Study of physiological growth indices in maize (Zea mays L.) hybrids under different plant densities

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Abstract

In order to study of physiological growth indices in maize (Zea mays L.) hybrids under different plant densities, a factorial experiment based on randomized complete block design was conducted at Research Farm of University of Mohaghegh Ardabili in 2007. Factors were different plant population (8, 10 and 12 plants m⁻²) with maize hybrids at three levels (SC-404, DC-370 and SC-504). Study of trend of variances total dry matter accumulation in treatment compounds corn hybrids × different plant densities showed that in all of treatment compounds, it increased during plant growth with increasing plant population and reached to a maximum level at 108-118 days after planting. From 118 days after sowing till harvest time, it decreased due to decreasing of leaf area index and net assimilation rate. Increase in plant population also significantly increased the crop growth rate, leaf area index and net assimilation rate. The grain yield varied between 3.91 ton ha⁻¹ in 8 plants m⁻² and 4.65 ton ha⁻¹ in 12 plants m⁻². Maximum grain yield was produced by SC-504 hybrid (5.1 ton ha⁻¹) while minimum by DC-370 hybrid (3.38 ton ha⁻¹). Thus, it can be suggested that in order to increasing of grain yield, dry matter accumulation, crop growth rate and the other of physiological indices should be applied SC-504 hybrid with 12 plants m⁻² in conditions of Ardabil Plain.

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**Introduction**

Corn (*Zea mays L.*) is one of the most important cereal crop grown principally during the summer season in Iran. The yield of corn in Iran is very low as compared to other corn producing countries. One of the most important effective factors is no application of optimal plant population per hectare and corn hybrids differ in their response to plant density. It is particular importance in production of cereal such as corn, because maize does not have tillering capacity to adjust to variation in plant stand. Optimum plant densities vary greatly between areas according to climatic conditions, soil, sowing time and varieties. Application of optimum plant density in corn production helps for the proper utilization of solar radiation, which influences leaf area, interception and utilization of solar radiation, and consequently maize dry matter accumulation and yield (Pepper, 1987). On the other hand, in order to increasing yield, maize must be planted at proper plant population. Sangoi *et al.* (2002) supported the results of Vega *et al.* (2000), that maize grain yield is associated with the number of kernels per area, which depend on the number of plants per area, number of ears per plant and the number of kernels per ear. Ziegler *et al.* (1994) reported that grain yield increased with increasing plant density from 54000 to 94000 plants/ha, but decreased after 97000 plants/ha. Aldrich *et al.* (1986) have promoted high plant density as a practice for maximizing yield. Echarte *et al.* (2000) found grain yield response to plant density to be positively and strongly related to number of kernels m$^{-2}$ and negatively and weakly related to weight per kernel. Otegue (2000) found that ear per plant and ear mass are negatively corrected with plant population, while grain yield commonly varies slightly over a wide range of plant population.

Growth analysis is still the most simple and precise method to evaluate the contribution of different physiological processes in plant development. The physiological indices such as leaf area index (LAI), total dry matter (TDM), crop growth rate (CGR) and relative growth rate (CGR) are influenced by genotypes, plant population, climate and soil fertility (Murphy *et al.*, 1996). Edwards *et al.* (2005) reported dry matter accumulation increase for maize hybrids at high than at low density due to light interception. Dwyer and Tewart (1986) reported that leaf area index is major factor determining photosynthesis and dry matter accumulation. Crop growth rate is related to leaf area index, for this reason that crop growth rate changes is depended to two parameters: namely leaf area index and net assimilation rate. Brongeham (2000) and Balbak *et al.* (1998) showed that NAR would decrease with increase LAI. Balbak *et al.* (1998) and Williams (1968) showed that NAR in per plant would decrease with increase LAI at high than at low density, but increase them in per area and this trend decrease will continue from the beginning till the end of growth season. Boyat *et al.* (1990) reported that increasing plant density accelerated leaf senescence, increased the shading of leaves, and reduced the net assimilation of individual plants but increase NAR in per area. Saberali (2007) investigated the effects of plant density and planting pattern on growth and physiological indices of maize (*Zea mays L*). They reported that in high maize density, leaf area index, total dry weight and crop growth rate increased than low maize density in and throughout of growth season. The objective of this study was to obtain the best of plant density for obtaining maximum physiological growth indices and grain yield in maize hybrids.

**Material and methods**

**Experimental design**

In order study of physiological growth indices in maize (*Zea mays L.*) hybrids under different plant densities application in conditions of Ardabil Plain, a factorial experiment based on randomized complete block design was conducted at Research Farm of University of Mohaghegh Ardabili in 2007. Factors were different plant population (8, 10 and 12 plants m$^{-2}$) with maize hybrids at three levels (SC-404, DC-370 and SC-504). The table 1 shows physicochemical properties of farm soil used in the experiment. Temperature mean and rainfall during the period of corn growth season (May-October), is presented in Figure 1.
Climatically, the area placed in the semi-arid temperate zone with cold winter and hot summer. Average rainfall was about 347.5 mm that most rainfall concentrated between winter and spring. The soil was silt loamy with pH about 7.83. The field was prepared well before sowing by plowing twice with tractor followed planking to make a fine seed bed. In each plot there were 6 rows 6 m long. Plots and blocks were separated by 75 m unplanted distances. Corn seeds were planted in the third week of May. Nitrogen fertilizer was applied 120 kg/ha as 1/3th at sowing, 1/3th at 6-7 leafy and 1/3 at appearance of tasseling in the form of urea. Weeds were controlled manually. All other agronomic operations except those under study were kept normal and uniform for all treatments.

**Dry weight**

For estimation of growth analysis, from 2 m² in each plot was sampled randomly in each treatment compound and average for recording the change in dry weight in shoots (above ground). Sampling intervals were ten days at different stages of the corn growth (38, 48, 58, 68, 78, 88, 98, 118 and 128 days after sowing). For dry weight determination, samples were oven dried at 70 ±5 °C to constant weight.

**Physiological growth indices**

Leaf area index was determined by dividing leaf area over ground area and was estimated with using of equation 5 (Watson, 1997). The variances trend of total dry matter (TDM), crop growth rate (CGR), net assimilation rate and relative growth rate (RGR) were determined with using of 1-4 equations (Acuqaah, 2002; Gupta and Gupta, 2005).

\[
\text{TDM} = e^{a+bt+ct^2+dt^3}
\]  
(1)

\[
\text{RGR} = b + 2ct + 3dt^2
\]  
(2)

\[
\text{CGR} = (b + 2ct + 3dt^2) \times e^{(a+bt+ct^2+dt^3)}
\]  
(3)

\[
\text{NAR} = \frac{\text{CGR}}{\text{LAI}}
\]  
(4)

\[
\text{LAI} = e^{(a+bt+ct^2)}
\]  
(5)

In these equations, t is the intervals of sampling or in the other hand, the beginning and end of the interval sampling and a, b and c are coefficient of equations.

**Grain yield**

Grain yield was estimated from 1 m² long from the three middle rows in each plot.

**Statistical analysis**

Analysis of variance and regression were performed using SAS version 9.1 (SAS Institute Inc., Cary, NC, USA) and Excel computer software packages.

**Results and dissection**

Study of trend of variances total dry matter accumulation in treatment compounds corn hybrids × different plant densities in Figure 2 showed that in all of treatment compounds, it increased during plant growth with increasing plant population and reached to a maximum level at 108-118 days after planting, then showed a declining trend at time of harvest (118-128 DAS). Similar results were also reported by Egly and Guffy (1997). The increase in total dry matter with the increasing of plant population indicates the favorable response of biomass produced corn to plant population. It is perhaps related to accelerating the photosynthesis activity that is caused dry matter accumulation increased. Cirilo and Andrade (1994) reported that dry matter is faster before silking and slower after silking in high plant densities compared to low plant densities.

**Table 1.** Soil physicochemical properties at depth of 0-30 cm.

<table>
<thead>
<tr>
<th>K available (mg/kg)</th>
<th>P available (mg/kg)</th>
<th>N (%)</th>
<th>total O.C (%)</th>
<th>Texture</th>
<th>Sand (%)</th>
<th>Silt (%)</th>
<th>Clay (%)</th>
<th>Caco3 (%)</th>
<th>SP(%)</th>
<th>pH</th>
<th>Depth of sampling (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>272</td>
<td>29.8</td>
<td>.62</td>
<td>.62</td>
<td>Silty - loam</td>
<td>35</td>
<td>42</td>
<td>23</td>
<td>14.45</td>
<td>49</td>
<td>7.83</td>
<td>0-30</td>
</tr>
</tbody>
</table>

Study of total dry matter trends in SC-370 hybrid in various levels of plant population shows that dry matter increased slowly until 38 days after sowing and then increased rapidly till 118 days after sowing.
From 118 days after sowing till time of harvest, accumulated dry matter decreased due to increasing aging of leaves, decreasing of crop growth rate, leaf area index and net assimilation rate (Figs 3, 5 and 6). On the other hand, total dry matter in unit of area increased with increasing levels of plant population, as the maximum and the minimum biomass in unit of area obtained from 8 and 12 plants m\(^{-2}\), respectively (Fig 2). Study the total dry matter in other corn hybrids (SC-404 and SC-504) indicated that in all of them, it increased with increasing of plant population and trend of variances were similar to dry matter accumulation in SC-370. Increasing leaf area index is one of the ways of increasing the capture of solar radiation within the canopy and production of dry matter. Began (1996) suggested that high plant density increases total light interception by the crop canopy, which convert only 5% of incident solar radiation into chemical energy during the crop–growing season. Hence, total dry matter decreases when leaf area index is decreased (Fig 5). In this study, the maximum value of total dry matter was obtained in the maximum value of leaf area index. It is perhaps related to relationship between leaf area index and total dry matter. Our findings are in agreement with observations made by Winter and Ohlrogg (1993) in corn. Tollenaar et al. (1997) found that high plant density increases dry matter production under optimum growing conditions, but tend to decrease as water and nutrient stress occur.

Study of trend of variances crop growth rate showed that in all of treatment compounds, the crop growth rate was low in the beginning of sampling, thereafter increased considerably up to 68-70 days after planting with a peak in 70 days after planting (Fig 3), and then showed a declining trend at 70-72 days after planting. Trend of variances crop growth rate was almost similar to leaf area index, for this reason that crop growth rate changes is depended to two parameters: leaf area index and net assimilation rate. Study of crop growth rate trends in SC-370 hybrid in various levels of plant population shows that it increased slowly until 38 days after sowing and then increased rapidly till 68-70 days after sowing. From 70-72 days after sowing till time of harvest, it decreased due to increasing aging of leaves, decreasing of leaf area index and net assimilation rate (Figs 5 and 6). On the other hand, crop growth rate in unit of area increased with increasing levels of plant population, as the maximum and the minimum biomass in unit of area obtained from 8 and 12 plants m\(^{-2}\), respectively (Fig 3). Study the crop growth rate in other corn hybrids (SC-404 and SC-504) indicated that in all of them, it increased with increasing of plant population and trend of variances were similar to dry matter accumulation in SC-370. The increase in CGR with the increasing rate of plant population may be due to accelerating the photosynthesis activity and the positive response of crop growth rate to plant population. Similar results were also reported by Jeffrey et al (2005). The decrease in crop growth rate to time of harvesting is due to senescence of leaves and decrease of leaf area index (Fig 4). Similar results were reported by Egly and Guffy (1997).

**Relative growth rate**

In the initial stages of the plant growth the ratio between alive and dead tissues is high and almost the entire cells of productive organs are activity engaged in vegetative matter production. In all of treatment compounds, RGR decreased during plant growth with decreasing plant population and reached to a minimum level at 108-118 days after planting (Fig 4). The reason of decreasing in RGR at the final stage can be related to increasing of the dead and woody tissues.
comparing to the alive and active texture and decrease of leaf area index. Similar observations have been reported by Shukla et al. (2002) in Indian mustard and Jeffrey et al. (2005) in corn.

![Graphs of dry matter accumulation and crop growth rate](image)

**Fig. 2.** Dry matter accumulation in DC-370 (above left), SC-404 (above center) and SC-504 (above right) hybrids at different plant densities.

**Fig. 3.** Crop Growth Rate in DC-370 (above left), SC-404 (above center) and SC-504 (above right) hybrids at different plant densities.

**Net assimilation rate**

Study of trend of variances net assimilation rate showed that in all of treatment compounds, it was high in the beginning of sampling (38 days after sowing) due to high light penetration in the crop canopy and less shading and competition between plants for light and other resources (Fig 6). Thereafter decreased considerably up to harvesting time. This might be related to shading and competition between plants for light and other resources. The increase in NAR with the increasing of plant population may be due to accelerating the photosynthesis activity. Moderras et al. (1998) reported that increasing plant density is one of the ways of increasing the capture of solar radiation within the canopy and increasing of net assimilation rate. In this study, net assimilation rate per area increased with increasing of plant population. Maize hybrids had differential response to net assimilation rate. The highest of it was obtained in SC-504 with 12 plants m$^{-2}$ and the least of it was in DC-370 with 8 plants m$^{-2}$ (Fig 6). Boyat et al. (1990) reported that increasing plant density accelerated leaf senescence, increased the shading of leaves, and reduced the net assimilation of individual plants but increased in per area. Similar results have been reported by Weber et al. (1996) in soybean.
Fig. 4. Relative Growth Rate in DC-370 (above left), SC-404 (above center) and SC-504 (above right) hybrids at different plant densities.

Fig. 5. Leaf Area Index in DC-370 (above left), SC-404 (above center) and SC-504 (above right) hybrids at different plant densities.

Fig. 6. Net Assimilation Rate in DC-370 (above left), SC-404 (above center) and SC-504 (above right) hybrids at different plant densities.

Leaf area index
Study of variances trend of leaf area index in Figure 5 showed that in all of treatment compounds, leaf area index increased during plant growth with increasing plant population and reached to a maximum level at 90 days after planting. Then showed a declining trend at 90-92 days after planting. From 92 days after sowing till time of harvesting, leaf area index decreased rapidly due to increasing aging of leaves, shading and competition between plants for light and other resources.
Olson and Sander (1988) and Hunter (1980) concluded that one of the simplest ways of increasing leaf area index is to increase plant density. Olson and Sander (1988) reported that leaf area index can be improved by increasing plant density. Began (1996) reported that leaf area index increases linearly as the plant density increases, but the leaf area per plant decreases as the plant density increases. Hence, dry matter produced decreases with decreasing of leaf area index. In the present study, trend of variances leaf area index was according to crop growth rate. Similar results have also been reported by Faris and De Pauw (1981) and Wiersma (2002) in wheat. In this study, increase plant density increased leaf area index, net assimilation rate and dry matter accumulation (Figs 2, 5 and 6). Shaver (1983) pointed out that leaf area index can be improved in two ways: breeding for increased leaf area per plant and increasing plant density.

Fig. 7. Mean comparison of grain yield in corn hybrids.

Fig. 8. Mean comparison of grain yield in various levels of plant population.

**Grain yield**

Grain yield is the main target of crop production. The grain yield was significantly affected by both maize hybrids and plant density. Plant density significantly increased the grain yield. The grain yield varied between 3.91 ton ha⁻¹ in 8 plants m⁻² and 4.65 ton ha⁻¹ in 12 plants m⁻² (Fig 7). A similar trend in yield differences across planting density has been reported by (Tyagi et al., 1998). Ziegler et al. (1994) reported that grain yield increased with increasing plant density from 54000 to 94000 plants/ha, but decreased after 97000 plants ha⁻¹. Aldrich et al. (1986) have promoted high plant density as a practice for maximizing yield. Since yield reduction/ha at high plant densities is due to the effects of interplant competition for light, water, nutrition and other potentially yield-limiting environmental factors, a plant population above a critical density has a negative effect on yield per plant (Moddares et al., 1998). According to Vega et al. (2001), maize grain yield is more affected by variations in plant density than other members of the grass family due to its low tillering capacity. Our findings are in agreement with observations made by many researchers (Roy and Sigh, 1986; Bangarwa et al., 1988). In addition, this suggests that the optimum plant density depends upon environmental conditions and the cultivars used. Maximum grain yield (Fig 8) was produced by SC-504 hybrid (5.1 ton ha⁻¹) while minimum by DC-370 hybrid (3.38 ton he⁻¹).

**Conclusion**

In this experiment, plant population showed significant effects on maize hybrids yield and physiological indices of corn hybrids such as total dry matter, crop growth rate, relative growth rate, net assimilation rate and leaf area index. The highest yield and physiological indices recorded in application of 12 plants m⁻² with SC-504 hybrid. Hence, it can be suggested that in conditions of Ardabil Plain be applied 12 plants m⁻² with SC-504 hybrid.

**References**


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