Evaluation of the residual value of phosphorus fertilizer for Sorghum *(Sorghum bicolor* L.) grown on a Vertisol

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Bestimmung der Nachwirkung von Phosphordünger bei Sorghum *(Sorghum bicolor* L.) auf Vertisol

1. Introduction

Phosphorus makes a significant contribution to the cost for producing cereals and the price of phosphate fertilizer can be expected to increase in the future (BATTEN, 1992). This means efficient P fertilizer management would be indispensable in crop production in general and for limited resource farmer in particular. Efficient P fertilizer management strategy requires accounting for the residual value of P fertilizer (MEDHI and DE DATTA, 1996; WARREN, 1992).The residual P has a significant effect on next crop due to its carry-over effect (TANDON, 1975). The long-lasting residual value of fertilizer P has been shown by several workers (GOEDERT, 1983; JOHNSON and POULTON, 1979; LARSEN et al., 1965). SAHRAWAT et al. (1995) reported that residual P fertilizer effects are strong and significant for sorghum in the immediate preceding season of P application. In the Hararghe highlands, Ethiopia, sorghum (*Sorghum biocolor* (L.)) is the most important staple food crop occupying about 60 % of the total crop land of the region (NAIR, 1983). The crop generally responds to P application (SHARMA et al., 1988). Sorghum response to applied P was reported to differ among soil orders in the order: Alfisol > Cambisol > Vertisol (KANWAR, 1986) suggesting the significance of residual P on Vertisols which conforms to the sorption capacity of Vertisols for applied P. Similarly, MENDOZA et al. (1990) has suggested that the residual value of phosphate fertilizer differs among soils and should be considered for rational use of fertilizers. RAO and RAO (1991) have reported that on Vertisols, high doses of P were required for optimum yield using pearl millet and sorghum as test crops. They attributed the high P dose requirements to the high P sorption capacity of Vertisols.

Residual P value for subsequent cropping has not been evaluated for the cropping systems of the Hararghe Highlands, Eastern Ethiopia, where farmer access to fertilizers is limited by several influencing factors. Therefore, this study was conducted with the main objective of evaluating the comparative effects of residual P applied only at the beginning of the first crop season for sustaining yield for the subsequent crop seasons (residual P) and yearly application of P fertilizer (direct P).

Zusammenfassung

Die Nachwirkung von Phosphordünger für den Hirseertrag (*Sorghum bicolor* L.) wurde zwischen 1993 und 1996 auf einem kalkhältigen Vertisol der Versuchsstation der Agraruniversität Alemaya (Ost-Äthiopien) untersucht. Die Studie bezieht sich auf die Vegetationsperiode 1993 als Basisjahr, wobei Phosphor mit Niveaus von 0, 23, 46, 69, 92 und 115 kg/ha P_2O_5 gedüngt wurde. Die Ergebnisse zeigten, dass die Nachwirkungen von Phosphordünger von Jahr zu Jahr in Abhängigkeit von Regenmenge und –verteilung. Generell war zu beobachten, dass Niveaus von 23 und 46 kg/ha P_2O_5 - von den Ertragsreaktionen her betrachtet – keine signifikante Nachwirkung für Folgefrüchte besitzen. Andererseits war die Nachwirkung signifikant und von praktischer Bedeutung, sobald das Düngungsniveau 69 kg/ha P_2O_5 erreichte oder überstieg. Über diesem Niveau erwies sich die Nachwirkung des Phosphordüngers als ungefähr gleich wichtig – zumindest für die erste und zweite Nachfrucht – wie die jährliche Düngung selbst. Lineare Regressionsanalysen zeigten einen deutlich signifikanten Zusammenhang zwischen Restphosphorertrag bei der Folgefrucht und des Phosphorversorgungsniveaus un der vorhergehenden Vegetationsperiode, was die Bedeutung der Rest-phosphordüngermengen für die Nachfrucht unterstreicht.

Schlagworte: Direktphosphordüngung, Äthiopien, Phosphordüngernachwirkungen; Sorghum, Vertisol.

Summary

The residual value of P fertilizer for sorghum (*Sorghum bicolor* L.) grain yield was evaluated on a calcareous Vertisol at Alemaya University of Agriculture field experiment station, eastern Ethiopia, from 1993-1996. The study was conducted using 1993 crop season as a base year whereby the phosphate levels 0, 23, 46, 69, 92 and 115 kg/ha P_2O_5 were applied. Results showed that the residual P fertilizer effects varied from year to year depending on rainfall amount and distribution. Generally it was observed that 23 and 46 kg/ha P_2O_5 levels were not of significant importance to have practical residual value for subsequent cropping as observed from the yield responses. On the other hand, when the phosphate level was greater than or equal to 69 kg/ha P_2O_5, the residual P fertilizer value was of practical significance. Beyond this level, the residual value of P fertilizer was observed to be of equal importance for at least 1–2 subsequent crop seasons compared to the annual application. Linear regression analysis of residual P yield of the subsequent crop season and the preceding crop season for the respective P levels showed strong significant correlation confirming the importance of residual P fertilizer for the subsequent cropping.

Key words: Direct P, Ethiopia, Residual P, Sorghum, Vertisol.

2. Materials and Methods

2.1 Description of the study area

The study was conducted at Alemaya University of Agriculture field experiment station on a Vertisol, eastern Ethiopia. It is located at 9° 26' N and 41°55'E at an average altitude of 1980 m above sea level. A climatic characterization made using 28 years of data (AUA, 1987) revealed that the annual average total rainfall is 872 mm and the average potential evapotranspiration based on PENMAN (1948) method is 1227 mm while the mean annual air temperature is 16.8 °C.

Mean monthly rainfall for the crop seasons considered is given in Table 1. The Vertisol at Alemaya has a moderate nitrogen and relatively high P contents (TAMIRIE, 1975) compared to other soil types occurring in the area. For the plow layer (0–30 cm soil depth), the available water capacity and the average bulk density were 30.8 mm/cm and

Table 1: Mean monthly rainfall (mm) for the crop seasons considered at Alemaya (The 1994 rainfall data was not recorded for the station; Source: AUA, 1997)

Tabelle 1: Mittlere monatliche Regenmenge (mm) während der Vegetationsperiode gemessen in Alemaya (Werte für 1994 wurden nicht erhoben; Quelle: AUA, 1997)

Month	Year		
	1993	1995	1996
January	60.6	0.0	47.0
February	52.1	0.0	12.4
March	24.1	0.0	32.5
April	126.5	0.0	144.4
May	164.6	22.2	169.4
June	45.8	20.3	81.8
July	59.9	194.6	92.1
August	76.4	131.2	139.5
September	57.0	142.1	147.7
October	0.0	6.9	0.0
November	0.0	0.0	32.7
December	0.0	0.0	0.0

Table 2: Selected Physico-chemical characteristics or Vertisol at Alemaya

Tabelle 2: Ausgewählte physiko-chemische Merkmale des Vertisols in Alemaya

Depth (cm)	Particle size (%)			O.M. (%)	pH (1:1)		P^b (mg/Kg)	Total N^a (%)
	Sand	Silt	Clay		H_2O	KCl		
0–25	13	17	70	3.1	8.0	6.6	38.8	0.33
25–75	13	17	70	3.0	8.1	6.8	4.2	0.28
75–100	11	15	74	1.8	8.3	6.7	4.0	0.10
100–140	11	15	74	1.8	8.3	6.7	5.3	0.16
140+	15	15	70	0.9	8.5	4.9	4.9	0.08

a: Regular Macro-Kjeldahl method
b: OLSEN et al. (1954)

1.4 g/ cm^3 (HELUF and MITIKU, 1991). Some selected physico-chemical properties of the Vertisol at Alemaya are given in Table 2.

2.2 Experimental Design and Management

To study the comparative effects of residual and direct P fertilizer, six levels of phosphate (0, 23, 46, 69, 92 and 115 P_2O_5 kg/ha) were considered. The first year, 1993 crop season, was used as a base year whereby the respective fertilizer levels were arranged in Randomized Complete Block Design (RCBD) with four replications on a plot size of 7 m x 4 m. For the subsequent three crop seasons, each plot was divided into two plots with 3 m x 4 m plot size each. These were arranged in a split-plot design with four replications wherein the residual and direct P were taken to be main plot and the P levels were considered as sub-plot factors. In each case, the plots were not rotated yearly. For the residual P fertilizer, the levels indicated were applied only at the beginning of the study (for the 1993 crop season only) while in the case of direct P the respective levels were also applied annually for the three subsequent crop seasons. Recommended rate of N for Vertisol at Alemaya, 69 kg N/ha (TAMIRIE, 1975), was used for every treatment to remove the limitation that might be imposed by nitrogen.

Nitrogen (urea) was split-applied half at planting and the other half at 30-40 days after planting. P (Triple superphosphate) was applied all at planting whereby the fertilizer was placed at 5 cm below the seed and planting of the seed was done at 10 cm depth. The plots were plowed by hand, for the subsequent crop seasons, to avoid mixing of treatments.

The sorghum (*Sorghum bicolor* L. cv. ETS-2752), an improved variety and released from Alemaya University of Agriculture was used. The seed rate used was 7 kg/ha, whereby planting was done by hand using 2 grains per hole, later thinned out to 1 per hole after emergence.

In characterizing the Vertisol, the particle-size distribution was determined by hydrometer method (BOUYOUCOS, 1962). Organic matter and available P were determined by WALKLEY and BLACK (1934) and OLSEN et al. (1954), respectively.

To monitor the annual residual P left at harvesting composite soil samples were collected (0–30 cm depth) on plot basis for the respective P levels used and analyzed according to OLSEN et al. (1954). The effectiveness of residual P for sorghum production can be evaluated using grain yield (BOLLAND and GILKES, 1998) whereby the residual value was calculated by dividing the amount of current P required to produce a target yield by the amount of residual P required to produce the same yield. To do so the relationships between and the level of P applied for both residual and current P must be adequately defined (BOLLAND and GILKES, 1998). In the current study this was established using regression. The residual value of P was evaluated by comparing the amount of P required to produce a target yield of 4 tons/ha for both direct and residual P. In each case the relationships between P level and yield was established using regression as given in Table 3.

Table 3: The relationships between residual P or direct P and sorghum grain yield on a Vertisol at Alemaya, Ethiopia
Tabelle 3: Beziehungen zwischen RestP bzw. DirektP und Sorghum-Kornertrag auf einem Vertisol in Alemaya

	1994	1995	1996
a)	Y = 946.23 + 8.82*P	Y = 1685.25 + 89.56*P	Y = 2313 + 48.99*P
b)	Y = 928.69 + 3.14*P	Y = 2605.71 + 12*12	Y = 2841 + 5.76*P
R	0.91*	0.96*	0.97*
R^2	0.83	0.93	0.94

a: for residual P
b: for direct P
Y: grain yield (kg/ha)
*: significant at 5 % level of significance

2.3 Data Collection and Analysis

Grain yield was measured for each year after air drying (at 15 % moisture content) in which the two middle rows were harvested excluding the outside rows. The treatments were analyzed using MSTATC statistical package and were separated using Duncan's multiple range test (DMRT).

3. Results

There was significant correlation between residual P of the preceding crop season and yield of the subsequent crop season (Table 3). The agronomic value of residual P as calculated from equations given in Table 3 showed that 64 %, 78 % and 83 % more P would be required for the 1994, 1995 and 1996 crop seasons, respectively, for annual P applications compared to reliance upon residual P.

For the base year, 1993 crop season, the highest yield was obtained from 115 P_2O_5kg/ha application followed by the 92 P_2O_5 kg/ha (Table 4). Applying 23 P_2O_5 kg/ha did not give yield significantly different from the control.

The yield of the base year was higher than the subsequent years for the respective fertilizer levels used (residual P). The year 1994 was a relatively droughty year although rainfall data was not recorded for the season. Hence the yield for the 1994 crop season was observed to be lower than the rest of the crop seasons for the respective levels of P fertilizer applied, both residual and direct P (Table 4). For the 1994 crop season, the highest yield was obtained from 115 P_2O_5 kg/ha direct application which was the only treatment significantly higher than the residual. During the 1995 crop season a relatively wet and fairly distributed rainfall, yields the respective P levels for the residual and direct P were not significantly different. In 1996 crop season, only 115 P_2O_5 kg/ha resulted in yield significantly higher than the corresponding residual P levels. During this season, except the 115 P_2O_5 kg/ha, all the other residual P levels were not significantly different from the control indicating the diminishing significance of the residual value of P with time. Generally except for the 1996 crop season, a P level greater than or equal to 69 kg/ha gave significantly higher yield than the control.

Results of analysis of soil samples collected at harvesting for the residual P for each P levels used (residual and direct P) is given in Table 5.

4. Discussion

P fertilizers have a residual value that is of economic significance for resource limited farmers because it reduces the need for fertilizers in the subsequent years (BOLLAND and GILKES, 1998). The residual value of fertilizer P can be almost enough to give a full crop because P from a fertilizer application not used by a crop continues to be of value to succeeding crop (WILD, 1988). The residual P in soils is generally due to adsorption or precipitation reactions (SCHULTZ et al., 1991). The rate at which these reactions proceed depends on several parameters among which the type of the soil, the fertilizer his-

Table 4: The comparative effects of the residual and direct P fertilizer on the grain yield of sorghum (kg/ha) for the three years as grown on Vertisol at Alemaya (means followed by the some letter – within a year – are not significantly different at 5 % using Duncans Multiple Range Test)

Tabelle 4: Relative Effekte des RestP bzw. des DirektP-Düngers auf den Sorghum-Kornertrag (kg/ha) ermittelt für 3 Jahre auf Vertisol in Alemaya (Mit dem gleichen Buchstaben – innerhalb eines Jahres – gekennzeichnete Mittelwerte unterscheiden sich nach dem Duncan Multiplen Skalen Test bei einer Irrtumswahrscheinlichkeit von 5 % nicht signifikant voneinander)

P_2O_5 (kg/ha)	Base year (1993)	1994		1995		1996	
		RP	DP	RP	DP	RP	DP
0	3916c	1002c	1002c	2186d	2186d	2648d	2648d
23	4920b	1046c	1068c	3328c	3445c	2730cd	3274b
46	5116b	1175bc	1090bc	3735bc	3764bc	3008bcd	3429b
69	5339b	1208b	1163bc	3915bc	4269ab	3128bcd	3499b
92	6130a	1256b	1320ab	4028abc	4318ab	3138bcd	3574b
115	6294a	1267b	1468a	4198ab	4691a	3236bc	4378b
$LDS_{0.5}$	737	196		831		539	

RP: Residual P
DP: Direct P

Table 5: The slowly available soil P (mg/kg) as determined from analysis of soil samples collected at harvesting

Tabelle 5: Langfristig verfügbarer Boden P (mg/kg) bestimmt durch Analyse von Bodenproben zum Erntezeitpunkt

P_2O_5 level (kg/ha)	1993	1994		1995		1996	
		RP	DP	PR	DP	RP	DP
0	5.3	4.4	4.4	5.8	5.8	8.8	8.8
23	18.4	13.1	32.0	8.8	14.5	11.7	15.8
46	19.7	14.2	29.2	19.0	19.2	8.8	43.8
69	23.1	16.2	31.0	29.2	37.5	11.7	40.6
92	36.1	18.9	70.0	33.1	105.0	16.0	45.8
115	38.6	17.5	74.4	30.2	105.0	18.2	58.8

RP: Residual P
DP: Direct P

tory of the field, climatic conditions and the specificity of the crops are among the most important (VANDERDEELEN, 1995).

The cause of low response to P fertilizer in Vertisol is often attributed to phosphate sorption (MURTHY, 1988). Nevertheless, it has been reported that Vertisol sorb P in an easily desorbable form (SAHRAWAT and WARREN, 1989; SHAILAJA and SAHRAWAT, 1990) and hence the residual value of fertilizer P in Vertisol would be of economic significance.

The fertilizer history of the Vertisol at Alemaya was such that since 1980 it was used for soil fertility trial on maize, sorghum, wheat and teff (HELUF and MITIKU, 1991). However, in 1993, when this study was initiated the soil was characterized on plot basis and similar fertility status was found. This implies that in the current study fertilizer history of the field was not a factor of variation.

Increased P uptake during early growth stages, when growing season and soil conditions are ideal, strongly affects yield through its influence on seed setting (BERRY and MILLER, 1989). The role of timing of onset and distribution across the growing season of rainfall in this study was apparent. Virtually rainfall affects soil moisture regime and soil moisture can affect P uptake from the soil by changing the P flux to the root surface (NYE and TINKER, 1977) as well the growth (MACKAY and BARBER, 1985) and physiology (DEAN and GLEDHILL, 1956) of the root system.

The effect of soil moisture on P flux has been shown to be due to its change on effective diffusion coefficient (GAHOONIA et al., 1994). Though rainfall was not recorded for the 1994 crop season it was known that it was drier compared to the other crop seasons considered in the current study. This might have caused a slightly lower yield for some levels of P directly applied (Table 4). Dry weather conditions affect the extent of P diffusion and hence its plant availability. Moreover, inhibited root growth would reduce P acquisition under dry soil conditions. The 1996 rainfall was observed to be an exceptional one in that it was distributed across the year and was also higher in total amount. But its relative rainfall amount during the critical months of June and July were lower than that of 1995 which are an important influence for booting and flowering in the subsequent months. The improved sorghum variety used, ETS-2752, was reported to respond to fertilizer application (HELUF and MITIKU, 1991; ASFAW et al., 1997).

In alkaline soils like that of the calcareous Vertisol of Alemaya, the activity of calcium is high (TISDALE and NELSON, 1966) and this favors the precipitation of relatively insoluble dicalciun phosphate. In calcareous soils, phosphate chemistry is rather dominated by a precipitation reaction with calcium ions (VANDERDEELEN, 1995). Ultimately sorption and/or precipitation of phosphate would account for residual P fertilizer in calcareous Vertisol.

Although Vertisol have low phosphate sorption capacity compared to other tropical soils such as Ultisol and Oxisol (SAHRAWAT et al., 1995), it has been established that calcareous Vertisol would sorb P to an appreciable extent (TISDALE and NELSON, 1966; SCARSETH, 1935). Nevertheless, since in Vertisol the sorbed P is in an easily desorbable form it is to be inferred that for subsequent cropping the sorbed P would be of more practical significance than the precipitated form. Desorption is the key process governing the availability of P in such soils (SHAILAJA and SAHRAWAT, 1990).

Generally for Vertisols, to have a residual practical significance, higher P application than other soils would be required because of their high clay content and greater reactive surfaces/components. This agrees with the arguments of FARDEAU (1996) who stated that whatever the rate of P application, the main source of P for plants in the field conditions is the pool of bio-available P. Moreover, the percentage of utilization of the P of a fertilizer is rarely higher than 15 % (DEAN et al., 1947) and 85 % or more of the P applied in one year remains in the soil and continues to react with soil components.

The recommended P rate for sorghum on the Vertisol at Alemaya was 92 kg/ha P_2O_5 (TAMIRIE, 1975). According to the current study, the yield response for this rate was observed to be of practical significance. Both residual and direct P were high for the 1995 crop season compared to the 1994 and 1996 which might have to do with the timing of onset of rainfall and its distribution across the growing season. For the 1996 crop season, the residual P was observed to be lower than the 1993, 1994 and 1995 probably due to the fact that the residual effect of P decreases with time. Under Alemaya conditions, response of sorghum and maize to crop residue were reported to be strongly influenced by the residual N and P fertilizers whereby the influences might be comparable to yearly applications (GEBREKIDAN et al., 1999; ASFAW et al., 1997). Results of analysis of soil sample collected at harvesting revealed that for the control treatment, residual P has slightly increased from 1994 to 1996 probably due to the confounding effect of organic P contributed from crop residues.

The value of the residual P for the succeeding crop is confirmed by the significant correlation between residual P of the preceding crop season and yield of the subsequent crop season (Table 3). In Vertisols, phosphate ion is adsorbed on the edge of a montmorillonite crystal (FORD et al., 1940;

WARKENTIN and MILLER, 1958). This means in montmorillonite dominated soils like Vertisols, the sorption of phosphate can be visualized as a surface reaction between exposed –OH groups on the mineral crystal and H_2PO_4 (SCARSETH, 1935) which is expected to be a loose coupling making recovery of "sorbed" P by a subsequent crop relatively easy.

5. Conclusion

Though plant tissue analyses were not made for measuring P uptake, the residual value of P for subsequent crop seasons (2–3 years) was observed to be of practical significance as deduced from the highly significant correlation of P of the preceding crop season and yield of the subsequent season. For a Vertisol like that of Alemaya, applying greater or equal to 69 P kg/ha would be of practical significance for the subsequent 2–3 years for achieving higher yield over non-fertilized conditions comparable to fertilized conditions. So the limited resource farmer can apply a P rate greater or equal to 69 kg/ha P_2O_5 for sustaining yields for 2–3 years.

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