Original Research Article

Evaluating Heritability and Relationships among Phosphorus Efficiency Traits in maize under low P soils of western Kenya.

Abstract

Low available phosphorus (P) remains a major limitation to maize (*Zea mays* L.) productivity in low P soils across the world. Selection for P efficiency is key as part of strategies to achieving agricultural sustainability in these soils. The objectives of this study were to: (i) determine the phenotypic and genetic relationships among P-efficiency traits commonly used in screening maize for adaptation to low P and (ii) determine the heritability of some of these traits under similar conditions. A total of 32 experimental maize hybrids were evaluated for tolerance to low P in a replicated trial at four locations for one season. The experiment was laid out in a split plot arrangement in RCBD replicated 3 times across two P levels (36 kgP/ha and 6 KgP/ha). Grain yield had the highest correlation (0.44-0.95) with most P- efficiency traits at both P conditions.The correlation between grain and shoot P concentration and grain P content with majority of the P efficiency indices (P acquisition efficiency, P efficiency (PE) and P Utilization efficiency) at both P levels was low & tended to be negative and non-significant indicating that seed P reserve, and stover P concentration, had minimal contribution to differential P efficiency. However, the relationship between shoot P content with P-efficiency traits was significant (r= 0.51-0.95), suggesting that shoot P content is a useful parameter in selecting for P efficiency in maize. Moderate to high heritability (0.50-0.95) was observed for the various traits showing that a large proportion of the observed variations were due to genetic differences among the hybrids. This study has determined genetic and phenotypic associations among P selection parameters that can help in flexing the selection methodologies to suite unique circumstances and environments.

Key words: genetic correlation, heritability, Maize, phosphorus efficiency, grain yield

Introduction

Nearly 50% of the tropical soils are classified either Oxisols or Ultisols which characteristically over 95% of them have low P as a major yield constraint (Sanchez and Salinas, 1981). Phosphorus (P) is essential to plants and animal nutrition and is the second most limiting nutrient after nitrogen (N) for plant growth and crop production in many agricultural lands in the tropics (Parentoni et al., 2010; Lynch, 2011; Ouma et al., 2016). Deficiency in P is known to reduce growth and delay maturity in many crops (Chen et al., 2008; Cichy et al., 2008). Phosphorus exists in various mineral forms in the soil including phosphate rock (PR), which is partially made of apatite (an impure tri-calcium phosphate mineral) (van Kauwenberg, 2006). Approximately 90% of the entire PR that is mined is used for food production, fertilizers, feed and food additives and it can either be used as raw materials in the industrial manufacture of water-soluble phosphate (WSP) fertilizers or as P sources for direct application in agriculture (Cordell, 2008b). The non-renewable phosphate reserves in the world will be exhausted in the near future hence possible inorganic P fertilize crisis (Obersteiner et al., 2013; Azizi J., 2018). Plant roots acquire P from the rhizosphere solution as phosphate (Pi), whose concentration in the soil solution is often low (2–10 µM). Consequently, the supply of Pi to the root surface by diffusion is slow hence hardly available (Batjes, 1997; White and Hammond, 2008). The problem of low available P in western Kenya is due to soil acidity hence the formation of poorly soluble P complexes as a result of P fixation by aluminium and iron (Oztuk et al., 2005; Kochian et al., 2015), the inherent low P content of parent rock material and insufficient replenishment of P removed through crop harvests (Kisinyo et al., 2013b). In these soils, the level of available P is very low (2 -5 mg P/kg soil) and below optimal range (10-15 mg P/kg soil) hence cannot sustain crop productivity. (Kisinyo et al., 2013a; Ouma et al., 2015). The results are evident in low maize and sorghum productivity (< 2 t/ha) in this region (Kisinyo et al., 2019; Ligeyo et al., 2014).

The use inorganic fertilizers to maintain soil fertility and yields in low P soils is very popular in Kenya since they are readily available due to many government initiatives of subsidising farm inputs (Nyangweso, 2018). However accessibility to subsidized fertilizers is still challenging for majority of the farmers in western Kenya because of poorly developed infrastructures and inefficient supply chains. Moreover many small holder farmers especially in sub-Saharan Africa have limited resources and unable to afford recommended quantities for soil replenishment (Leiser et al., 2014b; Kisinyo et al., 2019) Overreliance on inorganic fertilizers is unsustainable due to geopolitical conflicts which are likely to hinder its use across the globe since P reserves are heavily concentrated in certain parts of the world with Morocco holding about 75% of the global share, followed by China 6%, Algeria 3% and the rest in the USA, Near East and other African Countries (Jasinski, 2013). Other factors challenging the use of inorganic fertilizers include the poor fertilizer recovery rate by most crops, fixation to the soil colloids, leaching and depletion of the world's rock P reserves due to over exploitation (Cordell and white, 2013; Aziz, 2018).

The integration of P efficient genotypes and micro-dosing can potentially offer sustainable crop production in the low P acid soils. Research strategies aimed at selecting P efficient cultivars therefore remain very relevant in achieving sustainable agricultural production systems. Breeding and selection for phosphorus efficiency is therefore key as part of synergies to enhancing agricultural sustainability in low P soils. Further, utilization of crops that acquire and/or use P more efficiently can greatly improve environmental health by reducing the use of Pi fertilizers in agricultural systems. Part of the information required for the development of breeding strategies to increase P use efficiency in tropical maize include: An understanding of correlations among phosphorus efficiency traits; identification of appropriate selection criteria; determination of the relationship among of these selection criteria in both low and high P soils and variation in heritability of these traits in low and high P environments.

Several authors have proposed several criteria for selecting P efficient genotypes including grain yield (GY) under low P conditions, agronomic P use efficiency (AE), P acquisition efficiency (PAE), P utilization efficiency (PUE), P efficiency (PE) (Moll, 1982; Baligar et al., 1997; Oztuk et al., 2005; White and Hammond, 2008; Hammond et al., 2009; Serpher et al., 2009, Parentoni et al., 2010). The use of GY under low P has prevailed as the most reliable criteria for selecting cultivars for better performance in low P soils (Serpher et al., 2009; Parentoni et al., 2010, Ouma et al., 2012; Ouma et al., 2015).

However, due to enormous environmental challenges experienced during maize screening in low P environments where certain genotypes often fail to produce grain yield, alternative parameters are of necessity under such circumstances. Heritability is the measure of the correspondence between breeding values and phenotypic values (Allard, 2010). Thus, heritability plays a predictive role in breeding, expressing the reliability of phenotype as a guide to its breeding value. (Wolie et al, 2013). Further, it determines the response to selection (Ceccarelli, 1994). According to this author response to selection under low input conditions is often considered less efficient due to low heritability as a result of higher experimental error and lower genetic correlations expected. However contrary results have been reported for this assumption. Further studies by Ceccarelli (1996) reported higher genetic variation under highly stressed environments especially with the inclusion of locally adapted lines in the trial. These authors concluded that heritability under low input conditions can be comparable to high input conditions or even higher if appropriate genetic materials are included in the study and if experimental error is of similar magnitude. Knowledge of heritability of the P-efficiency parameters in both high and low P conditions is therefore key for successful breeding. Additionally, information on phenotypic and genetic relationships between P-efficiency parameters is still inadequate yet such information is critical for flexing the selection methodologies to suite unique circumstances and environments. The objectives of this study were to: (i) determine the phenotypic and genetic relationships among P-efficiency traits commonly used in screening maize for adaptation to low P using experimental hybrids and (ii) determine the heritability of some of the traits under similar conditions.

MATERIALS AND METHODS

Plant Material and experimental conditions

A total of 32 experimental maize hybrids comprising 9 three way cross hybrids, 5 double cross hybrids, 9 back crosses, 5 single crosses and 4 standard checks (efficient and inefficient) were evaluated for tolerance to low P in a replicated trial at four locations (Sega, Chepkoilel, Migori and Koyonzo) for one season. Chepkoilel site is located at 0º34′37.24″N; 35º15′10.04″E, 2143 m above sea level (a.s.l), and has average annual rainfall of 1300 mm with average temperature range of 22^{0}C. The soils are chromic ferralsols characterized by low pH 4.8, with P levels of 4.4 mg P kg^{-1} of soil (Ouma et al., 2015). Sega site is located at 0^{o}15′N and 34^{o}20′E. It has an elevation of between 1,140 and 1400 m (a.s.l) with a bimodal annual rainfall pattern with an average of 1000 mm. The mean temperature is 25 ^{o}C. The soils are Orthic Acrisols characterized by low pH 4.5 low P of 2.2 mg P kg^{-1} of soil. Migori site is located at 1 ^{o} 03′S and 34^{o}24′E. It has an elevation of 1381 m (a.s.l) with a bimodal annual rainfall pattern with an average of 1200 mm. The mean temperature is 23 ^{o}C. The soils are humic ferralsols characterized by low pH 5.5 low P of 3 mg P kg^{-1} of soil. Koyonzo site is located at 0 ^{o} 25′N and 34^{o}25′E. It has an elevation of 1310 m (a.s.l) with a bimodal annual rainfall pattern with an average of 1400 mm. The mean temperature is 23 ^{o}C. The soils are Luvisols characterized by low pH 5.7 low P of 6 mg P kg^{-1} of soil (Ouma et al., 2015).

Experimental Design

The experiment was laid out in a split plot arrangement in RCBD replicated three times. Main plot contained 2 levels of P (6 KgP/ha and 36 KgP/ha supplied as TSP) while the genotypes were randomized in the sub-plot. Each genotype was planted in a two row plot measuring three meters long with inter and intra-row spacing of 0.75 m x 0.30 m respectively. Two seeds were sown per hill and later thinned to one per hill. GenStat version 18 software was used to generate randomization design and field layout. All the plots were side-dressed using calcium Ammonium Nitrate (CAN) at the rate of 75 Kg N/ha. All standard agronomic practices were followed.

Data collection

Data was collected at anthesis and at maturity. During anthesis, destructive sampling was done on 6 randomly selected plants according to Bell and Fischer, (1994). Root sampling was done using the root box technique as described by Vepraskas and Hoyt, (1988) and Manske, (2002) in order to determine root length per unit of soil volume (root length density). Root length density measurement were based on methods described by Tennant (1975), Pérez-Harguindeguy et al., 2013. At maturity, data was collected on grain yield, (GYLD-t/ha), plant height (PHT-cm), Stover yield (STV= leaves, stalks, ear husks and cobs- t/ha), ear height (EHT-cm), internode length (INL-cm), grain P concentration (GPC %), grain P content (GPcnt Kg/ha), days to 50% silking (DASLK) and days to 50% anthesis (DANTH). All the cobs in a row for each entry were harvested and adjusted to 13% moisture content while assuming an 80% shelling percentage. The moisture content was then determined from a sample of 7 randomly selected cobs. PHT was recorded in 10 competitive plants per plot, from the soil surface to the tip of the highest tassel branch, and the plot means used for analysis. Stover samples were collected from 6 plants and a sample of 200g of grain obtained from each plot. These samples were oven dried at 80^{o}C to a constant weight and grain and stover dry matter determined. Grain and stover samples were ground and analyzed for P concentration using the vanadomolybdate method (Westerman, 1990). Based on grain and stover dry matter yields, and on P concentration in these plant components, the phosphorus content in the grain and in the stover were determined. The P efficiency parameters were then obtained on a plot basis following the procedures of Moll et al. (1982, Hammond et al. (2009) and Parentoni et al. (2010) as follows:

a. Agronomic P use efficiency (AE) =$Y_{high}–Y_{low})/D_{Papp}$ (kg/Kg Pf)

b. P uptake efficiency (PAE) = $[(P_{high}\ xY_{high})–(P_{low}xY_{low})]/D_{Papp}$ (KgP/kgPf)

c. P utilization efficiency (PUE) = $(Y_{high}–Y_{low})/[(P_{high}xY_{high})–(P_{low}\ xY_{low})]$ (kg/ kg)

d. P efficiency ratio (PER) = $Y_{high}/(P_{high}xY_{high})$ or $Y_{low}/(P_{low}xY_{low})$ kg/kg

e. Phosphorus Efficiency (PE) = $Y_{low/}\ Y_{high}$ x 100%

Where: Y_{high} - is the yield on a high P or fertilized soil; Y_{low} - is the yield on a low P/unfertilized soil; P_{high} – is the tissue P concentration on a high P or fertilized soil; P_{low} - tissue P concentration on a low P or unfertilized soil; D_{Papp} - difference in amount of P applied as fertilizer between high and low P treatments; Pf- P fertilizer.

Statistical Analysis

All means computation and variance analysis (ANOVA) were done using Genstat Version 21, VSN International (2020) and means separated using protected DMRT. ANOVA was done by fitting the split plot model for the data:

Where Y_{ijkm} is the observation on the *ijkm*th plot,

$\mu -$ the general mean,

$$Y_{ijklm} = \mu + Si + B_{k(i)} + P_j + SP_{ij} + \grave{\varepsilon}_{ijk} + G_{km} + SG_{ikm} + SPG_{ijm} + \underline{\grave{\varepsilon}}_{ijkm}$$

Where Y_{ijkm} is the observation on the *ijkm*th plot, $\mu -$ the general mean, S_i -the effect due to the *i*th location, $B_{k(i)}$ the effect due to the *k*th replication in *i*th location, P_j -effect due to the jth phosphorus level, SP_{ij}-effects due the interaction of the jth phosphorus level with the ith location, $\grave{\varepsilon}_{ijkl}$-is the residual effect due to *ijkl* th whole plot, G_m is the effect due to the *m*th genotype in the *k*th replicate , SG_{im} is the effect due to the *m*th genotype in the *k*th replicate in the ith location, SPG_{ijm} is the effect due to the *m*th genotype in jth level of phosphorus in the *k*th replicate in the ith location $\grave{\varepsilon}_{ijkm}$ is the residual effect due to *subplot*

Estimation of heritability

Broad sense heritability (H^2) was estimated by variance components using linear mixed models (REML) of Genstat version 21**.** It was calculated as follows:

$H^2 = \sigma^2{}_g / \{(\sigma^2{}_g + \sigma_{ge}{}^2{}_+ (\sigma_{error}{}^2/r)\}$

Where H^2 is broad sense heritability,

σ^2_g is the generic variance; σ_{ge}^2 is the variance due to Genotype x environment interactions,

σ_{error}^2 is the error variance, r is the number of replicates per genotype (Knapp et al. 1985; Ribaut et al., 1996).

Genetic correlations

Data from 10 different pairs of traits (GYLD, PHT, EHT, Cob L, INTL, STV, STVP (%), GPC(%), GPCNT and STPCNT) measured at both high and low P levels at each location was used for genetic correlation studies. The genetic coefficient of correlation (r_g) of traits X and Y was calculated according to Kearsey and Pooni (1996) as follows:

- $r_g = \sigma xy / \text{sqrt}(\sigma^2 x * \sigma^2 y)$
- σxy = covariance between x and y while $\sigma^2 x$ and $\sigma^2 y$ the variances of traits x and y, respectively

RESULTS

Phenotypic correlation among P-efficiency traits

Under both P conditions (36 KgP/ha & 6 KgP/ha), genotypes showed both positive and negative phenotypic correlation indices for the various traits measured. Grain yield (GY) had the highest phenotypic correlation (0.44-0.95) with both P- efficiency traits (AE, PER, PAE, PE and PUE) and other agronomic traits at both high and low P supplies (Table 1a & b). The correlation between GY with stover yields (STV) and stover P content (STPCNT) was higher under low P (r = 0.71, 0.55) compared to high P (r = 0.60, 0.53). Further, for stover P concentration, grain P content, the phenotypic correlations with grain yield followed a similar trend and were generally low at high P compared to low P conditions. However for grain P concentration (GPC) the correlations were higher at high P (r = 0.18) compared to low P (r = 0.085) although both were insignificant. (Table 1a & b). The phenotypic correlation between grain yield and P- efficiency traits among the genotypes were of higher magnitude at high P supply compared to low P except for PE where the result was reverse (PE & GYLD r = 0.55 vs 0.68, AE & GYLD r= 0.69 vs 0.62, PAE & GYLD, r=0.60 vs 0.56 and PUE & GYLD r= 0.64 vs 0.54) (Table 1a & b). There was no significant correlation between P acquisition efficiency

(PAE) and P utilization efficiency (PUE) or between PAE and grain P concentration (GPC) in both low and high P conditions (Table 1a & b). Correlation between grain yield and GPC was not significant at both high (r = 0.18) and low P (r= 0.085). The phenotypic correlation between Stover P concentration (SPC) and the P efficiency indices was also low and tended to be negative under both P conditions.

Table 1a: Correlation between Grain yield and other agronomic traits of maize hybrids across four locations under high P.

	PHT (cm)	STV (t/ha)	GYLD (t/ha)	GPC (%)	STPC (%)	GPCNT kg/ha	STPCNT kg/ha	AE Kg/Kg	PER Kg/Kg	PAE KgP/kgf	PE (%)	PUE Kg/Kg
PHT	-											
STV	0.7	-										
GYLD	0.82***	0.60**	-									
GPC	0.33	0.33	0.18	-								
STPC	0.37	0.34	0.22	0.35	-							
GPCNT	-0.27	-0.21	-0.031	0.087	-0.32	-						
STPCNT	0.26	0.1	0.53*	0.29	0.76***	0.053	-					
AE	0.35	0.44*	0.69***	0.34	0.36	0.00031	0.076	-				
PER	0.71***	0.49*	0.58*	0.26	0.50*	0.77***	0.21	0.27	-			
PAE	0.3	0.21	0.60**	0.039	0.6	-0.05	0.69	0.37	0.25	-		
PE	0.41*	0.045	0.55*	0.051	-0.018	-0.023	0.51	0.52*	0.25	-0.22	-	
PUE	0.29	0.37	0.64**	0.11	0.27	-0.33	-0.045	0.80***	0.39	0.045	0.43*	-

Table 1b: Correlation between Grain yield and other P-efficiency traits of maize hybrids across four locations under low P

	PHT (cm)	STV (t/ha)	GYLD (t/ha)	GPC (%)	STPC (%)	GPCNT kg/ha	STPCNT kg/ha	AE Kg/Kg	PER Kg/Kg	PAE KgP/kgf	PE (%)	PUE Kg/Kg
PHT	-											
STV	0.78***	-										
GYLD	0.77***	0.71***	-									
GPC	0.09	0.13	0.085	-								
STPC	0.17	0.32	0.25	0.043	-							
GPCNT	-0.32	-0.26	-0.095	0.073	-0.084	-						
STPCNT	-0.1	-0.064	0.55*	0.076	0.56*	0.48*	-					
AE	0.37	0.3	0.62**	0.22	-0.036	-0.13	-0.22	-				
PER	0.61**	0.57*	0.57*	0.077	0.37	0.80***	-0.176	0.23	-			
PAE	0.24	0.27	0.56*	-0.13	-0.17	-0.3	-0.038	0.38	0.27	-		
PE	0.41*	0.27	0.68***	0.073	0.30	0.041	0.66	0.52*	0.25	-0.22	-	
PUE	0.3	0.32	0.54*	0.35	-0.1	-0.24	-0.34	0.80***	0.39	0.05	0.43*	-

NB.PHT-plant height, STV-stover yield, GYLD-grain yield, GPC- grain P concentration, STPC-stover P concentration, GPCNT-grain P content, STVPCNT- stover P content, AE-agronomic efficiency, PER- phosphorus efficiency ratio, PAE- P acquisition efficiency, PE-phosphorus efficiency, PUE- phosphorus utilization efficiency

Heritabilities for grain yield and other agronomic traits under low and high P conditions.

Low, medium and high estimates of heritability (H^2) were measured for different plant traits (Table 2). For grain yield under high P, the highest heritability was attained at Koyonzo (0.94) while the lowest was at Chepkoilel (0.89).Under low P, the highest H^2 was realized at Chepkoilel (0.91) and was lowest at Migori (0.89). Overall, moderate values for H^2 were measured for internode Length, days to 50% anthesis and days to 50% silking.

Table 1: Heritability of maize hybrids in 4 locations

Location	Phosphorus level	PHT Cm	EHT cm	INT cm	STV t/ha	DANTH days	DASLK days	GYLD t/ha	GPCNT Kg/ha
Chepkoilel	36 kgP/ha	0.88	0.84	0.63	0.95	0.90	0.78	0.89	0.59
	6 kgP/ha	0.95	0.96	0.69	0.95	0.95	0.80	0.91	0.70
Migori	36 kgP/ha	0.87	0.91	0.53	0.92	0.75	0.72	0.92	0.781
	6 kgP/ha	0.88	0.88	0.71	0.9	0.77	0.76	0.890	0.696
Koyonzo	36 kgP/ha	0.88	0.83	0.24	0.71	0.82	0.76	0.94	0.89
	6 kgP/ha	0.77	0.74	0.18	0.87	0.20	0.38	0.90	0.79
Sega	36 kgP/ha	0.90	0.87	0.82	0.88	0.62	0.49	0.92	0.83
	6 kgP/ha	0.91	0.85	0.78	0.88	0.20	0.38	0.90	0.78

GYLD-grain yield, PHT-plant height, STV-stover yield, DANTH-days to 50% anthesis, DSLK-Days to 50% silking, GPCNT-grain P content

Genetic correlation between grain yield and other agronomic traits.

Genetic correlations between trait pairs were significantly different among the tested maize experimental hybrids under the 2 P conditions. Under Low P, grain yield (GYD) was highly correlated with plant height (r_g = 0.72**) ear height (r_g = 0.54*), internode Length (r_g = 0.73**), cob Length (r_g =0.81***) and stover yield (r_g = 0.61**) (Table 3). However grain yield was negatively correlated with days to anthesis and silking. GYD also exhibited high positive correlation with grain P content (r_g = 0.90***). Under high P conditions greater magnitudes of the genetic correlation coefficient (r_g) were observed for PHT (0.74**), EHT (0.56*) and Cob L (0.56*) while the r_g values were lesser in magnitude for STV (0.54*), days to anthesis (-0.16) and days to silking (-0.15) (Table 4). GYD was low and positively correlated with Root Length Density (RLD) at both P levels although the correlations were higher at high P (r_g= 0.37) compared to low P (r_g=0.34) (Fig 1a & b).

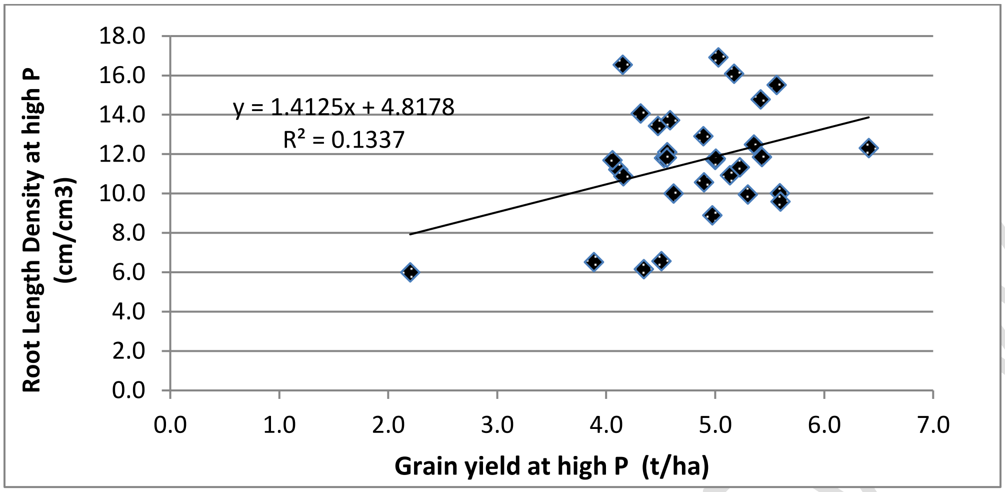

Figure 1a: Genetic Correlation between GYLD and RLD of maize hybrids in high P

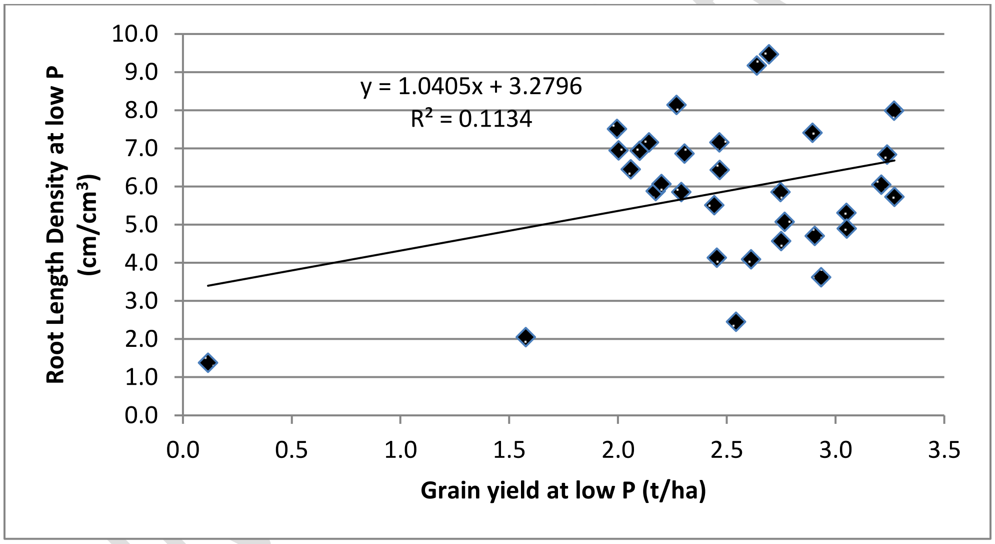

Fig 1b: Genetic Correlation between GYLD and RLD of maize hybrids tested in low P

Table2: Genetic Correlations between Grain yield and agronomic traits of maize hybrids in four locations under low P

	PLHT (cm)	EHT (cm)	INTL (cm)	CobL (cm)	SYLD (t/ha)	DANTH (days)	DSLK (days)	GYD (t/ha)	GPCNT (Kg/ha)
PLHT (cm)	-								
EHT (cm)	0.85	-							
INTL (cm)	0.88	0.78	-						
CobL (cm)	0.74	0.63	0.71	-					
SYLD (t/ha)	0.77	0.80	0.72	0.65	-				
DANTH (days)	–0.23	–0.01	–0.33	–0.31	0.006	-			
DSLK (days)	–0.27	–0.05	–0.40	–0.40	–0.03	0.95	-		
GYD (t/ha)	0.72	0.54	0.73	0.81	0.61	–0.36	–0.44	-	
GPCNT (Kg/ha)	0.48	0.57	0.41	0.45	0.67	–0.39	–0.45	0.37	-
STPCNT(Kg/ha)	0.72	0.62	0.73	0.75	0.87	0.26	0.24	0.90	0.41

Table 4: Genetic correlations between Grain yield and agronomic traits of maize hybrids across four locations under high P

	PLHT (cm)	EHT (cm)	INTL (cm)	CobL (cm)	SYLD (t/ha)	DANTH (days)	DSLK (days)	GYD (t/ha)	GPCNT (Kg/ha)
PLHT (cm)	-								
EHT (cm)	0.80	-							
INTL (cm)	0.78	0.54	-						
CobL (cm)	0.77	0.79	0.65	-					
SYLD (t/ha)	0.71	0.75	0.50	0.62	-				
DANTH (days)	–0.11	0.069	–0.22	–0.034	0.21	-			
DSLK (days)	–0.086	0.15	–0.20	0.046	0.21	0.93	-		
GYD (t/ha)	0.74	0.56	0.65	0.81	0.54	–0.16	–0.15	-	
GPCNT (Kg/ha)	0.25	0.39	0.45	0.20	0.47	–0.10	–0.12	0.25	-
STPCNT(Kg/ha)	0.69	0.52	0.65	0.79	0.72	0.45	0.45	0.95	0.037

Note. PHT-plant height, EHT-Ear height, INTL-Internode length, Cob L-Cob length, STV-stover yield, DANTH-days to 50% anthesis, DSLK-Days to 50% silking, GYLD-grain yield, GPCNT-grain P content, STPCNT- stover P content

Discussions

Results showed that, genotypes showing higher P efficiency traits (PE, PAE, PUE, AE, PER) had higher grain yield production under low P supply. Consequently, their correlation with the grain yields at low P supply were significant. (PE & GYLD r = 0.68***, AE & GYLD r= 0.62**, PAE & GYLD, r=0.56* and PUE & GYLD r= 0.54*). These correlations were equally significant at high P level. These results suggests that, grain yield under P deficiency is one of the most reliable parameter for screening genotypes for P efficiency which compare well with those of Ligeyo et al., 2014; Parentoni et al., 2010). The lack of significant correlation between grain P concentration, grain yield and other P efficiency parameters has also been reported in maize (Parentoni et al., 2010). Additionally, the correlation between Stover P concentration (SPC) and the P efficiency indices was also low and tended to be negative which suggest that GPC and SPC may not be suitable criteria for determining P efficiency in maize. Earlier studies by Fageria and Baligar (1999) also reported a lack of correlation between plant P concentration and P efficiency in wheat cultivars. Other studies such as (Zhu and Smith, 2001) have suggested that Seed P concentration can greatly affect plant performance under low P supply especially at early growth stages. Further, suggestions by Liao et al., 2005 indicated that higher seed size and higher P concentration of seed can contribute to higher P efficiency in larger crops like bean, and therefore, should be considered in evaluation of genotypes for P efficiency. In contrast, this study did not find significant correlation between grain P concentration and P efficiency parameters studied indicating that genotypic variation for P efficiency found in the present study is inherent and not related to seed P concentration. However grain yield at both low P (r= 0.55*) and high P supply (r= 0.53*) significantly correlated with Stover P content while the correlation with grain P content was negative and non-significant at both P levels. Seemingly, grain P content, like grain P concentration, had a minimal contribution to differential P efficiency in all genotypes. These results imply no or very low contribution of seed P reserves to the presented variation in P efficiency observed in maize. The results of this study further compares well with those of Oztuk et al. (2005); Seperhr et al. (2009), Parentoni et al. (2010) who also reported minimal contribution of seed P reserve to P tolerance variation in Wheat, maize, Barley and Oat genotypes. The better relationship between stover P content and P efficiency traits of genotypes may indicate a contribution of enhanced P uptake in expression of high P efficiency in studies where the total amount of P per shoot or per plant (shoot or stover P content) is considered as ‘P uptake’. Such studies include: Gill et al. (1994); Jones et al. (1992) and Fageria and Baligar (1999).

Heritabilities for grain yield and other agronomic traits under low and high P conditions.

Low, medium and high estimates of heritability (H^2) were measured for different plant traits (Table 2). This may be an indicator of the modifying effects of the various locations and the presence of genotype by environment interactions (GXE) in determining H^2. For grain yield under high P, the highest heritability was attained at Koyonzo (0.94) while the lowest was at Chepkoilel (0.89).Under low P, the highest H^2 was realized at Chepkoilel (0.91) and was lowest at Migori (0.89). These results compare well with results from other researchers (c and Hasib, 2012). Similar studies by Hasib (2005) reported highest estimated H^2 in grain yield (0.99) and plant height (0.90) of rice among the traits under study. Overall, moderate values for H^2 were measured for internode Length, days to 50%

anthesis and days to 50% silking. Studies by Olakojo and Olaoye (2011) and Wannows (2010) also reported moderate heritability for these traits in maize hybrids. Moderate to high estimate of broad sense heritability of the various traits reported in this study showed that a large proportion of the observed variations were transmissible to the subsequent generations and indicated the potential for developing high yielding varieties through selection. Broad sense heritability was generally higher under low P compared to high P conditions across the four locations although this was not consistent for all the traits. This is an indication that selection for tolerance to low phosphorus is more feasible under low P compared to high P conditions. Under low P, Ear height exhibited the highest heritability (0.87) followed by grain yield (0.85) while the lowest heritability was recorded in grain and stover P concentration. This shows that grain and stover P concentration was greatly affected by the confounding environmental variations. This observation was expected due to the variations in soil available P among the locations. The implication is that the duo traits may not be suitable P efficiency selections criteria under P deficient soils.

Genetic correlation between grain yield and other agronomic traits.

Genetic correlations between trait pairs were significantly different among the tested maize experimental hybrids under the 2 P conditions. These findings also agree well with those of Aminu and Izge, (2012); Rafiq et al. (2010) and Mohan et al. (2002) who reported significant genetic correlation between GYD in maize and other agronomic attributes such as plant height, ear height and days to 50% flowering. The high positive correlation between plant height, ear height and grain yield may be an indication that these components have a direct effect on maize grain yield and hence selection for one, improves the other trait. However the negative correlation between grain yield and days to anthesis and silking was due to the longer duration of growth facilitating the synthesis of more photosynthates that contributed to higher yields especially in the late maturing genotypes. This finding did not agree with earlier studies of Yousuf and Saleem, (2001) who reported positive and non-significant association between grain yield and days to silking. This is probably because modern bred varieties may produce high yield despite early flowering. Gyd also exhibited high positive correlation with stover P content (r_g = 0.90-0.95). The better relationship between stover P content and grain yield may indicate a contribution of enhanced P uptake in expression of high P efficiency (Fageria and Baligar (1999). Under both low and high P conditions, there was no genetic correlation between GYD and both grain P and stover P concentration implying that both grain and stover P concentration are not suitable indices for selecting maize for tolerance to low P. GYD was also positively correlated with Root Length Density (RLD) at both P levels although the correlations were generally low at both P levels but with higher magnitude at high P compared to low P. These results agree with those of Manske (2000) who reported positive correlation between GYD and RLD in wheat. These authors also reported higher correlation under high P compared to low P conditions. According to Yasien (1993), genetic correlation is the heritable association between two variables and facilitates reliance on other parameters while selecting for others. The extent of reliability in such a selection therefore depends on the degree of the genetic correlation between the traits in question. From this study therefore selection for any of the tested traits which are significantly correlated with GYD will lead to indirect selection for GYD under high and low P conditions.

Conclusions and Recommendations

This study has determined both genetic and phenotypic correlation among selected P-efficiency traits. The magnitude of genetic correlation coefficients was higher under low P supply compared to high P for majority of the traits tested .Broad sense heritability was also generally higher under low P compared to high P conditions across the four locations although this was not consistent for all the traits. These are indications that selection for tolerance to low phosphorus is more feasible under low P compared to high P conditions. The correlation between grain and stover P concentration, grain P content with majority of the P efficiency indices (PAE, PE, PUE) at both high and low P supply was always low or tended to be negative and non-significant implying that seed P reserve, and stover P concentration, had minimal or no contribution to differential P efficiency observed in all genotypes and may not be suitable criteria for determining P efficiency in maize. Grain yield at low P had strong positive genetic and phenotypic correlation with most of the traits studied indicating that both genotypic and phenotypic correlations are suitable models for selection and yield improvement in maize under low P soils. The natural genetic variation observed between the maize genotypes demonstrates the potential for breeding cultivars with improved phosphorus efficiency. The study recommends further testing of these hybrids for consideration for release in Kenya.

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