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Full Length Research Paper

A study of nitrogen and boron impacts on yield and significance of cotton (*Gossypium hirsutum* L.)

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This study was carried out to determine nitrogen (N) and boron (B) effects on yield and quality of cotton (*Gossypium hirsutum* L.). N was applied to the soil at rates of 0, 100, 200 and 300 kg ha^{-1} and B was applied as foliar at rates 0, 500 and 1000 g ha^{-1}. Statistical results of study showed that N application significantly (P ≤ 0.05) increased boll number, boll weight, seed cotton weight of boll, seed cotton yield and lint yield. Moreover, leaf blade N concentration was affected by N application rate and increased significantly. Results of study also showed that the highest seed cotton yield was obtained in case of 200 kg ha^{-1} N application rate, and this application rate resulted in 19.6% increased seed cotton yield. Statistical results also indicated that foliar application of B significantly increased boll number, boll weight, seed cotton yield and lint yield. In addition, leaf blade B concentration was affected by B application rate and increased significantly. Results also demonstrated that the highest seed cotton yield was recorded in case of 1000 g ha^{-1} foliar application of B, and this foliar application rate resulted in 25% increased seed cotton yield. Statistical results showed that effect of different application rates of N was not significant for all fiber properties (fiber length, fiber strength and fiber fineness). Conversely, results of study indicated that different application rates of B significantly affected some fiber properties. On the whole, application of 200 kg ha^{-1} N and 1000 g ha^{-1} B (two time foliar B application) resulted in the highest boll number, boll weight, seed cotton yield and lint yield, and enhanced fiber properties. The interaction of N × B was not significant for all studied traits.

Keywords: Nitrogen, boron, cotton, yield, quality, Iran.

INTRODUCTION

In Iran, main portion of soils suffer from lack of organic matter and show nitrogen (N) deficiency. For this reason, N is one of the most important elements for crop production, and agricultural productions highly depend on this element (Rashidi and Seilsepour, 2009). Like most crops, cotton requires N for normal growth and development, and farmers greatly rely on N fertilizers. Several studies have been done to study the effect of N on cotton (Wadleigh, 1944; McConnell et al., 1993; Boquet et al., 1995; Boquet and Breitenbeck, 2000; Ali et al., 2003). N is required for all stages of plant growth and development because it is the essential element of both structural (cell membranes) and nonstructural (amino acids, enzymes, protein, nucleic acids and chlorophyll) components of the plant. Without sufficient N, deficiency symptoms such as stunting, chlorosis, and fewer and smaller bolls are prevalent in cotton (Tisdale et al., 1993). Also, cotton canopy development is strongly influenced by N uptake (Wullschleger and Oosterhuis, 1990). During the vegetative stage of growth, rapid expansion of the leaves requires large amounts of N, and both fruit production and retention are dependent on leaf development and photosynthetic integrity (Oosterhuis et al., 1983). Hearn (1981) found that cotton requires about 90 kg ha^{-1} N for one bale of lint and about 140 kg ha^{-1} N

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for two bales of lint depending upon soil texture. However, N uptake can be as much as 230 kg ha^{-1}, and N removal at harvest can be as much as half of total uptake. Among the plant nutrients, N plays a very important role in crop productivity. It is an important determinant of growth and yield of irrigated cotton (Ahmad, 1998). Typically, applications of 100 to 215 kg ha^{-1} N fertilizers are required to optimize lint yield (Hussein et al., 1985; Constable and Rochester, 1988; McConnell et al., 1995; Jin et al., 1997).

Boron (B) is an essential element that cotton needs during all stages of growth and fruiting. It has been universally recognized as the most important micronutrient for cotton production, and cotton is very sensitive to B deficiency because of its high B requirement (Shorrocks, 1992). Soil applied B increased cotton yields even when B deficiency was not evident in the plants (Anderson and Boswell, 1968). It is also essential at all stages of plant growth, and critically during fruit development especially with today's fast-fruiting, high-yielding varieties. B fertilizers were beneficial to cotton production in sandy and silt loam soils in several parts of USA and Africa (Murphy and Lancaster, 1971; Mathews, 1972; Roberts et al., 2000). While B is essential for all stages of cotton plant growth, an available supply is most important during flowering and boll development. Relatively small amounts of B are required to support the process of growth and development of cotton fibers in the boll. Researches showed that as little as 1.12 kg ha^{-1} of B could increase seed cotton yield by more than 1235 kg ha^{-1}. B increases the nitrogen and carbohydrate metabolism and sugar translocation in cotton (Gascho, 1994). Foliar-applied B supplements and soil-supplied B can correct low B concentrations in cotton (Heitholt, 1994). Foliar application of B accelerates the translocation of nitrogen compounds, increases protein synthesis and stimulates fruiting. As small amounts of B are required, foliar application of B may be more efficient than soil application, especially when deficient conditions are suspected (Howard et al., 1998). There are many reports on the growth and yield responses of cotton to soil or foliar applications of B. Reports of yield response to soil or foliar applications of B have been contradictory. For example, Heitholt (1994) reported no yield response to B utilizing non-buffered spray solutions, whereas Howard et al. (1998) observed that buffering B spray solutions to pH 4.0 increased yields relative to buffering to pH 6.0. Research in Arkansas, USA, has also shown no yield response to soil or foliar applications of B irrespective of soil N status (Oosterhuis, 2001). Soil applied B increased first harvest lint yields by 9%, and four foliar applications, each at 0.11 kg B ha^{-1}, resulted in lint yields comparable to soil application of B at 0.56 kg B ha^{-1}, and doubling the B foliar rate did not increase yields, but the B petiole concentration was significantly increased (Howard et al., 1998). Lint yield, boll production, flower production, boll retention percentage and fiber properties were not affected by soil or foliar applied treatments. However, foliar B fertilization resulted in leaf blade B concentrations of 154 mg kg^{-1} without detrimental effects (Heitholt, 1994). Soil or foliar applied B may not have been beneficial for obtaining high cotton yields. Similarly, there were no positive responses to applied soil-B or foliar-B in the high N soil level in any of the five experiments, except for where the low N treatments responded to applied B on a silt loam soil in Arkansas (Oosterhuis et al., 2000). Oosterhuis and Brown (2002) reported no effects on yield, fiber quality, boll number per meter, average boll weight, lint percentages, or petiole or leaf B concentrations of soil and foliar applied B treatments observed over three years. No significant effect of B on lint yield, individual boll weight, or petiole nitrate-N level and no significant N and B interactions were found in a regional study conducted to evaluate the interaction of N and B rates on cotton yields (Oosterhuis and Steger, 1998).

In Iran, meager researches have been done to study nitrogen (N) and boron (B) effects on yield and quality of cotton, and there are no recommended application rates. As N and B can agronomically and physiologically affect cotton, the main objective of this study was to determine the effect of different application rates of N and B on yield and quality of cotton, and finding appropriate application rates of N and B for cotton production in the arid lands of Iran.

MATERIALS AND METHODS

Research site

This study was conducted at the Research Site of Tehran Province Agricultural and Natural Resources Research Center, Varamin, Iran on a clay loam soil identified as low in B (0.4 mg kg^{-1}) and average in total N (0.07%) for two successive growing seasons (2009 & 2010). The research site is located at latitude of 35° 19' N, longitude of 51° 39' E and altitude of 1000 m in arid climate (150 mm rainfall annually) in the center of Iran.

Weather parameters

The mean temperature and monthly rainfall of the experimental site from sowing (May) to harvest (November) during study years (2009 and 2010) are indicated in Figure 1.

Soil sampling and analysis

The soil of the experimental site is classified as an Aridisol (fine, mixed, active, thermic, typic haplocambids). A composite soil sample (from 36 points) was collected

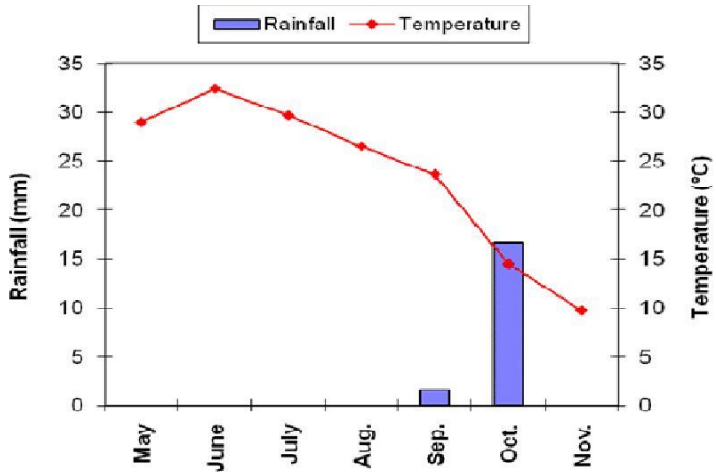

Figure 1. Mean monthly rainfall and temperature from sowing to harvest (mean of 2009 & 2010)

Table 1. Soil physical and chemical properties of the experimental site during study years 2009 & 2010 (0-30 cm depth)

Date	pH	EC (dS m^{-1})	OC (%)	TNV (%)	P (ppm)	K (ppm)	Fe (ppm)	Zn (ppm)	Cu (ppm)	Mn (ppm)	B (ppm)	Soil texture
2009	7.3	3.4	0.72	17	10.6	200	4.4	0.90	1.4	12.3	0.4	Clay loam
2010	7.6	3.0	0.81	17	9.50	224	5.2	0.42	0.5	11.5	0.5	Clay loam

from 0-30 cm depth 30 days prior to planting during the study years and was analyzed in the laboratory for pH, EC, OC, TNV, P, K, Fe, Zn, Cu, Mn, B and particle size distribution. Details of soil physical and chemical properties of the research site during the years of study (2009 and 2010) are given in Table 1.

Field methods

A split plot experiment was laid out in a randomized complete block design (RCBD) with three replications to randomize the different N application rates treatments and different B application rates treatments in the main and subplots, respectively. The experiment comprised of four levels of N fertilizer, i.e. 0, 100, 200 and 300 kg ha^{-1} N as Urea and three levels of B, i.e. 0, 500 and 1000 g ha^{-1} B as boric acid foliar application (without, one time and two time foliar B application). Each of the 100, 200 and 300 kg ha^{-1} N were split into two applications, i.e. one third at pre-planting and two third at pinhead square. Application rates were maintained on the same plots by banding application. Boric acid foliar was applied with concentration of 0.5% (500 L ha^{-1}). Foliar B applications began at the first flower stage, and were repeated two weeks after. The control treatment only received water spray. The treatments were carried out on the same plots in the 2009 and 2010 growing seasons. The size of each plot was 12.0 m long and 6.0 m wide. A buffer zone of 3.0 m spacing was provided between plots. In both growing seasons, one of the most commercial varieties of cotton cv. Varamin was planted manually on May 5, 2009 and May 7, 2010. Plots consisted of 6 rows of cotton planted with row spacing 0.8 m. Plots were over seeded and then thinned by keeping plant to plant distance 20 cm, or a population of 62,500 plants ha^{-1}, at approximately the first or second true leaf stage. Management was consistent with typical agronomic practices used for upland production in the region. For all treatments, irrigation scheduling was based on the basis of soil water content monitoring. Also, pest and weed control operations were performed based on common local practices and commendations. All other essential operations were kept identical for all the treatments.

Observation and data collection

Leaf samples were obtained for N and B analysis one week before first flower and one week after each foliar B

Table 2. Effect of different N application rate on yield, yield components and quality of cotton (mean of 2009 & 2010)

N application rate (kg ha^{-1})	Boll number * (plant^{-1})	Boll weight * (g)	Seed cotton weight of boll * (g)	Seed cotton yield * (kg ha^{-1})	Lint yield * (kg ha^{-1})	Leaf blade N concentration * (mg kg^{-1})	Leaf blade B concentration NS (mg kg^{-1})
0	12.9 c	6.26 b	4.11 b	3642 c	1489 c	2.22 c	56.9 a
100	17.2 b	6.50 ab	4.41 ab	4151 b	1596 b	3.16 b	53.9 a
200	19.8 a	6.90 a	4.49 a	4363 a	1659 a	3.61 b	58.9 a
300	19.6 a	6.80 a	4.47 a	4358 a	1649 a	4.21 a	60.3 a

NS = Non-significant
* = Significant at 0.05 probability level
Means in the same column with different letters differ significantly at 0.05 probability level according to DMRT

Table 3. Effect of different B foliar application rate on yield, yield components and quality of cotton (mean of 2009 & 2010)

B application rate (g ha^{-1})	Boll number * (plant^{-1})	Boll weight * (g)	Seed cotton weight of boll NS (g)	Seed cotton yield * (kg ha^{-1})	Lint yield * (kg ha^{-1})	Leaf blade N concentration NS (mg kg^{-1})	Leaf blade B concentration * (mg kg^{-1})
0	14.1 c	6.15 b	4.48 a	3541 b	1400 c	3.61 a	43.1 c
500	16.8 b	6.49 ab	4.61 a	3991 ab	1562 b	3.43 a	55.0 b
1000	18.1 a	7.02 a	4.52 a	4428 a	1752 a	3.54 a	67.6 a

NS = Non-significant
* = Significant at 0.05 probability level
Means in the same column with different letters differ significantly at 0.05 probability level according to DMRT.

application. Samples were obtained by removing 20 leaves from the uppermost fully expanded main stem leaves from each plot. After all bolls matured, all seed cotton at 10 meter lengths of the four center rows was hand harvested at approximately 70% open boll for yield analyses. Yield was determined by hand harvesting the four center rows from each plot twice and weighing the seed cotton. Twenty plants in each plot were randomly selected in mid-September of each year for measurement of number of open bolls. Boll weight and fiber data were obtained from 20 hand-harvested boll samples collected from 0.5 m of the two outer rows. Lint yields were calculated by multiplying the lint percentage by seed cotton weights. Fiber properties for each sample were determined in High Volume Instruments (HVI).

Statistical analysis

All data were subjected to the Analysis of Variance (ANOVA) following Gomez & Gomez (1984) using SAS statistical computer software. Moreover, means of the different treatments were separated by Duncan's Multiple Range Test (DMRT) at $P \leq 0.05$.

RESULTS AND DISCUSSION

Boll number

Statistical results of study indicated that different application rates of N and B (as foliar B) significantly ($P \leq 0.05$) affected boll number (Table 2 and Table 3). Results showed that boll number significantly increased with an increase in N application rate. The highest boll number (19.8) was obtained in case of 200 kg ha^{-1} N treatment but there was no significant difference between 200 and 300 kg ha^{-1} N treatments. The lowest boll number (12.9) was obtained in case of 0 kg ha^{-1} N treatment (Table 2). Results also demonstrated that boll number significantly increased with an increase in B application rate. The highest boll number (18.1) was obtained in case of 1000 g ha^{-1} B treatment (two time foliar B application) and the lowest boll number (14.1) was obtained in case of 0 g ha^{-}

^{1}B treatment, i.e. no foliar B application (Table 3). These results are in agreement with those of Oosterhuis and Steger (1998) who concluded that N application and foliar B application considerably increased boll number. Interaction of N × B was not significant for this trait.

Boll weight

Results of study also showed that different application rates of N and B significantly influenced boll weight (Table 2 and Table 3). Results indicated that boll weight significantly increased by increasing N application rate. The highest boll weight (6.90 g) was recorded in case of 200 kg ha^{-1} N treatment but there was no significant difference among 100, 200 and 300 kg ha^{-1} N treatments. The lowest boll weight (6.26 g) was recorded in case of 0 kg ha^{-1} N treatment (Table 2). Moreover, statistical results showed that boll weight significantly increased by increasing B application rate. The highest boll weight (7.02 g) was recorded in case of two time foliar B application treatment but there was no significant difference between two and one time foliar B application treatments. The lowest boll weight (6.15 g) was recorded in case of no foliar B application treatment (Table 3). These results are also in line with the results reported by Oosterhuis & Steger (1998) that N application and foliar B application noticeably increased boll weight. Again, interaction of N × B was not significant for this trait.

Seed cotton weight of boll

Statistical results of study indicated that different application rates of N significantly affected seed cotton weight of boll (Table 2). Results showed that seed cotton weight of boll significantly increased with an increase in N application rate. The highest seed cotton weight of boll (4.49 g) was obtained in case of 200 kg ha^{-1} N treatment but there was no significant difference among 100, 200 and 300 kg ha^{-1} N treatments. The lowest seed cotton weight of boll (4.11 g) was obtained in case of 0 kg ha^{-1} N treatment (Table 2). Moreover, results indicated that effect of different application rates of B was not significant for seed cotton weight of boll (Table 2). Although effect of different application rates of B was not significant for this trait, the highest seed cotton weight of boll (4.61 g) was obtained in case of one time foliar B application treatment and the lowest seed cotton weight of boll (4.48 g) was obtained in case of no foliar B application treatment (Table 3). Once more, interaction of N × B was not significant for this trait.

Seed cotton yield

Results of study showed that different application rates of N and B significantly influenced seed cotton yield (Table 2 and Table 3). Results indicated that seed cotton yield significantly increased by increasing N application rate. The highest seed cotton yield (4363 kg ha^{-1}) was recorded in case of 200 kg ha^{-1} N treatment, and there was no significant difference between 200 and 300 kg ha^{-1} N treatments. Therefore, for reaching the highest seed cotton yield use of 200 kg ha^{-1} N can be recommended. The lowest seed cotton yield (3642 kg ha^{-1}) was recorded in case of 0 kg ha^{-1} N treatment (Table 2). The maximum increase in seed cotton yield with 200 kg ha^{-1} N treatment was about 19.6% as compare to 0 kg ha^{-1} N treatment. Additionally, results showed that seed cotton yield significantly increased by increasing B application rate. The highest seed cotton yield (4428 kg ha^{-1}) was recorded in case of two time foliar B application treatment but there was no significant difference between two and one time foliar B application treatments. The lowest seed cotton yield (3541kg ha^{-1}) was recorded in case of no foliar B application treatment (Table 3). Applied B may improve the utilization of applied N by cotton plants by increasing the translocation of N compounds into the boll. A restriction in the flow of carbohydrates out of the leaves could influence the number and size of the bolls. Yield increase was the consequence of enhanced boll setting and boll weight. With hot-water-soluble B in our experimental fields being 0.40 mg kg^{-1} B, the soils were low in B. It is generally accepted that a soil water-soluble B content of approximately 0.15 to 0.20 ppm approaches the deficiency level (Anderson & Boswell, 1968). Positive crop responses to B are attributed to a greater B requirement by cotton as compared with most other field crops (Shorrocks, 1992). The maximum increase in seed cotton yield with two time foliar B application treatment was about 25% as compare to no foliar B application treatment. Another time, interaction of N × B was not significant for this trait.

Lint yield

Statistical results of study indicated that different application rates of N and B significantly affected lint yield (Table 2 and Table 3). Results showed that lint yield significantly increased with an increase in N application rate. The highest lint yield (1659 kg ha^{-1}) was obtained in case of 200 kg ha^{-1} N treatment but there was no significant difference between 200 and 300 kg ha^{-1} N treatments. Therefore, for reaching the highest lint yield use of 200 kg ha^{-1} N can be recommended. The lowest lint yield (1489 kg ha^{-1}) was obtained in case of 0 kg ha^{-1} N treatment (Table 2). Results of this study suggested that greater lint yields at elevated levels of N may have been due to the greater number of bolls per plant. These results are in line with the results reported by Boquet et al. (1994) that application of optimal N rates may have beneficial effects on lint yield by producing larger bolls at a greater number of fruiting sites. Furthermore, results showed that lint yield significantly increased with an

Table 4. Effect of different N application rate on cotton fiber properties (mean of 2009 & 2010)

N application rate (kg ha^{-1})	Fiber length ^{NS} (mm)	Fiber strength ^{NS} (g tex^{-1})	Fiber fineness ^{NS}
0	29.6 a	28.1 a	5.2 a
100	29.5 a	28.6 a	5.4 a
200	29.2 a	28.7 a	5.3 a
300	30.1 a	29.1 a	5.4 a

NS = Non-significant
* = Significant at 0.05 probability level
Means in the same column with different letters differ significantly at 0.05 probability level according to DMRT.

increase in B application rate (Table 3). The highest lint yield (1752 kg ha^{-1}) was obtained in case of two time foliar B application treatment and the lowest lint yield (1400 kg ha^{-1}) was recorded in case of no foliar B application treatment (Table 3). The maximum increase in lint yield with two time foliar B application treatment was about 25% as compare to no foliar B application treatment. The similar results were also reported by Anderson and Boswell (1968) and Heitholt (1994) in field experiments where lint yield increased significantly with an increase in B application rate. Yet again, interaction of N × B was not significant for this trait.

Leaf blade N concentration

Results of leaf blade chemical analyses showed that different application rates of N significantly affected leaf blade N concentration (Table 2). The highest leaf blade N concentration (4.21 mg kg^{-1}) was recorded in case of 300 kg ha^{-1} N treatment and the lowest leaf blade N concentration (2.22 mg kg^{-1}) was recorded in case of 0 kg ha^{-1} N treatment (Table 2). Oosterhuis et al. (1983) studied the distribution of N in plant components. They found that leaf blade N concentration significantly increased by increasing N application rate. Results also indicated that effect of different application rates of B was not significant for leaf blade N concentration (Table 2). Again, interaction of N × B was not significant for this trait.

Leaf blade B concentration

Results of leaf blade chemical analyses indicated that effect of different application rates of N was not significant for leaf blade B concentration (Table 2). However, different application rates of B significantly influenced this trait (Table 3). The highest leaf blade B concentration (67.6 mg kg^{-1}) was obtained in case of two time foliar B application treatment and the lowest leaf blade B concentration (43.1 mg kg^{-1}) was obtained in case of no foliar B application treatment (Table 3). Similar results have been reported by Zhao & Oosterhuis (2003). They reported that leaf blade B concentration considerably increased with an increase in soil-applied B. Once more, interaction of N × B was not significant for this trait.

Fiber properties

Statistical results of study showed that effect of different application rates of N was not significant for fiber properties, i.e. fiber length, fiber strength and fiber fineness (Table 4). Earlier studies found no or inconsistent effects of the N application rate on fiber length (Grimes et al., 1969; Boman & Westerman, 1994). Similarly, other researchers found no relationship between fiber strength and N application rate (Boman & Westerman, 1994; Fritschi et al., 2003). Also, increased N application rates were reported to have no effect at all on micronaire or to increase or decrease micronaire readings (Boman and Westerman, 1994; Boman et al., 1997). Based on 11 years of data, Boman et al. (1997) reported that micronaire readings were reduced by applied N in low-micronaire environments and increased by applied N in high-micronaire environments. Results of study also indicated that different application rates of B significantly affected some fiber properties (Table 5). Fiber length was affected by increasing B application and increased significantly. The highest fiber length (31.7 mm) was obtained in case of two time foliar B application treatment and the lowest fiber length (29.2 mm) was obtained in case of no foliar B application treatment, but there was no significant difference between one and two time foliar B application treatments (Table 5). Although fiber strength was not influenced by increasing B application, the highest fiber strength (28.6 g tex^{-1}) was obtained in case of two time foliar B application treatment and the lowest fiber strength (28.1 g tex^{-1}) was obtained in case of no foliar B application treatment (Table 5). Moreover, results showed that fiber fineness was affected by increasing B application and increased significantly. The highest fiber fineness (5.8) was obtained in case of

Table 5. Effect of different B foliar application rate on cotton fiber properties (mean of 2009 & 2010)

B application rate (g ha^{-1})	Fiber length * (mm)	Fiber strength ^{NS} (g tex^{-1})	Fiber fineness *
0	29.2 b	28.1 a	4.9 b
500	31.4 a	28.2 a	5.7 a
1000	31.7 a	28.6 a	5.8 a

NS = Non-significant
* = Significant at 0.05 probability level
Means in the same column with different letters differ significantly at 0.05 probability level according to DMRT.

two time foliar B application treatment and the lowest fiber fineness (4.9) was obtained in case of no foliar B application treatment, but there was no significant difference between one and two time foliar B application treatments (Table 5). The beneficial effects of B application in enhancing fiber properties were also reported by Oosterhuis and Steger (1998) and Roberts et al. (2000). Another time, interaction of N × B was not significant for fiber properties.

CONCLUSION

For reaching the highest boll number, boll weight, seed cotton yield and lint yield, and enhanced fiber properties of cotton in the arid lands of Iran use of 200 kg ha^{-1} N and 1000 g ha^{-1} B (two time foliar B application) was found as the most appropriate and beneficial application rates of N and B, respectively.

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