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PHOSPHORUS REQUIREMENTS BY MAIZE VARIETIES IN DIFFERENT SOIL TYPES OF WESTERN KENYA

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ABSTRACT

Phosphorus and nitrogen deficiencies limit production of maize (*Zea mays* L.) in many soils of western Kenya. Considerable amount of work has been done on N nutrition of maize in the region. There is, however, paucity of information on which to base fertiliser P recommendations for increased maize production considering potential differences in responses due to varieties, soil type, and climate. External and internal P requirements, and P utilisation efficiencies of two open pollinated varieties (*Ababari* and *Oking'*) and one hybrid (H513) were examined at four P-deficient on-farm sites (2 Ferric Alisol, 1 Haplic Ferralsol, and 1Ferric Acrisol) in western Kenya. The varieties were grown under P fertilisation rates of 13, 26, 39, 52 kg P ha^{-1} and a check (no P application). Maize performance varied with site, rate of P application, and variety. The highest grain yields (15% moisture content) at the sites varied from 2,732 to 6,479 kg ha^{-1} for *Ababari*, 2,350 to 5,835 kg ha^{-1} for H513, and 2,299 to 4,459 kg ha^{-1} for *Oking'*. Internal P requirements ranged from 7 to 24 kg P ha^{-1} for *Ababari*, 4 to 18 kg P ha^{-1} for *Oking'*, and 5 to 18 kg P ha^{-1} for H513. Internal P requirements depended on both variety and environment, but more on environment than on variety. Phosphorus physiological efficiency (kg grain kg^{-1} P) ranged from 111 to 314 for *Ababari*, 145 to 277 for *Oking'*, and 127 to 390 for H513. *Ababari* performed as well as did H513, and the two were better than *Oking'*. *Ababari* is, therefore, recommended for the region since it is open pollinated and, hence, the peasant farmers do not have to buy the seeds every season. Row application of P is inappropriate in case determination of crop external P requirement is required.

Key Words: *Ababari*, internal P requirement, *Oking'*, *Zea mays*

RÉSUMÉ

Les carences en phosphore et en azote limitent la production du maïs (*Zea mays* L.) dans beaucoup de sols de l'Ouest du Kenya. Un nombre considérable de travaux ont été effectués sur la nutrition en N du maïs dans la région. Il y a, cependant, manque d'information sur laquelle se référer pour émettre des récommandations en engrais P pour la production accrue de maïs en considérant des différences potentielles dans les réponses dues aux variétés, aux types de sol, et au climat. Des exigences externes et internes en P, et efficiences dans l'utilisation du P pour deux variétés en pollinisation naturelle (*Ababari* et *Oking'*) et d'un hybride (H513) ont été examinées à quatre emplacements de champs caractérisés par des déficits en P (2 Alisol ferriques, 1 Haplic Ferralsol, et 1Acrisol Ferrique) à l'Ouest du Kenya. Les variétés ont été cultivées sous des taux de fertilisation en P de 13, 26, 39, 52 kg de P ha^{-1} et d'un contrôle (sans application de P). La production du maïs a changé avec l'emplacement, le taux d'application de P, et la variété. Les rendements en grains les plus élevés (contenu d'humidité de 15%) aux emplacements varient de 2.732 à 6.479 kg ha^{-1} pour *Ababari*, 2.350 à 5.835 kgs ha^{-1} pour H513, et 2.299 à 4.459 kg ha^{-1} pour *Oking'*. Les exigences internes en P se sont rangées de 7 à 24 kg P ha^{-1} pour *Ababari*, 4 à 18 kg P ha^{-1} pour *Oking'*, et 5 à 18 kg P ha^{-1} pour H513. Les exigences internes en P ont dépendu aussi bien de la variété que de l'environnement, mais plus de l'environnement que sur la variété. L'efficience physiologique du phosphore (kg grain kg^{-1} P) s'est étendue de 111 à 314 pour *Ababari*, 145 à 277 pour *Oking'*, et 127 à 390 pour H513.

Ababari a produit autant que H513, et les deux étaient meilleures qu'*Oking'*. *Ababari* est par conséquent recommandée pour la région d'autant plus qu'elle est pollinisée naturellement et, ainsi, les agriculteurs ruraux n'auront plus à acheter les graines chaque saison. L'application du P en ligne de culture est inadéquate au cas où l'apport du P à la plante est exigé.

Mots Clés: *Ababari*, exigence d'apport du P, *Oking'*, *Zea mays*

INTRODUCTION

Maize (*Zea mays* L.) is the staple food crop for majority of Kenyans. Both commercial farmers and smallholders grow the crop, but in most areas in Kenya production is constrained by low soil nitrogen and phosphorus availability (Sanchez, 2002; Bunemann, 2003; FAO, 2004). Phosphorus deficiency in many of the soils is largely due to low occurrence of P-containing minerals (Nyandat, 1981; Bunemann, 2003) and P-fixation (Van der Eijk, 1997). Continuous cropping without commensurate nutrient replenishment is reported to contribute to low P content of many soils (Smaling *et al*., 1997; Sanchez, 2002; Bunemann, 2003; FAO, 2004). This scenario is typical of the maize growing soils of western Kenya where smallholder farmers continuously grow the crop without adequate nutrients. Most of these smallholder farmers are resource poor and often grow open pollinated varieties in preference to hybrid maize due to high costs of hybrid seeds. Fertiliser use as a strategy for replenishing soils with limiting nutrients is a critical component in improving the productivity of maize in the region (FAO, 2004). However, there is need for guidelines to promote efficient fertiliser use in maize production with both economic and environmental perspectives duly considered (Keerthsinghe *et al*., 2003; Oenema and Pietrzak, 2002).

Substantial work has been done on N nutrition of maize in western Kenya (Njui and Musandu, 1999; Sanchez, 2002; Sigunga *et al*., 2002). With respect to P, there is paucity of information on which to base fertiliser P recommendations for increased maize production, considering potential differences in P requirements by open pollinated varieties and hybrids grown in the different soil types. Some of the soil types associated with maize growing in the region are Ferralsols, Acrisols, Alisols, Nitisols and Luvisols in the uplands; and Vertisols, Gleysols and Planosols in the low-lying depressions (Jaetzold and Schmidt, 1982).

Maize varieties are known to vary in P uptake and utilisation efficiencies, as well as in adaptability to different soil types (Nielsen and Barber, 1978; Walker and Raines, 1988; Duncan and Baligar, 1990; Horst *et al*., 1993; Machado *et al.*, 1999). This implies that there are differences among maize varieties with respect to P requirements. Hence, there is a need to quantify the differences.

Phosphorus demands by maize varieties can be viewed in terms of internal and external requirements. Internal P requirement of a crop refers to the minimum uptake that is associated with a specified yield (usually 80% of the maximum yield); while external P requirement refers to the maximum concentration of P in soil solutions equilibrated with soils associated with near maximum attainable yield (usually 80% of the maximum yield) for the crop (Fox, 1981; Hedley, 1995; Hue *et al.,* 2000; Obaid-ur-Rehman *et al*., 2004).

This study quantified internal and external P requirements as well as P utilisation efficiency by open pollinated and hybrid maize varieties grown on some of the P deficient soils in western Kenya.

MATERIALS AND METHODS

Experimental sites. Field experiments were carried out at 4 on-farm sites: Ayora, Wagai, Aboke and Ukwala located in Siaya District of western Kenya. The sites were selected to represent 4 different agro-ecological zones. Details of the experimental sites with respect to positions and climatic conditions are presented in Table 1. Data on potential evapotranspiration at the sites were obtained from ACT version 3.0 (Corbett *et al*., 2001). Soils at Ayora and Wagai were classified as Ferric Alisols, while those at Aboke and Ukwala were classified as Haplic Ferralsol and Ferric Acrisol (FAO-UNESCO, 1997). Selected physical and chemical properties of the experimental soils are presented in Table 2.

Experimental procedure. The treatments comprised of 3 maize varieties and 4 fertiliser P levels, that is, 13, 26, 39, and 52 kg P ha^{-1}. A check (i.e., plot without P application) was included. The maize varieties used were *Oking'* and *Ababari* (open pollinated varieties) dominantly grown by farmers in the study area, and H513 (hybrid) recommended for the area. *Oking'* and *Ababari* were obtained from smallholder farmers in the region, while H513 was purchased from

TABLE 1. Summary of location and climate data of experimental sites

Parameter	Site			
	Ayora	Wagai	Aboke	Ukwala
Position†				
Longitude	034.4023º	034.4220º	034.1649º	034.2009º
Latitude	00.0530º	00.0566º	00.2468º	00.2043º
Altitude (m)	1198	1202	1065	1043
Climate				
Rainfall (mm)	459	470	380	452
Rainy days‡	60	61	35	39
Potential evapotranspiration (mm)	477	477	476	492

† Site position details were obtained using a Global Positioning Tool, GPS 12XL (1998, Garmin, Olathe, USA)

‡ A rainy day was considered as one with 2 mm or more of rainfall

TABLE 2. Some chemical and physical properties of soils (0-30 cm depth) at the 4 sites

Parameter	Site				Critical value[1]
	Ayora	Wagai	Aboke	Ukwala	
pH (water)	5.1	4.8	5.4	5.5	-
pH ($CaCl_2$)	4.8	4.4	5.0	4.9	-
Organic Carbon (%)	1.5	0.9	0.7	0.6	0.5
Exchangeable cations ($cmol_c$ kg^{-1} soil)					
Magnesium	4.7	5.8	1.2	1.8	1.0
Potassium	8.9	8.0	3.1	3.6	0.4
Calcium	5.2	4.6	1.8	2.0	2.0
Exchangeable acidit ($cmol_c$ kg^{-1} soil)	14.6	9.2	3.0	2.8	-
Al saturation (%)	44.0	33.0	23.0	20.0	(e"30)*
CEC ($cmol_c$ kg^{-1} soil)	38.7	39.0	16.0	18.5	-
Total P (mg kg^{-1})	35.0	33.0	48.7	50.0	-
Available P (mg kg^{-1})	3.8	3.5	6.2	8.0	10
Texture	Sandy Loam	Sandy Loam	Sandy Loam	Sandy Loam	-

[1]Source: Hinga *et al*., 1980; Okalebo *et al*., 2002; *At this level Al is toxic to maize plant

Kenya Seed Company, the leading government-backed seed company in the country. The 15 treatment combinations were factorially arranged in a randomised complete block design (RCBD) and replicated three times at each of the 4 experimental sites.

Both nitrogen and phosphate fertilisers were row applied at planting along furrows and mixed with soil to avoid direct contact with seed. Triple superphosphate (TSP) was used to supply P. Calcium ammonium nitrate (CAN) was applied to supply N at 80 kg ha^{-1} to all plots to ensure that N did not constitute a constraint. The *Furadan* (carbofuran) pesticide was applied (5 kg ha^{-1}) with the seed at planting to protect the seeds against soil borne pests. *Kombat*, a permethrine-based commercial stock borer control dust was applied at a rate of 4 kg ha^{-1} into the whorls of maize plants at 4 weeks after planting to protect the crop against damage by maize stalk borer (*Busseola fusca*).

Soil sample analysis. Composite soil samples, obtained from 0-30 cm depth were collected from each of the sites before land preparation and used to characterise the soils at the sites. At harvest, soil samples were collected from within rows (0-30 cm depth) in each of the experimental plots for analysis of soil solution P concentration values that were subsequently used in determination of external P requirements. Soil pH (water and 0.01 *M* $CaCl_2$) analysed at 1:2.5 soil-solution ratio, was determined electrometrically (Van Lierop, 1990). Soil texture was determined by the hydrometer method (Gee and Bauder, 1986). Soils were analyzed for exchangeable acidity following extraction by 1 *M* potassium chloride and titration of the extract against sodium hydroxide solution following the procedure described by Okalebo *et al.* (2002).

Organic carbon was determined using Walkley-Black procedure (Nelson and Sommers, 1982). Organic carbon was determined following procedure described by Okalebo *et al.* (2002). Potassium was determined using flame spectrometer, while Ca and Mg were determined using Atomic Absorption Spectrophotometer (Okalebo *et al.*, 2002).

Exchangeable acidity was determined following routine procedures (Anderson and Ingram, 1993; Okalebo *et al.*, 2002).

In the determination of total P, 0.30g of air-dry was digested in 2.5 ml of digestion mixture (salicylic acid, sulphuric acid, and selenium) until the digest became clear. The pH of the digest was adjusted by 6 M NH_3 solution and then 1 M HNO_3 drop wise. Ammonium molybdate/ ammonium vanadate mixture (5 ml) was added to the digest, the volume made to 50 ml with distilled water and left to develop yellow colour; the P concentration was read from a colorimeter set at 400 nm (Okalebo *et al.*, 2002). The initial soil physical and chemical properties at the experimental sites are presented in Table 2.

Plant sample analysis. At harvest (early August), above-ground portion of plants were harvested from the 3 middle rows in each plot. The harvested plants from the harvest area (2.25 m x 4.8 m) in each plot were divided into stover (stalk and leaves), cob, and grains. The stover portion was chopped into small pieces, weighed and sub-sampled for dry matter determination. The cobs were similarly treated. The grain was weighed, and moisture content measured using moisture meter (Agromatic Mark II, Farmer Tronic, Denmark), and then sub-sampled for dry matter determination. Plant sub-samples for dry matter determination were oven-dried at 70°C in a ventilated oven to constant weight. The weights of oven-dry sub-samples were recorded and used to calculate total above-ground dry matter yields. Plant sub-samples were then fine ground for subsequent digestion and analysis for P content, using the procedure described above for total P in soil.

Calculation procedures and statistical analysis of data. Stand count, grain, cob, and stover weights were recorded for each of the treatments. Total dry matter yield, grain yield (at 15% moisture content), and total P uptake were calculated using the following formulae:

Total dry matter yield (above-ground) = (GY + SY + CY)……………………....…………................... (i)

Grain yield (at 15% moisture content) = GW x (100 - MCA)/(100 - MCD)………………........... (ii)

Total nutrient uptake = (NCG x GY) + (NCS x SY) + (NCC x CY)....………………….................… (iii)

Where:

GY, SY and CY are grain, stover, and cob dry matter yields, respectively; GW, MCA and MCD are fresh grain weight, moisture content of fresh grain and moisture content of grains at 15% moisture, respectively;

NCG, NCS and NCC are nutrient concentrations in grain, stover and cob, respectively, for the nutrient in question, which in this case was P.

Harvest Index (HI) = GY/ Total dry matter ………………………………………..….......(iv)

Phosphorus physiological efficiency (PPE) = GY/ Total P uptake…......……….……..................….. (v)

Internal P requirement (IPR) = Minimum P uptake associated with 80% yield ……….…...........… (vi)

The IPR is defined as the minimum P uptake that is associated with a specified yield (Fox, 1981; Obaid-ur-Rehman *et al*., 2004). In this study IPR was calculated at 80% relative grain yield level using equations derived from graphical plots of relative grain yields against corresponding total P uptake values.

External P requirement (EPR) = concentration of P in the soil solution associated with 80% yield (Fox, 1981; Hue *et al.*, 2000; Obaid-ur-Rehman *et al*., 2004).The EPR were calculated using equations derived from graphical plots of relative grain yields against corresponding soil solution P concentrations at crop harvest.

Relative grain yield (RGY) = (Actual grain yield)/ (Maximum grain yield)x 100

Analysis of variance on data on grain and total dry matter yields, nutrient uptake and physiological P use efficiency was performed using Mstat C software (Michigan State University, 1991). The means were separated using Least Significant Difference (LSD), and the total P uptake was regressed on grain yields (Steel and Torrie, 1980).

RESULTS AND DISCUSSION

Soils. Some of the chemical and physical properties of soils at the 4 sites are given in Table 2. The soils are predominantly sandy loam in texture. Available P at the sites was below critical level of 10 mg kg^{-1} (Okalebo *et al.*, 2002). The very low soil available P obtained at the sites is illustrative of P insufficiency that is endemic in many farms in the region (Sanchez *et al.*, 1997; Sanchez, 2002; Bunemann, 2003; Millennium Villages Project, 2005). Organic carbon in the soils was within 0.5-1.5%, a range considered low (Okalebo *et al*., 2002). The cations Ca, Mg, and K levels were adequate at all the experimental sites (Hinga *et al*., 1980). Aluminum saturation levels for the soils at Ayora and Wagai sites were above 30%, the critical level for toxicity on maize (Okalebo *et al*., 2002). It is acknowledged, with regret, that Mn content of experimental soils was not determined and yet the element, besides Al, constitutes hindrance to plant growth in soils with $pH \leq 5.5$.

Grain yields. Phosphorus application significantly increased maize grain yields at all the four sites (Table 3). The check (0 kg P ha^{-1}) and 39 kg P ha^{-1} treatments resulted in significantly ($p < 0.05$) lowest and highest grain yields. Significant increase in maize grain yields due to P application at the 4 sites is indicative of low inherent soil P at these sites. These yield responses underscore the significance of fertiliser P use in enhancing maize yields in the study soils.

The effects of P application rates varied with the varieties at the sites (Table 3). *Ababari* compared well with H513 at all the sites except at Ayora. The lack of significant grain yield responses of *Ababari* to P application rates beyond 13 kg P ha^{-1} at Ayora in contrast to situations at the other sites was probably due to the high Al saturation at Ayora (Table 2). The lower grain yields of *Ababari* at Ayora than at

TABLE 3. Maize grain yields (at 15% moisture content), above ground dry matter production, and harvest index at the four sites as influenced by variety and fertiliser P application

Site	P rate, (kg P ha^{-1})	Variety								
		Ababari	*Oking'*	H513	*Ababari*	*Oking'*	H513	*Ababari*	*Oking'*	H513
		Grain yield (kg ha^{-1})			Total dry matter yield (t ha^{-1})			Harvest index		
Ayora	0	1345	234	695	2.83	1.99	2.13	0.21	0.11	0.14
	13	2812	1473	3488	4.98	5.01	7.08	0.43	0.26	0.41
	26	2921	3107	3885	6.39	7.12	7.85	0.42	0.36	0.46
	39	3259	4072	5090	6.54	7.91	11.08	0.39	0.40	0.35
	52	2783	3717	3915	7.60	7.38	8.79	0.36	0.40	0.40
$LSD_{0.05}$			1094			2.0			0.14	
Wagai	0	1367	1546	3080	3.03	5.36	4.05	0.19	0.19	0.22
	13	3940	3597	3945	8.02	8.56	8.79	0.42	0.34	0.36
	26	5155	4345	4371	12.57	9.52	9.09	0.40	0.36	0.32
	39	5656	4459	5478	12.96	10.39	10.74	0.40	0.39	0.42
	52	6479	5219	5835	13.46	11.60	10.07	0.41	0.35	0.40
$LSD_{0.05}$			1850			4.60			0.10	
Aboke	0	1514	310	304	4.15	1.68	1.61	0.38	0.18	0.22
	13	2567	1521	1056	7.57	5.32	3.53	0.35	0.23	0.30
	26	2721	2986	2116	6.71	8.36	6.40	0.39	0.34	0.31
	39	3781	3113	3185	9.59	8.56	7.68	0.38	0.33	0.37
	52	2964	2223	2002	6.69	6.94	5.58	0.35	0.31	0.24
$LSD_{0.05}$			1006			3.04			0.17	
Ukwala	0	1250	903	661	3.32	3.56	2.47	0.20	0.17	0.25
	13	1771	1137	1810	3.74	4.77	2.99	0.19	0.30	0.30
	26	1957	1817	2177	7.67	4.61	3.75	0.31	0.20	0.25
	39	2732	2299	2530	5.15	3.75	7.34	0.24	0.17	0.35
	52	1689	1515	2350	6.32	3.44	6.41	0.28	0.19	0.32
$LSD_{0.05}$			1106			2.91			1.10	

Wagai, both sites having received similar rainfall (Table 1), is indicative of negative effect of soil Al saturation on *Ababari*. In contrast, *Oking'* and hybrid H513 produced significant increases in grain yields to P application rates beyond 13 kg P ha^{-1} at Ayora, Wagai, and Aboke sites (Table 3). This probably indicated that both *Oking'* and hybrid H513 were less sensitive to Al saturation at least to the magnitude measured at Ayora (Baligar *et al.*, 1997).

There was significantly ($p < 0.05$) low grain production by all the 3 varieties at Aboke and Ukwala compared to the yields at Ayora and Wagai (Table 3). There was, however, no significant interaction effect among the main treatments. Striga [*Striga hermonthica* (Del.) Benth.] occurrence at Aboke and Ukwala sites could be a constraining factor to maize growth and yields at the 2 sites. Low grain yields at Aboke are also attributable to comparatively low rainfall received at the site during the season (Table 1).

Interaction effects among the main treatments were possibly subdued by high Al at some sites (Ayora and Wagai) and striga infestation at other sites (Aboke and Ukwala), coupled with low rainfall at other sites (Aboke).

Total dry matter yields and harvest index. Total dry matter production by the three maize varieties increased with the increasing P application rate at the 4 sites, in a pattern similar to that of grain production (Table 3). Higher P rate than 26 kg P ha^{-1} did not result in significantly higher total dry matter yield. There was no consistent difference in varieties with respect to total dry matter yield. Wagai site had the highest total dry matter yields by all the 3 maize varieties with the mean values of 10, 9 and 8 t ha^{-1} for *Ababari*, *Oking'*, and H513, respectively. Ukwala site had the lowest dry matter yields from each of the three varieties. The relatively better performance by all the varieties at Wagai site compared to other sites is attributed to a combination of favorable growth conditions, namely high rainfall (Table 1), low Al saturation (Table 2), and absence of striga weed.

Fertiliser P application significantly ($p < 0.05$) increased harvest index (HI) over the check in all the 3 maize varieties at the 4 sites (Table 3). However, there was no difference between the P rates higher than 13 kg P ha^{-1}. The implication here is that P rates higher than 13 kg P ha^{-1} did not improve dry matter partitioning to grains under the experimental conditions. The lack of significant differences in HI due to P rates above 13 kg P ha^{-1} was attributed to simultaneity increases in grain and total dry matter production in addition to low plasticity within the varieties in terms of dry matter partitioning to the grains within the P application range. At 39 kg P ha^{-1} the mean HI values for Wagai, Aboke, Ukwala, and Ayora were 0.42, 0.37, 0.35, and 0.35, respectively. The HI value for Wagai is comparable to the values reported by Sigunga *et al*. (2002) for H513 also grown in western Kenya. The authors applied 44 kg P and 60 kg N ha^{-1} to the crop grown on a Vertisol and obtained HI values ranging from 0.43 to 0.46. The relatively lower HI values at the other sites are attributed to adverse environmental growth conditions as constituted by high Al (Ayora site), low rainfall (Aboke site), and heavy striga infestation (Ukwala site).

Internal P requirements of maize. Phosphorus application significantly ($p < 0.05$) increased P uptake by the varieties at the four sites (Table 4). Internal P requirements varied for the three maize varieties at the four sites as quadratic functions obtained from graphical plots of relative grain yields against total P uptake illustrated in Figure 1. The varieties had internal P requirements of 7.2, 10.4, and 9.5 kg P ha^{-1} at Ayora site for *Ababari*, *Oking'*, and H513, respectively while at Wagai site the internal P requirements were 16.5, 12.5, and 12.0 kg P ha^{-1} for *Ababari*, *Oking'*, and H513, respectively. Variety internal P requirements were 23.7, 18.2, and 18.1 kg P ha^{-1} for *Ababari*, *Oking*, and H513, respectively, at Aboke site. The values at Ukwala were 6.5, 4.2, and 5.4 kg P ha^{-1} for *Ababari*, *Oking*', and H513, respectively. Internal P requirements for *Oking'* and H513 were similar at all the sites. *Ababari* exhibited higher internal P requirement than the other 2 varieties at all the sites except at Ayora. The internal P requirements varied with both maize variety and experiment site, but more with latter than the former. This is probably because the environmental factors influence, to a large extent, the sink expression of the crop. The variation in P uptake and internal P requirements of maize varieties with site (Table 4 and Fig. 1) are attributed to growth conditions as constituted by soil factors and climatic constituents, as well as biotic factors particularly striga weeds. Sites with unfavorable growth conditions like Ayora (high Al saturation) and Ukwala (heavy striga infestation) resulted in relatively low P uptake and showed low internal P requirements. The variation of internal P requirements with variety found in the current study (Fig. 1) is in conformity with the results of other workers (Duncan and Baligar, 1990; Horst *et al.*, 1993).

Results from Wagai and Ayora sites, where similar climatic conditions prevailed (Table 1) and soils were both *ferric Alisols*, illustrated that even within the same soil type, differences in soil properties such as Al saturation influenced variety internal P requirements. *Ababari* and *Oking'*, unlike hybrid H513, had higher internal P requirements at Wagai than at Ayora indicating that the two varieties responded to the differences in Al saturation at the sites. Furthermore, the magnitudes of change in internal P requirements

TABLE 4. Uptake of P by maize at the 4 sites as influenced by variety and fertiliser P application rates

Variety	P rate (kg P ha^{-1})	Site			
		Ayora	Wagai	Aboke	Ukwala
		P uptake (kg ha^{-1})			
Ababari	0	3.59	4.75	11.60	3.43
	13	8.57	13.76	22.13	3.95
	26	9.82	18.12	22.67	6.86
	39	9.21	18.47	29.23	6.00
	52	12.15	25.13	15.07	6.50
Oking'	0	2.26	3.51	2.45	3.42
	13	6.95	11.94	12.90	8.64
	26	11.83	13.51	19.15	4.00
	39	11.53	13.70	22.18	3.40
	52	10.83	14.10	20.43	3.98
H513	0	2.71	4.25	4.37	2.76
	13	7.69	12.65	6.90	6.54
	26	8.70	7.46	16.76	2.81
	39	9.51	14.22	22.06	9.33
	52	16.08	15.98	21.91	6.93
LSD $_{0.05}$		4.84	8.40	10.28	3.45

for the two varieties between the two sites were 9.3 kg P ha^{-1} for *Ababari* and 2.1 kg P ha^{-1} for *Oking'*. These changes in internal P requirements could be due to differences between the two varieties in terms of sensitivity to change in Al saturation levels. The reduction in internal P requirement by the two open pollinated varieties with increase in Al saturation levels at Ayora site could have resulted from a reduction in uptake of P and other essential nutrients due to negative Al saturation effects (toxicity) on the root systems, which reduced dry matter production. Reduced root volume as a result of Al toxicity has been reported to contribute to low dry matter production by Al sensitive varieties (Baligar *et al*., 1997). Reduced root zone volume reduces P uptake by maize (Masoni *et al*., 2002). Since dry matter production is a functional component of internal P requirements, a reduction in its production is likely to lower the internal P requirements of the crop. Striga occurrence at Ukwala site could be a contributing factor to reduced total P uptake and variety internal P requirements through its negative effect on total dry matter production.

External P requirements of maize. High variations characterised data on soil solution P concentrations at crop harvesting. This is illustrated by coefficients of variations of 88.8 and 178.8%, which were associated with soil solution P concentration data for Ayora and Aboke sites, respectively. Phosphorus application rates at the sites did not significantly influence ($P>0.5$) soil solution P concentrations at crop harvesting possibly as a result of masking effect of high coefficient of variation in the data. High variations in the data could in part be attributed to row application of fertiliser P and in part to effects of hand weeding that could have lead to uneven spatial redistribution of the row-applied fertiliser P within the plots. The uneven redistribution of fertiliser P coupled with usual low within-soil mobility of P could have led to low equilibration of soil solution P within plant rhizosphere and soil sampling area. This could

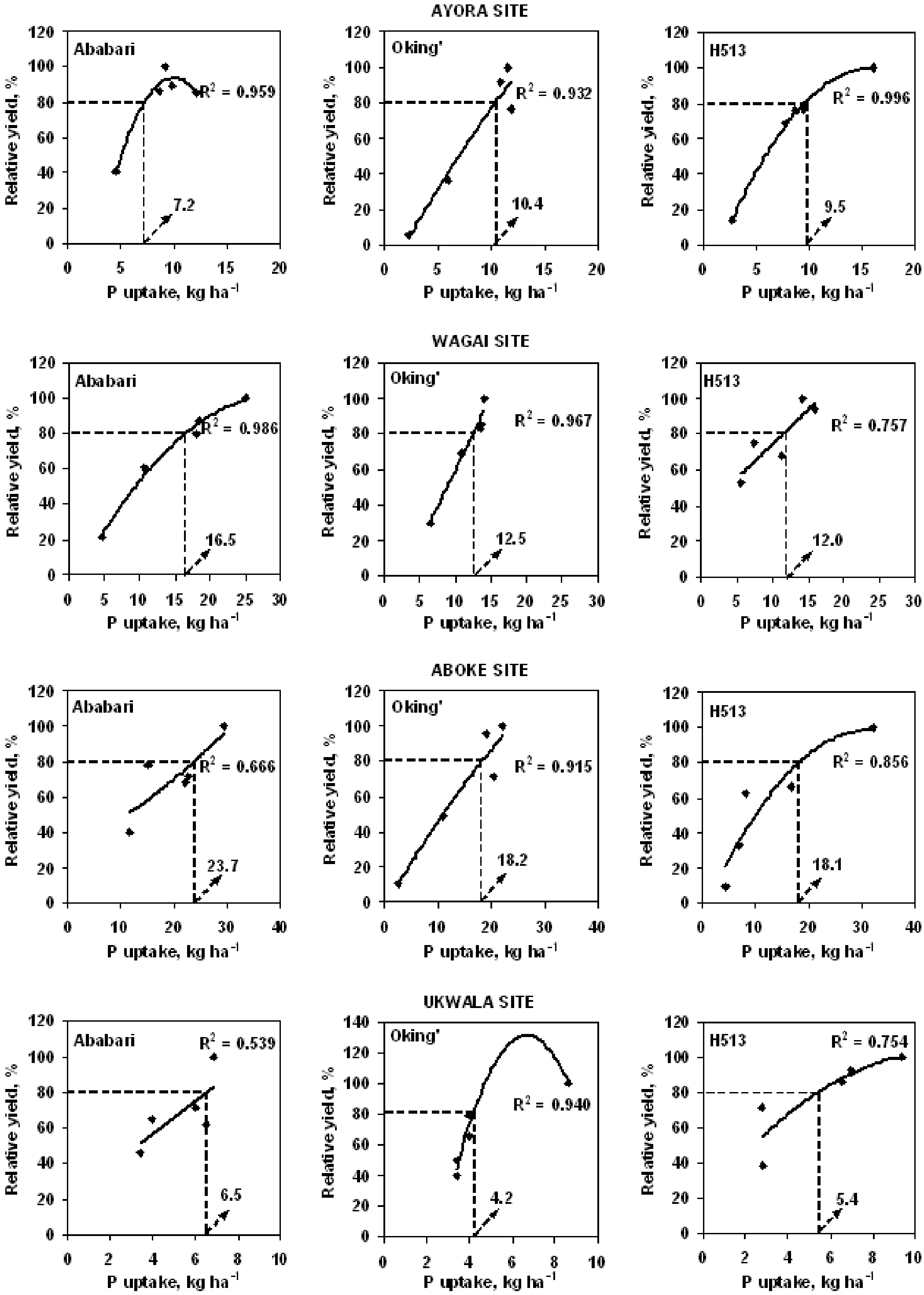

Figure 1. Relationships between maize variety, and total P uptake, relative grain yield, variety. internal P requirements at the experimental sites.

have rendered the soil sampling procedure and timing of the soil sampling to be inappropriate. Consequently, external P requirements by the varieties could not be reliably determined using the soil solution P concentration data obtained from the sites. We suggest that broadcast application of P would enhance even distribution of P and lower soil P variability. This would possibly be suitable for soil sampling for the determination of soil solution P plot by plot.

Phosphorus physiological efficiency. In respect of each of the three varieties, the check (plots that did not receive fertiliser P) had significantly ($p < 0.05$) lower phosphorus physiological efficiency (PPE) than plots that received P applications. This was consistent across the 4 sites (Table 5). There was no significant difference in PPE due to P application rates 13 to 52 kg ha^{-1} across the sites in the case of *Ababari* and *Oking'*. For H513, however, there were differences though inconsistent. There were no differences between the varieties within a site, except at Ayora, where H513 had significantly ($p < 0.05$) higher PPE than the other varieties. The PPE at 80% relative grain yields at Ayora site were 241, 251, and 390 kg grain kg^{-1} P for *Ababari*, *Oking'*, and H513, respectively. At Wagai site, PPE values were 314, 277, and 340 kg grain dm kg^{-1} P for *Ababari*, *Oking'*, and H513, respectively. The values at Aboke site were 111, 145, and 127 kg grain dm kg^{-1} P for *Ababari*, *Oking'*, and H513, respectively. At Ukwala site, the values were 245, 231, and 245 kg grain dm kg^{-1} P for *Ababari*, *Oking'*, and H513, respectively.

The significantly higher PPE in the plots that received fertiliser P over the check was possibly due to a number of interacting factors. To a P-deficient soil , as is the case with the experimental sites in the current experiments, P application is likely to improve root system and enhance uptake of P, in addition to other essential plant nutrient elements as well as moisture. Increased nutrient and water uptake inevitably results in increased

TABLE 5. Phosphorus physiological efficiency (PPE) of maize variety as affected by variety and fertilizer P application rates at the 4 sites (n = 3)

Variety	P rate (kg P ha^{-1})	Site			
		Ayora	Wagai	Aboke	Ukwala
		- PPE (kg grain kg^{-1} P uptake) -			
Ababari	0	123	159	120	175
	13	247	312	164	197
	26	271	291	112	351
	39	290	280	125	192
	52	226	218	160	246
Oking'	0	106	150	109	174
	13	227	265	141	256
	26	225	264	175	223
	39	269	299	126	176
	52	274	305	112	153
H513	0	176	228	80	274
	13	369	255	157	249
	26	413	387	116	187
	39	326	315	89	267
	52	279	255	161	291
$LSD_{0.05}$		118.0	109.8	86.1	130.9

total dry matter and grain yields (Table 3). It was reported (Colomb *et al*., 2000; Pellerin *et al*., 2000) that the increase in dry matter production following P application is a result of improved root system, increased leaf area index and its subsequent effect on photosynthetically active radiation absorption and carbohydrate nutrition of plants. The lack of significant difference in PPE by *Ababari* and *Oking'* at 13-52 kg ha^{-1} P application range indicates low variation in P utilisation within this range possibly because of genetic effects. In comparison to H513, low PPE by *Ababari* and *Oking'* at Ayora site could be attributed to low efficiency in grain dry matter production relative to P uptake possibly due to effects of high % Al saturation at the site.

CONCLUSIONS AND RECOMMENDATION

Open pollinated *Ababari* is as good as hybrid H513 in terms of grain yield, P uptake and phosphorus physiological efficiency. Internal P requirements depends on both maize variety and environment, but more on environment than variety. Harsh environmental factors, namely high % Al, striga, and low rainfall reduce the response of the maize varieties to P application. Row application of P results in high infield spatial variation in soil solution P that made crop external P requirement determination unreliable.

We recommend *Ababari* for the resource poor farmers since its performance is virtually as good as the commercially recommended hybrid H513 for the study area in light of the fact that farmers do not need to purchase the high cost hybrid H513 seed.

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