QUANTITY AND SOME QUALITY COMPONENTS OF GROUNDNUT (*Arachis hypogaea* L.) AS AFFECTED BY BORON FERTILIZATION

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A thesis submitted to the post-graduate committee of the Yezin Agricultural University in partial fulfillment of the requirements for the Degree of Master of Agricultural Science (Soil & Water Management)

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The thesis attached hereto, entitled "**Quantity and Some Quality Components of Groundnut (*Arachis hypogaea* L.) as Affected by Boron Fertilization**" was prepared under the direction of the candidate's supervisory committee and has been approved by all members of that committee and board of examiners as a requirement for the degree of **Master of Agricultural Science (Soil and Water Management)**

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DECLARATION OF ORIGINALITY

This thesis represents the original work of the author, except where otherwise stated. It has not been submitted previously for a degree at any other University.

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DEDICATED TO MY BELOVED PARENTS

U MAUNG KO AND DAW TIN KYI

4.2 Winter Season Experiment

The winter season cultivation (November 2011 to March 2012) was conducted with the same layout of the rainy season. Groundnut is grown during this season mainly as a winter season crop after paddy in lower Myanmar and after sesame in upper Myanmar. It can also be successfully cultivated in winter wherever irrigation water is available in upper Myanmar and alluvial plain along the river side of Myanmar. Winter season groundnut cultivation acreage was 416,000 ha and occupies 57% of the total groundnut growing area of Myanmar (MOAI, 2011).

4.2.1 *Seed Yield*

Seed yield of groundnut as affected by B fertilization is shown in Table 4.7. B fertilization treatments showed positive effect on seed yield of groundnut significantly higher than B-untreated one.

The seed yield of BF2 was significantly higher than that of any other treatments except BS2. Therefore, B fertilization is needed to maximize seed production of groundnut without considering timing, method and amount during winter season (irrigated groundnut) cultivation.

Among soil-splits application, there was statistically no difference in seed yield, but two times split (BS2) showed higher response than three times (BS3) followed by one time (BS1). The most suitable times for soil-split application may be early bloom and pegging stages for higher seed yield of groundnut. Because of easily-leaching nature of B in soil, applied B as basal can disappear and may not be sufficient to maintain reproductive growth. In foliar-split application, BF2 gave significantly higher seed yield than those of the other two treatments. This result agreed that the additional supply of B via the phloem to the buried fruit can be the only explanation for the response of foliar B in the number of mature pods, seed yield and percentage of hollow heart in groundnut (Kongsaeng *et al.*, 2010). Hobbs (1974) also explained that groundnut yield was increased 60% over control after foliar B application at the rate of 0.6 kg B ha^{-1}.

Treatment B0F4 produced significantly higher seed yield than B0, but it gave the lowest yield among all B-treated plots. This may be due to low soil available B for yield maximization of groundnut. Even B is not deficient in soil, application of B has been reported to boost yield for several crops (Woodruffs, 2006; Reinbott and Blevins 1995).

The seed yield resulted from B0 was highly significantly lower than those from all B treated plots. Blamey *et al.* (1997) reported that B deficiency drastically reduced the seed yield of sunflower. Li and Liang (1997) concluded that adding B to B deficient soils increased the yield of maize, soybean, rice and sugar beet by 8.5, 4.0, 6.6 and 10.2%, respectively. Among the micronutrients, B is stated to influence many growth parameters especially in filling up of seeds (Blamey, 1976).

4.2.2 *Pod Yield*

Pod yield of groundnut as affected by B application in the winter season cultivation is shown in Table 4.6. The pod yield of BS3 was the highest among all treatments and that of B0 the lowest. BS3 produced significantly higher pod yield than BS1 and B0, but not significantly different from other B treated plots.

This indicated that appropriate method of B application as basal together with three soil-splits in small amount for each time might be the best way to maximize pod yield of groundnut. In contrast, only one soil-split (higher amount of 1 kg B ha^{-1} applied at that time) at pegging did not maintain the B uptake for successive developing pod in later growth stages and thus produce lower pod yield.

Soil-splits, such as BS2 and BS3 gave higher pod yield compared to all foliar-splits. Among foliar-splits, BF1 gave higher yield than BF2 and BF3, but not significant different. Vishwakarma *et al.* (2008) reported that the highest number of pods $plant^{-1}$, pod yield and kernel yield were recorded with the application of borax as soil application in groundnut.

4.2.3 *Seed weight*

Seed weight of groundnut showed good response to applied B as shown in Table 4.6. The seed weight resulted from BS2, BF2 and BS3 were significantly higher than that of B0, which was not statistically different from BF4, BF3, BF1 and BS1. Two- to three-time soil-splits showed a little higher seed weight per plant than only one-time split at pegging stage but not significantly different among soil-split treatments. Similarly, soil application of B increased 53% over control in seed yield of sunflower has been reported by Naik (1991). B fertilization also enhanced yields of different crops such as soybean, mustard, wheat and chickpea (Schon and Blevins, 1990; Reinbott and Blevins, 1995; Islam, 2005; Shil *et al.*, 2007).

Table 4.6 Effect of different Timing and Method of B fertilization on pod yield, yield components, and harvest index on groundnut during winter season, 2011-12

Treatment	Pod yield (kg ha^{-1})	No. of pods $plant^{-1}$	No. of seeds pod^{-1}	100 seed weight (g)	Shelling percentage (%)	Harvest Index
B0	3546 b	14.38 b	1.49 ab	42.10 c	70.74	0.52
B0F4	3842 ab	16.94 ab	1.41 b	50.45 ab	72.83	0.56
BF1	4014 ab	17.14 ab	1.42 b	46.55 abc	69.31	0.56
BF2	3976 ab	17.36 ab	1.56 a	49.80 ab	74.39	0.57
BF3	3865 ab	16.90 ab	1.42 b	50.83 a	71.79	0.57
BS1	3687 b	16.95 ab	1.45 ab	43.75 bc	76.45	0.54
BS2	4089 ab	18.00 a	1.52 ab	49.95 ab	76.93	0.57
BS3	4317 a	17.44 ab	1.41 b	50.75 a	72.32	0.56
	**	*	**	**	ns	ns
Pr > F	0.01	0.08	<0.001	<0.001	0.19	0.7
$LSD_{0.05}$	266.8	1.49	0.051	2.95	4.14	4.47
CV%	6.81	8.81	3.52	6.14	5.79	8.03

Means followed by the same letter in each column are not significantly different at the 5% level of Least Significantly Different (LSD).

B0 (B-untreated plot)

BS1 (basal + soil-split at Peg)

BS2 (basal + 2 soil-split at EB & Peg)

BS3 (basal + 3 soil-split at EB, Peg & FPF)

BF1 (basal + foliar-split at Peg),

BF2 (basal + 2 foliar-split at EB & Peg),

BF3 (basal + 3 foliar-split at EB, Peg & FPF)

B0F4 (foliar 4 times at SSF, EB, Peg & FPF)

[Peg = Pegging; EB = Early Bloom; FPF = Fifty Percent Flowering; SSF = Side Shoot Formation]

Table 4.7 Effect of different Timing and Method of B fertilization on seed yield and some parameter of groundnut during winter season, 2011-12

Treatment	Seed yield (kg ha^{-1})	Dry wt. plant^{-1} (g)	No. of branch plant^{-1}	No. of pod plant^{-1}	No. of seed plant^{-1}	Pod Wt. plant^{-1} (g)	Seed Wt. plant^{-1} (g)
B0	1451 c	27.34	4.97	14.38 b	21.18 b	14.15 b	10.02 b
B0F4	1741 b	29.79	4.84	16.94 ab	23.83 ab	16.72 ab	12.13 ab
BF1	1780 b	31.87	5.06	17.14 ab	24.32 ab	17.88 a	12.41 ab
BF2	2177 a	31.10	5.22	17.36 ab	26.88 a	17.92 a	13.38 a
BF3	1735 b	30.20	4.74	16.90 ab	23.92 ab	17.16 ab	12.22 ab
BS1	1806 b	30.21	4.82	16.95 ab	24.47 ab	16.45 ab	12.59 ab
BS2	1977 ab	31.59	4.78	18.00 a	27.30 a	17.92 a	13.77 a
BS3	1878 b	31.85	4.85	17.44 ab	25.12 ab	17.73 ab	12.79 a
	**	ns	ns	ns	*	**	**
Pr>F	<0.0001	0.13	0.22	0.08	0.02	0.03	0.006
$LSD_{0.05}$	106.20	2.24	0.27	1.49	1.54	1.55	1.14
CV%	6.17	7.35	5.4	8.81	9.08	9.14	9.23

Means followed by the same letter in each column are not significantly different at the 5% level of Least Significantly Different (LSD).

Although BF2 gave the highest seed weight plant^{-1}, it was not statistically different from each other in foliar-split and foliar application treatment. These results were also endorsed by the findings of Heithholt (1994), in which he depicted that soil and foliar applied B also can correct B-low concentration in cotton whereas foliarly applied B also can speed up the process of translocation of N-compounds and enhance protein synthesis, which in return promote fruiting. Havin *et al.,* (1999) reported that flowering and fruit development were restricted by a shortage of B. Seed yield was increased significantly with each increment of B in groundnut (Chowdhury *et al.,* 2000).

Therefore, basal together with two- to three-time soil-splits and also with two-time foliar-splits B application provided appreciable seed weight in groundnut cultivation during the winter season.

4.2.4 *Yield components*

Yield components of groundnut such as number of pods per plant, number of seed per pod, hundred seed weight and shelling percentage for the rainy season were recorded in Table 4.6. All the above parameters except shelling percentage showed statistical difference ($P < 0.05$) by B fertilization.

***Number of pods per plant*:** The number of pods plant^{-1} was significantly affected by B fertilizations during the rainy season as shown in Table 4.6 and Figure 4.17. BS2 produced the maximum number of pods plant^{-1} significantly higher than B0, but not different from other B treated plots. Similarly, Vishwakarma *et al.* (2008) reported that the highest number of pods plant^{-1} and pod kernel yield of groundnut were obtained in the soil application of borax. Abid *et al.* (2007) stated that the application of B at the rate of 1.5 and 2 kg ha^{-1}were the best for optimum number of bolls plant^{-1} in cotton. In contrast, the highest number of pods plant^{-1} was obtained at 2 kg B ha^{-1} in our study. However, more researches will be necessary for application rates in different soils.

***Number of seeds per pod*:** The number of seeds pod^{-1} was also significantly different by B-fertilizer application during the winter season. BF2 produced significantly higher number of seeds than those of all foliar-splits and only foliar application. The highest number of seeds per pod was obtained from BF2, but BF3, in which additional foliar application was conducted at fifty percent flowering, produced the low number. It can be suggested that foliar B at fifty percent flowering reduced the number of seeds per pod.

***Hundred seed weight*:** The highest hundred seed weight was obtained from BF3 and BS3 and the lowest from B0. And also Hundred seed weight resulted from BS1 was the lowest among B treated plots but not statistically different among all B-treated plots except BF3 and BS3. The more the splitting times of B application, the higher the hundred seed weight of groundnut were observed in both soil-split and foliar-split. B0F4 produced the third largest hundred seed weights after BF3 and BS3. Therefore, subsequent application of B, which is required for seed filling, could increase hundred seed weight of groundnut. Blamey (1976) reported that B influenced many growth parameters and filling up of seeds. Nasef *et al.* (2006) also reported that foliar application of B (200 ppm) with or without rhizobium increased hundred seed weight of groundnut.

***Shelling percentage*:** The shelling percentages were not significantly different by B fertilization. The highest value was obtained from BS2 and the lowest from BF1 followed by B0. Although BF1 produced more number of pods plant^{-1} than B0, all of the developing pods did not receive adequate amount of B for pod filling. According to the result of this study, B fertilization did not show significant effect in shelling percentage of groundnut. Shelling percentage is one of the most important parameters for groundnut yield, but the variations in this parameter is very difficult to manage by fertilization with a micronutrient especially B. However, B application at appropriate time would be very important to get higher shelling percentage because BF1 and B0 showed the low value due to its B insufficiency.

4.2.5 *Total Dry Matter (TDM)*

B application did not show significant difference on total dry matter of groundnut during the winter season as shown in Table 4.7. The highest TDM was obtained from BF1 and the lowest one from B0. Dexit and Elamathi (2007) stated that foliar B application increased dry weight plant^{-1} on groundnut crop. In soil-split B application, the more the splitting produced the higher the TDM and which showed opposite effect of B on TDM in foliar-split application in the present study. Shaaban *et al.* (2004) reported that the application of B as foliar together with addition 25 ppm of B or 50 ppm of Zn significantly increased both fresh and dry weight of cotton plants under high $CaCO_3$ level in the soil. Moreover, Zahoor *et al.* (2011) reported that soil application of 2 kg B ha^{-1} at ray floret stage proved to be the best treatment for dry matter accumulation among all interactive sowing and B combination in sunflower and also exogenous application of B reportedly responded in increasing plant dry matter of sunflower (Oyinlola, 2007).

4.2.6 *Harvest Index (HI)*

Harvest index of groundnut was not significantly affected by B fertilization during the winter season as shown in Table 4.6. The highest HI was obtained from BF2 and the lowest one from B0. Sarker *et al.* (2002) reported that different levels of B showed a significant variation in relation to biological yield and HI of soybean, in which the highest values were found at 1 kg B ha^{-1} application rate and lowest from B-untreated plot.

4.2.7 *Hollow Heart Percentage (HH%)*

The significant reduction of hollow heart percentage was evident by B fertilization in the winter season cultivation of groundnut as shown in Figure 4.11 and Table 4.8. The highest HH% was observed at B0 (14.50%) significantly higher than BF1, B0F4, BS2, BS3 and BF2 but not different from BF3 and BS1 in decreasing order. The lowest percentage was observed in BF2 followed by BS3. Therefore, basal application together with two times foliar-split and three times soil-split applications produced minimum HH% and attained desirable quality of groundnut for this season. Konsaeng *et al.* (2010) observed that B fertilization had no effect on the number of mature pods in groundnut variety Tainan 9, foliar B partially alleviated the adverse effect of B deficiency on percent hollow heart and also almost doubled the number of mature pods in TAG 24 and depressed hollow heart from 39 to 8%. Nevertheless, the incidence of hollow heart in small seeds of groundnut was still as high as 9 - 11% in groundnut (Keerati-Kasikorn *et al.*, 1987).

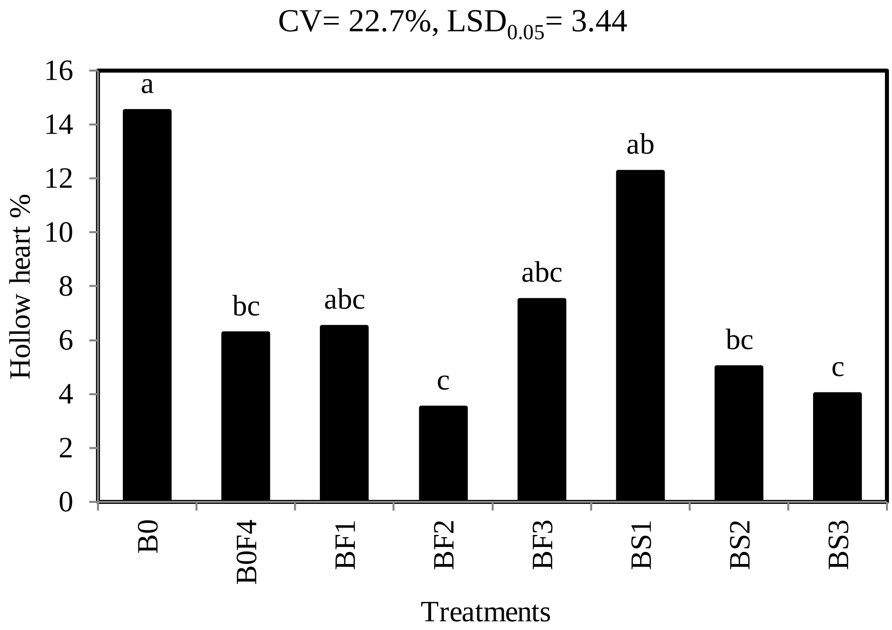

Figure 4.11 Comparison of Hollow Heart as affected by different timing and methods of B fertilization on groundnut during winter season, 2011-12

B0 (B-untreated plot)

BF1 (basal + foliar-split at Peg),

BS1 (basal + soil-split at Peg)

BF2 (basal + 2 foliar-split at EB & Peg),

BS2 (basal + 2 soil-split at EB & Peg)

BF3 (basal + 3 foliar-split at EB, Peg & FPF)

BS3 (basal + 3 soil-split at EB, Peg & FPF)

B0F4 (foliar 4 times at SSF, EB, Peg & FPF)

[Peg = Pegging; EB = Early Bloom; FPF = Fifty Percent Flowering; SSF = Side Shoot Formation]

Table 4.8 Effect of different timing and method of B fertilization on number of pod, seed plant^{-1} and hollow heart percentage of groundnut during winter season, 2011-12

Treatment	No. of pod plant^{-1}	No. of seed plant^{-1}	Hollow Heart %	
			Original	Transformed[a]
B0	14.38 b	21.18 b	14.50 a	22.11 a
B0F4	16.94 ab	23.83 ab	6.25 bc	14.02 bc
BF1	17.14 ab	24.32 ab	6.50 bc	14.71 bc
BF2	17.36 ab	26.88 a	3.50 c	10.35 c
BF3	16.90 ab	23.92 ab	7.50 abc	15.64 abc
BS1	16.95 ab	24.47 ab	12.25 ab	20.29 ab
BS2	18.00 a	27.30 a	5.00 bc	12.75 bc
BS3	17.44 ab	25.12 ab	4.00 c	11.24 c
	*	**	**	**
Pr>F	0.03	0.006	0.0005	0.0005
$LSD_{0.05}$	1.14	0.731	3.19	3.56
CV%	9.53	9.44	44.03	22.71

[a] Arcsine transformation before analysis of variance. Means followed by the same letter in each column are not significantly different at the 5% level of Least Significantly Different (LSD).

4.2.8 *Oil and Protein content*

Oil content of groundnut seed showed good response to B application. Oil contents of B0F4, BF1 and BF3 were significantly higher than that of B0 but not different from those of BF2, BS1, BS2 and BS3. Among soil-split treatments, the higher the splitting the lower the oil content of groundnut seeds was analyzed. Similarly, Galavi *et al.* (2012) reported that foliar B together with Fe gave the highest oil percentage of safflower among foliar micronutrients applications with the value of 19.16% higher than control.

The protein content of groundnut was not significantly affected by B fertilization during the winter season. Mean values analyzed for seed protein content in all treatments except BS1 were generally lower than that of B0. Similarly, Noor *et al.* (1997) reported that B decreased protein content of groundnut. Loomis and Durst (1991; 1992) declared that low intracellular B concentration in plants should keep optimal protein synthesis and that B toxicity partially leads to the inhabitation of protein synthesis through the formation of borate ester with ribose. Moreover, Goldbach (1997) stated that any control of nucleic acids or protein metabolism can hardly be responsible for the different requirements of B in plant species. He added that the experimental evidence for a direct and specific involvement of B in nucleic metabolism or protein synthesis is scanty.

4.2.9 *Plant Height*

Plant height was measured at ten day interval from 30 to 90 DAS and finally at harvest. After the first time of B application, there were not significantly differences in plant heights of groundnut (Figure 4.12). Plant height sharply increased for all plots during early vegetative growth stages. However, it was nearly retard during 40 - 50 DAS might be due to the temporary drought (Figure 3.1). Irrigation was carried out at about 55 DAS and normal growth was retained after that. There was no evidence difference in plant height observed during the later growth stages. Vishwakama *et al.* (2008) reported that maximum plant height of 60.33 cm was recorded with soil application of borax in groundnut and B also increased plant height in green gram with foliar B application (Dixit and Elamathi, 2007).

Table 4.9 Oil and Protein content as affected by different timing and methods of B fertilization on groundnut during winter season, 2011-12

Treatment	Oil content (%)	Protein content (%)
B0	42.44 b	39.96
B0F4	48.70 a	37.55
BF1	48.40 a	38.21
BF2	47.40 ab	37.51
BF3	48.56 a	37.35
BS1	46.51 ab	40.46
BS2	45.69 ab	38.75
BS3	44.88 ab	38.48
	**	Ns
Pr > F	0.01	0.13
$LSD_{0.05}$	2.09	1.62
CV%	4.83	3.71

Means followed by the same letter in each column are not significantly different at the 5% level of Least Significantly Different (LSD).

B0 (B-untreated plot) **BF1** (basal + foliar-split at Peg),

BS1 (basal + soil-split at Peg) **BF2** (basal + 2 foliar-split at EB & Peg),

BS2 (basal + 2 soil-split at EB & Peg) **BF3** (basal + 3 foliar-split at EB, Peg & FPF)

BS3 (basal + 3 soil-split at EB, Peg & FPF) **B0F4** (foliar 4 times at SSF, EB, Peg & FPF)

[Peg = Pegging; EB = Early Bloom; FPF = Fifty Percent Flowering; SSF = Side Shoot Formation]

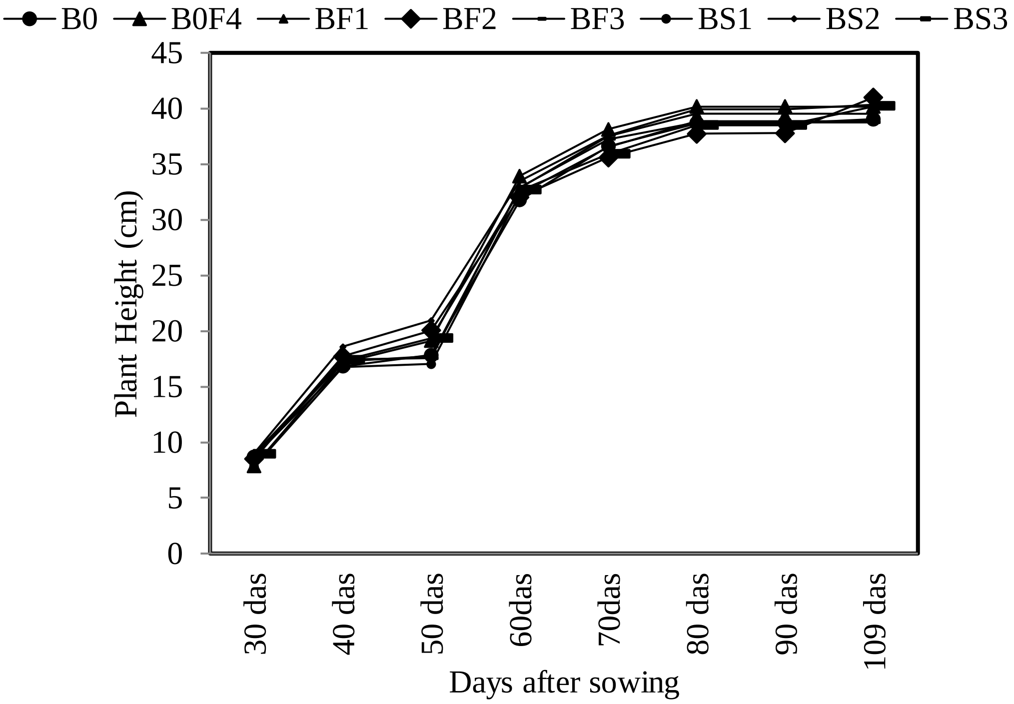

Figure 4.12 Mean values of plant height as affected by different timing and methods of B fertilization during winter season, 2011-12

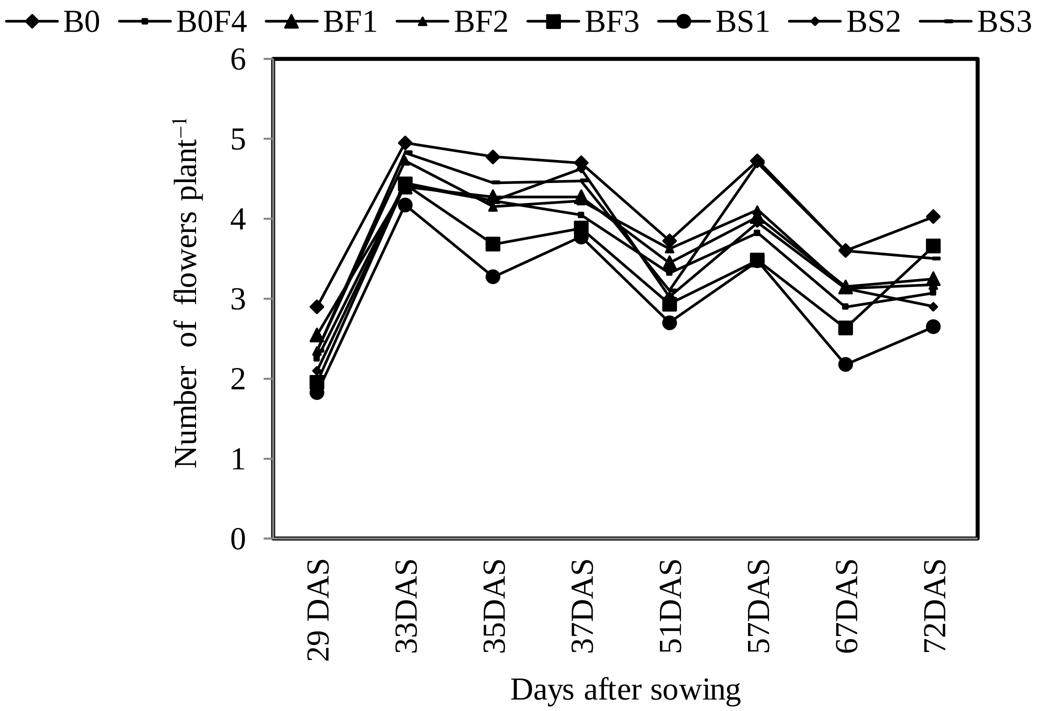

Figure 4.13 Mean values of number of flowers as affected by different timing and methods of B fertilization during winter season, 2011-12

4.2.10 *Flowering Pattern*

The number of flowers produced by groundnut plants was recorded 2 days interval within flowering time for the winter season as shown in Figure 4.13. Flowering started at 29 DAS and total flowering period was from 29 to 72 DAS (44 days). B application did not show significant effect on number of flowers plant^{-1} during the winter season cultivation. The number of flowers was higher in B0 compared to all B treated plots. B0 produced large amount of flowers but the flowers took longer period for fertilization and therefore hardly proceed peg formation in visual observation. Konsaeng *et al.* (2010) observed that, 30 days after withdrawal of B treatment in groundnut, pants which received 10 μM B before withdrawal were able to produce flowers but the number of flowers were fewer than in plants which received B continuously. Moreover, the same authors continued that only a small number of these flowers produced pegs, and none progressed to pods.

4.2.11 *Nodulation of groundnut*

The nodulation data of groundnut was of the same trend as in the rainy season as shown in Table 4.10 and Figure 4.16. The total nodules plant^{-1} were significantly different by B application only at 40 DAS. At 40 DAS, total and effective numbers of nodules plant^{-1} at B0F4, BF2 and BS3 were significantly higher than those of other B treated plots and the lowest one was in B-untreated plot. BF2 gave the highest percentage of effective nodule and not significantly different from that of BS3. The lowest of both total and effective nodules plant^{-1} was observed in B0 throughout the growing season. Gregor and George (2001) stated that the process of nodule setting was found to be most negatively affected by the absence of B during 20 - 30 days after planting in soybean. Inadequate supply of B during early stages of nodule development limited both the development and number of root nodules, and N fixation. The early stage of nodule development in soybean was particularly sensitive to B deficiency (Yamagishi and Yamamoto, 1994; Balanos *et al.*, 1996).

At 60 DAS and harvest, the recorded data were not significantly different by B application and the lowest value was observed in B0 (Figure 4.18). Lower nodulation was observed in the winter season in comparison with the rainy season. The results of lower nodulation and B uptake seem to be the effects of insufficient moisture in the drought period of the winter season. At 80 DAS, the total and effective number of nodules plant^{-1}

from BF2 and BF3 were high then BS2 and BS3. Total nodules plant^{-1} from BF3 was significantly higher than that of B0. It suggests that foliarly-applied B was more effective than soil application. Similar to our results, many researchers reported that B application increased nodule numbers in groundnut (Kanzaria and Patel, 1985; Kulkani *et al.*, 1989) as well as in blackgram (Rerkasem *et al.*, 1987).

In comparing the efficiency of different method and timing of B fertilization on groundnut, it was observed that BS2 and BS3, BF2 and B0F4 were more beneficial in increasing percent effective nodules than control, especially at 40 DAS as 31.2, 39.6, 42.2 and 41.3% respectively, higher than control. At 80 DAS, BS2, BS3, BF2 and B0F4 resulted in 42.6, 42.7, 42.9, and 45.7%, respectively higher over control. Yakubu *et al.* (2010) reported that the application of 0.5 kg B ha^{-1} increased 20, 21 and 5 nodules per plant and 89, 126 and 5% N fixation over control in cowpea, groundnut and bambara groundnut, respectively.

4.2.12 ***Relationship between total dry matter, weight of pod and number of nodules per plant***

The correlation between number of nodules and weight of pod plant^{-1} fitted with positive linear response in the winter season groundnut experiment (R^2 = 0.74) as shown in Figure 4.14. Nodules plant^{-1} were highly related to weight of pods plant^{-1} during winter season. Both total number of nodule and weight of pod plant^{-1} were higher in BF2 treatment.

The total effective nodules plant^{-1} fitted in a positive linear function with total dry matter (R^2 = 0.699) in the winter season as shown in Figure 4.15. According to R^2 value, total dry matter was related to total effective nodules plant^{-1} by B fertilization on groundnut.

Therefore, total number of nodule plant^{-1} was an important factor for increasing both total dry matter and weight of pod plant^{-1}.

4.3 Suitable Amount and Timing Effects of B fertilization on Groundnut Production

As an essential microelement, the important functions of B were reported by many researchers for several crops. For example, B application increased pod weight, significantly enhanced chlorophyll content and photosynthetic intensity of the leaves, increased dry matter accumulation of the plants, advanced their flowering and promoted the transport of photosynthates to the reproductive organs, and thus resulting in significant improvement of the groundnut yield (Niaz, 2010). As stated in our objectives, this study was conducted to clarify mainly on amount and timing of B fertilization for groundnut.

Among all treatments, BS3 was the best for pod yield in both seasons, and the best for oil content and nodulation (60 DAS and harvest) for the rainy season. On the other hand, BS2 is the best in minimizing the incidence of hollow heart for the rainy season with higher yield at the same time. In soil-split treatments, 2 kg ha^{-1} of B was separated into 1 kg as basal and another 1 kg was used for one, two or three application by splitting as required. The amount of B for one time split was 1 kg B ha^{-1} applied at pegging stage, as the same way, two times of 0.5 kg ha^{-1} each at EB and Peg, and three times of 0.33 kg ha^{-1} each at EB and Peg and FPF. Among the soil-split treatments, BS1 showed the lowest value in some important parameter such as pod yield, seed yield, hundred seed weight and oil content. It suggests that large amount of B application may affect the reduction in good response of B. In contrast, better responses were observed in the smaller amount of B split application treatments as BS2 and BS3. Therefore, appropriate amount for B splitting may be 0.33 to 0.5 kg B ha^{-1} with suitable timings.

In foliar-split treatments, 1 kg ha^{-1} of B applied as basal and additional application rate was 0.25 kg ha^{-1} for each time. Therefore, the total amount of B for one time split treatment was 1.25 kg ha^{-1} (i.e. foliar-split at Peg), two times of 1.50 kg ha^{-1} (i.e. foliar-split at EB & Peg) and three times of 1.75 kg ha^{-1} (i.e. at EB, Peg & FPF).

BF2 was the best treatment for seed yield in both seasons for yield and yield components and nodulation (at 40, 60 DAS and harvest) in the rainy season and then again gave the lowest incidence of hollow heart percentage in the winter. B0F4 gave the highest oil content for the winter season. In winter, foliar application, such as BF2 and B0F4 and those were less laborious, gave the highest response of B application. It suggests that foliar-applied B was more efficient in winter season where insufficient soil moisture induced unfavorable B uptake.

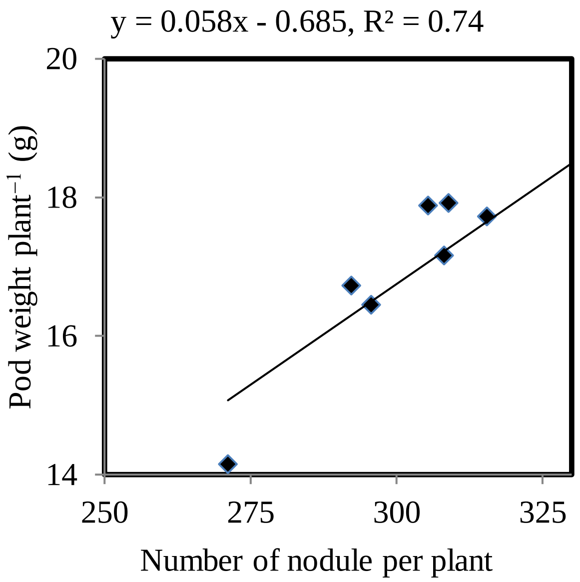

Figure 4.15 Relationship between weight of pods and number of nodules of groundnut as affected by B fertilization during winter season, 2011-12

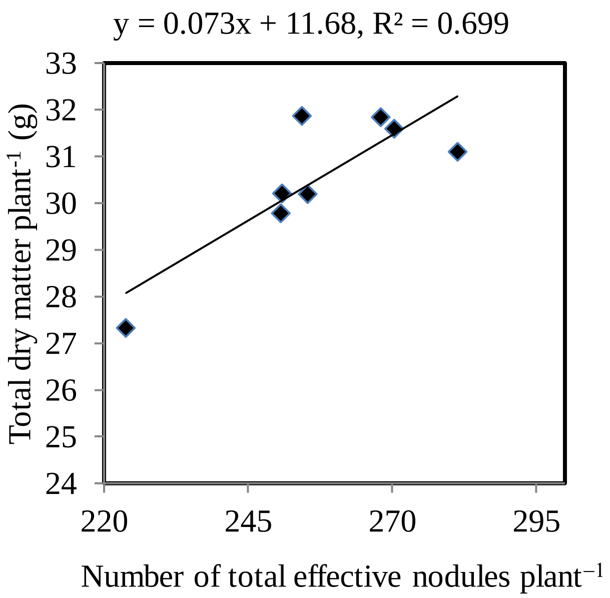

Figure 4.16 Relationship between total dry matter and number of effective nodules on groundnut as affected by B fertilization during winter season, 2011-12

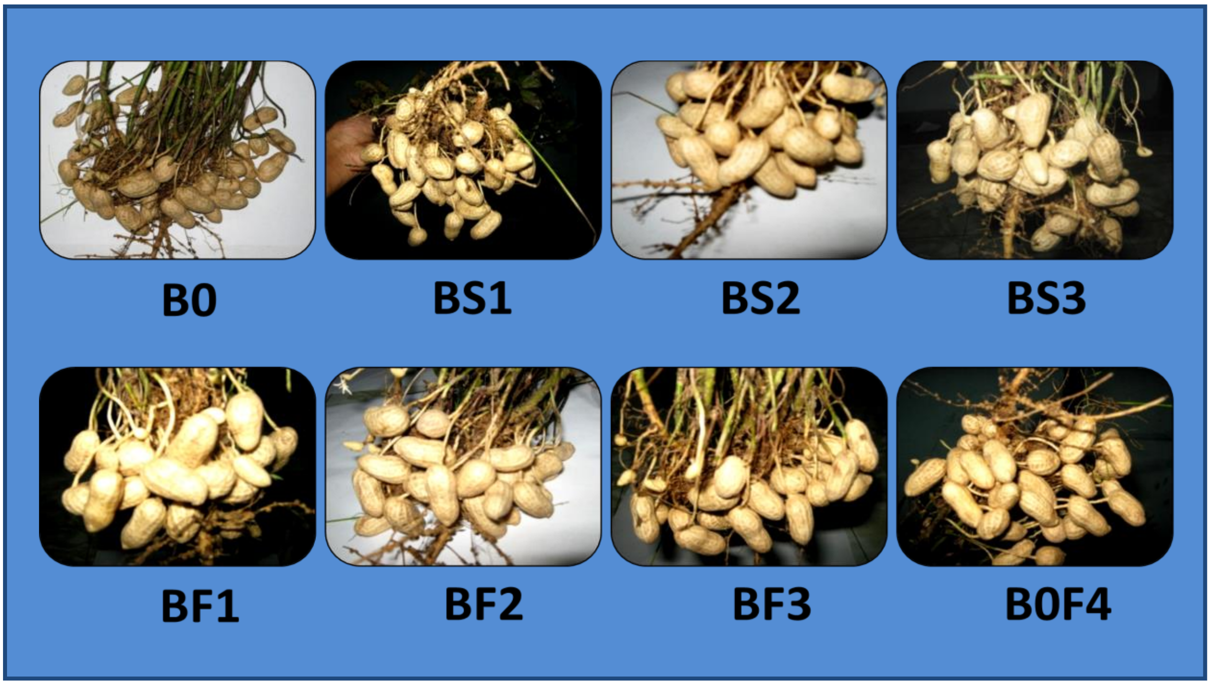

Figure 4.17 Number of groundnut pods as affected by different timing and method of B fertilization during winter season, 2011-12

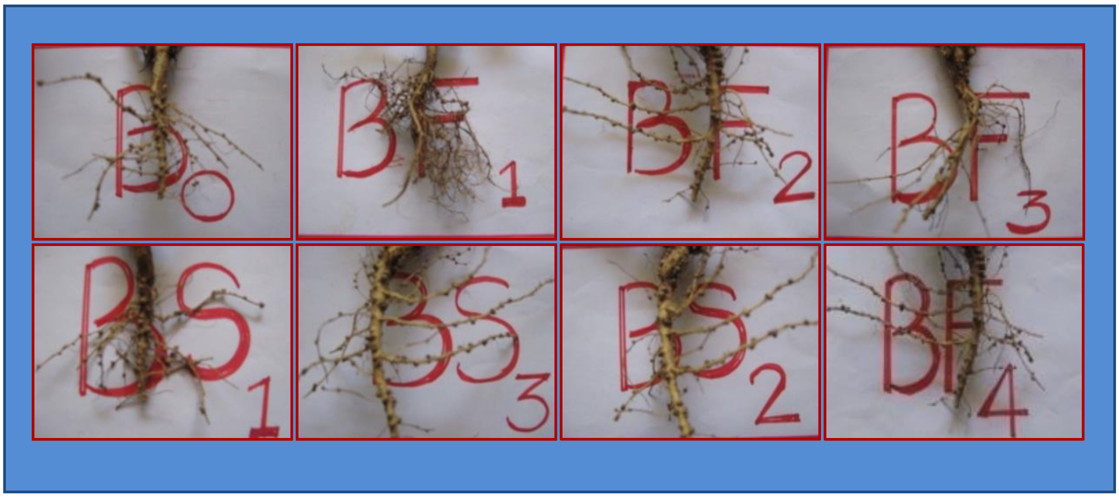

Figure 4.18 Groundnut nodules as affected by different timing and method of B fertilization during winter season, 2011-12

CHAPTER V
CONCLUSION

The present study emphasized the effect of different timing, method of boron fertilization on both quantity and some quality factors of groundnut cultivation during rainy season, 2011 and the winter season, 2011-12.

The highest pod yield was observed in BS3 (soil application as basal and 3 splits at EB, Peg & FPF at the rate of 2 kg B ha^{-1}) while it was the lowest in B0 for both seasons. The level of 2 kg B ha^{-1} as only soil application method with three-time splits was the best to increase the pod yield of groundnut.

Two to three-time foliar-splits applications might be the best way to produce the highest seed yield and appropriate method for minimizing residual effect of B in soil. BF2 (basal + foliars, EB & Peg, at the rate of 1.50 kg B ha^{-1}) also gave the good results in plant growth characters, seed yield and number of seed pod^{-1}. Therefore, the strategic timing and method of application as basal with two to three foliar splits application at the level of 1.5 and 1.75 kg B ha^{-1} respectively to increase seed and pod weight and finally seed yield of groundnut in the rainy season.

All B fertilization treatments attained higher hundred seed weight than B untreated treatment for both seasons. Basal B application together with additional soil or foliar splits should be carried out to increase hundred seed weight of groundnut. Plant height, flowering pattern, shelling percentage, harvest index was not significantly different by B application for both seasons. Total dry matter and weight of pod with number of nodules per plant showed positive correlation by timing, method and level of boron fertilization on groundnut.

Some quality factors such as oil and protein content are very important in nutritional value of groundnut. Such quality factors in groundnut were affected by B application. Boron application, irrespective of method and timing, increased oil content of groundnut compared to B0, where the lowest oil percentage was analyzed. Among the B application, the highest oil content was obtained from BS3 in rainy season. In winter, B0F4 (only 4 foliar splits at SSF, EB, Peg & FPF) gave maximum oil content and the higher the splitting times, the lower the oil content of groundnut seeds was observed among soil-split treatments. It suggests that foliar-applied B was more efficient in winter season, where insufficient soil moisture induced unfavorable B uptake from the soil. The maximum protein content was observed in BF1 and BS1 in both seasons. However, B application seems to have little effect on protein content of groundnut seed.

Hollow heart (HH%) is the most yield-limiting factor of groundnut. The highest hollow heart percentage obtained from B0 was significantly different from those of all other B-treated plots. Basal together with two time foliar-split and soil-split applications produced minimum HH% and higher yield on the other hand. The results showed that lack of B fertilization in groundnut cultivation can hasten hollow heart formation that might cause lower quality and yield reduction. Therefore, B application might be the best way to minimize HH% and enhance groundnut production.

Good response to B fertilization of nodulation (for both total and effective nodules) by different timings & methods at different growth stages was observed in both seasons. Soil application method with two to three splits (BS2 and BS3) and foliar-split application method with two splits (BF2) was sufficient to obtain higher nodulation for groundnut production during both seasons.

Suitable timing of split application for B was discussed and reported in detail in previous section; however, to improve the quantity and some quality components of groundnut in major groundnut growing area in Myanmar, more researches concentrated on the amount of B splitting will still be needed. Projects for B fertilization using different groundnut varieties in different places have to be extended out to boost up the production of oil and protein via an economically very important crop, groundnut, in Myanmar. Moreover, studies of B interactions with other macro- and micro-nutrients, especially Ca and N, are still needed to be explored for enhancement of B use efficiency and effects on groundnut production.

RECOMMENDATION

1. Boron fertilizers should be applied for optimum groundnut yield and seed oil content.
2. Soil application of boron at the rate of 2 kg B ha^{-1}: as basal (1 kg) and 3 splits at EB, Peg and FPF (1 kg) to increase groundnut production and for some important parameters including oil content in rainy season.
3. Soil application (1 kg B ha^{-1}) as basal with 2 foliar splits at EB and Peg (0.5 kg B ha^{-1}) increased seed yield and yield components in both seasons.
4. Foliar application is preferable for efficient B uptake in winter season cultivation.

   Boron fertilization should be completed with soil testing or recommendation of soil scientist for specific area.

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ABSTRACT

Boron (B) is an essential micronutrient and required for normal growth and development of most plants. Its deficiency became a widespread problem in many crops cultivated on much wider range of soils. The application of B on groundnut (*Arachis hypogaea* L.) might be very important for its quantity and quality components. This study was carried out with the objectives to investigate the effects of B fertilization on growth, yield and some quality components of groundnut, and to determine the effective method and appropriate time of B application. The experiment was conducted on the Yezin Agricultural University Farm, Yezin, during rainy and winter season (2011 - 2012). Randomized Complete Block (RCB) design was laid out with four replicates. Treatments were composed of application methods (foliar, soil-split and foliar-split with different timings). They consisted of **B0** (B-untreated plot), **B0F4** (only foliar 4 times: at side shoot formation (SSF) + early bloom (EB) + pegging (Peg) + fifty percent flowering (FPF)), **BS1** (basal + soil-split at Peg), **BS2** (basal + 2 soil-splits at EB & Peg), **BS3** (basal + 3 soil-splits at EB, Peg & FPF), **BF1** (basal + foliar-split at Peg), **BF2** (basal + 2 foliar splits at EB & Peg), **BF3** (basal + 3 foliar-splits at EB, Peg & FPF). Basal application was conducted at the rate of 1 kg B ha^{-1}. Each foliar-split was at the rate of 0.25 kg B ha^{-1} in 0.03% solution. However, in soil-split, total amount of 1 kg B ha^{-1} was separated according to the schedule for B fertilizer application.

The highest pod yields (5046 kg ha^{-1} and 4317 kg ha^{-1}) were observed in BS3, while they were the lowest in B0 for both seasons. BF2 gave the best plant growth characters, seed yield and number of seeds pod^{-1}. B application, irrespective of method and timing, increased oil content of groundnut compared to B0. However, B application seems to have little effect on protein content of groundnut seeds. The highest hollow heart percentage (HH%) was observed in B0 among all treatments. BS2 in rainy and BF2 in winter season showed the lowest HH%. Therefore, B application might be one of the best ways to minimize HH% and enhance groundnut production. Good response to B fertilization was observed in nodulation at different growth stages in both seasons.

According to the result of this study, B fertilizers should be applied to get optimum groundnut yield and oil content. Soil-split application of B at the rate of 2 kg B ha^{-1} (BS3) increased groundnut production and some important parameters including oil contents in rainy season. Foliar-split application (BF2) increased seed yield and yield components in both seasons. Foliar application is preferable for efficient B uptake in

winter season cultivation. Therefore, basal B application together with additional soil or foliar splits should be carried out to achieve optimum groundnut production.
Keywords: *groundnut, boron, yield and yield parameters, oil and protein content, hollow heart, nodulation*.

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CHAPTER I

INTRODUCTION

Boron (B) is the 51st most common element found in the earth's crust and is found at an average concentration of 8 mg kg^{-1}. It is known as an essential element for plants as early as the beginning of the 20th century and the only nonmetal among the eight essential micronutrients required for normal growth of most plants. It is essential for cell division in meristematic tissues, good pollination through pollen tube germination and elongation, fruit set, seed development, translocation of sugars and starches as sucrose-borate complexes, and synthesis of amino acid and proteins (glutamine). It also helps in development of nodules in legumes and regulation of carbohydrate metabolism (Kabata-Pendia and Pendias, 2001). B plays an important role in both structural and functional integrity of plasma membranes which affected on ion transport for K, Ca, Mg and phosphates.

Although B uptake of crop plants is not higher than the uptake of other nutrients except molybdenum, its deficiency has been reported in many parts of the world (Fageria *et al*., 2002; 2009) and it was reported as the second most widespread micronutrients problem globally (Alloway, 2008). Without added B, B deficient soils depressed seed yield by 60% in soybean cultivar NW1, 30% in cultivar SJ5, 40% in cultivar 7016, 45% in groundnut and 93% in black gram (Reskasem *et al*., 1993). Rashid and Ryan (2004) stated that B deficiency is a widespread problem in many crops like cotton, rape seed, wheat, peanut, sorghum and rice. B deficiency has been reported from 80 countries and 132 crops around the world. B deficiency in wheat has also been reported in Myanmar, China, and Thailand (Rerkasem *et al.*, 1989). B deficiencies occur over a much wider range of soils and crops than do those of any other micronutrient elements. Recently Takano *et al.* (2008) reported that B toxicity and deficiency are equally the world's leading agricultural setbacks.

Groundnut (*Arachis hypogaea* L.), a member of legume family (Papilionaceae), is an important food and oil crop. It is the third major oilseed of the world after soybean and cotton and currently grown on approximately 42 million acres worldwide and its production is estimated at 34 million tonnes in 2006 - 07 (FAO, 2009). In Asia, it is a major crop in India, China, Indonesia, Myanmar, Thailand and Vietnam. In Asia-Pacific region, it is the second most important crop after cereals, occupying 13% of total cropping area. China is the world's single largest producer followed by India as 37% and 18% of the world's production respectively. Myanmar is among the top ten world producers and ranked as the world's sixth largest producer, with 2% of global production in 2005 (FAO, 2009). Myanmar is an agro-based country and oilseed crops occupy the third largest total crop-sown area (Mandal, 2008). Groundnut is one of the principle crops in Myanmar (MOAI, 2011) and it is the second largest among the total oilseed crops with 1.8 million acres (FAO, 2009).

And also groundnut is an important cash crop grown on a wide range of soils and under a variety of climates in the semiarid tropics (ICRISAT, 1991). It is sown mainly in monsoon and winter in Sagaing, Mandalay, Magway, Bago, Ayeyarwady Regions and Shan State. Among the major oilseed crops, Myanmar people like groundnut oil because of its delicious and attractive flavor and preference for consumer's health. The seeds contain about 50% oil, 25 - 30% protein, 20% carbohydrate, 5% fiber and ash (Gobarah *et al.*, 2006) and also have a high energy value of 2363 kJ 100 g^{-1} of seeds (ICRISAT, 1991). Oilseed crops also play a vital role according to Myanmar's high consumption of cooking oil compared to that of neighboring countries. Major oilseed crops include groundnut, sesame, sunflower, mustard and niger. As groundnut has a much greater yield of oil per unit area, it contributes to the largest share (33%) of edible oil produced in Myanmar (FAO, 2009).

Groundnut has played a pivotal role in agriculture sector of USA since many decades ago and more than 300 products were invented from it by George Washington Carva. Nowadays, groundnut seeds are used in the form of peanut butter and roasted nuts in many countries. Groundnut oil has both food use (cooking, and salad oil and dressing, margarine and other vegetable shortenings) and industrial use (as an ingredient in soap, face powder, shaving creams, shampoos, paints and explosive). It is undergoing test for fuel source by many investigators. The meal remained after oil extraction is used as protein-rich livestock feed and also the protein in the meal is used to make a textile fiber. Powdered peanut shells are used to make plastics, cook-substitutes, wallboard and abrasive. Besides its superior food value, groundnut provides a source of cash for resource-poor farmers. In areas where cereals are cultivated, groundnut is a suitable rotation crop that contributes to sustainable agriculture by maintaining soil fertility and breaking pest and disease cycles.

The yield potential of groundnut is 5784 kg ha^{-1} in Israel and productivity varies from 300 kg ha^{-1} to 10 ton ha^{-1} all over the world. The yield potential range of groundnut in Myanmar is 800 - 1800 kg ha^{-1} in dry season and 2000 - 2500 kg ha^{-1} when irrigated with the average yield of 1462 kg ha^{-1}. Although two major government policy objectives for oil crops subsector include achieving self-sufficiency in edible oil, average productivity is very low compared to that of China within ASIAN member countries and that of Israel among the world. Mineral deficiencies may be one of the important factors in groundnut production.

The nutrients removed by an average groundnut crop are 137.3 kg N, 16.6 kg P and 63.34 kg K ha^{-1} ((Deshmukh *et al.*, 1992). Groundnut also shows well responses to N, P, K, Ca, S and other micronutrients. Even though the soil is fertile, micronutrient may be deficient. B deficiencies may be suspected on coarse-textured soils and areas with low organic matter (OM) content, high pH especially above 6.5, heavy rains (by leaching), and drought. Over-limed or recently-limed soils cause temporary deficiency of B. The deficiency of micronutrients has been very pronounced under multiple cropping systems due to excessive nutrient removal of high-yielding varieties and hence exogenous supplies are urgently needed.

The critical level of hot-water soluble B for groundnut in most soils ranges from 0.2 - 0.5 ppm depending on pH, OM content and soil texture. Low soil B level (0.1 - 0.7 ppm) in Myanmar has been reported since 1984 by Gyul'akhmedov and Memedov. According to soil type, B deficient crops can be found on Acrisols in Shan and Kachin States and on Luvisols in Sagaing and Mandalay Regions. In B-deficient acid soils (below 0.4 ppm available B), low pod-filling, shriveled seeds and hollow darkening and off-colour in the center of the seeds are commonly observed causing 10 - 50% yield loss (Cox and Reid, 1964; Singh *et al.*, 2004; 2007). Deficiencies may also cause shell deformity, random shell cracking and reduce the quantity and quality (e.g. oil content), and finally economic value of the crop.

Dicotyledons generally require 3 - 4 times more B than monocotyledons (Fageria, 2009). Groundnut is a B-sensitive crop and has high B requirement for both quantity and quality factors. Kernel quality and flavor of groundnut also represent the important role of B. The importance of B application is proved to be increasing groundnut yield (Noor *et al.*, 1997). But the sufficiency and deficiency level is rather narrow and both excessive and deficient levels may be encountered during the same season (Mortvedt and Woodruff, 1993). Rates of B application depends on the crops, plant species, cultural practices, rainfall, liming the cultivated area and other environmental factors, but in general legumes and certain root crop require 2 to 4 kg B ha^{-1} while optimum rates are necessary for maximum yields in order to avoid toxicity problems. B fertilization can be done by using different B sources, for example borax, boric acid, solubor, etc. and they can be applied directly to soil or as foliar application and/or seed treatment. Seed treatment of B fertilization has not received much attention because of its toxic effect on seeds or seedlings. Soil and foliar application might be more effective. Most of the groundnut-growing areas in Myanmar may be B-deficient due to high pH and moisture deficit in middle regions, low pH and high rainfall in lower Myanmar and soil type and high rainfall in Shan State.

Groundnut has high B requirement and its deficiency causes hollow heart, which can highly reduce yield and quality. Moreover, yield reduction by hollow heart is the major problem in groundnut producing areas. Adequate B supply is necessary for obtaining high yields and good quality of agricultural crops (Saleem *et al*., 2011). The application of B increased oil and protein content and also maximized yield in groundnut (Nasef *et al*., 2006; Singh *et al*., 2009). However, the efficient technology on "how to use B fertilizer" is still deficient in Myanmar. Most of Myanmar farmers seldom use micronutrients especially B in intensive production of crops such as groundnut. And systematic researches on micronutrients management and their application are still needed for improvement of Myanma agriculture sector. Therefore, keeping in mind the importance and significance of B in groundnut production, this research was initiated with the following objectives.

1. To investigate the B fertilization on growth, yield and some quality components of groundnut, and
2. To determine the effective method and appropriate time of application for soil and foliar fertilization of B.

CHAPTER II

LITERATURE REVIEW

2.1 Boron (B)

Boron is one of the eight essential micronutrients, required for the normal growth of most plants. Plant requirements for this nutrient are lower than the requirements for all other nutrients except molybdenum and copper. B nutrition of soil and crops has assumed greater importance with the introduction of high-yielding crop varieties under intensive cultivation. B toxicity is not as widespread as B deficiency (Prasad and Power, 1997). B deficiency is the most common and widespread micronutrient deficiency problem, which impairs plant growth and reduces yield. B is leached from acid soils and this results in low availability. B availability is reduced by increasing pH due to strong B adsorption to mineral surfaces (fixation). Thus, B availability is at maximum in soils with intermediate pH. B deficiency tends to occur in dry weather probably because of reduced movement of B to roots by mass flow in water (Foth, 1990).

2.1.1 *Physiological and Biochemical Functions of B in Plants*

Boron is directly or indirectly involved in several physiological and biochemical processes in plant growth. Havlin *et al*. (1999) stated that plants require B for a number of growth processes:

- New cell development in meristematic tissue.
- Proper pollination and fruit or seed set.
- Translocation of sugars and starches, N, and P.
- Synthesis of amino acids and proteins.
- Nodule formation in legumes.
- Regulation of carbohydrate metabolism.

Moreover, several functions of B in plants are summarized as below:

***Carbohydrate Metabolism and Transport of Sugar*:** B nutrition of plant affects the metabolism of carbohydrates through its effect on the activities of enzymes catalyzing the interconversion of sugars (Sharma, 2006). B-deficient plants show diverse changes in the concentration of carbohydrates. The effect on the different carbohydrate fractions is possibly influenced by the severity of deficiency. In low-B sunflower leaves, starch decreased, but there were increases in sugars and protein and non protein nitrogen fractions (Gupta, 2007). B has been functional in the transport of carbohydrate and translocation of sugars which enhance the formation of borate-sugar complexes (Ketyal and Singh, 1983; Marcus-Wyner and Rains, 1982). The concentration of sugar and starch increased in leaves, decreased in seeds and thus lowered the seed quality in B-deficient pea (*Pisum sativum* L.)

***Phenol and Auxin Metabolism*:** B regulates auxin supply in plants by protecting the indole acetic acid (IAA) oxidase system through complexation of *o*-diphenol inhibitors of IAA oxidase. Excessive auxin activity causes excessive proliferation of cambial cells, rapid and disproportionate enlargement of cells, and collapse of nearby cells. B is responsible for the metabolic changes and cell damage in deficient tissues and it is thought that B complexes the phenolic compounds in plant cells by reducing their potential toxicity (Marschner, 1995).

***Tissue Development and Formation of Cell Walls*:** B is required for proper development and differentiation of tissues. It plays an important role in both structural and functional integrity of plasma membranes (Marschner, 1995). B is important in cell walls; both B deficiency and toxicity cause lower chlorophyll levels and the rate of photosynthesis by its influence on the activity of plasmalemma and they can disturb the maintenance of meristem in plants (Balanos *et al*., 2004). In B-deficient plants, the cell walls are dramatically altered as reflected at both macroscopic such as ‘cracked stem’ and ‘hollow stem disorder’ (Bergmann, 1988; 1992; Shelp, 1988) and microscopic levels (Loomis and Durst, 1991; 1992).

***Reproduction and Disease Resistance*:** B is involved in reproduction of plants, pollen germination and pollen tube growth (Balanos *et al.*, 2004). B obstructs the abortion of ovaries in rape, clover, alfalfa and beet. It reduces the proportion of sterile seeds in cotton, barley, corn, soybean, alfalfa, maize and sunflower (Bergmann, 1984). The role of B in seed production is very important because the plants fail to produce functional flowers and any seed even under moderate deficiency (Gupta, 1993).

B involvement in metabolism of phenolics and lignin biosynthesis contributes to strengthening of plant defense against pathogenic infections. B increases the disease resistance in plant such as potato scab disease, ergot in barley and damping off fungal diseases in tomato and cabbage (Bergmann, 1984; Shorrocks, 1984).

***Root Elongation and Nucleic Metabolism*:** B deficiency rapidly holds back the elongation and growth of roots and also decreases the nucleic content of plant tissues (Gupta, 1993). The presence of B resulted in the development of numerous roots in the lower part of the hypocotyls in sunflower cuttings (Josten and Kutschera, 1999). Withholding B for several days induced decreases of nucleic acid content in plant roots. B deficiency induced changes in the concentration of nucleic acid and enzymes of nucleic acid metabolism, which suggested that B was involved in nucleic acid metabolism (Dugger, 1983).

***Nitrogen Fixation and Nitrate Assimilation*:** B is involved in N_2 fixation. B is vital for N_2 fixation in heterocyst of the cyanobacterium (*Anabaena* PCC 7119) and observed to decrease the glycolipid content of heterocyst envelop following B deprivation (Mateo *et al*., 1986). Balanos *et al.* (1996) suggested that B is involved in *Rhizobium*-legume cell surface interaction by favouring the development of nodulation in groundnut. It is also implicated in N_2 fixation and in B-deprived conditions, nodule weight and N_2 fixation capacity of legumes usually decreased. B also plays an important role in N-based utilization and RNA metabolism. In plants poorly supplied with B, NO_3^--N accumulated in the roots, leaves and stems, showing that NO_3^- reduction and amino acid synthesis were inhabited. Only when a low level of B was resupplied to moderately B-deficient plants, there was enhanced protein synthesis. But there is no convincing evidence of a direct effect of B on N metabolism (nitrate reduction, amino acid and protein content), which might be higher or lower in B-deficient plants, depending upon severity of deficiency, plant age, and plant organ. Such changes are most likely to be secondary effects, for example, caused by different sink activities as demand for nitrogen (Shelp, 1993).

***Water Relations*:** B also regulates the intake of water into the cell. B-deficient plants show decreased moisture percentage, succulence, metabolic activity, water potential, stomata opening, transpiration and growth rate in comparison to B-sufficient plants

(Sharma and Ramchadra, 1990). However, the role of B in plant nutrition is still the least understood among all mineral nutrients.

2.1.2 *Boron in Soils*

In soil mass, B is distributed in various soil components such as mineral, soil solution, organic matter and clay minerals. The forms of B in soil are described below.

***Mineral B*:** Boron (B) occurs in low concentrations in the earth's crust, and in most igneous rocks (~10 ppm). Tourmaline, borosilicates, is the main B-containing mineral found in soils. The total B content of most agricultural soils ranges from 1 to 467 ppm, with an average content of 9 to 85 ppm (Gupta, 2007). Less than 5% of the total soil B is available to plants (Tisdale *et al*., 1985).

***Soil Solution B*:** Undissociated boric acid (H_3BO_3) is the predominant species in soils at pH values ranging from 5 to 9. At pH > 9.2, $B(OH)_3$ can hydrolyze to $B(OH)_4^-$. B can be transported from the soil solution to absorbing plant roots by both mass flow and diffusion.

***Adsorbed B*:** B adsorption and desorption can buffer solution B, which helps to reduce B leaching losses. The main B-adsorption sites are (1) broken Si-O and Al-O bonds at the edges of clay minerals, (2) amorphous hydroxide structures and (3) Fe/Al-oxy and -hydroxyl compounds. Increasing pH, clay content, and OM, and the presence of Al compounds favour adsorption of $B(OH)_4^-$. B adsorption capacities generally follow the order of mica > montmorillonite > kaolinite.

***Organically Complexed B*:** OM represents a large potential source of plant available B in soils, which increases with increasing OM. The B–OM complexes are probably the most important forms in soil for crop nutrition (Havlin *et al*., 1999).

2.1.3 *Factors Affecting B Availability of Soil and Plant*

Plants obtain all the essential nutrients from soil medium through their roots, consequently all the soil properties are directly associated with the availability of influential nutrients particularly B. The availability of B is influenced by a variety of factors. The most important factors are soil pH, soil texture, organic matter, amount and type of clay, the relationship with other elements, soil moisture, lime application and plant factors.

B primarily occurs in the soil as boric acid [H_3BO_3]. B is very water-soluble and is mobile in soil-water solutions in contrast to being highly immobile in plants. B moves in all directions in the soil by mass flow of water. B availability decreases with increasing pH and it becomes less available to plants (Gupta, 1993) due to more B fixation in soil. The variability of B fixation is due to different mechanisms of B-anion sorption, including ligand exchange, formation of surface complex, and incorporation into clay mineral lattices. Maximum fixation takes place at 6 to 9 pH (Peterson and Newman, 1976). In diverse soils, a small quantity of B is gradually complexed within organic matter and adsorbed on clays and, to some extent, it is precipitated with $CaCO_3$ and is quite unavailable for plant growth (Shorrocks, 1997). Application of lime increases the soil pH and this may cause B deficiency. Due to liming of acid soils, soluble B combines with Ca ions and forms the highly insoluble Ca-metaborate, which reduces the availability of B (Goldberg and Chuming, 2007).

Clay content can also influence B adsorption and its adsorption by fine-textured soil is 2 - 3 times greater than that by coarse-textured soils. Sandy soil is most likely to be B-deficient because of leaching. Organic matter is an important source of B in soils, and B in organic matter can be released for plant uptake by microbial action. Application of OM to soil can increase B concentration in plants and even cause phytotoxicity (Havlin *et al*., 1999).

B deficiency is often associated with dry weather and low moisture conditions. Although B levels in soil may be high, low soil moisture impairs B diffusion and mass flow to absorbing root surfaces. Low water may cause depressed mineralization of B from OM by microorganisms. B adsorption mechanism enhanced with rising soil temperature (Goldberg *et al*., 1993).

Plant species exhibits a wide range of response to B. Graminaceous species are found to be of low in B requirements, non-grass monocots are mild, the latex-containing species are high in B demand (Shaaban, 2011).

2.1.4 *Sources of B Fertilizers*

B compounds commonly used as fertilizers are borax ($Na_2B_4O_7.10\ H_2O$), fertilizer borate, anhydrous borax, solubor, boric acid, colemanite, ulexite and boron frits (Table 2.1). Many researchers used various B sources for B fertilization depending on the solubility of the material (Havlin *et al.*, 1999). H_3BO_3 and borax are easily dissolved in soils and are quickly available for plant uptake, but at the same time there is a problem of leaching if B is not adsorbed or up-taken. Borax is a popular water-soluble B fertilizer, generally used for soil application but it readily leaches in sandy soils. Boronated NPK fertilizers will ensure a more uniform application than most bulk blended fertilizers (Fageria, 2009). Nowadays, **s**low-released B fertilizers are efficiently used for crop production.

2.2 Importance of Groundnut

Groundnut (*Arachis hypogaea* L.) is originated in South America (Bolivia and adjoining countries) and now widely grown throughout the tropical and warm temperate regions of the world. Groundnut seeds contain 21 - 36% protein, 36 - 54% oil, and have a high energy value 2363 KJ $100g^{-1}$ of seed (ICRISAT, 1991). The oil content of groundnut kernels is 45 - 55%. It has high level of energy, fat-soluble vitamins (A D, E & K) and essential fatty acids. Groundnut oil can be used in various ways in food production and industries. Various parts of the groundnut plant are used as food, livestock feed, confectionary products, filler for fertilizer, etc. and also tested for fuel sources.

Groundnut is a major oilseed crops in the world as well as in Myanmar. It is a valuable cash crop cultivated by millions of small farmers, because of its economic and nutritional value. It is also an important oil and protein source to a large portion of the population in Asia, Africa and America. World production of groundnut is estimated at 34 million tonnes in 2006/07 (FAO, 2009). Major groundnut producing countries are China, India, Nigeria, USA, Indonesia, Argentina, Sudan, Senegal and Myanmar. India, China and the United States have been the leading producers for over the last 25 years and grow about 70% of the world's groundnut growing area. In Asia, it is a major crop in India, China, Indonesia, Myanmar, Thailand and Vietnam. Among the top ten world producers, Myanmar ranked as the world's sixth largest producer with 2% of global production in 2005 (FAO, 2009).

Groundnut is one of the principle crops in Myanmar (MOAI, 2011). Oilseed crops occupy the 3rd largest of total crop-sown area and groundnut occupies the 2nd largest among the total oilseed crops with 1.8 million acres. Among the major oilseed crops, Myanmar people like groundnut oil because of it delicious, attractive flavor and preference for consumer's health. As groundnut has a much greater yield of oil per unit area, and it contributes with the largest share (33%) of Myanmar edible oil produced. It is sown mainly in rainy and winter in Sagaing, Mandalay, Magway, Bago, Ayeyarwady Regions and Shan State.

The yield potential of groundnut sown in dry season ranges 800 - 1800 kg ha^{-1} without irrigation and 2000 - 2500 kg ha^{-1} when irrigated in Myanmar with the average yield of 1462 kg ha^{-1}. The national average yield of groundnut is 50.8 baskets per acre with shell (410 kg ha^{-1} without shell) as an over estimation from surveyed data (Mandal, 2008; FAO, 2009).

2.3 Soil and Climatic Requirements for Groundnut Production

Soils with a high potential for the production of groundnuts are typically deep, sandy loam to sandy in texture in the topsoil without physical limitations such as compaction. The ideal soil has been identified as well-aerated containing moderate amounts of organic matter and groundnut grows best on soils that are well drained, loosely textured and well supplied with calcium (Ca), potassium (K) and phosphorous (P). The optimum pH should be 5.5 - 6.5, and some cultivars grow well in alkaline soils to pH 8.5. Groundnut, especially very low salt-tolerant varieties, is unsuitable for production in saline soils (Mandal, 2008).

Groundnut is a subtropical crop thriving on abundance of sunshine and temperatures, locality ranging between 35 °S and 40 °N, but extending to 45 °N in Central Asia and North America. It can adapt to a wide range of climatic conditions. Groundnut generally grows best below 1250 m and some specific varieties will do well at much higher elevations. They are relatively drought-tolerant and require about a minimum of 400 mm rainfall during the growing period. For optimum growth, however, an annual rainfall range of 750 - 1250 mm is necessary. Duration of the growing period is cultivar-dependent and generally lies within a 90 - 140 days range. Groundnuts are day-neutral (i.e. flower initiation is unaffected by photoperiodism.) (Singh and Oswatt, 1995).

Temperature is the major limiting factor for groundnut yield. The temperature range of 15 - 45 °C is suitable for germination. During the growing period, an average temperature of 22 - 27 °C is required. Optimum mean daily temperature to grow is 30 °C and growth ceases at 15 °C. Temperatures above 35 °C inhibit the growth and adversely affect flower production. Flower formation is closely related to mean temperature on condition that the variation between day and night temperatures does not exceed 20 °C. The most flowers are formed at a day temperature of 27 °C, while a warm day (29 °C) and a cool night (23 °C) give the highest pod formation. Higher attitudes with cooler climates are not suitable for groundnut production. (Singh and Oswatt, 1995)

2.4 Mineral Nutrition of Groundnut

Plants require 17 essential elements or nutrients for optimal growth and development. Each of these essential elements performs a specific biochemical or biophysical function within plant cells. Hence deficiency of even one of these elements can impair metabolism and interrupt normal development (Glass, 1989).

Groundnuts respond to additional fertilizer applications, even if the soil is fertile. It has good responses to N, P, K, Ca, S and other microelements including B. In general, groundnut plants absorb approximately 10 percent of their total requirements of N, P, Ca, and Mg during the vegetative phase, 40 - 50 percent during reproduction, and the remainder in maturity.

N, in general, is the major structural constituent of the plant cell. It plays an important role in plant metabolism by virtue of being an essential constituent of metabolically active components like amino acids, protein, nucleic acid, flavins, purines and pyrimidines, nucleotides, enzymes and alkaloids. Groundnut, being a leguminous crop, depends on two major sources of N for their growth as atmospheric N and mineral N. The contribution of N in most legumes would be 25 kg ha^{-1}(Srinivas *et al*., 2005).

Phosphorous (P) is a constituent of nucleic acid, coenzyme, DNA, RNA and NADP and most importantly in ATP and also involved in metabolic processes required for normal growth such as photosynthesis, glycolysis, respiration, fatty acid synthesis, cell division, and many other plant growth and development processes.

The plant uses K in photosynthesis, carbohydrate transport, water regulation, and protein synthesis. Although not an integral part of cell structure, K regulates many metabolic processes required for growth, fruit and seed development and also is essential for oil content of oilseed crops. Groundnut absorbs K rapidly in early stages. An oversupply of K in the soil can induce Ca deficiency, which is reflected in a lower yield and quality. Approximately 10 kg ha^{-1} of K is probably sufficient for optimum growth of groundnut although it is very seldom required.

Calcium (Ca) is a structural component of plant cell walls and it influences on nucleic acid and nitrogen metabolism, serves as an activator of enzymes, and affects the selective permeability of cell membranes. Ca is very important for seed development and regarded as essential element in groundnut production. The recommended time to apply gypsum on groundnuts is at early bloom (depending on weather conditions). A lack of Ca can lead to empty pods and darkened plumule in seed (concealed damage), poor germination and potentially increase risk of aflatoxin when soil conditions are favorable for the development of the mold *Aspergillus flavus*. Gypsum application at the rate of 500 kg ha^{-1} together with micronutrient mixture is required for increasing groundnut yield.

Sulphur (S) is a constituent of several plant biochemical compounds which regulate plant growth. This element is also essential in the synthesis of chlorophyll and in photosynthesis reaction. S is an essential component in the synthesis of amino acids required to manufacture proteins. Along with Mg, S plays a role in the formation of oils within the seed.

About 15 - 20% of the plant Mg is contained in chlorophyll, without which the plant could not capture energy from the sun for growth and development. Mg also appears to activate a number of enzymes and play a role in protein synthesis and P reactions. Oilseed crops have much higher seed Mg than cereal seed.

Micronutrients play an essential role in many plant metabolic processes and are necessary for groundnut production. Among the micronutrients, the important role of B in groundnut production can be summarized as follows. B is instrumental in forming the conductive tissue that transports nutrients, in the formation of pollen tubes and bloom, in the translocation of N and sugars from the leaves to the fruits, in the formation of amino acids and proteins and in the utilization of absorbed phosphorus and water. B is relatively immobile in plants once it has been utilized in actively growing tissues. Therefore, it is necessary to have a continuous supply of B throughout active growth stages of plants. B deficiency symptoms occur in sandy soils and can affect the quality and quantity of groundnut. B deficiency will cause hollow heart (concealed damage) in the groundnut seeds. B can be applied as a foliar spray not later than normal gypsum application time (at pegging stage) or it may be mixed with fertilizer or herbicides and applied prior to planting or soil application.

2.5 Nutrient Uptake and Removal by Groundnut

Agricultural production and productivity are directly linked with nutrient availability and uptake of crops (Marschner, 1995). Nutrient requirement of groundnut crop varies with soils, climatic conditions, cultivars, crop yields, cropping systems and management practices. Oilseeds are energy-rich crops and hence the requirement of major nutrients as well as secondary and micronutrients is very high.

Groundnut removes fairly large quantities of nutrients from the soil. Nutrient removal by a crop producing 3 tonnes pods ha^{-1} in the United States of America was reported to be 192 kg N, 48 kg P_2O_5, 80 kg K_2O and 79 kg MgO (IFA, 1992).

The average extraction of 120, 11, 18, 13, 9 and 7 kg ha^{-1} of N, P, K, Ca, Mg and S respectively was observed to produce 3 tons of pods. And also, the extraction of 72, 11, 48, 64 and 16 kg ha^{-1} of N, P, K, Ca, Mg and S respectively was found to produce 5 tons of haulm and thus total removal amounted to 192, 22, 66, 77, 25 and 15 kg ha^{-1} of the above nutrients in the production of 8 tons of groundnut in India (Veeramani and Subrahmaniyan, 2011).

Manoharan *et al.* (1994) reported that the uptake of N, P and K increased with increasing levels of N. The nutrient removal varies considerably, depending upon crop productivity and soil fertility (Hegde, 2000).

2.6 Role of Boron in Groundnut

Groundnut is a B-sensitive crop and high in B requirement for both quantity and quality factors. B has been universally recognized as the most important micronutrients for groundnut production but its requirement is not as high as that for some other leguminous species such as pigeon pea, chickpea, etc. B is essential for all plant growth and it aids in the transfer of sugars and nutrients from leaves to fruits, and increased pollination and seed development. B is also an essential micronutrient for the process of nodule formation (Bhuiyan *et al*., 1998). B involves in synthesis of oil and protein and therefore it plays important roles in kernel quality and flavor of groundnut. In B-deficient acidic soils (below 0.4 ppm available B), low pod filling, shriveled seeds and hollow darkening or off-colour in the center of the seed are commonly observed as symptoms of B deficiency causing 10 - 50% yield losses (Cox and Reid, 1964; Singh *et al.*, 2004; 2007)

2.7 Boron Deficiency and Toxicity Symptoms in Crops, Especially in Groundnut

B is unique among the trace elements because relatively very small quantities are necessary for normal crop production. However, slightly high concentration may become toxic for the plant, as the range between B deficiency and toxicity is very narrow (Gupta, 1993).

Most cruciferous, leguminous and solanaceous crops show high susceptibility to B deficiency. B deficiency symptoms vary between crop species, but generally occur in the growing points or flower and fruiting parts of the plant. Groundnut plants seem to be tolerant to low B levels better than many other plants. Therefore, visual symptoms caused by severe deficiencies of B are rarely found in groundnut producing regions where B has been previously applied. Foliar symptoms of B deficiency include stubby, rosette branches (similar to the symptom of Ca deficiency), cracking of the branches, discolouration of nodal areas and leaves with a yellow-green mosaic appearance. Deficiencies also cause shell deformity and random shell cracking (other conditions may also cause cracking). The most distinct symptom is internal fruit damage termed ‘hollow heart’, in which the cotyledons are concave and discolored without showing any foliar symptoms in groundnut. These effects reduce kernel weight and lower the quality such as oil content and yield on groundnut production (Rerkasem *et al*., 1993; Nasef *et al*., 2006).

A number of physiological processes were reported to be affected by B toxicity include inhabitation of cell division and elongation, disruption of cell wall and metabolic disturbance (Reid *et al.*, 2004). B toxicity symptom appears in groundnut like potassium deficiency, with yellowing at the leaf margins and between the veins and eventually browning of the margins. However, B toxicity symptoms rarely occur in groundnut crop.

2.8 Timing, Method and Amount of Boron Fertilizer Application

Groundnut is B-sensitive and has high requirement for normal growth and yield, and excessive and deficient levels can be encountered during the same season (Mortvedt and Woodruff, 1993).Correct timing of B application is a very effective way to fulfill the plants’ need. The fertility of the soil in which pegs and pods develop is important because the pod absorbs most of its required B and Ca through the shell, rather than through the roots. This influence of the method and timing of fertilizer applications may differ considerably from other crops.

The critical level of B in upper mature groundnut leaves is about 25 ppm. Groundnut plants with leaf B contents below the critical level should be sprayed one or more times with B fertilizer such as *Solubor* at flower initiation and during pod development. Some researchers recommended that B applied during flowering and pod development gave the highest yield of groundnut. Groundnut produces good nut setting and yield with increasing side shoot formation by the application of B. Legumes and certain root crop required 2 to 4 kg ha^{-1} of B (Fageria, 2009). To correct B deficiency, application rate of 0.5 to 3 kg B ha^{-1} is suitable for optimum crop growth (Gupta, 2007).

Foliar application at an early growth stage cannot supply adequate B requirements on a low B soil. When crops are grown with irrigation, it is important to split B application to compensate for leaching losses of B. Foliar-split applications at different growth stages were effective in correcting B deficiency in many crops like soybean, blackgram and cotton. Two foliar applications at R4 and R5 stages of soybean caused a yield increase of 356 kg ha^{-1} on a Maxico silt loam in Missouri (Reinbott and Blevin, 1995). The highest level of B (300 ppm) application attained highest oil and protein percentage of groundnut seeds followed 200 ppm of B and then by 100 ppm (Nasef *et al.*, 2006). B application at the rate of 0.5 to 0.25 kg ha^{-1} in the first fungicide application at early crop growth or alone at pegging time is recommended to produce high quality and yields of groundnut especially on sandy soils (Singh, 1995).

The deficiency levels of B concentration are >13 µg g^{-1}in kernel, 10.6 ± 5.8 µg g^{-1} in seed and normal concentration is 16.4 ± 2.7 µg g^{-1} in seeds of groundnut. The sufficiency levels of groundnut are 29 ppm, 18 - 20 ppm and 25 ppm in young shoot, young leaves and mature leaves respectively and also the critical level is 0.2 - 0.5 ppm of hot water soluble B.

B fertilizer can be applied as broadcast, banding, foliar and seed treatment. However, application of B to seeds or even application in close proximity to seed is not advisable due to the toxic effect of this element (Shorrocks, 1997). Generally, soil and foliar applications are effective fertilization practices for increasing crop yield especially of field-crops. Higher rates of B are required for broadcast applications than for banding or foliar sprays. Soil application of 1 kg B ha^{-1} gave the highest yield of 3 tons ha^{-1} in mungbean and beans. The range of B application on optimum groundnut production is within 0.5 to 4 kg B ha^{-1} and higher than 4 kg B ha^{-1} produced B toxicity symptoms (Kumar *et al.*, 1996). Soil application is more effective and desirable compared to foliar application in annual crops. Soil applications are generally used for applying B to field crops, but foliar applications are more common on perennial crops such as fruit trees.

Deficiencies that developed during the growing season in annual crops may be treated successfully with foliar treatment and also simultaneously lower the risk of B toxicity.

2.9 Boron on Nodulation of Crops Especially in Groundnut

B is an obligatory requirement in normal nodule development and functioning because of smaller number and lower weights of nodule were observed from plants (*Phaseolus vulgaris*) grown without B in nutrient solution (Bonilla *et al*., 2001). Among micronutrients, the role of B on nodulation, growth and yield of different legumes as well as groundnut has been discussed by many workers (Nasef *et al.*, 2006; Nayak *et al*., 2009; Kamath *et al*., 2011). The main effects of B deficiency stress on nodulation and N_2 fixation in legumes are usually connected with changes in cell wall structure and permeability, transport of carbohydrates and synthesis of phenols (Preffer *et al*., 1998; Zehirov and Georgiev, 2001). B deficiency leads to formation of abnormal nodules containing no bacteroids in the infected area (Bolanos *et al.*, 1996). Moreover, its deficiency exerted a stronger negative effect on the nodule setting resulting in decreased number of nodules and reduced specific nodulation rate in soybean (Gregor and George, 2001).

Groundnut, unlike the other legumes, can sustain fixed-N which is likely to be attributable to the presence of stored photosynthates (as lipid bodies) in the nodules (Siddique and Bal, 1991). Patel and Golakia (1986) reported that application of B increase N concentration in groundnut, presumably due to the favourable effect of B on nodulation as nodule counts.

2.10 Role of B on Hollow Heart of Crops Especially in Groundnut

Hollow heart symptom occurs when low B limits Ca translocation and inhibits cell wall development and cell division. This reduces the competition for assimilates, resulting hollow heart symptoms in large-seeded groundnut cultivars. Abnormal growth manifests when B supplies become limited during later development stages. B application at later growth stages may reduce the incidence of hollow heart in leguminous crops (Rerkasem, 1989).

The average concentration of B in deficient groundnut seeds was about 10.5µg B g^{-1}, while the level in seeds with adequate B concentration was about 16.5. In the case of soybean and groundnut, low B levels in the seed are associated with physical damage which may lead to other quality problems. ‘Hollow heart’ symptoms of B deficiency in groundnut were found in soils with a hot water soluble level of B less than 0.14 ppm. There was no hollow heart in kernels with a B concentration greater than 13µg B g^{-1}, but below this level, the percentage of kernels with hollow heart increased sharply with lower levels of B in the kernel (Netsangtip *et al.*, 1985).

2.11 Boron on Oil and Protein Content of Crops

B is involved in the synthesis of oil (Malewar *et al.,* 2001) and protein (Sauchelli, 1969). B is involved in a number of metabolic pathways such as sugar transport, respiration, carbohydrates, RNA, IAA, and phenol metabolism. B fertilization improves photosynthetic activity, enhances activity of enzymes and plays a significant role in protein and nucleic acid metabolism (Kolesnik, 1962). Maximization of protein in groundnut pods through combined application of phosphorous and B was reported by some workers (Bhuiyan *et al.,* 1998; Murthy, 2006). Any control of nucleic acids or protein metabolism can hardly be responsible for the different requirements in plant species Goldbach (1997). Application of B stimulated N content of potato tubers and might have increased protein synthesis and subsequent storage of protein as suggested by Yadav and Manchanda (1979).

B is important in post-fertilization development and seed maturation. In sunflower, deprivation of B supply, even as late as the time of anthesis, produces morphological aberration in seeds and reduce the seed content of non-reducing sugars, starch and oil (Chatterjee and Nautiyal, 2000). Seeds of low B sesame plants showed enhanced accumulation of phenolic compound and decreased oil content (Sinha *et al.*, 1999). Nasef *et al.* (2006) reported that the application of B with *Rhizobium* inoculation increased oil content of groundnut seed and he added that the increasing level of B application as 200 - 300 ppm progressively increased oil percentage of groundnut seeds. The highest value of oil and protein contents in groundnut were achieved by the B foliar application at highest concentration of 300 ppm (Rifaat *et al.*, 2004; Khalifa *et al.*, 2005).

Table 2.1 Boron compounds commonly used as fertilizers

B source	Chemical formula	Solubility in water	(%) B
Borax	$Na_2B_4O_7.10H_2O$	Soluble	11.3
Fertilizer borate	$Na_2B_4O_7.5H_2O$	Soluble	14.3 - 14.9
Anhydrous borax	$Na_2B_4O_7$	Soluble	21.5
Solubor	$Na_2B_8O_{13}.4H_2O$	Very soluble	20.5
Boric acid	H_3BO_3	Soluble	17.5
Colemanite	$Ca_2B_6O_{11}.5H_2O$	Slightly soluble	15.8
Ulexite	$NaCaB_5O_9.8H_2O$	Slightly soluble	13.3
Boron frits	Boric oxide glass	Very slightly soluble	2.0 - 11.0

Source: Mortvedt and Woodruff (1993)

CHAPTER III
MATERIALS AND METHODS

3.1 Experimental Site

The experiment was conducted in a field of Yezin Agricultural University, located at 19° 10′ N latitude and 96° 07′ E longitude with the elevation of 213 meters above sea level. The study areas receives an average annual rainfall of 1297 mm and mean annual maximum and minimum temperature of 36.43 °C and 14.24 °C, respectively. Field experiments were conducted during rainy season (May - October, 2011) and winter season (November, 2011 - March, 2012).

3.2 Experimental Design and Treatments

In both growing seasons, the experiments were laid out in randomized complete block (RCB) design with four replicates. The experimental area was 512 m^2 and the size of each plot was 3 m × 3 m. Groundnut seeds were sown in rows at spacing of 45 cm between rows and 15 cm between plants. In each plot, the total plant population was 140. The spacing is 1 m between individual plots and 0.5 m between blocks. Treatments were composed of application methods (foliar, soil-split and foliar-split) with different timings. They consisted of eight treatments as follows.

B0 (B-untreated plot)

BS1 (basal + soil-split at Peg)

BS2 (basal + 2 soil-split at EB & Peg)

BS3 (basal + 3 soil-split at EB, Peg & FPF)

BF1 (basal + foliar-split at Peg),

BF2 (basal + 2 foliar-split at EB & Peg),

BF3 (basal + 3 foliar-split at EB, Peg & FPF)

B0F4 (foliar 4 times at SSF, EB, Peg & FPF)

[Peg = Pegging; EB = Early bloom; FPF = Fifty percent flowering; SSF = Side shoot formation]

Basal application was conducted at the rate of 1 kg B ha^{-1}. Each foliar-split was at the rate of 0.25 kg B ha^{-1} in 0.03% solution. However, in soil-split, the total amount of 1 kg B ha^{-1} was separated according to the schedule. The treatments are expressed in detail (Table 3.1).

3.3 Soil Sampling and Analyses

Representative soil samples (0 - 30cm depth) were collected for physical and chemical analyses. Randomly-collected 20 cores were sampled and then thoroughly mixed, air dried and ground to pass through 2 mm sieves. The soil samples were analyzed for organic carbon and available N, P, K and measured for soil pH, bulk density, soil texture and cation exchange capacity (CEC). Soil pH was measured using a pH meter (1:2.5 w/v soil:water), and available N, available P, and available K were determined by alkaline permanganate, Olsen's and Ammonium acetate extraction method respectively. Organic carbon (Tyurin's method), soil texture (Pipette method) and cation exchange capacity (Bascomb's method) were determined. Soil samples were analyzed at the Department of Agricultural Research (DAR) and physical properties were analyzed in the laboratory of Department of Agricultural Chemistry, Yezin Agriculture University, Yezin, Nay Pyi Taw. The physicochemical properties of experimental soil are shown in Table 3.2.

3.4 Crop Management

Groundnut variety Sinpadethar 11 was used as a test crop in this study. Germination test was done before planting. The seeds were sown within the second week of May in rainy season (2011) and the first week of November (2011) in winter season after land preparation. About 2 - 3 seeds were sown in each planting hole. Groundnut seeds were inoculated with the nodulation bacteria of groundnut-specific *Rhizobium* inoculants just before sowing at the rate of 190 g ha^{-1} recommended by the Department of Agricultural Research, Yezin, Nay Pyi Taw. Thinning and refilling were done two times at 14 and 21 days after sowing (DAS). Only two healthy plants were left at each hill in final thinning.

Intercultivation, earthening-up, plant protection (weed, insect and disease control) and all agronomic practices including irrigation during pod development stage were undertaken as necessary. The plants were harvested at crop maturity around 96 DAS in rainy season and 109 DAS in winter season.

3.5 Fertilizer Application

All experimental units were fertilized with 40 kg N ha^{-1} as urea, 50 kg K_2O ha^{-1} as muriate of potash (MOP), dividing each in three equal doses, at sowing time, early bloom and pod development stages of groundnut. Triple super phosphate was applied as the rate of 50 kg P_2O_5 ha^{-1} at only planting time. Gypsum (500 kg ha^{-1}) as source of Ca and S was applied near pegging zone of the plants at the time of 50% flowering and pod development. Band placement method was used in applying all the above fertilizers.

Sodium tetraborate ($Na_2B_4O_7.10H_2O$) or borax is generally used for soil application. It is a popular water-soluble B fertilizer which consists of about 11.3% B. At room temperature (~25 °C), elemental B persists as a solid form. It can dissolve in boiling water. Soil application of B was conducted in solution form and placed near pegging zone while foliar fertilization was applied by a hand sprayer. For foliar B application, borax was dissolved in hot water (70 - 100 °C) to get 0.03% B solution i.e. 2.05 g of borax were dissolved and volume made up to 0.75 liter with water for foliar spraying.

3.6 Data Collection

3.6.1 *Plant Growth and Yield Investigation*

During the groundnut cultivation period, plant heights were recorded at 10 day interval from ten plants fixed with labels for each plot; it was measured from the base to uppermost growing point of the plant. The number of flowers $plant^{-1}$ was also recorded 2 days interval within 8:00 - 10:00 in the morning. At harvest, yield and yield components (number of plants $plot^{-1}$, number of branches $plant^{-1}$, number of pods $plant^{-1}$, number of seeds pod^{-1}, percentage of filled seeds, 100 seeds weight), percentage of hollow heart, number of pegs per plant, dry weight of biomass and shelling percentage were investigated. Number of nodules $plant^{-1}$ (effective and ineffective) were also recorded at 40, 60, 80 DAS and at harvest. For nodulation, three stands from each plot were randomly selected in the row next to the border and carefully uprooted, ensuring the roots were not left in the soil. The roots were washed with water to clear of adhering soil and then number of nodules per plant was counted by excising them from the roots. Harvest index (HI) were also calculated. Shelling percentage was estimated from a random pod sample (100 g per plot), the seeds were hand separated and then shelling percentage was calculated.

3.6.2 *Analysis for Oil and Protein Content in Seed*

Seeds sample were analyzed at the Department of Physiology and Biochemistry, University of Veterinary Science, Yezin, Nay Pyi Taw. Seed nitrogen content was analyzed using semi-micro distillation apparatus by semi-micro Kjeldahl’s digestion and distillation. Protein content was calculated by conversion factor for total N content. Groundnut seeds were analyzed using Soxhlet's apparatus to determine its oil content. In oil content determination, 10 g sample of groundnut seed was placed in filter paper and tied tightly with thread and placed in the thimble. Then it was placed in the extractor and set up the Soxhlet's apparatus. Then 150 ml petroleum ether was used as solvent for one set of sample. Extraction was completed within 18 hours. The flask with contents was oven dried to get a constant weight.

3.6.3 *Calculations*

Total crude protein content, oil content, harvest index and shelling percentage were calculated by the following equations;

$$\text{Protein content} = \text{Total Nitrogen Content in Seed} \times 6.25$$

(A.O.A.C, 1990)

$$\text{Oil content (\%)} = \frac{\begin{matrix}\text{Weight of Oil Flask} \\ \text{after Extraction}\end{matrix} - \begin{matrix}\text{Weight of Oil Flask} \\ \text{before Extraction}\end{matrix}}{\text{Weight of oven dried sample}} \times 100$$

$$\text{Harvest Index (HI)} = \frac{\text{Economic Yield}}{\text{Biological Yield}}$$

$$= \frac{\text{Dry Weight of Pods}}{\text{Total Plant Dry Weight}}$$

$$\text{Shelling (\%)} = \frac{\text{Seeds Weight}}{\text{Pods Weight}} \times 100$$

3.7 Weather Data

All weather data for both seasons were obtained from the meteorological station at DAR.

3.8 Statistical Analysis

All the collected data were statistically analyzed by using JMP software (version 8.0.1, SAS Institute Inc., 2009), and the difference between means were compared using the least significant difference (LSD) test at 5% probability level.

Table 3.1 The experimental treatments and their B application times and methods

Treat-ment	Abbre-viation	Basal (kg B ha^{-1})	Split application (Number of splits at different growth stage)		
			Soil application	Foliar application	Total amount (kg B ha^{-1})
T1	B0	-	-	-	0
T2	BS1	1	1 (Peg)	-	2
T3	BS2	1	2 (EB + Peg)	-	2
T4	BS3	1	3 (EB + Peg + FPF)	-	2
T5	BF1	1	-	1 (Peg)	1 .25
T6	BF2	1	-	2 (EB + Peg)	1.50
T7	BF3	1	-	3 (EB + Peg + FPF)	1.75
T8	B0F4	-	-	4 (SSF + EB + Peg + FPF)	1

Peg = Pegging; EB = Early bloom; FPF = Fifty percent flowering; SSF = Side shoot formation

Foliar application rate was 0.25 kg B ha^{-1} for each time

Split application for soil was done at the rate of total 1 kg B ha^{-1} for each treatment.

Table 3.2 Physicochemical properties of experimental soil

Properties	Rating (Content)
Texture	Loamy sand
Bulk density (g cm^{-3})	1.22
pH	6.4 (slightly acid)
Organic matter (%)	1.12 (low)
Available N (ppm)	30 (low)
Available P (ppm)	4 (low)
Exchangeable K (ppm)	56 (low)
Cation Exchange Capacity (cmol $_{(+)}$ kg^{-1})	5.94 (low)

CHAPTER IV
RESULTS AND DISCUSSION

4.1 Rainy Season Experiment

Groundnut is widely grown in rainy season which is suitable for groundnut production in Myanmar especially in rainfed dry zone area and upper Myanmar (Sagaing, Mandalay, Magway Regions and Shan State). In rainy season, May to October 2011, groundnut cultivation was conducted in Yezin Agricultural University farm and the experimental results are as following.

4.1.1 *Seed Yield*

Seed yield of groundnut as affected by different timing, method and amount of B fertilization are shown in Table 4.2. Seed yield is a more profit-determining factor than pod yield because it represents the edible portion and nutritious for consumers. The applications of N, P, K and Ca seem to be provided the optimum amount for groundnut production. Therefore, seed yield was found to be responsive to added B fertilizer with different timing, method and amount. The highest seed yield was obtained from BF2 while the lowest from B0. The seed yields of BF2 and BF3 were significantly higher than B0 as 30% and 27% higher over control but not statistically different from those of BF3, BS3, B0F4, BS2 and BS1 as the percentage of 21, 14, 13, 11 and 7 higher over control respectively.

Seed yields resulted from B soil-split applications showed no difference from one another, but BS3 gave more yield than BS2 followed by BS1. Among foliar-split treatments, BF2 gave the highest yield followed by BF3. The significantly lower yield was obtained from BF1 compared to other foliar-splits. Only-foliar treatment (B0F4) produced higher seed yield than BF1, BS1 and BS2. The results suggested that B application as basal together with two foliar splits at the rate of 1.50 kg B ha^{-1} seems to be the optimum timing and method for achieving maximum seed yield of groundnut. Moreover, it may be assumed that the plant B uptake was higher in more foliar-splits, such as BF2, although the total amount of B uptake was lower than those of soil-splits. Hobb (1974) and Nasef *et al.* (2006) stated that whether B in the soil is inadequate, foliarly-applied B can be retranslocated from leaves to the buried fruit (pod), especially in the case of groundnut and so, increase seed yield. This finding confirmed that foliarly-applied B in B-withdrawal treatments at different growth stages still increased number of pods per plant, seed yield and it was evident in B retranslocation to the buried fruit as B mobilization mechanism (both xylem and phloem transport) in groundnut (Konsaeng *et al*., 2009).

Sarker *et al*. (2002) reported that a significant variation on seed yield of soybean with each increment of B at the rate of 0, 0.5 and up to 1.0 kg B ha^{-1}, 1.0 kg B ha^{-1} produced highest yield among all the treatments. Also, two foliar-sprays of B at R4 (Pod Setting stage) and R5 (Pod development stage) of soybean significantly increased seed yield on Maxico silt loam in Missouri (Rainbott and Blevins**,** 1995). Foliar B applications, however, have long been known to be effective means of enhancing bud and flower B concentrations resulting in increased fruit set and yield in *Prunus*, *Malus* and *Pyrus* species (Batjer *et al*., 1978; Callan *et al.*, 1978). In the present study, it is noticeable that two to three-time foliar-splits application might be the best way to produce the highest seed yield and appropriate methods for minimizing residual effect of B in soil.

4.1.2 *Pod Yield*

The results pointed out that pod yield of groundnut responded to applied B (Table 4.1). BS3 produced the highest yield among all B treatments while the lowest in B0. The pod yield of BS3 was significantly higher than BS1, BF1 and B0, but not different from BS2, BF2, BF3 and BF4. This result indicated that B fertilization was needed for increasing pod yield of groundnut. Asokan and Raj (1974) studied the response of groundnut on pot culture to various forms and levels of B and reported that the application of 15 kg ha^{-1} boric acid or borax increased the yield of crop appreciably and it also improved the formation of pods. On B-deficient acid sedentary soils having 0.3 kg ha^{-1} of hot-water-soluble B in Ranchi, India, groundnut significantly responded to B application and increased pod yield remarkably from 1140 kg ha^{-1} in control to 1530 kg ha^{-1} with 3 kg B ha^{-1}. However, Kumar *et al.* (1996) reported that the larger amount at 4.5 kg B ha^{-1} significantly reduced pod yield in groundnut production. In the present study, the rate of B fertilizer use was as low as 2 kg B ha^{-1} for soil application and any toxic effect of B was not observed in both vegetative and reproductive growth of groundnut. Therefore, this rate may be suitable for groundnut, especially for the tested variety Sinpadethar 11.

Among the soil-split applications, the more the splits, the higher the pod yield of groundnut were achieved. This may be due to the requirement of B to split at strategic time and the effectiveness in B uptake throughout the growing period for increasing groundnut pod yield. If only one time split application at pegging was conducted, it could support the required amount of B at that time. B was directly taken up by developing pods however, no longer B would be available after that period for the subsequent growth stages. Eguchi and Yamanda (1997) reported that only 10% of B applied to soil was absorbed by plants, 30 - 40% was left in the soil, while 40 - 60% was leached out from the top soil in a long term field experiment on 26 - 29 successive crops. Developing pod directly absorbed B from soil with split application and therefore, the treatments BS2 and BS3 showed better response to continuous liberation of B in the soil**.**

Singh *et al.* (2009) reported that soil application with the same amount of B at 1 kg ha^{-1} as borax, Agricol, or Solubor showed similar response among different methods (soil, foliar and seed treatment). They extended that soil application, at the rate of 1 kg B ha^{-1} regardless of B sources, enhanced productivity by improving pod filling in groundnut. On the other hand, the application rate of 2 kg B ha^{-1} also gave the higher yield response of 29.9 percent over control in acid soil of Orissa, India (Kumar *et al*, 1996).

Among foliar-split applications, BF2 gave higher pod yield than BF3 while BF1 gave the lowest. Although the same amount of B was provided to the plant as basal application, BF2 produced the highest pod yield due to B splitting at right times such as early bloom (EB) and pegging (Peg). However, BF1 with only one foliar spray at the rate of 1.25 kg B ha^{-1} was inadequate to get good yield.

B0F4 did not give the optimum pod yield compared to BF2 or BF3 because four-time foliar applications, without basal B, did not support the adequate B for groundnut in which developing pod can absorb B directly from soil.

In the present study, B fertilization was necessary to increase pod yield of groundnut and basal B with more splitting times whether soil-split or foliar-split except BF3 was effective among the treatments. Soil-split application with three times is the best for achieving maximum yield in groundnut.

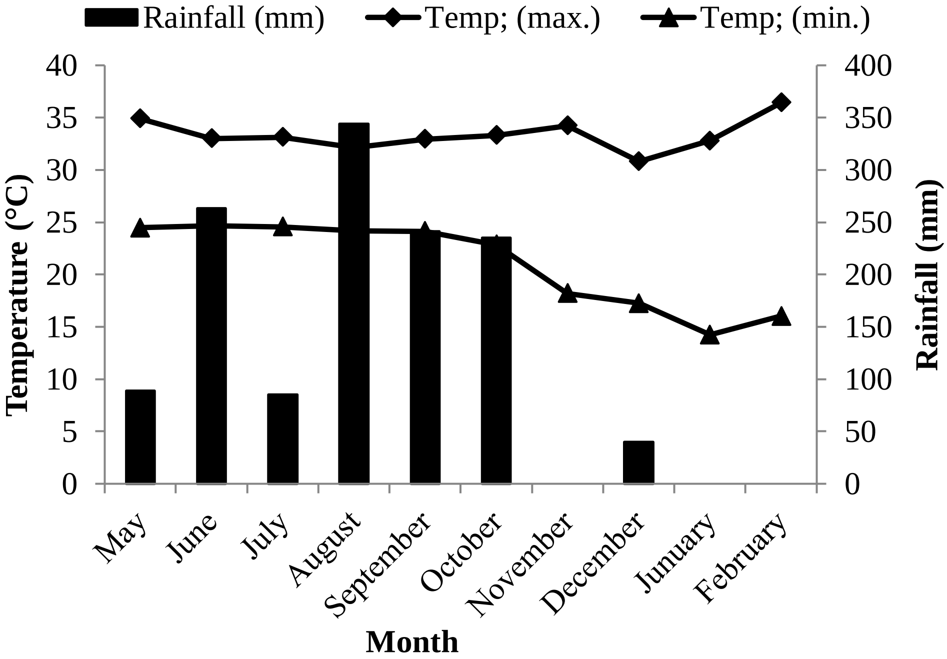

Figure 4.1 Monthly maximum and minimum temperature and total rainfall during experimental period in Yezin (May, 2011 - Feb, 2012)

Table 4.1 Effect of different Timing and Methods of B fertilization on pod yield, yield components and harvest index on groundnut during rainy season, 2011

Treatment	Pod yield (kg ha^{-1})	No. of pods plant^{-1}	No. of seeds pod^{-1}	100 seed weight (g)	Shelling percentage (%)	Harvest Index
B0	3897 c	23.10	1.49	47.30 b	72.47	0.43
B0F4	4657 ab	24.83	1.51	50.44 ab	74.56	0.43
BF1	4542 b	24.87	1.42	51.78 a	73.77	0.42
BF2	4915 ab	27.09	1.51	52.39 a	77.33	0.46
BF3	4599 ab	26.67	1.49	52.33 a	75.80	0.44
BS1	4501 b	27.36	1.34	50.44 ab	74.44	0.43
BS2	4714 ab	25.53	1.36	51.87 a	74.78	0.47
BS3	5046 a	28.45	1.40	50.96 ab	74.24	0.45
	**	ns	ns	*	ns	ns
Pr>F	< 0.01	0.13	0.56	0.02	0.21	0.37
$LSD_{0.05}$	212.5	2.55	0.15	1.91	2.52	3.16
CV%	4.61	9.81	10.67	3.75	3.12	7.16

Means followed by the same letter in each column are not significantly different at the 5% level of Least Significantly Different (LSD).

B0 (B-untreated plot)

BS1 (basal + soil-split at Peg)

BS2 (basal + 2 soil-split at EB & Peg)

BS3 (basal + 3 soil-split at EB, Peg & FPF)

BF1 (basal + foliar-split at Peg),

BF2 (basal + 2 foliar-split at EB & Peg),

BF3 (basal + 3 foliar-split at EB, Peg & FPF)

B0F4 (foliar 4 times at SSF, EB, Peg & FPF)

[Peg = Pegging; EB = Early Bloom; FPF = Fifty Percent Flowering; SSF = Side Shoot Formation]

Table 4.2 Seed yield and plant growth as affected by timing and methods of B fertilization on groundnut during rainy season, 2011

Treatment	Seed yield (kg ha^{-1})	Dry wt. $plant^{-1}$ (g)	No. of branch $plant^{-1}$	No. of pod $plant^{-1}$	No. of seed $plant^{-1}$	Pod wt. $plant^{-1}$ (g)	Seed wt. $plant^{-1}$ (g)
B0	2467 c	57.36 b	7.26	23.10	33.89	23.72 b	17.19 c
B0F4	2810 abc	59.96 ab	7.75	24.83	37.48	26.29 ab	19.58 abc
BF1	2661 bc	59.61 ab	7.58	24.87	35.22	25.13 ab	18.54 bc
BF2	3222 a	62.70 a	8.44	27.09	41.10	29.01 a	22.45 a
BF3	3124 ab	66.48 a	8.43	26.67	39.73	28.70 a	21.77 ab
BS1	2739 abc	60.26 ab	7.78	27.36	36.33	25.61 ab	19.09 abc
BS2	2778 abc	57.07 b	7.83	25.53	34.55	25.89 ab	19.35 abc
BS3	2978 abc	62.90 ab	8.15	28.45	39.36	28.05 ab	20.75 abc
	**	*	ns	ns	ns	**	**
Pr>F	0.002	0.03	0.43	0.13	0.03	0.01	<0.001
$LSD_{0.05}$	225.3	3.74	0.62	2.55	3.22	2.04	1.57
CV%	7.91	6.17	10.24	9.81	8.64	7.69	7.91

Means followed by the same letter in each column are not significantly different at the 5% level of Least Significantly Different (LSD).

4.1.3 *Seed weight*

The response of seed weight of groundnut to applied B fertilizer is shown in Table 4.2. Seed weight was calculated as an average of 10 individual plants for each treatment. The seed weight of BF2 was significantly higher than those of B0 and BF1 but not different from other B treated plots. All soil-split application treatments were not significantly different in seed weight.

Two to three times of splitting in both soil and foliar methods except BS2 produced higher seed weights than all treatments. B0F4 also showed the higher seed weight with the fourth largest value. Thus, it can be suggested that foliar application methods with suitable frequency were superior in seed weight production. Foliar B application also showed the higher yield in groundnut seed yield (Hobb, 1974; Nasef *et al.*, 2006) as well as in other crops such as cotton, in which an average of 40% increase was fond over control (Dordas, 2006; Niaz, 2010).

Groundnut is a crop with indeterminate nature in vegetative and reproductive development and has a long period of time for seed setting. Therefore, sufficient B is continuously required to get higher yield as well as higher quality. Several authors reported that B application enhanced yield and other components of soybean in various experiments (Touchton and Boswell, 1975; Schon and Blevins, 1990; Reinbott and Blevins, 1995). Albert (1968) stated that B is essential in the synthesis of N-base uracil, which is very important for the storage of carbohydrate and protein.

4.1.4 *Yield components*

Yield components of groundnut such as number of pods per plant, number of seed per pod, hundred seed weight and shelling percentage for the rainy season were recorded in Table 4.1. Hundred seed weight was the only yield component that showed statistical difference in different timing and methods of B fertilization.

***Number of pods per plant*:** The number of pods per plant on groundnut was not significantly different by B application. However, the minimum number was resulted from B0 (Figure 4.8). The maximum number of pods per plant was found in BS3 and it was 23% higher than the B-untreated plot.

***Number of seeds per pod*:** The number of seeds per pod was mostly 1 to 2 in the tested variety Sinpadethar 11. In the present study, no significant difference in number of seeds per pod was observed by B fertilization in the rainy season.

***Hundred seed weight*:** Hundred seed weight is a fundamental yield determining factor in groundnut because the healthier and heavier the seed, the greater the seed yield will be. All foliar-splits and BS2 gave significantly higher hundred seed weight than B0. Therefore, in comparing application methods for B, foliar-split was more effective than soil-split with respective timing. However, in only foliar application treatment (B0F4), relatively lower hundred seed weight was obtained and it might be due to insufficient B supply to increase seed filling. And basal B application is preferable for the optimum healthier seed. Many researchers reported that B application also hastened the healthier growth and grain yield of wheat in soils with low B availability (Ahmad and Irshad 2011; Fageria, 2002; Turan *et al.*, 2006). B affected cell division, sugar and starch formation, carbohydrate metabolism, sugar transport and fruit and seed development, and in turn increased the size and weight of grain (Kabata-Pendia and Pendias, 2001).

***Shelling percentage*:** The present study showed that the shelling percentage was not significantly affected by B fertilization. Similarly, Singh *et al.* (2009) also reported that the different rates, timing and methods of B fertilization did not give significantly difference in shelling percentage of groundnut. Moreover, application of B did not show significantly difference in shelling percent of mung bean (Kyaw, 2010). Irrespective of the soils, increasing levels of B increased the filling and shelling percentage of groundnut and it might be due to the role of B in sugar transport and B utilization by developing pollen and embryos, fruit and seeds and its unique role in cell wall structure and function (Sathya *et al*., 2009).

4.1.5 *Total dry matter (TDM)*

Total dry matter of groundnut was a sum of aboveground and underground portion of the plant. There was significant difference ($P < 0.05$) of total dry matter by B during the rainy season as shown in Table 4.2. The highest value was obtained from BF3. It might be due to continuous uptake of B favored by three-time foliar-split applications (early bloom, pegging and fifty percent flowering) which induced the highest total dry matter of groundnut. Galavi *et al.* (2012) stated that biological yield was significantly higher by B foliar spray combined with Zn or Fe in safflower. It suggests that foliar application of B with other micronutrients might increase biological yield of groundnut.

4.1.6 *Harvest Index (HI)*

Harvest index of groundnut was not significantly different by B fertilization (Table 4.2). The highest value of HI was obtained from BF2 and the lowest value from B0. It agreed with the report by Galavi *et al.* (2012). He stated that B foliar sprays did not significantly affect HI of safflower.

4.1.7 *Hollow heart percentage (HH%)*

Hollow heart, the most yield limiting factor, of groundnut significantly responded to different timing, method and amount of B fertilization as shown in Figure 4.2 and Table 4.3. The highest percentage (11.94%) was observed in B0 and it was significantly different (*Pr* < 0.05) from those of all other B treated plots. As the results of our study show, without the use of B in groundnut cultivation hasten hollow heart formation that might cause lower quality and yield reduction. The lowest HH% was observed in BS2 and the incidence was in ascending order of BF2, BS3, BF1, BS1, B0F4 and BF1. Reskasem *et al.* (1993) observed hollow heart symptoms on groundnut in the treatment without B in B deficient soil. The incidence of hollow heart in large- and small-seed varieties due to boron deficiency was minimized with B applications at 0.5 and 1 kg ha^{-1}, respectively. Harris and Brolman (1966) reported that B deficient treatment produced seed with 85.4% hollow heart. In a groundnut cultivation study, the treatments withdrawing B at flowering caused 53.4% hollow heart, but later B withdrawal at pod set resulted in only 10.3% being defective (Konsaeng *et al.*, 2010).

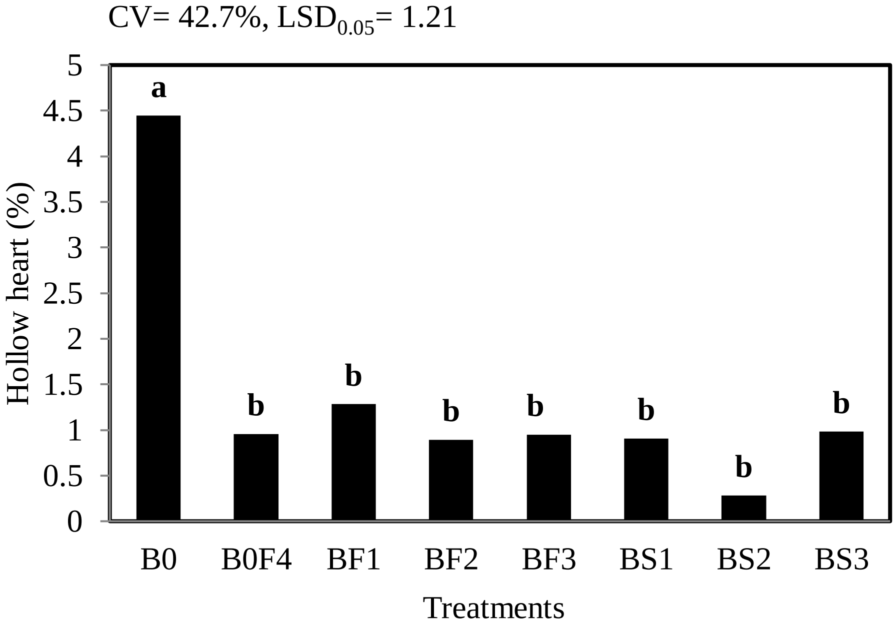

Figure 4.2 Comparison of Hollow Heart Percentage as affected by different timing and methods of B fertilization on groundnut during rainy season, 2011

B0 (B-untreated plot) **BF1** (basal + foliar-split at Peg),

BS1 (basal + soil-split at Peg) **BF2** (basal + 2 foliar-split at EB & Peg),

BS2 (basal + 2 soil-split at EB & Peg) **BF3** (basal + 3 foliar-split at EB, Peg & FPF)

BS3 (basal + 3 soil-split at EB, Peg & FPF) **B0F4** (foliar 4 times at SSF, EB, Peg & FPF)

[Peg = Pegging; EB = Early Bloom; FPF = Fifty Percent Flowering; SSF = Side Shoot Formation]

Table 4.3 Effect of different timing and methods of B fertilization on number of pod, seed plant^{-1} and hollow heart percentage of groundnut during rainy season, 2011

Treatment	No. of pod plant^{-1}	No. of seed plant^{-1}	Hollow Heart %	
			Original	Transformed[a]
B0	23.10	33.89	4.45 a	11.94 a
B0F4	24.83	37.48	0.72 b	4.83 b
BF1	24.87	35.22	1.28 b	6.36 ab
BF2	27.09	41.10	0.67 b	4.71 b
BF3	26.67	39.73	0.95 b	5.25 b
BS1	27.36	36.33	0.91 b	5.43 b
BS2	25.53	34.55	0.21 b	3.47 b
BS3	28.45	39.36	0.74 b	4.62 b
	ns	ns	**	**
Pr > F	0.13	0.56	<0.01	<0.01
$LSD_{0.05}$	2.34	0.13	1.13	1.21
CV%	9.8	10.7	91.1	42.7

[a] Arcsine transformation before analysis of variance. Means followed by the same letter in each column are not significantly different at LSD 5% level.

B0 (B-untreated plot)

BF1 (basal + foliar-split at Peg),

BS1 (basal + soil-split at Peg)

BF2 (basal + 2 foliar-split at EB & Peg),

BS2 (basal + 2 soil-split at EB & Peg)

BF3 (basal + 3 foliar-split at EB, Peg & FPF)

BS3 (basal + 3 soil-split at EB, Peg & FPF)

B0F4 (foliar 4 times at SSF, EB, Peg & FPF)

[Peg = Pegging; EB = Early Bloom; FPF = Fifty Percent Flowering; SSF = Side Shoot Formation]

Table 4.4 Oil and Protein content as affected by different timing and methods of B fertilization on groundnut for rainy season, 2011

Treatment	Oil content (%)	Protein content (%)
B0	45.14 b	41.05
B0F4	48.13 ab	38.50
BF1	50.44 ab	42.57
BF2	48.73 ab	38.41
BF3	50.03 ab	40.54
BS1	48.98 ab	40.97
BS2	50.47 ab	40.74
BS3	52.40 a	38.30
	*	ns
Pr > F	0.04	0.47
$LSD_{0.05}$	2.47	2.66
CV%	4.49	6.74

Means followed by the same letter in each column are not significantly different at the 5% level of Least Significantly Different (LSD).

4.1.8 *Oil and Protein content*

Some quality factors such as protein and oil content are very important in nutritional value of groundnut. Groundnut is one of the major oil seed crops in Myanmar and improvement of its oil content is the most important factors for economic return. Good response of B fertilization to oil content of groundnut was studied by several authors (Rifaat *et al.,* 2004; Khalifa, 2005 and Nasef *et al.,* 2006). B application significantly increased oil content in groundnut seeds in both soil and foliar treatment compared to B0 (Table.4.4). The highest oil content was analyzed in BS3 and it was significantly higher than that of B0, but not different from those of all B-treated plots. For foliar application, BF1 produced the highest oil content among foliar-split treatments and B0F4. It can suggest that the more the splitting times, the higher the groundnut oil content was analyzed in soil-split application. Therefore, the optimum rate of B for increasing oil content of groundnut in rainy season is 2 kg ha^{-1} and suitable timing is as basal with three soil-splits at early bloom, fifty percent flowering and pegging stages. Zahoor *et al.* (2011) and Oyinlola (2007) reported that the optimum soil application of B in sunflower was 2 kg ha^{-1} for increasing oil content (%). The beneficial effect of spraying with B may be attributed to the role of B element in fundamental metabolic reactions and acceleration of protein synthesis, B is also involved in a number of metabolic pathways such as sugar transport, respiration, and carbohydrate, ribonucleic acid (RNA), indole acetic acid (IAA) and phenol metabolism of a cascade effect (Nasef *et al.,* 2006).

Protein content of groundnut seeds showed no significant difference by B fertilization (Table 4.4). The highest protein content was analyzed in BF1 and the lowest in BS3. Brady (1999) reported that B is involved in protein synthesis. In contrast, in the present study it was observed that the larger B application rates produced the smaller protein contents of the groundnut seeds. Muthukrishnan (2007) reported that the highest protein content was recorded at 1.0 ppm and further increase in B level decreased protein content correspondingly in groundnut crop. Heitholt (1994; 1992) reported that, however in wheat, the decrease of protein content might be due to high B toxicity which disturbed the nutrients balance and also affected the N and other sugar (carbohydrate, glucose and fructose) assimilates to the grain. The effects of B varied in diverse crops. Crude protein content was increased by foliar application of B in mungbean (Rizk and Abdo, 2001) and sunflower (Jabeen and Ahmad, 2011) whereas it was decreased in soybean (Tamak *et al.,* 1997).

In recent study, there was faint evidence that the protein synthesis was negatively correlated with the oil formation in groundnut seeds. However, further systematic studies will be necessary to verify this statement.

4.1.9 *Plant Height*

Plant height of groundnut was not significantly affected by B application throughout the growing period in rainy season (Figure 4.3). Although slightly higher plant height was observed from BF3 than that of all treatments after complete B application, B fertilization did not effect on plant height of groundnut. It agreed with the report of Blamey *et al.* (1997), in which storage boron had not desirable effect on plant height for the general growth of sunflower. In contrast, the application of B at the rate of 5 kg ha^{-1} produced the tallest plant height in wheat (Kaisher *et al.*, 2010) and B played an important role in the development and differentiation of tissue, cell division and nitrogen absorption from the soil that enhance plant growth and ultimately increase plant height.

4.1.10 *Flowering Pattern*

To evaluate the fluctuation of number of flowers produced by plant, number of flowers $plant^{-1}$ was recorded 2 days interval within flowering time of groundnut (Figure 4.4). The life span of Sinpadethar 11 is 100 - 105 days. During the rainy season, flowering began at 26 DAS and total flowering period was 26 - 55 DAS (totally 30 days). The maximum number of flowers $plant^{-1}$ was recorded at 30 - 39 DAS and after that flowering gradually decreased to an average of 2 flowers $plant^{-1}$ day^{-1} at about 45 DAS. About 46 DAS, the number of flowers again increased with an average of 2 - 4 flowers $plant^{-1}$ day^{-1}. This might be due to adequate moisture and optimum temperature for flowering during this period. However, B application did not show significant effect on number of flowers $plant^{-1}$ during the rainy season groundnut cultivation.

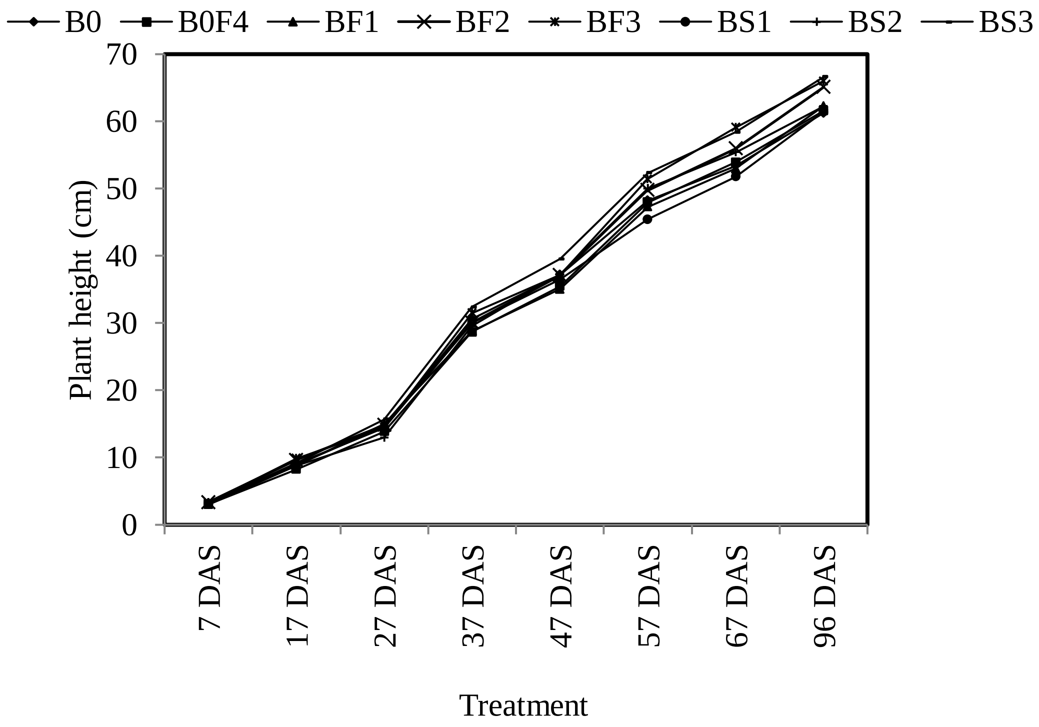

Figure 4.3 Mean values of plant height as affected by different timing and methods of B fertilization during rainy season, 2011

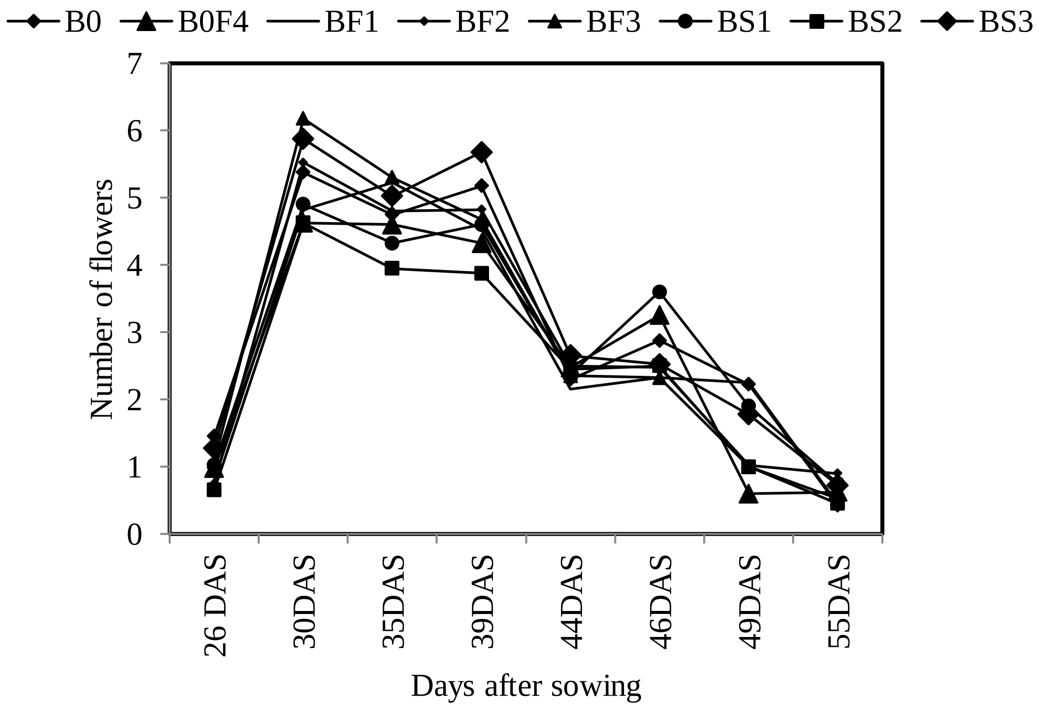

Figure 4.4 Mean values of number of flowers as affected by different timing and methods of B fertilization during rainy season, 2011

4.1.11 ***Nodulation of groundnut***

Nodules on groundnut root were counted at 40, 60, 80 DAS and at harvest as shown in Table 4.7 and Figure 4.5. Both total and effective nodules plant^{-1} were low initially at 40 DAS, but increased to the highest during early pod formation stage (60 DAS), after that gradually decreased at late pod-development stage (80 DAS) and finally to minimum at harvest. The total nodules plant^{-1} was not significantly influenced by B application at 40 DAS. But, effective nodules plant^{-1} in B0F4 was significantly higher at 40 DAS than those of B0 but not different from other B-treated plots. This indicated that the effective nodules plant^{-1} were less during early stage of crop growth and therefore N fixation is low during this stages (20 - 40 DAS) (Nambiar, 1990; Kamath *et al.,* 2011).

At 60 and 80 DAS, the total nodules plant^{-1} were significantly affected ($P < 0.05$) by B application (Figure 4.9). BS2 and BS3 gave more total and effective nodules plant^{-1} compared to other B treatments at 60 DAS. And, the highest total and effective nodules plant^{-1} were obtained in BF2 at 80 DAS followed by BF3 and BS3. Although the highest number of nodules was found in BS3, the total and effective number of nodules plant^{-1} were significantly decreased at harvest. Similarly, nodulation of groundnut by different sources, method and rate of B has been reported by Kamath *et al.* (2011). B being an essential nutrient for nodule forming bacteria, therefore B application increased in higher nodule count was reported by Srinivasan and Angayarkanni (2008). Good response of B on nodulation was reported in several crops by many authors (Yakubu *et al.* (2010) in groundnut, cowpea and bambara groundnut, Gregor and Gorge (2001) in soybean and Luis *et al.* (1996) in peas). Rhoden and Allen (1982) reported that, with the high rate of B (5.5 kg ha^{-1}) on cowpea, B fertilization decreased nodulation at low pH of 5.5, whereas it significantly increased at pH 6.5. The experimental soil used in the present study had a pH of 6.4 and hence the effect of B fertilization on groundnut nodulation might be significantly increased.

In comparing the efficiency of different method and timing of B fertilization, it was observed that BS2 and BS3 were far more beneficial in increasing effective nodules, especially at 60, 80 DAS and even at harvest during the rainy season. At 60 DAS, BS2 and BS3 resulted in 21.9 and 37.9% higher over control. The corresponding data for BS2 and BS3 were 24.1, 61.7 at 80 DAS and 52.8, 62.2% at harvest, respectively. Therefore, soil application method with two to three splits, i.e. BS2 and BS3, was sufficient to obtain higher nodulation for groundnut production during the rainy season.

4.1.12 ***Relationship between weight of pod, total dry matter and number of nodules per plant***

The correlation between weight of pod plant^{-1} and total number of nodule plant^{-1} is shown in Figure 4.6. The total number of nodules fitted with weight of pod as positive linear correlation function (R^2 = 0.778). According to R^2 value, the higher nodulation was highly related to the weight of the pod in groundnut. Both the higher number of nodules and the higher pod weight plant^{-1} were concurrently observed in BF2, BF3 and BS3.

The total effective nodules plant^{-1} moderately fitted in a positive linear function with total dry matter (R^2 = 0.395) in the rainy season experiment as shown in Figure 4.7. According to R^2 value, total dry matter was related to total effective nodules plant^{-1} by B fertilization on groundnut.

Therefore, number of nodule plant^{-1} was one of the most responsible parameters to increase weight of pod plant^{-1} and total dry matter due to B application.

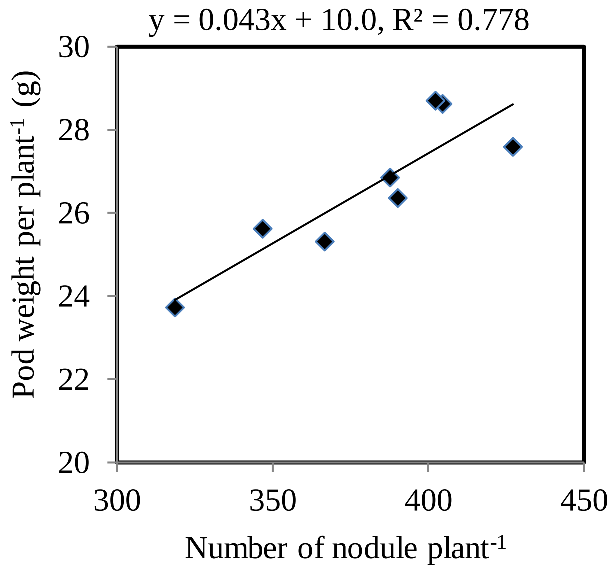

Figure 4.6 Relationship between weight of pods and number of nodules of groundnut as affected by B fertilization during rainy season, 2011.

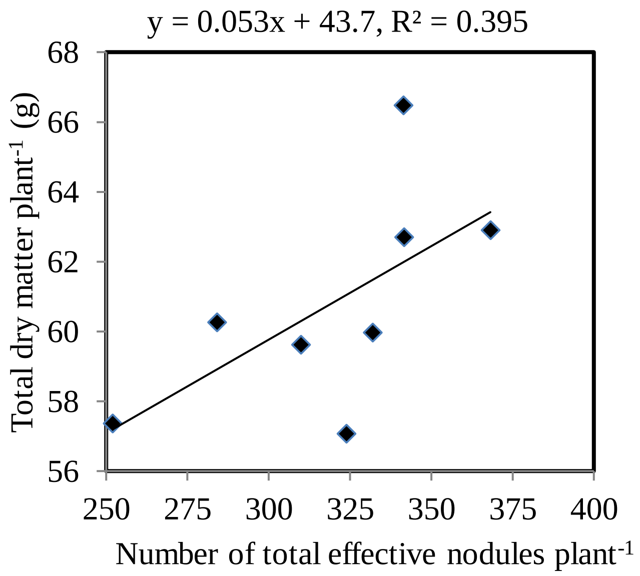

Figure 4.7 Relationship between total dry matter of pods and number of effective nodules of groundnut as affected by B fertilization during rainy season, 2011.

Figure 4.8 Number of groundnut pods as affected by different timing and method of B fertilization during rainy season, 2011.

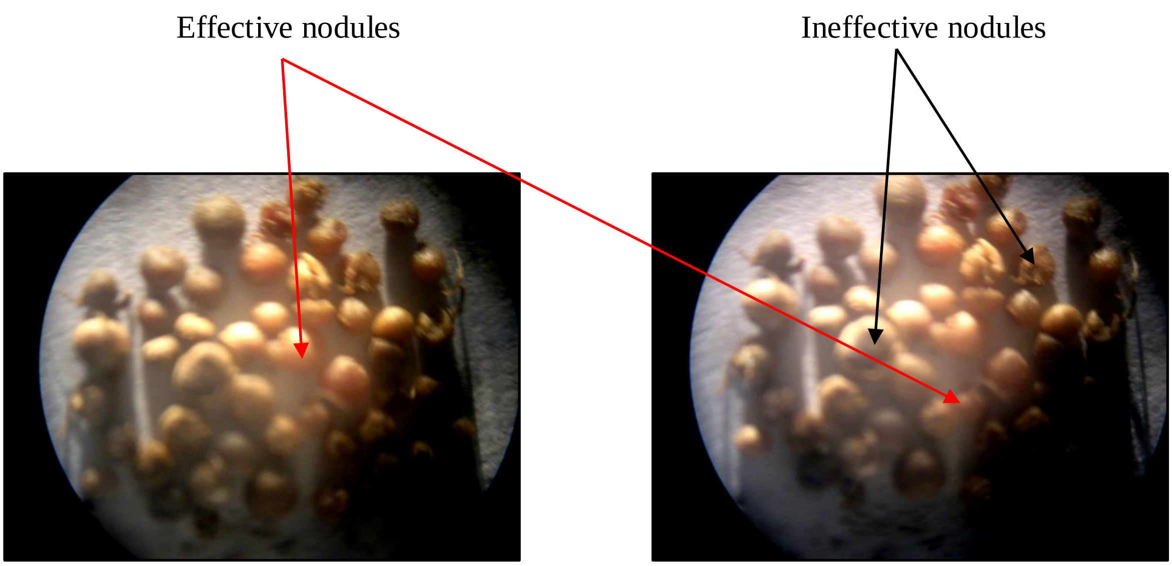

Figure 4.9 Effective nodules (pink colour) and ineffective nodules (white and black colour) of groundnut as affected by B fertilization

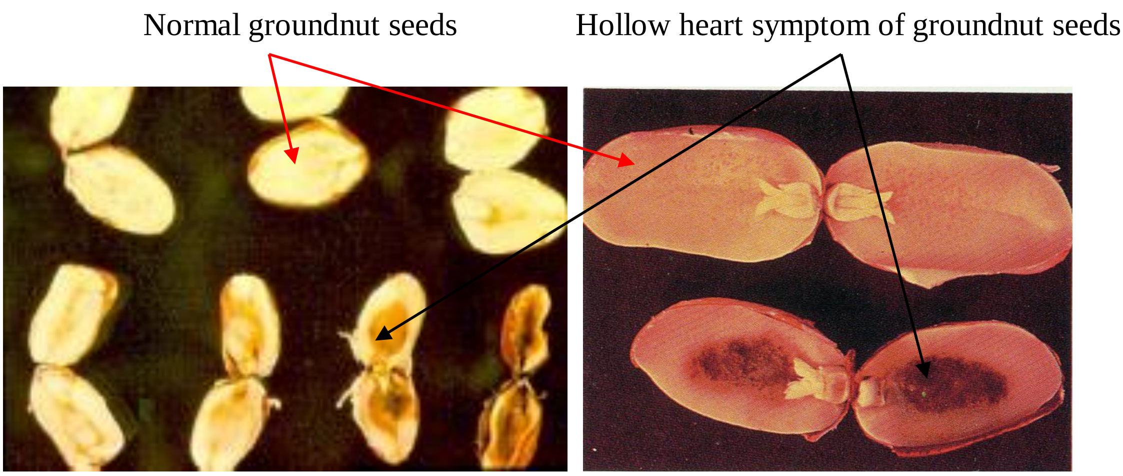

Figure 4.10 Internal cavity abnormality (Hollow Heart symptom) of groundnut seeds caused by B deficiency

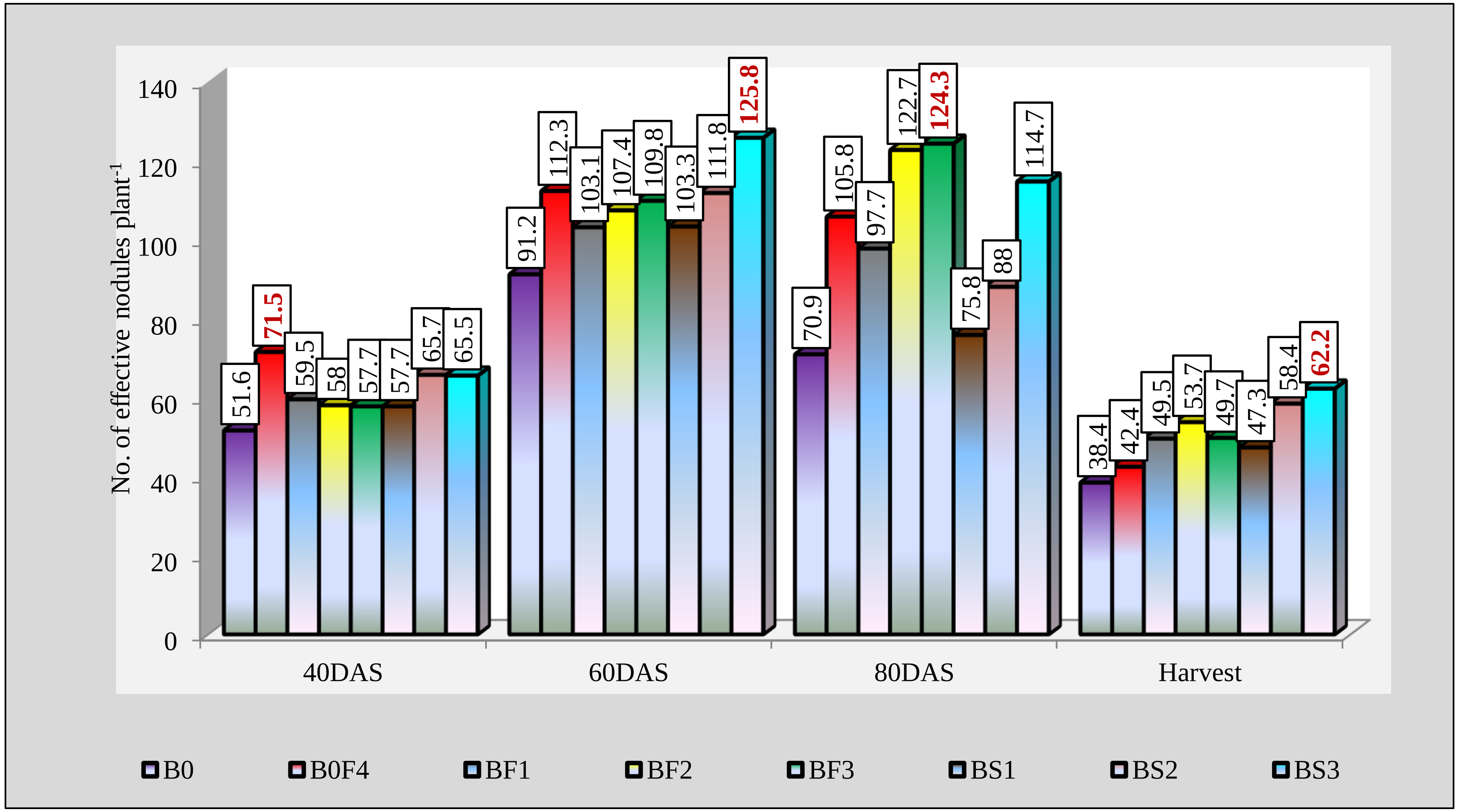

Figure 4.5 Effect of different timing, method of B fertilization on effective nodules per plant at 40, 60, 80 DAS and harvest during rainy season (2011)

Table 4.5 Nodules per plant at different growth stages as affected by timing and method of B fertilization on groundnut during rainy season, 2011

Treatment	Nodules $plant^{-1}$ (40 DAS)				Nodules $plant^{-1}$ (60 DAS)				Nodules $plant^{-1}$ (80 DAS)				Nodules $plant^{-1}$ (At harvest)			
	Total	Effective	% effective	% effective over control	Total	Effective	% effective	% effective over control	Total	Effective	% effective	% effective over control	Total	Effective	% effective	% effective over control
B0	64.7	51.6 b	79.7		113.8 c	91.2 c	80.2 b		90.3 c	70.9 c	79.2		49.9 d	38.4 c	76.8	
B0F4	81.1	71.5 a	88.0	38.6	129.2 ab	112.3 b	87.0 ab	23.2	124.5 abc	105.8 abc	85.0	49.2	52.8 cd	42.4 cd	79.6	10.4
BF1	68.8	59.5 ab	86.5	15.4	120.5 bc	103.1 b	85.5 ab	13.1	116.3 abc	97.7 abc	84.1	37.8	61.2 abcd	49.5 abcd	81.3	28.9
BF2	68.0	58.0 ab	85.2	12.4	123.9 bc	107.4 b	86.6 ab	17.8	146.1 a	122.7 a	82.9	73	66.7 abc	53.7 abc	80.2	39.8
BF3	68.2	57.7 ab	84.6	11.8	128.0 b	109.8 b	85.9 ab	20.5	143.3 a	124.3 a	86.8	75.3	62.8 abcd	49.7 abc	78.9	29.4
BS1	68.8	57.7 ab	84.1	11.8	123.8 bc	103.3 b	83.5 ab	13.3	96.5 bc	75.8 bc	79.4	6.92	57.8 bcd	47.3 abc	81.9	23.2
BS2	76.1	65.7 ab	86.2	27.5	131.2 ab	111.8 b	85.2 ab	21.9	111.1 abc	88.0 abc	83.1	24.1	71.8 ab	58.4 a	81.3	52.1
BS3	76.9	65.5 ab	85.2	26.9	141.3 a	125.8 a	88.9 a	37.9	133.2 ab	114.7 ab	85.7	61.7	75.8 a	62.2 a	82.1	62.2
	ns	*	ns		**	**	**		**	**	ns		**	**	ns	
Pr>F	0.09	0.02	0.09		<0.01	<0.01	0.01		<0.01	<0.01	0.13		<0.01	<0.01	0.63	
$LSD_{0.05}$	3.05	2.66	0.03		5.71	4.76	0.03		11.7	17.8	0.04		7.29	7.03	0.04	
CV%	11.2	12.10	4.03		4.38	4.45	3.40		13.6	17.7	4.94		10.9	12.88	5.15	

Means followed by the same letter in each column are not significantly different at LSD 5% level.

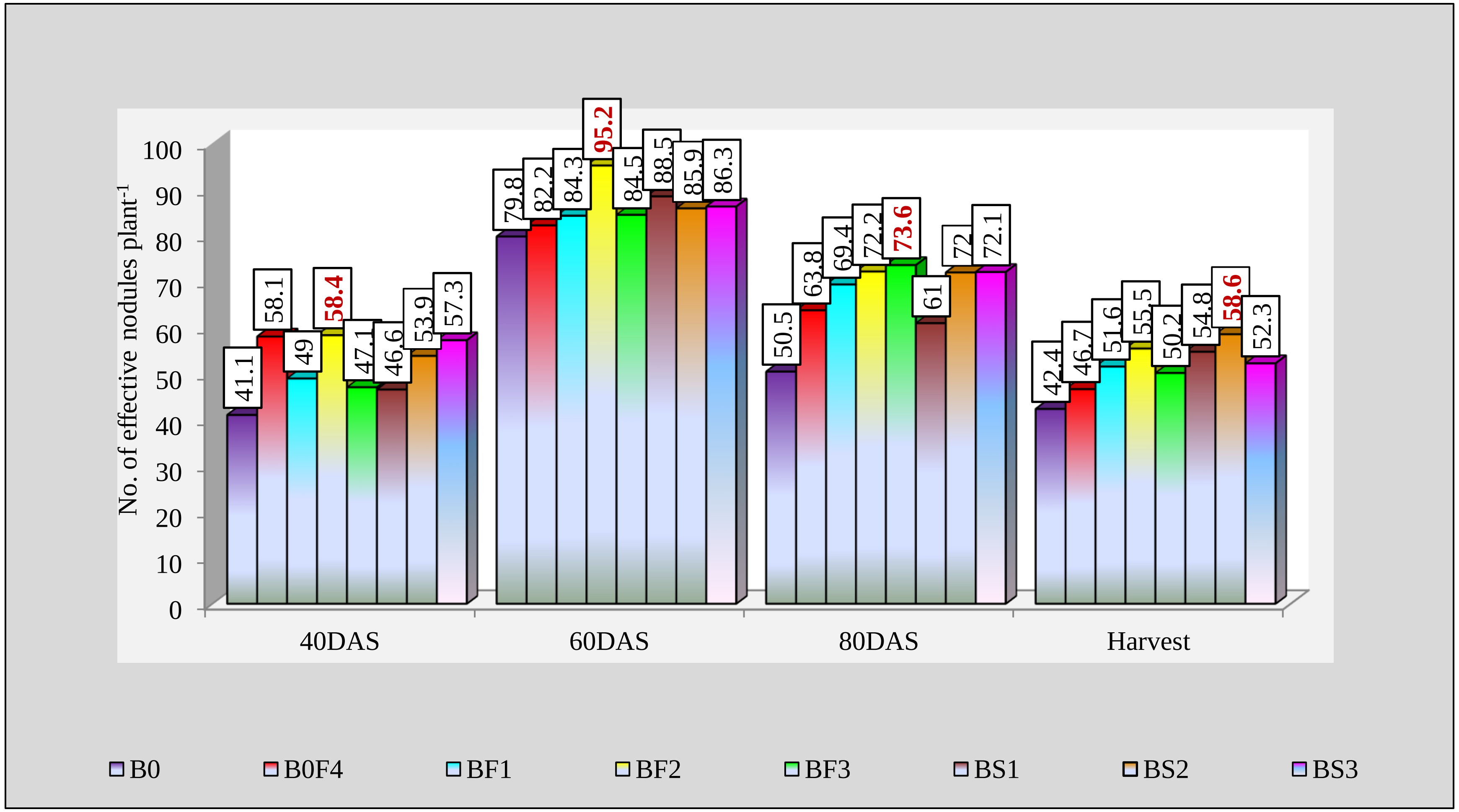

Figure 4.14 Effect of different timing, method of B fertilization on effective nodules per plant at 40, 60, 80 DAS and harvest during winter season

Table 4.10 Nodules per plant at different growth stages as affected by timing and method of B fertilization on groundnut during winter season, 2011-12

Treatment	Nodules plant^{-1} (40 DAS)				Nodules plant^{-1} (60 DAS)				Nodules plant^{-1} (80 DAS)				Nodules plant^{-1} (At harvest)			
	Total	Effective	% effective	% effective over control	Total	Effective	% effective	% effective over control	Total	Effective	% effective	% effective over control	Total	Effective	% effective	% effective over control
B0	47.2 b	41.1 b	86.9 c		95.0	79.8	84.12		72.8 b	50.5	69.4		56.1	42.4	74.9 b	
B0F4	62.7 ab	58.1 a	92.7 abc	41.3	92.9	82.2	88.32	2.93	78.2 ab	63.8	81.5	26.2	58.5	46.7	79.8 ab	10.0
BF1	52.7 ab	49.0 ab	92.9 abc	19.2	99.2	84.3	85.19	5.65	88.5 ab	69.4	78.4	37.5	65.0	51.6	79.3 ab	21.6
BF2	62.2 a	58.4 a	93.8 a	42.2	113.5	95.2	84.11	19.32	92.0 ab	72.2	78.4	42.9	68.7	55.5	80.4 ab	30.8
BF3	52.0 ab	47.1 ab	90.7 abc	14.6	98.4	84.5	86.18	5.85	95.6 a	73.6	76.9	45.7	62.2	50.2	80.6 ab	18.3
BS1	53.4 ab	46.6 ab	87.1 bc	13.4	101.8	88.5	87.10	10.86	76.0 ab	61.0	80.3	20.8	64.5	54.8	85.1 ab	29.3
BS2	57.7 ab	53.9 ab	93.5 ab	31.2	98.8	85.9	87.59	7.63	84.3 ab	72.0	85.4	42.6	68.1	58.6	86.1 a	38.1
BS3	60.7 a	57.3 a	94.4 a	39.6	103	86.3	83.81	4.99	89.2 ab	72.1	80.8	42.7	62.6	52.3	83.0 ab	23.4
	**	**	**		ns	ns	ns		**	ns	ns		ns	ns	*	
Pr>F	<0.01	<0.01	<0.01		0.36	0.34	0.64		<0.01	0.04	0.07		0.20	0.09	0.05	
$LSD_{0.05}$	6.1	6.1	2.8		12.3	9.3	4.06		7.7	6.5	3.6		7.5	7.2	4.5	
CV%	10.0	10.9	3.1		11.5	9.8	4.7		10.6	10.1	4.4		11.1	14.1	5.6	

Means followed by the same letter in each column are not significantly different at LSD 5% level.

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