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WEED-FERTILIZER INTERACTIONS IN RICE

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WEED-FERTILIZER INTERACTIONS IN RICE[1]

ABSTRACT

When plants compete with one another, several environmental factors may be altered and thereby adversely affect plant growth. This paper deals with the role that nutrients play in competition.

Weeds have a large requirement for nutrients and may have higher mineral nutrient contents than rice. The amounts of nutrients required by weeds growing in association with rice are extremely variable and dependent on many factors. As a result, the extent to which yield is affected by weed competition for nutrients varies greatly.

This paper discusses:

- factors responsible for the different weed-fertilizer interactions in rice.
- ways of overcoming crop-weed competition by fertilizer addition or by weeding. The complementarity between fertilizer addition and weeding is highlighted;
- the use of herbicide-fertilizer tank mixtures to improve weed control and increase crop yields; and
- the growth responses of weeds to added fertilizer and the effect of altering the soil fertility on the composition of the weed flora.

Azolla and blue-green algae are important sources of nitrogen in transplanted rice. Further research is needed to study the weed control aspect of azolla culture and to clarify the interactions between weeds and blue-green algae.

Nutrients other than nitrogen are dealt with briefly.

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WEED-FERTILIZER INTERACTIONS IN RICE

Crops and weeds have the same requirements for growth and development. Competition begins when crops and weeds grow in close proximity to each other and the supply of a single necessary factor falls below the demands of both. Once this occurs, the other factors necessary for plant growth cannot be used effectively even though they may be present in abundance. Thus, modification of the growth and development of a plant is likely to occur as a result of its association with other plants. The overall effect of competition is a reduction in the biomass and a reduction in the reproductive potential of the competitors. The outcome of competition will depend not only on the competing species but also on their density and the level of fertility.

When plants compete with one another, several environmental factors may be altered and thereby adversely affect the growth processes of the plant. The most important of these factors are light, moisture, and nutrients. It is often extremely difficult in actual competition to determine the role each factor plays in causing injury to the crop because they are intimately related. It is seldom that only one factor is involved. More often than not there is a complex interaction. However, this paper considers only the role that nutrients play in competition fully realizing that competition for light and water contribute to yield reduction.

The three most commonly limiting nutrients are nitrogen, phosphorus, and potassium. Usually, nitrogen is the first nutrient to become limiting as a result of crop-weed competition. According to Arai (1967), competition for nitrogen begins from about 20 days after transplanting (DT), the time at which Deomampo (1968) observed the effect of nitrogen application on weed weight. Zimdahl (1980) stated that although nitrogen has been investigated extensively and may be the most important element in plant competition, competition may occur for any element required for plant growth.

Inadequate fertilizer practices often seriously limit production. However, a substantial proportion of the nutrients available from the soil is utilized by weeds.

Weeds have a large requirement for nutrients and may have higher mineral nutrient contents than crop plants.

Alkamper (1976) made the following observations:

- The nitrogen concentrations of weeds range from 1.0 to 3.8% and are usually higher than those of crop plants.
- The phosphorus content of weeds is about 0.5%, about the same as that in growing cereal plants.
- Potassium contents in most weeds are extremely high (levels range from 1.5 to 5.0%); in growing cereal plants they range from 1.8 to 2.2%.

A certain amount of nutrients taken up by the rice will suffice for the production of 1 kg dry matter. Weeds consuming the same amount of nutrients will produce considerably less (Grummer 1970).

Chakraborty (1973) reported that almost every weed species in a mixed vegetation contained more nitrogen at all stages of rice growth than did Dular rice grown in upland conditions indicating the severe nature of nitrogen competition due to weeds (Table 1). The nitrogen content of the grassy weeds was higher than that of the sedges, a feature also observed by Pande and Bhan (1966).

Pande and Bhan (1966) reported that the nitrogen and phosphorus contents of weeds were much higher than those of rice plants especially at low fertilizer rates. The nitrogen and phosphorus contents of the weeds decreased with increase in nitrogen fertilizer rate. Those for rice decreased initially at low fertilizer levels and then increased at higher fertilizer levels (Table 2).

The data of Varamisra (1976) indicate that in the nonweeded plots, the nitrogen content increased, remained relatively stable or decreased as the nitrogen level increased, depending on the time of sampling (Table 3). The nitrogen content at any one nitrogen level also varied with sampling time. For rice in competition with weeds, the nitrogen content increased with nitrogen level at 30 and 60 DT. At 94 to 99 DT, no difference was observed. For all nitrogen levels, the nitrogen content of the rice decreased as the plant grew older. Similar relationships were observed in the weeded plots. Weeding led to a significant increase in the nitrogen content of the rice.

The difference in the plants' ability to absorb nutrients from the soil may depend on the size of the root system and the inherent characteristics of the roots themselves. A large ramifying root system is important in absorbing available nutrients and water from deep soil layers as well as in more completely exploiting supplies in the plow layer.

Period of greatest competition for nutrients

Weeds usually grow faster than crop plants and thus, absorb the available nutrients earlier

resulting in a lack of nutrients for the crop plants. Competition between cereal crops and weeds is primarily for nitrogen with the most intense competition occurring in the early stages of crop growth (Blackman and Templeman 1938).

Singh and Singh (1939 as cited in Chakraborty 1973) found that the maximum uptake of nitrogen by weeds occurred at preflowering. Noda (1973) stated that competition for nitrogen is most severe during the first half of the rice growing season. Shetty and Gill (1974) observed that the rate of increase in the uptake of nutrients was proportional to the increase in dry matter and was rapid during the first 6 weeks after transplanting (WT). The most critical period of weed competition was 4 to 6 WT and competition for nitrogen was maximum from 4 to 8 WT.

Uptake of nutrients by weeds invariably results in a reduced nutrient uptake by the crop resulting in decreased yield.

Reduced yields from weeds are generally proportional to the extent and duration of weed infestation because the production potential of land during the growing period is utilized jointly by the crops and weeds.

Table 1. Nitrogen content (%) of weeds and Dular rice plants at different growth stages. (From Chakraborty 1973)

Weed species	N content (%) Growth stage			Av
	Early vegetative	Flowering	Seed formation	
Lindernia ciliata	2.07	1.74	1.26	1.69
Murdannia nudiflora	2.10	1.43	1.51	1.68
Cyperus exaltus	2.44	1.57	0.50	1.50
Digitaria sp.	3.14	0.78	0.25	1.39
Echinochloa colona	2.80	0.78	0.64	1.41
Fimbristylis littoralis	2.07	1.57	0.52	1.39
Gomphrena celosioides	1.74	1.26	0.78	1.26
Ludwigia perennis	3.50	1.43	0.76	1.90
Melochia concatenata	2.81	2.72	2.24	2.59
Mollugo pentaphylla	2.07	1.74	1.26	1.69
Hedyotis corymbosa	2.44	1.43	1.26	1.71
Trianthema monogyna	2.87	2.62	2.52	2.67
Vandellia crustacea	4.01	2.21	0.25	2.16
Av, all weed species	2.62	1.64	1.06	1.77
Rice	2.15	0.77	0.50	1.44

Table 2. Effect of weed population and nitrogen application on the nutrient content of weeds and dryland rice. (Adapted from Pande and Bhan 1966)

N fertilizer rate (kg/ha)	Nutrient content (%)[a]					
	Nitrogen			Phosphorous		
	Weeds	Rice		Weeds	Rice	
		Nonweeded	Weeded		Nonweeded	Weeded
0	3.15	1.11	1.22	0.247	0.147	0.164
30	2.24	1.09	1.36	0.223	0.135	0.162
60	1.73	1.45	1.55	0.154	0.161	0.181

[a] 2-year averages.

Amounts of nutrients absorbed

Noda et al (1968) reported that crops plus weeds from a nonweeded area will absorb about the same amount of nitrogen as the crop from a weed-free plot (Table 4). The data of Boerema (1963) indicate that about the same amounts of nitrogen and phosphorus were taken up by plants in the nonweeded and weeded plots (Table 5). A similar observation has been made for nitrogen uptake in dry-seeded wetland rice at IRRI (Table 6). Ike (1963) observed this relationship after peak tillering and stated that the amount of nitrogen absorbed by the rice plants was inversely proportional to the amount of weeds growing. Kleinig and Noble (1968) stated that the final grain yield for any given level of nitrogen or phosphorus was inversely related to the density of Echinochloa crus-galli (L.) Beauv. prior to permanent flooding. Superphosphate intensified competition as the nitrogen level increased.

Chisaka (1966) reported that the weight of rice at maturity decreased approximately proportionally to the amount of nitrogen absorbed by the weeds irrespective of the weed species.

Several authors support the findings of Noda et al (1968) with respect to the uptake of nitrogen, phosphorus, and potassium (Table 7). On the other hand, data of other authors reveal that the uptake of these elements may be greater or less in the weed-free plot than in the nonweeded plot (Table 7).

For example, Chakraborty (1973) reported that the uptake of nitrogen by rice in a plot hand weeded 3 times was 54.7% less than that taken up by weeds in the nonweeded check. The total amount of nitrogen taken up by rice and weeds was 1.8 times higher in the nonweeded check than in the plot weeded 3 times. In contrast, the amount of nitrogen taken up by the rice in the weeded plot was an average of 1.9 times higher than that taken up by rice and weeds in the nonweeded plot (Mukhopadhyay et al 1972).

Table 3. Effect of nitrogen fertilizer on nitrogen content (%) of rice and weeds in the nonweeded plots at different sampling times. (From Varamisra 1976)

Time of sampling[a/]	N level (%)		
	0	50	100
Weeds			
30 DT	0.84	0.95	1.02
60 DT	0.86	0.88	0.86
94-99 DT	1.18	0.95	0.92
Rice			
30 DT	1.85	1.83	2.08
60 DT	0.89	0.93	1.10
94-99 DT	0.70	0.69	0.68

[a/] DT = days after transplanting.

Table 4. Changes in the amount of nitrogen absorbed (mg/m^2) by rice and weeds as affected by growth stage and weed density. (From Noda et al 1968)

Plant species[a/]	Sampling date		
	22 Jul	22 Aug	12 Sep
R	5.7	12.7	12.4
E (0)	0	0	0
R + E (0)	5.7	12.7	12.4
R	5.9	11.9	10.6
E (5)	0.3	0.1	1.2
R + E (5)	6.2	12.0	11.8
R	5.3	9.3	9.1
E (20)	0.8	0.7	3.8
R + E (20)	6.1	10.0	12.9
R	4.5	7.4	5.6
E (80)	1.2	4.0	6.9
R + E (80)	5.7	11.4	12.5
R	3.8	3.9	3.4
E (320)	3.0	8.3	9.2
R + E (320)	6.8	12.2	12.6

[a/] R = rice, E = Echinochloa crus-galli. Numbers in parenthesis indicate number of Echinochloa crus-galli plants per square meter.

Table 5. Nitrogen and phosphorus uptake (kg/ha) by rice and Echinochloa crus-galli as affected by herbicide application. (Adapted from Boerema 1963)

	Experiment 1				Experiment 2	
	Nonweeded		Weeded[a/]		Nonweeded	Weeded[b/]
	N	P	N	P	N	N
Rice	36.8	7.3	99.7	18.5	15.5	111.8
Echinochloa crus-galli	56.3	14.4	-	-	94.1	1.1
Total	93.1	21.7	99.7	18.5	109.6	112.9

[a/] 4.5 kg propanil/ha applied at the 1-3 leaf stage of the grassy weeds 4 days before irrigation.
[b/] 4.5 kg propanil/ha applied at the 4-7 leaf stage of the grassy weeds 6 days before irrigation.

The amounts of nutrients removed by weeds growing in association with rice are extremely variable (Table 8) and dependent on many factors. As a result, the extent to which yield is affected by weed competition for nutrients varies greatly.

Table 6. Nitrogen uptake (kg/ha) by dry-seeded wetland rice and weeds 60 days after emergence as affected by weed control.

Method of weed control	Experiment 1[a]			Experiment 2[b]		
	Rice	Weeds	Total	Rice	Weeds	Total
Weeded twice[b]	42.2	5.1	47.3	51.0	8.8	59.8
No weeding	22.8	24.5	47.3	26.0	24.9	50.9

[a] Av of eight methods and times of application of nitrogen and three replications. [b] 2 and 5 weeks after emergence.

The obvious agronomic approaches to minimize the magnitude of weed competition for nutrients are to add fertilizers and to remove weeds. The possibility of substituting fertilizer for weed control needs to be explored. However, because fertilizer is more expensive than weeding it is unlikely that this will occur.

Addition of fertilizer

In California, high nitrogen fertilizer compensated for yield losses from poor weed control in two cultivars (Rice Research Board 1976). However, increased fertility levels need not necessarily overcome weed competition. On the contrary, higher fertility levels often cause proportionately greater weed growth and crop yield reduction. According to Alkamper (1976), damage from weeds can be eliminated by increased fertilizer rates only in field crops where the level of infestation is

Table 7. Comparison between the total nutrient uptake by rice and weeds in weeded and nonweeded plots.

Weeded > nonweeded (at least 10% greater)	Reference
N	
Transplanted rice	Nanjappa and Krishnamurthy 1980, Shahi et al 1979
Wet-seeded rice	Moorthy and Dubey 1979
Dryland rice	Mukhopadhyay et al 1972
P	
Transplanted rice	Shahi et al 1979
Weeded = nonweeded (within 10%)	
N	
Transplanted rice	Mani et al 1976, Noda et al 1968, Sankaran et al 1974a, Shetty and Gill 1974
Wet-seeded rice	Reddy and Hukkeri 1980
Dry-seeded wetland rice	Boerema 1963
P	
Transplanted rice	Nanjappa and Krishnamurthy 1980, Reddy and Hukkeri 1980, Sankaran et al 1974a, Shetty and Gill 1974
Dry-seeded wetland rice	Boerema 1963
K	
Transplanted rice	Nanjappa and Krishnamurthy 1980, Sankaran et al 1974a, Shetty and Gill 1974
Wet-seeded rice	Reddy and Hukkeri 1980
Weeded < nonweeded (at least 10% less)	
N	
Dryland rice	Chakraborthy 1973
P	
Dry-seeded wetland rice	French and Gay 1963
K	
Transplanted rice	Shahi et al 1979

low. In heavily infested fields, fertilization will often have an opposite effect and stimulate weed growth to such an extent that the crop plants will consequently suffer severe damage. At low fertility levels, competition will be primarily for soil nutrients; at high fertility levels, competition will be for light.

Alkamper and Do van Long (1978) stated that because weeds take up nutrients faster than most crops, it must be expected that applications of fertilizers must lead to more competition between weeds and crops. Weeds absorb a substantial proportion of the nutrients from fertilizer applications and may benefit from applied fertilizer to a

Table 8. Nutrient uptake (kg/ha) of weeds growing in association with rice grown in different methods of culture. [a]

	Nutrient uptake (kg/ha)						
	Nitrogen		Phosphorus		Potassium		Calcium
	Range	Mean	Range	Mean	Range	Mean	Mean
Transplanted rice	2.8-73.1	24.9(9)	0.8-22.8	11.2(7)	3.1-126.6	36.5(7)	18.3(1)
Wet-seeded rice	7.3-62.1	27.0(8)	0.8-20.0	6.6(5)	27.5- 64.8	44.8(5)	-
Dry-seeded wetland rice	24.0-94.1	58.1(3)	-	5.1(1)	-	48.4(1)	-
Dryland rice	14.8-93.1	44.7(10)	1.4-24.9	9.3(3)	-	90.5(1)	-

[a] Figures in parentheses indicate number of observations. References: Transplanted rice: Kakati and Mani 1977, Mani 1975, Mani et al 1976, Mukhopadhyay 1974 (cited in Mukhopadhyay 1978), Pillai et al 1976, Sankaran et al 1974a, Shahi et al 1979, Taguchi 1931 (cited in Ike 1963). Wet-seeded rice: Kaushik and Mani 1977, 1980; Mani et al 1976; Moorthy and Dubey 1979; Mukhopadhyay and Maiti 1975; Ramamoorthi et al 1974a,b; Reddy and Hukkeri 1980; Rethinam and Sankaran 1974. Dry-seeded wetland rice: Boerema 1963, Kakati and Mani 1977. Dryland rice: Chakraborty 1973, Mukhopadhyay et al 1972, Pande and Bhan 1966, Pillai et al 1976.

Table 9. Effect of fertilizer application on weed weight, yield reduction due to weeds, and yield of transplanted rice. [a]

Range of fertilizer applied (kg/ha)	Effect of increase in applied fertilizer on		Yield of nonweeded fertilized vs weeded nonfertilized	Cultivar	Reference
	Weed weight	% yield reduction due to weeds			
N					
0-60	+	-	-30%	H4	De Datta et al 1969
0-60 (wet season)	-	+	-87%	C4-63	Vega et al 1971
0-60 (dry season)	+	+	-92%	C4-63	Vega et al 1971
0-100	-	+	+86%	C4-63	Varamisra 1976
0-120	?	+	-25%	C4-63	Vega and Punzalan 1968
0-120	?	+	-94%	IR8	Vega and Punzalan 1968
0-120	+	+	- 1%	IR8	De Datta et al 1969
0-120	+	+	-26%	C4-63	IRRI 1973
0-120	+	+	-81%	IR305-4-12	IRRI 1973
0-?	+	-	+17%	B462e-Pn-1-3	Bahar and Abbas 1977
NP					
0:0-60:30 (wet season)	+	-	-81%	C4-63	Vega et al 1971
0:0-60:30 (dry season)	+	+	-87%	C4-63	Vega et al 1971

[a] + = increase, - = decrease. Other references: Deomampo 1968, Francisco 1974, Kakati and Mani 1977, MARDI 1977, Siriwardana and Amarasinghe 1981.

greater extent than crop plants. Although weed weights generally increase as a result of fertilizer application (Tables 9 to 11), decreases (Vega et al 1971, Varamisra 1975) and variable responses (Pande and Bhan 1966, Okafor and De Datta 1976) have been reported. Pande and Bhan (1966) found that the relationship between weed dry weight and level of applied nitrogen was quadratic.

Sarkar and Ghosh (1978) reported that the number and weight of weeds 30 DT were highest at the highest nitrogen level. At 60 DT and at maturity, the highest number and weight of weeds were at the lowest level of applied nitrogen.

Increasing fertility not only increases weed weight but also generally decreases weed density. Weeds at high fertility grow faster and to larger sizes than those at low fertility. The most successful of these plants exert strong competition on the slower-growing individuals. The death rate from this competition is high, and at maturity only a few, large plants remain. At lower fertility levels, the weeds grow more slowly, the death rate from competition is lower, and at maturity, there are a large number of small plants. Thus, increasing environmental severity reduces both plant stature and overall plant mortality. A good illustration is in the data of Kim and Moody (1980) for Monochoria vaginalis (Burm.f.) Presl.; plantheight, leaf area, and dry weight of individual plants increased and plant density decreased as nitrogen level increased.

Density and mean plant weight are linked together by an exponential or logarithmic relationship. Yoda et al (1963) presented data on the average weight per surviving plant and the numbers surviving per unit area in self-thinning populations. For a number of species, the data could be fitted approximately by a straight line on a log versus log plot with a slope close to -3/2. The mean area per plant (which is the reciprocal of density) varies as the square of a linear dimension such as diameter or height, whereas the mean weight per plant varies as the cube of a linear dimension. Mean weight per plant then varies as the 3/2 power of the mean area per plant, or the -3/2 power of density.

The data of Kim and Moody (1980) provide a good illustration.

The relationship between the mean weight per M. vaginalis plant (w) and plant density (p) at rice heading at 3 fertility levels at a rice spacing of 20 x 20 cm is given in Figure 1. The calculated regression line was $\log w = 3.93 - 1.54 \log p$, or $w = 3.93\ p^{-1.54}$. The slope of the line is close to the idealized gradient of -1.5 reported by Yoda et al (1963).

Increasing the rate of applied fertilizer will generally result in increased yield in the absence of weeds. In the presence of weeds, yields also generally increased as the level of applied fertilizer increased (Tables 9 to 11).

The magnitude of increase was usually greater in the weeded plots than in the nonweeded plots. However, yield decreases occurring as a result of fertilizer application in nonweeded plots were reported by Vega and Punzalan (1968), Vega et al (1971), and IRRI (1973) for transplanted rice; De

Table 10. Effect of nitrogen application on weed weight, yield reduction due to weeds, and yield of wet-seeued and dry-seeded wetland rice. a/

Range of nitrogen applied (kg/ha)	Effect of increase in applied nitrogen on: Weed weight	% yield reduction due to weeds	Yield of nonweeded fertilized vs weeded nonfertilized	Cultivar	Reference
		Wet-seeded rice			
0-60	+	+	+30%	H4	De Datta et al 1969
0-120	+	+	-22%	IR8	De Datta et al 1969
		Dry-seeded wetland rice			
0-120	+	+	-65%	IAC 435 and IR841	Alvarenga et al 1979
0-135	?	+	+42%	Bg11-11	Siriwardana and Amarasinghe 1981

a/ + = increase, - = decrease. Other references: Dry-seeded wetland rice: Kakati and Mani 1977; Kleinig and Noble 1968, 1969.

Datta et al (1969) for wet-seeded rice; Alvarenga et al (1979) for dry-seeded wetland rice. Greater yield increases in the nonweeded plots than in the weeded plots were reported by De Datta et al (1969), Vega et al (1971), and Bahar and Abbas (1977) for transplanted rice; and Pande and Bhan (1966) and Okafor and De Datta (1976) for dryland rice. Thus, the percentage of yield reduction due to weeds decreased as the level of applied fertilizer increased (Tables 9 to 11).

Blackman and Templeman (1938) also observed that application of nitrogenous manure to cereals raised the yield of the weedy crops to a level similar to that of a weed-free crop grown without added nitrogen. French and Gay (1963) stated that yield increase obtained by fertilization without appropriate weed control measures are about the same order as those achieved by weed control alone without the addition of fertilizers.

For example, Sanguansri et al (1970 as cited in Varamisra 1976) found that hand weeding once 30 DT gave a 20% yield increase over the nonweeded check which was equivalent to that obtained from the addition of 160 kg N/ha without weeding.

However, in the majority of cases, the yield of the nonweeded fertilized plot was considerably lower than that of the weeded plot to which no fertilizer has been added (Tables 9 to 11). Higher yields have also been reported but in only one other instance (De Datta et al 1969) was the yield of the nonweeded fertilized plot equivalent to that of the weeded nonfertilized plot.

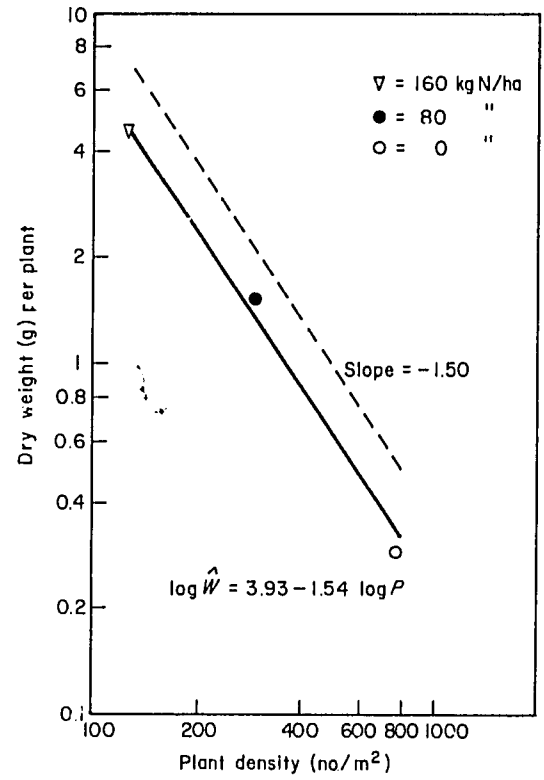

Fig. 1. Relationship between mean weight per plant and plant density for three levels of applied nitrogen. (Adapted from Kim and Moody 1980)

Table 11. Effect of fertilizer application on weed weight, yield reduction due to weeds, and yield of dryland rice. a/

Range of fertilizer applied (kg/ha)	Effect of increase in applied fertilizer on: Weed weight	Effect of increase in applied fertilizer on: % yield reduction due to weeds	Yield of nonweeded fertilized vs weeded nonfertilized	Cultivar	Reference
N					
0-80	+ (to 40 kg then -)	-	+11%	?	Pande and Bhan 1966
0-120 (early wet season)	+ (to 60 kg then -)	-	+46%	IR5	Okafor and De Datta 1976
0-120 (late wet season)	+	+	+100%	IR5	Okafor and De Datta 1976
0-120	+	+	+50%	IR442-2-58	Okafor and De Datta 1976
NP					
0:0-60:60 (1961)	+	+	-29%	?	Pande and Bhan 1966
0:0-60:60 (1962)	+	+	-23%	?	Pande and Bhan 1966

a/ + = increase, - = decrease. Other references: CRIA 1976, Riyanto 1977.

At low nitrogen levels, plants compete first for nitrogen in the soil and later for light whereas with an adequate supply of nitrogen plants compete primarily for light (Kawano et al 1974, Kim and Moody 1980, Zimdahl 1980). Greater yield losses due to weeds have been observed at low and high levels of applied nitrogen than at intermediate levels (Fig. 2; BRRI 1980, Kim and Moody 1980). Thus, where weed control is poor, it is probably best to apply fertilizer at some level lower than that needed to produce maximum yields. However, Pande and Bhan (1966) reported that nitrogen applied at rates up to 60 kg/ha increased both crop and weed growth; an increased rate (up to 80 kg N/ha) nearly doubled the crop yield but reduced that of the weeds indicating that rice became more competitive as nitrogen level increased. Similar results were observed in California (Rice Research Board 1976).

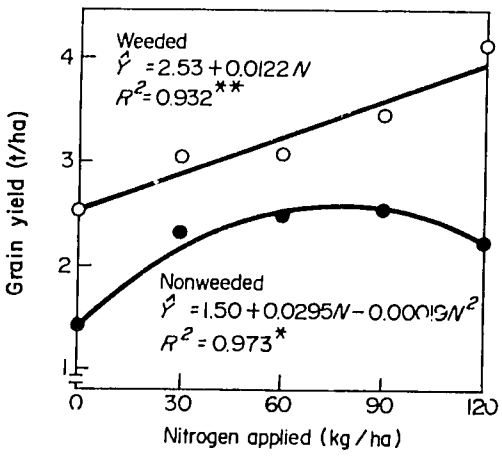

Fig. 2. Nitrogen response of transplanted rice grown under intermittent irrigation as affected by weed control levels. IRRI, 1973 wet season. (From IRRI 1974)

Kim and Moody (1980) also reported that the yield reduction due to weed competition varied depending on the nitrogen level. A lower weed weight was required to reduce rice yield 50% when 0 or 160 kg N/ha had been applied than when 80 kg N/ha was added.

Chang (1970) stated that weeds such as E. crus-galli and Cyperus difformis L. which compete highly with rice for light are more likely to compete more severely with rice in fields to which high fertilizer rates have been added. However, in fields where a low fertilizer rate has been applied, weeds such as M. vaginalis and Marsilea quadrifolia L. which compete more for soil nutrients may have a greater effect on rice. Kim and Moody (1980) observed that at 0 and 80 kg N/ha, the canopy level of M. vaginalis plants was located below the rice plants (Fig. 3). At 160 kg N/ha, however, the situation was reversed; the rice canopy was located below the M. vaginalis canopy indicating that M. vaginalis was much more competitive for light at the highest level of applied nitrogen (Fig. 3).

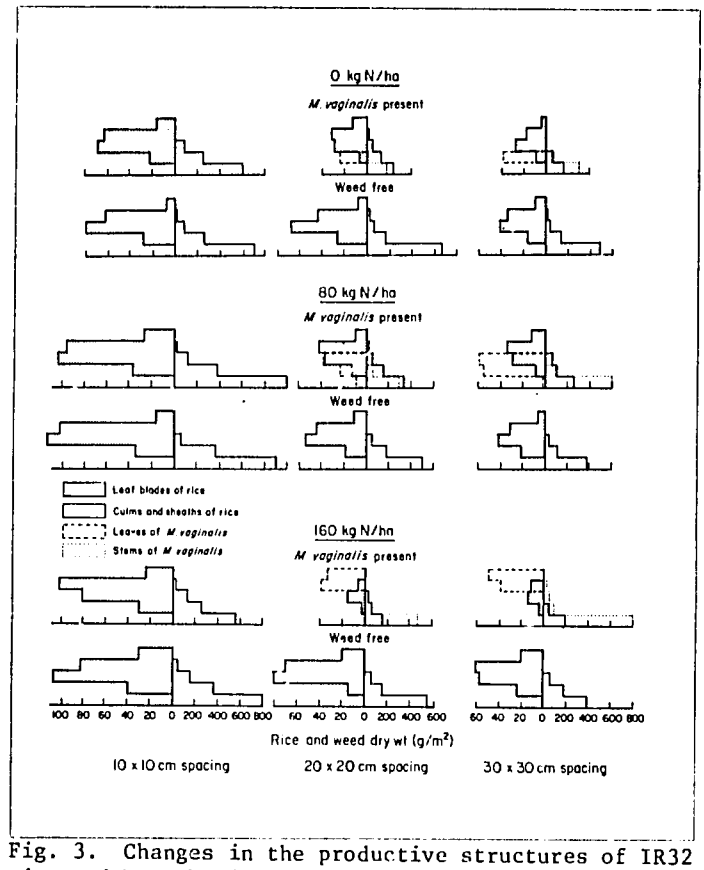

Fig. 3. Changes in the productive structures of IR32 rice and Monochoria vaginalis as affected by crop spacing and nitrogen level. IRRI, 1978 wet season. (Adapted from Kim and Moody 1980)

Time of fertilizer application

Weed growth in rice is usually stimulated by the application of nitrogen and phosphorus but the amount of weed growth and the resultant competition can be reduced by selecting methods and times of fertilizer application that are more advantageous to the rice than to the weeds.

Fertilizer application should be timed so as to prevent weed proliferation and yet obtain maximum benefit for the crop from the applied fertilizer (Moody 1977).

However, the method chosen may not result in maximum yield. It may be merely a compromise to reduce weed competition to a minimum.

The degree of damage due to weeds varies with the time and method of fertilizer application even though the same total amount is applied during the growing season.

Nitrogen

If nitrogen is applied to the rice crop, its effect on the rice will be maximized if weeds are not present. Therefore, weeds should be controlled before nitrogen application otherwise weed competition may increase to such an extent that crop

yield may be lower than if no fertilizer had been applied. Also a considerable portion of the added nitrogen may be used by the weeds, thus higher amounts of nitrogen will be needed to obtain maximum rice yields (Smith 1960, Hoopper 1981).

Matsunaka (1970) suggests that where effective control of weeds is not possible, nitrogen application should be delayed until the rate of nitrogen uptake by the weeds has slowed and more will be available to the competing crop. However, whether this will be effective or not will depend on the growth stage of the crop when the fertilizer is applied.

Application to or carry-over from the previous crop

Boerema and McDonald (1965) found E. crus-galli competition to be more severe in rice planted after pasture and they attributed this partly to improved soil fertility.

Kleinig and Noble (1968) noted that the soil nitrogen accumulated from a pasture consisting of subterranean clover (Trifolium subterraneum L.) and Wimmera rye grass (Lolium rigidum Gaud.) increased the competitive ability of Echinochloa spp. against rice.

Moody (1979) reported that weeds grew more profusely in the fallow period prior to transplanting rice and in transplanted rice in areas where watermelon (Cucumis melo L.) had been planted and fertilized in the previous dry season. Data in Table 12 for two provinces in the Philippines support these findings.

In Iloilo province, the rice plants and the weeds were significantly taller in the areas that had been previously fertilized. There was no significant difference between the number of weeds growing in each area.

Application before planting

Transplanted rice. Method of fertilizer placement affects the degree of weed competition in transplanted rice (Table 13). Deep placement resulted in the highest yields in both the weeded and the nonweeded plots and the least yield reductions due to weeds. These differences in yield reduction between placement methods could be related to the weed flora and the fact that when the fertilizer was deep placed, the rice plants were taller, produced more tillers, and had a greater leaf index than when applied by other means. In Indonesia,

Table 12. Effect of fertilizing watermelon during the dry season on weeds growing in the subsequent fallow or transplanted rice crop in two provinces in the Philippines.

Province and field number	Weed weight (g/m^2)		
	Previously fertilized area	Adjacent nonfertilized area	Difference[a]
Laguna (Fallow)			
1	320.4	122.3	198.1**
2	301.5	153.0	148.5**
3	213.9	117.8	96.1*
4	242.2	53.0	189.2**
5	204.8	40.9	163.9**
6	209.1	67.4	141.7**
Laguna (Transplanted rice)			
1	293.6	74.6	219.0**
2	274.9	60.2	214.7**
3	209.6	48.3	161.3**
Iloilo (Transplanted rice)			
1	78.3	47.1	31.2^{ns}
2	172.1	65.4	106.7**
3	118.5	84.4	34.1^{ns}
4	116.2	58.3	57.9**
5	70.9	65.4	5.5^{ns}

[a] * = significant at the 5% level, ** = significant at the 1% level, ns = not significant.

Sundaru (pers. comm.) observed that deep placement of fertilizer resulted in vigorous growth of the rice plants and decreased weed infestation.

However, De Datta et al (1974) reported that the greatest yield loss due to weeds occurred when the first fertilizer application was made 10 DT and the least when made before transplanting (Table 14). However, in terms of yield in the weeded plots, the best time to apply a small amount of nitrogen was 5 to 7 days before panicle initiation (De Datta et al 1974). Thus, the presence of weeds necessitated a change in timing of fertilizer application to optimize yields.

Water-seeded rice. In California, the fertilizer is drilled or disced 5 to 10 cm below the soil surface just before flooding for seeding. This technique enables the rice to compete successfully with weeds (Adair et al 1962). However, Smith and Shaw (1966) note that nitrogen application before seeding stimulates growth of aquatic weeds and reduces efficient utilization of nitrogen by rice.

Dry-seeded wetland rice. In dry-seeded wetland rice, weed growth is stimulated if nitrogen is applied before planting (Moody 1977) or just after rice emergence (Smith 1960). The nitrogen fertilizer applied at planting will stimulate weed growth and be used up by the weeds since the small rice plants cannot compete strongly with the weeds (Ignatief and Page 1960, Moody and Mian 1979).

Placing the fertilizer so that it is more available to the crop than to the weeds is a useful technique to reduce weed competition.

In Indonesia, Saefuddin et al (1978) reported that in weedy conditions, yields were superior when 40 kg N/ha was placed in the root zone compared to 80 kg N/ha applied as a surface band. In the Philippines, in the wet season, Polthanee (1980) observed, at 20 days after emergence (DE), a significantly greater weed weight in the plots that

Table 13. Yield (t/ha) of weeded and nonweeded plots and percentage of reduction in yield due to weeds in transplanted rice as affected by method of nitrogen application.

Method of N application	Yield[a] (t/ha)		% yield reduction due to weeds
	Weeded twice	Nonweeded	
Mudball[b]	5.2	4.2	19.2
Supergranule[c]	4.9	3.8	22.4
Split application[d]	4.2	3.1	26.2
Split application[e]	3.8	2.8	26.3
Sulfur-coated urea[f]	4.4	2.9	34.1
Band application[g]	4.8	3.1	35.4

[a]Av of two cultivars. [b]All applied 5 days after transplanting (DT). [c]All applied 4 DT. [d]One-third 10 DT, one-third 30 DT, one-third at panicle initiation. [e]Two-thirds basal, one-third 5 to 7 days before panicle initiation. [f]All applied basal. [g]All applied 10 DT.

Table 14. Interactions of weed control methods and time of nitrogen application of grain yield of transplanted rice. (Adapted from De Datta et al 1974)

Fertilizer treatment[a]	No weed control	Weeded[a]			% yield reduction due to weeds
		2,4-D	Hand weeding 30 + 40 DT	Av	
All basal	3.0	3.7	4.3	4.0	25.0
2/3 basal + 1/3 at PI	2.5	4.7	4.1	4.3	41.9
1/3 basal + 1/3 30 DT + 1/3 at PI	3.2	3.5	4.4	4.0	20.0
All 5-7 days before PI	3.1	4.1	5.0	4.6	32.6
1/3 10 DT, 1/3 40 DT, 1/3 at PI	2.2	4.3	4.2	4.3	48.8
Nonfertilized	2.5	3.6	4.0	3.8	34.2

[a]PI = panicle initiation, DT = days after transplanting.

received a broadcast application of nitrogen than in those that received a band application or when the fertilizer was broadcast before the first plowing. In the dry season, there was no significant difference in weed weight as a result of method or time (basal or 10 DE) of nitrogen application. Pernito (1981) reported that neither weed weights nor weed counts were affected as the level of nitrogen applied basally increased from 0 to 80 kg/ha.

Ahmed and Moody (1981) reported that weed counts and weights 2 weeks after crop emergence increased linearly as the rate of basal nitrogen applied increased from 0 to 40 kg/ha. At 5 weeks after emergence, weed counts increased linearly as the rate of nitrogen applied as a topdressing increased from 20 to 60 kg N/ha. In another trial at IRRI, application of nitrogen during land preparation or at planting resulted in a significant increase in weed weight particularly grasses (Table 15). Suvanjinda (1980) observed that basal application of nitrogen significantly increased weed weight 20 DE whereas nitrogen application 30 DE significantly increased weed weight at 40 DE (Table 16).

Dryland rice. Singh et al (1975) reported no significant difference in weed weight at 50% heading and at harvest as a result of method of placement of nitrogen.

However, Noguchi and Nakayama (1978) reported that *Digitaria ciliaris* (Retz.) Koel., *Portulaca oleracea* L., and *Cyperus microiria* Steud. grew better intrarow than interrow when the fertilizer was band placed in the row but better interrow when the fertilizer was broadcast. The growth of *P. oleracea* and *C. microiria* was better when the fertilizer was broadcast than when band placed (Table 17).

Application after planting

Transplanted rice. Arai and Kawashima (1956) and Chisaka (1966, 1977) reported greater yield loss when nitrogen was applied as a split application than when applied as a basal dressing. Chisaka (1966) claimed that this was because the weeds benefited most when nitrogen was topdressed (Fig. 4), which resulted in enhanced competition for light at a later growth stage and a significant reduction in rice yield. Chisaka (1966) saw little possibility in reducing the damage by using split fertilizer applications.

However, the data of De Datta et al (1974) and Bahar and Abbas (1977) indicate that whether the yield loss due to weeds is greater when the fertilizer is applied as a split application or when it is applied basally depends on the time of fertilizer application (Table 14).

Wet-seeded rice. In Iloilo province, Philippines, the first fertilizer application in wet-seeded rice is applied 20 to 25 days after seeding after the crop has been weeded. One of the reasons given is to avoid abundant and vigorous weed growth.

Table 15. Weed weight (g/0.5 m^2) 3 weeks after emergence as affected by method of nitrogen application. IRRI, 1980 wet season.[a]

Method of fertilizer application	Weed weight (g/0.5 m^2)		
	Broadleaf weeds	Grasses	Sedges
Broadcast-incorporated	21.2 ab	76.2 a	6.7 ab
Broadcast-surface applied	23.9 a	67.8 a	10.6 a
Broadcast-plowed down	16.4 ab	60.1 a	5.0 b
Broadcast-after first weeding[b]	9.3 b	26.8 b	5.5 b

[a] Av of two methods of weeding and three replications. In a column, means followed by a common letter are not significantly different at the 5% level. [b] Not applie before weed sampling.

Table 16. Weight of weeds growing in association with dry-seeded rice as affected by time of nitrogen application. (Adapted from Suvajinda 1980)

Time and rate (kg/ha) of nitrogen application		Weed weight[a] (g/m^2)	
Basal	30 days after emergence	20 days after emergence	40 days after emergence
0	0	64.0 a	21.3 a
0	30		38.9 b
30	0	83.2 b	21.0 a
30	30		36.4 b

[a] Plots were hand weeded 20 days after emergence.

Table 17. Weed dry weight (g/m^2) as affected by weed location and method of fertilizer placement. (From Noguchi and Nakayama 1978)

Fertilizer placement method	Weed location	Weed species		
		Digitaria ciliaris	*Portulaca oleracea*	*Cyperus microiria*
Band	Intrarow	0.55	0.18	0.03
	Interrow	0.25	0.08	0.01
Broadcast	Intrarow	0.18	0.30	0.04
	Interrow	0.48	0.69	0.09

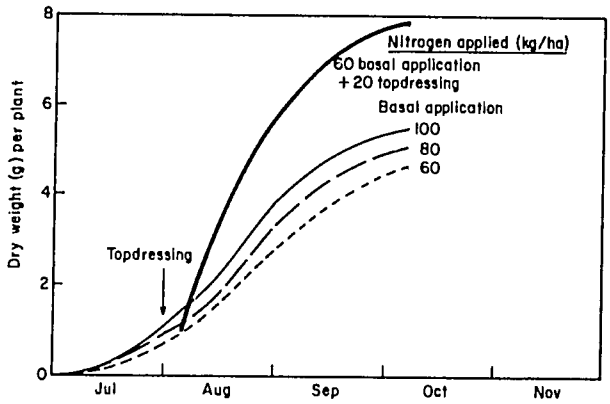

Fig. 4. Growth of Echinochloa crus-galli as affected by time and amount of nitrogen application. (From Chisaka 1966)

Dry-seeded wetland rice. Nitrogen stimulates the growth of Echinochloa spp. if applied either before dry seeding or during the vegetative growth of the weed. Nelson (1931) reported that yield increases were sometimes obtained when fertilizer was applied 3 to 4 weeks after seeding. However, these increases were not consistent and weeds also increased with this practice. Smith (1960), Adair et al (1962), and Matsunaka (1970) observed that nitrogen applications that were delayed until after Echinochloa spp. headed benefited rice more than when nitrogen was applied earlier. Mature grass plants utilize less nitrogen than young vegetative ones. Therefore, nitrogen applied when grass weeds are mature is more available to the rice than to the grass (Smith and Shaw 1966). Whether such a practice is effective in increasing crop yield will depend on the growth stage of the crop when the fertilizer is applied. Generally, though, for short-duration cultivars, if stimulation of weed growth is avoided by delaying nitrogen application until heading of the grass, it will probably be too late for the crop to benefit. According to Kleinig and Noble (1969), there was no yield advantage in applying nitrogen later than 20 days after sowing even though there was a marked increase in the number of tillers when nitrogen was applied 80 to 120 days after sowing in the presence and absence of weeds.

When rice plants are small, they do not require nor can they use much nitrogen. Nitrogen application should be delayed until after weeds have been removed (Saefuddin et al 1978, Moody and Mian 1979) or until after some weed control has been achieved by flooding (Evatt 1965). This way the crop, not the weeds, will benefit from the added nitrogen.

Dryland rice. Riyanto (1977) reported that the weed biomass was unaffected by the rate or time of nitrogen application. Yield reductions due to weeds ranged from 71 to 80% whether the fertilizer was applied all basally or as split applications.

Sequential fertilizer application

Nelson (1931) reported that fertilizer applied to dry-seeded wetland rice for 2 consecutive years resulted in an increase in weeds and reduced rice yields in nonweeded plots.

Method of land preparation

Olofintoye (1980) reported that for dryland rice, the response of weeds to the time and method of nitrogen application was dependent on the method of land preparation (Table 18). With conventional tillage, greater weed weight was obtained when the nitrogen was applied as a split application. With zero tillage, greater weed weight was obtained when all the nitrogen was applied basally. With the stale-seedbed technique, the weed weight was unaffected by the time of nitrogen application.

Table 18. Weed weight (g/m^2) at harvest of C-22 rice grown in dryland conditions as affected by method of land preparation and time and method of fertilizer application (From Olofintoye 1980)

Method of land preparation	Time of N application[a]		Method of N placement[a]	
	Basal[b]	Split[c]	Band	Broadcast
Zero tillage	658.8 e	420.3 d	434.8 c	641.3 d
Stale-seeded	261.1 c	300.8 c	281.4 b	281.5 b
Conventional tillage	29.6 a	84.0 b	54.5 a	59.1 a

[a] Within a time or method of nitrogen application in a column or row, means followed by a common letter are not significantly different at the 5% level. [b] All nitrogen applied at seeding. [c] One-third N applied at seeding, one-third 15 days after seeding (DS), and one-third 50 DS.

With zero tillage, greater weed weights were recorded when the fertilizer was broadcast than when band applied. With the other tillage methods, the method of fertilizer placement had no effect on the weed weight.

In wet-seeded rice, puddling twice at 15 day intervals and soil compaction resulted in better weed control and reduced uptake of nitrogen, phosphorus, and potassium by weeds compared to puddling once and the conventional land preparation techniques (Reddy and Hukkeri 1980).

Cultivar grown

The modern cultivars which are short statured and have upright leaves allow more light to penetrate the crop canopy and respond better to nitrogen

than the taller, leafier, traditional cultivars. They do not compete with weeds as well as the traditional cultivars. Adoption of modern cultivars and increased application of nitrogenous fertilizers have generally resulted in increased weed growth as well. Higher light penetration through the crop canopy combined with high levels of nitrogen stimulate weed growth (Johnston et al 1967, Smith 1970). Thus, there is the potential for substantial yield reductions in the improved cultivars as a result of weed competition. However, for two modern cultivars, the Rice Research Board (1976) reported that weed control increased yields by nearly the same amount in each cultivar with the increases greatest where nitrogen was low and least where nitrogen was high.

Traditional cultivars extract nitrogen and other nutrients from the soil with great efficiency. They develop extensive root systems, drawing on a large soil volume, and exhibit vigorous growth which suppresses weeds that compete for the available nutrients (Jennings 1976). Kawano et al (1974) listed high rate of nitrogen absorption in the early growth stages as one of the most significant characters related to competitive ability.

Vega and Punzalan (1968) showed that yield reduction due to weeds at all nitrogen levels was consistently higher in IR8, a short stiff-strawed high-tillering cultivar, than in C4-63, a cultivar having medium height and tillering (Table 19). More Scirpus maritimus L. grew in association with IR305-4-12, a semidwarf cultivar, than with C4-63 regardless of the level of nitrogen applied (IRRI 1973). The yield reduction due to weeds was greater with the shorter cultivar.

For two modern cultivars, Kim and Moody (1980) reported that when no nitrogen was applied, weeds caused greater yield reductions competing against IR38 than against IR32. However, when 80 or 160 kg N/ha was applied, the reverse was observed (Table 20).

Table 20. Effect of plant spacing and level of applied nitrogen on yield losses (%) of two transplanted rice cultivars. (Adapted from Kim and Moody 1980)

Cultivar and plant spacing (cm)	Nitrogen level (kg/ha)		
	0	80	160
IR32			
10 x 10	0	0	0
20 x 20	12.0	26.7	83.9
30 x 30	52.2	41.2	100.0
IR38			
10 x 10	0	0	0
20 x 20	25.0	10.0	76.0
30 x 30	75.0	35.3	100.0

Table 19. The influence of nitrogen on the effect of weeds on the yield of two rice cultivars. (From Vega and Punzalan 1968).

Level of applied N (kg/ha)	Weeding treatment	IR8		C4-63	
		Yield (kg/ha)	Yield reduction due to weeds (%)	Yield (kg/ha)	Yield reduction due to weeds (%)
0	Weed free	2706	72	2202	54
	Not weeded	760		1006	
30	Weed free	2547	78	2911	81
	Not weeded	549		548	
60	Weed free	3054	85	3368	83
	Not weeded	462		583	
90	Weed free	3537	87	3321	69
	Not weeded	451		1037	
120	Weed free	3177	95	3614	79
	Not weeded	168		760	

The data of De Datta et al (1969) indicate that the effect of added nitrogen on yield losses caused by weeds is dependent on the method of planting and the cultivar grown. For both cultivars, IR8 and H4, and both methods of planting, transplanting or wet seeding, the weed weight increased as the nitrogen level increased. When the cultivars were transplanted, the percentage of yield reduction due to weeds decreased from 47 to 36% for H4 as the nitrogen level increased from 0 to 60 kg N/ha; for IR8, it decreased from 26 to 22% as the nitrogen level increased from 0 to 60 kg N/ha and then increased to 40% as the nitrogen level was further increased to 120 kg N/ha.

When the rice was wet-seeded, the yield loss due to weeds increased as the nitrogen level increased for both cultivars. Losses at all nitrogen levels were, however, greater for IR8 than for H4.

Yield losses caused by Cyperus rotundus L. competing with IR5 and IR442-2-58 grown in dryland conditions increased as the nitrogen level increased in the late wet season and dry season, respectively (Okafor and De Datta 1976). Losses were greater for IR442-2-58 than for IR5.

Nanjappa and Krishnamurthy (1980) reported that the uptake of nutrients by IR20, a short-statured cultivar, was significantly greater than that by S-317, a tall, traditional cultivar, in both weeded and nonweeded conditions. There was no significant difference between cultivars in the nutrients taken up by weeds in the nonweeded plots. The grain yield of IR20 was significantly higher than that of S-317 in both weeded and nonweeded conditions. However, the yield loss due to weeds was greater with IR20 than S-317.

Crop canopy and plant population

Weed growth is usually greater at high fertility levels, which usually results in higher losses due to weeds. On the other hand, abundance of available nitrogen encourages vegetative growth of rice plants with resultant increase in the shade produced and increased ability to suppress weeds. Likewise, with diminishing fertility, the crop canopy is sparser and the crop-weed balance may be shifted in favor of the weeds. For example, Guh and Lee (1974) observed greater weed weights and greater yield losses in nonfertilized plots than in fertilized plots. They attributed this to the greater competitiveness of the rice at higher fertility levels.

The closer rice plants are sown the more competitive they are against weeds. As a result fewer weeds grow in association with them. Less nutrients should, therefore, be removed by weeds at high plant populations. Kim and Moody (1980) reported that yield losses due to weeds increased as plant spacing increased for two rice cultivars irrespective of the nitrogen level (Table 20). At the closest plant spacing, no yield loss was observed at all nitrogen levels. Complete yield loss was observed for both cultivars at the widest plant spacing and the highest nitrogen level.

Table 21. Effect of increasing the seeding rate of broadcast-seeded rice on nutrient removal 90 days after seeding by weeds growing in association with the crop. (Adapted from Ramamoorthi et al 1974b)

Seeding rate (kg/ha)	Nutrient uptake (kg/ha)		
	N	P	K
40	25.8	0.5	27.3
60	16.8	0.3	21.8
80	7.3	0.4	11.1

Ramamoorthi et al (1974b) reported decreased removal of nutrients by weeds as the seeding rate increased in broadcast-seeded rice (Table 21). In transplanted rice in Japan (Noda et al 1968) and Malaysia (MARDI 1976), weed populations increased at wider plant spacings and higher fertilizer levels. In Japan (Noda et al 1968), yield losses were significantly higher at higher rates of applied fertilizer whereas in Malaysia (MARDI 1976), competition between rice and weeds was most serious at low nitrogen levels.

Pande and Bhan (1966) observed that as the row spacing of dryland rice increased from 15 to 45 cm, weeds increased in density and biomass. The yield reduction due to weeds increased from 42.1 to 56.3% as the row spacing increased from 15 to 45 cm as a result of increased weed growth and increased uptake of nitrogen by weeds at the wider row spacing.

Composition of the weed flora

The competitiveness of weeds varies with the composition of the weed flora. Arai and Kawashima (1956) reported that the difference in composition between different weed floras was due to the growth habit and the population of the weeds. The competitiveness of the same weed varied with differences in the community structure (Table 22). As the proportion of E. crus-galli in the weed flora increased, the yield reduction due to weeds increased.

It may be possible to alter the composition of the weed flora and the effect of the weeds by altering soil fertility. Such a technique will not eliminate weeds but may affect the level of importance of a particularly troublesome species.

Transplanted rice

Varying results as to the effect of increasing nitrogen levels on the weed population growing in association with transplanted rice have been reported. De Datta et al (1969) reported that added nitrogen benefited the grass population but had

little effect on broadleaf weeds and sedges. Sarkar and Ghosh (1978) observed that as nitrogen increased, grasses increased slightly and broadleaf weeds and sedges decreased slightly. Bahar and Abbas (1977) reported that the proportion of grasses in the weed flora increased and broadleaf weeds decreased when nitrogen was applied. The degree of change was dependent on the method of application (Table 23).

On the other hand, Terasawa (1943 as cited in Ike 1963) observed that nitrogen application decreased perennial weeds remarkably. Guh and Lee (1974) reported that as soil fertility increased, the number of broadleaf annual weeds such as M. vaginalis increased and perennial weeds such as Eleocharis kuroguwai Ohwi decreased. Kim and Moody (1980) al observed that M. vaginalis became more dominant in the weed community as the level of applied nitroge increased. When no nitrogen was applied, M. vagin lis comprised 44.8 to 64.9% of the weed community; when 160 kg N/ha was applied, it comprised 67.7 to 98.3% of the weed community.

Data in Table 24 also indicate the important role of method of fertilizer application in determining the weed flora. Grasses were the most important weeds and sedges were virtually eliminated wher nitrogen was deep placed. Broadleaf weeds were

Table 22. The competitiveness of weeds against transplanted rice as affected by the competition of the wee flora. (Adapted from Arai and Kawashima 1956)

Weed species	Weed community			
	A		B	
	Number of weeds (% of total)	Weed weight (g/plant)	Number of weeds (% of total)	Weed weigh (g/plant)
Echinochloa crus-galli	1.1	1.062	10.4	1.991
Cyperus difformis	11.3	0.336	14.9	0.232
Monochoria vaginalis	27.1	0.558	17.3	0.278
Rotala indica	42.2	0.021	34.2	0.009
Others	18.3	-	23.2	-
Total number of weeds	2612	-	4965	-
Yield reduction due to weeds (%)	-	18.0	-	42.9

Table 23. The effect of time of nitrogen application on weed weight and the composition of the weed flora. (Adapted from Bahar and Abbas 1977)

Time of nitrogen application	Weed weight (kg/ha)	Composition of the weed flora (%)			Yield reductio due to weeds (%)
		Broadleaf weeds	Grasses	Sedges	
No fertilizer	681	37.2	23.3	39.5	22.3
1/4 basal, 3/4 1 week before panicle initiation	703	24.9	46.1	29.0	8.2
All 1 week before panicle initiation	1033	13.5	61.0	25.5	7.4
All basally	1040	19.1	63.8	17.1	11.7
1/2 30 days after transplanting, 1/2 1 week before panicle initiation	1242	13.7	35.5	50.8	15.5

most important when the fertilizer was applied as sulfur-coated urea and incorporated before planting or as liquid urea in a band below the soil surface 10 DT.

Table 24. Weed weight (g/0.5 m^2) 60 days after transplanting as affected by method of application of nitrogen.

Method of N application	Weed weight[a] (g/0.5 m^2)			
	Broadleaf weeds[b]	Grasses[c]	Sedges[d]	Total
Mudball[e]	5.7(12.1)	41.6(87.9)	0	47.3
Supergranule[f]	9.6(18.8)	41.3(80.8)	0.2(0.4)	51.1
Split application[g]	13.8(28.4)	31.9(65.8)	2.8(5.8)	48.5
Split application[h]	9.9(28.4)	22.2(63.8)	2.7(7.8)	34.8
Sulfur-coated urea[i]	20.8(54.4)	15.0(39.3)	2.4(6.3)	38.2
Band application[j]	39.7(52.9)	33.3(44.3)	2.1(2.8)	75.1

[a]Percentages indicated in parentheses. [b]*Monochoria vaginalis* and *Sphenoclea zeylanica*. [c]*Echinochloa crus-galli* ssp. *hispidula*, *E. colona*, and *Leptochloa chinensis*. [d]*Cyperus difformis* and *Scirpus maritimus*. [e]All applied 5 days after transplanting (DT). [f]All applied 4 DT. [g]One-third 10 DT, one-third 30 DT, one-third at panicle initiation. [h]Two-thirds basal, one-third 5 to 7 days before panicle initiation. [i]All applied basal. [j]All applied 10 DT.

Kim et al (1980 as cited in Kim 1981) reported that an annual weed, *M. vaginalis*, was dominant when the organic matter content of the soil ranged from 2.1 to 2.8% and the phosphorus content ranged from 80 to 110 ppm. Perennials such as *Sagittaria pygmaea* Miq. and *S. trifolia* L. were dominant when the phosphorus content was high (120-140 ppm) and *Cyperus serotinus* Rottb. when the organic matter content was high (2.9-3.3%).

When cultivation was stopped and weeds were allowed to grow in a rice field after 40 years of fertilization and cultivation, *Scirpus juncoides* Roxb., a perennial sedge, *Lapsana apogonoides* Maxim., and *Fimbristylis littoralis* Gaud. dominated in plots to which no phosphorus had been applied (Ueda et al 1977). Plots to which phosphorus and potassium but no nitrogen had been applied were favorable for the growth of leguminous weeds such as *Vicia sativa* L. and *Trifolium repens* L.

Dry-seeded wetland rice

Nelson (1931) reported that the first obvious effect of the addition of fertilizer to dry-seeded rice was not improvement in appearance and development of the rice but a dense growth of weeds particularly *Echinochloa colona* (L.) Link and a relatively poor appearance of the rice. Plots that received no fertilizer had fewer grassy weeds than the fertilized plots.

Dryland rice

In Indonesia (CRIA 1976), broadleaf weeds became more important and grasses less important as the amount of applied nitrogen increased. When no fertilizer nitrogen was applied, broadleaf weeds comprise 61.5% of the weed flora; when 90 kg N/ha was applied, they comprised 82.1% of the weed flora.

Effect of added fertilizer on various weeds

Competition is greatest between plants whose growth habits such as root growth and foliage characteristics are similar because they make nearly the same demands upon the environment.

The environment associated with the crop determines the weed community and the abundance of the weeds growing in association with the crop. The amount of competition increases with the number of individuals per unit area and with their size.

Cyperus difformis. Chang (1969) reported that yield losses due to *C. difformis* ranged from 49.1 to 90.2% (Table 25). Yield losses increased as the number of weeds, the fertility level, and the temperature increased.

Swain et al (1975) also observed that competition by *C. difformis* was more severe at higher fertility levels. The rice yield was reduced by an average of 64.4 kg/ha for each day of competition when the fertility level was high and by only 29.9 kg/ha per day when the fertility level was low. The greater competition at the higher fertility level reflected the more vigorous growth of the weed. At the early tillering stage of the crop, *C. difformis* at the high fertility level produced more than twice as much dry matter as that produced at the low fertility level (812 g/m^2 vs 385 g/m^2).

Cyperus iria. In a pot experiment, yield reduction due to *Cyperus iria* L. competing against the rice cultivar Chandina was the same irrespective of whether fertilizer had been applied or not (Table 26).

Cyperus rotundus. The data of Okafor and De Datta (1976) indicate the following:

- Yield losses in dryland rice increased as *C. rotundus* population increased irrespective of the nitrogen level.
- For the rice cultivars IR5 and IR442-2-58, yields of the nonweeded plots where 60 and 120 kg N/ha were applied were greater than the yield of the weeded plots where no nitrogen was applied.

- During the early wet season, the yield depression when 150 C. rotundus plants/m^2 competed against rice was greater when fertilizer was applied than when no fertilizer was applied. For all other C. rotundus populations, the greatest yield depression occurred when no fertilizer was applied.

- Yield depressions due to C. rotundus were greater in the late wet season when fertilizer had been applied. There were no differences between the levels of applied fertilizer.

- In the dry season, yield depression increased as the nitrogen level increased.

Cyperus serotinus. Yamagishi et al (1976) observed that

- Yield losses due to C. serotinus were greater at recommended fertilizer levels than at higher fertilizer levels.

- Yield losses were greater when the fertilizer was topdressed than when applied basally.

- C. serotinus caused decrease of the nitrogen content of the rice leaf blade.

Echinochloa colona. Alkamper et al (1975 as cited in Alkamper 1976), Alkamper (1976), BRRI (1977), and Alkamper and Do van Long (1978) reported that yield reduction due to E. colona competition increased as the level of applied fertilizer increased (Table 26).

Table 26. Percentage of rice yield reduction caused by competition with different weed species at three fertility levels. (Adapted from BRRI 1977)

Competing weed	Fertilizer applied (kg/ha)		
	0-0-0	60-40-20	120-80-40
Cyperus iria	78.6	75.4	79.1
Echinochloa colona	59.6	69.1	89.3

Nutrient content levels of E. colona were invariably higher than those of the rice plants (Alkamper 1976, Alkamper and Do van Long 1978). Alkamper (1976) reported that the nitrogen, phosphorus, and potassium contents of E. colona were 3.14, 0.47, and 3.00%, whereas those for rice were 2.91, 0.46, and 1.80%. As the number of grass weeds competing with the rice increased, the nutrient content levels of the rice often declined. This decline was particularly pronounced for potassium at the later stages of crop growth (Alkamper 1976).

Rice absorbed more nutrients than E. colona at a low fertilizer level (Alkamper 1976). However, at higher fertilizer levels, the weed profited more from the added fertilizer than the rice. At the highest fertilizer level, the rice absorbed only 110-160 mg N/pot. By contrast, E. colona absorbed between 300 and more than 500 mg N/pot. Similar relationships were observed for phosphorus and potassium uptake (Fig. 5).

Table 25. Percentage of yield reduction in transplanted rice as affected by weed species, fertility level, crop season, and weed population. (From Chang 1969)

Weed species	Crop season	High fertility (160-80-80)		Low fertility (80-40-40)	
		100 plants/m^2	300 plants/m^2	100 plants/m^2	300 plants/m
Echinochloa crus-galli	First	85.5	91.8	76.1	90.2
	Second	37.0	90.6	71.4	86.1
Monochoria vaginalis	First	31.2	35.7	25.4	65.3
	Second	84.0	84.5	81.2	86.5
Cyperus difformis	First	73.6	81.4	49.1	57.8
	Second	80.9	87.6	53.5	90.2
Marsilea quadrifolia	First	56.5	61.7	45.1	87.3
	Second	52.2	64.3	54.7	64.5
Spirodela polyrhiza	First	8.5	10.4	10.6	26.6
	Second	5.2	3.3	0	13.5

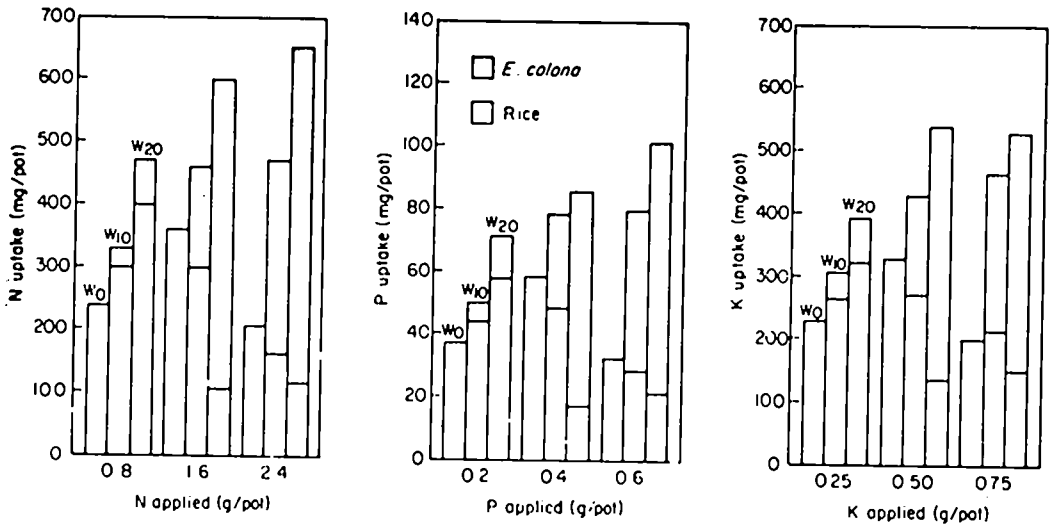

Fig. 5. Effect of weed density and level of applied fertilizer on uptake of nitrogen, phosphorus, and potassium by rice and Echinochloa colona 109 days after sowing. (Adapted from Alkamper 1976)

Echinochloa crus-galli. Miyazaki (1967) as cited in Matsunaka 1981) stated that E. crus-galli which resembles rice has a higher growth rate than rice and, if not removed, will plunder the mineral nutrients from the soil and inhibit the growth of rice plants.

Boerema (1963) reported that E. crus-galli took up 1.5 times as much nitrogen as rice in one experiment and 6.1 times as much in another experiment (Table 5). The nitrogen, phosphorus, and potassium contents of E. crus-galli were reported by Pillai et al (1976) to be 2.13, 0.57, and 2.07%.

In a pot experiment, E. crus-galli caused the greatest yield losses of the five weeds tested at both high and low levels of added fertilizer (Chang 1969). The season had no effect on the level of yield loss but losses increased as the weed population increased (Table 25).

Koda et al (1968) reported that the relationship between E. crus-galli weight and rice yield could be expressed by one regression equation irrespective of the fertilizer level. A similar relationship was described by Chisaka (1966). According to Koda et al (1968), the patterns of nitrogen uptake by rice and E. crus-galli differ considerably. Total nitrogen absorbed by rice reached a maximum at 8 DT; that by E. crus-galli continued to increase until 89 DT.

The nitrogen concentration in E. crus-galli was reported by Arai (1967) to be about the same as that in rice. However, Pons and Utomo (1979) reported that E. crus-galli had a higher nitrogen content than rice 4 WT but the content decreased sharply in E. crus-galli so that by 6 WT, it was lower than that of rice.

Kleinig and Noble (1968) reported that E. crus-galli maturity was progressively delayed with increasing levels of nitrogen application. Phosphorus alone did not affect maturity but reduced the delaying effect of nitrogen when both were applied.

Fimbristylis littoralis. Pons and Utomo (1979) reported that F. littoralis had a lower nitrogen content than rice and when competing with rice did not have a significant effect on the nitrogen content of the rice.

Marsilea species. According to Chang (1969), losses due to M. quadrifolia were similar at both high and low fertility levels (Table 25). Losses increased as the weed population increased but little seasonal variation was observed (Chang 1969). Pons and Utomo (1979) reported that competition from M. minuta was greatest at the lowest nitrogen level used.

Monochoria vaginalis. Yield losses due to M. vaginalis increased with increase in the fertility level, number of weeds per unit area, and temperature (Table 25).

Arai (1967) reported that the nitrogen content in M. vaginalis was almost double that of rice but Pons and Utomo (1979) reported that M. vaginalis had about the same nitrogen content as rice and had no effect on the nitrogen content of the rice when competing with it.

Chisaka (1966) suggested that competition between M. vaginalis and rice for nutrients was more significant than competition for light but Kim and Moody (1980) reported that this was dependent on the nitrogen level.

Increasing levels of applied nitrogen resulted in a significant increase in the number of M. vaginalis seeds per fruit and the number of fruits per plant. Seed viability was unaffected by nitrogen level (Kim and Moody 1980).

Rotala indica. Arai (1967) reported that the nitrogen concentration in Rotala indica (Willd.) Koehne was about double that of rice.

Sagittaria pygmaea. Noda (1968 as cited in Noda 1969) reported that S. pygmaea increased from 1 to about 60 in 50 days regardless of fertilizer level because it reproduced rapidly by underground rhizomes and tubers.

Scirpus maritimus. In transplanted rice, application of 120 kg N/ha greatly increased the weight of S. maritimus per unit area (IRRI 1973). Yield reduction increased as the nitrogen level increased for cultivars C4-63 and IR305-4-12. Losses were greater for the shorter-statured IR305-4-12.

Spirodela polyrhiza. Yield losses due to Spirodela polyrhiza (L.) Schleid. were greater at low fertility levels during the first season when temperatures were lower than at high fertility levels and at higher temperatures (Table 25). Yield losses generally increased as the weed population increased (Chang 1969).

Other dryland weeds

Noguchi and Nokayama (1978) reported that the response of weeds to fertilizer was greater than that of dryland rice. In all cases, plant height or main stem length, the number of stems or branches, and the dry weight of the aerial parts of the plants increased as the applied fertilizer increased. The differences between the response of weeds and that of rice to fertilizer were greatest in the early and middle stages of growth but decreased in the later stages.

In the fertilized plots, the dry weight of Chenopodium album L. and Digitaria ciliaris (Retz.) Koel. exceeded that of dryland rice from 51 days after seeding. At the ripening stage, both weeds had dry weights about three times that of dryland rice.

At the ripening stage in the nonfertilized plots, the dry weight of D. ciliaris nearly equaled that of rice in the fertilized plots whereas C. album in the nonfertilized plots had a dry weight 1.7 times that of the dryland rice in the fertilized plots.

The plant height or main stem length, the number of stems or branches, and the dry weight of P. oleracea, C. microiria, and Amaranthus lividus L. were less than those of dryland rice. Lack of fertilizer delayed heading and flowering especially of A. lividus.

Comparison of competition caused by different weeds

Echinochloa crus-galli and Monochoria vaginalis. Arai and Kawashima (1956) reported that the concentration of nitrogen in M. vaginalis was higher than that of E. crus-galli throughout the growing season (Table 27).

Table 27. Nitrogen concentration (%) of rice and weeds throughout the growing season.[a] (From Arai and Kawashima 1956)

Plant species	Date of sampling			
	5 Jul	26 Jul	21 Aug	19 Sep
Rice	3.6	1.69	1.02	0.73
Echinochloa crus-galli	-	1.23	0.76	0.73
Cyperus difformis	-	2.02	0.97	1.09
Monochoria vaginalis	-	2.53	1.46	1.85

[a] Date of transplanting: 15 Jun.

Matsunaka (1970) reported that the effect of M. vaginalis on yield loss was more severe than that of E. crus-galli. The higher nitrogen content of M. vaginalis was given as a possible reason. Chisaka (1977) agrees with Matsunaka (1970) when comparisons are made on the basis of equivalent weights of the weeds at maturity. However, on the basis of individual plant weight, E. crus-galli is more competitive (Arai 1967, Chisaka 1977) because an individual E. crus-galli plant at maturity is 60 to 80 times as large as a M. vaginalis plant and there is a greater similarity in root distribution between rice and E. crus-galli than between rice and M. vaginalis (Arai 1967).

Chisaka (1977) reported that the grain yield of transplanted rice infested with M. vaginalis was slightly increased by increasing the amount of nitrogen applied basally. No increase was observed when the crop was infested with E. crus-galli.

Echinochloa colona and Oryza sativa. According to Alkamper and Do van Long (1978), E. colona, an early-developing weed, is extremely competitive against rice and losses increased as the level of applied fertilizer increased. In contrast, in the case of Oryza sativa L. (red rice), a late-developing weed, addition of fertilizer nitrogen could actually reduce injury to the rice crop although there was some competition for nutrients (Fig. 6).

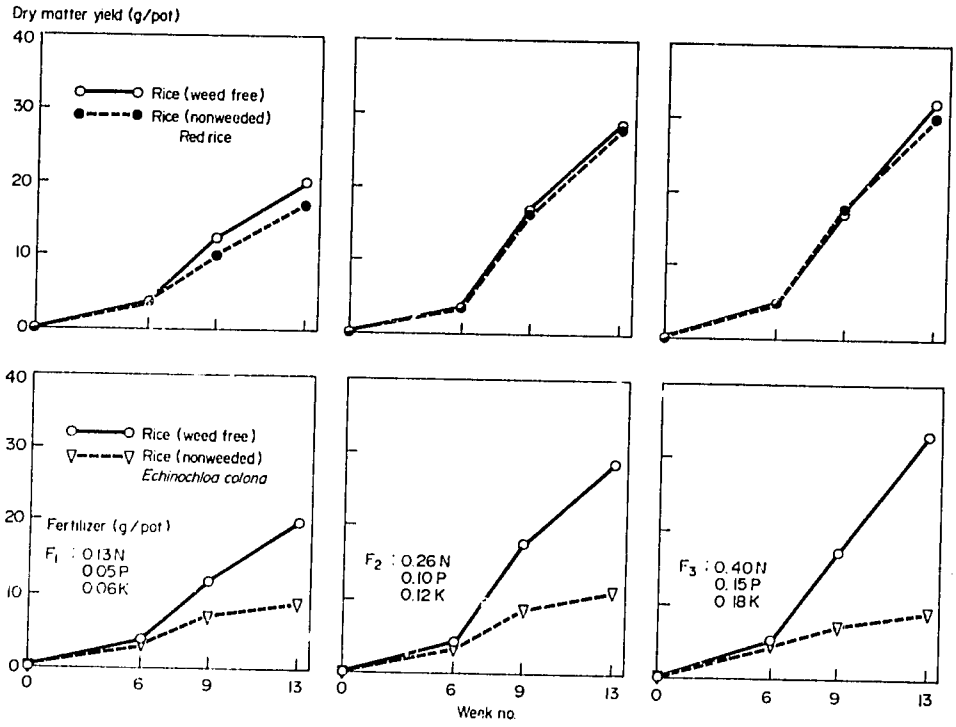

Fig. 6. Effect of weed maturity and level of applied fertilizer on growth of rice. (Alkamper and Do van Long 1978).

At the highest level of applied nitrogen, E. colona reduced grain yield by 84.4% and straw yield by 69.8%. With O. sativa, a 3.1% increase in grain yield and a 12.9% decrease in straw yield were observed.

Nitrogen content of the soil

Changes in the ammonical-nitrogen content in the soils of weeded and nonweeded plots were investigated by Inoue et al (1950 as cited in Ike 1963). No significant difference was observed between these plots prior to 24 July but after that date, a great decrease of nitrogen occurred in the nonweeded and nontreated plots (Fig. 7). Ike (1963) reported that the difference between weeded and nonweeded plots was not significant until 13 DT but by the 18th day, the amount of nitrogen in the nonweeded plots was significantly lower than in the weeded plots. Arai (1967) made a similar observation. The amount of ammonium-nitrogen remaining was dependent on the soil layer and the type of weed. Arai and Kawashima (1956) observed that the greater the amount of grass present, the smaller the amount of ammonium-nitrogen.

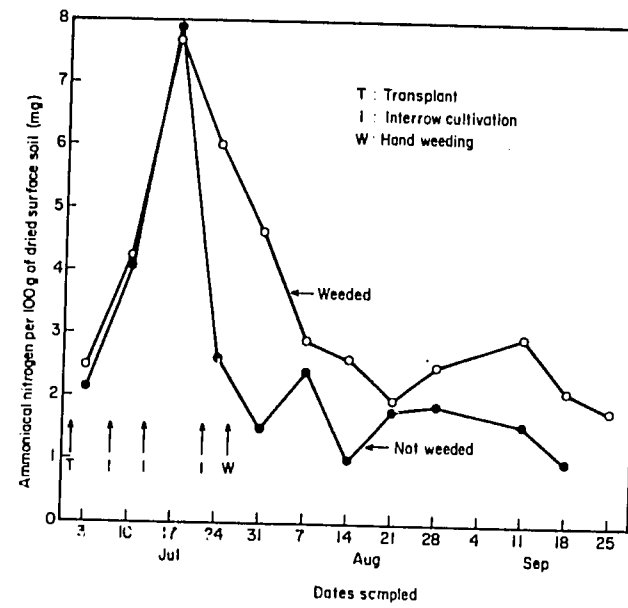

Fig. 7. Soil ammoniacal nitrogen level as affected by weeding. (From Ike 1963)

Arai (1967) reported that because the roots of M. paginalis and R. indica are primarily distributed in the upper (0-5 cm) layer of the soil, there was little ammonium-nitrogen in this layer. On the other hand, because the roots of E. crus-galli were distributed through both the upper and lower (5-10 cm) layers of the soil, there was little ammonium-nitrogen remaining in both layers (Table 28).

Singh (1979) reported that after 2 years of experimentation in a rainfed wetland rice field, there was no difference in total nitrogen between fields maintained as a weed-free fallow and those as a weedy fallow during the dry season. On the other hand, Hundal (pers. comm.) found that total nitrogen (ammonium-nitrogen and nitrate-nitrogen)

was lower in weedy-fallow plots than in weed-free fallow plots just before planting dry-seeded wetland rice.

Weed control

Weeds affect crop response to nitrogen fertilizer and, therefore, are one of the factors that determine the national, regional, or global nitrogen requirements for rice (Stangel 1979). Increased fertilizer application is most effective only if improved cultural practices are used at the same time. Therefore, to realize the maximum benefits from fertilizer use, weeds must be controlled. Fertilizers are too expensive to use to grow weeds.

When crops are left nonweeded, weeds not only consume the bulk of fertilizers added but may also deplete the natural fertility of the soil. Indiscriminate fertilization will meet the needs of both crops and weeds whereas timely weed removal ensures that the nutrients in the soil or added to it benefit the crop only. By controlling weed growth, it is possible to maintain crop production at a lower level of nitrogen fertilization.

When weeds are controlled, the quantity of nutrients removed by the weeds is reduced and nutrient uptake by rice should increase. Crop response to weed removal in terms of nutrient uptake is dependent on the time of weed removal and growth stage of the crop, the same way that response to fertilizer application is dependent on the time of application. Generally, though, the earlier the removal of the weed, the greater the response of the crop plant.

For example, Mani (1975) reported an increase in nitrogen uptake and crop yield due to chemical weeding over physical weeding. The herbicide caused an appreciable decrease in nitrogen depletion by weeds in the early crop growth stages compared to physical weeding. As a result, nitrogen uptake by the crop was improved and crop yield was enhanced. Likewise, Sankaran et al (1974a) observed enhanced uptake of nutrients by rice plants when weeds were controlled by a preemergence herbicide application than when they were removed by hand weeding. Better nutrition of the rice plant is then achieved in the absence of weeds.

Nanjappa and Krishnamurthy (1980) reported that nutrient uptake by the crop was greater when weed weight competing with the crop was less, so that there was a highly significant negative correlation between nutrient uptake by crop and weeds.

In Bangladesh, addition of fertilizer (60-40-40 NPK/ha) to dry-seeded rice without weed control resulted in an insignificant yield increase over the nonweeded check. Weed control without fertilizer addition resulted in a significant increase in yield. Further significant yield increase was obtained when fertilizer and weed control were applied together (Rahman, pers. comm.).

For transplanted rice, De Datta et al (1974) reported that in the absence of weed control, the application of nitrogen resulted in a maximum yield increase of only 0.7 t/ha. Without added nitrogen but with weed control, the yield increase ranged from 1.1 to 1.5 t/ha. When the crop was fertilized and weeded, a maximum yield increase of 2.5 t/ha was obtained when all the fertilizer was applied 5 to 7 days before panicle initiation (Table 15).

Table 28. Effect of weeds on the ammonium nitrogen content in soil. (From Arai 1967)

Sampling date (days after transplanting)	Weed flora	Ammonium nitrogen (mg/100 g dry soil) Upper layer (0-5 cm)	Lower layer (5-10 cm)	Av
33	None	0.78	0.64	0.71
	Monochoria vaginalis + *Rotala indica*	0.26	0.36	0.31
	Echinochloa crus-galli	0.20	0.19	0.20
49	None	0.20	0.07	0.13
	Monochoria vaginalis + *Rotala indica*	0.15	0	0.07
	Echinochloa crus-galli	0.12	0	0.06

These data emphasize the interaction between fertilizer response and weed control. In many instances, without weed control, little response from nitrogen can be expected. Following application of fertilizers plus weed control measures, a yield increase frequently equivalent to the added single effects of both measures is observed (French and Gay 1963).

This is well illustrated in the data of Varamisra (1976). Two hand weedings without fertilizer addition resulted in a yield increase of 436 kg/ha. Fertilizer addition without weed control gave a yield increase of 1,402 kg/ha. Fertilizer addition plus weed control resulted in a further increase of 1,845 kg/ha which is essentially equivalent to the addition of the single effects alone.

In trials conducted in transplanted rice in Bangladesh, weed control and fertilizer played a significant role in increasing grain yield. Weed control alone resulted in an average yield increase of 13% and fertilizer alone, 39%. However, when fertilizer and weed control were applied together, a 78% yield increase over the nontreated check was obtained (Table 29).

De Datta and Barker (1977) showed the complementarity between weed control and fertilizer addition and showed that the benefits from added fertilizer increased with higher levels of weed control (Table 30).

Deomampo (1969) reported that nitrogen and weeding together increased net returns per hectare more than if nitrogen was applied without weeding or if weeding was done without nitrogen fertilization. The application of nitrogen decreased yield and hence, increased monetary losses when weeding was not done. Losses were due to a loss in yield as a result of weeds and cost of nitrogen (Table 31). The net return to 15 kg N/ha without weeding was greater than that from weeding with or without

Table 29. Relative contribution of fertilizer and weed control and their interaction on grain yield (t/ha) of transplanted rice. (Rahman, pers. comm.)

Input	Season and year						Yield increase over untreated (%)
	T. Aman 1972	T. Aman 1974	Boro 1974-75	T. Aman 1976	T. Aman 1977	Av	
Nothing	1.7	2.5	1.1	2.3	4.0	2.3	-
Weed control	1.4	2.7	1.1	3.7	3.6	2.6	13.0
Fertilizer[a]	3.2	2.7	1.5	3.9	4.5	3.2	39.1
Weed control and fertilizer	3.5	3.4	4.5	4.7	4.6	4.1	78.3

[a] T. Aman, 80-60-40 N-P-K; Boro, 100-60-40 NPK.

Table 30. Interaction between the effect of fertilizer use and weed control on yield and net income. (From De Datta and Barker 1977)

Fertilizer level[a]	Weed control level[b]	Yield (t/ha)		Net return[c]	
		Philippines	Thailand	Philippines	Thailand
Low	Low	3.0	2.4	128	78
Low	High	2.9	2.5	121	76
High	Low	3.4	3.0	137	87
High	High	4.2	3.9	171	127

[a] Fertilizer level: in the Philippines, low = 35 kg N/ha, high = 75 kg N/ha; in Thailand, low = 5 kg n/ha, high = 25 kg N/ha. [b] Weed control level: in the Philippines, low = $9/ha, high = $18/ha; in Thailand, low = 1 labor day/ha, high = 15 labor days/ha. [c] Return above variable costs.

Table 31. Effect of weeding and nitrogen alone and in combination on net returns. (Adapted from Deomampo 1

Nitrogen level (kg/ha)	No weeding Net return to N ($/ha)	Weeded 21 DT Net return to weeding ($/ha)	Net return to plus weedin ($/ha)
0	0	- 5.87	- 5.87
15	9.98	- 8.40	- 2.61
30	13.25	- 3.13	22.67
45	4.60	25.73	67.53
60	-15.33	483.47	542.36
75	-46.47	487.07	697.83

fertilizer application. Thus, a farmer would prefer applying 15 kg N/ha to weeding unless the cost of weeding was less than the cost of applying 15 kg nitrogen.

Good production practices such as weed control will increase the yield potential and, therefore, make feasible the use of greater quantities of fertilizer by the crop or the more efficient use of limited quantities.

Application of herbicide-fertilizer mixtures

Phenoxy herbicides. Pellegrini et al (1958 as cited in Mukhopadhyay 1971) reported that 2,4-D mixed with urea or ammonium sulfate was effective in controlling weeds in both direct-seeded and transplanted rice. Mani et al (1973) found that urea combined with a low rate of 2,4-D and MCPB performed a dual role of improving herbicidal efficiency and stimulating crop growth. In direct-seeded rice, Mani et al (1973) achieved a yield increase of 1.6 t/ha over the nonweeded control with MCPB at 1 liter/ha and MCPB at 0.5 liter/ha + 3% urea. Kaushik and Mani (1980) reported no significant difference in rice grain yield between MCPB applied at 1.0 kg/ha and a mixture of MCPB at 0.5 kg/ha and 3% urea. However, the yields were significantly lower than that from the hand weeded check. In contrast, Sankaran et al (1974b) observed that the addition of urea to 2,4-D had no effect on the efficiency of the herbicide or its selectivity.

Smith et al (1977) warned that rice may be injured when nitrogen is applied 10 to 15 days before or after phenoxy herbicide application even though the herbicide is applied at a tolerant stage of rice development. When nitrogen was applied 15 days before herbicide application, rice growth was stimulated in 4 or 5 days and when the herbicides were applied, rice was green and grew rapidly. Th herbicide caused chlorosis and reduced yields. Th rice was not injured when nitrogen was applie from 5 days before to 5 days after herbicide ap plication. The yields, however, were reduced whe nitrogen was applied 15 days after herbicide ap plication at a tolerant growth stage.

Thus, nitrogen should be applied 1 to 5 day before or after applying phenoxy herbicides eve though the weeds may be less susceptible to th herbicides than if the nitrogen was applied at a earlier stage (Smith and Shaw 1966).

Patro and Tosh (1975) observed that the applica tion of MCPA-fertilizer mixtures produced yellow ing of leaves and burning of leaf tips. Applica tion of the herbicide-fertilizer mixture was supe rior to herbicide alone in controlling weeds an as a result higher grain yields were obtained.

Application of nitrogen may also help overcom herbicide toxicity. Smith et al (1977) reporte that nitrogen application within 5 days afte phenoxy herbicide treatment when rice is in th early jointing stage may help the rice recove from herbicide injury.

Propanil. Application of nitrogen as urea or am monium sulfate any time before or after propani treatment had no effect on the selectivity o propanil to rice nor on the control of rapidl growing susceptible weeds (Smith et al 1977).

Smith et al (1977) reported that propanil applie in water injured rice less and controlled E. crus galli better than propanil applied in nitrogen so lution (Table 32). The rice recovered in 1 to weeks after treatment. Patro and Tosh (1975) als observed injury with a propanil-fertilizer mixtur but this combination resulted in a significant re duction in weed population and a corresponding in crease in grain yield compared to propanil applie

alone. Sankaran et al (1974b), on the other hand, reported that a propanil-urea mixture resulted in better weed control but had no influence on crop yield and Mukhopadhyay (1971) observed that propanil was compatible with urea fertilizer and this mixture was as effective as hand weeding in controlling weeds.

Table 32. Effect of nitrogen solution used as a carrier for propanil applied at 3.4 kg/ha on Echinochloa crus-galli control and rice yield. (Adapted from Smith et al 1977)

Carrier and spray volume (liters/ha)		Echinochloa crus-galli control (%)	Rice yield (kg/ha)
Water	Nitrogen solution		
0[a]	-	99	6574
0[b]	-	0	2128
187	0	80	5858
94	94	35	3830
47	140	42	3517
0	187	30	3102
LSD (5%)		14	1445

[a] Hoe-weeded check. [b] Nonweeded check.

Dubey and Thomas (1977) stated that the cost of weed control could be reduced by decreasing the propanil rate and applying the herbicide in a 3% urea solution. However, Kaushik and Mani (1980) reported that propanil at 1 kg/ha plus 3% urea was not as effective as propanil at 2 kg/ha without urea.

Butachlor. Sankaran et al (1974b) reported that crop yield was significantly increased when a butachlor-urea mixture was applied compared to when butachlor was applied alone. However, the efficiency of the herbicide in controlling weeds was not increased significantly by the addition of urea.

Other herbicides. In China, ammonium bicarbonate is mixed with nitrofen and prometryn to enhance the activity of the herbicides (Li, pers. comm.).

Thus, herbicides can be used in combination with fertilizers for improved weed control and increased crop yields. The effectiveness of these combinations may be due to a) synergism, a consequence of which could be the reduction in the amount of herbicide applied in the mixture to achieve the same weed control compared to that obtained when the herbicide is applied alone, or b) more efficient utilization of the nitrogen applied in the herbicide-fertilizer mixture by the crop.

Effect of soil nutrient level on herbicide activity

In general, the limited evidence from field experiments suggests that effects of soil nutrient level on herbicide activity are small compared with those from other soil properties and because fertilizers are themselves important in crop production, it is unlikely that variation in their use could be employed specifically to modify the activity of herbicides (Walker 1980).

Effects of herbicides on nitrogen transformation

Little information has been published on the relationship between herbicides and nitrogen transformation.

In an upland soil, butachlor, propanil, and nitrofen applied at rates recommended for weed control had no effect on hydrolysis of urea to ammonia (Kim 1978). In a waterlogged soil, butachlor inhibited the rate of ammonification of urea slightly for 2 days after treatment at 30°C at pH 4.9 or 15°C at pH 4.9 and 6.8 (Chen et al 1981).

Kim (1978) reported that in an upland soil, butachlor had no effect on the nitrification process when applied at rates recommended for weed control. At the same rate, in a waterlogged soil, butachlor stimulated the rate of nitrification slightly for 2 weeks at 30°C when the pH was 6.8 (Chen et al 1981). At 15°C and pH 4.9, butachlor had no effect on nitrification.

Protein content

The percentage of protein content in rice grains was not affected by weed control methods (Kaushik and Mani 1977).

Azolla

Azolla is a free-floating fern known for its nitrogen fixation capacity. In Vietnam and China, it is used as a green manure in transplanted rice fields. However, in some parts of the world, it is considered a weed. For example, in Japan, suppression of young rice plants can occur when the water level is high (Fujiwara et al 1947 as cited in Moore 1969) or the water level rises after transplanting (Tuzimura et al 1957, Singh 1977) such that the azolla is above the rice plants. When the water level falls, the azolla suppresses the rice and may eventually kill it. In Indonesia, Heddy et al (1979) reported that Azolla pinnata R. Br. inhibited rice tiller development and reduced yield as much as 17%. The harmful effects of azolla on rice are illustrated in Figure 8. With proper management, little interference occurs between rice and azolla and the competitive effects between azolla and weeds may be advantageous to the rice.

Fig. 8. Suppression of rice seedlings by azolla is seen here. As water level in the paddy dropped, the azolla stuck to rice leaves as seen on the plant at top center.

Because azolla is capable of rapid reproduction and covers the surface of the water rapidly, it should be able to compete against weeds. Azolla has been observed to suppress weeds in rice (Braemer 1927a, b; Nguyen-Cong-Tieu 1930; Dumont 1935; Shen et al 1963; Ngo-gia-Dinh 1979; Lumpkin and Plucknett 1980; H. H. Hagerman, IRRI, pers. comm.; L. D. Haws, IRRI, pers. comm.; Yang-Han-Li, Nanking Agricultural College, China, pers. comm.; I. Watanabe, IRRI, pers. comm.). In Vietnam, azolla rapidly forms a cover in rice fields (Nguyen-Cong-Tieu 1930) and under this cover, weeds such as Utricularia aurea Lour., E. crus-galli, and Sagittaria sp. which normally invade the field to the detriment of the rice, get very little sunlight, and eventually die. Srinivas (1981) observed less M. quadrifolia in fields where azolla grew densely than in fields where azolla was absent. Ngo-gia-Dinh (1979) attributed the effect of the azolla cover to limited air diffusion and decreased light intensity necessary for germinatic

Nguyen-Cong-Tieu (1930) observed that when transplanted rice was inoculated with azolla, the farmer, instead of doing several costly and prolonge weeding operations, did only one. Dumont (1935 reported that in weedy rice fields, only one weeding was needed when azolla was grown. Without azolla, two or three weedings were usually required. In relatively clean fields, the one customary weeding could be dispersed with when azolla was grown.

Ngo-gia-Dinh (1979) reported that azolla suppressed E. crus-galli and the degree of suppression increased as the percentage of azolla cove and the water depth increased. In Californi (Talley et al 1977), the growth of C. difformi was not suppressed by Azolla mexicana Presl. because the azolla failed to develop a cover on th surface of the water before the C. difformis gre above the water surface (Table 33). However, a early cover of Azolla filiculoides Lam. eliminate C. difformis and Polygonum sp. from the field bu did not reduce E. crus-galli. The overall effec of azolla, though, was to keep the biomass o weeds in the rice field below that in fields wit no azolla cover.

Janiya and Moody (1981a) reported that azoll caused a 79.1% reduction in total weed weight 5 DT. The major weed, C. difformis, which comprise 65.5% of the weed flora, was 91.8% suppressed b azolla. Yields from the azolla-inoculated plot were not significantly different from those fro the hand weeded plots but were significantly high er than those from the nonweeded check (Table 34)

Table 33. Effect of different azolla treatments on weight of weeds growing in association with rice. (Adapted from Talley et al 1977)

Treatment	Weed weight (kg/ha)			
	Cyperus difformis	Echinochloa crus-galli	Polygonum sp.	Total
Azolla filiculoides incorporated	848	184	112	1144
Azolla mexicana cover	649	95	28	772
Azolla mexicana cover, A. filiculoides incorporated	740	28	55	823
Azolla filiculoides cover, A. filiculoides incorporated	0	512	0	512

Lumpkin and Plucknett (1980) noted that weeds with strong stature and abundant food supply can push through an azolla mat, and that weeds growing on the water surface before mat development and large floating weeds will be unaffected by azolla. Heddy et al (1979) failed to suppress the growth of Salvinia molesta D. S. Mitchell with A. pinnata. In fact, the reverse was observed. At IRRI, I have observed that azolla grows poorly in association with S. polyrhiza.

Table 34. Weed weight and yield of transplanted IR36 rice as affected by method of weed control. IRRI, 1980 dry season.[a] (From Janiya and Moody 1981a)

Treatment	Weed weight (g/0.5 m^2)	Yield (t/ha)
Weeded twice	9.0 c	3.7 a
Azolla inoculated	20.6 b	3.4 a
Weeded once	12.1 bc	2.8 a
No weeding	98.6 a	1.8 b

[a] Av of two nitrogen levels. In a column, means followed by a common letter are not significantly different at the 5% level.

Janiya and Moody (1981b) reported that whether or not weed suppression occurred was dependent on the weed species. Weed species suppressed by azolla were M. vaginalis, Echinochloa glabrescens Munro ex Hook f., C. difformis, and Paspalum sp. Azolla failed to suppress S. maritimus (Table 35) and Echinochloa crus-galli ssp. hispidula (Retz.) Honda.

The weed control aspect of azolla culture needs further study and may prove to be an important agronomic management tool in rice-azolla dual culture systems (Rains and Talley 1979). However, azolla is susceptible to herbicides such as 2,4-D (Cohn and Renlund 1953), Kleinschmidt 1969, Khare 1977), MCPA (Khare 1977), thiobencarb, propanil, piperophos-2,4-D, and butachlor (Table 36). Therefore, herbicides cannot be used for weed control when rice is to be inoculated with azolla. The weeds will have to be controlled by other means such as the suppressive effect of azolla itself, hand weeding, or the use of a rotary weeder when the azolla is incorporated into the soil.

Blue-green algae

Blue-green algae were one of the first agents recognized to fix nitrogen in flooded rice soils (Roger and Kulasooriya 1980). The detrimental effects of algae on rice have been reviewed by Roger and Kulasooriya (1980). On the positive side, Subrahmanyan et al (1965) reported that blue-gree algae suppress weeds such as Panicum sp., Cyperus sp., Hydrolea sp., and Ludwigia sp. However, Kulasooriya et al (1980) observed that

Table 35. Percentage of reduction in weight of the major weeds at rice flowering by Azolla pinnata in three fields having different weed floras.[a] (Adapted from Janiya and Moody 1981b)

Weed species	Dry weight (g/0.5 m^2) Nonweeded check	Azolla inoculated	% reduction[b]
	Field 1		
Monochoria vaginalis	48.4	5.2	89.3
	Field 2		
Monochoria vaginalis	50.3	2.2	95.7
Echinochloa glabrescens	25.6	0.7	97.3
Cyperus difformis	5.3	0.0	100.00
	Field 3		
Monochoria vaginalis	40.2	7.0	82.6
Scirpus maritimus	12.4	29.7	+139.5
Paspalum sp.	8.7	2.7	69.0

[a] Av of two nitrogen levels and three replications. [b] + = increase.

submerged weeds seem to compete with floating Gloeotrichia, a nitrogen-fixing blue-green algae. Further research is needed to clarify the interactions between weeds and blue-green algae.

Herbicides such as 2,4-D and MCPA have been reported to inhibit N_2-fixation by blue-green algae (Inger 1970 as cited in Roger and Kulasooriya 1980). Other herbicides that have been tested for their effects on blue-green algae include butachlor, molinate, and propanil (Roger and Kulasooriya 1980).

Table 36. Fresh weight of azolla 30 days after transplanting (DT) as affected by herbicide application. IRRI, 1980 wet season.

Treatment[a/]	Rate of application (kg/ha)	Time of application (DT)	Azolla fresh wt (g/m^2)[b/]	
Thiobencarb	1.0	4	478.0	d
Propanil	3.0	21	536.3	d
Piperophos - 2, 4-D	1.5	4	667.7	cd
Butachlor	1.0	4	814.3	cd
2,4-D (liquid)	0.5	21	1420.6	bc
2,4-D (granule)	0.8	4	1650.3	b
Nontreated	-	-	2840.0	a

[a/]A spaced dash (-) indicates that the herbicides were formulated as a proprietary mixture. [b/]Means followed by a common letter are not significantly different at the 5% level.

Nutrients other than nitrogen

Relatively little investigation has been aimed at nutrients other than nitrogen leading to insufficient knowledge of plant competition for them (Zimdahl 1980).

Phosphorus. Phosphorus applied directly to rice helps stimulate growth of Echinochloa sp., Heteranthera limosa (Sw.) Willd., and algae (Nelson 1931, Smith 1967) whereas phosphorus incorporated into the soil before dry seeding rice stimulates growth of young grass plants (Smith and Shaw 1966). Phosphorus applied after flooding stimulates the growth of aquatic weeds (Smith and Shaw 1966), algae (Adair et al 1962, Smith and Shaw 1966), and grasses (Adair et al 1962) or may be used ineffectively by the rice (Smith and Shaw 1966).

There are several possible alternatives for applying phosphorus to prevent excessive weed growth in dry-seeded rice.

1. Smith and Shaw (1966) recommend applyin it to a crop in the rotation other tha rice. For example, in a rice-soybean rota tion, phosphorus is generally applied t the soybean crop. However, Kleinig and No ble (1968) warn that the residual phospho rus available in the soil from superphos phate applied to a previous grass-legum pasture could accentuate the weed proble in rice.

2. Because seeds of most weeds germinate ar grow near the soil surface, phosphorus ma be placed below the rice seed durir planting, where it is less available t to the weeds (Smith and Shaw 1966).

3. In fields lightly infested with Echinocl loa spp., phosphorus application may be delayed until just before the first floo ing to take advantage of the inhibition weed growth by water (Smith and Shaw 19

Vega et al (1971) observed that the application o 30 kg P_2O_5/ha increased weed weight in transplanted rice in the nonweeded plots in the we season but had no effect on the weed weight in th dry season (Table 37). No additional rice yiel benefit was obtained from the addition of phospho rus in the weeded plots but a slight yield benefi was obtained in the nonweeded plots. Thus, yiel losses due to weeds were slightly less when phosphorus was added than when no phosphorus wa applied.

Kleinig and Noble (1969) reported that the addi tion of phosphorus to dry-seeded wetland rice in creased the number of rice tillers and panicle when rice was grown alone. In the presence of E crus-galli, the number of tillers and panicles wa depressed when phosphorus was added (Table 38).

Phosphorus increased rice yield substantially whe rice was grown alone but a significant decreas occurred when the rice was competing with E. crus galli. The addition of phosphorus greatly in creased dry matter yield of E. crus-galli bot when grown alone and in competition with rice.

Pernito (1981) reported that neither weed weight nor weed counts were significantly affected as th level of phosphorus applied to dry-seeded wetlan rice increased from 0 to 30 kg/ha.

Potassium. Potassium applied directly to rice ha little or no effect on weed growth (Smith 1967).

Calcium. Accordin to Taguchi (1931 as cited i Ike 1963), the amount of calcium removed by 10.9 weeds/ha about 1 month afte transplanting wa 18.3 kg/ha.

Weed growth does not appear to be stimulated b the addition of lime. Nelson (1931) reported tha for dry-seeded rice, when lime was applied, th growth of weeds in the nonfertilized plots wa about the same as that in the plots that receive no lime.

Table 37. Effect of application of nitrogen and phosphorus on weed weight and yield of transplanted rice. (Adapted from Vega et al 1971)

Fertilizer applied kg ha N	P	Yield (kg/ha) Weeded	Nonweeded	Yield reduction due to weeds (%)	Weed weight (g/0.125 m^2)
1969 wet season					
0	0	4038	490	87.8	40.9
60	0	4857	520	89.3	55.7
60	30	4762	758	84.0	98.7
1970 dry season					
0	0	3342	1016	69.5	17.5
60	0	5105	272	94.6	45.7
60	30	5146	437	91.5	43.0

Table 38. The influence of phosphorus on rice tiller and panicle production, rice yield, and Echinochloa crus-galli dry matter. (Adapted from Kleinig and Noble 1969)

Level of applied P (kg/ha)	Tillers/pot Weeded	Nonweeded	Panicles/pot Weeded	Nonweeded	Rice yield (g/pot) Weeded	Nonweeded	Echinochloa crus-galli dry matter (g/pot) Weeded	Nonweeded
0	29.0	18.8	25.3	15.5	21.2	11.3	32.8	18.9
89.6	88.5	12.8	37.0	6.5	32.9	4.8	113.7	102.7

Sulfur. Kleinig and Noble (1969) reported that as the amount of sulfur applied increased, there was no significant increase in the number of tillers of rice or Echinochloa spp. Interspecific competition resulted in reduced tillering of both species but the influence on Echinochloa spp. was less than on rice.

There was no rice yield response or increase in Echinochloa spp. dry matter as sulfur increased when rice and Echinochloa were grown alone. When they competed with each other, rice yield and the dry weight of Echinochloa spp. decreased significantly.

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