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Effects of time and rate of nitrogen application on phenology and some agronomical traits of maize (*Zea mays* L.)

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Maintaining soil fertility and the use of plant nutrient in sufficient and balanced amounts is one of the key factors in increasing crop yield and decreasing adverse environmental effects and pollutions arising from nonpoint fertilizer usage. The effects of time and rate of nitrogen application on phenology and some agronomical traits of corn (*Zea mays* L.) were investigated at the research farm of the University of Mohaghegh Ardabili. The trial was laid out in a split plot design based on a randomized complete block scheme with three replications. Experimental factors were nitrogen fertilizer at four levels (0, 75, 150, and 225 kg ha^{-1}) in the main plots and three levels of nitrogen application time [($^1/_3$ at sowing + $^1/_3$ at V_{8-10} + $^1/_3$ at tasseling), ($^1/_2$ at sowing + $^1/_2$ at tasseling), and ($^1/_2$ at sowing + $^1/_4$ at V_{8-10} + $^1/_4$ at tasseling) as T_1, T_2, and T_3, respectively] as subplots. The results showed that the maximum values of grain yield and its components, days to 50% tasseling (63.85 days), days to 50% silking (68.2 days), days to physiological maturity (128.9 days) were observed in the plots treated with 225 kg N ha^{-1} as T_1. The maximum nitrogen use efficiency (38.16 kg kg^{-1}) was obtained at application of 75 kg N ha^{-1} as T_1, and the minimum values of this index (19.41 kg kg^{-1}) were obtained in the plots that received 225 kg N ha^{-1} as T_2. Based on the results, it was concluded that application of the highest N fertilizer rate (225 kg ha^{-1}) in three equal splits can be recommended for profitable corn production.

Key words: corn, grain yield, nitrogen use efficiency, phenology, physiological traits, yield components

INTRODUCTION

Corn (*Zea mays* L.) is one of the most important crops all over the world and is often known as the king of cereals. The production of corn in developing regions is low as compared to developed countries. There are several reasons for this low productivity. Among them, mismanagement of plant nutrition is considered to be the major one. Hence, there is a need to improve this major component of production technology for getting higher corn production.

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Nitrogen (N) is the most important nutrient supplied to most non-legume crops, including corn. The most important role of N in the plant is its presence in the structure of protein and nucleic acids, which are the most important building and information substances of every cell. In addition, N is also found in chlorophyll that enables the plant to transfer energy from sunlight by photosynthesis. So, N supply to the plant will influence the amount of protein, amino acids, protoplasm, and chlorophyll formed. Moreover, it influences cell size, leaf area, and photosynthetic activity (Lawrence et al., 2008; Uribelarrea et al., 2009; Diacono et al., 2013; Namvar, Khandan, 2015). Therefore, adequate supply of N is necessary to achieve high yield potential in crops. Corn is usually considered to have a high soil fertility requirement to achieve maximal yields (Paponov et al., 2005; Uribelarrea et al., 2009), and thus large quantities of N are required. Torbert et al. (2001) and Ullah et al. (2007) found that yield and yield components of maize increase by increasing of applied N rate. Halvorson et al. (2001) reported a significant increase in grain yield with rates up to 224 kg N ha^{-1} under irrigated conditions, while Ma et al. (2005) observed that maize grain yield increased significantly with rates up to 120 kg N ha^{-1}. Although N is the key element in increasing productivity and the increase of agricultural food production worldwide and over the past four decades has been associated with a 7-fold increase in the use of N fertilizers, but a large amount of fertilizer N loss in the environment could cause a serious environmental problem such as groundwater contamination (Chen et al., 2004). Therefore, ideal N management optimizes yield, ensures farming profitability, and enhances nitrogen use efficiency (NUE), also minimizes the potential for leaching of N beyond the crop rooting zone (Rahmati, 2009). Raun and Johonson (1999) reported that NUE is variable and only 33% of applied N are recovered by cereal crops. NUE may be affected by crop species, soil type, time and rate of N application (Raun, Johnson, 1999; Halvorson et al., 2001). Lopez-Bellido and Lopez-Bellido (2001) showed that nitrogen efficiency indices are significantly affected by N fertilizer rate.

The time of N application plays a very important role in corn yield (Mariga et al., 2000; Scharf et al., 2002). Pre-anthesis uptake is necessary in order to accumulate N in the vegetative sink for later remobilization to the ear. Post-silking uptake supplements remobilized N and prevents excessive N relocation from the vegetative sinks to the ear, which is essential for maintenance of appropriate N partitioning between grain and stover to maintain photosynthesis and grain yield formation (Banziger et al., 2002). Post-silking uptake is also critical to many physiological processes, including spikelet differentiation and kernel formation (Andrade et al., 2000; Paponov et al., 2005). Availability of sufficient N during this phase of corn growth has clear agronomic benefits. Silva et al. (2005) reported that N fertilization at booting and silking stages caused significant increments in grain yield and kernel crude protein content. Furthermore, Scharf et al. (2002) observed significant increase in maize yield when N was applied in split form. Split application of N during the growing season is considered an important agronomic practice to enhance crop utilization (Boman et al., 1995). Mariga et al. (2000) reported that yield of maize considerably increased when N was applied up to the tassel initiation stage. Gehl et al. (2005) observed that maize N uptake improved and grain yield increased with split N fertilization compared to one single application at planting under irrigation system. Mungai et al. (1999) found that application of N in two splits at V_6 and R_1 stages gave significantly more yield than other modes of N regimes. Hammons (2009) reported that the maximum N uptake by maize occurs during the month prior to tasseling and silking.

Crop phenology is one of the most important aspects of crop yield determination (Carcova, Oteguai, 2001). Therefore, it is essential to predicting physiological responses under varying field conditions. Gungula et al. (2007) noted that there will be more synchrony in flowering with application of higher N. Dolan et al. (2006) reported that higher nutrient availability and favourable soil conditions due to organic source of N may delay phenology. Khaliq et al. (2008) stated that application of N delays the silking of maize crop. Moreover, Gungula et al. (2007) reported increased physiological maturity with increasing levels of N in open pollinated varieties of maize. Increases in N rates significantly delay the duration of the vegetative and reproductive period that results in high grain yield (Namvar, Seyed Sharifi, 2011).

It is important to develop and identify the proper fertilization strategies for various crops that enhance the competitive ability of the crop, maximize crop production, and reduce the risk of nonpoint source pollution from fertilizers. Moreover, most of the farmers use high amount of N fertilizer haphazardly, since there is little information available on the time and rate of N application on agro-physiological traits of corn. But it is important to elucidate the effects of different agronomical factors on these parameters in order to improve crops agronomic performances. So, this research work was conducted to investigate the effects of time and rate of N application on phenology, nitrogen use efficiency, and some agronomical traits of corn.

MATERIALS AND METHODS

The effects of time and rate of nitrogen application on phenology and some agronomical traits of corn (*Zea mays* L.) were investigated at the research farm of the University of Mohaghegh Ardabili during spring season. The trial was laid out in a split plot design based on a randomized complete block scheme with three replications. Experimental factors were nitrogen fertilizer at four levels (0, 75, 150, and 225 kg ha^{-1}) in the main plots applied in the urea form and three levels of nitrogen application time [($^1/_3$ at sowing + $^1/_3$ at V_{8-10} + $^1/_3$ at tasseling), ($^1/_2$ at sowing + $^1/_2$ at tasseling), and ($^1/_2$ at sowing + $^1/_4$ at V_{8-10} + $^1/_4$ at tasseling) as T_1, T_2, and T_3, respectively] as subplots.

The area is located at 38°15'N latitude and 48°15'E longitude with an elevation of 1350 m above mean sea level. Climatically, the area is placed in the semiarid temperate zone with cold winter and hot summer. Average rainfall was about 254.3 mm that mostly concentrated between winter and spring. Mean temperature and precipitation of the corn growing season are presented in Figure.

The field was prepared well before sowing by ploughing twice with a tractor followed by

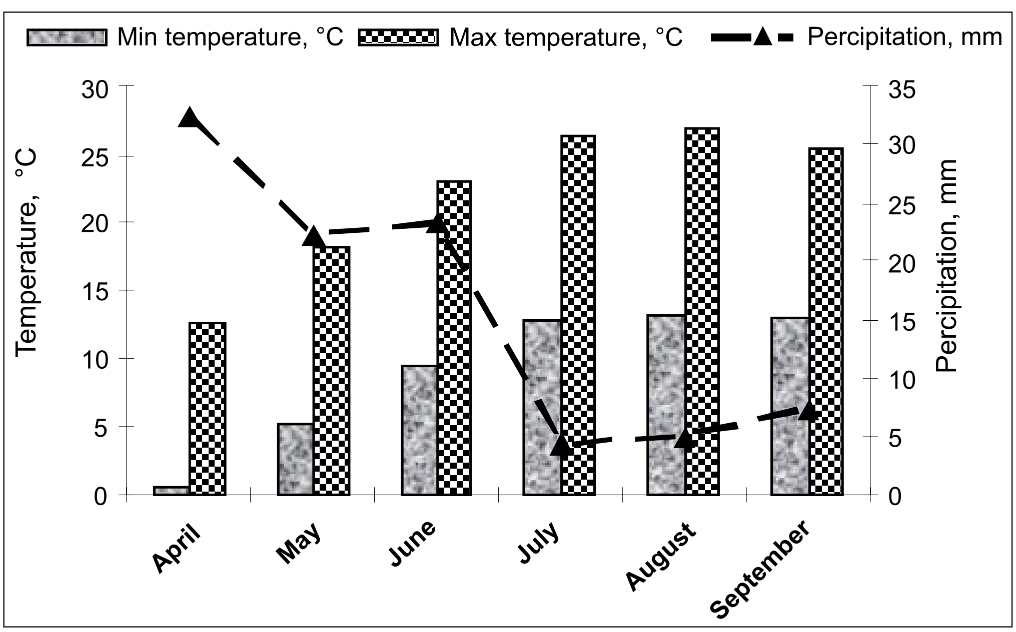

Figure. Minimum and maximum temperatures and rainfall recorded during the growth period of corn planking to make a fine seed bed. All phosphorous (100 kg ha^{-1} in the form of super phosphate) and potassium (100 kg ha^{-1} in the form of potassium sulphate) fertilizers were applied as a basal dose at the time of seedbed preparation. Irrigation, weeding and all other agronomic practices, except those under study, were kept normal and uniform for all treatments. Prior to crop sowing, soil samples were collected from a depth of 50 cm with a soil auger and analyzed for various physico-chemical properties, and test results are presented in Table 1.

In each plot there were 5 rows 4 m long. Plots and blocks were separated by 0.75 m unplanted distances. Seed placement was done by hand in individual hills at inter-row and intra-row spacing of 75 × 13.3 cm. Corn seed (var. Cordona) was planted in the second week of May. Two seeds were sown per hill and two weeks after emergence and at 4–5 leaves stage thinned to one plant per hill. The field was immediately irrigated after planting to ensure uniform germination.

Yield components and some morphological traits

The number of grains rows, number of grains per ear row, and number of grains per ear at all the treatments in each replication were measured with ten randomly selected plants from the three central rows, and then the average was calculated.

Nitrogen use efficiency

This trait was determined for each treatment using the agronomic efficiency (*AE*) index (Dobermann, 2007):

$$AE = (Y - Y_0) / F,$$

where F is the amount of (fertilizer) applied nutrient (kg ha^{-1}), Y is the crop yield with applied nutrient (kg ha^{-1}), and Y_0 is the crop yield (kg ha^{-1}) in a control treatment without nutrient.

Grain yield

For determination of grain yield, 2 m from each of three central rows were harvested in all plots. The ears were dehusked, dried and then threshed. The total grain weight for the sampled material was recorded and converted into grain yield (kg ha^{-1}).

Days to silking, tasseling and tasseling-silking interval

Silking refers to the stage when silk emerged on 50% of the observed plants. Tasseling was reached when 50% of the plants shed pollen from the main branch of the tassel and from a few other branches. Silking date was recorded when 50% of the plants had extruded silks. The anthesis-silking interval (ASI) is the number of days from anthesis to silking. It was calculated as a difference between the recorded anthesis and silking dates. On the other hand, the ASI was estimated counting the difference in the number of days required for 50% of the plants within each plot to present pollen shed and 50% of the plants to have visible silks.

Days to physiological maturity

The appearance of a black layer in seeds was used as a criterion for physiological maturity. It was determined by counting the number of days from the planting date to harvesting time.

The data recorded were statistically analyzed by using computer software SAS (ver 9.1). Analysis of variance technique was used to test the significance, and LSD (least significant difference) at 5% probability level was used to compare the treatment means.

Table 1. Soil physicochemical properties at a depth of 0–50 cm

Texture	Sand (%)	Silt (%)	Clay (%)	$CaCO_3$ (%)	Organic Carbon (%)	Total N (%)	Exchangeable K (mg kg^{-1})	Extractable P (mg kg^{-1})	pH	SP
Silt loam	35	42	23	14.45	0.026	0.062	212	29.8	7.83	49

RESULTS AND DISCUSSION

As shown in Table 2, the rate and N application time had significant effects on phenolgy, yield and some agronomic traits of corn.

Plant height

The rates and time of N application significantly affected plant height. It increased with increasing N rates. So, the maximum plant height (185.2 cm) was obtained with the highest N rate (225 kg N ha^{-1}), while the least value (151.2 cm) was recorded in plots without N application. Similar results have been reported by Torbert et al. (2001). Increase in plant height due to more N may be attributed to better vegetative development that resulted in increased mutual shading and internodal extension. The comparison of means indicated that the maximum plant height (180.4 cm) was recorded for N application time as T_1 and the minimum value (161.8 cm) was recorded for T_2 (Table 2). Thakur et al. (1997) suggested that higher N application increased cell division, cell elongation, nucleus formation as well as green foliage. Increase in plant height may also be due to prolonged vegetative growth which increased the plant height. So, the comparison of means showed that days to tasseling or vegetative growth period increased when N rates were enhanced (Table 2). The increase of the N fertilization rate from 0 to 225 kg ha^{-1} induced a statistically significant increase of the days to tasseling from 58.8 to 62.73 days. Similar results have been reported by Bakht et al. (2006).

Number of grains ear^{-1}

The response of the number of grains ear^{-1} to N rates and application time was significant (Table 2). The comparison of means of N rates × application time indicated that the highest values of the number of grains ear^{-1} (502) were recorded with 225 kg N ha^{-1} when applied in three equal splits (T_1), and the least (350) was recorded under N-control treatment. Our results concur partly with observations made by Torbert et al. (2001) who reported that the grain number increased with increasing N rates. Increase in the number of grains ear^{-1} at higher N rates might be due to the lower competition for the nutrient allowing the plants to accumulate more biomass with higher capacity to convert more photosynthesis into sinks resulting in more grains ear^{-1} (Zeidan et al., 2006). Uribelarrea et al. (2009) suggested that the effect of N stress on grain number occurs indirectly through effect on photosynthesis and also via its effect on phenology stages such as physiological maturity, silking date, and anthesis-silking interval. So, in this experiment maize took more time to silking (67.28 days) and physiological maturity (127.33 days) in plots that received the highest rate of N (225 kg N ha^{-1}) and it was vice versa in the anthesis–silking interval (Table 2). Bolaños and Edmeades (1996) suggested that decrease in the anthesis-silking interval or close synchrony between male and female inflorescence is desirable to improve the number of grains ear^{-1}. These results are in conformity with the results obtained by Mariga et al. (2000). The greater number of grains ear^{-1} with higher N rates might have resulted from the greater assimilates partitioning to the grains as a result of a longer growth period, delay in phenology stages such as physiological maturity, decrease in the anthesis-silking interval, and higher photosynthate availability during the grain filling period (Amanullah et al., 2009).

Number of grain rows ear^{-1}

The data recorded on the average number of grain rows ear^{-1} is presented in Table 2. Statistical analysis of the data revealed that N rates and interaction of N rates × N application time are not significant. Similar results have been reported by Roy and Biswas (1992) who reported that N rates and their application time had no significant effect on the number of grain rows ear^{-1}. It seems that environmental factors have a low influence on the number of grain rows and this trait is significantly affected by genetic factors compared with other sources.

Number of grains per ear row

The data regarding the effects of rates and N application time on the number of grains per ear row are given in Table 2. The maximum number

Table 2. Comparison of means of N application time and rates on phenology and some agronomic traits of corn (*Zea maize* L.)

Treatments	GY, kg ha^{-1}	NGR	NGER	NGE	GTW, g	HI, %	PH, cm	CL, cm	GPC, %	50% Tasseling, day	50% Silking, day	ASI, day	Physiological maturity, day	NUE
Nitrogen rates (kg ha^{-1})														
$N_0 = 0$	4744.8 c	15.3 a	24.7 c	348.4 c	151.3 c	33.7 c	151.2 c	15.8 d	9.9 c	58.8 d	63.5 c	5.3 d	121.5 d	–
$N_1 = 75$	5535.3 b	15.0 a	25.9 b	392.6 b	158.3 b	36.8 b	159.2 b	18.3 c	12.3 b	59.6 c	64.6 b	4.9 a	123.6 c	31.1 a
$N_2 = 150$	7160.9 a	15.7 a	29.6 a	464.8 a	173.5 a	40.2 a	183.9 a	20.8 b	14.2 a	60.1 b	64.8 b	4.7 b	126.2 b	27.5 b
$N_3 = 225$	7355.5 a	15.8 a	30.0 a	472.9 a	174.6 a	41.4 a	185.2 a	22.0 a	14.6 a	62.7 a	67.2 a	4.5 c	127.3 a	19.4 c
LSD ($p < 0.05$)	**506.38**	**1.1477**	1.058	22.07	4.58	1.39	6.89	1.12	0.855	0.3418	0.293	0.0543	0.410	3.28
Significance	**	ns	**	**	**	**	**	**	**	**	**	**	**	**
Application time														
T_1	6598.3 a	15.3 a	28.5 a	438.9 a	166.7 a	39.1 a	180.4 a	20.1 a	12.9 a	61.9 a	66.4 a	4.5 c	126.7 a	31.0 a
T_2	5884.4 c	15.0 a	26.9 b	405.4 c	162.7 c	37.3 b	161.8 c	18.6 c	12.5 c	59.8 c	64.7 c	4.9 a	124.2 c	21.4 b
T_3	6114.7 b	15.2 a	27.2 b	414.7 b	163.8 b	37.6 b	167.5 b	19.1 b	12.7 b	60.7 b	65.5 b	4.7 b	126.2 b	25.5 c
LSD ($p < 0.05$)	**165.2**	**0.693**	**0.385**	**7.84**	**0.936**	0.437	4.32	0.346	0.0907	0.3418	0.261	0.0342	0.216	2.23
Significance	**	ns	**	**	**	**	**	**	**	**	**	**	**	*
Interaction (N × T)														
Control	4800 f		24.7 e	350.0 g	152.3 e	34.0 f	–	16.1 f	10.1 c	56.2 g	61.5 h	5.3 a	121.5 g	–
N_1T_1	6250 d	–	27.5 d	420.2 e	162.3 b	38.5 c	–	19.3 d	12.2 b	60.7 d	65.3 de	4.6 ef	124.0 e	41.9 a
N_1T_2	5000 ef	–	25.6 e	387.1 f	151.0 e	35.2 e	–	17.8 e	11.8 b	58.5 f	63.7 g	5.2 b	122.7 f	22.6 de
N_1T_3	6500 e	–	25.6 e	391.0 f	157.2 c	36.3 d	–	18.4 e	12.3 b	59.8 e	64.8 ef	5.1 c	124.2 e	28.8 b
N_2T_1	7500 b	–	32.0 a	500.1 ab	155.6 cd	42.0 a	–	22.3 b	14.1 a	61.2 cd	65.7 d	5.0 c	127.3 bc	29.2 b
N_2T_2	6800 c	–	28.5 c	442.3 d	175.7 a	41.2 a	–	21.1 c	14.0 a	59.2 ef	64.2 fg	5.1 c	124.6 de	25.4 cd
N_2T_3	7250 bc	–	30.0 b	478.1 c	174.2 a	41.4 a	–	21.5 bc	14.2 a	59.9 e	64.7 f	4.8 d	126.8 c	27.9 bc
N_3T_1	7700 a	–	32.2 a	502.0 a	174.3 a	42.1 a	–	24.0 a	14.3 a	63.8 a	68.2 a	4.5 h	128.9 a	22.0 e
N_3T_2	7100 c	–	30.2 b	479.2 c	172.4 a	39.8 b	–	21.8 bc	14.1 a	61.7 c	66.4 c	4.7 d	125.3 d	16.3 f
N_3T_3	7300 bc	–	30.3 b	483.4 ab	173.5 a	39.5 bc	–	22.2 b	14.11 a	62.6 b	67.5 b	4.5 fg	127.8 b	19.7 e
LSD ($p < 0.05$)	**365.28**	–	**0.931**	18.13	3.47	1.01	–	0.838	0506	0.747	0.645	0.1097	0.808	2.25
Significance	**	ns	**	*	*	*	ns	*	**	**	**	**	**	*

GY – grain yield, NGR – number of grains rows, NGER – number of grains per ear row, NGE – number of grains per ear, GTW – grain thousand weight, HI – harvest index, PH – plant height, CL – cob length, GPC – grain protein content, ASI – anthesis-silkinkg interval, NUE – nitrogen use efficiency. $T_1 = (^1/_3$ at sowing + $^1/_3$ at $V_{8–10}$ + $^1/_3$ at tasseling); $T_2 = (^1/_2$ at sowing + $^1/_2$ at tasseling); $T_3 = (^1/_2$ at sowing + $^1/_4$ at $V_{8–10}$ + $^1/_4$ at tasseling). Mean values followed by same letters in each column showed no significant difference. *, **, and ns showed significant differences at 0.05, 0.01 probability levels, and no significant, respectively.

of grains per ear row (30) was recorded at application of 225 kg N ha^{-1} and the minimum values of this trait (24.7) were recorded at control treatment. The comparison of means of rates × N application time indicated that the highest value (32.2) was recorded at application of 225 kg N ha^{-1} as T_1, and the minimum number of grains per ear row (24.7) was recorded at the control plot (Table 2). A greater number of grains per ear row with higher N rates might have resulted from the greater assimilates partitioning to the seeds as a result of a longer growth period and higher photosynthate availability during the grain filling period (Amanullah et al., 2009). Dawadi and Sah (2012) suggested that decrease in the number of grains per ear row under lower N application might be attributed to poor development of sinks and reduced translocation of photosynthates. In this study, high N rates delayed the appearance of phonological stages, and it seems that can be one of the reasons for increasing the number of grains per ear row. Similar results have been reported by Mariga et al. (2000).

Days to 50% silking

Maize took more time to silking and physiological maturity in plots that received the highest rate of N application in three equal splits. Increasing N level increased days to 50% silking (Table 2). A similar trend (as for tasseling) for silking was observed regarding N fertilization and was delayed by all N treatments as compared to the control. The comparison of means indicated that the maximum of days to 50% silking (68.2 days) was recorded at application of 225 kg N ha^{-1} as T_1, and the minimum (61.56 days) was recorded at control treatment (Table 2). Similar results are reported by Dolan et al. (2006) who stated that higher nutrient availability and favourable soil conditions due to N fertilizer may cause vigorous crop growth and delay phenology such as silking. Our results are in line with the findings of Khaliq et al. (2008) and Namvar and Seyed Sharifi (2011) who observed that phenological events were significantly delayed by the increasing rate of mineral N than by other sources.

Anthesis-silking interval (ASI)

The N application time and rates significantly affected the anthesis-silking interval. The maximum ASI was recorded at application of N as T_2 (4.96 days), and the minimum of this trait was recorded at application of N as T_1 (4.5 days). Plots that were not treated with N fertilizer took more days (5.3 days) to ASI. A shorter ASI with higher N was because of inducing early and rapid growth. Gungula et al. (2007) reported that there will be more synchrony in flowering with higher nitrogen. Bolaños and Edmeades (1996) showed that close synchrony between male and female inflorescence is desirable to improve grain yield and yield components. An asynchronous flowering may limit grain production per ear due to lack of pollen, loss of silk receptivity or early kernel abortion caused by dominance of early formed ovaries from the base of the ear on the late formed from the tips (Carcova, Otegui, 2001). So, the results indicated that the minimum of ASI (4.35 days) was recorded at application of 225 kg N ha^{-1} as T_1, and the maximum of it (5.36 days) was recorded at control treatment (Table 2). In agreement with the results of the present study, decrease in ASI has been reported with increasing of N levels by Gokmen et al. (2001) and Akbar et al. (2002).

Days to physiological maturity

The data along with the comparison of means are presented in Table 2, which indicates that the time and rate of N application had a significant effect on days to physiological maturity. The process of physiological maturity was delayed by the time and rate of N application and their combinations as compared to the control. Days to maturity were delayed significantly with the high levels of 150 and 225 kg N ha^{-1} (Table 2). The comparison of means of N application time effect on days to maturity showed that N splits as T_1 delayed maturity as compared to T_2 and T_3 (Table 2). These results are in line with N application time and rate effects on days to tasseling and silking. The prolonged stages of days to maturity due to rates and time of N application were reported by Dolan et al. (2006) who showed that higher nutrient availability and favourable soil conditions due to N fertilizer could be a possible reason for delayed phenology in N-treated plots. Namvar and Seyed Sharifi (2011) reported that increasing in N rates significantly delays the duration of the vegetative and reproductive period what is a proof of the lengthening of the time to maturity.

Cob length

Cob length generally declined with decreasing of N rates. Application of 225 kg N ha^{-1} had the longest cob, and the shortest was recorded without N application. Moreover, the longest cob was produced at N application time as T_1 (20.1 cm), and the shortest was at application time as T_2 (18.6 cm). The interaction of application time × N rates was significant. The maximum cob length (22.3 cm) was obtained at application of 225 kg N ha^{-1} as T_1, and the minimum of it (16.1 cm) was recorded at control treatment (Table 2). A significant increase in maize cob length with N application over control was reported by Turgut (2004).

Harvest index

The physiological efficiency and ability of a crop for converting the total dry matter into economic yield is known as the harvest index (HI). N rates showed significant difference for the HI. The comparison of means indicated that the maximum harvest index (42.1%) was recorded at application of 225 kg N ha^{-1} as T_1, and the minimum of it (34.2%) was recorded at control treatment (Table 2). Lawrence et al. (2008) and Zeidan et al. (2006) reported that the harvest index in corn increases when N rates increase.

Grain protein content

There were significant differences between different treatments in grain protein content (Table 2). The comparison of means of N rates × application time indicated that the maximum of grain protein content (14.3%) was recorded at application of 225 kg N ha^{-1} as T_1, and the minimum value of this trait (10.1%) was recorded without N application (Table 2). It seems that the availability of N in the grain filling stage of corn increased grain protein content. Patel (2004) reported that application of N in split doses increased grain protein content by 1.55%. Furthermore, Triboi et al. (2000) reported that N supply is the most important environmental factor affecting protein content and composition.

Nitrogen use efficiency (NUE)

The results indicated that NUE decreased with increasing N rate. The comparison of means indicated that the highest NUE (41.92 kg kg^{-1}) was recorded at application of 75 kg N ha^{-1} as T_1, and the lowest of it (16.38 kg kg^{-1}) was recorded at 225 kg N ha^{-1} as T_2 (Table 2). These results agree with the finding of Raun and Johnson (1991) who reported that high rates of N decrease NUE in cereal. Lopez-Bellido and Lopez-Bellido (2001) indicated that decrease in NUE with increasing fertilizer rates is because yield rises less than the N supply in soil and fertilizer. Sower et al. (1994), Limon-Ortega et al. (2000), and Zhao et al. (2006) reported similar results and indicated that NUE decreased with increases in N rate. Limon-Ortega et al. (2000) stated that generally NUE decreases with increasing of N fertilizer rate, but increases yield and N loss.

Grain yield

Grain yield is the main target of crop production. The grain yield was significantly affected by both N application time and rates. N rates significantly increased the grain yield. The grain yield varied between 4744.8 kg ha^{-1} without N application to 7355.5 kg ha^{-1} at application of 225 kg N ha^{-1} (Table 2). A similar trend in yield differences across N rates has been reported by Zeidan et al. (2006). Our findings are in agreement with observations made by many researchers such as Lawrence et al. (2008) who reported that grain yield increased with increasing N rates. Results of interaction effects of rates and N application time indicated that the maximum grain yield (7700 kg ha^{-1}) was obtained at application of 225 kg N ha^{-1} as T_1, and the minimum (4800 kg ha^{-1}) was recorded at control treatment (Table 2). Mariga et al. (2000) and Scharf et al. (2002) reported that grain yield in maize increases with increasing of rate and split application for N. The increase in grain yield at the high N rates application might be due to the delay in the maturity period, decrease in the number of barrenness plants, and increase in the number of seeds per ear. These results are in conformity with the results obtained by Subedi and Ma (2005) who reported a significant increase in maize yield with N split application. Akbar et al. (1999) showed that N application with increase in split application proved an additional source for a higher rate of photosynthesis and transport of photo-assimilates during grain filling that resulted in a higher grain yield of maize. Namvar and Seyed Sharifi (2011) stated that increases in N rates significantly delay the duration of the vegetative and reproductive period and could be possible a reason for increasing of grain yield. Dolan et al. (2006) indicated that higher nutrient availability and favourable soil conditions due to N could be a possible reason for delayed phenology in N-treated plots.

CONCLUSIONS

There are several causes of low productivity of corn. Among them, mismanagement of plant nutrition, such as rate and N application time, can be one of reasons for decrease in grain yield. According to the results of this study, application of higher rates of N (225 kg ha^{-1}) and about 50% more than the recommended N rate (150 kg N ha^{-1}) with three splits resulted in the maximum yield of maize. So, the highest values of yield, yield components, and phenology stages (except for the gap time between anthesis and silking) were observed at high levels of N application (225 kg N ha^{-1}) in equal splits as ($^1/_3$ at sowing + $^1/_3$ at $V_{8–10}$ + $^1/_3$ at tasseling).

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AZOTO KIEKIO IR VEIKIMO LAIKO POVEIKIS FENOLOGIJAI IR KAI KURIOMS AGRONOMINĖMS KUKURŪZŲ (*Zea mays* L.) SAVYBĖMS

Santrauka

Dirvožemio derlingumo išsaugojimas ir augalų maistinių medžiagų pakankamų bei subalansuotų kiekių naudojimas yra vienas svarbiausių veiksnių, didinančių derlių ir mažinančių nepalankius aplinkos veiksnius bei taršą, atsiradusią naudojant pasklidąjį tręšimą. Azoto veikimo laiko ir kiekio poveikis fenologijai bei kai kurioms agronominėms kukurūzų (*Zea mays* L.) savybėms buvo tiriamas Mohaghegh Ardabili (Iranas) universiteto mokslinių tyrimų ūkyje. Tyrimas atliktas atskiruose sklypuose remiantis atsitiktinio visiško blokavimo schema ir trimis pakartojimais. Pasirinkti šie eksperimentiniai veiksniai: trijų lygių azoto tręšimas (0,75, 150 ir 225 kg / ha) pagrindiniuose sklypuose ir trijų lygių azoto veikimo laikas (T_1 = $^1/_3$ sėjant + $^1/_3$ esant $V_{8–10}$ + $^1/_3$ burbuolėms formuojantis; T_2 = $^1/_2$ sėjant + $^1/_2$ burbuolėms formuojantis; T_3 = $^1/_2$ sėjant + $^1/_4$ esant $V_{8–10}$ + $^1/_4$ burbuolėms formuojantis). Rezultatai rodo, kad sklype, kuris tręštas 225 kg / ha azotu, o azoto veikimo laikas T_1, buvo didžiausias kukurūzų derlius; kiti duomenys – 63,85 dienos iki 50 % burbuolių formavimosi, 68,2 dienos iki 50 % šilko tarpsnio, 128,9 dienos iki fiziologinės brandos. Maksimalus naudojamo azoto efektyvumas (38,16 kg / kg) buvo gautas veikiant 75 kg azoto / ha ir esant T_1 azoto veikimo laikui, o mažiausia šio indekso vertė (19,41 kg / kg) buvo gauta veikiant 225 kg azoto / ha azoto ir esant T_2 veikimo laikui. Remiantis gautais rezultatais padaryta išvada, kad tręšiant didžiausiu azoto kiekiu (225 kg / ha) trimis lygiomis dalimis (T_1) gaunama gausiausia kukurūzų produkcija.

Raktažodžiai: kukurūzas, kukurūzų derlius, azoto naudojimo efektyvumas, fenologija, fiziologiniai bruožai, derliaus komponentai