EFFICIENCY OF NITROGEN FERTILIZATION ON UPLAND CROPS GROWN IN MULTIPLE CROPPING SYSTEMS IN TAIWAN

S. Lian
Department of Agricultural Chemistry
Taiwan Agricultural Research Institute
Wufeng, Taichung 41301,
ROC on Taiwan

ABSTRACT

Because of the nature of the crops as well as for the purpose of obtaining high yields, upland crops are often given higher rates of N than they require. Consequently, the productive efficiency of N is generally low, because of low efficiency in absorption and utilization. The nitrogen applied in excess of the uptake remains in the soil predominantly in the form of nitrate, which is commonly lost through leaching, or denitrification, or both. The denitrification loss is most significant in a rice-based cropping system, in which the soil after upland cropping is submerged and puddled for rice cultivation. With vegetable cropping in which a lot of organic manure has been used, much residual N is in the manure itself as well as the crop residues. These organic residues are mineralized during the following cropping season and release much of their N, particularly during the later stages of the crop. The effect of this can be either favorable or unfavorable.

Adopting an appropriate cropping system in combination with soil testing, measuring the residual N after upland cropping, and adjusting the application of fertilizer-N for the subsequent crop, may increase the efficiency of absorption and consequently of the production system. Method and timing of application, and cultural practices which improve the conditions of plant and soil, are also effective in increasing the efficiency of absorption, and consequently the yield of the crops.

Besides the efficiency of absorption, the efficiency of absorbed-N in producing yield (NE) is another factor affecting the efficiency of fertilizer-N. Factors affecting NE are mostly genetic, but the interaction between the genetic character of the variety and the environment is also important. Timing of nitrogen application is also fairly effective in increasing NE.

PROBLEMS IN THE USE OF NITROGEN FERTILIZER FOR UPLAND CROPS IN MULTIPLE CROPPING SYSTEMS

Consumption of fertilizer in Taiwan

Fertilizer consumption in Taiwan has been increasing steadily over the past four decades. Current estimates indicate that Taiwan's farmers use approximately 1.3 million mt of fertilizer each year, equivalent to 0.4 million mt of nutrients. Before 1970, almost 80% of the total fertilizer distributed was used for rice production. With a rice surplus and the adoption of a crop diversification program, the fertilizer used for rice has declined to less than 40%, while 60% is now applied to upland crops (Ku 1987) (Fig. 1). The average rate of consumption of N-P_2O_5-K_2O in Taiwan, at 269-78-112 kg/per hectare of arable land, or 188-55-79 kg/ha per crop, is one of the highest in the world.

Keywords: N fertilizer, nitrate, residual N, multiple cropping

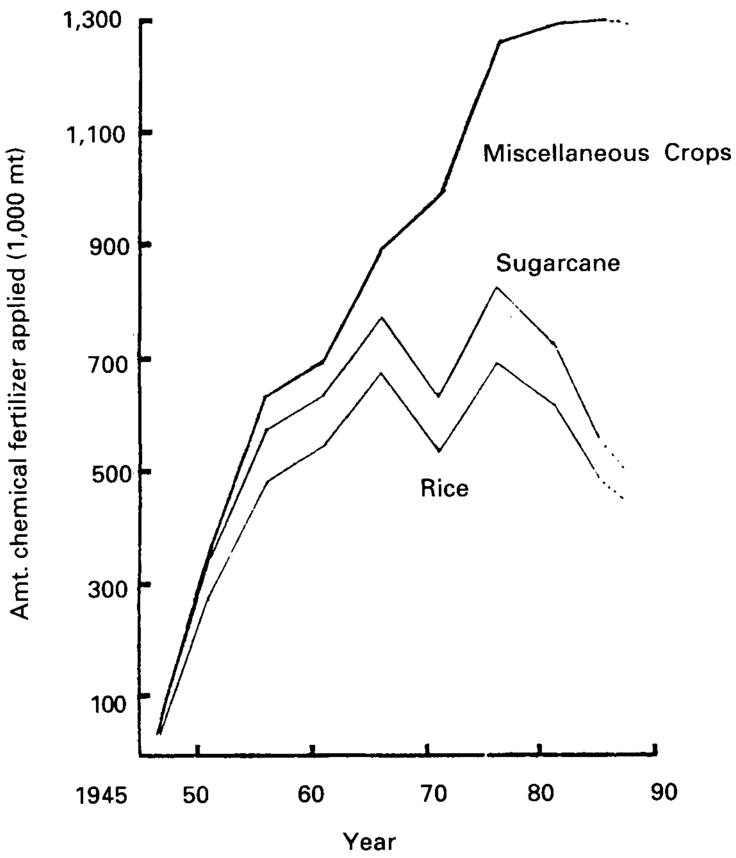

Fig. 1. Fertilizer consumption for main crops in Taiwan
Source: Ku 1987

Upland Crops and Excessive N Applications

The response of upland crops to fertilizer N is generally higher than that of rice, as shown by the much lower yield indices of the -N plots with upland crops compared to those with rice (Table 1).

The productive efficiency of fertilizer N in fertilizer experiments is thus generally higher for upland crops than for rice (Table 2).

The higher productive efficiency when fertilizer N is applied to upland crops may give the impression that problems related to nitrogen use are less important for upland crops than for rice. However, the situation is in fact the reverse. Fertilizer applications for upland crops are much higher than the recommended rates, and are often in excess of the ability of the crop to absorb them. Since the response of crops to nitrogen is generally high, farmers are inclined to use higher rates of nitrogen than are required.

As seen in Table 3, the yields of upland grain crops in the farmer's plots (= check) are lower than those in the demonstration plots, despite the higher rates of nitrogen applied. The higher efficiency of fertilizer-N in the demonstration plots was generally because of better application techniques and related cultural practices.

The rate of N applied to vegetables, in particular, is far higher (often 3-5 times) than that absorbed by the crops. (Fig. 2). Vegetable crops receive such heavy applications of fertilizer partly because heavy applications of nitrogen fertilizer give rapid growth of leafy vegetables, with consequent good quality and high prices in the market. Furthermore, the majority of vegetables are harvested during the vegetative growth period, during which a higher concentration of N is needed up to the time of harvest.

Fruit trees in Taiwan also generally receive high rates of N. Examples of the rates of N applied in citrus orchards are shown in Table 4. N is applied in the form of both chemical fertilizer and organic manure. Large quantities of various kinds of beancake, meal and livestock manure are applied as organic fertilizer, with a fairly rapid rate of decomposition in the soil. Consequently, the amount of the nitrogen applied is estimated to be six to twelve times higher than that removed by the harvested fruit.

High Residual N in Soil after Upland Cropping

Amount and form of residual N

Fertilizer N added in excess of crop requirements accumulates in the soil, predominantly in inorganic forms. The content remaining in the

Table 1. Effect of fertilizer applications on yield of major crops

Crop		Average yield (mt/ha)	Yield index			
			-N	-P	-K	NPK
Rice	(single cropping)	3.9	73	97	99	100
	(double cropping)	4.3	77	97	89	100
Barley		5.8	52	66	72	100
Rye		3.1	44	70	68	100
Wheat		3.2	46	69	72	100
Upland rice		2.3	46	66	90	100
Irish potato		16.5	47	47	70	100

Table 2. Recommended application rates of fertilizer elements for major field crops in Taiwan and their productive efficiency (average yield increment from each unit of application)

Crop	Recommended rate of application (kg/ha)			Productive efficiency (kg yield/kg N)		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O
Rice 1st Crop[1)]	140	40	40	11.6	0.1	1.8
2nd Crop[2)]	120	40	40	8.2	2.1	1.9
Sugarcane[3)]	150	75	150	28.0	2.9	7.1
Sweet potato[4)]	75	50	150	37.3	22.7	30.9
Maize [5)] (Fall crop)	170	80	50	20.9	3.9	–
Soybean[6)]	40	60	60	13.0	16.7	7.5

Table 3. Nutrient rates and yields of various crops obtained in large-scale fertilizer field demonstrations in Taiwan

Crop	Season	Year	Plot	No. of locations	Average rate of $N\text{-}P_2O_5\text{-}K_2O$ (kg/ha)	Average Yield (mt/ha)	yield increase (mt/ha)
Corn	Fall	1990[1)]	Demonstration	4	210-105-70	7.55	+0.55
			Check	4	245-110-115	7.00	–
	Fall/winter	1979[2)]	Demonstration	6	130-64-58	5.65	+0.49
			Check	6	181-54-75	5.16	–
Sorghum	Spring	1979[2)]	Demonstration	3	131-99-50	4.08	+0.54
			Check	3	176-61-50	3.54	–
Soybean	Fall/winter	1979[2)]	Demonstration	2	52-51-55	3.00	+0.49
			Check	2	38-27-60	2.51	–
	Spring	1979[2)]	Demonstration	2	22-65-47	2.20	+0.12
			Check	2	37-47-49	2.08	–
Peanut	Spring	1979[2)]	Demonstration	7	24-56-35	2.51	+0.31
			Check	7	38-26-38	2.20	–
Rice	1st	1975[3)]	Demonstration	120	120-55-49	6.82	+0.64
			Check	120	128-49-68	6.18	–
	2nd	1976[3)]	Demonstration	90	106-41-59	5.69	+0.44
			Check	90	116-44-70	5.25	–

Sources: 1) Lian and Wang 1990a. The size of each plot was at least 0.1 ha.
2) Cheng 1981. The size of the demonstration plot was at least 0.2 ha, while that of the check plot was 0.05 ha.
3) Huang 1978. The size of each plot was at least 0.1 ha.

soil after upland crops have been grown is usually high, because of excessive application of N fertilizer. The residual inorganic nitrogen in the top (0-30 cm) layer of soil when corn was harvested from a plot to which 180 kg/ha of N had been applied was 257 kg/ha (Table 5). It is not clear why the difference in the amount of residual inorganic N in the plot to which 60 kg/ha of N had been applied and that receiving 180 kg/ha exceeded the difference in the amount of applied N given to these plots. However, the fact of the high residual N left in the soil must be recognized.

The amount of residual inorganic nitrogen in strawberry fields was also great, i.e. 309 kg/ha, as shown in Table 6. In all cases, nitrate was the major constitutent of the inorganic nitrogen. The level of residual inorganic nitrogen in fields producing vegetable crops was also high. One example, a field of Chinese leeks after one year of cultivation and given different levels of N, is shown in Table 7.

Some of the nitrogen fertilizer applied, in addition to that remaining as inorganic nitrogen, must have been immobilized in the form of organic N. The percentage of this fraction in the residue is lower than the fraction of inorganic under excess chemical N applications. The level of organic nitrogen remaining from organic fertilizer applications, on the other hand, can be high when there is a high rate of application.

Amount of Residual N Related to the Rate of N increase in application rate. However, according to Broadbent and Carlton (1978), this generalization is not valid with regard to optimum nitrogen fertilization for field grain crops. Much evidence indicates that the efficiency of fertilizer-N absorption remains relatively constant with increasing rates of nitrogen fertilizer, at least until the level at which the

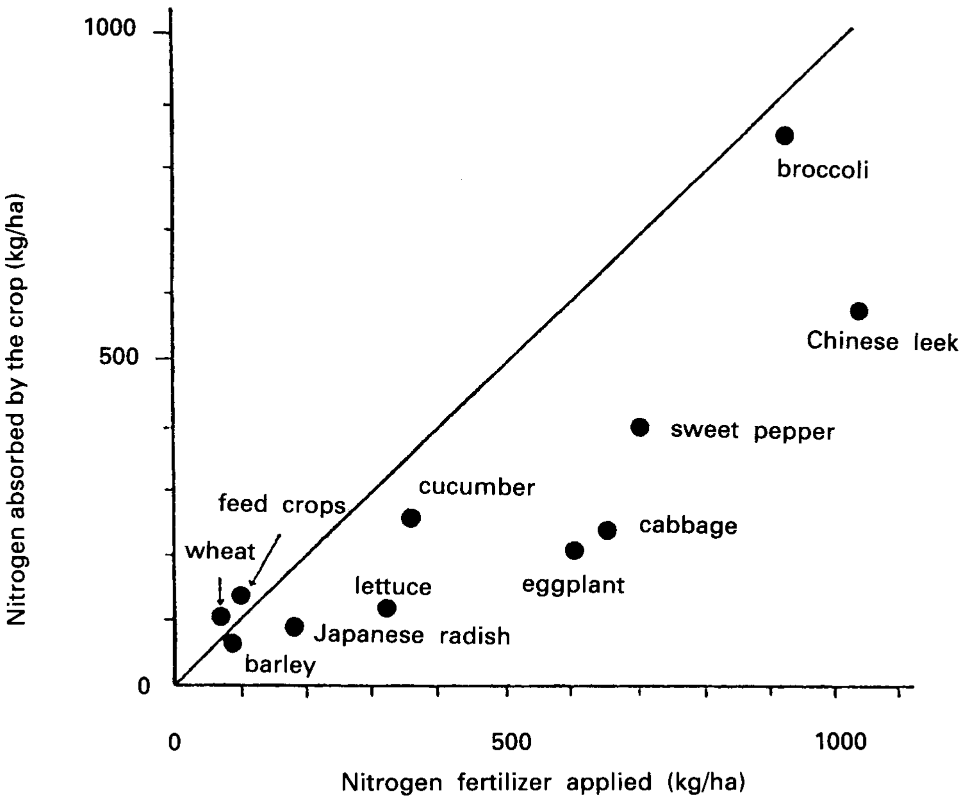

Fig. 2. The relation between the amount of nitrogen fertilizer applied to vegetables and other crops, and the amount of nitrogen absorbed by the crop

Source: Miyoshi 1981

Table 4. Comparison of the amount of fertilizer N conventionally applied to citrus, and that removed by the crop and the fruit harvested

Crop variety	No. of orchards surveyed	Yield of fruit kg/tree	Rate applied N (kg/tree)		Uptake estimated N (kg/tree)		Applied/ uptake	
			Chemical	Chemical plus organic	Total	Fruit only	Total	Fruit only
Pongkan tangerine 1982-1983	19	84 (32)	0.96 (0.68)	1.54 (0.70)	0.50	0.13	3.1	11.8
Pongkan tangerine 1987	15	88 (23)	1.22 (0.45)	1.76 (0.58)	0.54	0.16	3.3	11.0
Sweet orange 1982-1983	10	110 (56)	0.97 (0.41)	1.14 (0.47)	0.66	0.18	1.7	6.3

Numbers in parentheses are standard errors.

Numbers in parentheses are standard errors.
Source: Lian *et al.* 1989

Table 5. Residual inorganic nitrogen in the soil at harvest of corn to which had been applied different rates of nitrogen, in a rice-corn cropping system. (January 1990)

N (kg/ha) applied \ Items / Soil depth (cm)	Inorganic N (ppm)		Inorganic N (kg/ha)			% of NO_3-N	
	0-15	15-30	0-15	15-30	Total	0-15	15-30
60	33	15	48	32	80	92	91
120	65	32	108	69	177	77	85
180	106	44	161	96	257	90	89

All data are the mean of 2 replications.

Table 6. Residual inorganic nitrogen in the soil at the harvest of strawberry in a strawberry-corn cropping system (April 1991)

Soil stratum (cm from surface)	Inorganic N ppm	Inorganic N kg/ha	% NO_3-N
0-21 (ridge)	188	257	87
21-39	28	52	82
Total	–	309	–

Growth periods: strawberry, September-April; sweet corn, April-July; fallow and flooded, July-August

All data are the mean of 5 replications. Ridges were 70 cm wide, and the plants were 30 cm apart.

Source: Lian and Wang 1991

Table 7. Content of inorganic nitrogen in the soil at various depths after one year of cultivation of Chinese leek (February 1974)

N applied (kg/ha)	Inorganic N (ppm) 0-15 cm	15-20 cm	30-45 cm
0	69 (8)	16 (2.6)	10 (1.7)
515	107 (23)	24 (5.1)	
1030	186 (33)	55 (23)	
1545	327 (31)	92 (16)	

The data are the means of 4 replications. Numbers in parentheses are standard errors of mean.

Source: Lian and Wu 1977

maximum yield is obtained (Fried 1978). If the levels of applied N then continue to increase, the uptake rate tends to fall rapidly, while the yield does not increase further but in fact decreases. Thus, maximization of yield is not contradictory to the maximization of nitrogen uptake efficiency and the conservation of energy. Crop yields are maximized at N application rates with maximum uptake efficiency and at these input rates, little fertilizer N is retained in the soil. Residual inorganic N in the soil increases at application levels above that value (Fig. 3).

If fertilizer applications were always at the level to give an efficient response, as shown by Broadbent and Carlton, losses of N from N-fertilized cropland would be minimal. However, maximum economic efficiency of production usually requires above-optimum inputs of N fertilizer (Keeny 1982), particularly with regard to vegetable crops. As a result, N recovery by agronomic crops is seldom more than 70%, and the average value is probably nearer to 50% (Olsen and Kurtz 1982). In addition, the optimum rate of fertilizer application is influenced by a multitude of site-specific conditions and by the weather (Keeney 1982). Our experimental results also indicated that residual inorganic N in the soil increased with the rate of N applied, in spite of the fact that the yield was still increasing (Fig. 4).

Residual N in Soil and Its Impact on the Succeeding Crop and Environment

A long-term fertilizer trial conducted over 48 years has indicated that the loss of nitrogen is marked under the subtropical and tropical conditions of Taiwan.

The data in Table 8 indicates that of the 8075 kg of N/ha added over 48 years to the plot treated with NPK fertilizer (total of 85 crops, each with 95 kg of N/ha), only 25% was absorbed by the rice plants. On average, 4.5% was left in the soil, and about 70% was lost from the soil. The same tendency, although to a lesser extent, was observed in the plot treated with farm-yard manure. Similar experiments conducted in temperate countries usually show that a significantly higher percentage of the nitrogen added accumulates in the soil. The turnover of organic carbon in soil is apparently more rapid in tropical and subtropical countries than in temperate regions.

Residual N in soil which is present in the form of nitrate is commonly lost through leaching, or denitrification, or a combination of these.

The loss of N from leaching in wet rice cultivation is usually small, but losses from soil producing upland crops can be quite high. Leaching losses range from 13 to 102%, and generally averaged 25 to 50% of the N applied in most cropping situations in southern California under irrigation (Legg and Meisinger 1982).

The loss of the residual N in the form of nitrate through denitrification is significant when the soil after upland cropping is flooded and prepared for rice cultivation. As shown in the previous table (Table 5), the content of nitrate N was high in the plot with a high N level compared to that with a low N level at the harvest of corn. However, the yields of paddy rice in these plots, to which no fresh fertilizer N application was made, are much the same, showing no residual N effect from the previous crop (Table 9).

A tracer study in the same field also indicated that the uptake by the rice crop following corn of residual fertilizer N from the soil is small, only 1.4-1.9% of that added to the previous crop, while the amount remaining in the soil was also small (about 14%) (Lian 1990b).

The nitrate nitrogen leached from the soil may pollute groundwater, while that which runs off may pollute surface water. It has been reported that in Techi Reservoir in Central Taiwan, eutrophica-

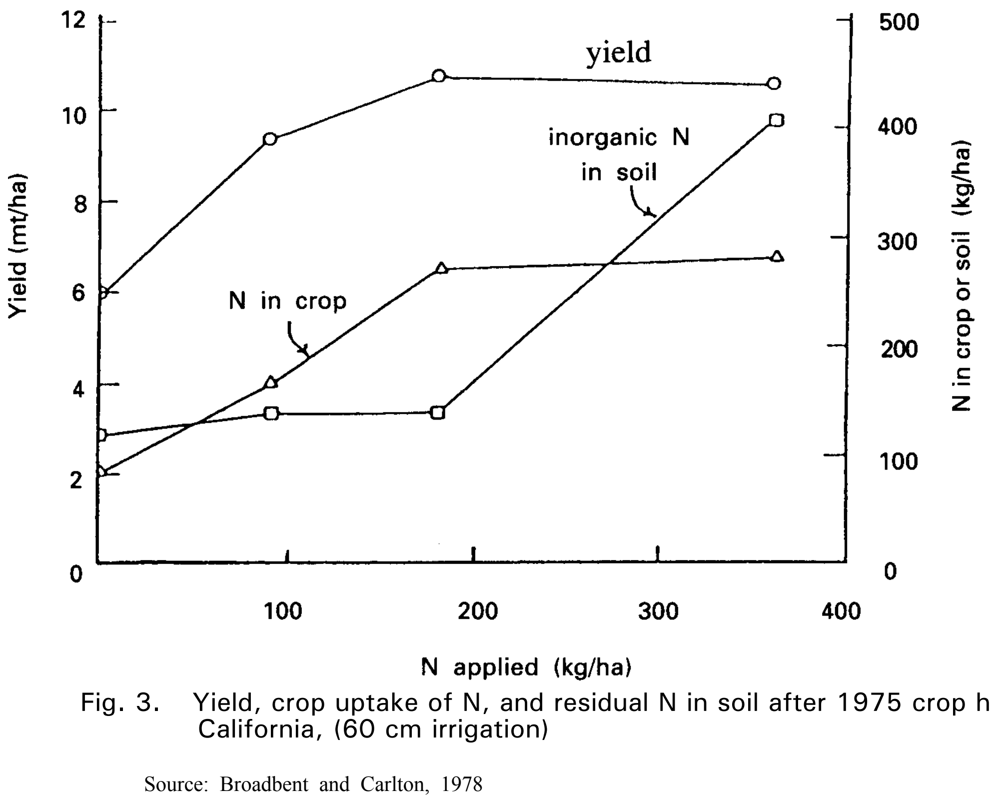

Fig. 3. Yield, crop uptake of N, and residual N in soil after 1975 crop harvest, California, (60 cm irrigation)

Source: Broadbent and Carlton, 1978

tion exacerbated by fertilizer run-off from surrounding orchards and vegetable gardens is a serious problem (Hsieh *et al.* 1989). An increase of the nitrate content in the groundwater of certain areas under intensive cropping has also been reported (Chi 1975).

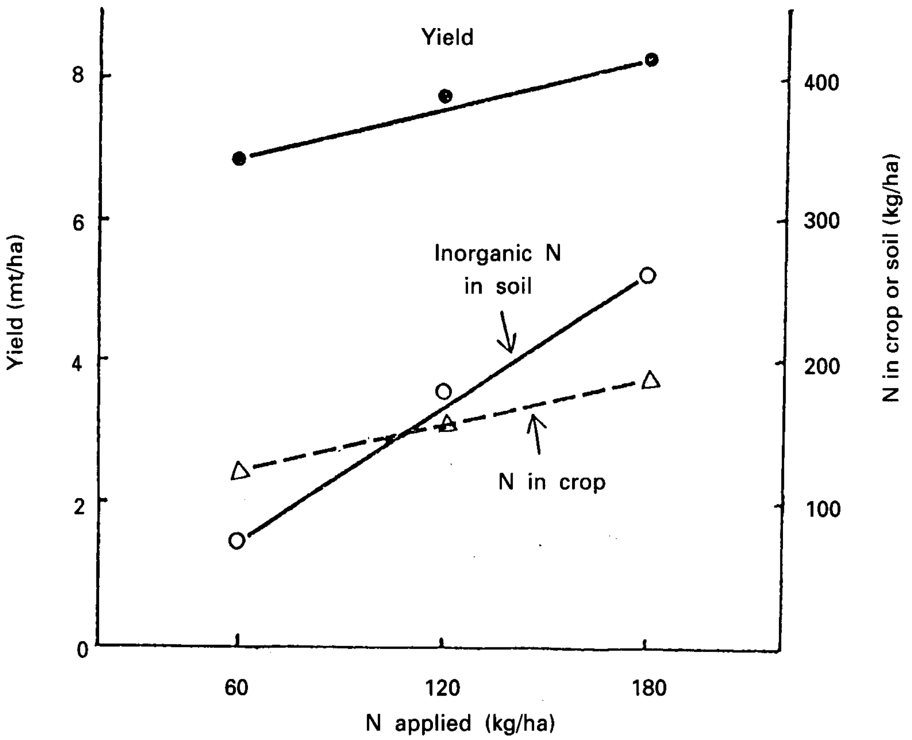

Fig. 4. Corn yield, crop uptake of N, and residual N in soil after 1989 crop harvest

Source: Lian and Wang 1990b

Table 8. Estimated loss of added N after a 48-year long-term field trial

Treatment	N added in 48 years (kg/ha)	N-uptake by rice plant (kg/ha)	% of added N absorbed by rice plant	Total N in soil after 48 yrs (kg/ha)	Amount of applied N left in soil	% of loss of added N
Check	0	2,812	0	A 2,700 B 2,700	–	–
NPK	8,075 fertilizer	4,832	25.0	A 3,060	4.5% B 2,700	70.5
Farmyard	8,075 manure	4,885	25.7	A 3,600	14.9% B 3,000	59.4

A – surface soil; Apparent density = 1.2; Soil depth = 15 cm; Weight = 1,800,000 kg/ha.
B – subsoil; Apparent density = 1.5; Soil depth = 20 cm; Weight = 3,000,000 kg/ha.

Source: Lin 1978

Flooding followed by plowing, levelling and draining is considered to be an effective way of avoiding salt accumulation on the soil surface after continuous cropping of vegetables with high fertilizer inputs. However, it has been pointed out that the N_2O emitted during the denitrification process may contribute to the depletion of the ozone layer in the stratosphere (Keeney 1982).

On the other hand, the residual N in the form of organic N or the crop residue itself is mineralized, released and utilized during the growth of the succeeding crop, particularly at the later stages of growth. The residual nitrate nitrogen is also utilized by the succeeding crop when there is continuous upland cultivation. The residual effects of heavy nitrogen applications to vegetables grown before rice can be carried over to the subsequent rice crop from flower initiation to the heading stage (Hayami 1975). If the supply of nitrogen is too great, ripening of the rice is retarded and there may be lodging.

Furthermore, the acidity induced by the fertilizer N must be neutralized sooner or later, if good soil condition and productivity are to be maintained. It is generally accepted that 1.8 kg of effective lime is required to neutralize each kg of NH_4-N applied in fertilizer (Olson and Kurtz 1982). The induced acidity is greater with larger excess applications of N which result in a higher level of residual N.

Efforts to Minimize and Utilize Residual N

Since the amount of residual N generally increases with higher rates of N application, many scientists have suggested that N fertilizer applica-

Table 9. Yields of paddy rice after corn in a rice-corn cropping system (1st crop 1990)

N (kg/ha) applied to the previous corn crops[1)]	60	120	180
Yield (mt/ha) from rice crop[2)]	4.28[a]	4.09[a]	4.36[a]
Inorganic N (ppm) in soil at harvest of rice crop	28.3	29.9	41.4

1) The same as in Table 5.
2) No fertilizer was applied for the rice crop to see the residual effect of the treatments in the previous corn crops. All the data are the mean of two replication plots. The same alphabetical character attached to the data on the same line indicates no statistical difference at a 5% level.

Source: Lian and Wang 1990b

Table 10. Percent uptake by rice crop following corn of the residual tagged fertilizer nitrogen (1st crop 1987)

N application to the previous corn crop[1)] (1/3 tagged)	Uptake (%) by rice crop[2)]	Residual N (%) in soil at harvest of rice[2)]
Basal, at sowing	1.37 ± 0.18	–
Knee-high stage	1.45 ± 0.06	14.3 ± 5.7
Tasseling stage	1.85 ± 0.64	–

1) The rate of N at each application was 60 kg/ha, giving a total rate of 180 kg/ha.
2) Mean of two replication plots with standard error

Source: Lian 1990b

tions be restricted to the rates that are significantly below the economic optimum in order to minimize pollution from fertilization (see e.g. Keeny 1982). Such a proposal, however, may not be acceptable to farmers, who may lose the opportunity for higher yields and profits.

The adoption of an appropriate cropping system, combined with soil testing which measures the residual N after upland cropping, and adjusting the application of fertilizer N to meet the needs of the subsequent crop, may be able to both reduce and utilize the residual N.

Although studies on soil testing for paddy rice have been carried out for some time, practical application is limited, since fertilization techniques are quite well established among farmers in Taiwan and fertilizer is readily available. However, the amount of residual N after upland cropping is quite variable and may have an important impact on the succeeding crop and the environment, so that the application of soil testing to upland cropping, particularly under a multiple cropping system, merits attention.

A suitable cropping system may be enough to utilize residual N and increase N use efficiency. For example, the cultivation of sweet corn after strawberry is considered effective in utilizing the high residual N after the strawberry harvest. In plastic greenhouses, the cropping of amaranth over the summer and the rotation of other types of vegetables during the rest of the year may reduce problems caused by the application of too much fertilizer to vegetables (Chang and Liao 1989). More studies of the N balance in various cropping systems are needed.

FACTORS AFFECTING EFFICIENCY OF APPLIED N AND YIELD IN CROP PRODUCTION

Fertilizer nitrogen applied to soil is absorbed and used for the production of yield (i.e. the harvest organ). Efficiency of fertilizer N can be formulated as follows (Yoshida 1981) (see Formula 1).

Efficiency of fertilizer-N (kg yield/kg N applied)	=	Absorption percentage of fertilizer N (kg N absorbed/kg N applied)	×	Efficiency of absorbed-N for production (kg yield/kg N absorbed)

Meanwhile, the crop yield can be further expressed by the following formula (Tanaka et al.):

$Y = N (plant) \times NE$

$N (plant)$ = N accumulated in plant

= Soil-N absorbed + (Fertilizer-N applied × Absorption percentage of fertilizer-N)

NE = Efficiency of N accumulated in plants (absorbed-N) to produce yield, as in the preceding formula.

Efficiency of Fertilizer N Absorption in Relation to Yield

In most cases, yield is proportional to the N in the plant, which implies that nitrogen uptake is often insufficient for a crop to attain its potential yield in a given environment (Fig. 5 Fig. 6 Fig. 7). This insufficiency is usually due to either the limited amount of applied nitrogen, or to low efficiency in absorption. The relationship between crop yield and the efficiency of fertilizer N absorption is as follows:

- With limited applications of nitrogen, yield is directly related to the rate and the efficiency of absorption. Variation in the efficiency of absorption between different crops is great (10-70%), depending on soil conditions and the method and timing of application. Application which minimizes the loss of nitrogen in soil increases crop absorption and yield.
- In many cases, ample amounts of fertilizer N, which are more than the crop requires, are applied in the field. Even so, the amount of nitrogen absorbed by the plant may still be insufficient for the crop to attain its yield potential, because of low efficiency of absorption. Low efficiency in such cases is caused by the unfavorable condition of the plants or the soil, rather than by the nitrogen supply.

As well as those examples mentioned in the previous section, some of the ways in which N uptake efficiency in corn production can be improved are as follows:

Spacing of Plants

A significant positive interaction between the rate of nitrogen application and density of planting was found. In the fall corn crop, a maximum yield of 8.9 mt/ha was obtained with dense plant spacing (70 x 20 cm, i.e., 71,400 plants/ha) and heavy rates of N (150 - 200 kg/ha) (Fig. 5). There was a good correlation between yield and the amount of N absorbed. N absorption was higher with denser planting and heavier N applications.

In-row Subsoiling and Deep Placement of Fertilizers

In-row subsoiling with deep banding of fertilizers was found effective in drained paddies converted to corn production. The compactness of the subsoil, which tends to restrict root development, was improved by this practice, so that the efficiency of fertilizer-N absorption was improved and the yield increased (see Fig. 6).

Timing of Application

The timing of N applications is an important factor affecting the efficiency of nitrogen absorption, because the time interval between application and crop uptake determines the length of exposure of the fertilizer nitrogen to loss processes such as volatilization, denitrification and leaching. Efficiency is also affected by the timing of uptake itself, as the behavior relating to grain production differs according to the growth stage at which the nitrogen is absorbed by the plant.

The uptake was low when N was banded basally at sowing (28%). It was highest (58%) when N was top-dressed (banded) and covered by uphilled soil when corn was at the knee-high stage (Table 11). Although uptake was also low for N which was top-dressed at tasseling (also banded, but without covering soil), the percentage distribution of absorbed N to grain was higher when N was applied at this stage than when it was applied basally at sowing, or at the knee-high stage. This may be related to a higher grain production efficiency when nitrogen is absorbed during this stage (see below).

Top-dressing of nitrogen when rice is at the panicle initiation stage is a common practice (Su 1975). It is also effective for corn, as was shown in a field experiment in which corn was treated with differently timed applications. N topdressing at tasseling had a favorable effect. Both the efficiency of fertilizer-N uptake, and the ability of the N absorbed to produce yield (NE), were promoted by the top-dressing of N at tasseling, as shown in Fig. 7 (compare left and right) and Fig. 8.

Efficiency of Absorbed N in Producing Yield

There is considerable variation in the efficiency of absorbed N in producing yield (i.e., NE), although this is not as marked as the variation in efficiency of absorption. There is variation between different cultivars of the same species, and even

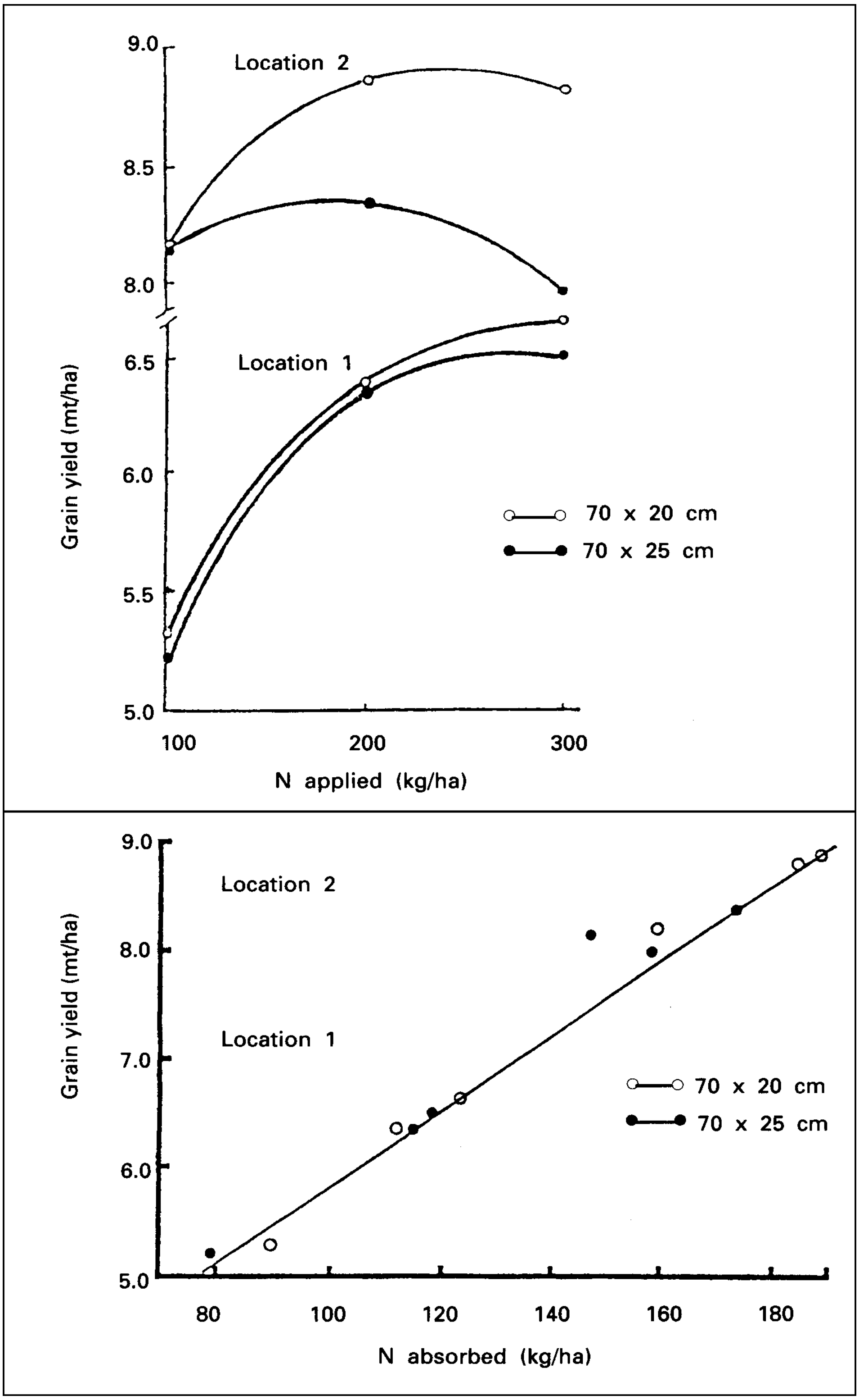

Fig. 5. Nitrogen response of corn at two plant spacings in different locations, and relationship between nitrogen absorbed and yield. (1983 fall crop)

Source: Lian and Wang 1989

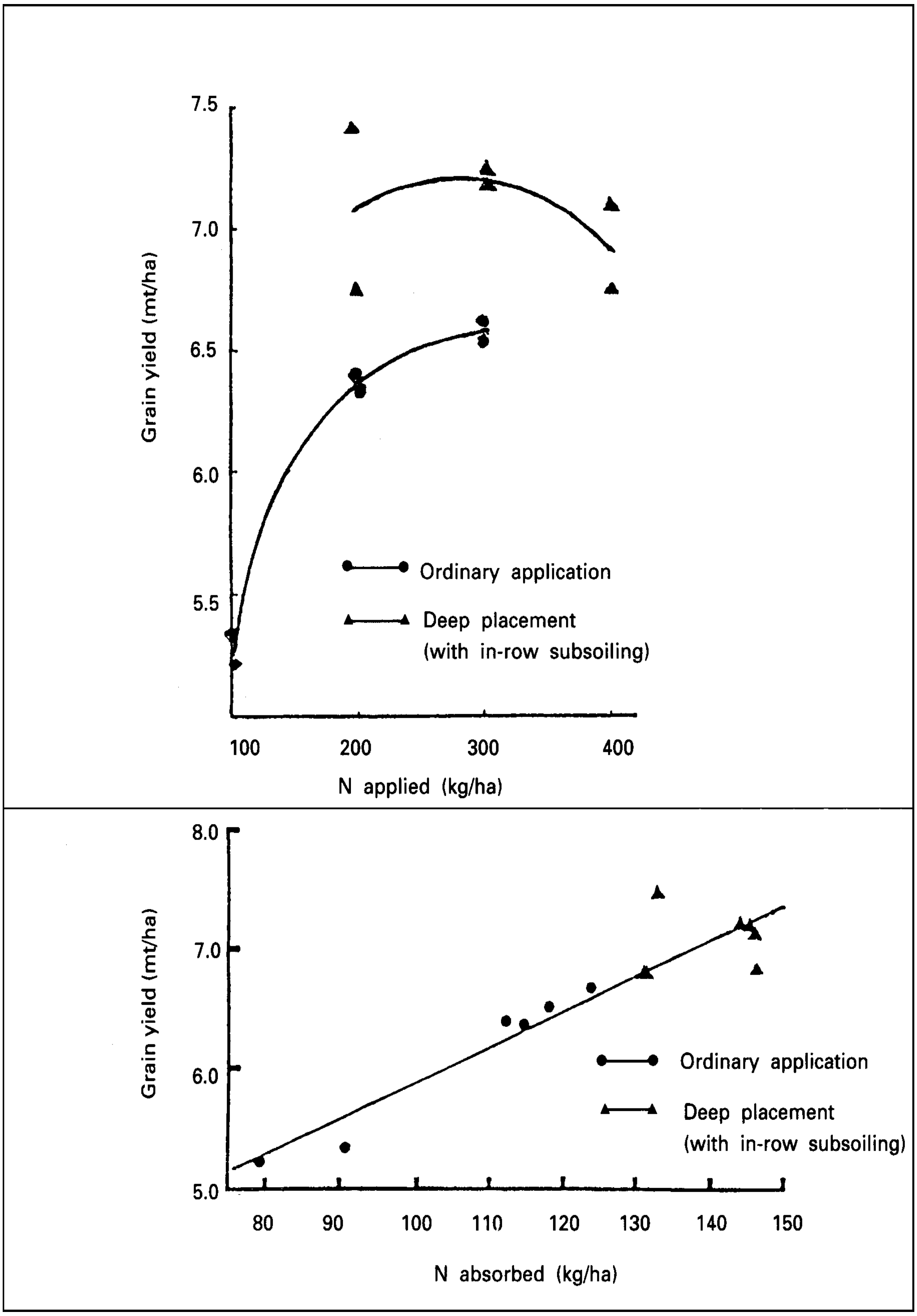

Fig. 6. Nitrogen response of corn at two different depths of fertilizer placement, and relationship between the nitrogen absorbed and yield (1983 fall crop)

Source: Lian and Wang 1988

Table 11. Effect of time of application on percent uptake and distribution in grain and stover of tagged nitrogen at harvest of corn (1986 fall crop)

Time of N application (1/3 tagged)[1]	Plant uptake[2] %	% distribution[3] Grain	Stover
Basal at sowing	28.4 ± 7.4	58.0	42.0
At knee-high stage	57.9 ± 13.7	51.6	48.4
At tasseling	24.9 ± 12.0	68.1	31.9

1) The rate of N at each application was 60 kg/ha, giving a total rate of 180 kg/ha
2) Mean of two replication plots with standard error
3) Total as 100

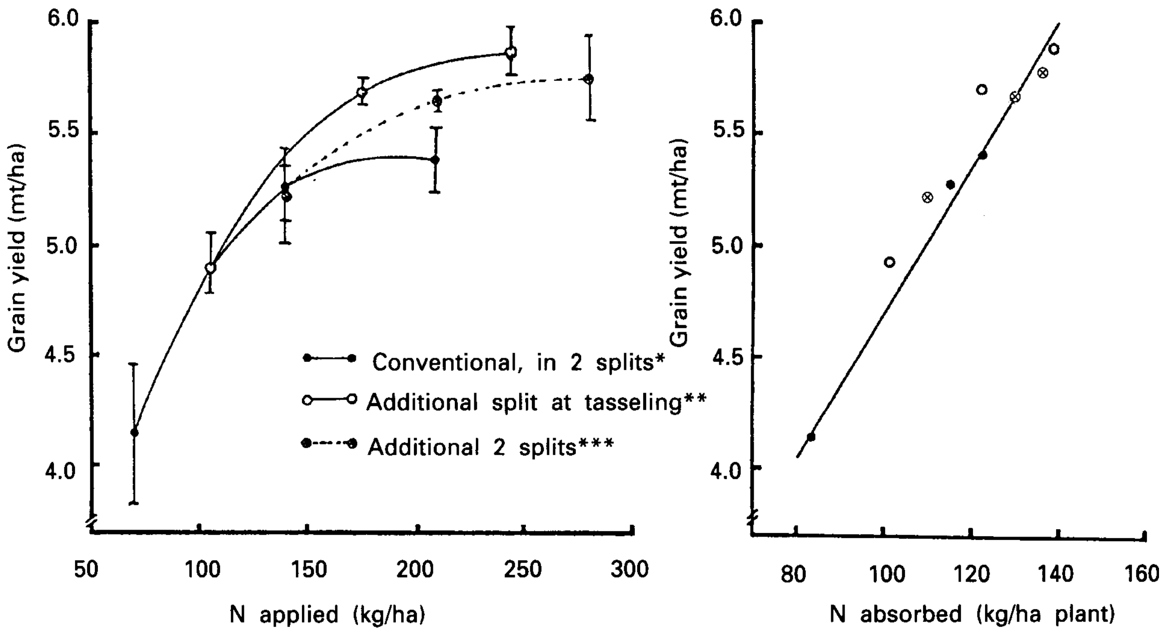

Fig. 7. Nitrogen response of corn under N applications, and relationship between N absorbed and yield (1985 fall crop)
Source: Lian and Wang 1987
* Two splits, one as basal plus top-dressing at knee-high stage.
** Two splits plus additional application at tasseling.
***Three splits plus additional application at the blister stage, ca. 2 weeks after silking.

more, between crops of different species.

Efficiency generally declines with increased fertilizer N applications. It is this type of response which determines the productivity of crops (Fig. 9). Varietal differences in nitrogen response and NE between traditional rice varieties and improved ones are mainly due to the differences in their nitrogen uptake and leaf morphology (Taraka *et al.* 1964). The higher NE of potato and sugar beet compared to other crops, on the other hand, is a result of their longer period of sink activity (Tanaka *et al.* 1984). Thus, the factors affecting NE are mostly genetic, although environment, as well as the interaction

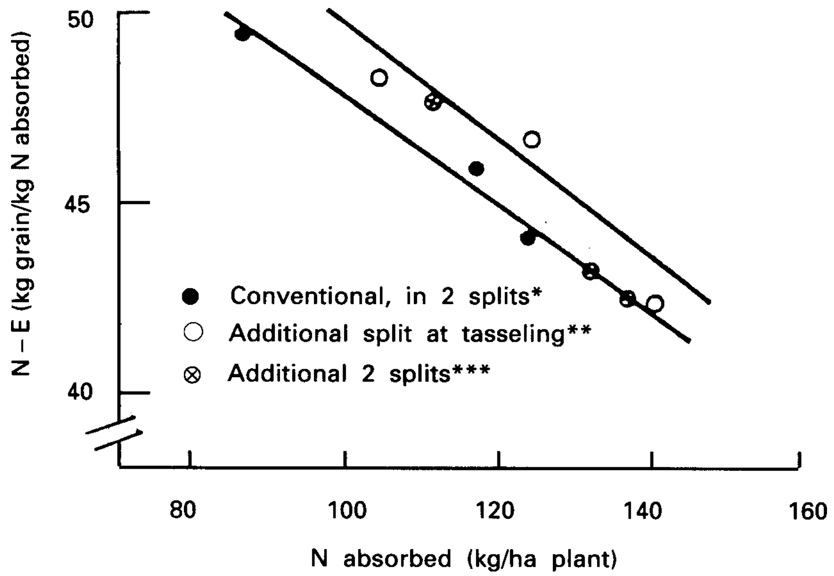

Fig. 8. Relationship between nitrogen absorbed under different N applications, and efficiency of absorbed nitrogen to produce yield (NE)

Source: the same experiment as in Fig. 7
* Two splits, one as basal plus top-dressing at knee-high stage.
** Two splits plus additional application at tasseling.
***Three splits plus additional applicationa at the blister stage, ca. 2 weeks after silking.

between the genetic character of the variety and the environment, are also important. The growth of the crop is closely affected by these factors, resulting in different patterns of growth. As the pattern of nitrogen uptake during growth is the main factor which can be manipulated to affect the growth pattern, the timing of nitrogen applications not only improves the absorption efficiency but also the NE.

The ability of absorbed nitrogen to produce grain or straw varies according to the growth stage at which the nitrogen is absorbed (Ishizuka 1980). The nitrogen absorbed at different stage of growth affects the harvest index of nitrogen, HI (N), and the nitrogen concentration of the harvest organ, N% (h.o.), as indicated by the following formula (Tanaka *et al.* 1984).

$$NE = HI(N) / N\% \text{ (h.o.)}$$

As mentioned above (Table 11), the percentage distribution of absorbed N to grain is higher when N is applied at tasseling rather than basally at sowing or at the knee-high stage. Results are even clearer when maize was grown by water culture and treated with ^{15}N tagged fertilizer at various growth stages (Lian and Chang 1991). The greater distribution to grain of the N absorbed at tasseling causes a higher HI (N), which in turn may be related to a higher NE.

Top-dressing with nitrogen at the tasseling stage (corn) or the panicle initiation stage (rice) usually promotes a higher NE, particularly when application rates are low.

REFERENCES

Broadbent F.E. and A.B. Carlton. 1978. Field trials with isotopically labeled nitrogen. In: *Nitrogen in the Environment*, D.R. Nielsen and J.G. MacDonald (eds.). Academic Press, New York, pp. 1-41.

Chang, S.K. and F.S. Liao. 1989. *Problems in the Continuous Cultivation of Vegetables in Plastic Houses*. Extension Bulletin No. 300. Food and Fertilizer Technology Center for the ASPAC Region,

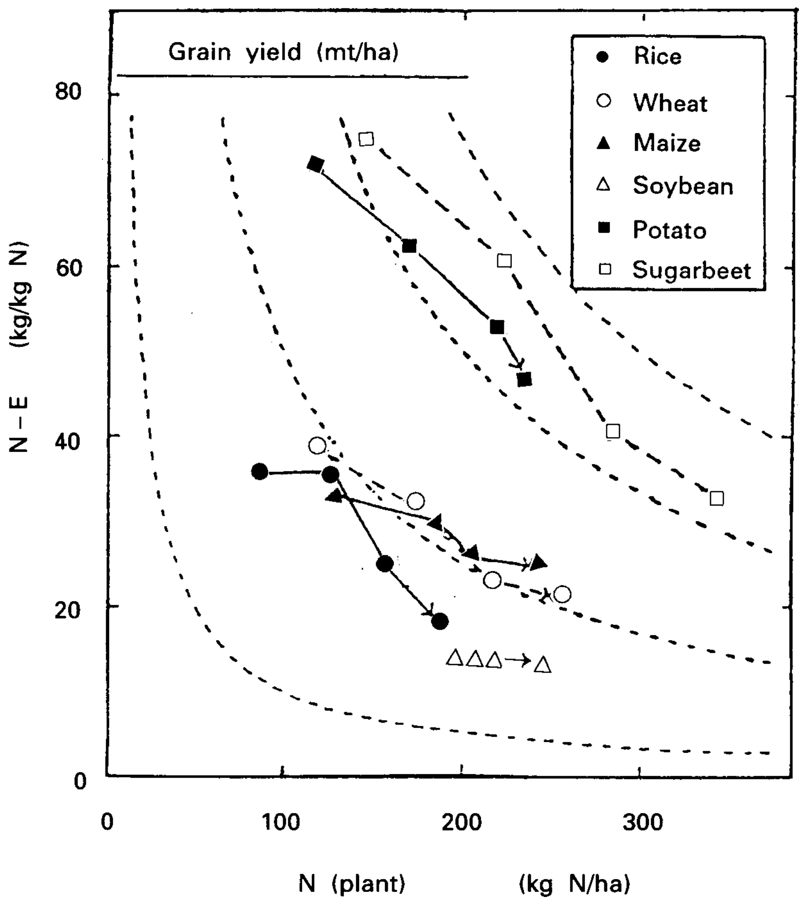

Fig. 9. Relationship between nitrogen accumulated in plant (N (plant)) and efficiency of nitrogen (NE) in various crops at graded fertilizer-N levels.

Source: Tanaka *et al.* 1984

Taipei, Taiwan R.O.C.

Cheng, J.H. 1983. Experiments on fertilizer requirement of soybean (Kaohsiung No. 8). Reports on Soil and Fertilizer Experiments, 1982 and 1983. Department of Agriculture and Forestry, Taiwan Provincial Government. Unpub. Mimeo.

Cheng, Y.H. 1981. Demonstration of fertilization techniques for upland field crops. Reports on Soil and Fertilizer Experiments, 1981. Department of Agriculture and Forestry, Taiwan Provincial Government. Unpub. Mimeo.

Chi, C.L. 1975. Primary investigation of water pollution by fertilizing practices. *Taiwan Agriculture Quarterly* 11, 3: 191-203.

Fried, M. 1978. Critique of "Field trials with isotopically labeled nitrogen". In: *Nitrogen in the Environment.* Vol. 1. *Nitrogen Behavior in Field Soil,* D.R. Nielsen and J. G. MacDonald (eds.). Academic Press, New York, pp. 43-64.

Hayami, A. 1975. *Cropping Sequences and their Effect on Soil Fertility.* Technical Bulletin No. 23, Food and Fertilizer Technology Center for the ASPAC Region, Taipei, Taiwan R.O.C.

Houng, K.H. 1980. Mineralization of soil organic matter. In: *Increasing nitrogen Efficiency for Rice Cultivation*, Y. Ishizuka *et al.* (eds.). FFTC Book Series No. 18. Food and Fertilizer Technology Center for the ASPAC Region, Taiwan

R.O.C., pp. 39-53.
Hsieh, C.F., Z.S. Chen, L.H. Chen, and J.M. Chang. 1989. Effectiveness of riparian zones in preventing transport of fertilizers from orchards at Techi Reservoir. Poster presented at the International Workshop on Conservation Farming on Hillslopes. March 20-29, 1989. National Chung Hsing University, Taiwan R.O.C.
Huang, W.L. 1978. Report on extension of improved fertilizer use for rice. *Taiwan Agriculture Quarterly* 14, 1: 111-138.
Ishizuka, Y. 1980. The importance of nitrogen for the growth of the rice plant. In: *Increasing Nitrogen Efficiency for Rice Cultivation*", Y. Ishizuka *et al.* (eds.). FFTC Book Series No. 18. Food and Fertilizer Technology Center for the ASPAC Region, Taipei, Taiwan R.O.C., pp. 1-14.
Keeney, D.R. 1982. Nitrogen management for maximum efficiency and minimum pollution. In: *Nitrogen in Agricultural Soils,* F.J. Stevenson (ed.). Agronomy Monograph No. 22, ASA-CSSA-SSSA, pp. 605-650.
Ku, T.Y. 1987. The supply and management of fertilizers and pesticides in the Republic of China on Taiwan. Council of Agriculture, Executive Yuan, R.O.C. Unpub. Mimeo.
Legg, J.O. and J.J. Meisinger. 1982. Soil nitrogen budgets. In: *Nitrogen in Agricultural Soils*, F.J. Stevenson (ed.). Agronomy Monograph No. 22, ASA-CSSA-SSSA, pp. 503-557.
Lian, S. and C.T. Wu. 1977. A study on nutrient uptake and fertilizer response of vegetables. II. Response of Chinese leek to different source of nitrogen fertilizer. *Jour. Agri. Res. China* 26, 3: 195-204.
Lian, S. 1986. Fertilizer requirements of corn in the drained paddies related to soil fertility. *Jour. Agric. Res. China* 35, 3: 318-334.
Lian, S. and C.H. Wang. 1987. Effect of nitrogen top-dressing at and after tasseling on grain production in corn. *Progress Report (Experiments on Soils and Fertilizers), 1987*. Department of Agriculture and Forestry, Taiwan Provincial Government.
Lian, S. and C.H. Wang. 1988. Characteristics of corn production in the drained paddies and their fertility managements. 1. Difference of yield between crop seasons and soils, and the relevant factors. *Jour. Agric. Res. China* 37, 1: 32-64.
Lian, S., S.S. Chang, W.T. Huang and W.L. Wu. 1989. Bases of leaf diagnosis for citrus and the nutritional status in Taiwan. In: *Application of Nutritional Diagnosis in the Orchards of Taiwan*, C.C. Tu and S. Lian (eds.). Special Publication No. 28. Taiwan Agricultural Research Institute, pp. 1-25.
Lian, S. 1990a. *Improved Field Corn Production in Paddy Fields through Soil Management, with Particular Reference to the System of Cropping and Tillage*. Extension Bulletin No. 317. Food and Fertilizer Technology Center for the ASPAS Region, Taipei, Taiwan R.O.C.
Lian, S. 1990b. Fate of nitrogen applied to corn under the cropping system of paddy rice and corn. Poster presented at the 14th International Congress of Soil Science, Kyoto, Japan.
Lian S. and C.H. Wang. 1990a. A large scale observation of the effect of interseason cropping of sesbania and using it as a mulch for corn under no-tillage in the rice-corn system in Taiwan. Reports on Soil and Fertilizer Experiments, 1990. Department of Agriculture and Forestry. Taiwan Provincial Government.
Lian, S. and C.H. Wang. 1990b. Fate of residual nitrogen after corn cropping in the rice-corn system. Taiwan Agricultural Research Institute, Taichung, ROC on Taiwan. Unpub. Mimeo.
Lian, S. and G.P. Chang. 1991. Behavior of nitrogen absorbed at various growth stages associated with grain production in maize. *Jour. Agric. Res. China* 40 (In Press).
Lian, S. and C.H. Wang. 1991. A study on balance and requirement of plant nutrients in various cropping systems in Taiwan. Unpub. mimeo.
Lin, C.F. 1978. *The Fertility of Paddy Soils in Taiwan.* Technical Bulletin No. 41. Food and Fertilizer Technology Center for the ASPAC Region, Taipei, Taiwan R.O.C.
Lin, C.F. 1982. Investigation of criteria for soil fertility capability classification of Taiwan soils. *Reports on Soil and Fertilizer Experiments 1982*. Department of

Agriculture and Forestry, Taiwan Provincial Government.

Lin, C.F. 1983. Investigation of criteria for soil fertility capability classification of Taiwan soils. *Reports on Soil and Fertilizer Experiments 1983*. Department of Agriculture and Forestry, Taiwan Provincial Government.

Miyoshi, H. 1981. Present situation of nutrient recycling in Japan. Paper Presented at Seminar on Mechanisms in the Recycling of Plant Nutrients in Agriculture, Food and Fertilizer Technology Center for the ASPAC Region. Unpub. mimeo.

Olson, R.A. and L.T. Kurtz. 1982. Crop nitrogen requirements, utilization, and fertilization. In: *Nitrogen in Agricultural soils*, F.J. Stevenson (ed.). Agronomy Monograph No. 22, ASA-CSSA-SSSA, pp. 567-604.

Su, N.R. 1975. *Fertilizer Applications to Rice in Taiwan*. Extension Bulletin No. 60. Food and Fertilizer Technology Center for the ASPAC Region, Taipei, Taiwan R.O.C.

Tanaka, A., S.A. Navasero, C.V. Garcia, F.T. Parao, and E. Ramirez. 1964. *Growth Habit of the Rice Plant in the Tropics and its Effect on Nitrogen Response.* Technical Bulletin 3. The International Rice Research Institute, Los Baños, Philippines.

Tanaka, A., J. Yamaguchi, S. Miura and H. Tamaru. 1984. Comparison of fertilizer nitrogen efficiency among field crops. *Soil Sci. Plant Nutr.* 30, 2: 199-208.

Wong, C.M. 1961. Economic appraisal of fertilizer application on sugarcane, sweet potato, jute and wheat. In "Soils and Fertilizer Uses in Taiwan, Republic of China". JCRR Plant Industry Series No. 20.

Yoshida, S. 1981. *Fundamentals of Rice Crop Science*. International Rice Research Institute, Los Baños, Philippines.

DISCUSSION

Q. (Y.D. Park)

The average rate of nitrogen fertilizer applied in Taiwan is one of the highest in the world. Is there any program to reduce this? What are your recommended application rates based on?

A. No harmful effects have been observed when fertilizer is applied at the recommended rates. The higher rates used by farmers give lower yields than we get from our demonstration plots. To some extent, the additional fertilizer does not have a favorable effect on yield, since the excess is not used.

Recommendations are usually based on many experiments carried out on a range of different soils. For example, there has been intensive research on rice production, and the rates of application of N, P and K are based on these experiments correlated with soil testing analysis. A similar system operates for upland crops.

Q. Why is that with higher rates of N application, the production efficiency goes down?"

A. It is a generally believed that both absorption (uptake) efficiency and NE (the efficiency of absorbed N to produce yield) generally fall with higher rates of N application. However the details are not so simple.

According to Broadbent, as cited in this paper, the uptake efficiency does not begin to fall until N applications reach the optimum rate to give maximum yield, though an example which may contradict this was given in the paper.

NE also generally decreases with an increase in N uptake, as a consequence of higher rates of N application. This decrease, however, is smaller for improved varieties than for traditional ones, as far as rice crops are concerned. Varietal differences are mainly due to the difference in nitrogen uptake and leaf morphology. The timing of nitrogen applications, which regulates N uptake during the growth process, and particularly the improvement of varietal characters on nitrogen uptake and leaf morphology through plant breeding, has had tremendous success in minimizing the tendency of NE to decrease with higher rates of N application in recent years.