The Journal of Animal & Plant Sciences, 22(2): 2012, Page: 309-317
ISSN: 1018-7081

RIDGE SOWING IMPROVES ROOT SYSTEM, PHOSPHORUS UPTAKE, GROWTH AND YIELD OF MAIZE (*Zea mays* L.) HYBRIDS

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ABSTRACT

Adequate and balanced supply of essential nutrients, promising cultivars and improved planting methods are prime important to realize the maximum potential of different maize hybrids. This study was conducted to evaluate the response of different planting methods on rooting system, crop growth, phosphorus (P) uptake and yield of different maize (*Zea mays* L.) hybrids. Three maize hybrids viz. 6621 (H_1), 919 (H_2) and KS-64 (H_3) were planted in flat sowing (P_1 = 75 cm spaced rows), ridge sowing (P_2 = 75 cm spaced ridges) and bed sowing (P_3 = 120-30 cm apart beds). Better root growth, P uptake, agronomic and yield related traits were observed in ridge sowing followed by bed sowing; although there was non-significant effect of sowing methods on plant population, cob length and harvest index. Amongst the hybrids tested, hybrid 919 showed better performance for most of the parameters studied; although there was no difference among the hybrids for plant population, plant height, number of rows per cob and harvest index. Interactive effect of planting methods and different maize hybrids was also significant for most of the traits studied except plant population, number of rows per cob and harvest index. Maize hybrid 919 when sown on ridges showed maximum root and crop growth, P uptake and yield than rest of the combinations. Strong correlation of lateral roots was observed with grain size, grain yield and grain P contents. To conclude, root growth better ensured the P uptake and use efficiency which resulted in better crop growth and yield while maize hybrid 919 grown on ridges efficiently utilized P and exhibited higher grain yield.

Key words: Ridge sowing, maize hybrids, P uptake, root growth rate, growth, grain yield.

INTRODUCTION

Adequate and balanced supply of essential nutrients, promising cultivars and improved planting methods are prime important to realize the maximum potential of different maize hybrids (Alias *et al.,* 2003). Among all nutrients, P plays a dominant role in the whole growth process; however, inorganic phosphorus is one of the least available nutrients in soils of many terrestrial ecosystems (Vance *et al.,* 2003). Large and well developed root systems that can explore greater soil volume has been recognized as one important adaptation of plants to ensure a sufficient uptake of P under deficient P conditions (Horst *et al.,* 2001). Root growth and development are critical for early P uptake by plants because P is relatively unavailable and immobile in many soils (Richardson *et al.,* 2009).

In Pakistan soils, P is the second most deficient nutrient element after nitrogen. Many of the field crops respond to the added P in terms of increased growth and yield (Yaseen and Malhi, 2009). Numerous scientists have investigated regarding the need for P addition to the soil for increased crop outputs in Pakistan (Shah *et al.,* 2006; Jabran *et al.,* 2011). Application of P increased the grain yield in mungbean (Shah *et al.,* 2006), wheat (Jabran *et al.,* 2011), cotton (Makhdum *et al.,* 2001), fodder (Niamatullah *et al.,* 2011) sugarcane and fruit crops (FAO, 2004).

Phosphorus is an essential element for all living organisms and involved in nucleic acid and phospholipids synthesis, and activating a wide range of enzymes (Lambers *et al.,* 2006). P also plays a key role in energy transfer and is thus essential for photosynthesis (Reich *et al.,* 2009). P deficiency resulted in net photosynthesis reduction and decreased shoot and root biomass production in maize crop (Wissuwa *et al.,* 2005). Leaf growth depression under P deficiency is well documented (Kavanova *et al.,* 2006). P deficiency affects the rate of emergence and number of maize adventitious nodal roots (Pellerin *et al.,* 2000; Kavanova *et al.,* 2006). Its deficiency also caused severely reduced LAI in maize that results low PAR absorption by canopy and reduced crop growth (Pellerin *et al.,* 2000).

Improved sowing methods not only help to maintain optimum plant population due to better germination but also enable the plants to utilize land, light and other input resources uniformly and efficiently. So it is imperative to develop such a planting pattern which may help in avoiding excessive crowding and thereby enabling the maize plants to utilize the resources more effectively and efficiently (Quanqi *et al.,* 2008). More bulk density or dense surface soil layer is a limiting factor for root growth resulting in shorter root length and concentrate the roots near soil surface. Thus plants are forced to extract water and nutrients from limited soil volume (Chassot and Richner, 2002). Ridges provide loose fertile layer of soil that results well developed root system. Phosphorus uptake is closely related to root growth and morphology (Bucher, 2007; Ao *et al.,* 2010). Better developed root system enhanced the phosphorus uptake under P deficient conditions and phosphorus supply through better root system is critical for the growth of maize seedlings (Chassot and Richner, 2002). Planting pattern and phosphorus application depth significantly affect the phosphorus uptake (Wei-Jun, 2009). Maximum number of leaves per plant, number of cobs per plant, number of grains cobs, taller plants, more grain and biological yield was recorded in ridge planting (Bakht *et al.,* 2006).

Different maize hybrids have different ability to uptake phosphorus from the soil due to their genetic make up and rooting systems. There are significant differences in dry matter production and phosphorus uptake among maize varieties (Alam *et al.,* 2002). Different varieties perform differently owing to their time to maturity and yield which were the most important factors that influence the maize yield (Maina *et al.,* 2006). Earlier, Kovacevic *et al.* (2004) and Raymond *et al.* (2009) also reported different P contents in leaves and grains of different maize hybrids, respectively due to different uptake rate of P.

Furthermore, the prices of fertilizers are very high during recent days, and it is very difficult for a farmer with small land holding to increase the application rate of the phosphorus fertilizers. Thus it is very important to determine an appropriate method of planting and suitable maize hybrids which maximize the uptake of available nutrients particularly phosphorus and enhance grain yield. The present study was designed to fulfill above said objectives.

MATERIALS AND METHODS

Site description: The study was conducted at Agronomic Research Area, University College of Agriculture, Bahauddin Zakariya University, Multan (71.43^o E, 30.2^o N and 122 meters a.s.l.), Pakistan, during autumn, 2009. The climate of the region is subtropical and semi-arid. The experimental area was quite uniform and soil analysis was done to assess the soil fertility status. The physico-chemical analysis of the soil is given in Table 2.

Experimental details: The experiment was laid out in randomized complete block design (RCBD) with split plot arrangement having net plot size of 5 m x 3 m and replicated three times. Planting methods and maize hybrids were kept in main plots and sub plots, respectively. Planting methods used in the experiment were flat sowing (P_1 = 75 cm spaced rows), ridge sowing (P_2 = 75 cm spaced ridges) and bed sowing (P_3 = 120-30 cm spaced beds). Three maize hybrids included in the study were 6621 (H_1), 919 (H_2) and KS-64 (H_3). A uniform dose of phosphorus was applied @ 150 kg ha^{-1} to all experimental units at the time of sowing. Weather data during the course of the study are given in Table 1.

Crop husbandry: Prior to seedbed preparation, pre-soaking irrigation of 10 cm was applied. When soil reached to workable moisture level, the seedbed was prepared by cultivating the field for 2 times with tractor-mounted cultivator each followed by planking. The crop was sown on 4 August, 2009. Sowing was done by hand dibbling by keeping plant to plant distance of 22.5 cm. Fertilizers were applied at the rate of 200 kg N and 150 kg P_2O_5 ha^{-1}, respectively by using urea and diammonium phosphate as a source. Full dose of phosphorus and one third dose of nitrogen was applied at the time of sowing. Second dose of nitrogen (1/3rd) was applied at the knee height stage of crop and remaining nitrogen was applied at tasseling stage. After first irrigation when soil reached to workable moisture level, hoeing was done to keep crop free from weeds and then earthing up was done. Carbofuran (Furadan 3G) was applied for the control of top borer @ 12.5 kg ha^{-1}. Crop was harvested on November 05, 2009.

Measurements: Plant population at harvest was recorded by counting the total number of plants in each plot. Plant height was recorded at maturity from 10 randomly selected plants with measuring tape and then averaged. To count number of cobs per plant, total number of cobs of ten randomly selected plants were counted and averaged. Data regarding cob length, number of rows per cob and number of grains per cob were recorded from 10 randomly selected cobs from each plot and then averaged. For 1000-grain weight, five samples, each of 1000 grains, were randomly taken from the seed lot of each plot, weighed by electronic balance and then averaged to calculate 1000-grain weight. To record grain yield, after harvesting the plants at maturity, the cobs were separated, sun dried, threshed manually and grain yield per plot was recorded. The random grain samples were taken from each plot to determine moisture contents. The grain yield was adjusted to 10% moisture content and presented in tons ha^{-1}. To calculate biological yield, weight of air-dried plants (except cobs) was recorded on plot basis and then converted into t ha^{-1}. The recorded weight was then added to the already calculated grain yield (t ha^{-1}) to obtain the biological yield. Harvest index (HI) was calculated as ratio between grain yield and biological yield expressed in percentage.

Leaf area was measured using a leaf area meter (DT Area Meter, model MK2, Delta T Devices, Cambridge, UK) by15 days interval. Thereafter, leaf area index (LAI) was calculated using the formula given by Watson (1947). Crop growth rate (CGR) was calculated following the procedures described by Hunt (1978).

Length of primary root**,** number of lateral roots per plant and root growth rate (RGR) was determined after fortnight intervals by selecting five plants randomly from each plot. The sampling was started 30 days after sowing (DAS) and terminated at the harvest of crop. Plants were uprooted with extensive care to avoid roots damage, washed them thoroughly with water and air dried for some time. Length of primary root was taken with the help of measuring tape and then averaged. Total number of lateral roots of all five plants were counted and averaged. Root growth rate (RGR) was calculated following Hunt (1978).

Phosphorus contents from roots, leaves and grains were determined according the procedure given by Moodie *et al.* (1959). Dried and powdered plant material (1.0 g) of roots, leaves and grain samples was digested by using diacid mixture of 20 ml of concentrated HNO_3 and 10 ml of perchloric acid (72 %), reduced to 3 ml upon heating, cooled and transferred to a 100 ml volumetric flask through filter paper. Ten ml from wet digested material was taken in 100 ml volumetric flask, added 10 ml each of H_2SO_4 (1+6), ammonium molybdate (5%) and ammonium venadate (0.25 %), made the volume and allowed to stand for 15-30 minutes to develop yellow color. Color intensity was measured on a spectronic-295 spectrophotometer at 400 nm wavelength.

Statistical analysis: The collected data were statistically analyzed by using Fisher's analysis of variance technique and LSD test at 5% probability was used to compare the differences among treatments' means (Steel *et al.,* 1997). Correlation coefficient between various traits was calculated using Microsoft Excel. Likewise graphical presentation of the data was done using Microsoft Excel.

RESULTS AND DISCUSSION

Sowing methods, maize hybrids and their interaction had non-significant effect on plant population (Table 3). Maximum plant height was recorded when maize was grown or ridges and beds compared with flat sown crop (Table 3). Different maize hybrids had non-significant effect on plant height. Maximum cob length was recorded in maize hybrid 6621 compared with 919 and KS-64 (Table 3). Regarding interactive effect of sowing methods and maize hybrids, maximum plant height was recorded when maize hybrid 919 was grown on ridges but it was at par with the combinations when 6621 was grown by flat and bed sowing methods and KS-64 was grown on ridges and beds. Minimum plant height was resulted when hybrid 6621 was grown on ridges but it was at par when 6621 was grown by all three methods and 919 was grown on ridges (Table 3). Maximum cob length was resulted when hybrid 6621 was grown on ridges but it was at par with the combinations when 6621 was grown on flat seedbed, 919 was grown on beds and KS-64 was grown on beds. Minimum cob length was recorded when 919 was grown on flat seedbed but it was at par with the combinations when KS-64 was grown by flat and ridge sowing method and 6621 was grown on beds (Table 3).

Maximum number of rows per cob, number of grains per cob and 1000-grain weight was also recorded in case of ridge sown crop compared with flat sown crop (Table 3). Maize hybrids had non-significant effect on number of rows per cob. Maize hybrids 6621 and 919 had maximum number of grains per cob compared with KS-64. More 1000-grain weight was recorded in maize hybrid 919 compared with KS-64 (Table 3). Interaction between sowing methods and maize hybrids had non-significant effect on number of rows per cob. Maize hybrids 6621 and 919 produced maximum number of grains when grown on ridges. Minimum number of grains was produced when KS-64 was grown on flat seedbed (Table 3). Maximum 1000-grain weight was recorded when 919 was sown on ridges against the minimum 1000-grain weight that was recorded when 919 was grown on flat seedbed and KS-64 was grown on ridges (Table 3).

Ridge sown crop resulted in highest grain and biological yield compared with flat sown crop (Table 4). Similarly, maize hybrids 919 produced highest grain and biological yield compared with KS-64 (Table 4). Regarding interactive effect of planting methods and maize hybrids, maximum grain yield was obtained when 919 was grown on beds against the minimum grain yield that was recorded when KS-64 was grown on beds and 919 was grown by flat sowing method (Table 4). Similarly maximum biological yield was obtained when 6621 and 919 was grown on ridges. Minimum biological yield was recorded when 6621 was grown on flat seedbed (Table 4). Sowing methods, maize hybrids and interaction between planting methods and maize hybrids had non-significant effect on harvest index (HI) (Table 4).

There was strong positive correlation of number of lateral roots with grain weight, grain yield and grain P contents in various hybrids, and grain weight and grain yield under various planting methods (Table 5). However root length was only correlated with grain weight and grain P contents in various planting methods (Table 5).

Length of primary root progressively increased with increasing growth period (Fig. 1). Ridge sowing showed more length of primary root compared with flat sowing throughout the growing period but it was at par with bed sowing at 75 and 90 DAS. Similarly, maize hybrid 919 had more root length compared with KS-64 (Fig. 1). Likewise, number of lateral roots progressively increased with growing period. Ridge sowing showed more number of lateral roots compared with flat sowing at 45, 60, 75 and 90 DAS but it was at par with bed sowing at 90 DAS. Similarly, maize hybrid 919 showed more number of lateral roots compared with KS-64 at 60, 75 and 90 DAS (Fig. 2). Root growth rate (RGR) declined at 45 DAS to 60 DAS and then remained a bit constant. Furthermore, ridge sown crop also had more root growth rate (RGR) at 45 and 75 DAS compared with other sowing methods. Likewise, maize hybrid 919 had more root growth rate (RGR) at 45 and 60 DAS than other hybrids but at par with hybrid 6621 at 60 DAS (Fig. 3).

Allometric data showed that LAI progressively increased and reached the maximum level at 60 days after sowing (DAS) and then declined (Fig. 4). Ridge sowing showed high LAI compared with flat sowing at 45, 60 75 and 90 DAS but at 90 DAS it was at par with bed sowing. Similarly, at 30 DAS, maize hybrid 919 and at 45 DAS, maize hybrid KS-64 had highest LAI compared with other hybrids (Fig. 4). Likewise, CGR progressively increased with increasing growth period because of increased dry matter accumulation (Fig. 5). Ridge sowing showed higher CGR than flat sowing throughout the growing season but it was at with bed sowing at 75 and 90 DAS. Similarly, maize hybrid 919 showed high CGR than hybrids 6621 and KS-64 throughout the growing season but it was at with 6621 at 30 DAS (Fig. 5).

Ridge sown crop resulted in maximum P contents in roots, leaves and grains of maize compared with flat sown crop. Furthermore, P contents in the grains of ridge sown crop at par with the bed sown crop (Table 4). Maize hybrid 919 had maximum P contents in roots, leaves and grains against the minimum P contents that were recorded in KS-64 (Table 4). Regarding interactive effect of planting methods and maize hybrids, maximum P contents in roots were recorded when 919 was grown on ridges but it was at par when 6621 and KS-64 were grown on ridges and 919 was grown on beds. Minimum P contents in roots were recorded when KS-64 was grown by flat sowing method but it was at par with all other treatments except when 919 and KS-64 were grown on ridges (Table 4). Maximum P contents in leaves were recorded when 919 was grown on ridges against the minimum P contents in leaves that were resulted when KS-64 was grown on flat seedbeds (Table 4). Similarly maximum P contents in grains were recorded when 919 was grown on beds and ridges against the minimum P contents that were recorded when KS-64 and 6621 was grown by flat sowing method (Table 4).

Ridge sowing resulted in maximum grain yield and P uptake due to well developed root system. Well developed root system resulted in more water and nutrient uptake which ultimately resulted in enhanced LAI, and enhanced CGR that results in more number of grains per cob and 1000-grain weight. Maximum plant height in ridge sown crop might be due to the improved soil conditions provided by ridges. Ridges might provide loose fertile soil with more aeration and moisture availability which ultimately enhanced the root length, number of lateral roots and root growth rate (Fig. 1, 2 and 3). The well developed root system ultimately enhanced water and nutrient uptake that resulted in high LAI and CGR (Fig. 4 and 5). The enhanced LAI and CGR resulted in more dry matter production and ultimately increased the plant height (Amin *et al.,* 2006). Maximum plant height and cob length produced by maize hybrid 919 might be due to the improved genetic makeup of the hybrid. Maize hybrid 919 also produced good root system (Fig. 1, 2 and 3) and resulted in high LAI and CGR (Fig. 4 and 5). The improved root system and high LAI and CGR result in more dry matter production which results in maximum plant height and cob length. Regarding interactive effect of hybrids and planting methods, both genetic makeup of the hybrids and the conditions created by ridge sowing method for root and crop growth of plants might be responsible for enhanced plant height and cob length.

More number of grains and 1000-grain weight in case of ridge sown crop might be due to the direct result of well developed root system (Fig. 1, 2 and 3) as there was a strong positive correlation of number of lateral roots and root length with grain weight (Table 5). Furthermore, well developed root system enhanced water and nutrients uptake particularly P (Chassot and Richner, 2002). More water and nutrient availability resulted in high LAI (Fig. 4) and hence more photosynthates were available. So it resulted in more number of grains per cob and more grain size due to more availability of photosynthates (Rasheed *et al.,* 2003). Maximum number of grains per cob and more 1000-grain weight produced by hybrids 6621 and 919 might be due to their better genetic makeup which resulted in better root system development as a positive correlation of number of lateral roots with grain weight was found in various hybrids (Liu and Tollenaar, 2009; Ahmad *et al.,* 2011). Both genetic makeup of the hybrids and the conditions created by ridge sowing that results in better root system (Fig. 1, 2 and 3) might be responsible for more number of grains per cob and enhanced 1000-grain weight in maize hybrids 919 and 6621 when grown on ridges (Daoui *et al.,* 2012).

Maximum grain yield in ridge sowing and maize hybrid 919 might be the direct result of more number of grains per cob and highest 1000-grain weight (Table 3) due to better root system and LAI (Fig. 1, 2, 3 and 4). There was strong positive correlation of number of lateral roots with grain weight, grain yield and grain P contents in various hybrids, and grain weight and grain yield under various planting methods (Table 5). However root length was only correlated with grain weight and grain P contents in various planting methods (Table 5). More biological yield might also be due to the favorable soil conditions created by ridges that result in better roots development; enabling the plants to uptake more moisture and nutrients to produce higher LAI (Rasheed *et al.,* 2003; Amin *et al.,* 2006; Abdullah *et al.,* 2007; Ghaffar *et al.,* 2012). Higher LAI means bigger assimilatory system which results in higher CGR and more dry matter production. Higher dry matter production ultimately leads to higher biological yield (Raymond *et al.,* 2009).

Both genetic makeup of the hybrid and the conditions created by ridges for the growth of plants might be responsible for more number of grains per cob and enhanced 1000-grain weight in maize hybrids 919 when grown on ridges might be the reason of the highest grain yield because number of grains per cob and 1000-grain weight had direct effect on final grain yield in maize. Higher LAI and CGR produced by hybrid 919 in ridge sowing resulted in higher dry matter production and biological yield. Loose fertile soil with more aeration and moisture supply and low resistance to new emerging roots might be the reason of long primary root and more number of lateral roots in ridge sown crop (Chassot and Richner, 2002). Better genetic makeup of hybrid 919 might be the reason of long primary root and more number of lateral roots. Higher LAI and CGR in ridge sown crop and maize hybrid 919 (Fig. 4 and 5) might be the reason of higher RGR due to more availability of assimilates.

Higher LAI might be attributed to favorable soil environment provided by ridge sowing. Loose fertile soil provided by ridges resulted in better root system development (Fig. 1, 2 and 3) and enhanced water and nutrient uptake that resulted in higher LAI. Higher LAI (Fig. 4) resulted in large assimilatory system producing more fresh and dry matter due to more photosynthesis. Large dry matter production resulted in enhanced CGR (Rasheed *et al.,* 2003; Hussain *et al.,* 2010). Similarly higher LAI in hybrids 919 and 6621 was also due to their genetic makeup which resulted in better root system which ultimately improved water and nutrient uptake. Higher LAI was also responsible of enhanced CGR due to more dry matter production (Akram *et al.,* 2010).

Well developed root system in ridge sown crop (Fig. 1, 2 and 3) might be the reason of more P contents in the leaves, roots and grains in ridge sown crop. Phosphorus uptake is closely related to root growth and morphology (Ao *et al.,* 2010). Large and well developed root systems can explore greater soil volume and has been recognized as an important adaptation of plants to ensure a sufficient uptake of P under deficient P conditions (Horst *et al.,* 2001). More P contents in roots, leaves and grains of hybrid 919 might also be due to its more effective root system (Fig. 1, 2 and 3) than other hybrids. Both genetic makeup of the hybrid 919 and favorable conditions created by ridges for root growth resulted in better root system which might increased the P uptake and ultimately P contents in roots, leaves and grains (Kovacevic *et al.,* 2004; Raymond *et al.,* 2009). There was also a strong positive correlation of number of lateral roots with grain P contents in hybrids, and root length was correlated with grain P contents in various planting methods (Table 5).

In conclusion, plant height, number of grains per cob, 1000-grain yield, grain and biological yield, primary root length, number of lateral roots, root growth rate and phosphorus contents in roots, leaves and grains were recorded in ridge sowing method. Likewise maize hybrid 919 also results in maximum number of grains per cob, 1000-grain yield, grain and biological yield, harvest index, primary root length, number of lateral roots, root growth rate and phosphorus contents in roots, leaves and grains compared with hybrids. So, maize hybrid 919 should be grown on ridges to obtain maximum yield and P uptake in maize crop.

Table 1: Weather data during the course of study

Month	Mean Monthly Temperature (°C)	Mean Monthly Relative Humidity (%)	Total Monthly Rainfall (mm)
August	33.0	62.3	6.09
September	31.1	62.2	5.08
October	25.4	56.4	0.00
November	18.2	64.2	0.00

Source: Agricultural Meteorology Cell, Central Cotton Research Institute, Multan, Pakistan.

Table 2: Physico-chemical analysis of soil

Determination	Unit	Value	Status
Physical Analysis			
Sand	%	66.6	
Silt	%	16.6	
Clay	%	16.8	
Textural class	Sandy clay loam		
Chemical Analysis			
pH		7.9	
EC	dS m^{-1}	1.32	
Organic matter	%	0.45	Very low
Total nitrogen	%	.028	Very low
Available phosphorus	Ppm	9.00	Low
Available potassium	Ppm	110	Medium

Table 3: Effect of different planting methods on plant population, plant height and yield components of maize hybrids

Treatments	Plant population (m^{-2})	Plant height (cm)	Cob length (cm)	No. of rows per cob	No. of grains per cob	1000-grain weight (g)
Planting methods (P)						
P_1 = Flat sowing	5.16	178.50^{b}	20.06	14.22^{b}	467.22^{c}	174.58^{c}
P_2 = Ridge sowing	5.33	183.90^{a}	20.70	14.67^{a}	538.55^{a}	188.42^{a}
P_3 = Bed sowing	5.45	182.77^{ab}	21.12	14.22^{b}	494.78^{b}	181.83^{b}
LSD at 5%	NS	5.31	NS	0.40	12.78	3.43
Maize Hybrids (H)						
H_1 = 6621	5.37	181.17	21.38^{a}	14.11	518.11^{a}	181.24^{b}
H_2 = 919	5.42	183.30	19.92^{b}	14.56	512.22^{a}	188.63^{a}
H_3 = KS-64	5.16	180.70	20.57^{b}	14.44	470.22^{b}	174.69^{c}
LSD at 5%	NS	NS	0.77	NS	13.91	5.01
Interaction (P X H)						
P_1H_1	68.33	182.7^{abc}	21.40^{ab}	13.67	522.33^{cd}	181.83^{bcd}
P_1H_2	68.33	181.3^{c}	18.20^{c}	14.33	501.67^{de}	156.33^{e}
P_1H_3	64.66	178.5^{bc}	20.60^{b}	14.67	377.67^{g}	185.57^{bc}
P_2H_1	68.33	175.1^{c}	22.30^{a}	14.67	565.33^{a}	174.07^{d}
P_2H_2	72.33	189.1^{a}	20.56^{b}	14.67	549.00^{ab}	229.77^{a}
P_2H_3	67.33	187.5^{a}	19.23^{bc}	14.67	501.33^{de}	161.43^{e}
P_3H_1	72.66	185.7^{ab}	20.46^{b}	14.00	466.67^{f}	187.83^{b}
P_3H_2	70.66	179.5^{bc}	21.00^{ab}	14.66	486.00^{ef}	179.80^{bcd}
P_3H_3	69.33	176.1^{ab}	21.90^{a}	14.00	531.67^{bc}	177.87^{cd}
LSD at 5%	NS	8.61	1.33	NS	24.08	8.68

Means not sharing the same letters with in a column differ significantly from each other at 5% level of probability

Table 4: Effect of different planting methods on yield, harvest index and P contents of maize hybrids

Treatments	Grain yield (t ha^{-1})	Biological yield (t ha^{-1})	Harvest index (%)	P contents (%) in roots	P contents (%) in leaves	P contents (%) in grains
Planting methods (P)						
P_1 = Flat sowing	5.77^{b}	28.92^{b}	19.95	0.09^{b}	0.71^{c}	0.12^{b}
P_2 = Ridge sowing	7.01^{a}	36.05^{a}	19.44	0.13^{a}	0.91^{a}	0.23^{a}
P_3 = Bed sowing	5.86^{b}	31.76^{b}	18.44	0.10^{b}	0.78^{b}	0.22^{a}
LSD at 5%	0.18	2.85	NS	0.02	0.03	0.03
Maize Hybrids (H						
H_1 = 6621	6.25^{ab}	32.5^{b}	19.23	0.10^{ab}	0.86^{b}	0.18^{b}
H_2 = 919	6.35^{a}	34.6^{a}	19.08	0.12^{a}	0.95^{a}	0.26^{a}
H_3 = KS-64	6.03^{b}	29.6^{c}	19.47	0.10^{b}	0.60^{c}	0.13^{c}
LSD at 5%	0.25	1.78	NS	0.02	0.02	0.05
Interaction (P X H)						
P_1H_1	5.66^{c}	25.67^{d}	22.03	0.10^{bc}	0.77^{e}	0.12^{de}
P_1H_2	5.06^{d}	30.64^{bc}	16.51	0.09^{c}	0.85^{d}	0.19^{bcd}
P_1H_3	6.58^{b}	30.44^{bc}	21.68	0.08^{c}	0.52^{h}	0.05^{e}
P_2H_1	6.54^{b}	38.32^{a}	17.06	0.12^{abc}	0.95^{b}	0.24^{bc}
P_2H_2	7.98^{a}	37.16^{a}	21.47	0.15^{a}	1.11^{a}	0.26^{ab}
P_2H_3	6.51^{bc}	32.68^{bc}	19.92	0.13^{ab}	0.69^{f}	0.18^{bcd}
P_3H_1	6.56^{b}	33.48^{b}	19.59	0.09^{bc}	0.87^{cd}	0.18^{bcd}
P_3H_2	6.01^{c}	32.05^{bc}	18.75	0.12^{abc}	0.90^{c}	0.33^{a}
P_3H_3	5.00^{d}	29.77^{c}	16.79	0.09^{c}	0.59^{g}	0.15^{d}
LSD at 5%	0.43	3.09	NS	0.03	0.04	0.09

Means not sharing the same letters with in a column differ significantly from each other at 5% level of probability

Table 5: Relationship between root traits and grain traits in various maize hybrids under various planting methods in maize (n = 3)

Variable	Grain weight		Yield		Grain Phosphorus	
	Sowing Method	Hybrids	Sowing Method	Hybrids	Sowing Method	Hybrids
Lateral roots	0.957**	0.999***	0.982**	0.967**	0.760ns	0.996***
Root length	0.943**	0.196ns	0.678ns	0.351ns	0.997***	0.291ns

*** = significant at p = 0.99, ** = significant at p = 0.95, ns = non-significant

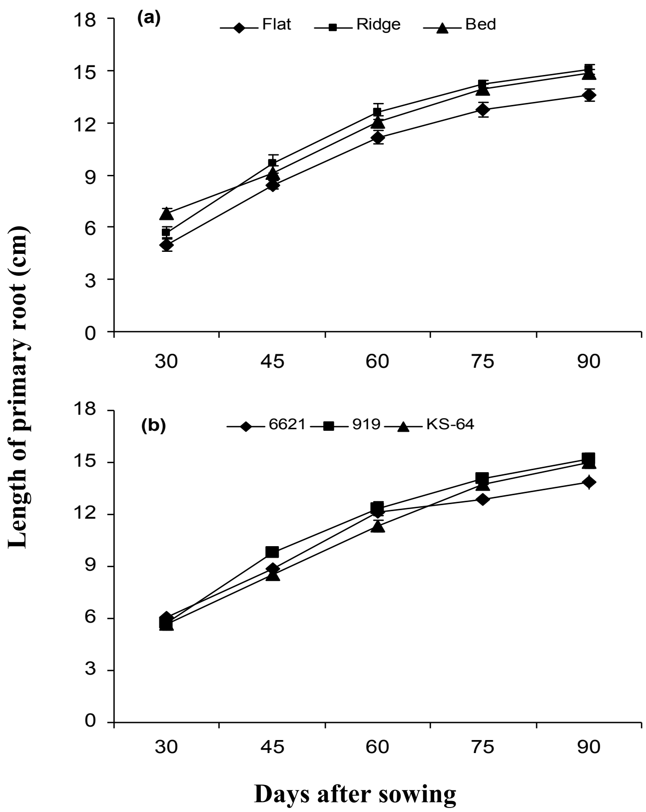


Fig. 1. Effect of planting methods (a) and maize hybrids (b) on length of primary root of maize ± S.E.

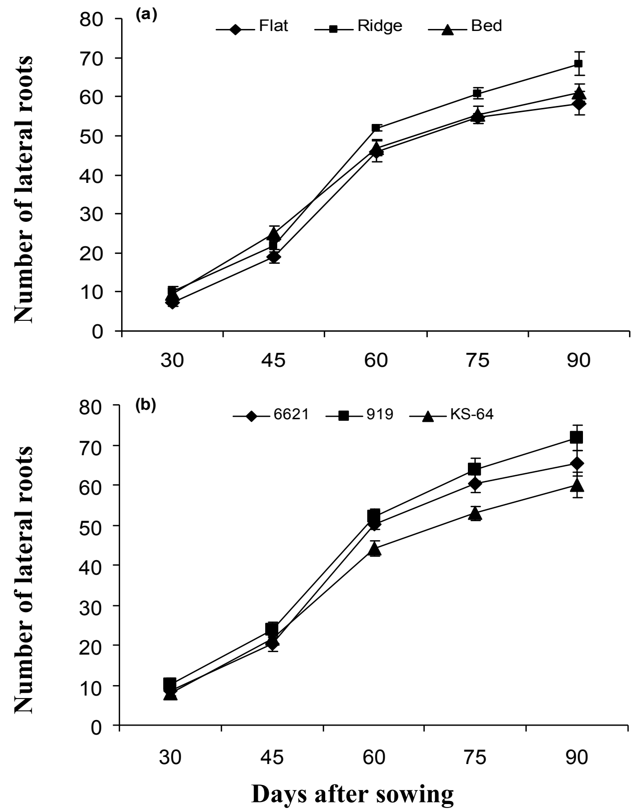
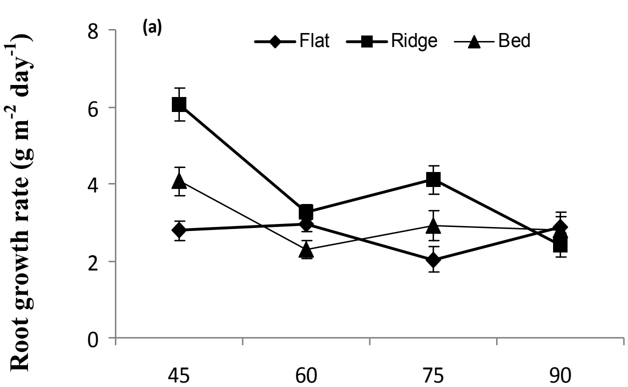
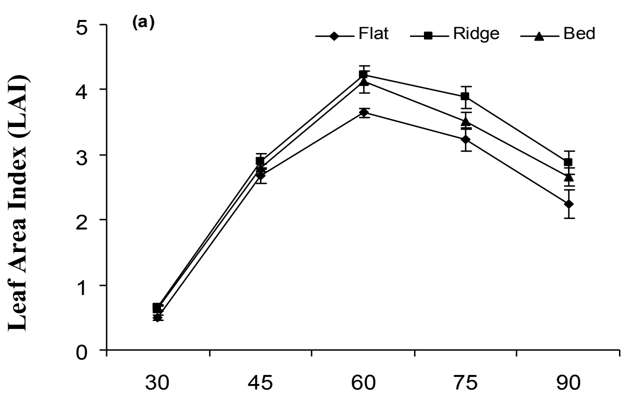


Fig. 2. Effect of planting methods (a) and maize hybrids (b) on number of lateral roots of maize ± S.E.





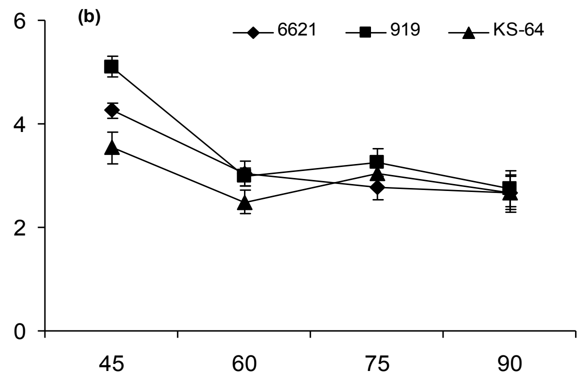


Fig. 3. Effect of planting methods (a) and maize hybrids (b) on root growth rate of maize ± S.E.

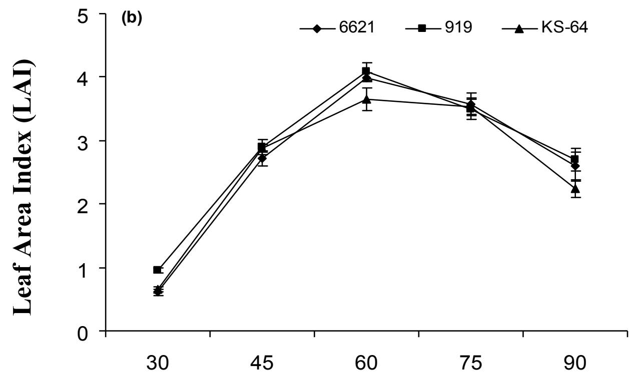


Fig. 4. Effect of planting methods (a) and maize hybrids (b) on leaf area index (LAI) of maize ± S.E.

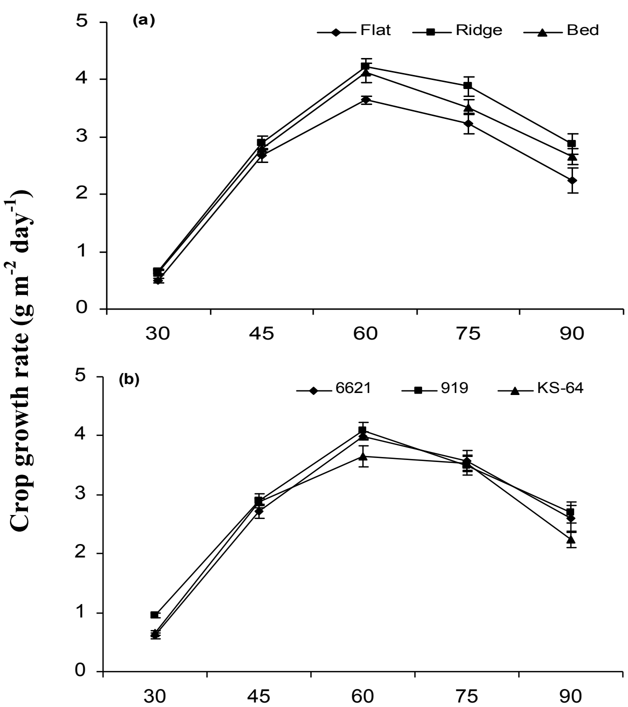


Fig. 5. Effect of planting methods (a) and maize hybrids (b) on crop growth rate (CGR) of maize ± S.E.

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