. The experiment was duplicated. Three rice seedlings (two weeks old, KDM 105) were transplanted in a pot on May 25, 1994 and harvested on November 20, 1994. Distilled water was used throughout.

*Laboratory Analyses*

*Soil.* Air-dried soil (sieved through a 0.5-mm mesh) was used throughout. A suspension of soil in water or KCl solution was used for the pH determination with a glass electrode.[3] Total C was determined by the method of Mebius [1960 : 120-124] with some modification [Dojo Hyojun Bunseki, Sokuteiho Iinkai 1986 : 86-94].[4] Total N was determined by the Kjeldahl digestion, steam distillation and the indophenol method [Weatherburn 1967 : 971-974].[5] Exchangeable $NH_4$-N was determined by the

3) A batch of 10 g of soil was suspended in 25 mL of distilled water or 25 mL of 1 M KCl solution. After the suspension had stood for 2 h, its pH was measured with a glass electrode.

4) A batch of 0.3 to 1.5 g of finely ground soil was used.

5) A 2 g portion of soil was digested in 10 mL of conc. $H_2SO_4$ and a catalyst ($K_2SO_4$-$CuSO_4$). After digestion, the volume was made up to 100 mL with water. Ammonium-N in the digestate was recovered in 4% boric acid using a steam-distillation apparatus and $NH_4$-N was determined by the indophenol method.

Bremner's method [Bremner 1966: 577-582].[6] Cation exchange capacity (CEC) was determined following the procedures of the Soil Science Laboratory, Kyoto University.[7] Total phosphorus in the soil digestate was determined by the malachite green method [Motomizu *et al.* 1983: 361-367],[8] and available P was determined by the Bray-II method.[9] The soil digestate[10] was subjected to flame photometry for the determination of total K.

*Plants.* A batch of 0.3 g of dried plant material was digested in a $H_2SO_4$-selenium mixture containing salicylic acid [Walnga *et al.* 1995]. Nitrogen was determined by the steam-distillation and the indophenol method as above. Phosphorus was determined by the molybdivanadophosphoric acid method [Kitson *et al.* 1944: 379-383], and K by flame photometry.

*Water.* Phosphorus was determined by the malachite green method [Motomizu *et al.* 1983: 361-367] using photometric cells having a light path of 5 cm. Potassium and Na were determined by flame photometry.

*Assumptions for Assessment of the Nutrient Cycling*

For gain-loss analyses of plant nutrients in a single plot of paddy, the following assumptions were made. The basic gain is from fertilizers, run-off water and

6) A 6-g batch of soil was extracted in 60 mL of 2 M KCl.

7) A 5-g batch of soil was taken in a polyethylene centrifugation tube (Nalgene) and 12.5 mL of 1 M ammonium acetate (pH 7.0, adjusted with $NH_4OH$) was added. The contents were mixed vigorously and shaken on a reciprocal shaker (100 rpm, 30 min), then centrifuged at 300 g for 10 min. The supernatant was taken in a volumetric flask after filtration through a No. 6 filter paper. Extraction with the ammonium acetate was repeated three times, the last cycle without shaking. The filtrate was made up to 50 mL with the ammonium acetate buffer and subjected to flame photometry for the analysis of exchangeable bases. The precipitate was suspended in 10 mL of distilled water, mixed vigorously, then centrifuged at 300 g for 10 min. The precipitate was washed and centrifuged with 80% (v/v) ethanol-water three times. Thirty mL of 10% NaCl solution was added to the precipitate, mixed vigorously, and shaken for 1 h, then the suspension was centrifuged (300 g for 10 min) and the supernatant was filtered as above. The supernatant from three successive washings was taken in a volumetric flask and made up to 100 mL with 10% NaCl. A portion of 20 mL of the NaCl extract was distilled with 0.2 g MgO, and the resulting $NH_4$-N was captured in 4% boric acid and determined [Weatherburn 1967: 971-974].

8) A batch of 1.0 g of soil was taken in a 100 mL Teflon beaker, and 5 mL of $HClO_4$ (70%) and 10 mL of HF (48%) were added. The soil-acid mixture was heated on a hot plate for 15 min after fumes of $HClO_4$ first appeared. After the beaker had cooled, 5 mL of HF was added and the contents were evaporated to dryness. Digestion with $HClO_4$ and HF was repeated once more. The contents were dissolved in 10 mL of 8N HCl and kept at 80℃ for 1 h. Then 15 mL of water was added and the mixture was covered with a watch glass and boiled for another 1 h. The contents were cooled and made up to 100 mL with water. Phosphorus in the digestate was determined by the malachite green method [Motomizu *et al.* 1983: 361-367]. A part of the $H_2SO_4$ in the reported assay mixture was replaced with HCl to achieve the same acidity as in the original report.

9) A batch of 1 g of soil was treated with 7 mL of the Bray-II solution.

10) The soil digestate prepared for the determination of total P was used.

sedimentation from the catchment, underground water, and precipitation. For nitrogen, nitrogen fixation is an additional source. The basic loss is through carrying-away of the product, leaching and erosion. For nitrogen, denitrification is another channel of loss. In 1994, there was neither flood nor heavy rain that might have had caused surface run-off over the bunds of the paddy fields. Therefore, the gain through sedimentation and the loss through erosion are considered to be negligible.

Exchangeable $NH_4$-N, Bray-II P and exchangeable K are regarded as available N, P and K, respectively. It was also assumed that rice plants take up nutrients from a surface layer of 20 cm depth, within which nutrients are distributed evenly, and the bulk density of the soil is 1 unit.

The total supply of P through rain, which may be associated with dust, is assumed to be 0.2 kg P/ha/rainy season in 1993 (data not shown). It is negligible compared with P in fertilizers.

Leaching was difficult to estimate, because the hydrology of the underground water in this region is little known. Accordingly, leaching was evaluated from the difference in the contents of nutrients in the surface layers before transplanting and after harvesting.

At harvest, farmers reap the plants at middle height with a sickle. The upper halves with grains are dried and threshed in the paddies. Straw from the upper halves is brought back home to feed water buffaloes, and their dung is returned to paddy fields just before the next cultivation period. The lower halves, including roots and stumps, are left and plowed into soil in the next cultivation period.

## III Results and Discussion

Chemical properties of the soils in the four plots in Um Mao were compared with the average values of 25 Northeast soils belonging to the soil series of Roi Et, Nam Phong, Ubon and Khorat [Japan 1979] (Table 1). According to the soil map produced by the Land Development Department [Thailand 1981], the lowland soils in Um Mao are classified as either Ubon or Khorat series. The soils of the village were taken after harvesting in 1994. They were inferior to the average soils in the region, especially in pH, total N, $NH_4$-N, CEC and exchangeable K. In total P and Bray-II P, however, they were richer than the average. For the determination of P in the soil and water in this region, where the amounts are far less than those in temperate areas such as Japan, the malachite green method [Motomizu *et al.* 1983: 361-367] in combination with photometric cells having a light path of 5 cm was especially useful. Otherwise P could not be determined.

The result of the pot experiment is presented in Fig. 2. With N, P and K, the total dry matter increased by 30% over the control. The most effective nutrient was N, although only 0.125 g N/pot was added as fertilizer. Since the soil contained about 4.4 g total-N/pot, only a small portion of the soil N was mineralized and utilized by plants.

**Table 1** Chemical Properties of the Soils of the Test Plots in Um Mao Village and of Northeast Thailand

| Farmer | Put<br>Plot **a** | Sawaeng<br>Plot **b** | Kaew<br>Plot **c** | Chaitchai<br>Plot **d** | Northeast<br>Average of 25 Soils |
|---|---|---|---|---|---|
| Texture(USDA) | Sand | Sand | Sandy loam | Loamy sand | |
| Clay (%) | 4 | 3 | 9 | 7 | |
| Silt (%) | 5 | 2 | 15 | 10 | |
| Sand (%) | 91 | 95 | 76 | 83 | |
| pH ($H_2O$) | 4.84 ± 0.06 | 4.50 ± 0.02 | 4.74 ± 0.16 | 5.28 ± 0.03 | 5.32 ± 0.69 |
| pH(KCl) | 4.08 ± 0.05 | 4.07 ± 0.02 | 3.75 ± 0.02 | 4.18 ± 0.05 | 4.40 ± 0.48 |
| Total N (%) | 0.038 ± 0.0033 | 0.030 ± 0.0027 | 0.045 ± 0.0048 | 0.040 ± 0.0020 | 0.047 ± 0.0255 |
| Total C (%) | 0.481 ± 0.032 | 0.325 ± 0.039 | 0.580 ± 0.055 | 0.844 ± 0.055 | 0.437 ± 0.2517 |
| C/N | 12.6 | 10.7 | 12.9 | 21.4 | 9.36 |
| $NH_4$-N (ppm) | 6.8 ± 3.7 | 7.2 ± 0.7 | 4.3 ± 0.5 | 10.8 ± 2.7 | 17.5 ± 12.6 |
| CEC (meq/100g) | 1.92 ± 0.05 | 1.20 ± 0.10 | 4.66 ± 0.50 | 3.17 ± 0.16 | 5.47 ± 5.01 |
| Ex K (meq/100g) | 0.05 ± 0.02 | 0.03 ± 0.00 | 0.06 ± 0.01 | 0.13 ± 0.01 | 0.14 ± 0.11 |
| Ex Na (meq/100g) | 0.09 ± 0.01 | 0.34 ± 0.04 | 0.17 ± 0.08 | 0.17 ± 0.02 | 0.99 ± 1.14 |
| Total P (ppm $P_2O_5$) | 154 ± 4.8 | 116 ± 9.6 | 192 ± 11.9 | 186 ± 5.8 | 109 ± 72.3 |
| Bray - II P (ppm $P_2O_5$) | 30.2 ± 2.48 | 21.7 ± 1.95 | 26.0 ± 1.99 | 17.8 ± 0.66 | 6.00 ± 6.71 |
| Total K (% $K_2O$) | 0.0183 ± 0.002 | 0.0151 ± 0.001 | 0.1522 ± 0.009 | 0.0353 ± 0.002 | 0.1303 ± 0.179 |
| Available K(ppm $K_2O$) | 24.5 ± 8.00 | 15.1 ± 1.46 | 30.1 ± 3.30 | 61.7 ± 4.71 | 68.2 ± 50.26 |

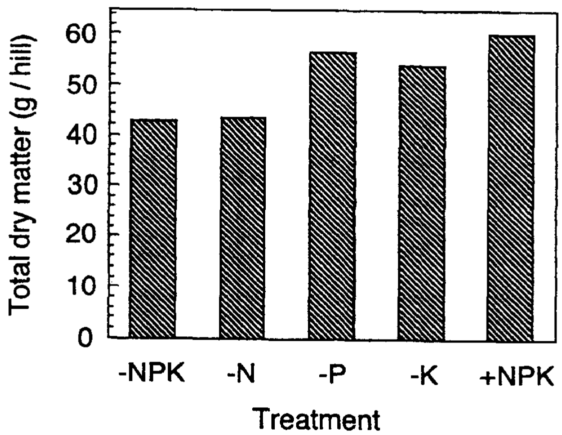


**Fig. 2** Effects of N, P and K on Total Dry-matter Production of Rice (Kao Dok Mali 105) in a Pot Experiment
The average values are presented.

Phosphorus and K in the presence of N were effective in increasing the dry matter production by about 10%.

The nutrient balance in the four test plots in 1994 is summarized in Table 2.

**Table 2** The Nutrient Balance in the Four Test Plots

| | Put Plot **a** | | | Sawaeng Plot **b** | | | Kaew Plot **c** | | | Chatchai Plot **d** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | N | P | K | N | P | K | N | P | K | N | P | K |
| | Nutrient kg/ha in available forms in soil, and total in fertilizer and plant | | | | | | | | | | | |
| At planting | 30 | 36 | 77 | 37 | 32 | 45 | 26 | 34 | 85 | 25 | 15 | 44 |
| In soil | 5 | 25 | 67 | 12 | 21 | 35 | 6 | 25 | 77 | 25 | 15 | 44 |
| In fertilizer (a) | 25 | 11 | 10 | 25 | 11 | 10 | 20 | 9 | 8 | | | |
| At harvesting | 58 | 38 | 124 | 49 | 31 | 75 | 32 | 30 | 93 | 22 | 16 | 103 |
| In soil | 14 | 26 | 41 | 14 | 19 | 25 | 9 | 23 | 50 | 22 | 16 | 103 |
| In plant | 44 | 12 | 83 | 35 | 12 | 50 | 23 | 7 | 43 | | | |
| In grain (b) | 27 | 7 | 9 | 17 | 5 | 6 | 16 | 4 | 7 | | | |
| In straw | 4 | 1 | 22 | 4 | 2 | 17 | 2 | 1 | 14 | | | |
| In stump and root | 13 | 4 | 52 | 14 | 6 | 27 | 5 | 2 | 22 | | | |
| The efficiency of Fertilizer (b/a) | 1.08 | 0.64 | 0.90 | 0.68 | 0.45 | 0.60 | 0.80 | 0.44 | 0.88 | | | |
| Yield (t/ha) | | | | | | | | | | | | |
| Total dry matter | | 5.8 | | | 4.6 | | | 3.9 | | | | |
| Grain | | 2.3 | | | 1.4 | | | 1.5 | | | | |

According to the farmers, rainfall and yields were normal in 1994. The variety planted was KDM 105. Mr. Chatchai did not cultivate rice in this year because rain started earlier than he expected so he failed to prepare seedlings in time.

In Plots **a**, **b** and **c**, the sums of available N in soil and fertilizer were 30, 37 and 26 kg/ha, while at harvest the sums of available N in soil and absorbed N by plants were 58, 49 and 32 kg/ha, respectively. There was net gain in N in a single rice season and it amounted to 28, 12 and 6 kg/ha, respectively. In the unplanted Plot **d**, however, available N in soil scarcely changed. Mineralization of soil organic N and nitrogen fixation by microorganisms might have been enhanced by rice-growing. Available N in soil appears to decrease during the dry season probably being incorporated into organic N and oxidized to $NO_3^-$. Nitrogen in grain was 16-27 kg/ha, which was equivalent to 0.68-1.08 times of the N in applied fertilizer.

Rice plants took up 7-12 kg P per ha when P at 9-11 kg/ha was applied as fertilizer. The high efficiency of fertilizer P in the test plots may be partly due to the low dose and partly to the low capacity of P fixation by the soil. As the soils contain 21-25 kg available P/ha, P requirement of rice plants should be met by this alone. However, as was indicated in the pot experiments, applied P enhanced growth, although not significantly as N (Fig. 2). This suggests that the concentration of P in soil solution (intensity) might have been not enough to support the initial growth of plants, even though its content (capacity) was high enough. Soluble P supplied as chemical fertilizer might have stimulated the initial growth. As shown in Table 1, more than 10 ppm of Bray-II P is seldom found in Northeast soils. Kawaguchi and Kyuma [1977] also stated that the Bray-II P in this region was less than 15 ppm $P_2O_5$, while the values for Um Mao soils were in a range of 18–30 ppm $P_2O_5$. As stated previously, Um Mao farmers have applied 16-16-8 fertilizer at a rate of 156.25 kg/ha (25 kg $P_2O_5$/ha) for at least the last eight years. It is likely, therefore, that the high Bray-II P in Um Mao soils is due to the accumulation of P resulting from successive applications of fertilizer. As the P-fixing capacity is low, a large portion of P may remain in soils in available forms.

Potassium in soil and plants at harvest was more than that in soil and fertilizer at planting: 124 vs. 77 in Plot **a**, 75 vs. 45 in Plot **b**, and 93 vs. 85 kg/ha in Plot **c**. There was evidently an enrichment of available K during the cropping. In soil, soluble or exchangeable K are in equilibrium with insoluble K. When the former is absorbed by plants, the equilibrium is re-established by solubilization of the latter. In Plots **a** and **b** where the soils were sandy, the sum of available K in fertilizer and soil at planting was roughly equal to the K absorbed by the plants, suggesting that an amount equal to the available K found in soil at harvest might have been derived from the insoluble K. This amounted to about 70% of the initial soil available K. The input of K in fertilizer was only 8–10 kg/ha, but the K application was effective, as was demonstrated by the pot experiment (Fig. 2).

Thus, a large portion of the enriched K was in plants, not in soil: the content in soil actually decreased during the cropping from 67, 35, and 77 kg/ha to 41, 25, and 50 kg/ha in Plots **a**, **b** and **c**, respectively.[11] Since only about 10% of the absorbed K was in grain and the rest in leaves, stems and roots, however, part of the absorbed K would directly and indirectly return to the soil. As was reported for Na ions in saline soils in the Northeast [Topark-Ngarm *et al.* 1990: 289–298], the vertical water movement in the dry season (capillary movement) and rainy season (percolation) may carry soluble salts, and this would be significant due to the low CEC of the soils. Accordingly, some K might have been leached out in the rainy season, but have raisen again in the dry season. This may partly explain the recovery of the level of K in soil in the next season.

Though the K loss in grain is well balanced with the K input through fertilizer (Table 2), the absolute amount of K which flows in the soil-plant cycle is enhanced by cropping. The enrichment of the available K was accomplished by depleting the insoluble stock: that is, the labile fraction of K, which was sensitive to leaching and erosion, increased under cropping. Accordingly, careful management to prevent the leakage of K

11) In Plot **d**, K in soil increased without rice planting, although N and P in soil scarcely changed. We can offer no explanation for this. The plot was left submerged throughout the cropping season and some weeds grew. The behavior of insoluble K under the submergence should be examined.

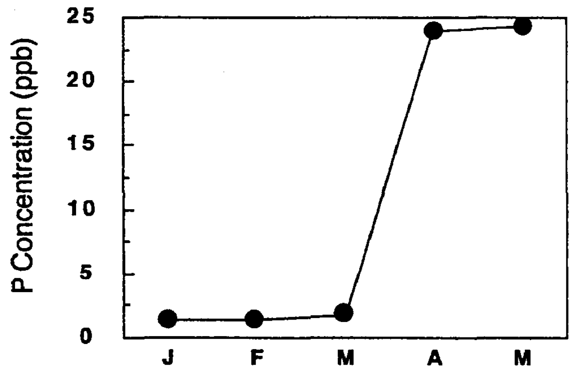


**Fig. 3**　Monthly Changes in P Concentration of the Siao River in 1995

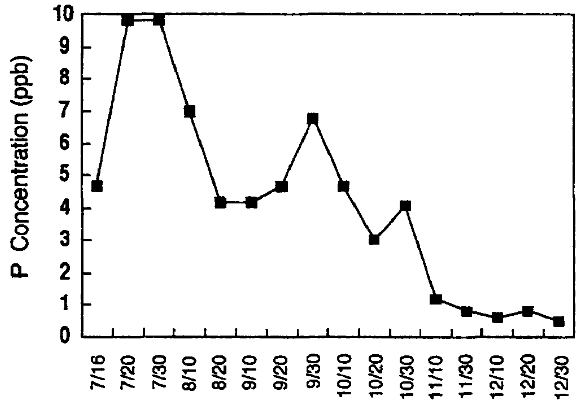


**Fig. 4**　Changes in P Concentration in the Chi River in 1993

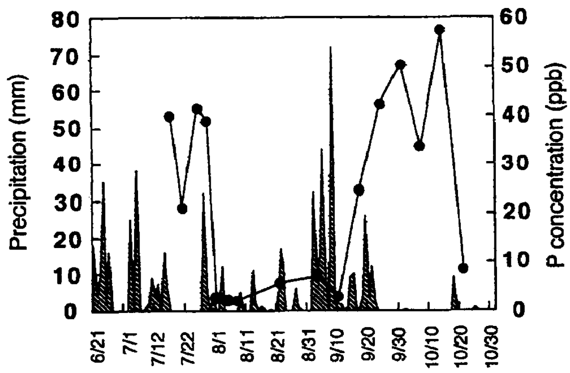


**Fig. 5**　Precipitation (Dashed Area) and P Concentration (-●-) in Water of a Well in Um Mao Village in 1993

from the system and efforts to return the plant K to the field are essential.

The changes in the concentration of P in water of the Siao River in 1995 and the Chi River in 1993 are presented in Figs. 3 and 4. In the Siao River, the concentration was low in the dry season and started increasing after the first rain in April. In the Chi River, the peaks correspond to the bimodal pattern of precipitation showing a drop in August. As the volume of water also increases in the rainy season, the concurrent increase in the concentration implies a net loading of a huge amount of P from the surroundings to the rivers. However, the highest concentration recorded in the Chi River was 10 ppb, which is still too low to result in eutrophication.

The water of a village well was also analyzed. Two peaks were detected in the rainy season in July and September (Fig. 5). The water table did not change significantly throughout the rainy season. The peaks of high concentration lagged about one month behind the heavy precipitation, suggesting that P might be derived from the leached P from soil profiles. The source of P is not known: whether it is inherent in soils or exogenously supplied as fertilizer-P. The fact that the concentration is higher than in the river waters, however, suggests that at least part of it originated from fertilizer. A comparison of P concentration in the underground water between forest and paddy lands is now in progress.

## IV General Discussion

The gain of nutrients in the form of fertilizer and the loss of them in the form of grain was apparently well balanced. This, however, does not necessarily guarantee the sustainability of agriculture, since it is not known how much of the nutrients in grain is actually derived from fertilizer. It is possible that the plant might have utilized the nutrients inherently contained in the soil, while most of those in fertilizer might have been lost in one way or another. Should this be the case, the village rice-farming would be degrading the environment and could be likened to "mining." The present study did not provide evidence either to prove or deny this. Further studies are needed focusing on the leaching of nutrients and the fate of nutrients in fertilizer. At present, it can be recommended that the prevailing fertilizer practice should be modified to give less P and more K application. A fertilizer shop in Kaset Wisai recommends a formula with K for sandy soils. According to a salesperson, 15-15-15 has recently been selling better than 16-16-8 even though it costs more, suggesting that the farmers are aware that their crops are prone to suffer from K deficiency. The bulk-blend method, in which several single-element fertilizers are mixed at individual farms, appear to be appropriate.

The ratio of the amount of a nutrient in grain to that in fertilizer was quite high for all of the three elements. Actually, it was much higher than that common in modern agriculture in developed countries. In terms of resource utilization as well as eutrophication of the environment, the fertilizer practice in Um Mao village can be said to be superior to the high-input-high-output farming elsewhere. However, the yield of rice is still very low in the village: it ranged between 1.4 and 2.3 ton of unhusked paddy per ha in the test plots. In other words, the good balance between the gain and loss is achieved by sacrificing the yield. The present yield level does not appear likely to satisfy the villagers' needs in the future. The high ratio of nutrients in grain to that in fertilizer implies that further increases in yield are possible only with heavier doses of fertilizer, not merely by improving the efficiency of fertilizer use at the present rate of application. It appears unlikely, however, that heavier applications of chemical fertilizer will be made in the near future. The rate of application has not increased since 1987, suggesting that the farmers themselves may have realized that a heavier dose would not bring about further yield increase in their sandy paddies. In general, a heavier dose brings about lower efficiency of fertilizer use, which is one of the major reasons for the law of diminishing yield. This problem is more serious in soils with low CEC, which is the case of Um Mao.

One remedy for the quickly diminishing yield in sandy soil area with low CEC is manuring organic matter [Willet 1994: 235-247]. Many report that organic matter is a key for improving the soil fertility in the Northeast. It is said that the minimum amount of organic matter needed is in the order of 10 to 20 t/ha for its effect to be substantial. According to villagers, the appropriate rate of water-buffalo dung (stable manure, *pui khok*) for rice is 1 t/*rai* (6.25 t/ha). As ten water buffaloes produce five tons of stable manure in a year, a paddy farm should raise two animals per one *rai* of paddy land (12.5 head/ha). For keeping water buffaloes, the residue of rice plants (2.4 to 3.2 t/ha, Table 2) and grasses in paddy fields alone are far from sufficient and a large area for grazing is required. Furthermore, labor for grazing water buffaloes is becoming scarce due to the increasing opportunities of off-farm employment, and buffaloes themselves are being replaced by power tillers. Thus, given the present landuse of the village and taking into account the socio-economic conditions (in other words, the human needs), one cannot expect much from organic manuring. Some other means should be sought after in order to minimize the loss of nutrients in fertilizers when applied at a high rate. Coated and slowly-releasing fertilizers might provide a breakthrough.

The villagers grew rice primarily for their own consumption before the late 1970s. The combination of fertilizer and improved varieties of rice changed the scene within a short period [Fukui 1991: 518-534]. The increased yield allowed them to grow glutinous rice for domestic consumption in about one half of their paddy fields and nonglutinous rice for sale in the other half. This is a significant phenomenon brought about by the yield increase. The further increase would similarly bring about changes in the farming system, perhaps greater diversification.

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