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Macro- and Micronutrients Removed by Upland and Lowland Rice Cultivars in West Africa

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ABSTRACT

Plant analysis is an important component of soil fertility and plant nutrition research. Plant analysis at harvest of the crop forms the basis for constructing nutrient balances and assessing the nutrient needs of production systems. Amounts of macro- and micronutrient elements removed by improved, upland and lowland rice cultivars were determined in field experiments at two sites in Ivory Coast. Amounts of nitrogen (N), zinc (Zn), and manganese (Mn) removed for 1 t rice grain yield by upland and lowland rice cultivars were similar, but the amounts of phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg) removed were higher for lowland than upland rice. The nutrient element harvest indexes (amount in grain/amount in grain plus straw) varied between the cultivars, but more importantly, among nutrient elements. On average the nutrient harvest index was highest for P (69%) and lowest for K (10%). The results suggest that the nutrient requirement of rice for K can be met to a large extent through the recycling of K in rice straw. The amounts of other major nutrients, N and P in the straw were small and hence less scope for supplying these nutrients through the recycling of rice straw.

INTRODUCTION

Plant analysis is an integral component of soil fertility and plant nutrition research. Plant analysis has been used as a diagnostic technique for assessing the nutrient element deficiencies and toxicities in crops. Plant analysis is also employed for determining the nutrient element status of crops which forms the basis for assessing the nutrient requirements and fertilizer needs. For example, knowledge of plant nutrient status of the crop during its vegetative growth stage, can determine when supplemental fertilizer applications are needed (Mills and Jones, 1996). Nutrient status of the crop at harvest is used for determining nutrient uptake and removal by the crop, and constructing nutrient balances. Sustainable maintenance of soil fertility requires that the nutrient elements removed by crop be replenished through the application of fertilizers.

In West Africa, little attention has been devoted to determining the nutrient status of rice grown under field conditions but the information is needed for determining the nutrient requirements and fertilizer needs of crops, for guiding to balanced and rational use of fertilizers. Research is also underway for developing improved and high yielding rice cultivars for growing in upland and lowland ecologies in the subregion. Simultaneously, we have been developing crop and nutrient management strategies to exploit the potential of improved rice cultivars (Sahrawat et al., 1995, 1996). Field experiments conducted for achieving the above objectives also provided an opportunity to determine nutrient status of the improved upland and lowland rice cultivars. This paper presents results on the removal of macro- and micronutrient elements by upland and lowland rice cultivars.

MATERIALS AND METHODS

Plant samples used for determining nutrient uptake and removal were sampled from the field experiments conducted at Mbe and Man in Ivory Coast. Description of the experimental sites and details of the field experiments are available in Sahrawat et al. (1996, 1999). Some relevant information, however, is provided. Soil at the Mbe site, in the forest-savanna transition zone, was an Alfisol and the soil at site near Man, in the humid forest zone, was an Ultisol. Some chemical characteristics in the surface (0-0.2 m) samples of the soils are given in Table 1. For soil analysis, pH was measured by a glass electrode using a soil to water or 1 *M* KCl ratio of 1:2.5. Organic carbon (C) was determined using the Walkley-Black method (Nelson and Sommers, 1982) and total N as described by Bremner and Mulvaney (1982). Bray 1 extractable P was determined as described by Olsen and Sommers (1982) and DTPA extractable Zn as described by Lindsay and Norvell (1978).

Field experiment at Mbe with lowland rice was conducted in the 1996 dry season (January-May) under irrigated condition, and the experiment at Man with upland

TABLE 1. Chemical characteristics of the soils at Man and Mbe (Ivory Coast) used for growing the upland and lowland rice cultivars.

	Man	Mbe
pH (water)	4.8	5.9
PH (KCl)	4.2	5.0
Organic C (g kg^{-1})	14.0	18.5
Total N (mg kg^{-1})	950	800
Bray 1 extr. P (mg kg^{-1})	9	6
DTPA extr. Zn (mg kg^{-1})	3	1

rice was carried out in the 1994 wet season (June-October) under rainfed condition. The lowland rice cultivar chosen for nutrient element analysis was Bouake 189, which is widely cultivated in the lowland ecology in the subregion. The upland cultivar selected was WAB 56-50, which is a WARDA-bred rice cultivar, and was released in 1998 to farmers in Ivory Coast for growing in the upland ecology. The cultivar is adapted to upland, acid soil conditions of the humid zone in West Africa (Sahrawat et al., 1995, 1999). The plots used for growing the test rice cultivars received 90 or 100 kg N ha^{-1} as urea, 50 kg P ha^{-1} as triple superphosphate and 80 kg K ha^{-1} as KCl.

Plant samples consisting of grain and straw samples, were analyzed for macro- and micronutrient elements using standard methods of plant analysis (Jones et al., 1991). Potassium, Ca, Mg, Fe, Mn, and Zn in the plant digests were determined by atomic absorption spectrophotometry. The uptake of nutrient elements in the plant biomass was determined by multiplying the nutrient content in grain and straw samples with grain and straw weights.

RESULTS AND DISCUSSION

The amounts of nutrient elements removed by the upland and lowland rice cultivars are shown in Tables 2 and 3. The yields were higher in the case of lowland rice than upland rice and lowland rice cultivar removed much higher amounts of all determined nutrients in the biomass than upland cultivar. The amounts of nutrients removed by the upland rice cultivar followed the following in decreasing order: N >K > Mg > Ca > P > Fe > Mn > Zn, and the trend in case of lowland rice cultivar was: K > N > Mg > Ca > P > Mn > Fe > Zn.

Total amounts of N, Zn, and Mn absorbed to produce 1 t rice grain yield by the upland and lowland rice cultivars were similar (Tables 2 and 3). The lowland rice cultivar, however, absorbed higher amounts of P, K , Ca, and Mg than did the upland rice cultivar. The availability of nutrients such as K, P, Ca, Mg, and Fe is

TABLE 2. Nutrient removed by upland rice cultivar WAB 56-50 in one crop producing 3.14 t ha^{-1} grain and 2.99 t ha^{-1} straw yield under rainfed condition on an Ultisol at Man, Cote d'Ivoire in 1994.[a]

Nutrient elements	Nutrients removed by one crop (kg ha^{-1})		Total nutrients removed by one t rice grain yield
	Total	Grain	
N	61.0	36.4	19.4 kg
P	6.5	4.6	2.1
K	58.1	6.3	18.5
Ca	9.4	1.4	3.0
Mg	11.4	3.4	3.6
Fe	1.93	0.40	616 g
Mn	1.70	0.14	541
Zn	0.08	0.03	25

[a]Crop was grown in the wet season (June-October) and received 100 kg N ha^{-1} as urea, 50 kg P ha^{-1} as triple superphosphate, and 80 kg K ha^{-1} as KCl.

TABLE 3. Nutrients removed by lowland rice cultivar Bouake 189 in one crop producing 6.77 t ha^{-1} grain and 7.00 t ha^{-1} straw under irrigated lowland condition on an Alfisol at Mbe, Cote d'Ivoire in 1996.[a]

Nutrient element	Nutrients removed by one crop (kg ha^{-1})		Total nutrients removed by one t rice grain yield
	Total	Grain	
N	127.7	73.1	18.9 kg
P	23.3	15.6	3.4
K	194.0	17.6	28.7
Ca	32.7	5.4	4.8
Mg	45.8	12.9	6.8
Fe	2.6	1.2	384 g
Mn	3.8	0.8	561
Zn	0.2	0.1	30

[a]Crop was grown in the dry season (January-May) and received 90 kg N ha^{-1} as urea, 50 kg P ha^{-1} as triple superphosphate, and 80 kg K ha^{-1} as KCl.

TABLE 4. Nutrient element harvest index[a] (%) of upland (cv. WAB 56-50) and lowland (cv. Bouake 189) rice cultivars.

Element	WAB 56-50	Bouake 189	Mean
N	60	57	59
P	71	67	69
K	11	9	10
Ca	15	17	16
Mg	30	28	29
Fe	21	46	34
Mn	8	21	15
Zn	38	50	44

[a]Nutrient harvest index = amount in grain/amount in grain plus straw.

generally increased and that of Zn decreased as result of flooding soils under water. The dynamics of nutrient release in flooded soils is a function of their characteristics, especially organic matter and texture (Ponnamperuma, 1972; Narteh and Sahrawat, 1999).

The upland rice cultivar also removed larger amount of Mn than those reported for the irrigated lowland rice in Asia (Yoshida, 1981). The amount was however, less than that absorbed by the lowland rice cultivar. The upland rice absorbed higher amount of Fe than did the lowland rice cultivar. We know that the Alfisol at the Mbe lowland site is relatively low in extractable iron and, moreover, there is little interflow of iron from soils in the upper slopes. On the other hand, the Ultisol at the upland site in Man is relatively high in iron which is *in situ* mobilized and absorbed by the rice plant (Narteh and Sahrawat, 1999).

The nutrient element harvest index (amount in grain/amount in grain plus straw) varied considerably for plant nutrients, and on average, the nutrient harvest index was highest for P (69%) and lowest for K (10%) (Table 4). Also, there were differences between the upland and lowland rice cultivars. For example, Mn harvest index was considerably lower in the case of upland rice cultivar (8%) than the lowland rice cultivar (21%), indicating that a higher proportion of Mn was found in the grain in the case of lowland rice. The iron harvest index was higher for the lowland rice cultivar (46%) than the upland rice cultivar (21%). Similar results were also obtained for Zn in that a higher proportion of Zn was found in the grain of the lowland rice than the upland rice. The harvest indexes of N, P, K, Ca, and Mg were generally similar for the upland and lowland rice cultivars.

The results on the nutrient harvest indexes of the rice cultivars indicate that returning rice straw to the land for the purpose of recycling nutrients, will result in returning about 90% of K back to the soil which should considerably reduce the need for applying fertilizer K. The contents of other major nutrients, N and P in the rice straw were small, and hence offer less scope for supplying these nutrients through the recycling of rice straw. Application of crop residues, however, is important especially for the upland soils for maintaining good soil physical properties (Larson and Clapp, 1984).

REFERENCES

Bremner, J.M. and C.S. Mulvaney. 1982. Nitrogen—Total. pp. 595-624. In: A.L. Page, R.H. Miller, and D.R. Keeney (eds.), Methods of Soil Analysis. Part 2. Agronomy 9. American Society of Agronomy, Madison, WI.

Jones, Jr., J.B, B. Wolf, and H.A. Mills. 1991. Plant Analysis Handbook: A Practical Sampling, Preparation, and Interpretation Guide. MacroMicro Publishing, Inc., Athens, GA.

Larson, W.E. and C.E. Clapp. 1984. Effects of organic matter on soil physical properties. pp. 363-385. In: International Rice Research Institute (ed.), Organic Matter and Rice. International Rice Research Institute, Manila, Philippines.

Lindsay, W.L. and W.A. Norvell. 1978. Development of DTPA soil test for Zn, Fe, Mn, and Cu. Soil Sci. Soc. Am. J. 42:421-428.

Mills, H.A. and J.B. Jones, Jr. 1996. Plant Analysis Handbook II: A Practical Sampling, Preparation, Analysis, and Interpretation Guide. MicroMacro Publishing, Inc., Athens, GA.

Narteh, L.T. and K.L. Sahrawat. 1999. Influence of flooding on electrochemical and chemical properties of West African soils. Geoderma 87:179-207.

Nelson, D.W. and L.E. Sommers. 1982. Total carbon, organic C, and organic matter. pp. 539-579. In: A.L. Page, R.H. Miller, and D.R. Keeney (eds.), Methods of Soil Analysis. Part 2. Agronomy 9. American Society of Agronomy, Madison, WI.

Olsen, S.R. and L.E. Sommers. 1982. Phosphorus. pp. 403-430. In: A.L. Page, R.H. Miller, and D.R. Keeney (eds.), Methods of Soil Analysis. Part 2. Agronomy 9. American Society of Agronomy, Madison, WI.

Ponnamperuma, F.N. 1972. The chemistry of submerged soils. Adv. Agron. 24:29-96.

Sahrawat, K.L, M.P. Jones, and S. Diatta. 1995. Response of upland rice to phosphorus in an Ultisol in the humid forest zone in West Africa. Fert. Res. 41:11-17.

Sahrawat, K.L., M.P. Jones, and S. Diatta. 1999. Phosphorus, calcium, and magnesium fertilization effects on upland rice in an Ultisol. Commun. Soil Sci. Plant Anal. 30:1201-1208.

Sahrawat, K.L., C.K. Mulbah, S. Diatta, R.D. DeLaune, W.H. Patrick, Jr., B.N. Singh, and M.P. Jones. 1996. The role of tolerant genotypes and plant nutrients in the management of iron toxicity in lowland rice. J. Agric. Sci. (Cambridge) 126:143-149.

Yoshida, S. 1981. Fundamentals of Rice Science. International Rice Research Institute, Manila, Philippines.