Current Journal of Applied Science and Technology

40(11): 83-96, 2021; Article no.CJAST.68931
ISSN: 2457-1024
(Past name: British Journal of Applied Science & Technology, Past ISSN: 2231-0843, NLM ID: 101664541)

Evaluating Heritability and Relationships among Phosphorus Efficiency Traits in Maize under Low P Soils of Western Kenya

Evans Ochieng Ouma[1*]

[1]Rongo University, P. O. Box 103-40404, Rongo – Kenya.

Author's contribution

The sole author designed, analyzed, interpreted and prepared the manuscript.

Article Information

DOI: 10.9734/CJAST/2021/v40i1131373
Editor(s):
(1) Dr. A. A. Hanafi-Bojd, Tehran University, Iran.
Reviewers:
(1) Kadhim Fadhil Nasir, Al-Furat Al-Awsat Technical University, Iraq.
(2) Retno Hartati, Diponegoro University, Indonesia.
Complete Peer review History: http://www.sdiarticle4.com/review-history/68931

Original Research Article

Received 15 March 2021
Accepted 25 May 2021
Published 28 May 2021

ABSTRACT

Low available phosphorus (P) remains a major limitation to maize (*Zea mays* L.) productivity across the world. Selection for P efficiency is key as part of strategies to achieving agricultural sustainability. The objectives of this study were to: (i) determine the phenotypic and genetic relationships among P-efficiency traits in maize under low P soils 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 (r= 0.44-0.95) with most P- efficiency traits at both P conditions. It also exhibited high positive and significant correlations with plant height (r_g = 0.72**) ear height (r_g = 0.54*), cob Length (r_g =0.81**) and stover yield (r_g = 0.61**) while it was negatively correlated with days to anthesis and silking. The correlation between grain and shoot P concentration and grain P content with majority of the P efficiency indices (P acquisition &Utilization efficiencies &P 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

**Corresponding author: E-mail: eoma@rongovarsity.ac.ke/ evans.ouma13@gmail.com;*

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.

Keywords: Genetic correlation; heritability; maize; phosphorus efficiency; grain yield.

1. 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 [1]. 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 [2-4]. Deficiency in P is known to reduce growth and delay maturity in many crops [5-6]. 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) [7]. 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 [8]. The non-renewable phosphate reserves in the world will be exhausted in the near future hence possible inorganic P fertilize crisis [9-10]. 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 [11-12]. 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 [13-14], the inherent low P content of parent rock material and insufficient replenishment of P removed through crop harvests [15].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. [15-16]. The results are evident in low maize and sorghum productivity (< 2 t/ha) in this region [17-18].

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 [19]. 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 [20,17] 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 [21]. 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 [22,10].

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 the selection criteria in both low and high P soils and variation in heritability of these traits in low and high P environments.

Majority of previous research work have examined correlation among maize yield and its components with a biased focus on few commonly easy to measure traits such as plant height, Ear height, biomass, number of leaves and days to Anthesis [23-26] [1] [27-28]. Moreover such experiments have been conducted in soils of high fertility or experimental stations with optimized conditions and therefore some of the recommendations from majority of these studies may not be applicable under low P soils. It is important to note that variation in yield and yield components could vary depending on the ecological conditions under which the experiment is conducted [29]. Additionally there are few studies that have focused on determining genetic relationships under P limiting conditions where the commonly measured traits may not be achievable. Therefore this study was conducted to partly address this challenge. 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) [30,31,13,12,32,33,2]. The use of GY under low P has prevailed as the most reliable criteria for selecting cultivars for better performance in low P soils [33,2;34,16]. 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 [35]. Thus, heritability plays a predictive role in breeding, expressing the reliability of phenotype as a guide to its breeding value [36]. Further, it determines the response to selection [37]. 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 [38] 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.

2. MATERIALS AND METHODS

2.1 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 0°34′37.24″N; 35°15′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 [16]. Sega site is located at 0°15′N and 34°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 °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 ° 03′S and 34°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 °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 ° 25′N and 34°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 °C. The soils are Luvisols characterized by low pH 5.7 low P of 6 mg P kg^{-1} of soil [16].

2.2 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.

2.3 Data collection

Data was collected at anthesis and at maturity. During anthesis, destructive sampling was done on 6 randomly selected plants according to [39]. Root sampling was done using the root box technique as described by [40-41] in order to determine root length per unit of soil volume (root length density). Root length density measurement were based on methods described by [42-43]. 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°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 [44]. 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 [30, 32, and 2] 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.

2.4 Statistical Analysis

All means computation and variance analysis (ANOVA) were done using Genstat Version 21, [45] 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,
μ – 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, μ – 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 *kth* replicate , SG_{im} is the effect due to the *m*th genotype in the *kth* replicate in the ith location, SPG_{ijm} is the effect due to the *m*th genotype in jth level of phosphorus in the *kth* replicate in the ith location $\grave{\varepsilon}_{ijkm}$ is the residual effect due to *subplot.*

2.5 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; $\sigma_{ge}{}^2$ is the variance due to Genotype x environment interactions,
$\sigma_{error}{}^2$ is the error variance, r is the number of replicates per genotype [46,47].

2.6 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 [48] 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

3. RESULTS

3.1 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 with grain yield 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).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.

3.2 Heritability 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.

3.3 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).

4. 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. Further correlations between 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**) was high and significant which is an indication that these components may have a direct effect on maize grain yield and hence selection for one, improves the other trait. These results further 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 [18,2]. The lack of significant correlation between

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*	-

*Note: *, **, ***stand for? .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*

Table 1. Heritability of maize hybrids in 4 locations

Location	Phosphorus	PHT	EHT	INT	STV	DANTH	DASLK	GYLD	GPCNT
	level	Cm	cm	cm	t/ha	days	days	t/ha	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

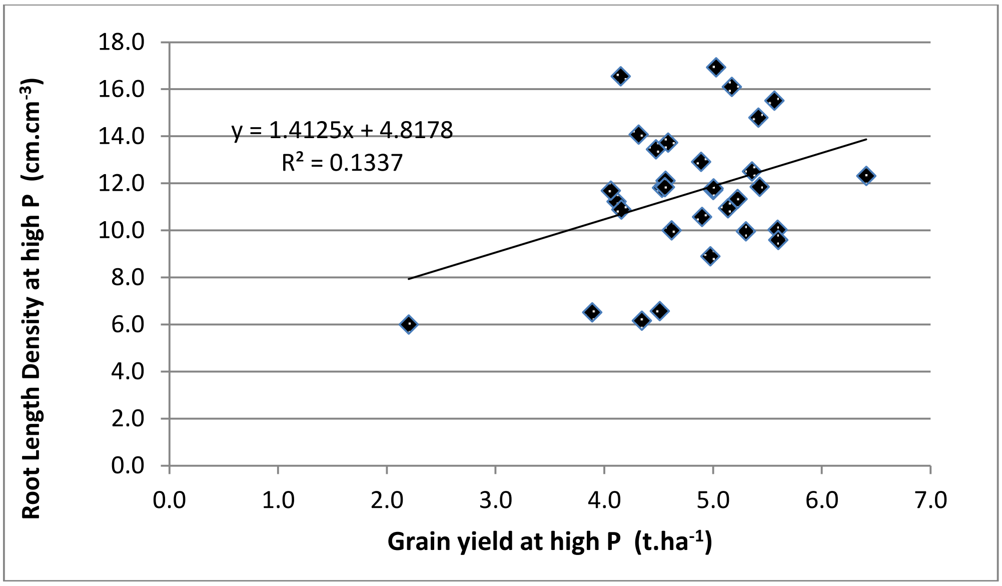

Fig. 1a. Genetic correlation between GYLD and RLD of maize hybrids in high P

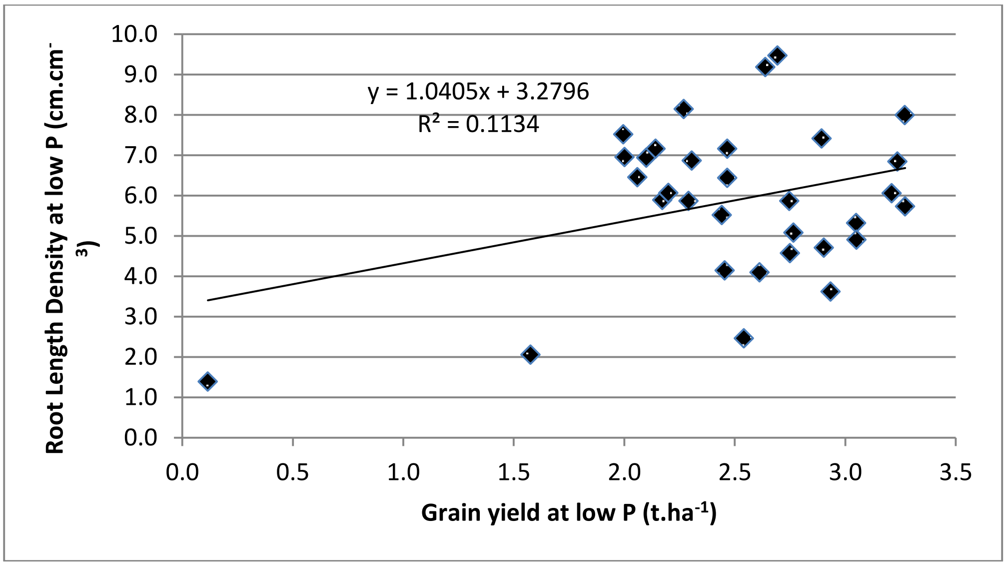

Fig. 1b. Genetic correlation between GYLD and RLD of maize hybrids tested in low P

Table 3. 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 grain P concentration, grain yield and other P efficiency parameters has also been reported in maize [2]. 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 [49] also reported a lack of correlation between plant P concentration and P efficiency in wheat cultivars. Other studies such as [50] have suggested that Seed P concentration can greatly affect plant performance under low P supply especially at early growth stages. Further, suggestions by [51] 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 [42; 51, and 43] 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’, [49].

4.1 Heritability 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 [1]. Similar studies by [52] 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 [53,45] 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.

4.2 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 [1, 27,54] 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 [55] 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 [49]. 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 [56] who reported positive correlation between GYD and RLD in wheat and implies that root length density could probably have positive contribution to yield increase under both P conditions. These authors also reported higher correlation under high P compared to low P conditions. According to [57], 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 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.

5. 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 it’s a suitable index for selecting maize for tolerance to low P. Further 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.

ACKNOWLEDGEMENT

The author acknowledge the financial support provided by the Generation challenge program (GCP). I also thanks Prof. Samuel Gudu for his inputs in editing the manuscript.

COMPETING INTERESTS

Author has declared that no competing interests exist.

REFERENCES

1. Aminu D, Izge AU. Heritability and correlation estimates in maize under drought conditions in Northern Guinea and Sudan Savannas of Nigeria. World Journal of Agricultural sciences. 2012;8(6):598-602.
   Available:https://link.citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1
2. Parentoni SN, Souza JR, Alves VMC, Gama EEG, Coelho AM, Oliveira AC, et al. Inheritance and breeding strategies for phosphorus efficiency in tropical maize (*Zea mays L.*). Maydica. 2010. 55: 1-15.
   Available:https://www.researchgate.net/publication/285752925.
3. Lynch JP. Root phenes for enhanced soil exploration and phosphorus acquisition: tools for future crops. Plant Physiol. 2011;156:1041–1049.
   Available:www.plantphysiol.org/content/156/3/1041
4. Ouma EO. Inheritance of Maize Phosphorus Efficiency in Acid Soils of

Western Kenya. International Journal of Information Research and Review. 2016;03:2091-2097
Available:https://www.ruforum.org/documents/inheritance.

5. Chen J, L Xu, Y Cai, J Xu. QTL mapping of phosphorus efficiency and relative biological characteristics in maize (Zea mays L.) at two sites. Plant Soil. 2008;313:251–266.
Available:https://pubag.nal.usda.gov/catalog/2114094
6. Cichy KA, Sieglinde SS, Matthew WB. Plant growth habit, root architecture traits and tolerance to low soil phosphorus in an Andean bean population. Euphytica. 2008;165(2):257-258.1007/s10681-008-9778-2.
Available:https://www.researchgate.net/publication/43273308.
7. Kauwenbergh SJ. Fertilizer raw material resources for Africa. Reference Manual IFDC R-16, IFDC Muscle Shoals, Alabama USA. 2006;440.
Available:https://www.amazon.com/Fertilizer-Raw-Material.
8. Cordell D. The story of phosphorus: 8 reasons why we need to rethink the management of phosphorus resources in the global food system. Sustainable Phosphorus Futures; 2008b.
Available:http://phosphorusfutures.net/why-phosphorus.
Available:https://www.sciencedirect.com/science/article/pii/S095937800800099X
9. Obersteiner M, Penielas J, Clais P, Van der Velde M, Janssen IA. The phosphorus Trielema. Nat. Geosci. 2013;6:897-898.
Available:https://www.nature.com/articles/ngeo1990
10. Jamal Azizi. Management of non-renewable resources: Market equilibrium, socio-economic impacts and potential channels of resource curse -An application to Phosphate Rock-. Economics and Finance. Université Paris sciences; 2018.
Available: https://pastel.archives-ouvertes.fr/tel-02171236
11. Baties NH. A world data set of derived soil properties by FAO- UNESCO soil unit for global modeling. Soil use Manag. 1997;13:9–16.
Available:https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1475-2743.1997.tb00550.x
12. White PJ, Hammond JP. Phosphorus nutrition of terrestrial plants. The ecophysiology of plant phosphorus interactions. Dordrecht, the Netherlands: Springer. 2008;51–81.
Available: https://doi.org/10.1007/978-1-4020-8435-5_4
13. Ozturk L, Eker S, Torum B, Cakmak I. Variation in phosphorus efficiency among 73 bread and durum wheat genotypes grown in a phosphours-deficient calcareous soil. J. Plant Soil. 2005; 269:69-80.
Available:https://link.springer.com/article/10.1007/s11104-004-0469-z
14. Kochian LV, Migue AP, Jiping L, Magalhaes JV. Plant Adaptation to Acid Soils: The Molecular Basis for Crop Aluminum Resistance. Annual Review of Plant Biology. 2015;66571-598.
Available:https://www.researchgate.net/publication/271534788
15. Kisinyo P, Gudu S, Othieno C, Okalebo J, Ochuodho J, Agalo J, et al. Phosphorus Sorption and Lime Requirements of Maize Growing Acid Soils of Kenya. Sustainable Agriculture Research. 2013a;2(2):116-123.
Available:https://ir-library.ku.ac.ke/handle/123456789/7697
16. Ouma, Gudu Samuuel. Genetic variation in phosphorus efficiency traits in in Tropical Maize in low P soils. International Journal of Current Research. 2015;7(12):23403-23412.
Available:https://www.journalcra.com/article/genetic.
17. Kisinyo PO, Opala PA, Gudu SO. Response of Sorghum (Sorghum bicolor (L.) Munch) and Chemical Characteristics of Soil to Organic and Inorganic Fertilizers on Kenyan Lower Midlands Acid Soil, IJPSS. 2019;28(1):1-8.
Available:https://www.researchgate.net/profile/Kisinyo-Peter.
18. Ligeyo DO, Ouma E, Gudu S, Kisinyo PO, Matonyei T, Okalebo JR, Othieno CO. Response of maize top cross hybrids to low phosphorous in acid soils of western Kenya. East. Africa. Forestry. J. 2014;80(1):25-30.
Available:https://www.researchgate.net/profile/Evans_Ouma2/
19. Nyangweso P. Determinants of Sorghum Producing Households' Expenditure and Implications for Food Security in Western Kenya and Eastern Uganda. Journal of Economics and sustainable development. 2018;9(12):1-11.
Available:https://www.iiste.org/Journals/index.php/JEDS/

20. Leiser WL, Frederick WR, Eva WZ, Bettina IGH. Phosphorus uptake and use efficiency of diverse west and central African Sorghum under field conditions in Mali. Plant soil. 2014b;377: 383-394.
DOI: 10.1007.
Available: https://www.gov.uk/research-for-development
21. Jasinski SM. Phosphate Rock; 2003.
Available:https://www.minerals.usgs.gov/minerals/pubs/comodity/phosphate_rock/mcs-2012-phosph.pdf
22. Cordell D, White, S. Sustainable measures: Strategies and Technologies for achieving phosphorus security. Agronomy. 2013;3:86-116.
DOI: 10.3390/Agronomy 3010086.
23. Mousavi SMN, Nagy J. Evaluation of plant characteristics related to grain yield of FAO410 and FAO340 hybrids using regression models. Cereal Research Communications. 2021;49:161–169.
Available: https://doi.org/10.1007/s42976-020-00076-3
24. Tucker SL, Dohleman FG, Grapov D, et al. Evaluating maize phenotypic variance, heritability, and yield relationships at multiple biological scales across agronomically relevant environments. Plant Cell Environ. 2020;1–23.
Available:https://doi.org/10.1111/pce.13681
25. Bramdeo K, Mousavi SMN, Mohammed S, Nagy J. Studying the relationships of various agronomic traits in maize using correlation analysis. 18th Alps-Adria Sci Workshop; 2019.
DOI:https://doi. org/10.34116/NTI.2019.AA.49.
Available:https://www.semanticscholar.org/paper/Studying-the.
26. Nzuve F, Githiri S, Mukunya DM, Gethi J. Genetic variability and correlation studies of grain yield and related agronomic traits in maize. Journal of Agricultural Science. 2014;6(9).
Available:https://doi.org/10.5539/jas.v6n9p166-176
27. Rafiq CM, Rafique M, Hussain A. Studies on heritability, path analysis in maize (*Zea mays* L.) Journal of Agricultural Research. 2010;48:1-35.
Available:https://apply.jar.punjab.gov.pk/upload/1374660174.
28. Majid K, Rogayyen ZM. Correlation Coefficient Analysis between grain yield and its components in corn hybrid. J. Agric & Environ.Sci. 2010;9(1):105-108.
Available:https://www.researchgate.net/publication/285887491
29. Carpici EB, Celik N. (2007). Determining possible Relationships between Yield and Yield Related components in Forage maize using correlation and Pathway analyses. Not. Bot. Hort. Agrobot. Cluj. 2007;38(3):280-285.
Available:https://www.notulaebotanicae.ro/index.php/nbha/article/view/5431
30. Moll RH, Kamprath EJ, Jackson WA. Analysis and interpretation of factors which contribute to efficiency of nitrogen utilization. Agronomy J. 1982;74:562-564.
Available:https://acsess.onlinelibrary.wiley.com/doi/abs/10
31. Baligar VC, Pitta GV, Gama EG, Schaffert RE, De AF Bahia C, Clark RB. Soil acidity effects on nutrient use efficiency in exotic maize genotypes. Plant and Soil 1997;192:9–13.
Available:https://link.springer.com/article/10.1023/A:1004260222681
32. Hammond JP, Martin RB, Philip JW, Graham JK, Helen CB, Rory H, et al. Shoot yield drives phosphorus use efficiency in Brassica oleracea and correlates with root architecture traits. Journal of Experimental Botany. 2009;7(60):1953–1968.
Available:https://pubmed.ncbi.nlm.nih.gov/19346243
33. Sepehra E, Malakouti MJ, Kholdebarinc B. Samadia A, Karimiand N. Genotypic variation in P efficiency of selected Iranian cereals in greenhouse experiment. International Journal of Plant Production. 2009;3(3):17-28
Available:https://www.researchgate.net/profile/Ebrahim-Sepehr.
34. Ouma E, Ligeyo D, Matonyei T, Were B, Agalo J, Emily T, et al. Development of maize single cross hybrids for tolerance to low phosphorus. African Journal of plant science. 2012;6(14):394-402.
Available:https://www.repository.rongovarsity.ac.ke/handle/123456789/455
35. Robert W. Allard. Principles of plant breeding. Wiley India; 2010.
36. Wolie A, Dessalegn T, Belete K. Heritability. Variance components and genetic advance of some yield and yield related traits in Ethiopian collections of finger millet (*Eleusine coracana* (L.)

Gaertn.) genotypes. African Journal of Biotechnology. 2013;5529-5531.
Available:https://academicjournals.org/article.

37. Ceccarelli S. Specific adaptation and breeding for marginal conditions. Euphytica. 1994; 77:205–219.
DOI: 10.1007/BF02262633 46.
Available:https://link.springer.com/chapter/10.1007/978-94-011-0966-6_15
38. Ceccarelli S. Adaptation to low/high input cultivation. Euphytica. 1996;92:203–214.
DOI: 10.1007/BF00022846.
Available:https://www.academia.edu/26094989/Adaptation_to_low_high_input_cultivation
39. Bell MA, Fischer RA. Guide to Plant and Crops Sampling: Measurements and Observations for Agronomic and Physiological Research in Small Grain Cereals. Wheat Special Report Mexico, D.F: CIMMYT.1994;32.
Available:https://repository.cimmyt.org/handle/10883/1191
40. Vepraskas MJ, Hoyt D. Comparison of the trench profile and core methods for evaluation of root distribution in tillage studies. Agron. J. 1988;80:166-177.
Available:https://acsess.onlinelibrary.wiley.com/doi/abs/10
41. Manske GGB, Ortiz-Monasterio JI, Van Ginkel RM, Rajaram S, Vlek PLG. Phosphorus use efficiency in tall, semi-dwarf and dwarf near-isogenic lines of spring wheat. Euphytica. 2002; 125:113–119.
Available:https://link.springer.com/article/10.1023/A:1015760600750
42. Tennant, D. (1975). A test of a modified line intersects method of estimating root length. J. Ecol. 63:995-1001.
Available:https://www.jstor.org/stable/2258617
43. Pérez-Harguindeguy N, DíazA S, Garnier E, Lavorel S, Poorter H, Jaureguiberry P, et al. New handbook for standardised measurement of plant functional traits worldwide, Australian Journal of Botany. 2013;61:167–234.
DOI: http://dx.doi.org/10.1071/BT12225
Available:https://conservancy.umn.edu/handle/11299/177647
44. Westerman RL. Soil Testing and Plant Analysis.3rd edition. American Society of Agronomy and Soil Science Society of America, Madison, Wisconsin; 1990.
45. Wannows AK, Azzam HA, Al-Ahmad SA. Genetic variances, Heritability, correlation and path coefficient analysis in yellow maize crosses. Agriculture and Biology Journal of North America. 2010;1(4):630-637.
Available:https://www.cabdirect.org/cabdirect/abstract/20103236539
46. Knapp SJ, Stroup WW, Ross WM. Exact confidence intervals for heritability on a progeny mean basis. Crop Sci. 1985;25:192–194.
Available:https://pubag.nal.usda.gov/catalog/1337558
47. Ribaut JM, Hoisington DA, Deutsch JA, Jiang C, Gonzalez-de- LD. Identification of quantitative trait loci under drought conditions in tropical maize. I. Flowering parameters and the anthesis-silking interval. Theor Appl Genet. 1996;92:905-914.
Available:https://pubmed.ncbi.nlm.nih.gov/24166558
48. Kearsey MJ, Pooni HS. The genetical analysis of quantitative traits. Chapman and Hall. London. U.K; 1998.
Available:https://www.cambridge.org/core/journals/genetics
49. Fageria NK, Baligar VC. Phosphorous use efficiency in wheat genotypes. J.PlantNut. 1999; 22:331–340.
Available:https://www.tandfonline.com/doi/abs/10.1080/01904169909365630
50. Zhu YG, Smith S, Barritt A. et al. Phosphorus (P) efficiencies and mycorrhizal responsiveness of old and modern wheat cultivars. Plant and Soil. 2001;237:249–255.
Available:https://doi.org/10.1023/A:1013343811110
51. Liao MT, Hocking PJ, Dong B. Screening for genotypic variation in P uptake efficiency in cereals on Australian soils. pp: 114-115. In: Li, (ed.), Plant Nutrition for Food Security, Human Health and Environmental Protection, Tsinghua University Press. Beijing, China; 2005.
Available:https://www.researchgate.net/publication/262982566
52. Hasib KM. Genetic variability interaction and path analysis for panicle characteristics in scented rice. Hisar Journal. 2005;30(1):37-39.
Available:https://www.cropresearch.org/volume-30-number-1-july-2005
53. Olakojo SA, Olaoye G. Correlation and heritability estimates of maize. African

Journal of plant science. 2011;5(6):365-369.
Available:https://academicjournals.org/journal/AJPS/article-abstract/71B52339736

54. Mohan YC, Singh K, Rao NV. Path coefficient analysis for oil and grain yield in maize genotypes. National Journal of plant improvement. 2002;4(1):75-76.
Available:https://www.researchgate.net/publication/326246902.

55. Yousuf M, Saleem M. Correlation analysis of S1 families of maize for grain yield and its components. Int. J. Agric. Biol. 2001;3:387-388.
Available: http://d-o-i.org/1.15/ijarbs-2016-3-6-19

56. Manske GGB, Ortiz-Monasterio JI, Van Ginkel M, Gonzalez RM, Rajaram S, Molina E, Vlek PLG. Traits associated with improved P-uptake efficiency in CIMMYT's semi dwarf spring bread wheat grown on an acid andisol in Mexico. Plant Soil. 2000;221:189–204.
Available:https://www.researchgate.net/publication/238492978

57. Yassien HE. Genetic analysis in three yellow maize (*Zea mays L.*) crosses. Journal of Agriculture, Mansoura University. 1993;24(10):5319-5331.
Available:http://dx.doi.org/10.5829/idosi.wjas.2012.8.6.1696

© 2021 Ouma; This is an Open Access article distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/4.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Peer-review history:
The peer review history for this paper can be accessed here:
http://www.sdiarticle4.com/review-history/68931