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SOIL FERTILITY, TILLAGE, AND MULCHING EFFECTS ON RAINFED MAIZE GROWN AFTER RICE

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ABSTRACT

Two experiments evaluated the effects of different rice production methods, fertilization rates and placement, and tillage and mulching treatments on rainfed maize grown after rice on Lipa clay loam with a shallow water table. Nonfertilized and fertilized maize was grown after nonpuddled nonflooded, nonpuddled flooded, and puddled flooded rice. Tillage included no tillage, row tillage, and complete tillage. In a second experiment, nonmulched and mulched maize grew after puddled flooded rice at 4 fertilizer rates, with the fertilizer placed at 5 or 20 cm depth at planting.

The nutrient availability was higher in soils after puddled flooded rice than after nonpuddled flooded rice. However, the high moisture content and compact soil after puddled flooded rice resulted in poorer maize establishment, growth, and yield. Tillage improved soil aeration after puddled flooded rice but reduced nutrient availability.

Maize yields from plots not tilled after rice harvest did not differ significantly from those from tilled plots. Maize responded less to fertilizer applied after puddled flooded than after nonpuddled flooded rice.

With complete tillage after flooded puddled rice, fertilizer and mulching treatments significantly affected lodging, root and top growth, and grain yield. Application of nitrogen and phosphorus greatly increased maize dry matter and grain yield. Deep fertilizer placement induced roots to grow deeper into the soil and absorb more nutrients and moisture. Mulching reduced top soil moisture losses and resulted in better fertilizer availability and maize yield. Maize plots that received deep-placed 120-26-25 fertilizer and mulch yielded 3,150 kg grain/ha.

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SOIL FERTILITY, TILLAGE, AND MULCHING EFFECTS ON RAINFED MAIZE GROWN AFTER RICE

Farmers who grow wetland rice prefer puddling to other soil management systems because it facilitates transplanting, reduces water loss by percolation (Duff and Bandyopadhyay 1966), increases nutrient availability (Ponnamperuma 1977), and, when combined with flooding, suppresses weed growth (De Datta et al 1970).

Because of puddling and flooding, the soil remains wet after rice harvest, may remain reduced for some time (Melhuish et al 1977), and can become hard and compact after drainage (Sanchez 1976). When a puddled soil dries, phosphate becomes less available than it was before puddling (Melhuish et al 1976, Willet et al 1977).

We determined the soil-water status and chemical soil properties resulting from three rice management methods, and their effects on rainfed maize grown after wetland rice with different tillage methods. Maize response to fertilizer management and mulching was also determined.

MATERIALS AND METHODS

The experiments were on a Lipa clay loam (Typic Haplaquoll, fine loamy, mixed isohyperthermic) that had grown puddled flooded rice for more than 50 years. The soil had a pH of 6.2, organic carbon content of 1.5%, cation exchange capacity of 35 meq/100 g soil, which was 80% satisfied by exchangeable bases. Available phosphorus (Olsen) was 7 ppm and exchangeable potassium was 0.7 meq/100 g for the top 20 cm soil layer. Permanent wilting point and field capacity were at 25 and 46% moisture for unpuddled soil, and at 27 and 48% moisture for recently puddled soil. The water table was shallow (about 60 cm in the dry season).

In both experiments the maize was planted at 3 seeds/hill at 100 x 20 cm spacing and thinned to 1 plant/hill at 30 days after seeding (DS) to obtain a population of 50,000 plants/ha. The maize was grown from December 1977 to March 1978 with monthly rainfall of 21.1, 21.5, 8.9, and 6.4 mm, and daily pan evaporation levels that increased from 4.5 mm in December to 7.5 mm by the end of March.

Experiment 1

Direct-seeded rice was grown in nonpuddled nonflooded, nonpuddled flooded, and puddled flooded plots. The nonpuddled plots were plowed and rototilled twice when the soil was moist. Puddled plots were plowed, rototilled twice, and harrowed with a combtooth harrow while shallowly flooded. Maize (Penjalinan, 80 days maturity) was planted after rice with and without fertilizer in 3 tillage treatments -- no tillage, row tillage, and complete tillage. Rice straw from all plots was cut at about 5 cm height and removed from the fields. Whenever soil moisture was suitable for land preparation, 20-cm strips (spaced 100 cm apart) were rototilled twice for row-tillage plots. For the complete-tillage plots the total surface was rototilled twice.

Fertilized plots received 30-13-25 (N-P-K) fertilizer rate at planting and another 30 kg N/ha 30 DS, dibbled about 7 cm from the maize hills at 5-cm depth. The treatments comprised a 3 x 3 x 2 split-split plot experiment. Plots were 5 x 7 m and were replicated 3 times.

Experiment 2

After sufficient drying of a puddled flooded rice field the soil was intensively tilled to about 20-cm depth by 2 carabao plowings and 3 rototillings. Maize was grown at 4 fertilizer (NPK) rates -- 0-26-25, 60-26-25, 120-0-25, and 120-26-25 -- either shallow (5 cm), or deep (20 cm). Mulch was applied at 8 t 50%-moisture-content rice straw/ha after seeding. The treatments comprised a 4 x 2 x 2 factorial randomized complete block. Plots were 5 x 10 m and were replicated 3 times.

Measurements

Soil moisture was measured gravimetrically and expressed as percent of oven dry weight (ODW). Soil chemical analyses included NH_4 + NO_3 nitrogen (Bremner), exchangeable K, available P (Olson), water-soluble Fe and Mn, and available Zn (Katyal and Ponnamperuma 1974). All analyses were of fresh (wet) samples immediately after sampling the 0- to 20-cm soil horizon.

For plant chemical analyses maize samples were taken from chopped above-ground parts of 5 randomly selected plants from each plot. After washing, drying at 80°C, and milling, 15 g subsamples were ground to 40 mesh for chemical analyses.

Root growth was estimated by the ^{32}P injection technique in selected treatments of Experiment 2. One ml of a solution containing 500 uCi^{32}P was

injected into a small hole made at the first internode from the base of the maize stem. The hole was closed and sealed. Soil cores were taken 7 days later at the center of the plant for 10-cm depth increments to 60 cm. A 50-g air-dried sample was ashed at 500° and ground. A 10-g subsample was compressed at 1,760 kg/cm^2 pressure and ^{32}P counts were taken and corrected for background and radioactive decay.

RESULTS

Fertilization increased maize yields significantly in Experiment 1 (Fig. 1). Generally, tillage and the rice-growing system affected yield only on fertilized plots. Nonfertilized plots suffered from nitrogen and phosphorus deficiency and severe drought stress. With added fertilizer, maize yields from the nonpuddled flooded plots were higher than from nonpuddled nonflooded plots, which in turn were higher (except with row tillage) than yields on plots after puddled flooded rice.

Row tillage had lowest yields in nonpuddled rice soils -- flooded and nonflooded. Completely tilled plots had the highest yields, irrespective of previous rice management, and showed the greatest yield difference (720 kg/ha) between previously puddled and nonpuddled plots that had been flooded.

Deep placement of fertilizer increased grain yield of maize significantly when planted after puddled flooded rice at 60-26-25 and 120-26-25 fertilizer rates and mulched (Fig. 2). Mulched plots, except the 0-26-25 rate at 5 cm placement and the 120-0-25 rate at 20 cm placement, gave higher maize yield than the nonmulched plots. Fertilizer placement had a greater effect on maize yield than mulching. In the mulching and fertilizer placement treatments, increased nitrogen and phosphorus produced increased grain yields. Total dry matter yields and seed weight showed the same trends as grain yields.

Crop stand

Fertilizer treatments did not affect maize stand in Experiment 1. Previous rice growing systems affected the stand only in row-tilled plots, in which the stand was poorer after puddled than after nonpuddled rice. No-tillage plots had the best stand among tillage treatments following all rice growing methods. Thinning 30 DS removed the differences in crop stand.

Experiment 2 treatments did not affect maize establishment. However, at 2 days before harvest, the maize stand was poorer in plots that received a 0-26-25 fertilizer rate than in those that received other rates, particularly in nonmulched plots and those with shallow fertilizer placement. This was because severe drought stress killed some plants during the growing period.

Crop lodging

Crop lodging was observed only in Experiment 2. The percentage of lodged maize ranged from 3 to 34% and was higher in plots that received incomplete (0-26-25 and 120-0-25) fertilizer than in plots that received complete fertilizer. Lodging percentage was low in mulched plots and in deep fertilizer placement. Plots with the combination of complete fertilizer, mulch, and deep fertilizer had only 3% lodged plants.

Soil moisture

Soil moisture observations were made in the 0- to 5-, 5- to 15-, 15- to 30-, 30- to 60-, and 60- to 90-cm soil layers. Because of the shallow water table, the soil moisture content below 30 cm remained high. However, the three upper layers were significantly affected by the treatments.

At maize planting in Experiment 1, the soil moisture content was higher in puddled flooded plots than in nonpuddled flooded plots. The latter had slightly higher moisture contents than nonpuddled nonflooded plots (Table 1). Soil moisture contents decreased when tillage intensity was increased. At 50 DS of maize the three rice growing systems did not show significant differences in soil moisture content. The major change in moisture content was caused by fertilizer treatments. Fertilized plots had more (21.5% ODW) moisture in the 0- to 5-cm layer than nonfertilized plots (16.8% ODW). This relationship was reversed in the 15- to 30-cm layer where moisture contents were 49.4% ODW for the nonfertilized plots and 45.5% ODW for the fertilized. Fertilization had no significant effects on soil moisture content at 50 DS of maize in the 5- to 15-cm layer.

Within fertilizer treatments, tillage reduced moisture in the 0- to 5-cm layer of nonfertilized plots, but not in fertilized plots. Completely tilled plots had more moisture in the 5- to 15-cm layer than row-tilled or nontilled plots. Tillage had no effect on the moisture content of the 15- to 30-cm layer at 15 DS of maize.

At 10 DS of maize in Experiment 2, the soil moisture content of the 0- to 5- and 5- to 15-cm layers was higher in mulched plots than in nonmulched plots (Table 2). Fertilizer rate and placement depth did not affect soil moisture content 10 DS. The soil moisture content of the 15- to 30-cm layer was not affected by the treatments. However, at 55 DS the 15- to 30-cm layer had a higher moisture content in mulched plots than in unmulched plots. With an increase in fertilizer rates, the soil moisture content of the 0- to 5- and 5- to 15- cm layers increased, but that of the 15- to 30-cm layer decreased. In mulched plots, soil moisture contents of the 15- to 30-cm layer were 2% lower with deep fertilizer placement than with shallow placement whereas the opposite was found in the 0- to 5-cm layer.

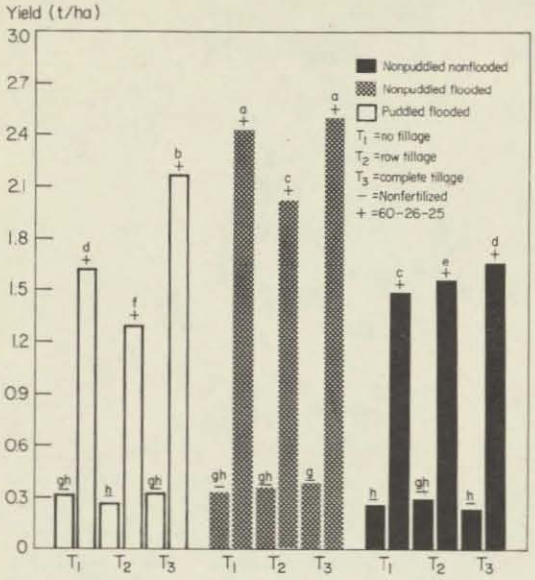

Fig. 1. Grain yield of maize as influenced by rice growing systems, tillage, and fertilizer treatments. Bars with a common letter are not significantly different at the 5% level.

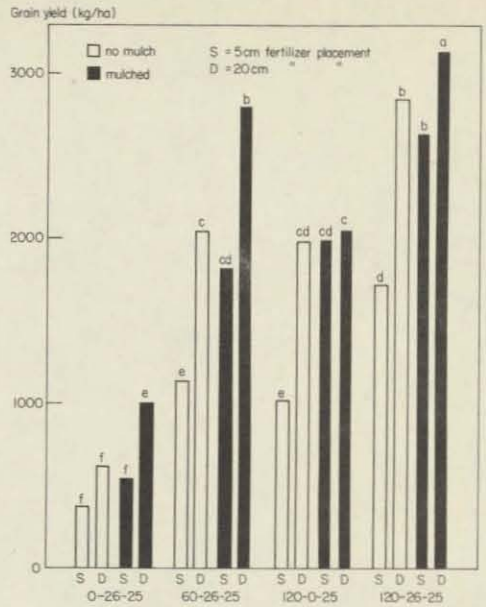

Fig. 2. Maize yield as influenced by fertilizer rates, mulching, and depths of fertilizer placement when planted after rice grown in a puddled flooded soil.

Table 1. Effects of previous rice-growing systems and tillage treatments on soil moisture content (% oven dry weight) at different depths at maize planting.

Tillage for maize	Previous rice-growing system: Nonpuddled nonflooded (S_1)	Nonpuddled flooded (S_2)	Puddled flooded (S_3)	$S_1 - S_3$	$S_2 - S_3$
		0- to 5- cm depth			
No tillage	40a	41a	45a	-5**	-4*
Row tillage	35 b	37 b	39 b	-6**	-2 ns
Complete tillage	30 c	31 c	36 c	-6**	-5**
		5- to 15-cm depth			
No tillage	49a	50a	51a	-2 ns	-1 ns
Row tillage	44 b	45 b	46 b	-2*	-1 ns
Complete tillage	41 c	42 c	43 c	-2 ns	-1 ns
		15- to 30-cm depth			
No tillage	52a	52a	56a	-4*	-4*
Row tillage	50ab	50ab	54ab	-4*	-4*
Complete tillage	48 b	49 b	53 b	-5*	-4*

[a]In a column of a respective sampling depth, means followed by a common letter are not significantly different at the 5% level by DMRT. * = significant at the 5% level by LSD, ** = significant at the 1% level by LSD.

Soil chemical analysis

At 3 weeks before rice harvest exchangeable NH_4-N was 4 ppm in the nonpuddled nonflooded, 32 ppm for the nonpuddled flooded, and 51 ppm for the puddled flooded rice soils. The NO_3-N contents were 11 ppm for the nonpuddled nonflooded, 4 ppm for the nonpuddled flooded, and 2 ppm for the puddled flooded. The total (NH_4-NO_3)-N of puddled and nonpuddled flooded soils were 3.3 and 2.3 times higher than that of the nonpuddled nonflooded soil.

Table 2. Effects of fertilizer rates and mulching on soil moisture content at different depths at 10 and 55 days after sowing (DS) of maize grown after puddled flooded rice.

Fertilizer rate (N-P-K/ha)	Mulching treatment	Soil moisture[a] (% oven dry weight)					
		10 DS at depths of			55 DS at depths of		
		0-5 cm	5-15 cm	15-30 cm	0-5 cm	5-15 cm	15-30 cm
0-26-25	No mulch	28 b	41 b	52a	19 e	25 e	43ab
	With mulch	34a	43ab	52a	26 bc	34a	44a
60-26-25	No mulch	28 b	42ab	51a	21 de	27 d	42ab
	With mulch	34a	43ab	52a	26 bc	33ab	43ab
120-0-25	No mulch	27 b	41 b	51a	22 d	29 c	41 b
	With mulch	33a	44a	52a	27ab	32 b	42ab
120-26-25	No mulch	27 b	42ab	51a	25 c	29 c	40 b
	With mulch	33a	43ab	51a	29a	31 b	42ab

[a]In a column, means followed by a common letter are not significantly different at the 5% level by DMRT.

The effects of flooding and puddling on NH_4-N were still observed at maize planting, although actual values had decreased (Fig. 3). The NH_4-N content was reduced more with increased tillage intensity, such that the difference between rice growing methods was no longer significant with complete tillage. The NO_3-N levels of previously flooded plots had increased after drainage to equal those of nonflooded plots (8-12 ppm) at maize planting.

At 40 DS of maize, previous rice growing methods and tillage treatments had no significant effect on the NO_3-N content. Fertilizer application significantly increased NO_3-N content from 2.5 to 5 ppm, a level less than half that at planting. Exchangeable NH_4 was absent.

At 3 weeks before rice harvest, the available phosphorus of nonpuddled nonflooded soils was increased from 7.5 to 11 ppm by flooding and to 14.5 ppm by flooding and puddling (Fig. 4). At maize planting, the available phosphorus values of the previously flooded fields had increased to 8 and 12 ppm. Available phosphorus was, therefore, still 4 ppm higher after puddled than after nonpuddled rice. Different tillage and fertilizer applications did not influence available phosphorus at this time. At 40 DS without fertilization, the available phosphorus had decreased to 3 ppm. There was no significant difference in available phosphorus due to different previous rice growing systems and tillage treatments. However, fertilizer application increased available phosphorus from 3 to 12 ppm.

Exchangeable potassium from puddled flooded soils was higher (0.64 meq/100 g) than that from nonpuddled soils (0.57 meq/100 g) at 3 weeks before rice harvest. Different previous rice growing methods, tillage treatments, and fertilizer application did not have significant effects on exchangeable potassium at maize planting, but at 40 DS exchangeable potassium was higher in fertilized plots (0.56 meq/100 g) than in nonfertilized plots (0.47 meq/100 g).

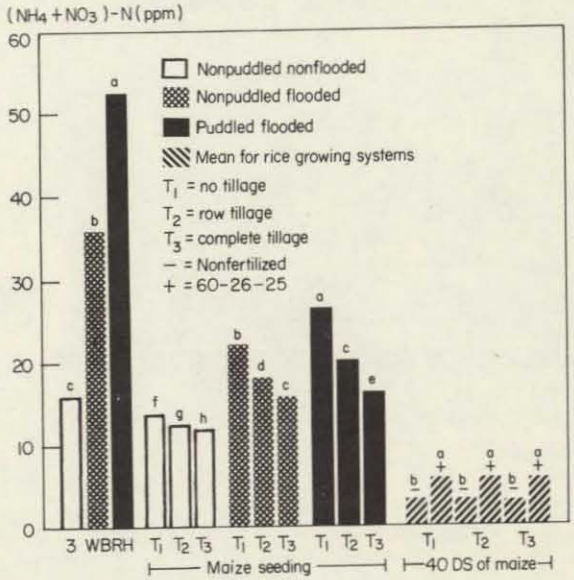

Fig. 3. Total available NO_3+NH_4-soil nitrogen at different sampling times as influenced by rice growing methods, tillage, and fertilizer treatments. NO_3-N is the amount below the lines across the bars. In each sampling time, NO_3 or NH_4 contents with a common letter are not significantly different at the 5% level.

The water-soluble manganese values from nonpuddled nonflooded soils at maize planting were similar to that obtained 3 weeks before rice harvest (3 ppm). However, the water-soluble manganese values from nonpuddled flooded and puddled flooded soils at maize planting had decreased from 13 to 7 and from 22 to 9 ppm at maize planting. These values were significantly influenced by tillage treatments, not by fertilizer application. The more intensive the tillage, the lower the water-soluble manganese at maize planting (Fig. 5). The water-soluble manganese had decreased to less than 3 ppm at 40 DS of maize, such that differences due to previous

rice growing systems and tillage treatments became small. The water-soluble manganese value in the puddled flooded nontilled plots was, however, still 5 ppm, significantly higher than those in the other plots.

At 3 weeks before rice harvest the water-soluble iron was 10 ppm from the nonpuddled nonflooded, 63 ppm from the nonpuddled flooded, and 86 ppm from the puddled flooded plots. At maize planting the water-soluble Fe from nonpuddled nonflooded soils decreased to about 5 ppm and was not affected by tillage treatments. In nonpuddled flooded plots iron decreased to 24 ppm for the zero-tillage treatment, 17 ppm for the row tillage, and 13 ppm for the complete tillage. For the puddled flooded plots these values were 32, 20, and 18 ppm. At 40 DS of maize, water-soluble iron values became small (less than 4 ppm) such that only the zero-tillage plots previously puddled and flooded had significantly higher values than the other tillage treatments. Water-soluble iron and manganese behaved similarly as the soil became reoxidized, but manganese levels appeared to reduce slower than iron levels.

At 3 weeks before rice harvest the available zinc content of nonpuddled nonflooded soils (0.16 ppm) were 2 and 4 times higher than that of nonpuddled flooded (0.08 ppm) and puddled flooded (0.04 ppm) rice soils. Tillage significantly modified the effect of the previous rice growing systems on the available zinc at maize planting. Compared to zero tillage complete tillage increased zinc levels from 0.11 to 0.15 ppm in nonpuddled flooded plots and from 0.07 to 0.14 in puddled flooded treatments. At 40 DS of maize available zinc was close to 0.14 ppm in all treatments and no effect of tillage could be detected. Fertilizer application did not affect available zinc.

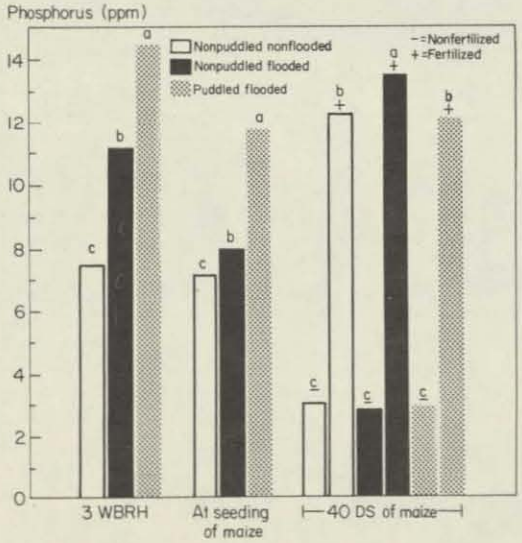

Fig. 4. Available soil phosphorus at different sampling times as influenced by rice growing systems and fertilizer treatments. WBRH = weeks before rice harvest. In each element and sampling time, bars with a common letter are not significantly different at the 5% level.

Nutrient contents and uptake

Maize in Experiment 1 was severely nitrogen-deficient in the nonfertilized plots. Fertilizer addition at 20-26-25 kg/ha increased nitrogen contents at 70 DS (Table 3) and increased nitrogen uptake from less than 8 kg N/ha for the check plot to more than 40 kg/ha. Differences due to previous rice management showed a significant increase in nitrogen content of maize from puddling and in potassium contents from flooding and puddling. In previously flooded plots, nitrogen contents at 70 DS increased with tillage from 0.94% for zero tillage to 1.14% for complete tillage. In nonflooded plots, tillage did not change nitrogen contents.

The higher nitrogen content of maize from tilled plots was generally reflected in higher nitrogen uptake. Maize from previously puddled plots, however, had lower nitrogen uptake than nonpuddled plots, even though the nitrogen content at 70 DS and the nitrogen availability at planting time was higher than in unpuddled plots.

Phosphorus and potassium contents of maize were lowest in nonfertilized plots, but remained in the sufficient range. Phosphorus and potassium uptake 70 DS was increased from 2.5 to 8 and from 10 to 40 kg/ha, respectively, by fertilization. The potassium content of maize from previously puddled plots was higher than that from the other rice management methods, but potassium uptake was lower. This was because of low dry matter production in nonpuddled plots.

In the completely tilled Experiment 2, plots that received no nitrogen fertilizer showed higher nitrogen contents at the lowest nitrogen uptake and dry matter yields. Deep placement of fertilizer and mulching increased yields and nitrogen uptake, but reduced nitrogen contents (Table 4). This same pattern occurred in less extreme form at the 60 N/ha level and for phosphorus in plots without phosphorus fertilizer. This indicates that in the shallow-fertilized nonmulched plots, yields were limited not by nitrogen or phosphorus in the 0-26-25 and the 120-0-25 treatments, respectively, but by drought. This was because complete tillage had reduced top soil moisture contents, which restricted crop growth.

Plant analyses for iron, zinc, and manganese showed that these elements were not deficient. Contents ranged from 120 to 160 ppm for iron, 62 to 114 ppm for manganese, and 21 to 40 ppm for zinc. Zinc contents were lower in higher-yielding plots. Manganese contents were significantly lower in the 0-26-25 plots, apparently because shallow roots in these plots did not reach the manganese-rich subsoil.

Root growth of maize

Rooting depth, as determined by the ^{32}P injection technique, was greatly increased by mulching, phosphorus-fertilizer addition, and deep placement of fertilizer (Fig. 6).

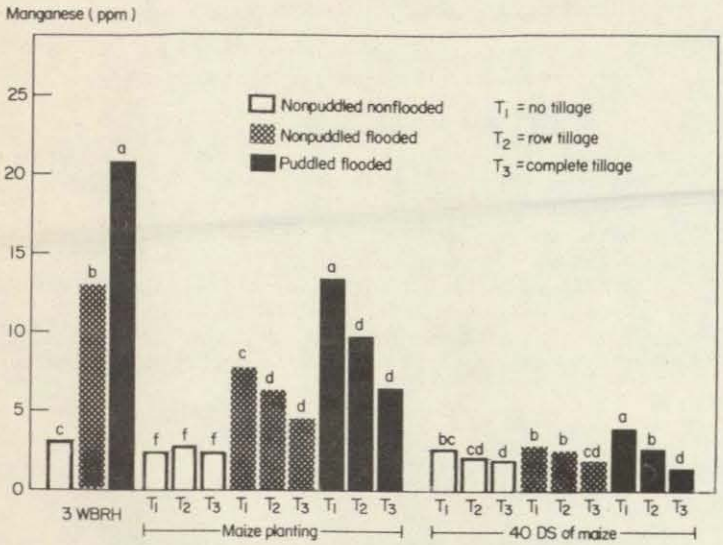

Fig. 5. Water-soluble soil Mn at different sampling times as influenced by rice growing systems and tillage treatments. WBRH = weeks before rice harvest. In each sampling time, bars with a common letter are not significantly different at the 5% level.

Table 3. Effects of previous rice-growing systems and fertilizer treatments on the nitrogen, phosphorus, and potassium content (%) of maize plants at 70 days after sowing. Average of 3 tillage methods.

Fertilizer maize (N-P-K/ha)	Previous rice-growing system: Unpuddled nonflooded	Unpuddled flooded	Puddled flooded
		N	
0-0-0	0.95 b	0.98 b	1.10 b*
60-26-25	1.29a	1.28a	1.35a *
		P	
0-0-0	0.40a	0.41a	0.38a
60-26-25	0.22 b	0.22 b	0.21 b
		K	
0-0-0	1.25a	1.45a *	1.83a *
60-26-25	1.06 b	1.13 b	1.34 b*

[a]In a column for each nutrient, means followed by a common letter are not significantly different at the 5% level by DMRT. * = significantly different from the two other means in the row.

Plots that received phosphorus fertilizer had more roots in the lower layers when the fertilizer was deep than when it was shallow placed. The response to deep placement was much smaller in mulched plots that in unmulched plots, because mulching maintained moisture contents high in the fertilized zone, thus increasing the opportunity of maize to absorb nitrogen and phosphorus.

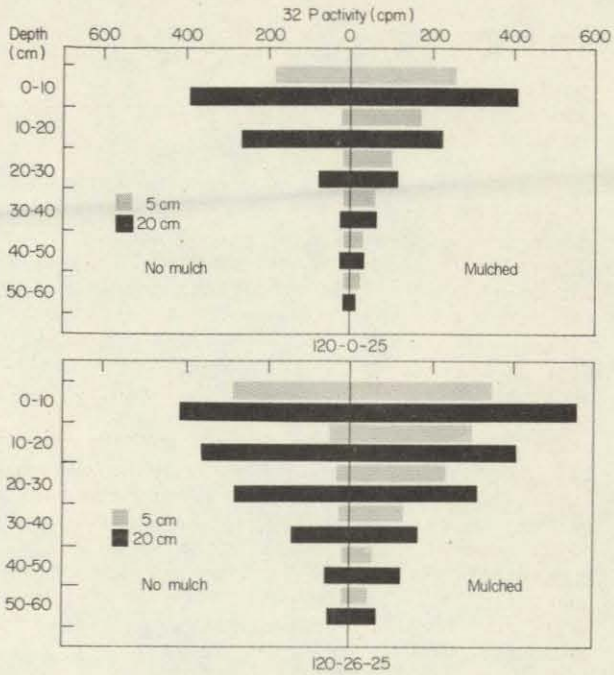

Fig. 6. ^{32}P counts at different depths as influenced by fertilizer rates, mulching, and depths of fertilizer placement.

DISCUSSION AND CONCLUSION

A considerable response of maize to applied nitrogen and phosphorus fertilizer was observed. However, dry matter and grain yield as well as the response of maize to nitrogen and phosphorus fertilizer were lower after puddled flooded rice than after nonpuddled flooded rice. Plants sufficiently supplied with nutrients had good root growth and absorbed more moisture and nutrients. The necessity for both nitrogen and phosphorus fertilizer was such that yield responses to placement and mulching were limited in the absence of either element in the fertilizer mixture (Fig. 2).

The effectiveness of fertilization was increased by deep (20 cm) placement of fertilizer. This could be attributed to increased root growth in the lower layer. Higher ^{32}P counts were found in the lower soil layers of plots with deep fertilizer placement than with shallow fertilizer placement. Because of the shallow water table, deep fertilizer placement led roots to substantially increased access to soil moisture. Under more common rainfed dry season conditions, the water table would be substantially deeper 20 DS. Soil moisture content would, however, still be high in the lower layers and deep-placed fertilizer would be more likely to be absorbed than shallow-placed fertilizer.

Fertilization increased topsoil moisture contents 55 DS particularly in nonmulched plots. This was noted shortly after sampling and field inspection showed that it was associated with dew formation. More dew formed on tall, fertilized plants than on nonfertilized plants as was evident from dark

Table 4. Nitrogen, phosphorus, and potassium contents (%) of maize grown after puddled flooded rice at 70 days after sowing.

Fertilizer rate (N-P-K/ha)	Mulching	Fertilizer placement	Content (%)[a]		
			N	P	K
0-26-25	No mulch	5 cm	1.38a	0.29a	1.42 d
		20 cm	1.31 bc	0.26 b	1.30 f
	With mulch	5 cm	1.24 ef	0.28a	1.30 f
		20 cm	1.05 h	0.24 c	1.25 g
60-26-25	No mulch	5 cm	1.31 bc	0.26 b	1.35 ef
		20 cm	1.28 cd	0.23 cd	1.30 f
	With mulch	5 cm	1.24 ef	0.22 cde	1.35 ef
		20 cm	1.17 g	0.22 cde	1.36 e
120-0-25	No mulch	5 cm	1.32 b	0.22 cde	1.39 de
		20 cm	1.27 de	0.19 fg	1.31 f
	With mulch	5 cm	1.28 cd	0.20 f	1.63 bc
		20 cm	1.27 fg	0.18 g	1.61 c
120-26-25	No mulch	5 cm	1.29 bcd	0.22 cde	1.36 e
		20 cm	1.29 bcd	0.23 cd	1.30 f
	With mulch	5 cm	1.29 cd	0.21 ef	1.68a
		20 cm	1.22 f	0.22 cde	1.66ab

[a]In a column, means followed by a common letter are not significantly different at the 5% level by DMRT.

rings of saturated soil at the base of the maize stalks at 0700 hours. Reduced plant size and higher leaf temperatures caused by drought stress -- leaf rolling and senescence were evident -- probably limited dew formation in nonfertilized plots.

Mulching was effective in reducing moisture loss by evaporation. The high moisture content of mulched plots kept the nutrient availability higher in mulched plots than in nonmulched plots. These effects resulted in better growth, increased access to subsoil water, and higher nutrient uptake, dry matter, and grain yield in mulched than in nonmulched plots. The reduced response of root growth, and dry matter and grain yield to deep placement of fertilizer in mulched plots (Figs. 2 and 6) was because the mulch increased topsoil moisture contents sufficiently to allow uptake of applied fertilizer during the first 50 days of crop growth. Even after 55 days, moisture in the 0- to 5-cm layer of mulched plots equaled or exceeded that at wilting point (26% ODW).

The soil was generally more compact and had a higher moisture content after puddled flooded rice than after nonpuddled rice. This caused slightly poorer maize establishment on puddled than on nonpuddled soil. The effect was, however, removed by thinning. Although the puddled flooded soil had higher nitrogen, phosphorus, and potassium availability than the nonpuddled soil, the nutrient uptake and dry matter yields were lower. The lower maize yields after puddled rice culture cannot, therefore, be explained from a nutritional point of view. Soil moisture was also more available than after the other rice culture methods. Zinc, manganese, and iron did not appear to be toxic or deficient, as judged by soil analyses and plant uptake. The low-soil test values for zinc indicate, however, that dryland crops planted in reduced, fine-textured soils will be susceptible to zinc deficiency during early establishment, particularly where native zinc fertility is marginal or soil pH is high.

The soil analyses for available zinc, water-soluble iron and manganese, and NH_4-N and NO_3-N showed that oxidation of the reduced topsoil (0-10 cm) was not complete at maize planting. Oxygen demand would, therefore, have been high in the topsoil and more so below the 10-cm depth, just after maize planting (11 days after drainage of the rice fields) in the previously puddled plots. This may have caused oxygen deficit for good root growth of the young maize plants. For the flooded but nonpuddled plots, iron, manganese, and ammonium analyses showed that even before rice harvest the soil was not as reduced as in the puddled plots. At maize planting, oxidation of nonpuddled plots had proceeded further than in puddled plots so that oxygen deficits to the maize roots may have been less severe.

Tillage improved soil aeration and consequently plant growth. However, oxidation of the soil reduced phosphorus and nitrogen availability in the puddled flooded rice soil. The final result of these two effects produced a slightly better nutrient uptake, growth, and yield of maize grown after complete tillage than after no tillage following puddled flooded and nonpuddled flooded rice. This was not the case for maize grown after

nonpuddled nonflooded rice as may be expected, because the soil was not as strongly reduced as after flooded rice.

The increase in maize yield due to tillage may be too small to pay the tillage cost. Therefore, intensive tillage may not be advisable for maize grown after puddled flooded rice. Our experiments have shown that maize can be established without tillage after puddled flooded rice. On fine-textured soils, such as those used in these experiments, early crop growth may be delayed by lack of oxygen in the root zone, but a delay in maize planting or complete tillage will cause drying of the topsoil and can limit root extension into the moisture rich subsoil if too little rain occurs after maize planting. If the crop depends on residual soil moisture, this can lead to poor crop yields. Fertilizer application and a straw mulch proved effective in this respect. In those treatments roots did extend into the untilled, previously reduced subsoil. This led to increased moisture availability to the crop and increased maize yields.

REFERENCES CITED

De Datta, S. K., G. Levin, and A. Williams. 1970. Water management practices and irrigation requirements for rice. Pages 89-105 in Rice production manual. University of the Philippines College of Agriculture-International Rice Research Institute.

Duff, N. K., and M. N. Bandyopadhyay. 1966. Improving rainfed rice in India. World Crops 18-26.

Katyal, J. C., and F. N. Ponnamperuma. 1974. Zinc deficiency: a widespread nutritional disorder of rice in Agusan del Norte. Philipp. Agric. 58:79-89.

Melhuish, F. M., W. A. Muirhead, and M. L. Higgins. 1976. Current views on effects of cropping history on nutrient availability in irrigation soils. Paper presented at the Australian Soil Science Society Conference Wagga, May, 1976.

Ponnamperuma F. N. 1977. Physico-chemical properties of submerged soils in relation to fertility. IRRI Res. Pap. Ser. 5. 32 p.

Sanchez, P. A. 1976. Properties and management of soil in the tropics. Chapt. 12. Soil management in multiple cropping systems. John Wiley and Sons, New York-London-Sydney-Toronto.

Willet, I. R., W. A. Muirhead, and M. L. Higgins. 1977. The effect of rice growing on phosphorus immobilization. Aust. J. Exp. Agric. Anim. Husb. 18:270-275.

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