Technology Section

Pakistan J. Sci. Ind. Res., Vol. 19, No. 2, April 1976

EFFECT OF RATES AND CARRIERS OF NITROGEN ON YIELD AND COPPER AVAILABILITY TO RICE AND CORN ON TWO CALCAREOUS SOILS

M. A. KAUSAR, F. M. CHAUDHRY,* A. RASHID and RAHMATULLAH

Nuclear Institute for Agriculture and Biology, Lyallpur

(Received June 11, 1976)

Abstract. Increasing N application from O to 150 ppm gradually increased Cu uptake by flooded rice on two calcareous soils. Two processes were mainly responsible : increased plant growth and enhanced Mn concentration in soil solution increased Cu absorption by rice roots. Urea and $(NH_4)_2SO_4$ increasing plant growth and Mn solubility more than NH_4NO_3 resulted in greater increase in Cu uptake. Soil acidification from NH_3-N application or lower redox potential from NO_3-N addition causing higher Cu contents in plants were not involved. The effect of $CO(NH_2)_2$ in enhancing HCO_3 contents of soils inducing decreased Cu availability was also not important. An interesting mechanism of N enhanced Cu retention in plant roots as an immobile Cu–protein complex inhibiting its translocation to plant shoots was evaluated.

Nitrogen was more efficient for dry matter yield of corn than of flooded rice. Only 37 ppm N resulted in maximum corn yield, but even 150 ppm N failed to completely overcome N deficiency in rice. All the three N sources were equally effective for corn, but for rice $(NH_4)_2SO_4$ and $CO(NH_2)_2$ were much better than NH_4NO_3 which strongly losses its NO_3-N due to denitrification in flooded soils. Proper management practices such as time and method of N application can increase N efficiency in Pakistan agriculture manifold. Their proper evaluation under the prevalent fertilization practices are urgently needed.

Patrick and Mikkelsen[21] indicated that even with the best management practices, the utilization of added N was generally poorer in flooded soil than in well drained soils Nitrogen sources also strongly differed under the two conditions. Thus NH_4NO_3 being almost as efficient as $(NH_4)_2SO_4$ and $CO(NH_2)_2$ for upland crops was much inferior for flooded rice Inconsistent results were obtained on calcareous soils of the Punjab.[23]

Flooded rice usually responds to N application on calcareous soils of Pakistan.[23] Copper deficiency has also been recognised on some soils.[14] The two elements strongly interact in the nutrition of upland crops.[5] Their mutual interaction and effect of N on Cu availability to flooded rice has never been studied critically.

Nitrogen fertilizers have been found to strongly depress Cu concentration in the shoots of upland plants and to induce or accentuate severe Cu deficiency in plants resulting in drastic reduction of vegetative and grain yields.[5] Gilbert[11] suggested that N may induce Cu deficiency in cereals by inhibiting its translocation from roots to shoots. Critical data are not available.

Nitrogen fertilizers have also been reported to enhance concentration and total Cu contents in upland plants. It achieves this effect in two ways: by promoting plant growth[5] and by depressing soil pH from application of acidifying N fertilizers such as $(NH_4)_2SO_4$.[2] Nitrogen effect on Cu absorption *per se* was never investigated.

The nature of N enhancement of Cu intake may strongly differ for flooded rice The pH depression may not be involved since many acidic and alkaline soils equilibrate at a pH of about 7.0 soon after flooding.[22] Moreover, submerged rice is usually grown on heavy textured soils with high buffering capacity against soil pH change. Growth promotion can, probably, affect total Cu uptake in rice[9] but the effect of various N carriers will then strongly differ. Thus, by contrast of their identical effect in upland crops, $(NH_4)_2SO_4$ is more efficiently utilized than NH_4NO_3 by lowland rice[21] and it may, therefore, result in greater increase of Cu uptake by plants.

Some additional factors may also be responsible for N-Cu interaction in lowland rice. Application of $CO(NH_2)_2$ may result in higher HCO_3 contents of soils inducing Cu precipitation or depressing its absorption by plants.[10] Similarly $(NH_4)_2SO_4$ enhancement of Zn solubility through formation of soluble Zn – NH_3 complex[16] may depress Cu uptake by Zn – Cu antagonism in metabolic Cu absorption by plants.[3] By contrast NH_4NO_3 may enhance Cu uptake by plants by alleviating Fe competition in Cu absorption through depression in soil redox potential.[15] Hussain *et al.*[13] indicated P to enhance Cu uptake by rice by increasing Mn solubility in soil solution. Nitrogen effect on Mn solubility is not known The current soil and solution culture experiments were conducted to test these hypotheses leading to a critical evaluation of the mechanism of N influence on Cu uptake by flooded rice. A soil-pot trial was also conducted on corn for yield comparison.

---

*Now at the Arab Development Institute, P.O. Box 8004. Tripoli, Libya.

Materials and Methods

Effect of Rates and Carriers of N on Cu Uptake by Rice and Corn from Soil. Surface samples to a depth of 15 cm were collected from Gujranwala and Miranpur soil series of rice area of the Punjab. They were air dried, crushed in a wooden mortar to pass through a 2 mm sieve and analysed for the relevant physicochemical properties [1] Both the soils were clayey in texture, had pH of 8.4 and 8.6, and contained 2.04 and 0.43% free $CaCO_3$, 0.99 and 1.10% organic matter, 4.4 and 4.1 meq/l HCO_3, 5.1 and 25.8 ppm $NaHCO_3$ extractable P and 1.8 3.0 ppm DTPA (diethylenetriamine pentaacetic acid) extractable Cu.

Soil portions of 4.5 kg were filled in polythene-lined plastic pots of 20 cm surface diameter and 22 cm depth. The basal fertilizer dressing consisted of 13 ppm P as KH_2PO_4. For the rice *(Oryza sativa* L.*)* experiment the treatments included were 0, 37, 75 and 150 ppm N as $CO(NH_2)_2$, $(NH_4)_2SO_4$ or NH_4NO_3 in the presence or absence of 5 and 25 ppm Cu as $CuSO_4$. Whereas, for the corn *(Zea mays* L.*)* experiment the treatments consisted of 0, 37 and 75 ppm N without any Cu application. The treatments with a control were imposed in triplicate. All the fertilizers were thoroughly mixed with soil before planting. Six 20-day old nursery seedlings of Basmati-370 rice were transplanted in each pot in August, 1974 and the pots kept flooded to 5 cm dept with deionized water throughout plant growth. For corn experiments, 10 seeds of J-1 maize hybrid were sown in each pot in September and the stand thinned to 5 healthy plants 10 days later. The soil in each pot was maintained at field capacity by daily addition of deionized water.

Rice and corn plants were harvested by cutting at ground level 36 and 43 days respectively after sowing, rinsed thoroughly in two baths of deionized water, dried in paper sacks at 70° and ground in a Wiley mill fitted with stainless steel blades and other interior parts of the cutting chamber. One g portions of the ground material of rice were digested with 25 ml redistilled HNO_3 and $HClO_4$ (4:1) mixture. Copper in the diluted digest was determined by atomic absorption spectroscopy. Total Cu contents in plant shoots were calculated by multiplying their concentration with plant yield.

Nitrogen Effect on Kinetics of Cu Solubility in Soil. The effect of N on the kinetics of Cu solubility in submerged soil was studied according to the method used by Rahmatullah *et al.*[24] Subsamples of Miranpur soil of 4.5 kg were filled in plastic pots. They received a basal dose of 13 ppm P as KH_2PO_4. The treatments consisted of $CO(NH_2)_2$, $(NH_4)_2SO_4$, and NH_4NO_3 each applied at 150 ppm N in triplicate. Pots were flooded with deionized water and a level of 5 cm standing water was maintained for 6 weeks during the main rice growing months of August and September. The pots were placed in open atmosphere near those sown under rice. About 150 ml of soil percolate was drawn out by gravity each week through side holes at the base of the pots in conical flasks previously filled with N_2 gas. The pH was immediately determined by drawing small portions of percolates in a specially designed O_2-free cell. Bicarbonate was determined directly on small aliquote of percolates. Six drops of concentrated H_2SO_4 were added to the remaining solutions to avoid oxidation. They were then analysed for Cu, Zn, Mn, Fe, and Ca by atomic absorption spectroscopy.

Effect of Various Cations on Cu Absorption from Solution. Rice seedings were grown on a complete nutrient solution for 10 days.[25] Roots of intact seedlings were then allowed to absorb Cu for 2 hr from solutions of $10\mu\ MCuCl_2$ and $500\mu\ MCaCl_2$ containing various treatments (Table 5). The pH of the absorbing solution was adjusted at 5.8 and temperature at 20°. The solutions were continously aerated during the absorption period. The electrostatically adsorbed Cu on roots was eliminated by washing them for 30 min in a solution of $500\mu M$ $CaCl_2$ at 5°.[3] The roots before and after Cu absorption were digested in redistilled HNO_3 - $HClO_4$ mixture and their Cu contents determined with an atomic absorption spectrophotometer. Rate of Cu absorption was calculated from difference in their Cu contents.

Results and Discussion

Effect of N on Dry Matter Yield of Corn and Rice. Increasing N application from 0 to 150 ppm progressively increased dry matter yield of flooded rice ($P < 0.05$ or 0.01, Tables 1 and 2). Even the highest dose was not sufficient to produce maximum growth of the plants since mild N deficiency symptoms still existed on rice shoots. By contrast, only 37 ppm N produced optimum dry matter yield of corn (Table 3) and completely restored dense green colour of plants. These results substantiate earlier observation indicating N to be less efficiently utilized under flooded than under upland soil conditions.[21]

Relative efficiency of $(NH_4)_2SO_4$, $CO(NH_2)_2$, and NH_4NO_3 for flooded rice and corn also strongly varied. Ammonium sulphate and $CN(NH_2)_2$ increased rice growth almost to the same extent on Gujranwala soil, but $CO(NH_2)_2$ was slightly more effective ($P < 0.01$) on Miranpur soil. Both were, however, more effective than $NH_4\ NO_3$ on the two soils ($P < 0.01$). These results support the earlier observations on several types of soils indicating $(NH_4)_2SO_4$ or NH_3-forming fertilizers to be more efficiently utilized by lowland rice than NO_3 fertilizers which result in severe N loss due to denitrification under reduced soil conditions.[21] All the three fertilizers were almost equally effective for corn (main effects not insignificant, Table 3). The yield depression from 75 ppm N as NH_4NO_3 was not true, but resulted from incidental water stress to plants.

Effect of N on Cu Uptake by Rice. Increasing Cu application from 0 to 25 ppm gradually enhanced concentration and total Cu contents in rice plants ($P < 0.05$ or 0.01, Table 1). Nitrogen application at lower rates of 37 and 75 ppm showed no effect on Cu concentration in plants on Gujranwala soil

TABLE 1. EFFECT OF COPPER AND RATES AND SOURCES OF NITROGEN ON DRY MATTER YIELD AND ON CONCENTRATION AND TOTAL CONTENTS OF COPPER IN RICE SHOOTS ON GUJRANWALA SOIL.

N application (ppm)	Dry matter yield (g/pot)			Cu concn (ppm) Cu application (ppm)			Cu contents (μg/pot)		
	0	5	25	0	5	25	0	5	25
Control									
0	2.2	1.6	1.4	5.7	6.5	9.7	12.3	10.1	14.0
Urea									
37	3.7	3.4	3.2	5.0	6.2	8.3	18.2	21.4	26.8
75	6.5	5.9	5.2	5.5	7.2	9.8	36.1	43.8	51.2
150	7.2	5.9	6.0	7.8	10.8	11.7	55.0	62.8	70.6
Ammonium sulphate									
37	3.3	3.6	3.3	4.8	5.2	7.8	16.2	18.8	25.6
75	5.0	5.0	5.7	4.8	6.3	10.0	24.1	31.5	46.6
150	8.2	7.7	6.0	7.2	10.8	13.0	59.0	84.3	78.3
Ammonium nitrate									
37	2.6	4.0	2.2	4.8	6.0	6.5	12.4	24.9	14.1
75	3.0	3.5	3.0	4.8	7.0	8.2	14.7	25.2	26.0
150	4.8	4.4	3.6	6.5	10.7	17.5	33.6	46.7	69.9

TABLE 2. EFFECT OF RATES AND SOURCES OF NITROGEN ON CONCENTRATION AND TOTAL CONTENTS OF COPPER IN RICE SHOOTS ON MIRANPUR SOIL.

N application (ppm)	Dry matter yield (g/pot)	Cu concn (ppm)	Cu contents (μg/pot)
Control			
0	3.3	5.8	18.9
Urea			
37	6.4	6.7	43.6
75	8.6	8.4	71.4
150	9.4	10.6	100.4
Ammonium sulphate			
37	4.4	6.2	27.1
75	6.8	6.4	43.6
150	8.9	9.2	82.1
Ammonium nitrate			
37	4.0	5.8	23.5
75	4.6	6.7	30.6
150	6.6	8.8	57.9

TABLE 3. EFFECT OF RATES AND SOURCES OF NITROGEN ON DRY MATTER YIELD OF CORN ON GUJRANWALA SOIL.

N application (ppm)	Dry matter yield of plants from various nitrogen sources (g/pot)		
	Urea	Ammonium sulphate	Ammonium nitrate
0	1.5	1.5	1.5
37	6.9	6.9	7.2
75	6.2	6.8	4.6

(small differences not significant, Table 1), but marked increase in Cu concentration of shoots occurred with the highest dose of 150 ppm N ($P < 0.05$). On Miranpur soil, both 75 and 150 ppm N generally increased Cu concentration in rice shoots (main effect, ($P < 0.05$). These results partly substantiated an early report indicating little effect of N application on Cu concentration in rice shoots on an Indian calcareous soil,[1] but strongly conflict with those on upland crops showing N to depress Cu concentration in shoots and to accentuate its deficiency in plants causing severe reduction in their vegetative and grain yield.[5,12]

Nitrogen application strongly enhanced total Cu contents in flooded rice both on Gujranwala and Miranpur soil ($P < 0.05$). This effect was consistent with all N carriers. Similar results were obtained in an early report, but the mechanism was not indicated.[9] Nitrogen appears to enhance total Cu contents in rice partly by increasing plant growth. Thus in most of the N and Cu treatments, increase in Cu uptake paralleled with an increase in plant yield. Highly significant correlation between plant yield and total Cu contents were found when whole data each of Gujranwala (r 0.86, $P < 0.01$) and Miranpur (r 0.80, $P < 0.01$) soils were considered together. Nitrogen stimulation of Cu uptake through growth promotion was also found in upland crops.[5] The effect of N carriers, however, seems to strongly differ under the two soil conditions. Thus in lowland rice, $(NH_4)_2SO_4$ and $CO(NH_2)_2$ increasing plant growth more than NH_4NO_3 (main effect, $P < 0.01$) also resulted in higher Cu contents ($P < 0.01$) in rice. In upland crops, all the three N fertilizers being almost equally efficient for plant growth (main effect not significantly different), may result in identical increase in Cu uptake by plants. Similar discrepancy in N-Zn interaction was earlier found under the two soil conditions.[4]

Nitrogen appears to enhance total Cu contents in rice also through additional mechanism, since in most of the treatments N effect on Cu concentration in rice shoots at least paralleled or excelled its influence on growth promotion (Tables 1 and 2). This effect was more pronounced on Miranpur soil (Table 2). Nitrogen was earlier shown to enhance micronutrient solubility in soil through a shift in soil pH. Thus $(NH_4)_2SO_4$ with acidic soil reaction increased and $NaNO_3$ with basic reaction decreased their solubility and thus their uptake by upland plants.[2,28] Such an effect did not operate in the present studies since none of the N carriers influenced pH or Cu solubility in soil percolates at any of the incubation periods (Table 4 small differences not significant). Even under upland conditions, pH shift was observed mainly on light textured soils receiving liberal N application. This effect is less likely to be involved for rice even on many other arable acidic and alkaline soils that usually equilibrate at a pH of about 7.0 soon after flooding.[22] Moreover, lowland rice is usually grown on heavy textured soils having high buffering capacity against soil pH changes. Thus, in several cases even 17 years of prolonged application of $(NH_4)_2SO_4$ failed to decrease pH of flooded soils.[17] Chaudhry *et al.*[4] similarly reported various N carriers to have no effect on soil pH of flooded soils. They increased Zn solubility in soil solution, but it had not occurred from soil pH depression.

Nitrogen had no effect on Fe concentration in soil solution, but increased Zn solubility in soil percolate at most of the soil incubation periods (Table 4). Zinc, however, does not appear to aggravate Cu solubility from its specific adsorption sites[27] as a $Zn-NH_3$ complex.[16] Neither did it affect Cu absorption by rice roots (Table 5) as has earlier been reported for upland crops.[3]

Nitrogen strongly enhanced Mn concentration in soil solution ($P < 0.01$); $CO(NH_2)_2$ and $(NH_4)_2SO_4$ being more effective than NH_4NO_3 (main effect significantly different, Table 4). Similar effect of N on Mn solubility was reported earlier.[1] By contrast of its little effect in upland crops,[3] Mn strongly stimulated Cu absorption by rice roots (Table 5, $P < 0.01$). The mechanism is not known. An earlier study indicating Mn inhibition of Cu absorption by swamp rice was inconclusive since it failed to distinguish metabolic Cu absorption from Cu adsorbtion.[8] Hussain *et al.*[13] also indicated Mn stimulation of Cu absorption to be partly responsible for P enhanced Cu uptake in flooded rice. It, thus, appears that at least two processes are invol-

TABLE 4. EFFECT OF RATES AND SOURCES OF NITROGEN ON THE SOLUBILITY KINETICS OF VARIOUS IONS IN THE SUBMERGED MIRANPUR SOIL.

N application		Weeks of soil submergence				
Rates (ppm)	Source	I	II	III	IV	VII
pH						
0	—	7.75	7.77	7.70	7.93	7.78
150	$CO(NH_2)_2$	7.73	7.63	7.73	7.87	7.72
150	$(NH_4)_2SO_4$	7.87	7.67	7.60	7.50	7.75
150	NH_4NO_3	7.80	7.80	7.67	7.87	7.80
Zn concn (ppm)						
0	—	0.50	0.32	0.36	0.28	0.32
150	$CO(NH_2)_2$	0.88	0.30	0.46	0.37	0.41
150	$(NH_4)_2SO_4$	0.53	0.57	0.48	0.46	0.41
150	NH_4NO_3	0.76	0.37	0.48	0.49	0.50
Cu concn (ppm)						
0	—	0.045	0.052	0.032	0.033	0.035
150	$CO(NH_2)_2$	0.048	0.035	0.043	0.027	0.031
150	$(NH_4)_2SO_4$	0.052	0.053	0.030	0.027	0.034
150	NH_4NO_3	0.050	0.047	0.030	0.030	0.034
Fe concn (ppm)						
0	—	0.41	0.23	0.21	0.29	0.27
150	$CO(NH_2)_2$	0.26	0.19	0.18	0.17	0.48
150	$(NH_4)_2SO_4$	0.25	0.21	0.13	0.28	0.33
150	NH_4NO_3	0.17	0.20	0.20	0.12	0.46
HCO_3 concn (meq/1)						
0	—	8.82	16.0	18.15	35.16	23.44
150	$CO(NH_2)_2$	9.25	16.45	18.13	34.68	24.90
150	$(NH_4)_2SO_4$	8.78	14.37	16.28	33.33	20.61
150	NH_4NO_3	6.43	14.32	17.43	36.93	22.81
Mn concn (ppm)						
0	—	0.15	0.39	0.48	0.23	0.37
150	$CO(NH_2)_2$	0.10	0.45	0.57	1.70	1.34
150	$(NH_4)_2SO_4$	0.16	0.98	3.73	6.20	2.84
150	NH_4NO_3	0.09	0.28	0.42	1.17	1.07

TABLE 5. EFFECT OF VARIOUS CATIONS ON COPPER ABSORPTION BY BASMATI-370 RICE FROM SOLUTIONS OF 10 μM $CuCl_2$ AND 500 μM $CaCl_2$ at pH 5.7.

Cation added	Rate of Cu absorption (μg atoms/g fresh root/hr.)
—	2.76
20 μM $ZnCl_2$	2.28
30 μM $FeCl_2$	2.44
50 μM $MnCl_2$	4.09
MCI pH 4.7	2.76

ved in N stimulation of Cu uptake: increased plant growth and enhanced Mn solubility in soil resulting in increased Cu absorption by rice roots. A third process of N enhancement *per se* of Cu absorption could also be important. Such studies have never been conducted on rice. Smith,[26] however, reported rate of Cu absorption by citrus roots from solution culture to be strongly related to their N concentration, Chaudhry and Loneragan[5] similarly reported N to strongly enhance rate of Cu absorption by wheat from soil during its 44 days of growth. Nitrogen pretreatment of earlirose rice seedlings during their 10 days preparation also resulted in marked stimulation of Zn absorption from nutrient solution.[6] Indeed Cu absorption by plants is a carrier-mediated process[3] and intensity and efficiency of protein carriers are likely to be stimulated by N supply to plants.

Forno[10] indicated that HCO_3 may reduce micronutrient contents in plants resulting in their severe deficiency causing drastic reduction in plant yield. Such a mechanism does not seem to operate on the present soils since $CO(NH_2)_2$ application did not increase HCO_3 contents of soil solution at any of the incubation periods (small differences not significant, Table 4). Probably normal doses of $CO(NH_2)_2$ as used in these studies, are less likely to appreciably increase HCO_3 contents of submerged calcareous soils. Kosuge[15] reported NO_3–N application to flooded soils to result in depression of Fe solubility through a decrease in soil oxidation reduction potential. Thus NH_4NO_3 was taken to increase Cu uptake by rice by alleviating Fe inhibition of Cu absoption.[3] Such an effect does not seem to be involved since NH_4NO_3 did not influence Fe solubility in soil. Moreover, strong inhibitory effect of Fe on Cu absorption which has, indeed, been reported in upland plants[3] does not appear to occur in rice (Table 5).

Discussion

The present studies have indicated efficiency of N fertilizers for flooded rice to be much lower than for upland crops. Thus, whereas only 37 ppm N was sufficient for maximum dry matter yield of, corn, even 150 ppm N was not enough for flooded rice. These results support earlier reports showing substantial additional N requirement for rice on soils supporting normal growth of upland crops. Many studies have similarly revealed that even with the best management practices, the utilization of added N was much less in flooded rice than in well-drained soils.[21] Many researchers have shown strong losses of N from volatilization, denitrification and leaching under reduced flooded soil conditions.[21]

Efficiency of N carriers for plant growth also strongly varied under the two soil situations. Thus NH_4NO_3 being identical to $CO(NH_2)_2$ and $(NH_4)_2SO_4$ in upland crops, was much inferior for lowland rice. Similar results were reported in several other studies indicating severe NO_3—N loss due to denitrification in reduced rice soils. Loss of NH_4-N was relatively much less. Patrick and Mikkelsen[21] have summarized the N recovery results for rice from several regions of rice growing countries and rated the three N sources as they influenced rice yield as $(NH_4)_2SO_4$ 100, $CO(NH_2)_2$ 92—100 and NH_4NO_3 57-70. Almost similar order of their efficiency was found in the present studies.

The current studies have, however, indicated that even $(NH_4)_2SO_4$ is much less effective for lowland rice than for upland crops. Earlier studies have indicated many methods to improve its efficiency for flooded rice. For example, incorporation of NH_4-N within 10 cm soil depth resulted in 30-50% higher N availability over unincorporated surface application.[18] Similarly its split application, two-thirds at planting and one-third at boot stage resulted in almost double N recovery than its complete application at planting or top-dressing it at tellering stage.[20] Such management practices have not been evaluated properly in developing countries like Pakistan. Nitrogen fertilizers are an extremely expensive commodity in these areas which force the poor farmers to under-fertilize their crops. Improved practices of N application can thus revolutionise the rice production in their countries. Nitrogen efficiency can be further increased if concomitant deficiency of Cu and Zn, wherever it occurs, is also recognized.[4]

The present studies also revealed the mechanism of N stimulation of Cu uptake by flooded rice to strongly vary from that in upland crops. Nitrogen increases Cu contents in upland plants mainly by promoting plant growth or by depressing soil pH. The pH effect appeared unimportant for rice since it is usually grown on strongly buffered clay soils and these flooded soils generally equilibrate at a pH of about 7.0.[22'24] Nitrogen enhanced Cu uptake at least by two processes in the present studies: (a) by promoting plant growth as, perhaps, also occurred in an earlier study[9], (b) by enhancing Mn solubility in soil resulting in stimulation of Cu absorption by rice roots. Such a mechanism was never reported before.

Nitrogen has been often reported to strongly depress Cu concentration in shoots of upland crops and to accentuate its deficiency in plants causing severe reduction in vegetative and grain yields[5]. This in certain cases, accrued from reduction in Cu solubility through soil pH elevation from alkaline N fertilizers such as $NaNO_3$.[2'28] pH shift is not important for flooded rice especially when normal N doses are involved. Gilbert[11] proposed N to increase protein concentration in plant roots resulting in higher retention of Cu as an immobile Cu -protein complex restricting its translocation to plant shoots. He suggested that this mechanism could be responsible for N induced Cu deficiency in plants. Smith[26] later on, also emphasized the possible importance of Cu-protein complex when he found strong correlation between N and Cu concentration in citrus roots. Ozanne[19] similarly reported this mechanism to be responsible for higher Zn-retention in plant roots. The recent studies of Chaudhry and Loneragan[5], however, showed this mechanism to be, perhaps, important only under optimum to luxury Cu supplies. Under marginal to deficient supplies, plant roots failed to retain Cu against its translocation to plant shoots, since in their studies, N in fact enhanced proportion of Cu in plant tops. Evaluation of such a mechanism on the basis of relative distribution of Cu in roots and shoots as has been done in earlier studies, appears to be misleading since it is strongly influenced by the relative distribution of dry weights in these organs which are influenced differently under a deficient and a sufficient nutrient supply.

Critical analysis of earlier results, however, indicate that N induces Cu deficiency in upland plant shoots mainly by a strong promotion of plant growth resulting in high dilution of absorbed Cu to a deficient level.[5] Nitrogen induced higher Cu requirement by plant shoots as was proposed by Dekock *et al.*[7] may perhaps, also aggravate the problem, but their studies need further critical documentation. Although N did not depress Cu concentration or induced its deficiency in rice in the present studies, but the current experiments involved soils with optimum to luxury Cu supplies not very deficient in available N. Consequently N stimulated plant growth only 2-4 times on the present soils used. Such a growth promotion paralleled with stimulation of total Cu contents in rice caused by plant yield and enhanced Mn solubility resulting in only a slight change in ultimate Cu concentration in plant shoots. By contrast, N induced Cu deficiency in other crops on soils much more deficient in available N. Thus on a soil identical in Cu supplies to those of the current studies, N increased shoot growth of wheat 7-10 times causing high dilution of absorbed Cu to a severe deficient level.[5] Under such situations, N enhanced plant growth will overshadow enhanced Cu contents causing severe Cu deficiency even in flooded rice and will result in severe yield depression. More efficient N carriers for rice such as $(NH_4)_2SO_4$ and $CO(NH_2)_2$ may then be more detrimental due to their higher stimulation of plant growth. Such effect will be still more pronounced on Cu-marginal and Cu-deficient soils. Such soils exist in many regions like Pakistan[4] and their prior evaluation for Cu supply may, therefore, be necessary for efficient N fertilization. Further studies using several rice soils ranging widely in N and Cu supplies should, however, be conducted to test this hypothesis. Proper recognition of Cu deficiency before N application may also help decrease blanking of rice grains which often results from excessive N fertilization. Copper deficiency has been reported to cause abortion of cereal grains.[7]

Acknowledgement. The investigations were supported by IAEA and USDA under grant Nos. 1407/RB and FG-Pa-221 (PK-ARS-3) respectively.

References

1. A. K. Bandyopadhya and M. Adhikari, Riso, **17**, 265 (1968).
2. L. C. Boawn, F. G. Viets Jr., C. L. Crawford, and J. L. Nelson, Soil Sci., **90**, 329 (1960).
3. J. E. Bowen, Plant Physiol., **44**, 255 (1969).
4. F. M. Chaudhry, M A. Kausar, A. Rashid and Rahmatullah, Plant Soil, in press.
5. F. M. Chaudhry and J. F. Loneragan, Australian J. Agri Res., **21**,865 (1970).
6. F. M. Chaudhry and A. Wallace, Plant Soil, in press.
7. P. C. Dekock, M. V. Cheshire and Hall, J. Sci. Food Agri., **22**, 437 (1971).
8. Y. Kokiya, N. Owa and S. Mitsui, Soil Sci. Plant Nutr., **14**, 167 (1968).
9. B.A.C. Enyi, Ghana J. Sci., **6**, 87 (1966).
10. D. A. Forno, M.Sc. Thesis. University of Queensland, Australia, 1971.
11. G. S. Gilbert, Plant Physiol., **26**, 398 (1951).
12. L. J. Hooper and D. B. Davies, J. Sci. Food Agri., **19**, 733 (1968).
13. F. Hussain, F. M. Chaudhry, A. Rashid, S. M. Alam and M. Sharif, Pakistan J. Sci. Ind. Res., in press.
14. M. A. Kausar, F. M. Chaudhry, A. Rashid A. Latif and S. M. Alam, Plant Soil, in Press.
15. N. Kosuge, Hokuriku Nogyo Shikensho Hokuku, **14**, 13 (1972).
16. D. A. Lauer, Ph.D. Thesis, Colorado State University, 1971.
17. I. C. Mahpatra, Indian Farming, **19**, 9 (1969).
18. H. Okajima, Indian Farming, **19**, 5 (1969).
19. P. G. Ozanne, Aust. J. Biol. Sci., **8**,47 (1955).
20. S. Patnaik and F. E. Broadbent, Agron. J., **59**, 287 (1967).
21. W. H. Patrick, Jr. and D. S. Mikkelsen, *in* R. A. Olsen (ed.). *Fertilizer Technology and Use*. Soil Science Society of America, Madison, (1971) 187.
22. F, N. Ponnamperuma, Advan. Agron., **24**, 29 (1972).
23. *Soil Fertility Survey*, Annual Report, Punjab Agricultural Research Institute, Lyallpur. Pakistan (1972-1973).
24. Rahmatullah, F. M. Chaudhry and A. Rashid, Plant Soil, in press.
25. A. Rashid and F. M. Chaudhry, Plant Soil, in press.
26. P. F. Smith, Botan. Gaz., **114**, 426 (1953).
27. K. G. Tiller and J. F. Hodgson, Clays Clay Minerals, **9**, 393 (1962).
28. F. G. Viets Jr., L. C. Boawn and C. L. Crawford, Soil Sci. Soc. Am. Proc., **21**, 197 (1957).