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Inherent Properties and Fertilizer Effects of Flooded Rice Soil

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Abstract: At the Fogera plain, Ethiopia rice is mainly grown under wet conditions. Therefore, understanding the nature of flooded soils is essential for better management of applied and native nutrients. Accordingly, field and laboratory experiments were conducted to study the major inherent properties and effects of applied mineral N and P fertilizers on soil total N and available P. A factorial combinations of N (0, 30, 60, 90, 120 and 150 kg N ha^{-1}) and P (0, 13.2, 26.4, 39.6 and 52.8 kg P ha^{-1}) fertilizers were applied using a randomized complete block design with four replications. The soil was characterized as Pellic Vertisol. Surface soil analyses indicated that the experimental field was clayey in texture (71.25% clay) and slightly acidic (pH 5.61) in reaction. Total N (0.28%), organic carbon (3.0%), percent base saturation (79.39%), cation exchange capacity (52.90 meq/100 g soils) and Olsen's available P (36.20 ppm) were high while available K was medium (265.23 ppm). In the soil profile study, clay content, pH, percent base saturation and cation exchange capacity increased with depth whereas total N, organic carbon, available K and P declined. The Olsen's method extracted the highest amount of P and was associated positively and strongly with number of panicles m^{-2} (r = 0.460**) and the number of spikelets panicle^{-1} (r = 0.487**) over Bray II. Besides, total N slightly decreased while available P slightly increased in the soil after harvest. The study revealed that the Olsen' method was superior over Bray II in predicting available P in flooded rice soil.

Key words: Available P, total N, Pellic Vertisol, flooded rice, Fogera plain

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INTRODUCTION

At the Fogera plain, in the North Western Ethiopia rice is the major food security crop which significantly improves the rural people livelihood. As a result of which its production has increased rapidly from year to year (Mulugeta, 1999; Mulugeta and Sete, 2002). Fogera plain is the major rice producing region which covered about 20% of the total cultivated land in Ethiopia during the 2009 cropping season (Government of Ethiopia, 2009).

Soil fertility management is among the key options to enhance rain fed lowland rice cropping system productivity. Fertilizer study conducted at the Fogera plain revealed that application of N and P significantly increased rice grain yield (Mulugeta, 2000; Mulugeta and Heluf, 2005; Gebrekidan and Seyoum, 2006). However, proper nutrition is essential for satisfactory crop growth and production. The use of soil fertility study can help to determine the status of plant available nutrients and other soil chemical factors to develop sound fertilizer recommendations to achieve optimum rice production and productivity.

At the Fogera plain, since rice is pre-dominantly grown under wet conditions it is important to understand the unique properties of flooded soils for better management of applied and native nutrients. Flooded rice soils are characterized by the limited availability of oxygen and by the unique chemical and biological transformations of different soil minerals such as N and C undergo compared to well-drained soils (Bouldin, 1986; Mikkelsen, 1987). Mineralization of N is reported to be high in flooded soils (Ono, 1989). However, it is estimated that under tropical conditions, the efficiency of applied N is less than 50% (Mengel, 1991). The causes for such low N recovery are ammonia (NH_3) volatilization; denitrification, leaching, immobilization and ammonium (NH_4^+) fixation (Sharma *et al*., 1992). Phosphorus deficiency is not as common in flooded rice as in upland crops due to the higher availability of native and applied P and lower P absorption (Roy and De Datta, 1985; Zia *et al*., 1992). In acidic soils, the increase in P availability is associated with direct reduction of iron (III) to iron (II) phosphates as a result of increase in pH (Ponnamperuma, 1977).

Several P extraction methods are devised in order to meet the specific soil conditions under which crops are grown. Mamo and Haque (1991) reported the superiority of the Olsen (0.5M $NaHCO_3$, pH 8.5) extraction method for predicting available soil P on some Ethiopian soils. Dabin (1980) found that with rice grown in soils

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dominated by Fe-P, alkaline extractants gave the best correlation with crop response to P fertilizer. For the Fogera plain soil, Mamo and Haque (1991) found that the distributions of active forms of P are in the order of Fe-P, Ca-P and Al-P.

On the other hand, scarcity of scientific information regarding properties of flooded rice soil has long been considered as a setback for efficient nutrient management and yield improvement efforts in rice. Therefore, this experiment was conducted to study the major physical and chemical properties of the soil, effect of applied mineral N and P fertilizers on soil N and P status and the Olsen's and Bray II methods for prediction of available soil P in flooded rice production.

MATERIALS AND METHODS

Description of the study area: A field experiment was conducted under rain fed conditions during the rainy season (June-October) of the 1999 in the Fogera plain, geographically located at 13°19' N latitude and 37°03' E longitude at an average elevation of about 1815 meters above sea level. The area receives an average annual rainfall of 1300 mm of which 1127 mm of rainfall was received between June and October. The average yearly minimum and maximum temperatures are 11.7 and 27.5°C, respectively (North Western Zone Meteorological Service in 1999: Unpublished data). The ecology and type of rice cultivation at the Fogera plain is categorized as rain fed lowland (IRRI, 1993). According to Mulugeta (2000), the soil on which the field experiment was conducted is classified as Pellic Vertisol. The land used for undertaking the field experiment had not been fertilized for a longer period of time either with organic or mineral fertilizers. The area is usually flooded for most of the time during the cropping season. During the season where the experiment was conducted, the depth of water above the surface of the soil between July and October ranged from 5-10 cm.

Experimental treatments, design and procedures: A soil profile was opened at the selected site in January (the month which is intermediate between the wet and dry season) and about 1 kg of soil sample was collected from each layer or genetic horizon for characterization. The soil profile was described using the procedures and guidelines of Soil Taxonomy (Soil Survey Staff, 1975; FAO, 1990). Surface soil samples (0 to 20 cm depth) were also collected before sowing on 20 spots from the experimental field and from each plot after harvest and bulked accordingly for determination of soil total N and available P. The fertilizer treatments considered in the study consisted of six levels of N (0, 30, 60, 90, 120 and 150 kg ha^{-1}), five levels of P (0, 13.2, 26.4, 39.6 and 52.8 kg ha^{-1}) and their full factorial combinations. The experiment was laid out in a Randomized Complete Block Design (RCBD) with four replications consisting of a total of 30 treatments. Nitrogen was applied in two equal splits, wherein 50% of the N rate was applied basal at planting and the remaining half was top dressed at the maximum tillering stage, as urea (46% N). Unlike N, the total dose of P was applied basal as triple super phosphate (20% P) during sowing.

Soil analysis: Soil samples were air dried and passed through a 2 mm diameter size sieve before analyses. Soil color was determined using the Munsell soil color chart. Soil pH was determined using a pH meter in 1:1 soil: H_2O ratio as described by Black (1965b). Soil texture was determined by the Bouyoucos hydrometer method (Bouyoucos, 1951). Soil organic carbon was determined by the Walkley-Black wet digestion method (Walkley and Black, 1934). Total N was determined by the Kjeldahl digestion method according to Bremner and Mulvancy (1982). Available soil P was determined using the Olsen $NaHCO_3$ and Bray II extraction methods (Bray and Kurtz, 1945; Olsen *et al*., 1954). Cation exchange capacity was determined by the 1N ammonium acetate extraction method as described by Black (1965a). Exchangeable cations (Ca, Mg, K and Na) were extracted with 1N ammonium acetate solution. Sodium and K were determined by flame photometer whereas Ca and Mg were determined by atomic absorption spectrophotometer. Available potassium was determined photometrically using the method described by Hunter and Pratt (1957).

Statistical analysis: Simple correlation coefficients were carried out for selected soil profile properties, soil available P, applied fertilizer P level, grain yield and major yield components of rice studied following statistical procedures appropriate for the experimental design as outlined by Gomez and Gomez (1984). Analyses were computed using MSTAT-C version 1.2 (Freed, 1990) statistical software.

RESULTS AND DISCUSSION

Major physical and chemical properties of the soil: Analytical results indicated that the composite surface soil is clayey in texture, slightly acidic in reaction and high in total N and organic carbon (Table 1 and 2a). The C: N ratio falls within the level of normal agricultural soils. Calcium was found to be the most dominant basic cation occupying 77.7% of the basic exchangeable cations or 61.7% of the exchange complex, followed by Mg, K and Na, respectively (Table 2b). The soil exhibited a high

Table 1: Some physical properties of flooded vertisol of Fogera plain

	Particle size distribution (%)				Soil color*	
Depth (cm)	Sand	Silt	Clay	Class	Dry	Moist
Soil profile						
0-33	12.50	18.75	68.75	Clay	V. dark gray (10 YR 3/1)	Black (10 YR 2/1)
33-85	6.25	15.00	78.75	Clay	V. dark gray (2.5 YR 3/0)	Black (2.5 YR 2.5/0)
85-130	8.75	12.50	78.75	Clay	V. dark gray (2.5 YR 3/0)	Black (2.5 YR 2.5/0)
130-175	10.00	10.00	80.00	Clay	Black (2.5 YR 2.5/0)	Black (2.5 YR 2.5/0)
Surface soil						
0-20	13.75	15.00	71.25	Clay	V. dk gr br (10 YR 3/2)	V. dk br (10 YR 2/2)

*V: Very, V. dk gr br: Very dark gray brown, V. dk br: Very dark brown

Table 2a: Major chemical properties of flooded vertisol of Fogera plain

							AP (ppm)	
Soil depth (cm)	pH (H_2O)	TN (%)	OC (%)	C:N ratio	PBS (%)	AK(ppm)	Olsen	Bray II
Soil profile								
0-33	6.10	0.28	3.08	11.00	91.76	215.95	31.00	-
33-85	7.45	0.13	1.52	11.69	97.65	175.85	7.30	-
85-130	7.91	0.11	1.13	10.27	102.55	169.35	9.70	-
130-175	7.95	0.10	1.09	10.90	113.32	130.00	4.30	-
Surface soil								
0-20	5.61	0.28	3.00	10.7	79.39	265.23	36.20	15.10

TN: total nitrogen, OC: Organic carbon, PBS: Percent base saturation, AK: available K, AP: available P

Table 2b: Major chemical properties of flooded vertisol of Fogera plain

	Exchangeable cations and CEC (meq/100 g soil)					
Depth (cm)	Ca	Mg	K	Na	SBC	CEC
Soil profile						
0-33	40.27	8.89	0.80	0.20	50.16	54.68
33-85	48.72	7.04	0.58	0.39	56.73	58.10
85-130	49.85	8.02	0.59	0.41	58.87	57.40
130-175	59.75	7.70	0.53	0.35	68.33	60.30
Surface soil						
0-20	32.65	8.25	0.93	0.17	42.00	52.90

SBC: Sum of basic cations, CEC: Cation exchange capacity

percent base saturation and very high cation exchange capacity, indicating that the soil at the experimental field is chemically a good agricultural soil. The soil is also medium in available K and high in available Olsen's P (Table 2a).

Evaluation of the soil profile indicated that the soil is clayey in texture throughout the profile with a clay content increasing with depth (Table 1). Similarly, the pH of the soil increased with depth from slightly acidic at the surface to slightly alkaline at the bottom of the profile (Table 2a) and associated positively and significantly ($p \leq 0.01$) with clay content (Table 3). Mitiku (1987) reported that the low clay content at the surface in Vertisol profile and the increase with depth could indicate translocation of clay from the surface horizon and its illuviation in the lower horizon along with a change in higher pH. On the other hand, an increasing in clay content at depth could be resulted from in situ synthesis and formation of clay.

The typical structure of the soil profile up to 130 cm was angular blocky but changed into massive at depth. An increase in the amount of clay with depth influenced the consistence of the soil. Accordingly it was found hard at the upper horizons to very hard down to the profile when dry and exhibited sticky and plastic at the upper horizon to very sticky and very plastic at lower depth when wet. The soil displayed a swell-shrink properties and had a 2-5 cm wide vertical cracks at an interval of 15-40 cm to a depth of 85 cm. Intersecting slicken side were also observed below the profile depth of 70 cm. Total N and organic carbon content in the upper horizon were high and declined with increase in depth (Table 2a). Positive and highly significant association was noted between total N and organic carbon ($p \leq 0.01$) (Table 3). Decomposition of tissue fragments and roots of the grass cover, which were grown at the site of the profile, are believed to contribute to the high content of total N and organic carbon content in the surface soil horizon. The C: N ratio remained almost constant with increase in depth (Table 2a) indicating that the rate of reduction in total N and organic carbon contents with depth followed a much more similar trend.

Among the exchangeable bases, Ca is the dominant cation (Table 2b), which accounted for 80.3% of the basic

Table 3: Simple correlation coefficients among selected properties of flooded vertisol profile of Fogera plain

Property	Clay	pH	TN	OC	PBS	CEC	AK	AP	ECa
Clay	-								
pH	0.975^{**}	-							
TN	-0.995^{**}	-0.992^{**}	-						
OC	-0.985^{**}	-0.998^{**}	0.997^{**}	-					
PBS	0.770	0.821	-0.788	-0.800	-				
CEC	0.899	0.866	-0.883	-0.868	0.917^{*}	-			
AK	-0.877	-0.889	0.880	0.880	-0.976^{**}	-0.979^{**}	-		
AP	-0.995^{**}	-0.955^{*}	0.983^{**}	0.968^{*}	-0.780	-0.926^{*}	0.891	-	
ECa	0.848	0.860	-0.850	-0.850	0.981^{**}	0.977^{**}	-0.998^{**}	-0.867	-

*, **Significant at 5 and 1% level of probability, respectively, TN: Total N, OC: Organic carbon, PBS: Percent base saturation, CEC: Cation exchange capacity, AK: Available K, AP: Available P, ECa: Exchangeable Ca

Table 4: Effects of N and P fertilizer levels on soil total N (%)† after harvest, Fogera plain

	Applied N (kg N ha^{-1})						
Applied P (kg P ha^{-1})	0	30	60	90	120	150	Mean
0.0	0.22	0.24	0.23	0.25	0.25	0.25	0.240
13.2	0.23	0.22	0.24	0.25	0.25	0.23	0.237
26.4	0.22	0.25	0.25	0.24	0.24	0.24	0.240
39.6	0.25	0.25	0.25	0.25	0.25	0.25	0.250
52.8	0.25	0.24	0.24	0.24	0.25	0.25	0.245
Mean	0.234	0.240	0.242	0.246	0.248	0.244	

†Total N determined on soil samples bulked over replications

cations in the exchange complex at the surface horizon and increased to 87.4% at depth. The correlation of exchangeable calcium with percent base saturation and cation exchange capacity were positive and highly significant ($p\leq 0.01$) (Table 3). The exchangeable Ca to Mg ratio increased from 4.5:1 at the surface horizon to 7.8:1 at depth which indicated the presence of high $CaCO_3$ content at lower depth of the profile. Percent base saturation was high throughout the soil profile and consistently increased with depth (Table 2b) and showed a positive and significant correlation with the amount of exchangeable Ca ($p\leq 0.01$) and cation exchange capacity ($p\leq 0.05$) (Table 3) and linearly increased with the amount of exchangeable Ca content with profile depth. Moreover, percent base saturation followed similar trends with pH and clay content of the soil profile. Mitiku (1987) also reported similar association between percent base saturation and pH in the soil profiles of Vertisols. High percent base saturation is an indication of fertile conditions of the soil in general, due to available bases.

The cation exchange capacity was very high in the surface horizon of the soil profile and increased further with depth (Table 2b) and showed positive and significant association with exchangeable Ca ($p\leq 0.01$) and percent base saturation ($p\leq 0.05$) (Table 3). Mitiku (1987) reported that cation exchange capacity increased with the amount of clay content. The upper soil profile had medium available K and declined with depth (Table 2b). Available Olsen's P was high at the upper most horizon of the profile and decreased further with depth (Table 2b). The lower concentration of available P at depth is due to fixation by clay and Ca, which were found to increase with profile depth. Yerima (1993) reported that since P is tied up to the humus and clay content of the soil, available P decreases regularly with soil depth. Distinct reddish yellow iron mottles were found within the upper horizons of the soil profile dominantly as alignments along grass roots indicating the prevalence of periodic flooding and water logging. Reddish black manganese nodules were also observed to a depth of 130 cm of the soil profile. Hard carbonate nodules occurred commonly below 85 cm of the profile depth.

Total N in the soil after harvest: Compared with total N determined before sowing (Table 1), total N in the soil declined after harvest by 0.03-0.06% (Table 4). The association between the applied level of N and total N determined after harvest was positive and non-significant (Table 7). The reduction of total N in the soil after harvest and lack of significant correlation with the applied fertilizer N could be attributed to the consumptive use of rice plant and losses due to different soil and environmental factors. Since N has low recovery under flooded soil condition, applied N is compensated for native soil N lost, which could be caused due to volatilization, denitrification, leaching, immobilization and ammonia fixation in the soil minerals. Generally, N fertilizer applied to cultivated crops have little effect on the level of soil organic matter or organic N in the soil and it can only be maintained by inclusion of a sod crop in the rotation or by frequent and heavy application of manure and crop residues (Wild, 1988). However, application of combined N and P fertilizers tend to increase slightly the concentration of N after harvest by 0.01-0.03 in 90% of the experimental

Table 5: Effects of N and P fertilizers level on Olsen extractable soil P (ppm)† after harvest, Fogera plain

	Applied N (kg ha^{-1})						
Applied P (kg ha^{-1})	0	30	60	90	120	150	Mean
0.0	35.60	35.40	36.20	39.00	36.20	39.20	36.93
13.2	34.40	32.60	37.60	38.60	42.60	38.20	37.33
26.4	31.80	34.20	35.60	36.60	36.00	36.00	35.03
39.6	36.20	36.00	36.40	36.80	39.00	38.20	37.10
52.8	38.80	36.60	36.40	38.40	35.20	36.20	36.93
Mean	35.36	34.96	36.44	37.88	37.80	37.56	

†Olsen P determined on soil samples bulked over replications

Table 6: Effects of applied N and P fertilizers levels on Bray II extractable soil P (ppm)† after harvest, Fogera plain

	Applied N (kg N ha^{-1})						
Applied P (kg P ha^{-1})	0	30	60	90	120	150	Mean
0.0	14.40	15.80	17.60	16.40	15.20	15.20	15.77
13.2	15.20	13.60	14.60	17.40	13.80	17.60	15.37
26.4	15.80	14.20	15.20	16.20	16.00	15.20	15.43
39.6	16.20	16.00	16.20	16.20	14.80	16.20	15.93
52.8	18.40	15.80	15.60	20.00	18.40	14.40	17.10
Mean	16.00	15.08	15.84	17.24	15.64	15.72	

†Bray II P determined on soil samples bulked over replications

plots over the control receiving no N and no P. Talukdar *et al*. (1996) reported that concentration of N, especially NO_3-N, tends to be increase with N fertilization under lowland rice production due to nitrification of NH_4-N in the oxidized zone of submerged soil.

Available Olsen's P and Bray II P after harvest: Available P determined with Olsen's and Bray II methods after harvest ranged between 31.8 to 42.6 ppm and 13.6 to 20.0 ppm, respectively (Table 5 and 6). Applied levels of N and P fertilizers increased the Olsen's P and Bray II P on 73.3 and 83.3% of the experimental plots over the control receiving no N and no P, respectively. Particularly, increment of available Olsen's soil P was observed with increasing the main effects of N level over P fertilizer. This indicates that at a given level of applied P fertilizer, increasing the rate of N fertilizer enhanced the solubility of applied and inherent soil P and its availability to the plant. Debnaz and Mandal (1984) reported that N fertilizer application could solubilize the non-extractable P or enhance mineralization of organic P in the soil. Available Olsen's and Bray II P generally increased in the soil after harvest (Table 5 and 6). Compared with the amount of P determined before sowing (36.20 ppm), Olsen's P increased by 0.2-6.4 ppm after harvest on about 50% of the experimental plots (Table 2b and 5). Roy and De Datta (1985) and Zia *et al*. (1992) have indicated that availability of native and applied P is increased under flooded soil rice production.

The association of Olsen's P with grain yield was positive and weaker. However, it showed positive and significant correlation with major yield components of rice such as number of panicles m^{-2} (r = 0.460**) and number of spikelets panicle^{-1} (r = 0.487**) (Table 7). On the other hand, the correlation of Bray II available P with grain yield was negative and non-significant, whereas it was positive and non-significant with the number of panicles m^{-2} and number of spikelets panicle^{-1} (Table 7). Because of the highest amount of available P extracted with Olsen's method and positive association with grain yield and positive and stronger association with major yield components of rice it can be concluded that the Olsen's method is superior over Bray II in predicting available P under flooded rice soil of the Fogera plain. The study is in agreement with the findings reported by Dabin (1980) and Mamo and Haque (1991).

Table 7: Simple correlation values of soil available P with applied p level, grain yield and major yield components of rice, Fogera plain

Available P	Applied P	Grain yield	Panicles m^{-2}	Spikelets panicle^{-1}
Olsen	-0.039	0.107	0.460**	0.487**
Bray II	0.722	-0.080	0.111	0.161

**Significant at 1% level of probability

CONCLUSION

The soil of the experimental site was characterized as Pellic Vertisol and exhibited about 71.25% clay content at the depth of plow zone. Although, the soil is said to be fertile from its chemical point of view it is difficult to work with. Temporary flooding and inundations during the rainy season also aggravates the problem. Therefore, at the Fogera plain's soil and hydrological condition, rice production could be regarded as one of the best alternative crop available to farmers in alleviating soil-crop-related problems. Understanding of the mechanisms by which N is lost and available and residual effects of P is increased in flooded rice soil, is needed for better management of applied fertilizers and improvement of crop yields. Compared with Bray II, the Olsen's method extracted the highest amount of P and associated positively with grain yield and positively and strongly with major yield components of rice crop. Hence, the Olsen's method is found to be superior over Bray II in predicting available P under flooded rice production.

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