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Allometery and Productivity of Autumn Planted Maize Hybrids under Narrow Row Spacing

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ABSTRACT

Modern maize (*Zea mays* L.) hybrids have the ability to tolerate narrow row spacing that helps enhancing yields per unit area. Variation in developmental plasticity and tolerance of present-day hybrids to reduced row spacing has been evaluated by using three maize hybrids for two years under field conditions. The objectives of the study was to determine whether hybrids belonging to different relative maturity groups respond differently in terms of growth dynamics and agronomic performance when grown at reduced row spacing of 60 and 45 cm compared with conventional rows of 75 cm. Results revealed that late maturing maize hybrid Pioneer-30Y87 exhibited not only maximum leaf area index, but exceeded in crop growth rate and plant height. During both the years of experimentation, early maturing hybrid DK-919 produced higher grain yield than mid and late maturity maize hybrids. Early (DK-919) and late (Pioneer-30Y87) maize hybrids performed best at 45 cm row spacing, while mid season hybrid (DK-5219) did best at 60 cm row spacing. Yield components such as cob length, number of grains per ear and 1000 grain weight significantly varied among maize hybrids and with varying row spacing. Although individual yield per plant (cob length, number of grains per ear, 1000 grain weight) decreased with reducing row spacing from 75 to 45 cm, but it was well compensated in early maturing hybrid than mid and late by increase in number of ears and number of grains per unit area. Study concluded that both early and late maize hybrids as DK-919 and Pioneer-30Y87can tolerate narrow row spacing but wider spacing is required for DK-5219-type hybrids.

Key Words: Maize hybrids; Row spacing; Growth yield components; Grain yield

INTRODUCTION

Maize (*Zea mays* L.) is ranked 3rd most important cereal crop after wheat and rice in Pakistan. The expanding use of maize in food and feed industry gives it a prominent place in the world's agricultural economy. Maize refineries use crop for producing an array of consumable products and it is estimated that worldwide maize yields almost 4000 industrial products (Sprague *et al*., 1988). The alarming population growth rates globally, in general, and in Pakistan specifically has evidently manifested the food security situation. Comparing the rate of increase in human population in the last few decades has not only nullified the increased cereal productions but also has urged Pakistan to import substantial quantities (1823 thousand tons during, 2007-2008) of wheat to supplement the domestic supplies (Government of Pakistan, 2008-2009). Thus, if Pakistani people are to enjoy diet without spending hard currency for grain, especially wheat imports, it appears that an increased domestic production and/or utilization of alternate cereals such as maize is the only solution on long term basis. Moreover, utilization of wheat for poultry feed in good years also necessitates to grow maize and save wheat as strategic reserve for food security.

At present, in Pakistan maize is grown on an area of 1.1 m ha with total annual production of 4.4 m tones and an average seed yield of 3.61 t ha^{-1} (Government of Pakistan, 2008-2009). Although, about 83% of the total area under maize is cultivated through use of hybrid seed (FSC & RD, 2005), the average yield of maize in the country is far below than the potential yield of many of the present day maize hybrids available with different morpho-physiological traits in the market which exhibit varying response to management options. Nevertheless, the farmers rarely take care of particular set of management required for such hybrids primarily due to lack of proper crop husbandry package. Among various crop husbandry practices appropriate planting geometry is of utmost importance. Plant population is the factor that changed most during the past six decades as a result of tolerance of newly introduced hybrids to high plant populations (Tollenaar & Lee, 2002).

Several factors, such as hybrid maturity group, water availability, soil fertility and row spacing (Sangoi *et al.*, 2002) are crucial in determining proper plant number per unit area. Reducing row width with a more equidistant planting pattern has shown the potential to increase maize

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grain yield especially when highly productive single-cross early hybrids are grown in soils with high fertility and irrigation (Sangoi *et al*., 1998). Conversely, when any environmental factor or inappropriate management practice hinders maize growth and development, narrowing the row spacing may have little effect on either improving grain yield or increasing the optimum plant population density necessary to maximize yield (Buntzen, 1992; Merotto *et al*., 1997). Periodic assessment of optimal plant density and row width for maize, that may vary with location is a continuous phenomenon and is an outcome of continued genetic improvement in ability of maize hybrids to withstand higher plant densities. The information on forming suitable plant population for each maize cultivar is one of the key factors for planning of successful maize production (Bavec & Bavec, 2002) as stand density affects plant architecture, alters growth and developmental patterns, influences carbohydrate production and partition in maize (Casal *et al*., 1985). Contrary to this, Liu *et al*. (2004) concluded that maize plant height, leaf area index, dry matter accumulation, net assimilation as well as harvest index were not significantly affected by varying plant spacing. Similarly Alford *et al.* (2004) stated that row spacing has no effect on maize grain yield.

These conflicting reports have led to renewed interests in the effects of narrow row spacing and high plant population densities on maize grain yield as newly evolved hybrids have a wider range of adaptability to different micro and macro environments affecting plant growth than old genotypes. So there is dire need to quantify the agro-physiological response of maize grown under reduced row spacing and their impact on the qualitative traits of the produce as well. The present studies were conducted to determine optimum row spacing for maize hybrids of diverse relative maturity.

MATERIALS AND METHODS

Maize hybrids of different relative maturity groups [early, DK-919 (100-105 days), mid, DK-5219 (105-115days) and late, Pioneer-30Y87 (115-125days)] were grown at the Agronomic Research Area, University of Agriculture, Faisalabad, Pakistan under varying row spacing for two successive seasons during autumn 2006 and 2007. The climate of the region was subtropical to semi-arid. The experimental area was located at 73^o East longitude, 31^o North latitude and at an altitude of 135 m above mean sea level.

Physico-chemical determinations revealed that soil was sandy loam in nature with a pH of 7.8, EC 0.5 dSm^{-1}, 0.905% organic matter, 0.055% total nitrogen, 935 ppm available phosphorus and 144 ppm available potassium. Three maize hybrids as cited above were sown by dibbling 2 seeds per hill. Six rows of each hybrid were sown at row spacing of 45 cm (98765 plants ha^{-1}), 60 cm (74074 plants ha^{-1}) and 75 cm (59259 plants ha^{-1}) with plant to plant distance of 22.5 cm in each case during 1st week of August each year and was harvested on physiological maturity as and when achieved by each hybrid during both the years. During both years, experiments were laid out in randomized complete block design (RCBD) with split plot arrangement and replicated four times. Fertilizer dose of NPK at the rate of 150, 100, 100 kg ha^{-1}, respectively was applied in the form of urea, diammonium phosphate and potassium sulfate. One third of the N, and all phosphorus and potash were applied at the time of sowing, while 1/3rd nitrogen was applied at vegetative (30 DAS) and reproductive (60 DAS) stage. Leaves of five randomly selected plants from each sub plot were detached and their fresh weights recorded. A sub-sample of 10 g was used to record leaf area at a regular interval of fifteen days by a leaf area meter (DT Area Meter, MK2). It was used to calculate leaf area index (LAI) by dividing with land area (Watson, 1947). The same plants harvested for leaf area determination were chopped and their fresh weight recorded. A sub sample of 100 g was placed in oven at 80^{o}C for drying to constant dry weight. Dry weights were computed on unit area (1 m^2) basis and were used to estimate crop growth rate (Hunt, 1978). Ten cobs from each sub plot were selected randomly. Cob length was measured with the help of measuring tape and average cob length computed. Plant height at harvest was measured from the soil surface to the top of stem of 10 randomly selected plants from the two central rows of each sub plot at physiological maturity and average is reported. For counting number of grains per cob, ten cobs were selected at random from each sub plot and number of grains per cob were counted and averaged. Three samples each of 1000 grains were taken randomly from the seed lot of each sub plot, weighed on electronic balance and then averaged for 1000-grain weight. For grain yield two central rows from each sub plot were harvested on physiological maturity, the cobs were air-dried and threshed manually. Grain weight was recorded (13% moisture content) and converted to kg ha^{-1}. Data were analyzed statistically using Fisher's analysis of variance and LSD test (P=0.05) was used to compare the difference(s) among treatments' means (Steel *et al.,* 1997).

RESULTS AND DISCUSSION

Leaf area index: Leaf area index (LAI) of the crop at a particular stage of growth indicates the size of assimilatory system that ultimately contributes towards dry matter accumulation. Differences in leaf area index (LAI) among maize hybrids were significant ($P \leq 0.05$) throughout crop growth season (Fig. 1). DK-919 exhibited highest LAIs than the other two hybrids till 60 days after sowing (DAS) showing a rapid leaf expansion early in the season. At 75 DAS, LAI of Pioneer-30Y87 exceeded than those for DK-919 and DK-5219, which were similar ($P \leq 0.05$). This trend was observed till 105 DAS. Maximum LAI recorded during 2006 and 2007 for DK-919 (5.76 & 5.42), DK-5219 (5.75 & 5.71) and Pioneer-30Y87 (6.26 & 6.17) were achieved at 60

DAS for the first and at 75 DAS for the later two hybrids. The time of achieving maximum leaf area indices for all hybrids corresponded to their respective silking times (data not shown here). Maximum LAIs achieved by Pioneer-30Y87 were 12.5% higher than that recorded for DK-919 and 8.5% higher than that of DK-5219. All the hybrids remained photo synthetically active by maintaining leaf area indices greater than 5 even at harvest.

Differences in LAI of maize planted at different row spacing were significant ($P \leq 0.05$) throughout the growing season (Fig. 1) and values of 6.15-6.23 were recorded for crop planted at 45 cm row spacing as against 5.37-5.29 recorded for 75 cm row spacing. There was significant difference between 45 cm and 75 cm row spacing, while a non-significant difference existed between 45 cm and 60 cm row spacing so that about 16% higher LAI was recorded at 45 cm row spacing than that of 75 cm row spacing, while the former was only 6% higher than recorded at 60 cm row spacing. Hybrid X row spacing interaction was non-significant during both years of experimentation. Nonetheless, hybrids belonging to different maturity groups in present studies differed in their patterns and extent of LAI development. Increasing trends in leaf area indices at higher densities (narrow row spacing) in present studies are in agreement with previous findings of Karlen and Camp (1985) who reported that leaf area index increased from 4.3 to 5.9 when planting density increased from 7 to 10 plants m^{-2}. Tollenaar and Aguilera (1992) reported that modern hybrids respond more favorably to high plant densities in part, because of a higher leaf area index at silking. A lower amount of vegetative biomass per plant allows the use of more individuals per unit area, which in turn increases leaf area index (LAI). The significantly higher leaf area index values recorded at narrow row spacing were because of the fact that with land area being constant the increasing plant population led to an increase in stand count, which translated to more leaves and leaf area index. Interactive effects of different maize hybrids and ridge spacing were non-significant ($P \leq 0.05$).

Crop growth rate: Mean crop growth rate (CGR) varied significantly ($P \leq 0.05$) among the maize hybrids during both the years (Fig. 2). During 2006, highest and similar mean CGR of 20.71 and 19.93 g m^{-2} d^{-1} were recorded by DK-919 and Pioneer-30Y87, respectively. During 2007 the relative trend for these hybrids was same but DK-919 exhibited significantly ($P \leq 0.05$) higher mean CGR than Pioneer-30Y87. Mean CGR for DK-919 during both years was 16-23% and 4-13% higher than DK-5219 and Pioneer-30Y87, respectively. Variation in crop growth rates of different maize hybrids has also been reported by many authors. Contrary to present results, Echarte *et al.* (2000) established that plant growth rate (PGR) decreased with increasing plant density in all four hybrids used in their studies. Highest mean crop growth rates were recorded for 45 cm row spacing, which was on average 37% higher than that recorded for maize planted at 75 cm row spacing (Fig. 2).

Fig. 1: Patterns of leaf area index of three different maize hybrids under various row spacing during (a) 2006 and (b) 2007

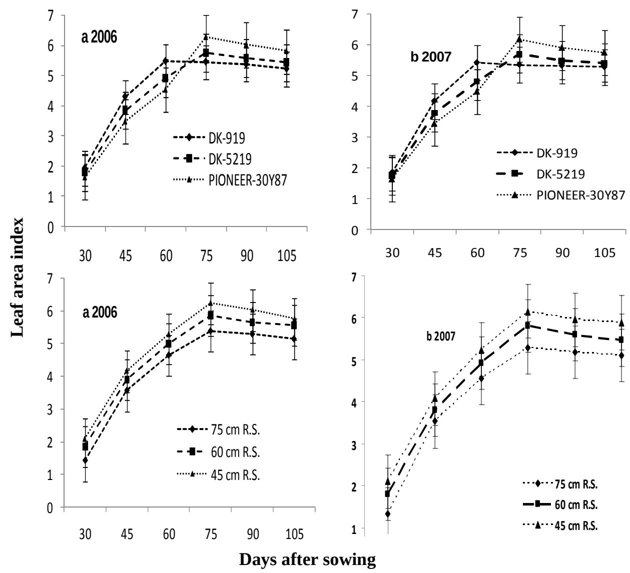
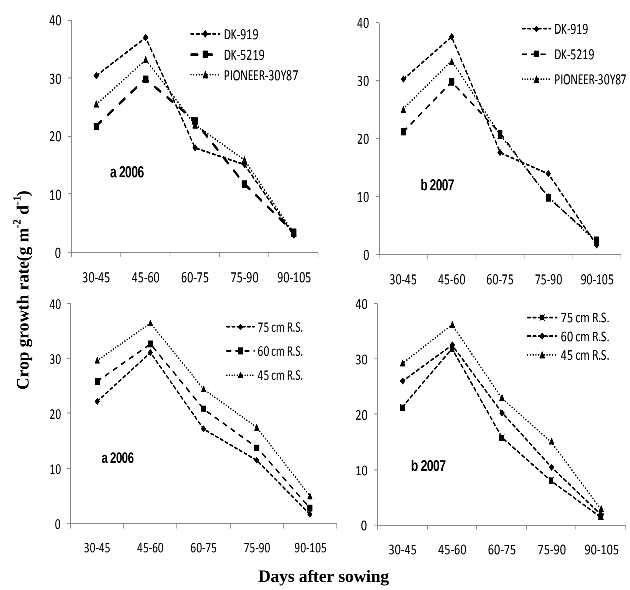


Fig. 2: Patterns of crop growth rate of three maize hybrids at varying row spacing (a) 2006 and (b) 2007



Mean CGR was enhanced by 16-18% when row spacing was reduced from 75 to 60 cm and from 60 to 45 cm, respectively. Tollenaar and Bruulsema (1988) reported that maize hybrid Pioneer 3925 exhibited greater crop growth rate (CGR) than Pioneer 3851. Gardner *et al.* (1990a) determined substantially greater CGR for modern maize hybrid as compared to ancient races of maize. Cox (1996) also recorded significant differences in CGR among the maize hybrids. Interaction between hybrids and row spacing was non-significant.

Fig. 3: Relationship between number of grains (m^{-2}) and grain yield (kg ha^{-1}) at varying row spacing during (a) 2006 and (b) 2007

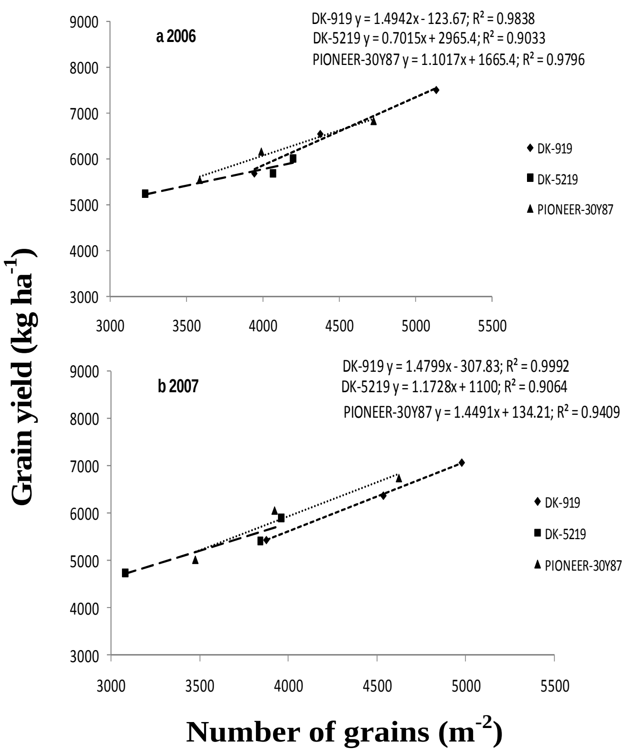
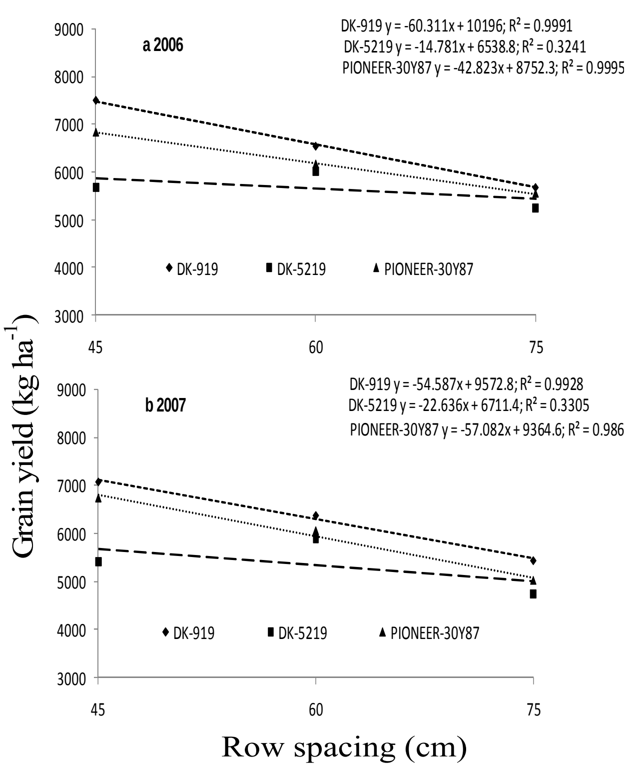


Fig. 4: Influence of row spacing on grain yield (kg ha^{-1}) of three maize hybrids during a) 2006 and (b) 2007



Crop growth rate depends on the amount of intercepted photosynthetically active radiation (PAR), hence the leaf area per unit ground area (i.e., leaf area index) plays an important role in dry matter production (Girardin & Tollenaar, 1994). They further concluded that changes in row or plant spacing's can affect crop canopy size and architecture, factors often associated with photosynthetic efficiency and plant growth.

Plant height: Maximum plant height (228 cm) was recorded for maize hybrid Pioneer-30Y87, which on an average was 6% and 3% higher than DK-919 and DK-5219, respectively during 2006 and 2007 (Table I). Higher plant heights associated with long season hybrids of maize are also reported by Sangoi and Salvador (1998). The differential response of maize hybrids regarding plant height may be attributed to variable genetic potential for this trait. Tallest plants (227 cm) were produced when crop was sown at 45 cm row spacing (Table I). Plant height increased by 6% when maize row spacing was narrowed from 75 cm to 45cm. Fernandes-Neto *et al.* (1998) reported that plant height increased up to a certain plant density with increases in sowing density and declined with further increase in population. Sener *et al.* (2004) also reported that plant height was significantly affected by maize hybrids and by intra row spacing and there were differences among intra row spacing in plant height.

Cob length: Early maturing hybrid DK-919 recorded maximum cob length (18.43 cm), which was 15% more than that of medium maturity DK-5219 hybrid (Table I). Two year mean data revealed that maximum cob length (18.22 cm) was recorded for maize planted on 75 cm spaced rows. Narrowing the row spacing from 75 to 60 cm resulted in 7% decrease in cob length, which was further decreased to 4% when row spacing was narrowed to 45 cm. During 2007, significant interaction between row spacing and hybrids (Table I) showed that response in cob length of hybrids depended upon row spacing. All hybrids sown in 75 cm spaced rows recorded higher cob lengths and it decreased when row spacing was narrowed to 45 cm. As observed in present studies, Aldrich *et al.* (1975) also indicated that maize hybrids react differently to increased planting rates, and population-tolerant hybrids usually produce a good sound ear even at high populations. Decreasing trend in cob length at increasing planting densities observed in present studies is similar to those observed by Gokeman *et al.* (2001) who attributed it to interplant competition for light, soil nutrients and soil water.

Number of grains per cob: Maximum number of grains per cob (557-568) was recorded by DK-919 that was on an average 11% higher than that of DK-5219 and 5% higher than recorded for Pioneer-30Y87 (Table I). Maximum number of grains per cob (558-576) was recorded when maize was planted at 75 cm apart rows. Narrowing row spacing had a suppressive influence on the number of grains per cob so that it decreased by 7 and 10.5% when row spacing was decreased to 60 cm and 45 cm, respectively.

Table I: Effect of different row spacing on plant height, cob length, number of grains per ear, 1000-grain weight and grain yield in maize hybrids

Hybrids (H)	Plant height (cm)		Cob length(cm)		Grains per ear		1000-grain weight (g)		Grain yield (kg ha^{-1})	
	2006	2007	2006	2007	2006	2007	2006	2007	2006	2007
H_1 = DK-919	2145 c	212 c	18.48 a	18.39 a	568 a	557 a	294 a	283 a	6577 a	6298 a
H_2 = DK-5219	221 b	219 b	15.95 c	15.97 c	514 c	501 c	238 c	232 c	5652 c	5353 c
H_3=Pioneer-30Y87	228 a	227 a	17.07 b	16.98 b	5403 b	527 b	274 b	262 b	6183 b	5940 b
LSD ($P \leq 0.05$)	4.46	4.19	0.91	0.53	6.24	16.40	10.86	13.26	371.52	210.51
R_1 = 45 cm	229 a	225 a	16.36 b	16.16 c	514 c	502c	251 c	243 c	6673 a	6409 a
R_2 = 60 cm	221 b	219 b	16.93 b	16.95 b	532 b	524 b	267 b	258 b	6244 b	6116 b
R_3 = 75 cm	214 c	214 c	18.21 a	18.23 a	576 a	558 a	289 a	277 a	5494 c	5066 c
LSD $P \leq 0.05$	6.57	2.66	0.57	0.39	17.55	13.00	11.80	5.99	299.70	247.84
$H_1R_{1=\text{DK-919X45 cm}}$	221	220	17.55	17.43	542	537	282	268	7998	7076
$H_1R_{2=\text{DK-919X60 cm}}$	215	211	18.12	18.08	560	556	292	278	6545	6378
$H_1R_{3=\text{DK-919X75 cm}}$	208	206	19.78	19.68	600	577	307	304	5688	5439
$H_2R_{1=\text{DK-5219X45 cm}}$	228	224	15.23	14.78	486	467	211	215	5689	5414
$H_2R_{2=\text{DK-5219X60 cm}}$	222	220	15.98	16.33	514	505	241	236	6022	5911
$H_2R_{3=\text{DK-5219X75 cm}}$	214	213	16.64	16.80	542	530	263	245	5245	4734
$H_3R_{1=\text{Poineer30Y87X45 cm}}$	237	232	16.31	16.29	511	504	258	246	6839	6737
$H_3R_{2=\text{Poineer30Y87X60cm}}$	227	226	16.69	16.44	523	511	267	259	6166	6058
$H_3R_{3=\text{Poineer30Y87X75 cm}}$	219	222	18.21	18.21	586	566	296	281	5549	5025
LSD $P \leq 0.05$	NS	NS	NS	0.76	NS	NS	NS	NS	562	408

Figures in the same column with different letters differ significantly at $P \leq 0.05$ by LSD test; ^{NS} Non significant

Gokeman *et al.* (2001) reported that the kernel number per cob declined by about 5% as the plant density increased from 5.7 to 14.0 plants m^{-2}. Echarte *et al.* (2000) also reported decrease in number of grains per plant with increasing plant density in four maize hybrids used in their studies.

Lemcoff and Loomis (1986) pointed out that plant density effects on the variation of grain number were due primarily to variation in grain set and not in the number of spikelet primordia. The potential number of spikelets is established when spikelet formation ceases a few days before silking, while the number of developing grains can diminish throughout the first three weeks after silking. Keeping in view this ontogenic sequence, Tollenaar and Daynard (1978) stated that the number of initiated spikelets is not limiting to grain yield in maize. Rather, these authors believe that sink reduction occurs after formation of primordia, through abortion of spikelets, lack of pollination and fertilization or abortion of young kernels. A higher-population-induced delay in silk emergence lead to decrease in grain number per cob, increase in number of barren plants, and hence, the differences in total grain yield (Hashemi-Dezfouli & Herbert, 1992). Higher populations are associated with prolonging the interval between anthesis and silking (Lemcoff & Loomis, 1986; Peixoto *et al*., 1997; Da Silva *et al*., 1999).

Wilson and Allison (1979) postulated the occurrence of a hormonal mechanism accounting for the influence of plant population on cob development before flowering. The maize shoot apex is differentiated into a tassel primordium when the plant has six to seven expanded leaves and is 40 to 50 cm tall (Ritchie & Hanway, 1992). Large amounts of phytohormones, especially auxins, are produced after a reproductive structure is produced which stimulate cell division and enlargement, triggering an intense increase in plant height and dry matter production. Under high densities less solar radiation reaches the growing point than under low densities (Gardner *et al*., 1985). Light in high intensity or amount may oxidize and inactivate auxins (Salisburry & Ross, 1992) so that under high densities there is less auxin inactivation and greater concentration of bioactive hormone. The tassel requires a greater auxin concentration for its development than the cob (Sangoi & Salvador, 1997). Therefore, high plant population may promote hormonally-mediated apical dominance over the ears, contributing to barrenness (Sangoi & Salvador, 1998).

1000-grain weight: During both the years, maximum 1000-grain weight (283-294 g) recorded for maize hybrid DK-919 was 22.5% higher than that for Dk-5219 and 7.5% higher than Pioneer-30Y87 (Table I). 1000-grain weight were linearly decreased with each 15 cm reduction in row spacing from 75 cm to 45 cm. Maximum 1000-grain weight (277-289 g) was recorded for crop sown at row spacing of 75 cm, which was 7.5% more than crop sown at 60 cm apart rows and 12.5 % more than 45 cm apart rows. Differential response of maize hybrids for 1000-grain weight has also been reported by Cox (1996) and Otegui *et al.* (1995), while suppressive effect of narrowing the row spacing on 1000-grain weight has been reported by Lemcoff and Loomis (1994) and Cox (1996). Such reports support the results of present studies wherein 1000-grain weight decreased with increasing planting density but increased when calculated on unit area basis.

The rather large differences in weight per grain observed at different plant populations may result from differences in the initial size of the spikelets, in growth rates during the exponential and linear (starch deposition) phases of grain growth or in the duration of those phases (Jones *et al*., 1985). Lemcoff and Loomis (1986) observed that the initial grain weight (W_0) after pollination was a key factor in the early growth of the kernel. At high plant populations, W_0 was smaller, which could in turn be due to delay in development (later initiation of spikelets) or smaller initial size of the spikelet primordia.

Grain yield: DK-919 produced grain yield of 6437 kg ha^{-1} (6577–6298 kg ha^{-1}) that was on an average, 6 and 17% higher than that of Pioneer-30Y87 and DK-5219 hybrids, respectively (Table I). Highest grain yield (6673-6409 kg ha^{-1}) was recorded when maize was planted at 45 cm apart row spacing during both the years followed by 60 cm apart row spacing, where yield were 6244 and 6116 kg ha^{-1}, respectively in 2006 and 2007 Narrowing the row spacing down from 75 cm to 45 cm resulted in 21-27% yield increase during both the years. A greater potential for yield enhancement existed with shift of row spacing from 75 cm to 45 cm directly as compared with that to 60 cm spacing. Narrowing the row spacing in DK-919 and DK-5219 from 75 cm to 45 cm resulted in grain yield enhancement of 31 and 11%, respectively in both the years (Table I). However, in Pioneer-30Y87 grain yield increased by 34% during 2007 that was only 23% during 2006. Increase in grain yield by reducing row spacing from 75 cm to 60 cm was in the range of 15 to 30% in all the hybrids during both the years of experimentation. Hybrid DK-5219 showed a different response in terms of grain yield wherein it decreased by 6-8% when row spacing was reduced from 60 cm to 45 cm during both the years. There was a significant and linear relationship between grain yield and grains per m^{-2} (Fig. 3). Regression accounted for 91 to 94% of variance in grain yield owing to number of grains m^{-2} during 2006 and 2007 for all the hybrids in study (Fig. 4). A positive and linear relationship was also observed between row spacing and grain yield of maize during both the years. Regression accounted for 99% variance in yield of DK-919 in 2006 and 2007, respectively while 98 and 99% of variance in grain yield of Pioneer-30Y87 was recorded during 2006 and 2007, respectively. A relatively low variance of 32-33% was recorded for grain yield of DK-5219 in 2006 and 2007, respectively (Fig. 5).

Maize has been identified as being more sensitive crop to variations in plant density than other members of the grass family (de Almeida & Sangoi, 1996). Many modern maize hybrids are mono stemmed and quite often produce only one cob per plant. Yield advantages of such hybrids have been associated with increased planting densities. Results for variation in grain yield among different maize hybrids in present studies are supported by findings of Gardner *et al.* (1990a & b) and Cox (1996). Shapiro and Wortmann (2006) reported that maize grain yield typically exhibits a quadratic response to plant density with a non-linear increase across a range of low densities a gradually decreasing rate of yield increase relative to density increase and finally a yield plateau at some relatively high plant density.

On the basis of two years results, it is concluded that maize hybrid DK-919 (an early maturing) should preferably be grown at narrow rows (45 cm) for obtaining higher grain yields and mid season hybrid DK-5219 need to be planted at 60 cm row spacing, while late season hybrid Pioneer-30Y87 also reflected an increasing trend in yield with narrowing row spacing in these studies.

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