YIELD AND QUALITY OF FORAGE MAIZE AS INFLUENCED BY PLANT DENSITY AND NITROGEN RATE

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ABSTRACT

The producers of silage maize need more information on agronomic managements such as plant density and nitrogen fertilization. Field studies were conducted in Bursa to evaluate dry matter yield and forage quality responses of silage maize to plant density and nitrogen rate. Five densities of 60 000, 100 000, 140 000, 180 000 and 220 000 plants ha\(^{-1}\) and five rates of 0, 100, 200, 300 and 400 kg N ha\(^{-1}\) were applied with split block design of three replications. As plant density increased, dry matter yield, stem percentage and ADF increased, but leaf number plant\(^{-1}\), stem diameter and ear percentage decreased with the highest dry matter yields of 180 000 plants ha\(^{-1}\) and 220 000 plants ha\(^{-1}\). However, there were no effects of plant densities on plant height, leaf percentage, crude protein and NDF. The dry matter yield, plant height, leaf number plant\(^{-1}\), stem diameter, leaf percentage, ear percentage, crude protein content and NDF responded linearly to nitrogen rates with the highest dry matter yields at 300 and 400 kg N ha\(^{-1}\), respectively. However, stem percentage decreased and ADF did not change as nitrogen rates increased. In conclusion, 180 000 plants ha\(^{-1}\) and 300 kg N ha\(^{-1}\) may be recommended for cultivation of silage maize under drip irrigation at Southern Marmara Region.

Key words: Dry matter yield, forage quality, nitrogen rate, plant density, Zea mays L.

INTRODUCTION

Maize (*Zea mays* L.) is the most important silage plants in the world because of its high yield, high energy forage produced with lower labor and machinery requirements than other forage crops (Roth et al., 1995). Many environmental, cultural and genetic factors influence maize forage yield and quality. Maize forage producers require more information on how nitrogen fertilization and plant density practices affect dry matter yield and forage quality.

Forage maize responds differently to plant densities under different environmental and cultural factors which influence maize forage yield and quality. The relationship between maize forage yield and plant density is not well established. Total dry matter increases from 6 to 40 % when plant density increases from about 55 000 to 88 000 plants ha\(^{-1}\) in some studies (Rutger and Crowder, 1967; Karlen et al., 1985) and 79 000 to 165 000 plants ha\(^{-1}\) in some other studies (Sparks, 1988; Graybill et al., 1991; Cox and Otis, 1993; Turgut et al., 2005; Yandim, 2006; Yilmaz et al., 2007). Olson and Sander (1988) indicated that optimum plant density may differ between maize grain and forage production with higher plant densities favoring forage rather than grain yield. Cox and Otis (1993) reported maximum dry matter yield at 81 500 plants ha\(^{-1}\) and maximum grain yield at 74 100 plants ha\(^{-1}\). Many other researchers also reported that plant density affected positively forage yield and most of its quality components (Kamel et al., 1983; Saglamtimur et al., 1989; Kara et al., 1999; Uslu and Karaaltun, 1999; Jiwang et al., 2004). However, Alexander et al. (1963), Cusicanqui and Lauer (1999) and Widdicombe and Thelen (2002) reported that crude protein content of forage maize was negatively associated with plant densities, but some of the researchers found no statistical relation between crude protein content and plant densities (Cuomo et al., 1998; Patricio Soto et al., 2002). ADF and NDF, a good indicator of forage quality, were reported that their relations with plant densities were controversial. NDF was affected by plant densities in some studies (Iptas and Acar, 2006), but it was unaffected in other studies (Cox and Cherney, 2001; Widdicombe and Thelen, 2002). There were no significant relations found between plant densities and plant height (Bangarwa et al., 1993; Dogan et al., 1997; Turgut et al., 1997; Kara et al., 1999; Turgut et al., 2005; Iptas and Acar, 2006; Azam et al., 2007; Yilmaz et al., 2007). Leaf number plant\(^{-1}\) values were affected by plant densities (Saruhan and Sireli, 2005) or not affected (Dogan et al., 1997; Iptas and Acar, 2003). Researchers indicated that plant densities had no significant effects on leaf percentage (Cuomo et al., 1998; Iptas and Acar, 2006). Stem percentages increased as plant densities increased (Oktem and Oktem, 2005). The results of the studies on the effects of plant densities on ear percentage were controversial (Cummins and Dobson, 1973; Yilmaz et al., 2007).

Nitrogen fertilization is one of the most important agronomic practices and therefore there are numerous studies conducted with nitrogen fertilizer. Optimum rate of nitrogen fertilizer for forage maize cultivation depends on numerous variable factors such as environmental conditions, management systems and genotypes. Nitrogen fertilization of maize influences dry matter yield by influencing leaf area index, leaf area duration and photosynthetic efficiency (Muchow, 1988; Muchow and Davis, 1988). O’leary and
Rehm (1990) reported that forage dry matter yields of maize responded linearly to nitrogen rates at three sites and curvilinearly at five sites. Likewise, these researchers determined that forage quality traits such as NDF and ADF responded inconsistently to nitrogen rates. Some other researchers also reported that there were positive effects of nitrogen on dry matter yield and forage qualities (Cox et al., 1993; Mullins et al., 1998; Kara et al., 1999; Cox and Cherney, 2001; Hamid and Nasab, 2001; Patricio Soto et al., 2002; Bayram et al., 2004; Patricio Soto et al., 2004; Keskin et al., 2005; Sahar et al., 2005; Saruhan and Sireli, 2005).

Management studies on maize in Turkey in recent years have focused primarily on forage production for silage. Nitrogen fertilization and plant density studies were the centre of these studies. Results of these studies indicated somewhat differences due to different ecological conditions, cropping system and genotypes. The objective of this study was to evaluate dry matter yield and forage quality responses of silage maize to plant densities and nitrogen rates.

The variety ADA-523 was used as plant material. Five plant densities (60 000, 100 000, 140 000, 180 000 and 220 000 plants ha$^{-1}$) and five nitrogen rates (0, 100, 200, 300 and 400 kg ha$^{-1}$) were evaluated. The experimental design was a randomized complete block in a split plot arrangement with three replications. Main plots consisted of plant densities and split plots consisted of nitrogen rates. Split plot size was 5 by 5.2 m with 8 rows. Three-fold seeds for each plant density were sown at split plots and hand-thinned to target plant densities. Half of the nitrogen rates with the starter amounts of P and K each at 100 kg ha$^{-1}$ were applied before planting. The rests of nitrogen rates were sidedressed when plants attained 40-50 cm heights. Weeds were controlled by a post-emergence application of 2,4-D at a rate of 2.0 l ha$^{-1}$ and mechanical hoeing whenever it was needed.

Ten plants from certain rows of each split plot were, just prior to forage harvest, cut to determine morphological characters such as plant height, stem diameter and leaf number plant$^{-1}$. Five out of each 10 sampled plants were assorted into stem, leaf and ear fractions to determine their percentages in a whole-plant weight.

After removing border effects, two center rows of each split plot were harvested and fresh-weighed in situ to determine forage yield when kernel was dough. After harvest, 2 plants from forage material of each split plot were taken, dried at 78 °C for 48 h, weighed and then ground in mill with a 1 mm screen. Data obtained from these procedures were used both for calculation of dry matter yield of split plots and for determination of total nitrogen, acid detergent fiber (ADF) and neutral detergent fiber (NDF). 1 g ground sample was used for the total nitrogen determination and 0.5 g for ADF and NDF. ADF and NDF were analyzed by sequential detergent analysis method (Van Soest et al., 1991) and total nitrogen by Kjeldahl method. Crude protein content was calculated by multiplying total nitrogen by 6.25 constant.

Before variance analysis, all data of parameters of single years were averaged across years. Then, all data obtained from measurements or analyses of morphological characters, dry matter yields and forage quality components were subjected to analyses of variance by using MINITAB and MSTAT-C programs. The LSD was used to separate means of plant densities, nitrogen rates and their interactions when the F-test was significant.

### RESULTS AND DISCUSSION

Data obtained from the research work, averaged across years and subjected to variance analysis are given in Table 2. Results of variance analysis indicated that the effects of plant densities and nitrogen rates were of significance on most of the parameters. Also, the effects of interactions on some parameters were observed significant.

### Table 1. Precipitation, mean temperature and relative humidity in 2006, 2007 and long-term (1929-2001) in Bursa.

<table>
<thead>
<tr>
<th>Months</th>
<th>Precipitation (mm)</th>
<th>Mean temperature (°C)</th>
<th>Relative humidity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>May</td>
<td>9.2</td>
<td>31.8</td>
<td>50.0</td>
</tr>
<tr>
<td>June</td>
<td>43.5</td>
<td>46.6</td>
<td>30.4</td>
</tr>
<tr>
<td>July</td>
<td>3.6</td>
<td>13.6</td>
<td>24.0</td>
</tr>
<tr>
<td>August</td>
<td>3.7</td>
<td>1.0</td>
<td>18.9</td>
</tr>
<tr>
<td>September</td>
<td>91.2</td>
<td>3.2</td>
<td>40.1</td>
</tr>
<tr>
<td>Total/mean</td>
<td>151.2</td>
<td>96.2</td>
<td>163.4</td>
</tr>
</tbody>
</table>

The variety ADA-523 was used as plant material. Five plant densities (60 000, 100 000, 140 000, 180 000 and 220 000 plants ha$^{-1}$) and five nitrogen rates (0, 100, 200, 300 and 400 kg ha$^{-1}$) were evaluated. The experimental design was a randomized complete block in a split plot arrangement with three replications. Main plots consisted of plant densities and split plots consisted of nitrogen rates. Split plot size was 5 by 5.2 m with 8 rows. Three-fold seeds for each plant density were sown at split plots and hand-thinned to target plant densities. Half of the nitrogen rates with the starter amounts of P and K each at 100 kg ha$^{-1}$ were applied before planting. The rests of nitrogen rates were sidedressed when plants attained 40-50 cm heights. Weeds were controlled by a post-emergence application of 2,4-D at a rate of 2.0 l ha$^{-1}$ and mechanical hoeing whenever it was needed.
Dry matter yield was influenced by plant densities. Dry matter yield increased and reached maximum at 180 000 plants ha$^{-1}$ and then declined as plant density increased further. These results indicate a close relationship between dry matter yield and plant density. Numerous workers have determined different plant densities for maximum dry matter yield changing from 79 000 to 165 000 plants ha$^{-1}$ (Sparks, 1988; Graybill et al., 1991; Cox and Otis, 1993; Turgut et al., 2005; Yandim, 2006; Yilmaz et al., 2007). In our study, plants did not encountered with water stress in the growing seasons due to drip irrigation system used, and this case created a good medium to grow more plants per unit area. Of course, there are other reasons of these differences such as variety, ecology and agricultural systems. Plant densities had no affects on plant height ranging from 277.84 to 285.28 cm (Table 2). These results coincided with the findings of Cox and Otis, 1993; Cummins and Dobson (1973) and Yilmaz et al. (2007) reported that ear percentage decreased with increasing plant density and ear percentage. Therefore, the highest value was obtained at the lowest plant density (60 000 plants ha$^{-1}$). Cummins and Dobson (1973) and Yilmaz et al. (2007) reported that ear percentage decreased with increasing plant density, conforming to our results. However, Turgut et al. (2005) reported reverse results. Plant density effect on crude protein content of maize was insignificant. Cuomo et al. (1998) and Patricio Soto et al. (2002) reported similar results, but Alexander et al. (1963), Cusicanqui and Lauer (1999) and Widdicombe and Thelen (2002) observed that crude protein contents of forage maize decreased with increased plant density. On the other hand, JiWang et al. (2004) reported that crude protein contents increased with increased plant density. Significant implications of plant densities on ADF concentration were determined in this study. Increasing plant densities increased ADF, the highest value was recorded at 300 kg N ha$^{-1}$ (Table 2). Iptas and Acar (2006) reported that plant density had no affect on ADF of forage maize. NDF did have no relation with plant density in this study (Table 2). These results agree with the findings of Cherney (2001) and Widdicombe and Thelen (2002) observed that crude protein contents of forage maize decreased with increased plant density. However, there were revers results reported by other workers (Iptas and Acar, 2006).

Nitrogen fertilization had significant effect on dry matter yield. As nitrogen rates increased, so did the dry matter yield and reached a peak value at 300 kg N ha$^{-1}$, then stayed stable at further nitrogen rate. The 300 kg N ha$^{-1}$ treatment produced 63% higher dry matter yield with a 30 kg dry matter per 1 kg N fertilizer. These results increased as plant density increased. The highest stem percentage was obtained at 220 000 plants ha$^{-1}$. These results were in agreement with those of Oktém and Oktém (2005). The effect of plant densities on ear percentage was significant. There was a negative relation between plant density and ear percentage. Therefore, the highest value was obtained at the lowest plant density (60 000 plants ha$^{-1}$). Cummins and Dobson (1973) and Yilmaz et al. (2007) reported that ear percentage decreased with increasing plant density, conforming to our results. However, Turgut et al. (2005) reported reverse results. Plant density effect on crude protein content of maize was insignificant. Cuomo et al. (1998) and Patricio Soto et al. (2002) reported similar results, but Alexander et al. (1963), Cusicanqui and Lauer (1999) and Widdicombe and Thelen (2002) observed that crude protein contents of forage maize decreased with increased plant density. On the other hand, JiWang et al. (2004) reported that crude protein contents increased with increased plant density. Significant implications of plant densities on ADF concentration were determined in this study. Increasing plant densities increased ADF, the highest value was recorded at 220 000 plants ha$^{-1}$ (Table 2). Iptas and Acar (2006) reported that plant density had no affect on ADF of forage maize. NDF did have no relation with plant density in this study (Table 2). These results agree with the findings of Cherney (2001) and Widdicombe and Thelen (2002) observed that crude protein contents of forage maize decreased with increased plant density. However, there were revers results reported by other workers (Iptas and Acar, 2006).

<table>
<thead>
<tr>
<th>Plant Density (plants/ha)</th>
<th>Dry matter yield (kg/ha)</th>
<th>Plant height (cm)</th>
<th>Leaf number plant$^{-1}$</th>
<th>Stem diameter (mm)</th>
<th>Leaf percentage (%)</th>
<th>Stem percentage (%)</th>
<th>Ear percentage (%)</th>
<th>Crude protein (%)</th>
<th>ADF (%)</th>
<th>NDF (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>60 000</td>
<td>18719 b$^1$</td>
<td>285.08</td>
<td>15.01 a</td>
<td>24.50 a</td>
<td>26.47</td>
<td>49.68 d</td>
<td>24.03 a</td>
<td>5.27</td>
<td>25.90 c</td>
<td>64.84</td>
</tr>
<tr>
<td>100 000</td>
<td>19450 b</td>
<td>285.28</td>
<td>14.58 ab</td>
<td>20.75 b</td>
<td>25.31</td>
<td>54.75 c</td>
<td>20.07 b</td>
<td>4.91</td>
<td>27.15 bc</td>
<td>62.50</td>
</tr>
<tr>
<td>140 000</td>
<td>20261 ab</td>
<td>284.80</td>
<td>14.48 ab</td>
<td>19.06 c</td>
<td>25.22</td>
<td>55.98 bc</td>
<td>18.81 b</td>
<td>4.81</td>
<td>27.89 ab</td>
<td>63.68</td>
</tr>
<tr>
<td>180 000</td>
<td>21263 a</td>
<td>284.02</td>
<td>14.16 b</td>
<td>17.47 d</td>
<td>24.59</td>
<td>57.13 b</td>
<td>18.44 b</td>
<td>5.04</td>
<td>28.40 ab</td>
<td>62.61</td>
</tr>
<tr>
<td>220 000</td>
<td>20639 ab</td>
<td>277.84</td>
<td>14.16 b</td>
<td>15.69 e</td>
<td>25.00</td>
<td>59.35 a</td>
<td>15.81 c</td>
<td>5.19</td>
<td>28.50 a</td>
<td>61.47</td>
</tr>
</tbody>
</table>

Table 2. Effect of plant densities and nitrogen rates on dry matter yield, some morphological traits and forage quality (across 2 years).

*F-test significant at p≤0.05, and p≤0.01, respectively. ns: not significant
coincide with the finding of most workers (Hamid and Nasab, 2001; Kara et al., 1999; Keskin et al., 2005; Patricio Soto et al., 2002 and Sahar et al., 2005). Plant height responded significantly to nitrogen fertilization. Effects of nitrogen rates on plant height were linear. That is, as nitrogen amounts increased, then plant height increased, and the highest plant height was recorded at 400 kg N ha\(^{-1}\). Plant height was 16 % higher at 400 kg N ha\(^{-1}\) than at 0 kg N ha\(^{-1}\) (Table 2). Leaf number plant\(^{-1}\) significantly increased with increasing nitrogen rates up to 300 kg N ha\(^{-1}\). After this rate, leaf number plant\(^{-1}\) stood still. Similar results were reported by Bayram et al. (2004). Response of stem diameter to nitrogen fertilization was statistically significant. Stem diameter increased up to 300 kg N ha\(^{-1}\) and then stayed stable at 400 kg N ha\(^{-1}\). These results were in accordance to those of some workers (Kara et al., 1999 and Saruhan and Sireli, 2005). The differences in leaf percentage were markedly great and increased as nitrogen rate increased. Leaf percentage was the lowest (23.02 %) at 0 kg N ha\(^{-1}\) and the highest (27.59 %) at 400 kg N ha\(^{-1}\). Keskin et al. (2005) reported positive correlation between nitrogen rates and leaf percentage in maize. Nitrogen fertilization had significant but negative effect on stem percentage. As nitrogen rates increased from 0 to 400 kg N ha\(^{-1}\), stem percentage decreased from 62.81 % to 49.68 %. Similar results were reported by Keskin et al. (2005), but Saruhan and Sireli (2005) reported reverse results. Ear percentage increased with increasing nitrogen rate until 300 kg N ha\(^{-1}\) and then stayed stable at 400 kg N ha\(^{-1}\). Similar effects of nitrogen fertilization were reported by Keskin et al. (2005) and Saruhan and Sireli (2005) in forage maize. Crude protein content significantly increased as nitrogen rates increased with the exception of the highest rate. These results coincided to those findings of some workers (Patricio Soto et al., 2002; Patricio Soto et al., 2004). Nitrogen rates had no effect on ADF concentration. But some workers reported meaningful results indicating that nitrogen fertilization decreased ADF concentration in maize (Keskin et al., 2005). NDF concentration was significantly impacted by nitrogen rate. Every rate of nitrogen produced NDF concentration higher than its previous rate, and therefore, the highest NDF concentration (64.68 %) resulted in the highest nitrogen rate (Table 2). However, there were researchers who reported results opposite to ours (Cox et al., 1993; Mullins et al., 1998 and Cox and Cherney, 2001).

**CONCLUSION**

Dry matter yield of forage maize responded positively to high plant densities with maximum dry matter yields occurring at 180 000 plants ha\(^{-1}\). Leaf plant\(^{-1}\), ear percentage and stem diameter decreased, stem percentage and ADF increased, plant height, leaf percentage, crude protein content and NDF did not change as plant densities increased. Increasing nitrogen rates increased the forage maize dry matter yield with a peak value occurring at 300 and 400 kg N ha\(^{-1}\). On the other hand, as nitrogen rates increased, plant height, leaf plant\(^{-1}\), stem diameter, leaf percentage, ear percentage, crude protein content and NDF increased, stem percentage was adversely affected and ADF was not influenced. The data from this study suggest that forage maize producers must carefully balance the potential benefits of higher dry matter yields and forage quality. 180 000 plants ha\(^{-1}\) and 300 kg N ha\(^{-1}\) may be practiced under drip irrigation system in Southern Marmara Region, provided that the variety ADA-523 must be grown.

**ACKNOWLEDGMENT**

The authors are grateful to The Scientific and Technological Research Council of Turkey (TUBITAK-TOVAG 1060148) because of financial support. This research contains a part of doctoral thesis of Emine BUDAKLI ÇARPICI.

**LITERATURE CITED**


