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Full Length Research Paper

Nitrogen dose and plant density effects on popcorn grain yield

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Popcorn (*Zea mays everta* Sturt.) is a popular and nutritious snack food. Environmental factors affecting grain yield and yield-related components of popcorn are needed to compensate increasing demand. This research was conducted to determine the effects of nitrogen fertilizer application rates and plant densities on grain yield and yield-related plant characteristics of popcorn in Hatay, located at Southern Mediterranean region of Turkey, during 2002 and 2003. The experiment was designed in a randomized complete block design with a split-plot arrangement with three replications. Nitrogen doses of 0, 120, 180 and 240 kg ha^{-1} were arranged in the main plots and plant densities of 60,000, 74,000, 88,000 and 102,000 plants ha^{-1} were arranged in the sub-plots. Popcorn grain yield and yield-related traits were significantly affected by nitrogen doses and plant densities. Our results indicated that suitable nitrogen dose and plant density were 180 kg N ha^{-1} and 88 000 plants ha^{-1} for popcorn grown as a second crop in Hatay ecological conditions in Eastern Mediterranean region of Turkey.

Key words: Popcorn, nitrogen, density, yield.

INTRODUCTION

Popcorn (*Zea mays everta* Sturt.) is a popular and nutritious snack food. Majority of the world's popcorn production is in the United States. Popcorn cultivation in Turkey is restricted and production value is low, but popularity of popcorn utilization and demand for it are increasing. Experimental results are limited regarding cultural practices for popcorn cultivation. Generally, the cultural practices used for growing dent corn can be used for growing popcorn, with some minor modifications (Ziegler, 2001).

Not only genetic potential of hybrid (Halluer, 1994), but also cultural practices such as nitrogen fertilizer rates and plant densities have important effects on popcorn yield (Babic and Pajic, 1992; Ziegler et al., 1987). Nitrogen fertilizer is also one of the most important factors affecting plant growth and grain yield of corn hybrids (Russel and Balko, 1980). Optimum plant density is another important factor for high grain yield. Yield can be increased with increased plant density up to a maximum for some maize genotypes grown under a set of particular environmental management conditions and declines when plant density is increased further (Tollenaar et al., 1994).

Roy and Singh (1986) evaluated the effects of nitrogen doses and plant densities on popcorn. Grain yield increased with increases in nitrogen doses and plant densities, the highest grain yield was obtained at 100 kg N ha^{-1} with 80 000 plant ha^{-1}. Thakur and Malhotra (1991) researched 0, 30, 60 and 90 kg N ha^{-1} nitrogen doses and 40, 50 and 60 cm inter-row spacings for popcorn and reported that the highest grain yield was obtained at the narrowest row spacing with the highest nitrogen dose applied.

Ülger (1998) reported the highest popcorn yield as 5850 kg ha^{-1}, obtained at 250 kg N ha^{-1} with 15 cm intra-row and 70 cm inter-row spacing. Özkan (2007) demonstrated that the highest grain yield was obtained at 200kg N ha^{-1} with 4530kg ha^{-1}. Findings of Gökmen et al. (2001) indicated that, for maximum grain yield of popcorn, 100-150 kg N ha^{-1} should be applied and the plant density should be 7.0 plants m^{-2}. Sezer and Yanbeyi (1997) demonstrated that ear characteristics were negatively affected by increases in plant densities, although plant height, ear height and grain yield increased with increases in plant densities. Researchers reported that effects of nitrogen fertilizer were positive and the highest grain yield was obtained at 71430 plant ha^{-1} and 160 kg N ha^{-1}

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applications.

A number of workers have experimentally demonstrated that grain yield of popcorn varied up on genotype and growth conditions (Ziegler et al., 1987; Babic and Pajic, 1992; Gökmen et al., 2001; Sade et al., 1996; Tekkanat and Soylu, 2005), site specific environmental conditions are needed to improve popcorn production in Eastern Mediterranean part of Turkey.

This research was conducted to determine the effects of nitrogen fertilizer application rate and plant densities on grain yield and yield-related plant characteristics of popcorn in Hatay, located at Southern Mediterranean region of Turkey.

MATERIALS AND METHODS

The field experiments were conducted at the Research Station of Mustafa Kemal University, Hatay, located at 36° 15' N and 36° 30' E in the Eastern Mediterranean region of Turkey, in the years 2002 and 2003. The soil of the experimental site, developed from alluvial deposits of river terraces, is typical for the Eastern Mediterranean region of Turkey, having relatively high clay content with the predominant clay minerals, smectite and kaolinite. The soil of experimental plots was a clay silt loam with pH of 7.12, having 1.93% organic matter and water holding capacity of0.51 cm^3. Weather conditions of the experimental site were hot and dry during growing seasons. Some climatological data of the experimental site during second crop popcorn growing seasons in 2002 and 2003 are summarized in Table 1.

The experiment was designed in a randomized complete block design with a split-plot arrangement with three replications. Nitrogen doses (0, 120, 180 and 240 kg ha^{-1}) were in the main plots and plant densities (60,000, 74,000, 88,000 and 102,000 plants ha^{-1}) were in the sub-plots. Each sub-plot consisted of four rows in 70 cm inter-row spacing and 5.0 m long. The harvest area of each plot was 5.6 m^{-2}. Ant-cin 98 popcorn variety was used as plant material in this study. The seeds were planted as a second crop in June 22, 2002 and June 26, 2003. Phosphate fertilizer (80 kg P_2O_5 ha^{-1}) and the half of the nitrogen fertilizer doses were applied at sowing. The remaining half of the nitrogen doses were applied at knee-height stage. Six irrigations were applied when nearly half of the available soil water was consumed. In the experiments, weeds were controlled by hand and harrowing. Grain yield and yield-related characteristics of popcorn were determined as follows:

Tasseling period (day), defined as 75% of the plants in a plot having extracted tassel, was recorded as the number of days after planting.

Plant height (cm) was measured from the soil surface to the lowest branch of tassel of 10 random plants sampled middle rows of each plot.

Ear height (cm) was measured from the soil surface to the ear node of the 10 random plants sampled from middle rows of each plot.

Stem diameter (mm) was measured on 10 plants selected at random from each plot in mm as the diameter of the first inter-node above ground.

Ear weight (g) was determined as average of the ears harvested from each plot.

Grain yield (kg ha^{-1}) was determined by harvesting the middle two rows of each plot.

All the data were analyzed with analysis of variance (ANOVA) procedures using the Statistical Software Package (MSTAT-C). The comparisons of the treatment means were made using the Duncan's multiple range test ($P < 0.05$).

RESULTS AND DISCUSSION

Responses to nitrogen doses

The effects of nitrogen doses on grain yield and yield-related characters of popcorn were significant in combined analysis of 2002 and 2003 years. Tasseling period was shortened by increases in nitrogen doses. The shortest tasseling period was observed at the highest nitrogen dose of 240 kg N ha^{-1} (Table 2). Popcorn is one of nitrogen positive plants and thus, increased nitrogen fertilizer application dose shortened the tasseling period. Plant height and ear height were positively affected by nitrogen doses and the highest values were obtained at 240 kg N ha^{-1} application dose (Table 2). Nitrogen is an important nutrient for popcorn growth and development. Ülger (1998), Gozubenli, et al. (2001), Khalifa et al. (1984) and Sezer and Yanbeyi (1997) reported positive effects of nitrogen applications on plant height and ear height of popcorn.

Nitrogen fertilizer applications enhanced plant development and, as a result, the stem diameter values were increased at nitrogen applied plots. Gozubenli, et al. (2001) declined that stem diameters were positively affected by nitrogen applications. Ear weights increased with increases in nitrogen dose applications and the heaviest ears were obtained at 240 kg N ha^{-1} dose application (Table 2). The effects of nitrogen doses on grain yield of popcorn were significant. Grain yield increased with increases in nitrogen doses, but similar grain yields were obtained at 180 kg N ha^{-1} and 240 kg N ha^{-1} applications (4185 and 4225 kg ha^{-1}, respectively).

The grain yield levels off when the nitrogen supply is high, reflecting sink limitation (example, small grain number per ear), sink competition (example, enhanced formation of tillers), or source limitation (example, mutual shading of leaves) (Marschner, 1993). Similar results were reported by Russel and Balko (1980), Muruli and Paulsen (1981), Thakur and Malhotra (1991), Feil at al. (1992) and Özkan (2007). Nitrogen is the main plant nutrient which limits plant productivity. Therefore, the use of efficient rate of nitrogen is an increasingly important feature of crop production systems. Corn may show large responses to nitrogen fertilizer applications depending on grown environment, the uniformity of the crop and the nutrient responses of the cultivated variety.

Responses to plant densities

Grain yield and yield-related characters of popcorn were significantly affected by plant densities except tasseling period. Tasseling period was not affected by plant densities and similar results were observed at all plant densities (Table 3). Average tasseling period was 47.1 day

Table 1. Some climatological data of experimental site during second crop popcorn growing seasons in 2002 and 2003.

Months	Year	Temperature (°C)			Total precipitation (mm)	Relative humidity (%)
		Maximum	Minimum	Average		
June	2002	33.4	19.2	26.2	2.8	47.3
	2003	33.3	19.2	26.3	-	50.7
July	2002	35.5	22.7	28.8	-	48.2
	2003	35.0	22.7	28.6	-	54.0
August	2002	34.0	22.7	27.8	-	59.4
	2003	35.7	23.2	28.9	-	50.8
September	2002	32.7	18.8	25.0	13.2	64.8
	2003	32.0	18.4	24.5	20.7	56.1
October	2002	29.6	13.6	21.1	14.1	52.3
	2003	29.4	15.2	21.6	78.3	59.8

Table 2. Effects of N doses on grain yield and yield-related characteristics of popcorn.

Traits	Nitrogen Doses (kg N ha^{-1})			
	0	120	180	240
Tasseling period (day)	49.67 A	46.29 BC	46.88 B	45.63 C
Plant height(cm)	165.1 C	174.5 B	179.2 AB	185 A
Stem diameter(mm)	17.45 B	18.73 A	18.50 A	18.53 A
Ear height(cm)	89.42 B	97.50 A	100.9 A	103.4 A
Ear weight(g)	64.00 C	70.63 B	71.71 B	76.21 A
Grain yield(kg/ha)	2953 C	3753 B	4185 A	4225 A

There were no significant ($P < 0.05$) differences among values having the same letter according to Duncan's multiple range test.

Table 3. Effects of plant densities on grain yield and yield-related characteristics of popcorn.

Traits	Plant Densities (plants ha^{-1})			
	60,000	74,000	88,000	102,000
Tasseling period (day)	47.29	47.04	47.21	46.92
Plant height(cm)	172.2 B	176.4 A	176.7 A	178.6 A
Stem diameter(mm)	18.55 A	18.67 A	18.37 AB	17.63 B
Ear height(cm)	94.46 B	99.04 A	98.25 A	100.5 A
Ear weight(g)	72.21 AB	73.38 A	70.21 B	66.75 C
Grain yield(kg/ha)	3581 C	3877 AB	3973 A	3685 BC

There were no significant ($P < 0.05$) differences among values having the same letter according to Duncan's multiple range test.

after sowing.

Higher plant densities produced taller plants with lower stem diameter (Table 3). Also, ear height was low at the lowest plant density and higher ears were observed at high plant densities (Table 3). These results showed that there were differences among plant densities in plant height, ear height and stem diameter. Some researchers reported that taller plants with lower stem diameter were obtained at higher plant densities as a consequence of interplant competitions (Ülger, 1998; Konuskan, 2000; Gozubenli, et al., 2003; Konuskan and Gözübenli, 2004; Sener et al., 2004). Ear weight decreased at higher plant densities and the lowest ear weight obtained was at the highest plant density with 66.75 g ear^{-1}. It is well known that plants grown under less competition have higher potential yields than those under dense plantings and the

Table 4. Year x nitrogen dose x plant density interactions for grain yield (kg/ha).

Years	Nitogen doses (kg N ha⁻¹)	Plant Densities (plants ha⁻¹)			
		60,000	74,000	88,000	102,000
2002	0	3343 e-j	3857 dh	3856 dh	3919 dg
	120	4195 c-e	4643 b-d	5238 ab	5229 ab
	180	5143 ab	5548 a	5429 ab	5167 ab
	240	5117 ab	5015 ab	4905 a-c	5243 ab
2003	0	2247 lm	2250 lm	2289 lm	1862 m
	120	2860 ı-l	3190 f-k	2406 k-m	2265 lm
	180	2851 ı-l	3004 h-l	3625 e-ı	2714 j-l
	240	2895 ı-l	3510 e-j	4032 d-f	3085 g-l

There were no significant (P < 0.05) differences among values having the same letter according to Duncan's multiple range test.

Table 5. Nitrogen dose x plant density interactions for grain yield (kg/ha).

Nitogen doses	Plant densities (plant ha⁻¹)			
	60,000	74,000	88,000	102,000
0 kg N/ha	2795 e	3054 de	3073 de	2890 e
120 kg N/ha	3528 cd	3917 abc	3822 bc	2747 bc
180 kg N/ha	3997 abc	4276 ab	4527 a	394 abc
240 kg N/ha	4006 abc	4262 ab	4468 a	4164 ab

There were no significant (P < 0.05) differences among values having the same letter according to Duncan's multiple range test.

grain yield of a single corn plant is reduced by proximity to its neighbors (Gozubenli et al., 2004).

Grain yield increased with increases in plant densities up to 88,000 plants ha^{-1}, but decreased at the highest plant density (102,000 plants ha⁻¹). The highest grain yield obtained was at 88,000 plants ha^{-1} density with 3973kg ha^{-1}. Grain yield is the product of crop dry-matter accumulation and the proportion of the dry matter allocated to the grain (that is, harvest index) and harvest index in corn declined when plant density increased above the critical plant density. For instance, the optimum plant density for corn hybrid 'Pride 5' was determined as 9.1 plants m^{-2} (Tollenaar et al., 1994).

Interaction effects

Grain yield was significantly affected by year x nitrogen dose x plant density interaction effects. These results indicated that the grain yield of popcorn was affected differently by different nitrogen doses and plant densities in different years (Table 4).

When years were evaluated together, the highest grain yields were obtained at 88,000 plants ha⁻¹ density in 180kg N ha⁻¹ nitrogen dose application with 4527 kg ha⁻¹ grain yield. It was followed by 240 kg N ha⁻¹ x 88,000 plants ha⁻¹ interaction with 4468 kg ha⁻¹ grain yield (Table 5). Yield increases with increasing plant density up to a maximum for a corn genotype grown under a set of particular environmental and management conditions and declines when plant density is increased further (Tollenaar et al., 1994).

Many researchers reported the relations between nitrogen doses and plant densities and there were differences in grain yield responses of corn genotypes grown under different nitrogen doses and plant densities (Khalifa et al., 1984; Gozubenli, et al., 2003; Konuskan and Gözübenli, 2004). Ülger (1998) reported that the highest grain yield was obtained at 25 kg N ha⁻¹ x 95 240 plants ha⁻¹ combination in popcorn. Sezer and Yanbeyi (1997) obtained the highest popcorn grain yield at 16 kg N ha⁻¹ with 71 430 plants ha⁻¹ density.

Conclusions

Environmental factors affecting grain yield and yield-related components of popcorn are needed to compensate increasing popularity. Popcorn production and researches on cultural practices are limited in the eastern Mediterranean region of Turkey. Our results revealed important effect of nitrogen fertilizer application doses and plant densities on popcorn grain yield and yield related plant characters. This research indicated that the suitable nitrogen dose and plant density were 180 kg N ha⁻¹ and 88,000 plants ha⁻¹ for popcorn grown as a second crop in

Hatay ecological conditions in Eastern Mediterranean region of Turkey.

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