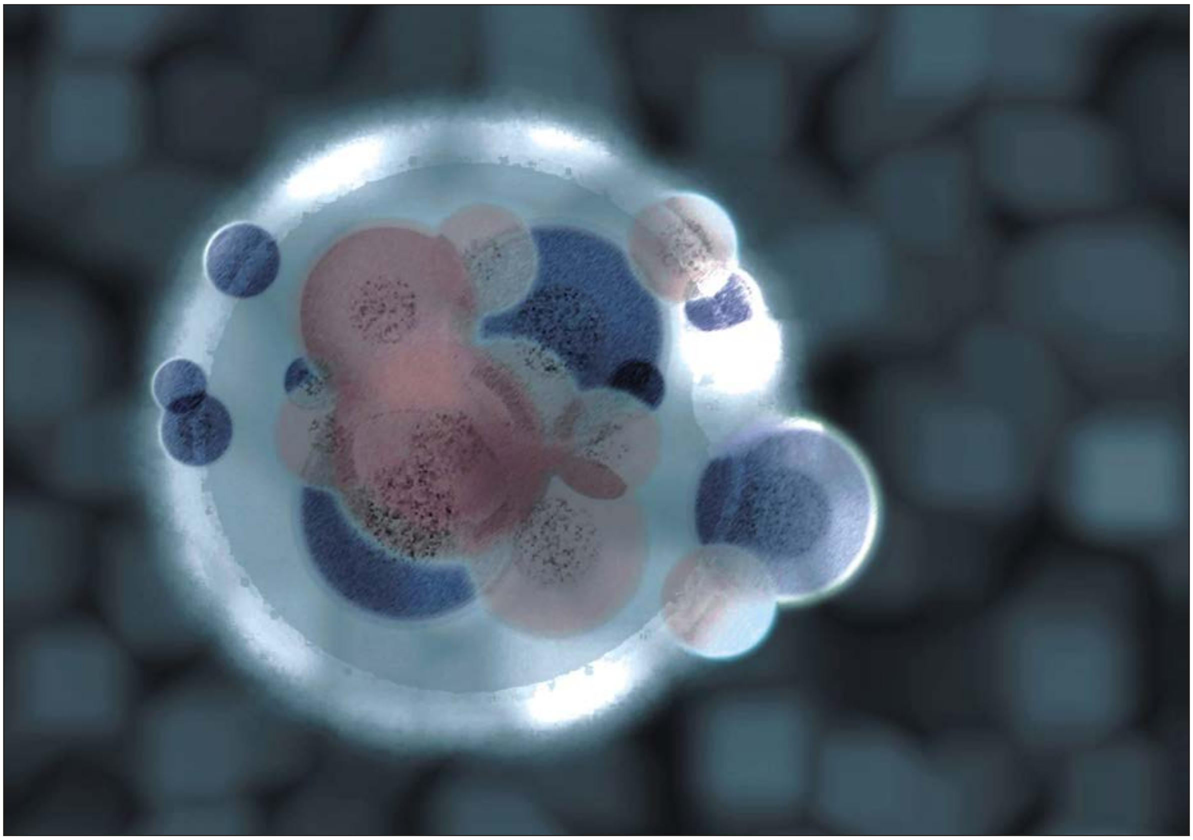

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Effect of Plant Density on Some Growth Indexes, Radiation Interception and Grain Yield in Maize (*Zea mays* L.)

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Abstract: We studied the effect of different row spacing and density of corn on Radiation Interception (RI), Total Day Weight (TDW), Leaf Area Index (LAI), Next Assimilation Rate (NAR), Crop Growth Rate (CGR) and grain yield. The experiment was conducted in the field at research station of Isfahan, Iran on loamy clay to compare row spacing and to determine optimum plant density for maize hybrid K704. The experimental design was a randomized complete block in a split-plot arrangement with four replicates. Plot treatments were row spacing (60, 75 and 90 cm). Split-plot treatments were within-row spacing (12, 14, 16 and 18 cm). An increase of PP from 10.5 to 13.9 plants m^{-2} increased LAI, TDW, CGR, RI and grain yield on average by 0.205 m, 48.4 g m^{-1}, 1.14 g m^{-2} day^{-1}, 0.89% and 222.7 kg ha^{-1} for each 1 plant per m^2 added .but decreased NAR by 0.205 g m^{-2} day^{-1} for each 1 plant per m^2 added. Moreover, when row spacing was reduced, RI, TDW, LAI, CGR and grain yield increased. But by reducing row spacing, NAR was decreased. The results show that the row spacing 60 cm, within-row spacing 12 cm and density 11.9 plant m^{-2} for conditions of Isfahan is suitable for maize hybrid K704.

Key words: Plant density, row spacing, leaf area index, total dry weight, net assimilation rate, crop growth rate, radiation interception, grain yield

INTRODUCTION

Plant density and ordination cropping has been recognized as a major factor determining the degree of competition between plants. In order to obtain maximum crop growth rate and operation, plant density and ordination cropping shall be selected in a manner that maximum leaf area index during flowering to be within the limits that attract the highest rate of sun light which irradiates on canopy and also during this time the rate of producing dry material in leaf area unit to be in its maximum rate. In this state the most rate of operation will be obtained (Bavec and Bavec, 2002).

Some researchers reported grain yield increases with increase the row spacing in the same density (Porter *et al*., 1997; Egli, 1994), but others have not (Cox and Cherney, 2001; Cox, 1996; Blamey and Zollinger, 1997). The rate of yield decrease is in response to decreasing light and other environmental resources available to each plant (Maddonni *et al*., 2006). Yield per plant is also affected by soil fertility (Katsvairo *et al*., 2002), planting date (Cirilo and Andrade, 1994), level of water availability (Schussler and Westgate, 1995) and genotype (Hashemi-Dezfouli and Herbert, 1992; Widdicombe and Thelen, 2002).

Leaf area is influenced by genotype, Plant Population (PP) (Murphy *et al*., 1996), climate and soil fertility. Some experiments have shown that a LAI between 3 and 4 may be optimal for achieving maximum yield (Lindquist *et al*., 1998). Also, Increase in PP and increase in row spacing at the same density reduce the leaf area index required to intercept 95% of the incident radiation due to an increase in the light extinction coefficient (Flenet *et al*., 1996). Crop growth rate is directly related to the amount of RI (radiation intercepted) by the crop (Jeffrey *et al*., 2005). Therefore, the response of grain yield to increasing PP can be analyzed in terms of the effect on the amount of RI at the critical periods for kernel set; also increasing PP may accelerate leaf senescence (Bavec and Bavec, 2002), increase the shading of leaves (Hashemi-Dezfouli and Herbert, 1992) and reduce the net assimilation of individual plants. An increase in PP of 2-13 plants m^{-2} decreased net assimilation per plant from 0.85 to 0.11 mg CO_2 m^{-2} sec^{-1}, but increased grain yield per area (Dwyer *et al*., 1991). This increase in grain yield can be explained by the increase in LAI and net crop assimilation. Under high PP of 130000 plants per ha, grain yield lost due to missing plants was poorly compensated by the increased yield of surrounding plants, when two or three

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adjacent plants were missing, compensation for missing plants was only 16 and 34%, respectively (Pommel and Bonhomme, 1998). Nafziger (1996) found that the two plants on either side of a missing plant compensate 47% of the yield lost because of the missing plant at 44,478 plants per ha.

In Ithaca, the low PP (45,000 plants ha^{-1}) averaged 15% lower grain yields than the high PP (90,000 plants ha^{-1}). Cultivars with lowest (higher) dry matter and grain yield in low PP showed linear (quadratic) responses to increases in PP, respectively (Cox, 1996), however, early maturing cultivars showed more linear responses than late maturing cultivars (Bavec and Bavec, 2002).

The objective of this study was to obtain the best ordination cropping and plant density for obtaining maximum operation through leaf area Index which attracts the most rate of irradiated sun light on canopy and also during this time the rate of producing dry mater in leaf area unit to be in its maximum rate, in this state the most rate of operation will be obtained.

MATERIALS AND METHODS

The experiment was conducted in 2006 at research station of Isfahan (32°30'N, 51°49'W). Before planting 100 kg N ha^{-1} and 50 kg P ha^{-1} were applied. Weeds were controlled by herbicides. No problems occurred with diseases or insects. Corn hybrid SC-704, with 1000-kernel weight of 250 g, emergence rating of 87% and purity of 92% was planted 5 cm deep on 5 May 2006 in north-south rows. The experimental design was a randomized complete block in a split-plot arrangement with four replicates. Each plot was 6 m long and 10.5 m wide. Plot treatments were row spacing (60, 75 and 90 cm). Split-plot treatments were within-row spacing (12, 14, 16 and 18 cm). Population densities are reported for each row spacing and within-row spacing in Table 1.

All measurements in the field experiments were taken from the center three rows of each plot at once time in every 10 days. At Plant Growth, each plot was divided into subplots for determination of aboveground DM production and grain yield. Leaf area was estimated by passing leaves from 20% of the fresh weight of the plants through an area meter (LI-COR .Lincoln, NE, model 3000). The leaf area estimated by measuring a sub sample and the leaf areas of the whole sample were highly correlated (r^2 = 0.991 slop = 0.988).

From these predicted plant growth parameters, equations provided by Hunt (1982) were used to examine plant growth rates, growth efficiencies and morphological patterns. In this paper we examine LAI (Leaf Area Index), which describes leaf surface area on a unit ground area basis; CGR (Crop Growth Rate), which describes the rate of DM (Dry Matter) accumulation on a unit ground area basis; NAR (Net Assimilation Rate), which is a measure of how efficiently the crop produces new DM with its leaf area. The following equations describe these variables:

Table 1: Population density in different ordination cropping

	Within-row spacing (cm)			
Row spacing	12	14	16	18
Population density (plants m^2)				
60 cm	13.9	11.9	10.4	9.3
75 cm	11.1	9.5	8.3	7.4
90 cm	9.2	7.9	6.9	6.2

$$LAI = \frac{1}{A} \times \left(\frac{\Delta LA}{\Delta T}\right) \quad (1)$$

$$CGR = \frac{1}{A} \times \left(\frac{\Delta DM}{\Delta T}\right) \quad (2)$$

$$NAR = \frac{CGR}{LAI} \quad (3)$$

Where:
A = Area unit of field
ΔT = Time variations as day

Fraction of PAR intercepted above the canopy (I0) and below the canopy (It) was measured under clear skies using a luxmeter (model L×101 Lotran) at once time in every 10 days. Five measurements were taken above the canopy and 15 below on a 1 m section of row. There were two such readings in each split plot. Light interception measurements were measured on the same section of row and on the same date as Leaf area. Radiation interception was calculated as (1 _ It/I0) _ 100, where It is incident Photosynthetically Active Radiation (PAR) just below the lowest layer of photosynthetically active leaves and I0 is incident PAR at the top of the canopy.

Corn in grain yield subplots was harvested with a combine equipped with a weigh tank and an on-board moisture meter. For ease of comparison, both grain yields and DM are reported on a 0 g kg^{-1} moisture concentration basis.

Differences among treatments were tested by analysis of variance and were compared using Duncan's (1958) multiple range tests at the 0.05 Level of significance.

RESULTS AND DISCUSSION

Row spacing affected on LAI (Leaf Area Index) was more significant at the 1% probability level (Table 2).

Table 2: ANOVA analysis Leaf Area Index (LAI), Total Dry Weight (TDW), Net Assimilation Rate (NAR), Crop Growth Rate (CGR) radiation interception increase (RI) and grain yield

		Means square					
Source of variation	df	LAI (m^2 m^{-2})	TDW (g m^{-2})	NAR (g m^{-2} day^{-1})	CGR (g m^{-2} day^{-1})	RI (%)	Grain yield (kg ha^{-1})
Repeat (Block)	3	3.32**	677918.4**	2.25**	377.1**	7.3	14344885.3**
Row spacing	2	5.04**	872861.1**	0.19	485.6**	280.0**	18470953.3**
Error A	6	0.2	34495.0	0.05	19.0	5.0	729968.1
Space of within row	3	2.95**	374831.0**	0.90**	208.5**	167.1**	7930722.3**
Interaction on A and B	6	0.01	7568.9**	0.14	4.2**	7.1**	160124**
Error B	27	0.04	1251.2	0.08	0.8	1.1	30869.2

*, **Significant at the 5 and 1% probability levels, respectively

Table 3: Means comparison row spacing and within-row spacing on Leaf Area Index (LAI), Total Dry Weight (TDW), Net Assimilation Rate (NAR), Crop Growth Rate (CGR), radiation interception (RI) increase and grain yield

Experimental factor	LAI (m^2 m^{-2})	TDW (g m^{-2})	NAR (g m^{-2} day^{-1})	CGR (g m^{-2} day^{-1})	RI (%)	Grain yield (kg ha^{-1})
Row spacing (cm)						
60	4.76^{a}	2128^{a}	10.43^{a}	49.67^{a}	95.65^{a}	9786^{a}
75	4.15^{ab}	1883^{ab}	10.75^{a}	44.62^{b}	91.80^{ab}	8662^{b}
90	3.64^{b}	1661^{b}	10.85^{a}	39.49^{c}	87.29^{b}	7638^{c}
Space of within row (cm)						
12	4.75^{a}	2060^{a}	10.61^{b}	48.68^{a}	95.58^{a}	9427^{a}
14	4.38^{ab}	1967^{a}	10.77^{b}	47.03^{a}	93.31^{ab}	9127^{a}
16	4.01^{bc}	1820^{b}	10.91^{ab}	42.93^{b}	90.51^{bc}	8373^{b}
18	3.60^{c}	1685^{c}	11.25^{a}	39.74^{c}	86.93^{c}	7750^{c}

All means followed by the same letter(s) in column are not significantly different at the 5% probability level

As increasing row spacing levels reduced significantly LAI (Table 3). Decreasing row spacing at equal plant densities decreases plant-to-plant competition for available water, nutrient and light and increases Radiation Interception (RI) and biomass production, therefore LAI increases too (Bullock *et al.*, 1988; Fernando *et al.*, 2002).

The contrast of between within-row spacing was more significant at the 1% probability level with LAI (Table 2), as highest mount of LAI was in spaces 12 and 14 cm, there were not any difference significantly between these spaces, the lowest was in space 18 cm (Table 3).

Reaction of row spacing and within-row spacing were not significant on the LAI.

An increase of PP from 6.2 to 9.5 plants m^{-2} increased LAI on average by 0.365 m m^{-1} for each 1 plant m^{-2} added, but by 0.205 m m^{-1} from 10.5 to 13.9 plants m^{-2} (Fig. 1).

In general, increasing density in a proper amount causes to increase photosynthesis area in cultivated plant and regarding the case that LAI is the ratio of green area or photosynthesis area on the ground, as a result with increasing green area LAI is increased as well. Present results are consistent with data (Dwyer *et al.*, 1991; Bavec and Bavec, 2002) that show that higher PP may increase maize LAI to more than 5.

Row spacing affected on TDW (Total Dry Weight) was more significant at the 1% probability level (Table 2), as increasing row spacing levels reduced significantly TDW (Table 3). Decreasing row spacing at equal plant densities produces a more equidistant plant distribution.

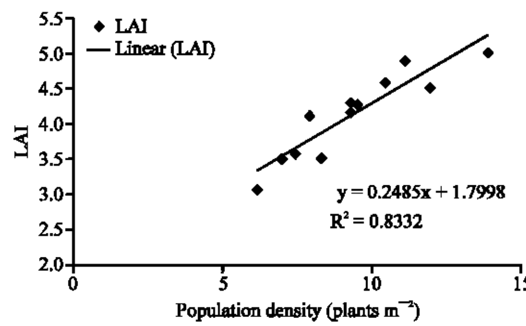

Fig. 1: Relationship between population density (plants m^2) with Leaf Area Index (LAI)

This distribution decreases plant-to-plant competition for available water, nutrient and light and increases Radiation Interception (RI) and biomass production (Bullock *et al.*, 1988; Fernando *et al.*, 2002).

The contrast of between within-row spacing was more significant at the 1% probability level with TDW (Table 2), as highest mount of TDW was in spaces 12 and 14 cm, there were not any difference significantly between these spaces, the lowest was in space 18 cm (Table 3).

Reaction of row spacing and within-row spacing were more significant on the TDW where as, the greatest depended on 60 cm row spacing in 12 and 14 cm space of between two plants and the lowest belonged to 90 cm row spacing in 18 cm space of between two plants (Fig. 2).

An increase of PP from 6.2 to 9.5 plants m^{-2} increased TDW on average by 151.3 g m^{-1} for each 1 plant m^{-2} added, but only by 48.4 g m^{-1} from 10.5 to 13.9 plants m^{-2} (Fig. 3).

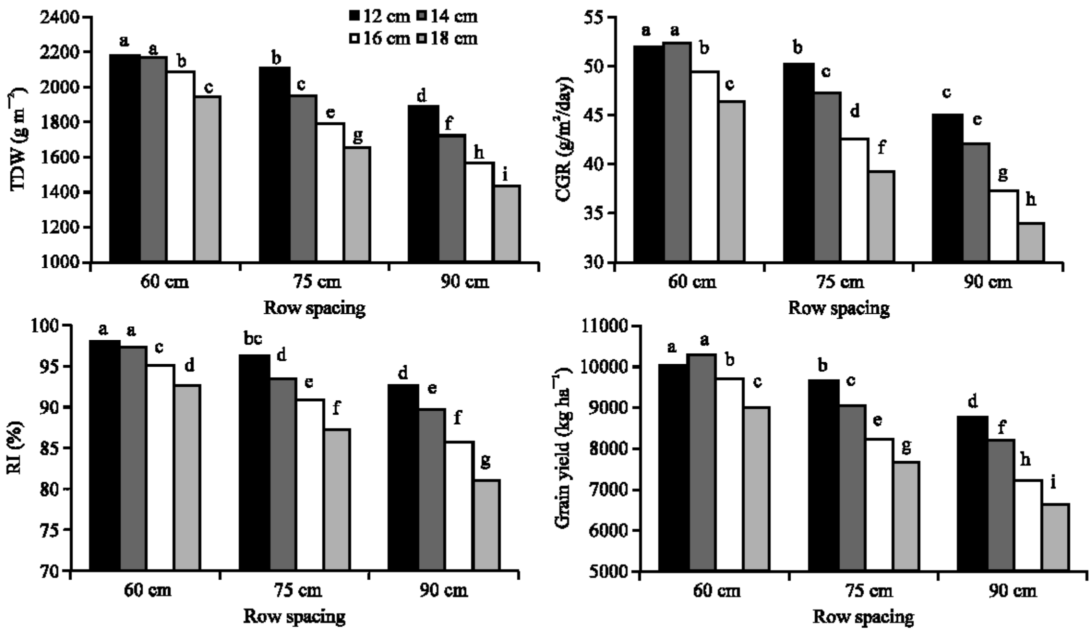

Fig. 2: Means of comparison Total Dry Weight (TDW), Crop Growth Rate (CGR), radiation interception (RI) and grain yield on reaction of row spacing and within-row spacing

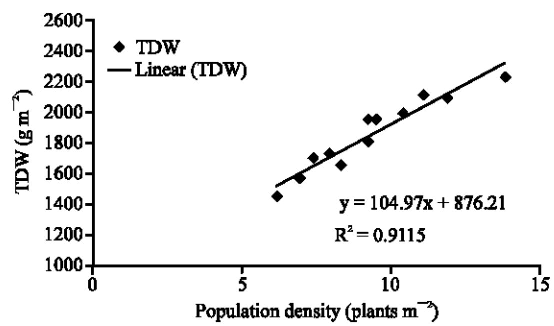

Fig. 3: Relationship between population densities (plants m^{-2}) with Total Dry Weight (TDW)

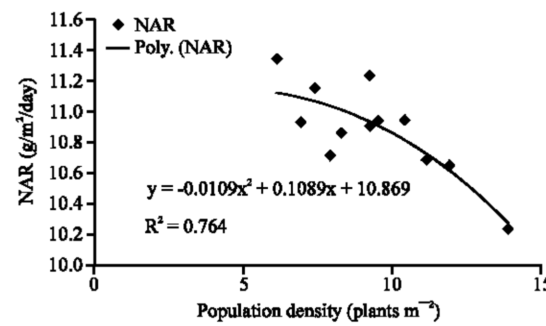

Fig. 4: Relationship between population density (plants m^{-2}) with Net Assimilation Rate (NAR)

Row spacing affected on NAR (Net Assimilation Rate) was not significant (Table 2).

The contrast of between within-row spacing was more significant at the 1% probability level with NAR (Table 2), as highest mount of NAR was in spaces 18 and 16 cm, the lowest was in space 12 and 14 cm, there were not any difference significantly between these spaces (Table 3).

Reaction of row spacing and within-row spacing were not significant on the NAR (Table 2).

An increase of PP from 6.2 to 9.5 plants m^{-2} decreased NAR on average by 0.118 g m^{-2} day^{-1} for each 1 plant per m^2 added, but by 0.205 g m^{-2} day^{-1} from 10.5 to 13.9 plants m^{-2} (Fig. 4).

NAR is mentioned as a standard for photosynthesis minus losses due to photosynthesis. Therefore increasing plant density or decreasing the distance on the cultivated row causes penetration of light to lower canopy decreases and this problem results in changing lower leaves to parasite leaves that these leaves principally have negative NAR (negative growth or weight reduction).

Row spacing affected on CGR (Crop Growth Rate) was more significant at the 1% probability level (Table 2), as increasing row spacing levels reduced significantly CGR (Table 3).

The contrast of between within-row spacing was more significant at the 1% probability level with CGR (Table 2), as highest mount of CGR was in spaces 12 and

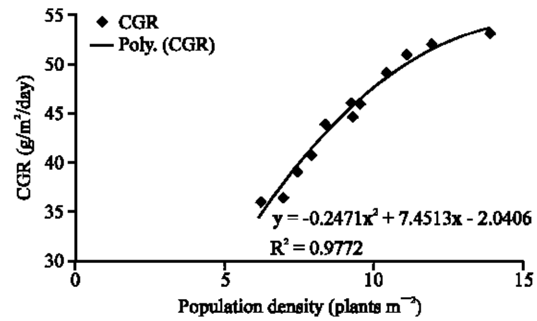

Fig. 5: Relationship between population density (plants m^{-2}) with Crop Growth Rate (CGR)

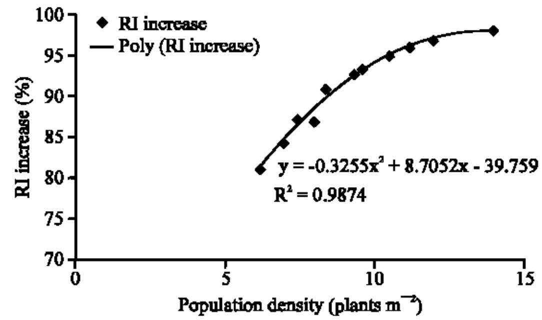

Fig. 6: Relationship between population density (plants m^{-2}) with radiation interception (RI)

14 cm, there were not any difference significantly between these spaces, the lowest was in space 18 cm (Table 3).

Reaction of row spacing and within-row spacing were more significant on the CGR where as, the greatest depended on 60 cm row spacing in 12 and 14 cm space of between two plants and the lowest belonged to 90 cm row spacing in 18 cm space of between two plants (Fig. 2).

An increase of PP from 6.2 to 9.5 plants m^{-2} increased CGR on average by 3.57 g m^{-2} day^{-1} for each 1 plant m^{-2} added, but only by 1.14 g m^{-2} day^{-1} from 10.5 to 13.9 plants m^{-2} (Fig. 5).

Row spacing affected on RI (radiation interception) was more significant at the 1% probability level (Table 2), as increasing row spacing levels reduced significantly RI (Table 3). In maize, the largest increases in RI at flowering and in grain yield in response to narrow rows were observed by Fernando *et al.* (2002).

The contrast of between within-row spacing was more significant at the 1% probability level with RI (Table 2), as highest mount of RI was in spaces 12 cm, there were not any difference significantly between these spaces, the lowest was in space 18 cm (Table 3).

Reaction of row spacing and within-row spacing were more significant on the RI where as, the greatest depended on 60 cm row spacing in 12 and 14 cm space of between two plants and the lowest belonged to 90 cm row spacing in 18 cm space of between two plants (Fig. 2).

An increase of PP from 6.2 to 9.5 plants m^{-2} increased RI on average by 3.66 % for each 1 plant m^{-2} added, but only by 0.89 % from 10.5 to 13.9 plants m^{-2} (Fig. 6).

Row spacing affected on grain yield was more significant at the 1% probability level (Table 2), as increasing row spacing levels reduced significantly grain yield (Table 3). Moreover, when row spacing was reduced, percentage yield increase was positively and directly related to percentage increase in RI. Therefore, the response of grain yield to narrow rows can be

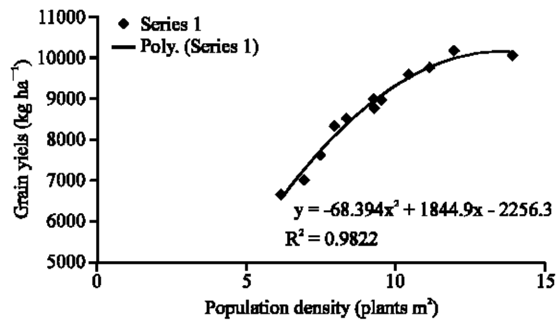

Fig. 7: Relationship between population density (plants m^2) with grain yield

analyzed in terms of the effect on the amount of RI at the critical periods for kernel set (Fernando *et al.*, 2002).

The contrast of between within-row spacing was more significant at the 1% probability level with grain yield (Table 2), as highest mount of grain yield was in spaces 12 and 14 cm, there were not any difference significantly between these spaces, the lowest was in space 18 cm (Table 3).

Reaction of row spacing and within-row spacing were more significant on the grain yield where as, the greatest depended on 60 cm row spacing in 12 and 14 cm space of between two plants and the lowest belonged to 90 cm row spacing in 18 cm space of between two plants (Fig. 2).

An increase of PP from 6.2 to 9.5 plants m^{-2} increased grain yield on average by 696.1 kg ha^{-1} for each 1 plant per m^2 added, but only by 222.7 kg ha^{-1} from 10.5 to 13.9 plants m^{-2} (Fig. 7).

In Ithaca, the low PP (45,000 plants ha^{-1}) averaged 15% lower grain yields than the high PP (90 000 plants ha^{-1}). Cultivars with lowest (higher) dry matter and grain yield in low PP showed linear (quadratic) responses to increases in PP, respectively (Cox, 1996), however, early maturing cultivars showed more linear responses than late maturing cultivars (Bavec and Bavec, 2002).

An increase in PP of 2-13 plants m^{-2} decreased net assimilation per plant from 0.85 to 0.11 mg CO_2 m^{-2} sec^{-1}, but increased grain yield per area (Dwyer *et al*., 1991). This increase in grain yield can be explained by the increase in LAI and net crop assimilation.

CONCLUSION

The results obtained by this experiment indicate that the row spacing 60 cm, within-row spacing 12 cm and density 11.9 plant m^{-2} for conditions of Isfahan is suitable for maize hybrid K704. Of course considering the number of various hybrids of corns and variety in weather conditions of each region more researches in this field are deemed necessary.

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