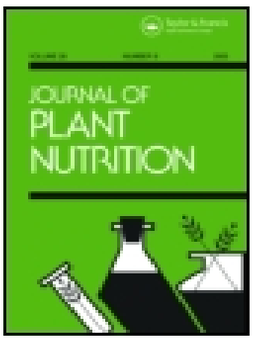

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# Scaling-up of boron sources for yield and quality of large seeded peanut cultivars under varied agro-ecological conditions in India

A. L. Singh[a], R. S. Jat[b], A. Zala[a], H. Bariya[a], S. Kumar[c], Y. S. Ramakrishna[d], G. Rangaraju[e], M. Rani Masih[f], T. B. Bhanusali[g], S. Vijaykumar[h], E. Somasundaram[i], and I. M. Singh[j]

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**ABSTRACT**

Boron (B) deficiency is a common factor in light-textured soils causing poor pod filling and yield in large seeded peanut. Field trials were conducted in soils having 0.20–0.45 mg kg$^{-1}$ available B to find out the effectiveness of commercial-grade B sources in large seeded peanuts. B application induced early flowering, increased pods, yield and yield attributes, shelling and 100-seed weight. Soil application of 2.0 kg B ha$^{-1}$ as commercial-grade Agricol, Solubor and Borosol increased these parameters to a similar degree as obtained by borax, but were superior over their foliar applications. Similarly, the responses of foliar applications of 1.0 kg B ha$^{-1}$ as Chemiebor, Solubor and Borosol were more effective in humid areas. However, foliar applications led to scorching of peanut leaves during dry weather. Thus, soil application of 2.0 kg B ha$^{-1}$ is essential to enhance productivity and pod filling in large seeded peanut.

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agricol; boron sources; large seeded peanut; pod yield

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## Introduction

Peanut (*Arachis hypogaea* L.) is an important legume, grown under tropical to subtropical climates, used as oilseed as well as a food crop worldwide. India has the largest peanut area in the world where it is grown throughout on all soil types mainly as rain-fed crop, but the average peanut productivity of this crop is low as compared to the United States and China mainly due to mineral deficiencies and unreliable weather conditions. In the recent cultivars with large seeds, boron (B) and calcium (Ca) deficiencies are the important factors responsible for low yield (Singh et al. 2004, 2007). Most of the light-textured soils of India where peanut grown are deficient in B, and there is good response of B application right from acid to calcareous and sandy soils (Ansari et al. 2013; Singh et al. 2008a, 2008b, 2009; Vishwakarma et al. 2008). In B-deficient soils (having <0.4 mg kg$^{-1}$ available B), low pod filling, shriveled seeds and hollow darkening or off-color in the center of the seed are common symptoms of B deficiency causing 10–50% yield losses (Cox and Reid 1964; Singh 2001b; Singh et al. 2004). The application of 0.5–2.0 kg ha$^{-1}$ B normally alleviated the B-deficiency disorder, but there is no clear-cut recommendation of any agriculture-grade B fertilizers in India (Singh 1994, 2001a, 2001b, 2002; Singh and Chaudhari 1996; Singh et al. 2004). Also, there are genetic variations for the response of B in the field (Singh 2013).

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With increase in human population, the demand of peanut, both as oilseed and food, is increasing, demanding an increase in the production of peanut, essentially through the recently released large seeded peanut, and latest fertilizer recommendations. In field, though 1.0 kg B $ha^{-1}$ is ideal for normal seed-size peanut cultivars (Singh 1994; Singh et al. 2004), the large seed-size peanut require higher amount, and 2 kg B $ha^{-1}$ was found well in neutral to alkaline light texture soils (Singh et al. 2007, 2008a, 2008b, 2009). Also, there are low-cost agriculture-grade B fertilizers available in the international market; thus, it becomes essential to test these B fertilizers in various soils of India and find out their suitability for soil, seed and foliar applications and recommend the most economic and effective sources and methods for peanut. Accordingly, field experiments were conducted at various locations in India right from north to south, and acid soils of northeastern to alkaline soils of western part of India to find out the effectiveness and feasibility of commercial-grade B sources for peanut, and this paper compiles the findings.

## Materials and methods

Field experiments, during wet season (June–September) of 2006–2009, were conducted at eight locations in India including Mainpuri (Groundnut Research Station, Mainpuri, Uttar Pradesh), Durgapura (Agricultural Research Station, Durgapura, Rajasthan), Hanumangarh (Agriculture Research Station, Hanumangarh, Rajasthan), Raichur (Oilseed Research Station, Raichur, Karnataka), Tindivanam (Oilseeds Research Station, Tindivanam, Tamil Nadu), Aliyarnagar (Coconut Research Station, Aliyarnagar, Tamil Nadu), Kolasib [Indian Council of Agricultural Research (ICAR)-Research Complex for North Eastern Hill (NEH) region, Kolasib, Mizorum] and Imphal (ICAR-Research Complex for NEH region, Imphal, Manipur). The location-wise climate type, soil type and experiemntal details are given in Table 1. The soils of all experimental locations in this study had less than 0.5 mg $kg^{-1}$ available B. The experiments were laid out in a randomized block design using 10 treatments as detailed in Table 2, each with three replications (30 plots each) using high yielding large-seeded peanut cultivars suitable for that area. The treatments consist of two levels of rate of application (1 and 2 kg B $ha^{-1}$) and three levels of mode of application (soil application: 50% as basal and 50% at 30 days after emergence; foliar

**Table 1.** Site description.

| Name of the Location | Coordinates/Sea Levels | Climate Type | Soil Type | Number of Experiments and Year | Variety |
|---|---|---|---|---|---|
| Mainpuri | 260 53′ to 270 31′ N latitude and 780 27′ to 790 26′ E longitude | Semi-arid | Sandy-loam with pH 7–8 | 3 experiments (2006, 2007 and 2008) | CSMG 9510 |
| Durgapura | 26 50′ N latitude to 75 47′ E longitude at 390 m sea level | Semi-arid | Neutral sandy | 2 experiments (2006 and 2008) | M 335 |
| Raichur | 105 09′ N latitude to 75 46′ E longitudes at 404 m sea level | Hot semi-arid | Deep black calcareous clayey | 1 experiment (2006) | TGLPS 3 |
| Hanumangarh | 28 45′ N latitude to 74 17′ and 75 15′ E longitudes at 177 m sea level | Hot and arid | Sandy loam to loam | 1 experiment (2009) | ICHG 00440 |
| Imphal | 24 45′ N latitude to 93 54′ E longitude at 775 m sea level | Warm perhumid | Alluvial sandy to sandy loam | 1 experiment (2009) | ICGS 76 |
| Kolasib | 240′ N latitude to 930′ E longitude | Warm perhumid | Acidic sandy | 2 experiments (2008 and 2009) | ICGS 76 |
| Aliyarnagar | 10 29′ N latitude to 76 58′ E longitude at 288 m sea level | Hot semi-arid | Sandy loam | 1 experiment (2009) | CO 3 |
| Tindivanam | 11 56′ N latitude to 79 29′ E longitude at 53.6 m sea level | Hot semi-arid | Sandy loam | 2 experiments (2008 and 2009) | TVG 0004 |

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**Table 2.** Details of the commercial boron sources, their mode and rate of application.

| Commercial Boron Source | Mode of Application | Boron Content (%) | Rate of Application (kg ha$^{-1}$) | Amount of Fertilizers Applied (kg ha$^{-1}$) |
|---|---|---|---|---|
| Control | No boron | — | 0 | 0 |
| Borax | Soil | 11 | 2 | 20 |
| Boric acid | Soil | 17 | 2 | 12 |
| Agricol® | Soil | 11 | 2 | 20 |
| Agricol® | Seed | 11 | 1 | 10 |
| Chemiebor® | Foliar | 20 | 1 | 6 |
| Solubor | Soil | 20 | 2 | 10 |
| Solubor | Foliar | 20 | 1 | 5 |
| Borosol | Soil | 20 | 2 | 10 |
| Borosol | Foliar | 20 | 1 | 5 |
| Chemiebor 11 | Soil | 11 | 2 | 18.5 |
| Maxibor | Soil | 20 | 2 | 10 |

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application: 0.1% aqueous solution at 30, 50, and 70 days after emergence; and seed dressing: 0.1–0.15% of seed weight).

Fields were prepared by ploughing and leveling at all the locations and divided into small plots of 25 m$^2$ (5 m × 5 m) by raising bunds. The 40 kg nitrogen (N) and 20 kg phosphorus (P) ha$^{-1}$ as di-ammonium phosphate and 50 kg potassium (K) ha$^{-1}$ as murate of potash as basal and 1000 kg ha$^{-1}$ gypsum at 40 days after emergence (DAE) during flowering were applied uniformly in all the treatments (Singh and Basu 2005). Additional lime @ 1000 kg ha$^{-1}$ was also applied as basal in acid soils of Kolasib and Imphal in NEH. The soil applications of B sources were made along with NPK fertilizers. For seed treatment, the B fertilizer was mixed with seeds forming a coating around the seed and sown in the field immediately. For foliar applications, the different B sources were applied as 0.1% aqueous solution thrice at 30, 50 and 70 DAE. The seeds of peanut cultivars were dressed with Thiram/Bavistin at 3 g kg$^{-1}$ seed and sown at 45 × 10 cm$^2$ spacing in the furrows (3–5 cm deep) and covered with soil. The crop was grown under recommended package of practices, and care was taken to protect it from weeds, insects, pests and diseases during the entire cropping season at all the locations. The sandy loam soils were infested with white grub (*Holotrichia consanguinea*) that were managed with the application of 25 kg ha$^{-1}$ of Phorate 10 G. All the experiments were conducted during wet season (June–September) except in Aliyarnagar during *Rabi-summer* seasons (February–May).

The crops were harvested at maturity, dried in sun for a week and pod and haulm yields, shelling out turn, 100-seed weight and length and width of the seeds were recorded. Five plants from each plot were uprooted randomly both at 60 DAE and at maturity and measured plant height and numbers of pods per plant. These plant samples were washed, separated into leaves, stem and pods and weighed after drying in an oven at 60°C for about a week. These oven-dried leaf and pod (seed and shell separately) tissues were ground to a fine powder and analyzed for Ca and K using atomic absorption spectrophotometer, and P and B (Curcumine method) by colorimetry. All the data were analyzed statistically and calculated critical differences at $p = 0.05\%$.

## Results

### *Plant height, flowering, pods and pegs*

The data for various locations reveals that the application of B, through various sources, induced early flowering, helped in converting more peg to pod and increased number of pods (Tables 3 and 5–8). These parameters, however, slightly varied with the various B sources, their mode of applications and places. The application of B did not influence the plant height at most of the locations and hence data are not given. However, at Durgapura, foliar applications of Chemiebor and Solubor and seed dressing of Agricol reduced the plant height, but soil application of borax and both soil and foliar application of Borosol increased the plant height (Table 5).

**Table 3.** Influence of various sources of boron on flowering and yield component of peanut at Mainpuri (cv. CSMG9510).

| | Days to Flower | | | | Shelling (%) | | | | 100 Seed Weight (g) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Boron Source | 2006 | 2008 | 2009 | Mean | 2006 | 2008 | 2009 | Mean | 2006 | 2008 | 2009 | Mean |
| Control | 34 | 35 | 36 | 35.0 | 69.5 | 70.6 | 71 | 70.4 | 49.8 | 50.6 | 52 | 50.8 |
| Borax (soil) | 32 | 34 | 34 | 33.2 | 70.1 | 71.0 | 72 | 71.0 | 50.2 | 51 | 52 | 51.1 |
| Boric acid (soil) | 31 | 31 | 31 | 31.0 | 69.8 | 70.7 | 72 | 70.8 | 50.5 | 51.8 | 53 | 51.8 |
| Agricol (soil) | 33 | 33 | 33 | 32.9 | 70.1 | 71.2 | 72 | 71.1 | 51.2 | 52.4 | 52 | 51.9 |
| Agricol (seed) | 31 | 32 | 33 | 32.0 | 69.4 | 70.7 | 72 | 70.7 | 50.4 | 51.2 | 53 | 51.5 |
| Chemiebor (foliar) | 29 | 30 | 30 | 29.7 | 71.0 | 72.5 | 71 | 71.5 | 51 | 52 | 54 | 52.3 |
| Solubor (soil) | 30 | 31 | 32 | 30.9 | 69.9 | 70.2 | 73 | 71.0 | 52 | 52.9 | 54 | 53.0 |
| Solubor (foliar) | 33 | 34 | 34 | 33.8 | 71.2 | 71.9 | 72 | 71.7 | 51.8 | 52.2 | 53 | 52.3 |
| Borosol (soil) | 32 | 33 | 33 | 32.6 | 72.1 | 72.8 | 73 | 72.6 | 51.2 | 52.7 | 54 | 52.6 |
| Borosol (foliar) | 31 | 32 | 32 | 31.7 | 71.5 | 72 | 72 | 71.8 | 51.5 | 53.4 | 54 | 53.0 |
| LSD ($p = 0.05$) | 2.0 | 1.5 | 2.0 | – | 0.6 | 0.7 | 0.9 | – | 0.5 | 0.8 | 1.0 | – |

Similarly, at Imphal (Manipur), the plant height, though reduced due to soil application of Borax and Agricol, increased due to soil application of Maxibor and foliar application of Chemiebor and Solubor as B sources (Table 6). In Kolasib, the plant height and the number of branches were much influenced by B; however, the number of pods, 100 pod weight and 100 seed weight were less influenced by most B sources except one or two B sources (Table 7).

In Mainpuri, the peanut cv. "Utakarsh" took 34–36 days to flower. The application of B induced early flowering and reduced the number of days taken to flower by 1–5 days during 2006, by 2–5 days during 2008 and by 3–6 days during 2009, which helped in early pod formation and finally increased the number of pods (Table 3). Induction of early flowering is desirable in groundnut for converting more pegs to pods and increased number of pods per plant. Though the application of B increased the number of pods per plant at all the locations, the significant increase was obtained at Durgapura, Aliyarnagar and Tindivinam where soil application of Borax, Agricol, Solubor and Borosol was at par. Similarly, foliar applications of Chemiebor, Solubor and Borosol showed the response at par. At Imphal, though the number of pod was greater in control plots, their sizes increased with B treatments.

It was noted that, at most locations, the soil applications of B sources were superior over their foliar applications in producing the pods and in conversion of pegs to pod.

### *Yields and yield attributes*

The data of field experiments on various B sources, at various locations, revealed that the application of B, which influenced flowering and pod formation also increased the yield and yield attributes, shelling percent, the number of sound mature kernels (SMK) and 100-seed weight at all the locations with most pronounced effect on pod yield and 100-seed weight (Tables 3–8). All the B sources whether

**Table 4.** Influence of various boron sources on pod and haulm yields of peanut at Mainpuri (cv. CSMG9510).

| | Pod Yield (kg ha$^{-1}$) | | | | Haulm Yield (kg ha$^{-1)}$ | | | |
|---|---|---|---|---|---|---|---|---|
| Boron Source | 2006 | 2008 | 2009 | Mean | 2006 | 2008 | 2009 | Mean |
| Control | 1904 | 2024 | 2168 | 2032 | 3998 | 4250 | 4536 | 4261 |
| Borax (soil) | 2050 | 2170 | 2314 | 2178 | 4468 | 4732 | 5042 | 4747 |
| Boric acid (soil) | 1984 | 2104 | 2258 | 2115 | 4642 | 4966 | 5328 | 4979 |
| Agricol (soil) | 2040 | 2160 | 2308 | 2169 | 4386 | 4644 | 4963 | 4664 |
| Agricol (seed) | 1944 | 2064 | 2202 | 2070 | 4472 | 4746 | 5064 | 4761 |
| Chemiebor (foliar) | 2010 | 2130 | 2254 | 2131 | 4220 | 4474 | 4734 | 4476 |
| Solubor (soil) | 1972 | 2092 | 2222 | 2095 | 4298 | 4560 | 5407 | 4755 |
| Solubor (foliar) | 2006 | 2126 | 2258 | 2130 | 4912 | 5208 | 5791 | 5304 |
| Borosol (soil) | 2070 | 2190 | 2340 | 2200 | 4864 | 5190 | 5524 | 5193 |
| Borosol (foliar) | 2030 | 2150 | 2294 | 2158 | 4668 | 4968 | 5236 | 4957 |
| LSD ($p = 0.05$) | 68 | 120 | 105 | — | 210 | 236 | 633 | — |

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**Table 5.** Influence of various boron sources on yield and yield components of peanut cv. M335 at Durgapura (wet season 2006 and 2008) and cv. TGLPS3 at Raichur (during wet season 2006).

| | Durgapura (cv. M335) | | | | Raichur (cv. TGLPS3) | |
|---|---|---|---|---|---|---|
| | | | Pod Yield (kg ha$^{-1}$) | | Pod Yield (kg ha$^{-1}$) | |
| Treatment | Plant Height (cm) | Number of Pods Plant$^{-1}$ | 2006 | 2008 | 2006 | Shelling (%) |
| Control | 66 | 10 | 2306 | 2280 | 836 | 58 |
| Borax (soil) | 70 | 22 | 2778 | 2892 | 878 | 61 |
| Boric acid (soil) | 69 | 14 | 2764 | 2833 | 872 | 59 |
| Agricol® (soil) | 63 | 19 | 2639 | 2781 | 886 | 57 |
| Agricol® (seed) | 62 | 12 | 2403 | 2390 | 818 | 62 |
| Chemiebor (foliar) | 60 | 21 | 2667 | 2772 | 1004 | 64 |
| Solubor (soil) | 64 | 24 | 2611 | 2730 | 874 | 62 |
| Solubor (foliar) | 61 | 26 | 2903 | 3007 | 1057 | 60 |
| Borosol (soil) | 80 | 14 | 2639 | 2660 | 872 | 63 |
| Borosol (foliar) | 84 | 25 | 2791 | 2930 | 893 | 61 |
| LSD (0.05) | 4 | 3 | 242 | 283 | NS | 3 |

used as soil or as foliar applications increased the pod yield of peanut. Though, slight variations over the locations were observed and, in general, the soil application of same amount of B (2.0 kg ha$^{-1}$ B) as Borax, Agricol, Solubor and Borosol were at par in their response to peanut and slightly superior over foliar applications of B sources at most of the locations. Similarly, the response of foliar applications of 1.0 kg ha$^{-1}$ B as Chemiebor, Solubor and Borosol were at par.

### *Mainpuri*

The data at Mainpuri, Uttar Pradesh, reveals that all the B sources increased the groundnut pod yield, shelling out turn and 100 seed weight, the significant increase in pod yield was only due to Borax, Agricol and Borosol (Table 3). The responses due to soil application of the same amount of B as Borax, Agricol and Borosol were at par. As foliar application, the responses of Chemiebor, Borosol and Solubor were at par and all these could increase yield significantly during 2006, but subsequently only Borosol could increase yield significantly over control. The seed dressing of Agricol® was not encouraging for groundnut. Interestingly, at this location, the B increased haulm yield due to all the B sources except Chemiebor during first 2 years, and increased with boric acid, Solubor and Borosol during 2009. B sources also increased shelling by 0.5–5% and 100-seed weight by 0.4–4 g. The peanut during 2006 showed 69.5% shelling out turn and 49.8 g 100-seed weight in control (without B), which increased to 70–72% and 50–52 g, respectively, with the application of B.

**Table 6.** Influence of various sources of boron on growth and pod yield of peanut cv. Mallika (ICHG00440) at Hanumangarh and cv. ICGS76 at Imphal (Manipur) during wet season 2009.

| | Hanumangarh | | Imphal, 2009 | | |
|---|---|---|---|---|---|
| B Sources | Pod Yield (kg ha$^{-1}$) | Shelling (%) | Plant Height (cm) | Pods Plant$^{-1}$ | Pod Yield (kg ha$^{-1}$) |
| Control | 1822 | 66.4 | 53.3 | 10 | 3853 |
| Borax (soil) | 2245 | 67.5 | 50.8 | 6 | 3827 |
| Agricol (soil) | 1822 | 66.3 | 50.2 | 8 | 4927 |
| Chemiebor 11S (soil) | 1289 | 65.6 | 52.0 | 5.7 | 3990 |
| Chemiebor (foliar) | 1533 | 66.0 | 58.0 | 7.7 | 3347 |
| Solubor (soil) | 1378 | 65.5 | 53.9 | 9 | 3567 |
| Solubor (foliar) | 1489 | 66.0 | 57.3 | 8 | 3703 |
| Borosol (soil) | 1555 | 66.4 | 54.6 | 8.3 | 4380 |
| Borosol (foliar) | 1845 | 66.0 | 54.3 | 9 | 4217 |
| Maxibor (soil) | 2089 | 67.0 | 60.8 | 7.3 | 3943 |
| LSD (0.05) | 201 | NS | 2.2 | NS | 89 |

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**Table 7.** Influence of B sources on yield and yield attributes of ICGS 76 peanut grown at Kolasib (Mizorum) during wet season 2008 and 2009, and cv. CO3 grown at Aliyarnagar (TN) during Rabi-summer 2009.

| | Kolasib | | | | | Aliyarnagar, 2009 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2009 | | | | | | | | | |
| B Sources | 2008 Pod Yield (kg ha$^{-1}$) | Pod to Kernel Ratio | 100 Seed Weight (g) | 100 Seed Weight (g) | Pod Yield (kg ha$^{-1}$) | Pods Plant$^{-1}$ | 100 Seed Weight (g) | Shelling (%) | Pod Yield (kg ha$^{-1}$) | Haulm Yield (kg ha$^{-1}$) | SMK (%) |
| Control | 1019 | 77.4 | 148.2 | 59.6 | 570 | 15.2 | 50.2 | 55.3 | 2167 | 2850 | 87.5 |
| Borax (soil) | 1134 | 77.3 | 134.4 | 53.0 | 756 | 19.2 | 55.2 | 66.3 | 2650 | 3550 | 91.7 |
| Boric acid (soil) | 1343 | 78.1 | 143.9 | 56.6 | 637 | 18.8 | 54.8 | 65.7 | 2567 | 3450 | 90.5 |
| Agricol (soil) | 1817 | 78.7 | 149.6 | 59.2 | 723 | 18.4 | 54.2 | 65.0 | 2450 | 2400 | 89.5 |
| Agricol (seed) | 1380 | 62.6 | 134.6 | 51.1 | 682 | 17.8 | 53.6 | 62.0 | 2380 | 3350 | 88.7 |
| Chemiebor (foliar) | 1273 | 78.1 | 152.5 | 60.4 | 917 | 18.2 | 54.0 | 62.7 | 2350 | 3300 | 88.3 |
| Solubur (soil) | 1435 | 78.8 | 143.2 | 57.7 | 573 | 18.2 | 53.8 | 64.7 | 2400 | 3350 | 89.0 |
| Solubur (foliar) | 1296 | 79.0 | 144.5 | 58.2 | 513 | 18.0 | 53.8 | 64.3 | 2367 | 3350 | 88.0 |
| Borosol (soil) | 1644 | 78.5 | 150.6 | 59.5 | 607 | 18.2 | 54.2 | 64.7 | 2400 | 3250 | 89.3 |
| Borosol (foliar) | 1528 | 77.7 | 127.7 | 52.6 | 710 | 17.6 | 53.4 | 63.3 | 2250 | 3150 | 89.7 |
| LSD (0.05) | 114 | 1.7 | 14.7 | 5.7 | 104 | 1.4 | 2.9 | 5.2 | 213 | 340 | NS |

**Table 8.** Influence of B sources on various yield parameters of peanut at Tindivanam during wet season 2008 and 2009.

| | Wet Season, 2008 cv. TVG0004 | | | | | Wet Season, 2009 cv. TMV13 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Treatments | Pods Plant$^{-1}$ | Pod Yield (kg ha$^{-1}$) | Haulm Yield (kg ha$^{-1}$) | Shelling (%) | 100 Seed Weight (g) | Pods Plant$^{-1}$ | Pod Yield (kg ha$^{-1}$) | Haulm Yield (kg ha$^{-1}$) | Shelling (%) | 100 Seed Weight (g) |
| Control | 7 | 415 | 811 | 71.0 | 45.4 | 12 | 675 | 1530 | 68 | 34.0 |
| Borax (soil) | 16 | 700 | 1358 | 73.0 | 47.2 | 23 | 1055 | 1930 | 74 | 36.3 |
| Agricol (soil) | 14 | 625 | 1008 | 73.1 | 47.0 | 23 | 988 | 1850 | 72 | 36.1 |
| Chemiebor 11S (soil) | 20 | 760 | 1354 | 74.5 | 48.2 | 29 | 1334 | 2435 | 74 | 37.0 |
| Chemiebor (foliar) | 19 | 718 | 1210 | 73.1 | 47.6 | 26 | 1093 | 2120 | 73 | 36.8 |
| Solubor (soil) | 22 | 812 | 1435 | 74.8 | 48.5 | 31 | 1365 | 2790 | 75 | 37.4 |
| Solubor (foliar) | 20 | 725 | 1258 | 74.0 | 48 | 29 | 1210 | 2268 | 74 | 37.1 |
| Borosol (soil) | 12 | 610 | 945 | 72.4 | 46.8 | 18 | 874 | 1795 | 72 | 36.0 |
| Borosol (foliar) | 8 | 518 | 918 | 71.8 | 46.0 | 16 | 860 | 1578 | 69 | 35.2 |
| Maxibor (soil) | 10 | 554 | 930 | 72.0 | 46.2 | 13 | 771 | 1770 | 70 | 35.4 |
| LSD (0.05) | 1.6 | 84 | 145 | NS | NS | 2.4 | 112 | 434 | NS | NS |

The average of 3 years data at Mainpuri showed maximum pod yield of 2200 kg ha$^{-1}$ in the treatment of Borosol, followed by Borax 2178 kg pod ha$^{-1}$ and Agricol 2169 kg pod ha$^{-1}$ as compared to 2032 kg ha$^{-1}$ in the control (Table 4).

### *Raichur*

At Raichur, Karnataka, statistically significant increase in the pod yield due to various B sources could not observed mainly due to low yields (Table 5). However, there was a clear tendency that the B sources increased the peanut pod yield by 4–26%. The foliar sprays of Chemiebor, Borosol and Solubor showed maximum response. The B sources at this location also increased shelling by 1–6%. However, the seed dressing of Agricol was detrimental to peanut causing lesser germination and poor yield.

### *Durgapura*

The data at Durgapura, Rajasthan, in irrigated coarse-textured micro-farming situations, reveals that all the B sources, irrespective of their mode of application, increased the peanut pod yield significantly over control during both the years (Table 5). Soil application of borax, boric acid, Agricol, Solubor and Borosol and foliar applications of Chemiebor, Borosol and Solubor led to pod yield at par; however, among these, the highest pod yield was obtained with foliar application of Solubor (0.1% aqueous solution sprayed three times at 30, 50 and 70 DAE) followed by foliar spray of Borosol and soil application of Borax. Interestingly, seed dressing of Agricol was also encouraging for peanut at this location, though no significant increase in yield was observed.

### *Hanumangarh*

At Hanumangarh, Rajasthan, there was no consistency in the performance of various B sources mainly due to erratic weather, and thus many treatments showed no response (Table 6). However, a few B sources increased the peanut yield with the highest pod yield (2245 kg ha$^{-1}$) obtained by borax @ 20 kg ha$^{-1}$ applied in soil followed by Maxibor (2089 kg ha$^{-1}$) as compared to 1822 kg ha$^{-1}$ in control. Thus, one has to be cautious while applying B and even other fertilizers in the dry areas of Rajasthan as it may not lead to higher yield and show negative impact of the fertilizer applications as well.

### *Manipur*

The data for Imphal, Manipur, on the responses of plant to B application reveals that, the plant height though reduced due to soil application of Borax and Agricol, it increased with soil application of Maxibor and foliar application of Chemiebor and Solubor as B sources (Table 6). However, the pod yield

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increased with soil application of Agricol, Chemiebor11S, Borosol and Maxibor only, and hence, these were proved to be promising.

### Mizorum

The data for two seasons at Kolasib, Mizorum, with cv. ICGS 76 reveals that all the sources of B increased yield significantly even seed treatment and foliar application (Table 7). Here, the effect of Agricol and Borosol was superior over Chemiebor, Borax and Solubor. The data showed maximum pod yield of 1817 kg ha$^{-1}$ with soil application of 2 kg B ha$^{-1}$ as Agricol followed by soil application of Borosol (1644 kg ha$^{-1}$) and foliar application of Borosol (1528 kg ha$^{-1}$) as against 1019 kg ha$^{-1}$ in control during 2008. However, during wet season, 2009, when the experiment was repeated by sowing it on 11 August 2009, in poor fertility soils of Kolasib with pod yield below 600 kg ha$^{-1}$, the soil B application of Agricol and Borax and foliar application of Chemiebor and Borosol increased the yield (Table 7). Though maximum pod yield of 917 kg ha$^{-1}$ was recorded with foliar application of Chemiebor (1 kg ha$^{-1}$), at par with soil application of Borax and Agricol and foliar spray of Borosol with pod yields 756, 723 and 710 kg ha$^{-1}$, respectively. Among other parameters, the plant height and the number of branches were much influenced by B, whereas the number of pods, 100 pod weight and 100 seed weight were less influenced by most B treatments. Interestingly, seed dressing of Agricol significantly increased yield at this location during both the years. The effect of Agricol, Borax and Chemiebor was superior over other B sources.

### Aliyarnagar

At Aliyarnagar, Tamil Nadu, the application of B increased pod and haulm yields, the number of pods, 100 seed weight and shelling percent (Table 7). It also increased the percentage of SMK; however, significant differences were not observed. The effects of Borax, Agricol and Boric acid were at par. Here, foliar application of Solubor and Borosol did not increase the yields. Interestingly, the seed dressing of Agricol was beneficial and increased yield significantly at this location. Among the B sources, soil application of borax @ 2 kg B ha$^{-1}$ gave the highest number of pods (19.2 plant$^{-1}$), 100 seed weight (55.2 g), shelling percentage (66.3) and SMK (91.7%), thus leading to higher pod (2650 kg ha$^{-1}$) and haulm (3550 kg ha$^{-1}$) yields in CO3 groundnut cultivar. This was closely followed by soil application of boric acid and Agricol, which were statistically at par.

### Tindivanam

At Tindivanam, Tamil Nadu, during wet season 2008, the results reveals that in groundnut cv. TVG0004, the B application increased the number of pods, pod and haulm yields, shelling out turn and 100 seed weight (Table 8). Though all the B sources increased the pod and haulm yields significantly, the responses of Solubor, Chemiebor 11S and borax were superior over other B sources. During 2009, in groundnut cv. TMV13, the B application increased the number of pods from 12 pods plant$^{-1}$ in control to 13–31 pods plant$^{-1}$ in B treatments, pod yield from 675 kg ha$^{-1}$ in control to 771–1365 kg ha$^{-1}$ in B treatment, haulm yield from 1530 kg ha$^{-1}$ in control to 1578–2790 kg ha$^{-1}$ in B treatments (Table 8). The various B sources also increased shelling from 68% in control to 69–75% in B treatment and 100 seed weight from 34 g in control to 35.2–37.4 g in B treatment. Here, all the B sources, except Maxibor, increased the pod and haulm yields significantly, and like previous year, the response of Chemiebor 11S and Solubor was slightly superior over all the other B sources.

### Nutrient concentrations in leaves, seeds and shells at harvest

The nutrient analysis of various plant tissues indicated that the application of B altered the concentration of P, K, Ca and B in leaves, seed and shell at harvest and found that soil application was most effective (Table 9). The application of B increased the concentrations of B in leaves and P, K, Ca and B in seed and K, Ca and B in shell, but reduced the concentration of Ca in leaves (Table 9). The seed B content was 12 mg kg$^{-1}$ in the peanut grown without B application (in control), which increased to

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**Table 9.** Influence of various sources of Boron on P, K, Ca and B contents in kernel at harvest at Durgapura during wet season 2008.

| | P (%) | | | K (%) | | | Ca (%) | | | B (mg kg$^{-1}$) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Treatment | Leaf | Seed | Shell | Leaf | Seed | Shell | Leaf | Seed | Shell | Leaf | Seed | Shell |
| Control | 0.13 | 0.35 | 0.03 | 1.19 | 0.45 | 0.97 | 3.84 | 0.029 | 1.27 | 19 | 12 | 9 |
| Borax (soil) | 0.13 | 0.42 | 0.02 | 1.14 | 0.64 | 0.71 | 3.5 | 0.038 | 1.33 | 24 | 17 | 12 |
| Boric acid (soil) | 0.12 | 0.40 | 0.03 | 1.07 | 0.58 | 0.95 | 3.04 | 0.050 | 1.31 | 23 | 15 | 12 |
| Agricol® (soil) | 0.11 | 0.42 | 0.02 | 1.09 | 0.63 | 0.71 | 3.27 | 0.055 | 1.34 | 26 | 16 | 15 |
| Agricol® (seed) | 0.13 | 0.41 | 0.04 | 1.26 | 0.53 | 1.14 | 3.1 | 0.031 | 1.42 | 22 | 16 | 14 |
| Chemiebor (foliar) | 0.13 | 0.37 | 0.03 | 0.87 | 0.44 | 0.98 | 3.42 | 0.032 | 1.25 | 26 | 15 | 14 |
| Solubor (soil) | 0.14 | 0.38 | 0.04 | 0.97 | 0.55 | 0.75 | 3.28 | 0.031 | 1.12 | 22 | 17 | 12 |
| Solubor (foliar) | 0.11 | 0.44 | 0.05 | 1.06 | 0.65 | 0.93 | 3.89 | 0.036 | 1.44 | 28 | 13 | 11 |
| Borosol (soil) | 0.13 | 0.46 | 0.04 | 0.78 | 0.73 | 0.66 | 3.66 | 0.029 | 1.36 | 23 | 19 | 13 |
| Borosol (foliar) | 0.14 | 0.39 | 0.07 | 1.11 | 0.66 | 0.99 | 3.45 | 0.032 | 1.23 | 25 | 14 | 11 |
| LSD (0.05) | NS | 0.06 | 0.02 | NS | 0.11 | 0.26 | 0.32 | 0.003 | NS | 2 | 3 | 1.5 |

13–19 mg kg$^{-1}$ with the application of various B sources. Similarly, the leaf B content was 19 mg kg$^{-1}$ in control, which with the application of various B sources increased to 22–28 mg kg$^{-1}$. Application of B also increases B content of shell from 9 mg kg$^{-1}$ in control to 11–15 mg kg$^{-1}$ in various B treatments. The Ca content of peanut leaf, in control plot (without B), was 3.82%, which is slightly higher than the adequate requirement, and the application of B reduced leaf Ca and increased the concentrations of P and K in seed.

## Discussion

The field studies at various locations in sandy to loam soils of India demonstrated that the application of B through various sources induced early flowering, helped in converting more peg to pod and increased the number of pods, shelling percent and 100-seed weight with most pronounced effect on pod yield. It also increased the plant height and haulm yield at few locations. These parameters, however, slightly varied with the B sources, their modes of applications (soil, seed dressing and foliar) and locations. All the B sources increased the peanut pod yield and soil application of the same amount of B (2.0 kg ha$^{-1}$) as borax, Agricol, Solubor, and Borosol were equally effective and slightly superior over their foliar applications. Similarly, the responses of foliar applications of Chemiebor, Solubor and Borosol, at 1.0 kg ha$^{-1}$ B, were at par.

The sufficiency level of hot water soluble B in soil for peanut is 0.5 mg kg$^{-1}$, and depending on soil and genotype, the critical limits of B vary from 0.2 to 0.4 mg kg$^{-1}$ (Singh 1994). Our earlier study demonstrated that B deficiency in the main peanut growing areas of India having 0.2–0.36 mg kg$^{-1}$ hot water soluble B in soils causes 15–26% yield reduction in peanut; thus, B application is highly essential (Singh 2001a; Singh et al. 2004). Soil application of 0.5–1.0 kg ha$^{-1}$ B either as basal or prior to bloom stage (20–30 days after emergence) or foliar application of 0.05–0.1% aqueous solution of boric acid corrected B deficiency and increased pod filling, seed size, 100-seed weight, percent sound mature seeds and pod yield (Singh et al. 2004, 2007, 2009).

B facilitates translocation of sugar and fat synthesis, and plays an important role in pollen germination, maturation and seed formation. In this study, the application of B caused early flowering and increased the number of pods per plant. B induced early flowering by 1–6 days, which helped in early pod formation and finally more number of pods. The various B sources increased the conversion of peg to pod by 4–15% in peanut cv. GG20 at Junagadh and 17–27% in cv. VG403 at Vriddhachalam (Singh, Jat and Misra 2009). The peanut under normal nutrient and photosynthate supply bear two seeds in each pod, but poor nutrition decreases the number of seeds in each pod and their size. The cv. VG403, a two seeded pod bearing peanut, showed 35% one-seeded pods without B, which by application of B was drastically reduced to 17–21% at Vriddhachalam, clearly indicating that the application of B provided better nutrition to pod and increased the number of two seeded pods, which resulted in lesser number of one-seeded pods (Singh et al. 2008a). In our earlier study, B increased 12–33% 100-seed weight, 7% shelling out-turn and 11% sound mature seeds (Singh, Chaudhari, and Basu 2007).

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However, at Vriddhachalam, various B sources increased shelling by 2–13% and 100-seed weight by 2–11 g (Singh, Jat, and Misra 2009). In Thailand, the application of 0.5 kg B $ha^{-1}$ increased the number and weight of pod and seed, and proportion of large seed to small seed and decreased the hollow-heart in seed from 13–49% to less than 1% (Kasikeran and Panya 1988).

There was a significant effect of foliar application of 0.1% aqueous solution (sprayed three times at 30, 50 and 70 DAE) of Chemiebor, Solubor, and Borosol at Durgapura, Raichur Aliyarnagar and Tindivinam, and Chemiebor and Borosol at Kolasib, Borosol at Manipur in NEH. However, this foliar application was best suited in wet and humid weather of NEH and southern India. During hot and dry weather of western India, it caused scorching on peanut leaves due to the accumulation of B salt on leaves. The micronutrients, due to their lesser quantity, are applied on foliage in solution form, and foliar application of B increased dry matter, kernel yield and crop quality (Murthy et al. 2003; Singh, Chaudhari, and Basu 2007). However, during dry weather, the leaves do not absorb it fully, and hence the scorching occurs. Boric acid caused scorching of leaves when applied on foliage, and as seed dressing it caused damage to seeds, reducing field germination (Singh 2001b, Singh, Chaudhari, and Basu 2007). In our earlier study at Vriddhachalam, pod yield increased by soil application of Agricol and Solubor, foliar sprays of Chemiebor, and seed application of Agricol, and interestingly, the foliar and seed applications of B sources were at par with or slightly superior over their soil applications (Singh et al. 2008a). Thus, the foliar application of B should be used only in eastern, NEH and southern India, but should be avoided during hot and dry weather of western and northern India. B is transported primarily in xylem, but is relatively less mobile in phloem, and hence from foliar application, the pod does not get continuous supply of B needed during pod filling stage. However, recent study has demonstrated re-translocation of B in peanut from leaves to seed where foliar application of B reduced hollow heart, a symptom of B deficiency in seeds, in cv. TAG 24 from 39% to 8% and in cv. Tainan 9 from 63% to 18% (Konsaeng, Dell and Rerkasem 2010). This was probably the reason for better performance of foliar application of B sources at certain locations in this study. Interestingly, the soil and foliar applications of various B sources showed similar response at Durgapura. Athough seed dressing of Agricol is useful in Kolasib and Aliyarnagar, it was detrimental to peanut as it damaged seed causing very poor germination under dry weather conditions of west part of India; hence, it should not be used as seed dressing. Our earlier study has demonstrated that boric acid, applied as seed dressing, caused damage to seed and reduced field germination and yield (Singh 2001b). Similar observation was reported in this study on Agricol. However, B application in soil showed excellent response.

In field, though a significant effect of B was observed from 0.5 to 2 kg B $ha^{-1}$, 1.0 kg B $ha^{-1}$ was ideal for normal seed-size peanut cultivars, and 2 kg B $ha^{-1}$ for large seed size peanut cultivars that increased pod yield by 23.3% (Singh, Chaudhari, and Basu 2007). Thus, the application of 2 kg B $ha^{-1}$ was recommended for large seed size in neutral to alkaline and light texture soils of India where peanut is mainly grown. Soils at most of the locations in this study were B-deficient, causing yield reductions in peanut, which were offset by external application of B fertilizers. The increase in shelling percent and 100-seed weight of peanut observed due to application of B indicates an important role of B on seed quality. The present multi-locational study clearly demonstrated the effectiveness of various B sources for enhancing the production and quality of peanut in light-textured soils.

In peanut, the application of B increased the concentrations of B in leaves and shell and K, Ca and B in seed and shell at harvest, but reduced the Ca concentrations in leaves. The peanut, in calcareous soil, absorb more Ca and generally show high Ca content in their leaf than the required amount (Singh et al. 2004, 2005). Also, in this study, more Ca was observed in peanut leaves, and the application of B reduced Ca and increased the concentrations of K and B in seeds. This increase was more pronounced for K in seed whose absorption is restricted due to high soil Ca. B helps in N absorption and acts as a regulator of K/Ca ratio in the plant. The seed B content was 12 mg $kg^{-1}$ in the peanut grown without B application, which however increased to 13–19 mg $kg^{-1}$ with the application of various B sources. The sufficiency level of B in the leaves during flowering and fruiting is reported to be 25–60 mg $kg^{-1}$ and the critical level 20 mg $kg^{-1}$ and peanut seeds containing less than 17 mg $kg^{-1}$ B showed the incidence of hollow-heart (Singh et al. 2004). However, at harvest, the leaf B content reduces due to its translocation to pods and as a result the leaf B content at harvest in this study, which was 19 mg $kg^{-1}$

in control plot, increased to 22–28 mg $kg^{-1}$ due to B application. In acid soils, 2.0 kg B $ha^{-1}$ gave the highest pod and straw yield, B content (20.5 mg $kg^{-1}$), and soil available B (0.59 mg $kg^{-1}$) in peanut; however, 1.0 kg B $ha^{-1}$ showed highest additional profit (Singh et al. 2004). In acid soils, the application of 1–2 kg B $ha^{-1}$ in soil builds up available B (0.53–0.59 mg $kg^{-1}$) in the soil after harvest of peanut (Singh et al. 2005). There is a strong correlation between B and organic carbon contents of soils, and the risk of B deficiency increases when organic matter declines as it has the ability to complex large amounts of B (Yermiyaho, Keren and Chen 1988).

## Conclusions

The field studies, at various locations in light-textured soils, clearly demonstrated that the application of B induced early flowering, helped in converting more peg to pod and increasedthe number of pods, pod yield and yield attributes, shelling percent and 100-seed weight, and hence B application is essential. Soil application of 2.0 kg B $ha^{-1}$ as Agricol, Solubor and Borosol increased pod yield to a similar degree as borax, but slightly higher than foliar applications. Similarly, the foliar application of 1 kg B $ha^{-1}$ as Borosol, Chemiebor and Solubor was at par in increasing pod yield; thus, these were more effective under humid conditions.

Thus, soil application of 2 kg B $ha^{-1}$, using any one of these B sources, is recommended to enhance the productivity and the quality of large seeded peanut in India.

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