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Full Length Research Paper

Nitrogen rate and plant population effects on yield and yield components in soybean

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This research was carried out to determine the effect of plant population and nitrogen rates on yield and yield components in soybean under Bursa, Mustafakemalpaşa ecological conditions. Trials were conducted during 2000 and 2001 at the experimental fields of the Mustafakemalpaşa Vocational High School, University of Uludag. Soybean cultivar A-3935 was tested at four plant densities (70 × 5, 70 × 10, 70 × 15 and 70 × 20 cm) and four different nitrogen doses (0, 30, 60 and 90 kg ha^{-1}). Plant height, lowest pod height, number of branches per plant, pod number per plant, yield per plant, harvest index, 100 seed weight and seed yield were researched in this experiment. It was observed that increase in plant density and nitrogen rate increased plant height, lowest pod height, harvest index and seed yield. Otherwise, the number of branches per plant, pod number per plant, yield per plant and 100 seed weight decreased as plant density and nitrogen rate increased.

Key words: Soybean, plant density, nitrogen doses, yield and yield components.

INTRODUCTION

Soybean (*Glycine max.* L.) is one of the most important oilseed crops in the world. It contains 18-22 % oil and 40-42 % protein (Mounts et al., 1987). Soybean is grown on an area of 14 000 hectares with an annual production of 50 000 tones given an average yield of 3571 kg per hectare in Turkey (FAO/STAT, 2004).

Row spacing and plant population recommendations may vary for each location. Seed yield increases with decreasing row spacing, up to a point (Oplinger and Philbrook, 1992), and declines when plant density is further decreased (Board and Harville, 1996). Plant population is a production factor which affects light interception by plant canopy (Board, 2001).

Plant height declines with reduced plant population. Stem sections of plants that receive more light usually tend to have slower elongation rates (Garrison and Briggs, 1972). The greatest plant height was obtained in a 30-cm row width, while the lowest was obtained in a 70 cm row width. First pod height values varied between 15.5 and 21.6 cm (Caliskan et al., 2007). First pod height effects harvest losses in soybean (Cober et al., 2000). Pods too close to the soil surface increase harvest losses since some combine harvester heads are unable to pick up the first pods (Caliskan et al., 2007).

Increased plant populations decrease number of side branches (Pawlowski et al., 1993; Ibrahim and Hala, 2007; Caliskan et al., 2007), pod number per plant (Shafshak et al., 1989), seed yield per plant (Shafshak et al., 1989; Pawlowski et al., 1993), 100 seed weight (Pawlowski et al., 1993), harvest index (Spaeth et al., 1984) while yield components such as first pod height (Palmer and Privette, 1992; Kolpak, 1992; Pawlowski et al., 1993), seed yield per hectare (Caliskan et al., 2007) were increased. Harvest index of smaller plants was less than for larger plants, but these smaller plants have little influence on total crop yield and harvest index (Spaeth et al., 1984).

According to Duncan (1986), there are three phases in the response of soybean yield to increased plant population. At very low plant population (1–2 plants m^{-2}) there is no interplant competition and yield per plant is maximized (Phase 1). Phase 1 ends and Phase 2 begins as plants compete with one another for needed resources. Phase 3 is characterized by a positive relationship to increased plant population, although marginal yield increases are smaller for each additional plant. This relationship continues for plant populations greater than those required to intercept all (i.e., ≥95%) of the available

ble photosynthetically active radiation (PAR), indicating that complete interception of PAR does not guarantee attainment of maximum yield. Finally, in Phase 3, soybean yield per unit ground area is maximized, and there are no further increases in soybean yield for increased plant population. Purcell et al. (2002) demonstrated that yield did not continue to increase at high population densities (Phase 3) because of the decreased radiation use efficiency.

Harvest index (HI) values generally increased slightly with increased plant population in MG 00 and 0 soybean, decreased slightly with increasing plant populations in MG 4 and 6 soybean, and had no response to increasing plant populations in MG 1 through 4 soybean (Edwards and Purcell, 2005).

In soybean the advantages for higher plant density generally are: increased yield, reduced erosion, increased harvesting efficiency and early crop canopy closure to help control weeds

Nitrogen is one of the most important nutrient elements affecting the yield of soybean (Penas and Wiese, 1987). Nitrogen requirement for soybean are typically met by a combination of soil-derived nitrogen and nitrogen provided through the process of symbiotic fixation from Rhizobia bacteria in root nodules. The relative nitrogen supply from these two sources can change widely depending on soil nitrogen supply and conditions for nodule development (Varco, 1999; Gan et al., 2003). Field studies measuring soybean response to applied N have been conducted by several researchers. N fixation alone cannot meet the N requirement for maximizing soybean yield. Best timing for N top-dressing during reproduction is at the flowering stage, which increased seed yield by 19 and 21%, compared to the treatment without N top dressing (Gan et al., 2003).

Nitrogen increases yield by influencing a variety of agronomic and quality parameters. In general, there was an increase in plant height and dry matter accumulation per plant in soybean (Manral and Saxena, 2003). Varon et al. (1984) reported an increase in plant height with the application of nitrogen fertilizer.

Grain yield response of soybean to the nitrogen application may be because nitrogen plays an important role in the synthesis of chlorophyll and amino-acids which are the indispensable ingredients of the process of autotrophization. Nitrogen influenced grain yield through source–sink relationships resulting in higher production of photosynthates and their increased translocation to reproductive parts (Tripathi et al., 1992).

Soybean without nodules or with ineffective nodules will respond to nitrogen like any other crop. Since legumes have the ability to fix nitrogen, inoculating soybean seed just before planting is important, especially on fields that have not recently been planted to soybean (Berglund and Helms, 2003).

The aim of the present work is to study the effect of nitrogen doses, plant density and their interaction on yield and yield components of soybean.

MATERIALS AND METHODS

A field study was conducted to determine the effect of different row spacing and nitrogen levels on the agronomic traits of soybean cultivar A-3935 at the Mustafakemalpasa Vocational School, University of Uludag, Bursa, Turkey (40°02'M, 28°24' E and altitude 25 m above sea level) on a clay soil having 0.1% total nitrogen content, 0.41 kg ha^{-1} phosphorus, 7.70 kg ha^{-1} exchangeable potassium and 3.0% organic matter.

Field experiments were arranged in a randomized complete block design in factorial fashion with three replications. The row spacings were 70 x 5 cm (280 571 plant ha^{-1}), 70 x 10 cm (140 286 plant ha^{-1}), 70 x 15 cm (93 523 plant ha^{-1}) and 70 x 20 cm (70 143 plant ha^{-1}) while the nitrogen rates comprised control (0 kg N ha^{-1}), 30, 60, and 90 kg N ha^{-1} . The net plot size measured 2.8 x 4.0 m. Half N and full P_2O_5 (50 kg ha^{-1}) was applied as a basal dose and remaining half N was applied at flowering (R_2).

Seeds were planted by hand on 20 April, 2000, and 21 April, 2001. Previous crop of the trial field was canola in both years. Seeds were not inoculated. Three hoeings were given to keep the crop free of weeds. Irrigation was applied four times (V_4, R_2, R_4 and R_6) with a rotary sprinkler to maintain the soil near field capacity. The timing of irrigation was estimated visually as the soil surface dried. Plant population was maintaned by thinning.

The local climate is temperate, summers are hot and dry, and winters are mild and rainy. Mustafakemalpaşa is located in the southern Marmara region of Turkey with an average annual rainfall of 703 mm and 14.6 °C mean monthly air temperature. Total monthly precipitation and mean air temperature data during the soybean of growing period are presented in Table 1. Total rainfall from April to September were 276.1 and 224.8 mm in 2000 and 2001, respectively. This corresponds to 39.2 and 31.9%, respectively, of the annual precipitation. Mean air temperature during the flowering of soybean was approximately 21. 8 and 23.6°C in 2000 and 2001, respectively (Anonymous, 2001).

Ten plants were randomly selected and harvested at maturity (Sep. 15, 2000 and Sep.18, 2001) from the second and third rows. After harvesting, plants were left in the field for sun drying for about three days then threshed. In this plants using, plant height, first pod height, number of branches per plant, pod number per plant, yield per plant, harvest index, 100 seed weight and seed yield were researched. Seed yield was calculated over all plants in the plot.

RESULTS AND DISCUSSION

The data pertaining to different agronomic traits are given in Tables 2 and 3. Nitrogen rate, plant density and their interaction significantly affected agronomic traits in soybean. All traits were individually examined.

Plant height

Nitrogen rate and plant density influenced plant height of soybean significantly over control. As nitrogen rate increased, plant height increased (Table 2). Similiar results were reported by Varon et al. (1984), Manral and Saxena (2003) and Starling et al. (1998).

Maximum plant height (96.9 cm) was recorded at plant density row spacing of 70 x 5 cm against the minimum (67.4 cm) at 70 x 20 cm row spacing. The most higher plant heights were measured 90 $kgha^{-1}$ nitrogen x 70 x 5 cm (104.4 cm), 90 $kgha^{-1}$ nitrogen x 70 x 10 cm (103.4

Table 1. Monthly mean temperatures and total rainfalls during the growing period of soybean in 2000 and 2001 at the Mustafakemalpasa.

Month	Temperature (°C)		Precipitation (mm)	
	2000	2001	2000	2001
April	15.0	13.7	108.8	86.4
May	17.7	18.2	48.9	65.0
June	21.8	23.6	16.1	16.7
July	25.5	27.7	9.4	1.7
August	24.8	26.5	11.1	13.1
September	21.2	22.6	81.8	41.9
Total			276.1	224.8

cm) and 60 kgha^{-1} nitrogen x 70 x 5 cm (102.7 cm). Our findings were similiar to findings of Cooper (1977), Boerma and Ashley (1982), Piggot and Farrel (1983), Kutlu et al. (1991), Board and Harville (1996), Bullock et al. (1998), Christmas (2002) and Yilmaz (2003).

Lowest pod height

Lowest pod height was significantly affected by nitrogen rate and plant density. Generally, increasing doses of the nitrogen raised lowest pod height. Nitrogen applied at 90 kgha^{-1} resulted in maximum lowest pod height (14.1 cm) compared to the minimum (11.4 cm) in control. Similar results have been reported by Kutlu et al. (1991), Kolpak (1992) and Yilmaz (2003).

Row spacing significantly affected lowest pod height. Among the row spacings, 70 x 5 cm gave significantly higher lowest pod height (14.1 cm) while 70 x 10 cm, 70 x 15 cm and 70 x 20 cm row spacings gave 14.1, 12.3 and 10.0 cm, respectively.

A typical harvest cutting height for soybean is between 7.5 and 12.5 cm above the soil surface (Grabau and Pfeiffer, 1990); therefore, if the lowest fertile node is below this harvest height, significant harvest losses can occur. The height of lowest fertile node generally increased as soybean plant population went up (Christmas, 2002; Edwards and Purcell, 2005).

Number of branches

Nitrogen rate affected branch number. N rate of 90 kg ha^{-1} nitrogen application had the highest branch number (7.0 plant^{-1}), and control had the lowest (6.0 plant^{-1}) values of number of branches. Increase in branches per pod with increasing doses of nitrogen were observed by Orellana et al. (1990) and Christmas (2002).

Number of branches significantly varied among plant densities. Maximum number of branches plant $^{-1}$ (7.9 plant $^{-1}$) was produced at the row spacing of 70 x 20 cm, followed by 70 x 15 cm row spacing which produced 7.1 branches per plant. The least value was measured at 70 cm x 5 cm (5.5 plant^{-1}). Parallel findings to our results have been obtained (Tunio et al., 1983; Bullock et al., 1998; Berglund and Helms, 2003; Yilmaz, 2003).

The nitrogen rate x row spacings interaction effects, the number of branches increased while plant density of a unit area decreased. Maximal values were measured at 70 x 20 cm row spacing (Table 2).

Pod number per plant

A perusal of Table 2 indicates that different nitrogen doses, plant density and interaction between them significantly affected pod number per plant. The treatment 90 kg ha^{-1} produced maximum pod number per plant (136.9 plant^{-1}), followed by 60 kg, 30 kg ha^{-1} and control treatments gave 128.2, 118.4 and 96.4 plant^{-1}, respectively. These findings are in agreement with those of Jayapaul and Ganesaraja (1990).

Different plant densities significantly affected the pod number per plant. Pod number per plant decreased while plant number of in unit area increased. The row spacing of 70 x 20 cm produced maximum (151.1 plant^{-1}) and 70 x 5 cm minimum pod number per plant (87.6 plant^{-1}). Our pod number per plant values generally concur with those of several earlier reports (Bullock et al., 1998; Kutlu et al., 1991; Christmas, 2002; Yilmaz, 2003).

Seed yield per plant

Nitrogen rate had no effect on seed yield per plant across all N rates. Increasing the population reduced yield per plant but increased yield per unit area (Ball et al., 2000).

The maximum seed yield per plant was measured on 70 x 05 cm of row spacings (35.2 g). Minimum seed yield per plant (13.1 g) was observed at 70 x 20 cm. Yield per plant decreased as population density increased. Yield compensation was primarily associated with decreased yield per plant as population increased. The decreased yield per plant was more than offset by population, resulting in yield per square meter increasing to an asymptote as population increased (Ball et al., 2000).

On the effects of nitrogen doses x row spacing interaction, maximum values were evaluated from interactions of 90 kg ha^{-1} x 70 x 20 cm, 60 kg ha^{-1} x 70 x 20 cm and 30 kg ha^{-1} x 70 x 20 cm (37.5, 37.6 and 36.9 g, respectively) (Table 3).

Harvest Index

N rate has no effect on harvest index. Some researchers reported that nitrogen applied at harvest index was not effective (Malik et al., 2006).

Row spacings of 70 x 5 cm and 70 x 10 cm produced similiar harvest index (50.8 and 50.4%). The lowest harvest index (48.8%) was observed at 70 x 20 cm row

Table 2. Plant height, first pod height, number per branches and pod number per plant of soybean as affected by nitrogen levels, plant density and their combined effects.

Treatment	Plant height (cm)	First pod height (cm)	Number of branches (plant^{-1})	Pod number per plant (plant^{-1})
Nitrogen dose				
N0	76.5 d	11.4 c	6.0 c	96.4 c
N1	82.8 c	12.7 b	6.7 b	118.4 b
N2	88.2 b	13.3 b	6.9 a	128.2 a
N3	93.0 a	14.1 a	7.0 a	136.9 a
LSD 0.05	3.168	0.655	0.230	9.193
Plant density				
D1	96.9 a	15.1 a	5.5 d	87.6 d
D2	91.3 b	14.1 b	6.3 c	106.0 c
D3	84.9 c	12.3 c	7.1 b	135.3 b
D4	67.4 d	10.0 d	7.9 a	151.1 a
LSD 0.05	3.168	0.655	0.230	9.193
Nitrogen dose x plant density				
N0D1	86.5 cd	13.2 cd	4.8 g	69.9 h
N0D2	81.3 de	12.8 de	5.5 f	82.6 h
N0D3	76.1 ef	10.9 fg	6.7 d	108.9 d-f
N0D4	62.0 h	8.8 h	7.2 bc	124.2 cd
N1D1	94.3 b	15.8 a	5.5 f	84.0 gh
N1D2	86.2 cd	12.9 de	6.2 e	97.2 fg
N1D3	84.7 d	11.8 ef	7.1 b-d	137.4 bc
N1D4	66.1 gh	10.2 g	8.0 a	154.8 ab
N2D1	102.7 a	15.2 ab	5.8 ef	95.4 fg
N2D2	94.4 b	14.4 bc	6.8 cd	116.9 de
N2D3	86.6 cd	13.0 de	7.1 b-d	139.9 bc
N2D4	69.6 g	10.7 fg	8.0 a	160.7 a
N3D1	104.4 a	16.1 a	6.0 e	100.9 e-g
N3D2	103.4 a	16.3 a	6.7 d	127.2 cd
N3D3	92.0 bc	13.5 cd	7.3 b	154.9 ab
N3D4	72.2 fg	10.4 g	8.2 a	164.7 a
LSD 0.05	6.336	1.311	0.461	18.390

N0: 0 kgha-1, N1: 30 kgha-1, N2: 60 kgha-1, N3: 90 kgha-1; D1: 70 x 5 cm (280 571 plant ha-1); D2: 70 x 10 cm (140 286 plant ha-1); D3: 70 x 15 cm (93 523 plant ha-1); D4: 70 x 20 cm (70 143 plant-1).

spacing. Some researchers obtained similiar findings (Bullock et al., 1998; Ball et al., 2000)

Harvest index (HI) values ranged from 0.38 to 0.65 over 2 years for all treatment combinations. Although there was a wide range of HI values, we found no consis-tent relationship between HI and yield. Harvest index decreased for each cultivar under drought condi-tions. There were significant population densityeffects on HI. Differences in HI among population densities were generally confined to the highest population. Harvet index was relatively stable and was not affected by population (Ball et al., 2000).

Previous research also found HI to be relatively stable within a variety except for conditions of extreme interplant competition. Harvest index of soybean increased with increasing plant population (Edwards and Purcell, 2005).

100 seed weight

100 seed weight of the variety was affected by the amounts of nitrogen doses and plant density. In general, all of the nitrogen doses produced 100 seed weight higher than the non-nitrogen application condition. 100 seed weight values varied among 16.6 (90 kg ha^{-1}) and 15.6 g (control). Nitrogen fertilizer have been found to positively affect 100 seed weight (Jayapaul and Ganesaraja, 1990; Taylor et al., 2005; Ebelhar and Anderson, 2007). There is also report that 100 seed weight is not affected by nitrogen application (Barker and Sawyer, 2005).

The average 100 seed weight tended to decline with increasing plant density. Maximum 100 seed weight (16.5 g) was recorded at 70 x 20 cm against the minimum

Table 3. Seed yield, harvest index, 100 seed weight and seed yield of soybean as affected by nitrogen levels, plant density and their combined effects.

Treatment	Seed yield per plant (g)	Harvest index (%)	100 seed weight (g)	Seed yield (kgha-1)
Nitrogen dose				
N0	20.5 b	46.7 b	15.6 c	1855 c
N1	26.7 a	50.7 a	16.0 b	2373 b
N2	27.1 a	50.6 a	16.3 ab	2499 ab
N3	27.5 a	50.5 a	16.6 a	2574 a
LSD 0.05	1.168	0.541	0.360	188.60
Plant density				
D1	13.1 d	50.8 a	15.7 c	2623 a
D2	23.0 c	50.4 a	16.0 bc	2451 a
D3	30.5 b	49.8 b	16.3 ab	2228 b
D4	35.2 a	48.8 c	16.5 a	1957 c
LSD 0.05	1.168	0.541	0.360	188.60
Nitrogen dose x plant density				
N0D1	10.2 g	47.8 i	15.1 f	1966 ef
N0D2	17.5 e	48.9 gh	15.4 ef	2026 ef
N0D3	25.6 d	48.6 hi	15.7 c-f	1881 fg
N0D4	28.9 c	46.7 j	16.0 b-e	1548 g
N1D1	13.8 f	52.2 a	15.5 d-f	2729 ab
N1D2	24.0 d	50.9 b-d	15.8 c-f	2459 b-d
N1D3	32.2 b	50.4 c-e	16.2 a-d	2244 d-f
N1D4	36.9 a	49.3 f-h	16.3 a-c	2058 ef
N2D1	13.9 f	51.3 a-c	16.1 b-e	2746 ab
N2D2	25.0 d	51.2 a-c	16.2 a-d	2646 bc
N2D3	31.9 b	50.3 c-f	16.4 a-c	2333 c-e
N2D4	37.6 a	49.8 e-g	16.6 ab	2105 d-f
N3D1	14.4 f	51.9 ab	16.3 a-c	3052 a
N3D2	25.6 d	50.5 c-e	16.5 c-f	2673 bc
N3D3	32.4 b	49.9 d-g	16.9 a	2455 b-d
N3D4	37.5 a	49.5 e-h	16.9 a	2115 d-f
LSD 0.05	2.337	1.083	0.720	377.20

N0: 0 kgha-1, N1: 30 kgha-1, N2: 60 kgha-1, N3: 90 kgha-1; D1: 70 x 5 cm (280 571 plant ha-1); D2: 70 x 10 cm (140 286 plant ha-1); D3: 70 x 15 cm (93 523 plant ha-1); D4: 70 x 20 cm (70 143 plant-1).

(15.7 g) at control (Table 3). Treatment combinations 90 kg ha^{-1} x 70 x 20 cm and 90 kg ha^{-1} x 70 x 15 cm gave significantly higher and same 100 seed weight (16.9 g). Results of the other researchers were not similiar to our findings (Yilmaz, 1999; Piggot and Farrel, 1983).

Seed yield

The seed yields per hectare obtained from the experiment are presented in Table 3. The variance analysis of seed yield showed that the effects of nitrogen doses and row spacings were significant. Seed yields varied from 1855 to 2574 kg ha^{-1}, with the lowest seed yield on the hectare with no nitrogen applicatian and highest seed yield on the hectare fertilized with 90 kg ha^{-1} nitrogen application. The difference between the lowest and the highest seed yields was 719 kgha^{-1}. In general, all nitrogen doses increased the seed yield of hectare when they were compared with control. As a result, 90 kgha^{-1} nitrogen dose produced as much higher seed yield as 38.7% than the control. Positive effects of N-fertiliser applications to soybean have been observed in some field investigations (Takahashi et al., 1991; Norhayati et al., 1988; Starling et al., 1998; Wesley et al., 1998; Taylor et al., 2005; Osborne and Riedell, 2006; Raggio and Raggio, 2007) but not in others (Herridge and Brockwell, 1988; Ying et al., 1992).

It is obvious from Table 3 that maximum seed yields were realized from 70 x 5 cm (2623 kg ha^{-1}) and 70 x 10 cm (2451 kg ha^{-1}) row spacings. The lowest plant population (70 143 plant ha^{-1}) produced the lowest yield

(1957 kg ha^{-1}). An increase in seed yield per hectare in response to plant density is due to increased number of plant per unit area. Christmas (2002), Berglund and Helms (2003) and Yilmaz (2003) have also reported parallel results.

As to the effects of nitrogen doses and row spacing interaction, higher seed yield (3052 kg ha^{-1}) was observed at 90 kg ha-1 nitrogen doses x 70 x 5 cm row spacing against the lowest (1548 kg ha^{-1}) at control (0 kg ha^{-1} nitrogen) x 70 x 20 cm.

In soybean one of the benefits of higher plant density is contribution to earlier canopy closure which makes weed control easier by increasing competition between the crop and weeds. Yield increase to emanating from plant density in unit area was mainly due to increased number of seeds per area rather than increased yield per plant. Increasing plant density may increased light interception (Andrade et al., 2002; Caliskan et al., 2007).

Conclusıon

Different nitrogen doses and plant densites significantly affected some important yield and yield characters in soybean. A rise in plant density and nitrogen rate increased plant height, lowest pod height, harvest index and seed yield, whereas number of branches per plant, pod number per plant, seed yield per plant and 100 seed weight decreased as plant density increased. It can be concluded that soybean should be sown on row spacing of 70 x 10 cm (140 286 plant ha^{-1}) with nitrogen application rate 60 kg ha^{-1} to obtain maximum return unit area.

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