

# INFLUENCE OF PLANTING METHODS ON ROOT DEVELOPMENT, CROP PRODUCTIVITY AND WATER USE EFFICIENCY IN MAIZE HYBRIDS

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Optimum planting methods better ensure water and nutrient supply through improved root development resulting in better crop growth and productivity. This study was conducted to evaluate the effects of planting methods on root development, crop allometry, water use efficiency (WUE), productivity and economic returns of different maize (*Zea mays* L.) hybrids. Maize hybrids NK-6621, Pioneer-30Y87, and Pioneer-30Y58 were sown on beds, ridges, and flat surface. Ridge sowing was better followed by bed sowing; while amongst the hybrids, 'Pioneer-30Y87' performed the best. Well-developed root system, with longer primary root, more number of lateral roots and higher root growth rate, was observed in 'Pioneer-30Y87' planted on ridges, which led to higher WUE, grain yield and its related traits. The same hybrid exhibited higher leaf area index and crop growth rate, and maximum net return and benefit:cost ratio sowed on ridges. Overall, the ridge sowing improved root development resulting in better allometry, productivity (5.45 t ha<sup>-1</sup>), and WUE (1.345 kg m<sup>-3</sup>), in all the maize hybrids. Although maize hybrids exhibited different response to different planting methods; maximum grain yield (5.63 t ha<sup>-1</sup>), WUE (1.41 kg m<sup>-3</sup>), and net economic returns were observed from hybrid Pioneer-30Y87.

**Key words:** Allometry, planting methods, root growth rate, water use efficiency.

Well developed root system with sufficient root elongation is imperative for better plant growth particularly with limited water and nutrient supply; whereas roots elongate with slower rate due to water stress and mechanical impedance in dry soils (Bengough *et al.*, 2011). Limited moisture, hypoxia or anoxia, and mechanical impedance or compactions are the main reasons of poorly developed root system. Amid them, mechanical soil impedance play a major role to limit root growth even in soil as wet as -100 kPa with higher effective stress between soil particles due to tension created in water films between soil particles (Whalley *et al.*, 2005). The problem is further aggravated with increased soil compaction due to heavy farm machinery used in arable systems; thus mechanical impedance becomes more important in limiting root growth than water stress (Bengough *et al.*, 2006). 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). Nonetheless, compacted soils are more vulnerable to water logging due to heavy rains and results in hypoxia limiting root growth (da Silva *et al.*, 1994). Mechanical impedance reduced leaf expansion in hard soils due to direct signaling between root and shoot growth (Masle and Passioura, 1987; Young *et al.*, 1997). But in case of ridges or raised bed, soil being loose and more or less weed free creates a better environment for aeration, light penetration, water movement, and root development (Roth *et al.*, 2005; Khan *et al.*, 2012).

Level of soil compaction, bulk density, and moisture condition are important factors influencing seedling emergence and final crop yield (Memon *et al.*, 2007). Tillage practices to craft seedbed cause soil compaction and disturb balance between air and water components of soil and also increase the soil strength to restrict root growth; although a little compaction is also required for better contact of seed with soil particles (Memon *et al.*, 2007). Well developed root systems with the ability to explore greater soil volume has been recognized as an important adaptation of plants to ensure sufficient water and nutrient uptake (Horst *et al.*, 2001). In this regard, improved sowing methods like ridges and raised beds play a significant role to enhance crop productivity due to well developed root system. Ridges provide loose fertile layer of soil that result in well developed root system and consequently higher nutrient and water uptake (Khan *et al.*, 2012). Recently, Bakht *et al.* (2011) reported better yield and related traits in ridge planted maize due to

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improved soil conditions for better root development, which helped in acquiring sufficient water and nutrients for plant growth and development.

Furthermore, improved sowing methods not only help to maintain optimum plant population with better emergence; but also enable plants to utilize land, light, and other input resources uniformly and efficiently. It is thus imperative to develop and optimize the planting method and geometry for avoiding excessive crowding and thereby enabling the plants to utilize these resources more effectively and efficiently (Quanqi *et al.*, 2008). Likewise, now a day, success of modern agriculture depends on the ample supply of irrigation water either from canals or tube well sources but unfortunately continuous supply of quality irrigation water has become a challenge and now the world is focusing on water-wise cultivation (Deng *et al.*, 2006). Water wise cultivation focuses on enhancing water-use efficiency (WUE) by harvesting higher economic yields on farmlands irrigated with minimum water (Ali and Ehsanullah, 2007; Farooq *et al.*, 2009). Maximizing WUE is a valuable tool to economize the full use of natural precipitations and proficient management of irrigation network by adopting a suitable planting method (Hussain *et al.*, 2010). Different planting methods not only improve water application efficiency, but they can also enhance the WUE. For instance, Abdullah *et al.* (2008) reported that ridge planting appreciably increased yield of maize and WUE compared with other planting methods.

Being polymorphic due to its cross pollinated nature, different maize hybrids behave differently to uptake water and nutrients from the soil due to their genetic makeup and rooting systems that largely depends on the soil and other environmental conditions. Hybrids with thicker roots pierce hard soil layers more efficiently and better maintain their root elongation rate in hard soils (Materchera *et al.*, 1991; 1992). There are significant differences in DM production and nutrient uptake among maize genotypes (Akram *et al.*, 2010). Different genotypes perform differently owing to their time to maturity and yield, which were the most important factors that influence maize yield (Maina *et al.*, 2006).

Many researchers studied the performance of different maize genotypes under different planting methods and concluded that maize planted on ridges and raised beds performed well regarding growth and final yield of maize (Bakht *et al.*, 2006; Abdullah *et al.*, 2008; Bakht *et al.*, 2011); but little information is available about the development of root system of maize hybrids under different planting methods. It was hypothesized that ridge sown maize perform better and produce higher grain yield owing to well-developed root system with higher root length and more root proliferation. This study was conducted to evaluate root development, crop productivity, and WUE of different maize hybrids sown by different planting methods.

## MATERIALS AND METHODS

The present experiment was carried out at Agronomic Research Area, Department of Agronomy, Bahauddin Zakariya University, Multan (71.43° E, 30.2° N, 122 m a.s.l.), Pakistan, during autumn 2010. The climate of the region is subtropical to semi-arid. The experimental soil was sandy clay loam (67.2, 17.2 and 15.6% sand, silt and clay contents) with pH 7.8, EC 1.39 dS m<sup>-1</sup>, and 0.5% organic matter content.

The experiment was laid out according to randomized complete block design (RCBD) with split plot arrangements having a net plot size of 4 m × 3 m and replicated four times. Planting methods and maize hybrids were randomized in main plots and sub plots, respectively. Three maize hybrids viz. NK-6621, Pioneer-30Y87, and Pioneer-30Y58, were sown on flat surface, ridges, and beds by keeping row to row distance of 75 cm and plant to plant distance of 20 cm. During the experimental period, mean monthly temperature ranged from 26.45 to 32.80 °C, relative humidity from 58.15 to 69.70%; whereas a total of 317 mm rainfall was received.

### Crop husbandry

Before crafting seedbed, pre-soaking irrigation of 10 cm depth was applied. When soil reached to workable moisture level, the seedbed was crafted by cultivating the field for two times with tractor-mounted cultivator each followed by planking. Sowing was performed on 10 July 2010 on well prepared seed beds of three types viz. ridges, beds, and flat seedbed. Sowing was done by using dibbler on flat seed bed and manually on ridges and beds by keeping plant to plant distance of 20 cm. Nitrogen and P were applied at 200 and 150 kg ha<sup>-1</sup>, respectively, using urea and diammonium phosphate (DAP) as a source. Full dose of P and half dose of N were applied at sowing, while second half dose of N was applied at knee height stage. After first irrigation, when soil reached to workable moisture level, hoeing was done to keep crop free from weeds. Crop was affected by shoot fly (*Atherigona soccata*) attack after 21 d after sowing (DAS). Furadan (carbofuran: 2,3-dihydro-2,2-dimethylbenzofuran-7-yl methylcarbamate) was applied for the control of shoot fly (*Atherigona soccata*) using three grains (1 g) of insecticide per head from the top of the plant. All other agronomic practices were kept normal and uniform to keep crop free from insects and diseases. Mature crop was harvested on 29 October 2010.

Total number of plants in each plot at harvest was counted to record plant population. Plant height was recorded at maturity from 10 randomly selected plants with measuring tape and then averaged. Number of cobs of 10 randomly selected plants was counted and averaged to record number of cobs per plant. 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. Five random samples, each of 1000

grains, were taken from seed lot of each plot, weighed and then averaged to compute 1000-grain weight. After harvesting the plants at maturity, cobs were separated, sun dried, manually threshed and grain yield per plot was recorded and converted into kg ha<sup>-1</sup> by unitary method and then adjusted to 10% moisture contents. To record biological yield, weight of air-dried plants (except cobs) was computed on net plot basis and then converted into kg ha<sup>-1</sup> and then recorded weight was added to the already calculated grain yield (kg ha<sup>-1</sup>) to obtain the biological yield. Harvest index (HI) was calculated as ratio between grain yield and biological yield expressed in percentage.

Water use efficiency (WUE) (kg m<sup>-3</sup>) was computed as (Viets, 1962):

$$\text{WUE} = \text{Grain yield} / \text{Water applied}$$

where grain yield was expressed in kg m<sup>-2</sup> and water used was expressed in mm (irrigation applied + rainfall during the whole crop growth period).

Five plants at random were selected from each plot fortnightly to compute primary root length, number of lateral roots per plant, and root growth rate (RGR). The sampling started 30 DAS and terminated at harvest. Plants were uprooted with intensive care to evade root damage, washed thoroughly with water and air dried. 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 computed following Hunt (1978).

Leaf area was recorded fortnightly by leaf area meter (DT Area Meter, Model MK2, Delta T Devices, Cambridge, UK) and leaf area index (LAI) was calculated following Watson (1947). Crop growth rate (CGR) was calculated following the procedures described by Hunt (1978). This sampling was also started 30 DAS and terminated at harvest.

## Statistical and economic analysis

The collected data were statistically analyzed by using Fisher's ANOVA technique and least significant difference (LSD) test at 5% probability level was used to compare differences among treatment means (Steel *et al.*, 1997). Graphical data presentation was done using Microsoft Excel.

Economic and benefit-cost analysis was conducted to estimate the economic feasibility of growing maize hybrids by different sowing. The production costs of maize included field preparation, seed, sowing, fertilizing, weeding, crop protection measures, and harvesting. The gross income was estimated using the prevailing average market price of maize in Pakistan. Net income was calculated by subtracting total expenditure from the gross income while benefit:cost ratio (BCR) was computed by dividing the gross income with total expenditure.

## RESULTS AND DISCUSSION

Sowing methods had significant effect on plant population, number of grains per cob, and 1000-grain weight while the effect was non-significant for cob length, number of cobs per plant, and number of rows per cob of maize (Table 1). Maize sown on ridges resulted in more plant population and 1000-grain weight while maize sown on beds exhibited higher number of grains per cob compared with the crop sown on flat surface (Table 1). There was significant difference amongst maize hybrids for plant population, cob length, number of grains per cob, and 1000-grain weight, there was no difference for number of cobs per plant and number of rows per cob (Table 1). Amongst hybrids, maximum plant population, number of cobs, number of grains per cob, and 1000-grain weight were observed in 'Pioneer-30Y87'; whereas minimum

**Table 1. Influence of different planting methods on plant population and yield components of different maize hybrids.**

Treatments	Plant population per plot	Cob length	Cobs per plant	Grain rows per cob	Grains per cob	1000-grain weight
		cm				g
Planting methods (P)						
P <sub>1</sub> = Flat sowing	44.60b	16.94	1.03	14.83	431.83b	287.16b
P <sub>2</sub> = Ridge sowing	48.17a	17.74	1.09	15.08	439.00b	310.41a
P <sub>3</sub> = Bed sowing	45.50b	17.38	1.12	14.50	448.67a	300.00ab
LSD at p 0.05	1.37	NS	NS	NS	7.69	14.58
Maize hybrids (H)						
H <sub>1</sub> = NK-6621	43.83b	16.558b	1.06	14.66	424.67c	282.33b
H <sub>2</sub> = Pioneer-30Y87	47.83a	18.158a	1.06	15.16	453.25a	324.08a
H <sub>3</sub> = Pioneer-30Y58	46.68a	17.344ab	1.13	14.58	441.58b	291.16b
LSD at p 0.05	1.84	0.831	NS	NS	10.16	15.51
Interaction P × H						
P <sub>1</sub> H <sub>1</sub>	44.25c	16.30	1.00	15.00ab	428.50d	276.50d
P <sub>1</sub> H <sub>2</sub>	43.50c	16.22	1.10	14.25bc	427.00d	303.00bc
P <sub>1</sub> H <sub>3</sub>	43.75c	17.15	1.08	14.75ab	418.50d	267.50d
P <sub>2</sub> H <sub>1</sub>	45.25c	17.47	1.08	15.00ab	445.25c	303.00bc
P <sub>2</sub> H <sub>2</sub>	50.00ab	19.15	1.10	15.50a	462.50ab	341.25a
P <sub>2</sub> H <sub>3</sub>	48.25b	17.85	1.00	15.00ab	452.00bc	328.00ab
P <sub>3</sub> H <sub>1</sub>	44.50c	17.05	1.03	14.50bc	421.75d	282.00cd
P <sub>3</sub> H <sub>2</sub>	51.00a	17.85	1.08	15.50a	427.50d	287.00cd
P <sub>3</sub> H <sub>3</sub>	44.50c	17.12	1.28	13.75c	475.50a	304.50bc
LSD at p 0.05	2.37	NS	NS	0.95	13.33	25.25

Means sharing the same letters in a column do not differ at p = 0.05; LSD: least significant difference; NS: Non significant.

plant population, smaller cobs and lesser number of grains per cob of small size were recorded in 'NK-6621' (Table 1). Interaction between sowing methods and maize hybrids had significant effect on plant population, number of grains per cob and 1000-grain weight while the interaction was non-significant for cob length, number of cobs per plant, and number of rows per cob of maize (Table 1). 'Pioneer-30Y87' exhibited maximum plant population on ridges and beds while all maize hybrids exhibited minimum plant population on flat surface (Table 1). Maximum number of grains per cob were recorded when hybrids Pioneer-30Y87 and Pioneer-30Y58 were sown on ridges and beds, respectively (Table 1). Likewise, higher 1000-grain weight was recorded in maize hybrids Pioneer-30Y87 and Pioneer-30Y58 sown on ridges (Table 1).

Different planting methods had significant effect on plant height, grain and biological yield and WUE; however the effect was non-significant for HI (Table 2). Maximum plant height, grain and biological yields and WUE were observed in ridge sown maize while crop sown on flat surface performed feebly (Table 2). Maize hybrids differed significantly for grain and biological yield and WUE; however, the difference was non-significant for plant height and HI (Table 2). Maximum grain and biological yield and WUE were obtained in 'Pioneer-30Y87' whereas minimum grain and biological yield and WUE were recorded in 'NK-6621' (Table 2). In case of interaction between sowing methods and hybrids, both 'Pioneer-30Y87' and 'NK-6621' attained more plant height when sown on ridges (Table 2). Similarly, maximum biological yield was observed in 'Pioneer-30Y58' sown on ridges and the minimum in the same hybrid sown on

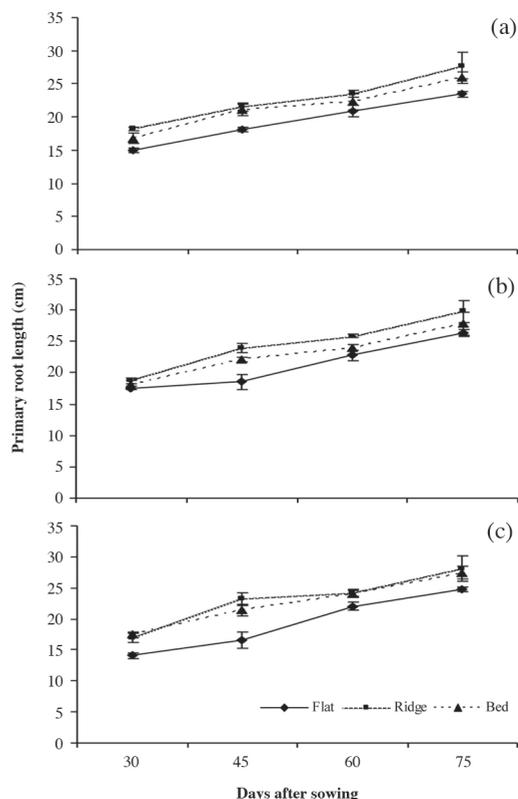
flat surface (Table 2). Nonetheless, maximum grain yield and WUE were harvested from 'Pioneer-30Y87' sown on ridges (Table 2).

Length of primary root and number of lateral roots per plant progressively increased with increasing growth period (Figures 1 and 2). All the tested maize hybrids observed sizeable improvement in primary root length sown on ridges followed by bed sowing, although the response of hybrids was different. 'Pioneer-30Y87' sown on ridges while 'NK-6621' and 'Pioneer-30Y58' sown both on ridges and beds observed higher primary root length than the crop sown on flat surface through the entire growth period (Figure 1). Maize hybrid NK-6621 observed same pattern of root proliferation under all sowing methods except 45 DAS, while 'Pioneer-30Y87' and 'Pioneer-30Y58' observed considerably higher root proliferation under ridge sowing up to 60 DAS and under ridge and bed sowing at 75 DAS compared with the crop sown on flat surface (Figure 2). The RGR progressively increased up to 60 DAS and then start declining (Figure 3). Sowing methods had non-significant effect on RGR of 'NK-6621' during entire growth period, while ridge sowing significantly improved RGR of 'Pioneer-30Y87' and 'Pioneer-30Y58' at 60 and 75 DAS but it was at par with bed sowing in case of 'Pioneer-30Y87' (Figure 3). Overall

**Table 2. Influence of different planting methods on plant height, crop productivity, harvest index and water use efficiency (WUE) of different maize hybrids.**

Treatments	Plant height cm	Grain yield t ha <sup>-1</sup>	Biological yield	Harvest index %	WUE kg m <sup>-3</sup>
Planting methods (P)					
P <sub>1</sub> = Flat sowing	193.69b	4.86c	25.79c	18.81	1.22c
P <sub>2</sub> = Ridge sowing	201.66a	5.45a	30.01a	18.24	1.34a
P <sub>3</sub> = Bed sowing	198.94ab	5.13b	28.51b	18.35	1.28b
LSD at p 0.05	6.77	0.19	0.78	NS	0.05
Maize hybrids (H)					
H <sub>1</sub> = NK-6621	195.22	4.63c	26.48c	17.86	1.16c
H <sub>2</sub> = Pioneer-30Y87	202.04	5.63a	30.18a	18.97	1.41a
H <sub>3</sub> = Pioneer-30Y58	197.03	5.14b	27.65b	18.57	1.29b
LSD at p 0.05	NS	0.24	0.98	NS	0.06
Interaction P × H					
P <sub>1</sub> H <sub>1</sub>	185.83d	4.51e	25.13d	17.96	1.13e
P <sub>1</sub> H <sub>2</sub>	199.43b	4.50e	31.33b	14.36	1.13e
P <sub>1</sub> H <sub>3</sub>	200.40ab	4.87d	22.99e	21.26	1.22d
P <sub>2</sub> H <sub>1</sub>	202.10ab	5.58b	26.47d	21.11	1.40b
P <sub>2</sub> H <sub>2</sub>	205.80a	6.13a	30.66b	20.01	1.53a
P <sub>2</sub> H <sub>3</sub>	198.23bc	5.20c	33.41a	15.78	1.30c
P <sub>3</sub> H <sub>1</sub>	193.163c	4.48e	25.78d	17.36	1.12e
P <sub>3</sub> H <sub>2</sub>	199.75b	5.71b	28.06c	20.35	1.43b
P <sub>3</sub> H <sub>3</sub>	198.20bc	5.24c	29.12c	18.01	1.31c
LSD at p 0.05	5.84	0.33	1.34	1.55	0.08

Means sharing the same letters in a column do not differ at p = 0.05; LSD: least significant difference; NS: Non significant.



**Figure 1. Influence of planting methods on primary root length of maize hybrids (a) NK-6621, (b) P-30Y87, and (c) P-30Y58.**

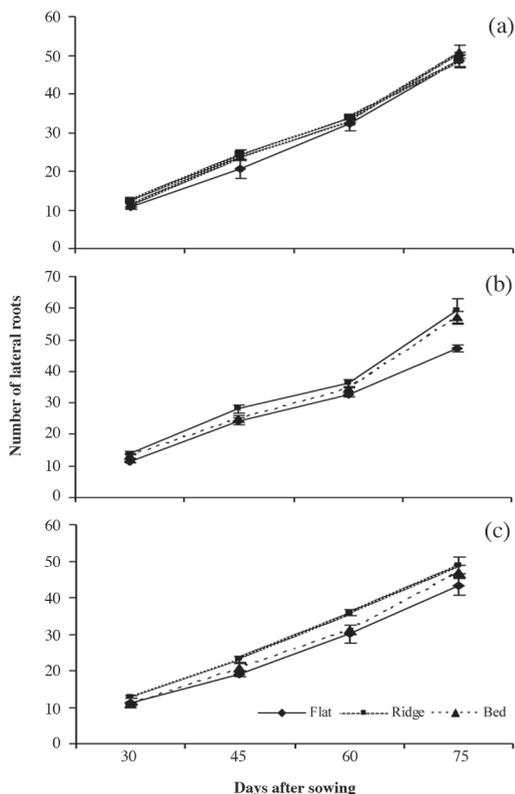


Figure 2. Influence of planting methods on number of lateral roots of maize hybrids (a) NK-6621, (b) P-30Y87, and (c) P-30Y58.

'Pioneer-30Y87' observed higher root length, root proliferation and RGR than other hybrids under study especially under ridge sowing (Figures 1-3).

Leaf area index and crop growth rate (CGR) progressively increased up to 60 DAS and then start declining (Figures 4 and 5). At 60 and 75 DAS, ridge sown crop shaped maximum LAI and CGR in all tested maize hybrids in almost similar fashion followed by bed sowing compared with the crop sown on flat surface; whereas at 30 and 45 DAS, planting methods had non-significant effect on LAI and CGR (Figure 4 and 5). Moreover, 'Pioneer-30Y87' observed a bit higher LAI and CGR throughout the growing season than other hybrids tested (Figure 4 and 5).

Maize sown on ridges exhibited higher while sown on flat surface exhibited lower net income and benefit:cost ratio (BCR), respectively (Table 3). Among maize hybrids, Pioneer-30Y87 outperformed with higher net income and BCR whereas, NK-6621 exhibited minimum net income and BCR. With respect to interaction between planting methods and maize hybrids, Pioneer-30Y87 sown on ridges outperformed with higher net income and BCR while NK-6621 sown on beds and all hybrids sown on flat surface performed feebly with minimum economic returns and reduced BCR (Table 3).

Maximum grain yield, its related traits and WUE

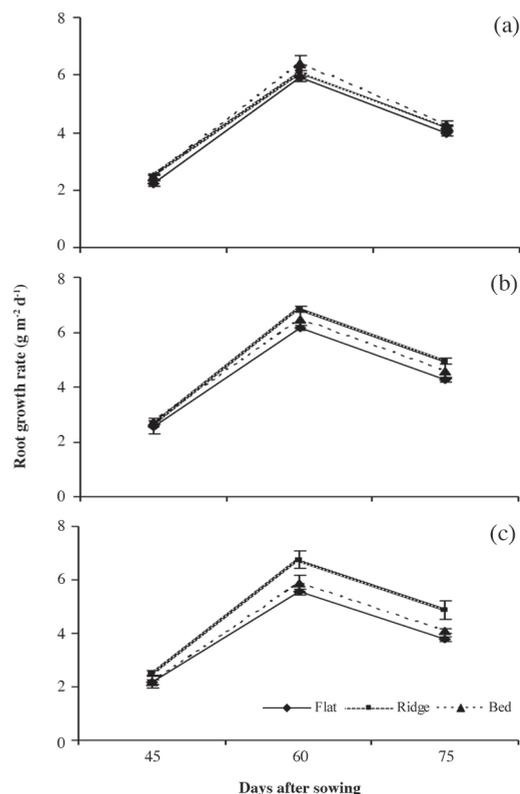


Figure 3. Influence of planting methods on root growth rate of maize hybrids (a) NK-6621, (b) P-30Y87, and (c) P-30Y58.

were observed in maize hybrids sown on ridges (Table 2) due to well developed root system (Figures 1-3). The well developed root system with long primary root and higher root proliferation might enhance water and nutrient uptake; resulting in better LAI (Figure 4), and CGR (Figure 5), leading to more bigger grains in cobs (Table 1).

Table 3. Influence of different planting methods on net income and benefit-cost ratio of different maize hybrids.

Treatments	Total expenditure	Gross income	Net income	Benefit-cost ratio
	Rs ha <sup>-1</sup>			
Sowing methods (P)				
P <sub>1</sub> = Flat sowing	72425	115425	43000	1.59
P <sub>2</sub> = Ridge sowing	74575	129438	54863	1.74
P <sub>3</sub> = Bed sowing	74575	121838	47263	1.63
Maize hybrids (H)				
H <sub>1</sub> = NK-6621	74575	109963	35388	1.47
H <sub>2</sub> = Pioneer-30Y87	74575	133713	59138	1.79
H <sub>3</sub> = Pioneer-30Y58	74575	122075	47500	1.64
Interaction P × H				
P <sub>1</sub> H <sub>1</sub>	72425	107113	34688	1.48
P <sub>1</sub> H <sub>2</sub>	72425	106875	34450	1.48
P <sub>1</sub> H <sub>3</sub>	72425	115663	43238	1.60
P <sub>2</sub> H <sub>1</sub>	74575	132525	57950	1.78
P <sub>2</sub> H <sub>2</sub>	74575	145588	71013	1.95
P <sub>2</sub> H <sub>3</sub>	74575	123500	48925	1.66
P <sub>3</sub> H <sub>1</sub>	74575	107350	32775	1.44
P <sub>3</sub> H <sub>2</sub>	74575	135613	61038	1.82
P <sub>3</sub> H <sub>3</sub>	74575	124450	49875	1.67

1 US\$ = 93.76822 Rs Pakistan.

Ridges provide apposite soil conditions like proper aeration and adequate availability of moisture essential for emergence that resulted in more plant population compared with flat seed bed (Abdullah *et al.*, 2008; Bakht *et al.*, 2011). Likewise, ridges and beds provided loose fertile soil with more aeration and moisture availability, and less mechanical compaction that permitted roots to grow profusely with more length, better proliferation and root growth rate (Figures 1-3). Chassot and Richner (2002) reported that more bulk density or dense surface soil layer is a limiting factor for root growth resulting in less root length and concentrate the roots near soil surface. Better root system enhanced the water and nutrient uptake resulting in high LAI (Figure 4). LAI indicates the size of assimilatory system of crop, which captures solar radiation for C assimilation; higher LAI thus provide more area for photoassimilation resulting in higher CGR (Figure 5). Earlier, Rasheed *et al.* (2003) and Hussain *et al.* (2010) also quoted higher LAI and CGR in ridge sown maize (*Zea mays* L.) and sunflower (*Helianthus annuus* L.), respectively compared with the crop sown on flat surface. That bigger assimilatory system due to higher LAI and higher CGR resulted in more DM production, and plant height, number of grains per cob and 1000-grain weight (Tables 1 and 2).

Significant improvement in yield contributing factors

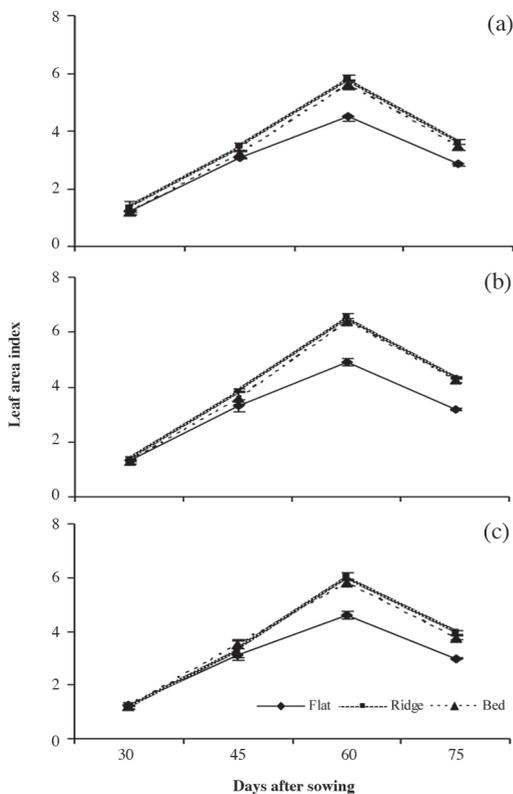


Figure 4. Influence of planting methods on leaf area index of maize hybrids (a) NK-6621, (b) P-30Y87, and (c) P-30Y58.

contributed in harvesting better grain yield in ridge sown crop (Table 2). Apposite soil conditions crafted by ridges for proper root development that ensured efficient accessibility of water and nutrients for proper growth might be the reason of improved grain yield of maize. Likewise higher biological yield in ridge sown maize was the result of positive soil conditions crafted by ridges resulting into better root system; enabling the plants to uptake more moisture and nutrients to produce higher LAI that resulted higher CGR (Figures 4 and 5) and in consequence higher DM production. Increased WUE in ridge sown maize was direct result of grain yield improvement; as same amount of water was applied in all sowing methods.

Amid maize hybrids under study, 'Pioneer-30Y87' outperformed with higher grain yield and WUE due to significantly better yield related traits owing to its better genetic makeup. 'Pioneer-30Y87' produced better root system with longer primary roots, more root proliferation and higher root growth rate (Figures 1-3) that might be due to its better genetic makeup; as different maize hybrids behave differently due to their genetic makeup (Akram *et al.*, 2010; Khan *et al.*, 2012). Due to better root system, 'Pioneer-30Y87' got better access to water and nutrients helping in growth and higher LAI (Figure 4). Higher rate of DM production due to better CGR resulted in more plant

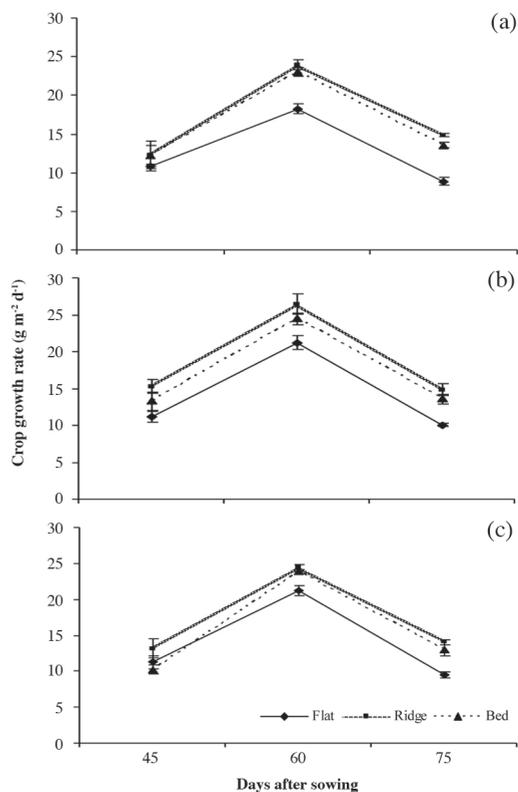


Figure 5. Influence of planting methods on crop growth rate of maize hybrids (a) NK-6621, (b) P-30Y87, and (c) P-30Y58.

height, cob length, number of grains per cob and grain weight (Tables 1 and 2). Due to significant improvement in yield components and more DM production, higher grain and biological yield were harvested from hybrid 'Pioneer-30Y87' (Table 2). Higher WUE in 'Pioneer-30Y87' was only due to its higher grain yield as same quantity of water was applied to all maize hybrids.

With respect to interactive effect of hybrids and sowing methods, 'Pioneer-30Y87' outperformed upon sowing on ridges with higher grain yield WUE (Table 2). Best performance of 'Pioneer-30Y87' on ridges was the pooled effect of better genetic makeup of hybrids and apposite conditions for growth created by ridges due to loose fertile soil with better aeration and moisture availability (Bakht *et al.*, 2011; Khan *et al.*, 2012). In consequence of that pooled effect, 'Pioneer-30Y87' sown on ridges attained better root system (Figures 1-3), higher LAI and CGR (Figures 4 and 5) and longer cobs with more gains of bigger size and ultimately higher grain and biological yield and WUE.

Higher net income and BCR exhibited by 'Pioneer-30Y87' sown on ridges was the direct result of enhanced grain productivity (Table 3) due to more efficient utilization of available resources due to well developed root system (Figures 1-3). Adoption of any technique ultimately depends on its economic feasibility and cost involved. Therefore, higher economic returns obtained by sowing of 'Pioneer-30Y87' sown on ridges highlight its economic feasibility and hence it may be practiced to harvest higher productivity.

## CONCLUSIONS

Maize hybrid Pioneer-30Y87 exhibited maximum plant population, number of grains per cob, 1000-grain yield, grain and biological yield, primary root length, number of lateral roots, root growth rate, and water use efficiency when sown on ridges. Likewise, maximum economic returns with higher benefit:cost ratio were also obtained from the same hybrid planted on ridges. Ridge sowing may be therefore promoted for higher productivity and water use efficiency.

**Influencia de métodos de siembra sobre el desarrollo radical, productividad y eficiencia del uso del agua en híbridos de maíz.** Métodos óptimos de siembra aseguran mejor suministro de agua y nutrientes a través del mejorado desarrollo de raíces que resulta en mejor crecimiento y productividad de los cultivos. Este estudio se realizó para evaluar los efectos de los métodos de siembra en el desarrollo de las raíces, alometría de cultivos, uso eficiente del agua (WUE), productividad y rentabilidad económica de diferentes híbridos de maíz (*Zea mays* L.). Híbridos de maíz NK-6621, Pioneer 30Y87, y 30Y58-Pioneer se sembraron en camas, surcos, y superficie plana. La siembra en surco fue mejor, seguida por siembra en cama, mientras entre los

híbridos, 'Pioneer 30Y87' tuvo los mejores resultados. Se observó un sistema radical bien desarrollado, raíz primaria más larga, mayor número de raíces laterales, y mayor tasa de crecimiento radical, en 'Pioneer-30Y87' plantado en surcos, lo que condujo a mayores WUE, rendimiento de grano y sus rasgos relacionados. El mismo híbrido sembrado en surcos presentó mayores índice de área foliar y tasa de crecimiento del cultivo, máximo rendimiento neto y relación beneficio:costo. En general, la siembra en surco mejoró el desarrollo radical resultando en mejores alometría, productividad (5,45 t ha<sup>-1</sup>), y WUE (1,35 kg m<sup>-3</sup>), en todos los híbridos de maíz. Aunque los híbridos de maíz mostraron respuesta diferente a los diferentes métodos de siembra, máximos rendimientos de grano (5,63 t ha<sup>-1</sup>), WUE (1,41 kg m<sup>-3</sup>), y retornos económicos netos se observaron en el híbrido Pioneer 30Y87.

**Palabras clave:** alometría, métodos de siembra, tasa de crecimiento de raíces, uso eficiente del agua.

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