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Interactive Effect of Phosphorus and Boron on Their Temporal Soil Availability under Black Gram [*Vigna mungo* (L.) Hepper] Cultivation and Nodulation in Acid Inceptisol

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ABSTRACT

Background: Meghalaya soils are highly acidic and phosphorus and boron are poor in supply leading to poor crop productivity. Low availability of phosphorus in these soils is due to fixation of phosphorus by Fe and Al oxides. Deficiency of boron in acidic soils of Meghalaya is due to coarse texture and leaching. The current study was conducted to find out the interactive effect of phosphorus and boron on their temporal soil availability, number of nodules in black gram and their dry weight.

Methods: A field experiment comprising of four levels of phosphorus *i.e.* 0, 25, 50 and 75 kg P_2O_5 ha^{-1} and four levels of boron *i.e.* 0, 0.5, 1.0, 1.5 kg B ha^{-1} was conducted during 2019 taking black gram cv. PU-31 as test crop. The treatments were laid out in split plot design with main plot as phosphorus and sub plot as boron with 16 different treatment combinations and replicated three times in humid sub tropical climate of Meghalaya with acid Inceptisol having pH 4.99, available phosphorus 13.68 kg ha^{-1} and available boron 0.054 ppm.

Result: The result revealed that temporal soil availability of phosphorus and boron increased with increase in phosphorus and boron doses, whereas it declined with progressive time intervals. Further, number of nodules in black gram and their dry weight show decrease with increase in time. Both these parameters increased significantly with increasing phosphorus and boron doses up to highest level. The optimum levels were recorded with combined application of 50 kg P_2O_5 ha^{-1} and 1.0 kg B ha^{-1} for number of nodules and 50 kg P_2O_5 ha^{-1} and 0.5 kg B ha^{-1} for dry weight of nodules.

Key Words: Acid soil, Boron, Black gram, Nodules, Phosphorus, Temporal soil availability.

INTRODUCTION

Phosphorus plays an important role in an array of cellular processes, including maintenance of membrane structures, synthesis of biomolecules, formation of high-energy molecules and also helps in cell division, enzyme activation/inactivation and carbohydrate metabolism. In addition, availability of P increases the N-fixing capacity of leguminous plants (Razaq *et al.* 2017). Boron is also an important micronutrient that plays crucial role in cell division and enlargement, cell wall formation, sugar translocation, metabolism of carbohydrates, metabolism of nitrogen and water relations (Oyinlola, 2007; Marschner, 2012). A key role of B includes the development of floral organs, flower male fertility and pollen tube growth (Gupta and Solanki, 2013). P and B have significant synergetic effect in improving the production, yield and quality of plant species (Kaya *et al.*, 2009; YuFan *et al.*, 2012). The growth and metabolism of plants is more inhibitory than the combined abundance of boron and phosphorus alone, here is synergistic relationship to rise in P uptake by plants under application of B (Huang *et al.,* 2012).

Pulses are rich in protein similar to other less expensive vegetables and can be grown as an inter crop and mixed crop. Black gram [*Vigna mungo* (L.) Hepper] is one of the most important pulse crops grown in India. It contains about 25-26% protein, 60% carbohydrates, 1.3% fat and is the richest in phosphoric acid among the all pulses (Tamang and Sanjay-Swami, 2017). Pulse productivity depends mainly on appropriate nutrient management practices (Kumpawat, 2010). Meghalaya soils are highly acidic and phosphorus and boron are poor in supply. Low availability of phosphorus in these soils is due to fixation of P by Fe and Al oxides. Deficiency of boron in acidic soils of Meghalaya is due to coarse texture and leaching (Takkar, 1996). Keeping in view the above facts, the present study was undertaken to investigate the interactive effect of phosphorus and boron on their temporal availability and nodulation of black gram in acid Inceptisol of Meghalaya.

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MATERIALS AND METHODS

The field experiment was conducted at research farm of School of Natural Resource Management, College of Post Graduate Studies in Agricultural Sciences, Umiam, Meghalaya in 2019 during the period of June to September. Geographically, the experimental site was located at 91°18′ to 92°18′ E longitude and 25°40′ to 26°20′ N latitude with an altitude of 950 m above the mean sea level with agro-climatic zone of mixed subtropical hill and falls in AES-III zone (Choudhury *et al*., 2012). The experiment comprises of four levels of phosphorus (0, 25, 50, 75 kg ha^{-1}) and four levels of boron (0, 0.5, 1.0, 1.5 kg ha^{-1}) with 16 treatment combinations laid in split plot design with three replications. Phosphorus was used as main plot and boron as sub-plot. These are randomly allocated in plots of size 2.1 m × 2 m. Phosphorus and boron were applied through Single Super Phosphate (SSP) and Borax, respectively. The experimental site was located in humid sub tropical climate. The experimental site has received an average temperature of 23.0°C, total rainfall of 1625.5 mm during the cropping period. The physico-chemical properties of the experimental soil exhibited sandy clay loam texture, pH 4.99, EC 0.42, organic carbon 1.32%, available nitrogen 251.35 kg ha^{-1}, available phosphorus 13.68 kg ha^{-1}, available potassium 233.24 kg ha^{-1} and available boron (0.054 ppm). To assess the temporal availability of phosphorus and boron, representative soil sample from each treatment were collected at 30, 60 days after sowing (DAS) and after harvesting of black gram. The available phosphorus was estimated by using Bray and Kurtz (1945) method whereas available boron was estimated by Berger and Troug (1939) method. Five plants from each treatment were taken at 30, 60 DAS, at maturity and number of nodules were counted and their dry weight and average per plant was worked out. The data obtained was subjected to statistical analysis as described by Gomez and Gomez (1984).

RESULTS AND DISCUSSION

Temporal soil available phosphorus

The effect of phosphorus and boron on temporal soil available phosphorus (kg ha^{-1}) is presented in (Table 1). The maximum soil available phosphorus (18.89, 16.17, 14.02 kg ha^{-1}) was obtained at phosphorus level 75 kg ha^{-1} at 30, 60 DAS and after harvesting, whereas the lowest available phosphorus was recorded at 30, 60 DAS and after harvesting at control as (14.15, 16.17 kg ha^{-1}); (10.36, 13.06 kg ha^{-1}); (9.29, 10.77 kg ha^{-1}) at P and B, respectively. Further, the scrutiny of data depicted that available phosphorus showed decreasing trend after 30 days of black gram sowing. The interaction effect of phosphorus and boron on soil available phosphorus at 30, 60 DAS and after harvest was found to be significant. The lowest soil available phosphorus at 30 DAS was found at control (P_0B_0) as 13.58 kg ha^{-1} and significantly highest value was found at $P_{75}B_{1.5}$ as 19.54 kg ha^{-1} in phosphorus within boron and boron within phosphorus as 19.10 kg ha^{-1}, at $P_{75}B_1$, whereas lowest soil available phosphorus was found in control *i.e.* P_0B_0 as 9.85 kg ha^{-1} and significantly highest soil available phosphorus was found at $P_{75}B_{1.5}$ as 16.67 kg ha^{-1} in phosphorus within boron and in boron within phosphorus as 16.10 kg ha^{-1} at $P_{75}B_{0.5}$ at 60 DAS and the lowest soil available phosphorus after harves was found at control *i.e.* P_0B_0 as 8.83 kg ha^{-1} and significantly highest soil available phosphorus was found at $P_{75}B_{1.5}$ as 14.52 kg ha^{-1} in phosphorus within boron and 12.53 kg ha^{-1} at $P_{50}B_1$ in boron within phosphorus. The per cent increase from control to significantly highest soil available phosphorus at 30 DAS was 43.92, 40.70. There was an increase in 69.24, 63.42 per cent from control to significantly higher soil available phosphorus at 60 DAS and per cent increase from control to significantly highest value after harvest was 64.37, 41.81. The results obtained are in agreement with those reported by Kamboj *et al.* (2018) after green gram cultivation and Phogat *et al.* (2021) after black gram cultivation. The results are also in close conformity with the results obtained by Tamang and Sanjay-Swami (2021) who assessed the temporal availability of phosphorus at 20, 40 DAS and after harvesting of black gram in acid Inceptisol of Meghalaya and reported that available phosphorus in soil increased with each successive increasing level of phosphorus application, however it showed decreasing trend with time intervals of 40 DAS and after harvesting of black gram at each successive dose of 40, 60 and 80 mg P kg^{-1} soil over 20 mg P kg^{-1} soil in the presence of sulphur fertilization.

Temporal soil available boron

Maximum soil available boron of 0.104, 0.097, 0.077 ppm was obtained with boron application @ 1.5 kg ha^{-1} at 30, 60 DAS and after harvesting (Table 2) whereas, the lowest boron was found in control as 0.072, 0.062, 0.051 ppm at phosphorus levels and at boron as 0.049, 0.042, 0.035 ppm, respectively. Further, the scrutiny of data revealed that available boron showed decreasing trend after 30 days of black gram sowing. The interaction effect of phosphorus and boron on soil available boron at 30, 60 DAS and after harvest was also observed to be significant. The lowest soil available boron at 30 DAS was found in control (P_0B_0) as 0.045 ppm and significantly highest value was found at $P_{25}B_{1.5}$ as 0.104 ppm in phosphorus within boron and boron within phosphorus as 0.112 ppm at $P_{75}B_{1.5}$, whereas the lowest soil available boron at 60 DAS was found in control *i.e.* P_0B_0 as 0.039 ppm and significantly highest soil available phosphorus was found at $P_{25}B_{1.5}$ as 0.097 ppm in phosphorus within boron and in boron within phosphorus as 0.103 ppm at $P_{75}B_{1.5}$ at 60 DAS and the lowest soil available phosphorus after harvest was found at control *i.e.* P_0B_0 as 0.028 ppm and significantly highest soil available phosphorus was found at $P_{75}B_{1.5}$ in phosphorus within boron and boron within phosphorus as 0.084 ppm. The per cent increase from control to significantly highest soil available boron at 30 DAS was 131.85, 148.14 with an increase in 150, 167.24 per cent from control to significantly higher soil available boron at 60 DAS and per cent increase from control to significantly highest value after harvest was 198.81 per cent. Similar results

Table 1: Effect of phosphorus and boron on temporal soil available phosphorus (kg ha^{-1}) at 30, 60 days after sowing (DAS) and after harvest of black gram.

Treatments	Temporal soil available phosphorus (kg ha^{-1})														
	30 DAS					60 DAS					Harvest				
	B_0	$B_{0.5}$	$B_{1.0}$	$B_{1.5}$	Mean	B_0	$B_{0.5}$	$B_{1.0}$	$B_{1.5}$	Mean	B_0	$B_{0.5}$	$B_{1.0}$	$B_{1.5}$	Mean
P_0	13.58	14.03	14.38	14.63	14.15	9.85	10.21	10.54	10.84	10.36	8.83	9.19	9.43	9.69	9.29
P_{25}	15.28	16.36	16.88	17.07	16.40	12.04	12.35	12.93	13.48	12.70	9.98	10.32	10.56	10.63	10.37
P_{50}	17.45	17.98	18.10	18.13	17.91	14.76	14.93	15.15	15.21	15.01	10.91	11.69	12.53	12.90	12.01
P_{75}	18.39	18.51	19.10	19.54	18.89	15.59	16.10	16.33	16.67	16.17	13.36	13.86	14.35	14.52	14.02
Mean	16.17	16.72	17.11	17.34	16.84	13.06	13.39	13.74	14.05	13.56	10.77	11.27	11.72	11.93	11.42
		SE(m)±		C.D (p<0.05)			SE(m)±		C.D (p<0.05)			SE (m)±		C.D (p<0.05)	
P		0.153		0.531			0.157		0.542			0.193		0.667	
B		0.082		0.753			0.062		0.180			0.086		0.252	
P within B		0.209		0.672			0.190		0.624			0.244		0.794	
B within P		0.165		0.481			0.124		0.361			0.172		0.503	

Table 2: Effect of of phosphorus and boron on temporal soil available boron (ppm) at 30, 60 days after sowing (DAS) and after harvest of black gram.

Treatments	Temporal soil available boron (ppm)														
	30 DAS					60 DAS					Harvest				
	B_0	$B_{0.5}$	$B_{1.0}$	$B_{1.5}$	Mean	B_0	$B_{0.5}$	$B_{1.0}$	$B_{1.5}$	Mean	B_0	$B_{0.5}$	$B_{1.0}$	$B_{1.5}$	Mean
P_0	0.045	0.068	0.081	0.093	0.072	0.039	0.054	0.069	0.087	0.062	0.028	0.046	0.058	0.072	0.051
P_{25}	0.048	0.070	0.083	0.104	0.076	0.041	0.057	0.074	0.097	0.067	0.036	0.050	0.061	0.075	0.055
P_{50}	0.051	0.072	0.087	0.108	0.080	0.043	0.061	0.080	0.101	0.071	0.037	0.052	0.063	0.078	0.058
P_{75}	0.052	0.075	0.094	0.112	0.083	0.044	0.065	0.084	0.103	0.074	0.040	0.054	0.064	0.084	0.060
Mean	0.049	0.071	0.086	0.104	0.078	0.042	0.059	0.077	0.097	0.069	0.035	0.051	0.062	0.077	0.056
		SE(m)±		C.D (p<0.05)			SE(m)±		C.D (p<0.05)			SE(m)±		C.D (p<0.05)	
P		0.001		0.005			0.001		0.005			0.001		0.004	
B		0.001		0.003			0.001		0.002			0.001		0.001	
P within B		0.002		0.007			0.002		0.006			0.001		0.005	
B within P		0.002		0.005			0.001		0.004			0.001		0.003	

were obtained by Dhakal *et al.* (2009) after harvest of cauliflower (*Brassica oleracea* var. Botrytis) with the application of boron and phosphorus in the soils of Rupandehi district of Nepal. The results of the present investigation also confirms the findings of Kamboj *et al.* (2018) who determined the soil availability of phosphorus and boron after harvest of green gram grown with four level of boron (0, 0.25, 0.5 and 1.0 mg kg^{-1}) along with five level of phosphorus (0, 25, 50, 75 and 100 mg P_2O_5 kg^{-1} soil) in pots and reported that with each graded level of boron application, soil boron and phosphorus concentration increased. Similarly, application of phosphorus increased the availability of soil boron and phosphorus concentration.

Number of nodules and their dry weight

Increased number of nodules and dry weight was observed with the advancement of crop development stages from 30 DAS to 60 DAS, whereas from 60 DAS to maturity, the number of nodules and dry weight decreased (Fig 1 and 2). It is also observed that increasing phosphorus and boron doses increased the number of nodules and dry weight in black gram. Under different phosphorus levels, significant number and dry weight of nodules were observed at 50 kg P_2O_5 ha^{-1} with 17.61 nodules and their dry weight as 26.14 mg $plant^{-1}$. Similarly, under different boron doses, the significant higher number of nodules (18.23) and their dry weight (26.46 mg $plant^{-1}$) was observed at 1.5 kg B ha^{-1}. Similar pattern was observed at 60 DAS and at maturity. At 60 DAS under different phosphorus levels, significant number and dry weight of nodules were observed at 50 kg P_2O_5 ha^{-1} with 19.41 nodules and their dry weight as 27.88 mg $plant^{-1}$. Similar to this under different boron doses, the highest number of nodules (20.03) and their dry weight (27.92 mg $plant^{-1}$) was observed at 1.5 kg B ha^{-1}. At maturity, the significant number and dry weight of nodules of black gram were 17.78 and 25.70 mg $plant^{-1}$ at 50 kg P_2O_5 ha^{-1}, whereas with different boron doses, the highest number of nodules (17.99) and their dry weight (25.73 mg $plant^{-1}$) was observed at 1.5 kg B ha^{-1}. The interaction effect of phosphorus and boron on number of nodules and their dry weight was significant at all crop development stages. Within the same level of boron, increasing phosphorus doses increased the number of nodules and their dry weight, but significantly highest number of nodules at 30 DAS and at maturity was found at $P_{50}B_1$ with 18.22, 18.38 whereas at 60 DAS, it was found at $P_{50}B_{0.5}$ with 19.54. Similarly, with same level of phosphorus, increasing boron doses increased the number of nodules but the significant highest number of nodules at 30, 60 DAS and at maturity was observed at $P_{75}B_1$ with 19.71, 21.97, 19.66. The lowest number of nodules was observed at control *i.e.* P_0B_0 with 11.25, 13.14, 9.48 at 30, 60 DAS and at maturity. The percent increase in number of nodules in $P_{50}B_1$ over control at 30 DAS and at maturity was 62.03 and 93.99 per cent, whereas at 60 DAS, the

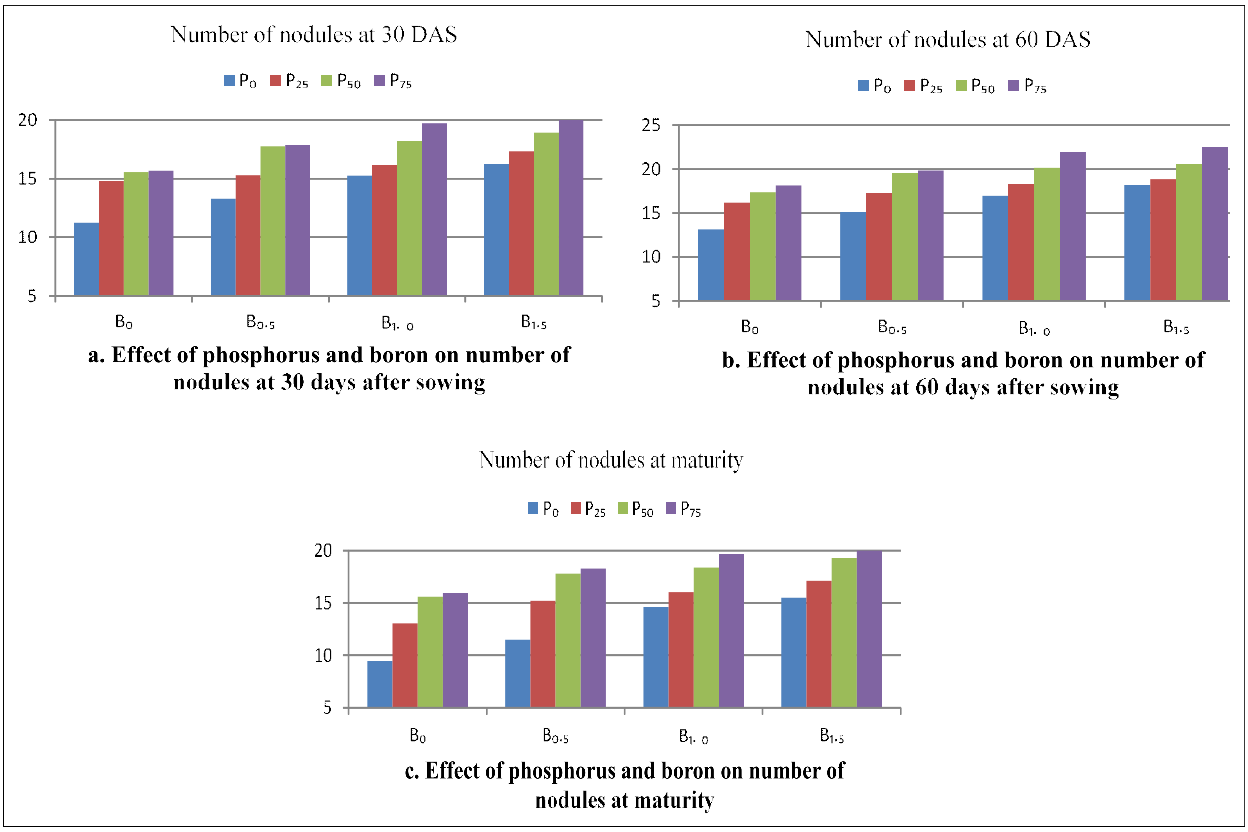
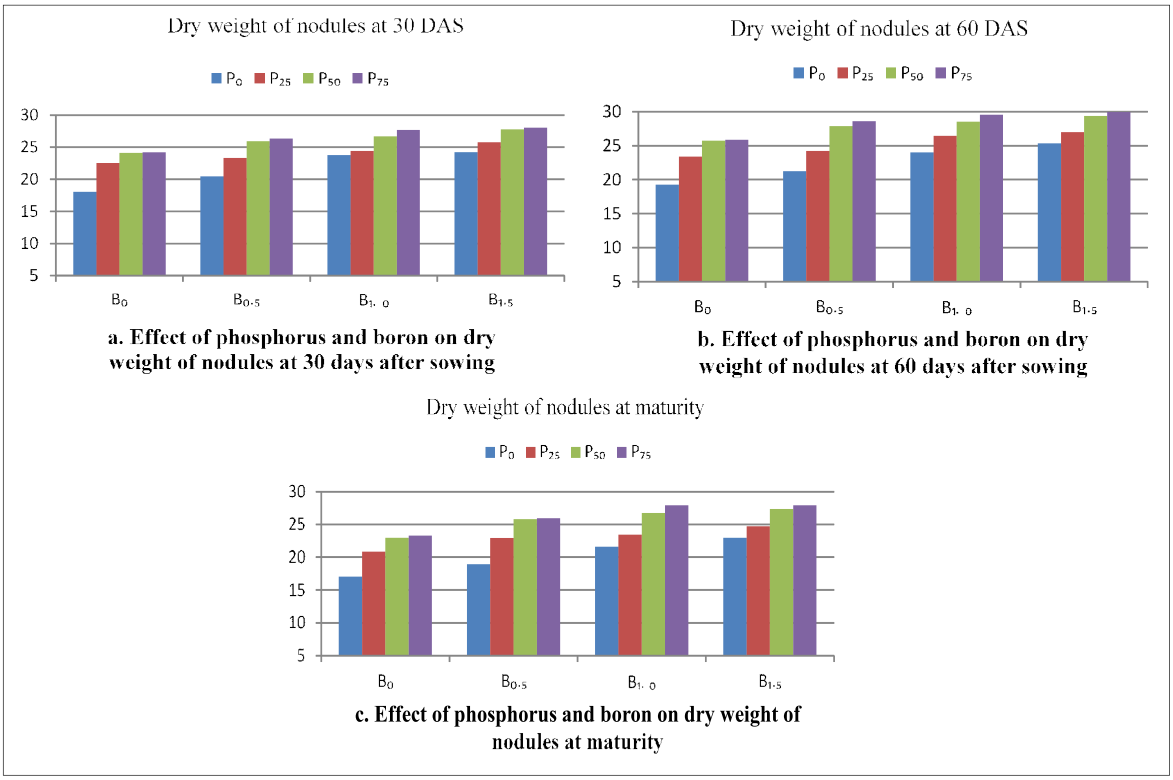


Fig 1: Effect of phosphorus and boron on number of nodules at 30, 60 DAS and at maturity of black gram.



a. Effect of phosphorus and boron on dry weight of nodules at 30 days after sowing

b. Effect of phosphorus and boron on dry weight of nodules at 60 days after sowing

c. Effect of phosphorus and boron on dry weight of nodules at maturity

Fig 2: Effect of phosphorus and boron on dry weight of nodules at 30, 60 DAS and at maturity of black gram.

per cent increase in number of nodules in $P_{50}B_{0.5}$ over control was 48.74 per cent. The per cent increase in $P_{75}B_1$ over control at 30 DAS, 60 DAS and harvest was 75.25, 67.24, 107.49 per cent. The results obtained are in conformity with Hellsten and Huss-Danell (2000), Laltlanmawia *et al.* (2005). The dry weight of nodules at different crop development stages in control (P_0B_0) was observed to be 18.07, 19.26 and 17.06 mg plant^{-1}, respectively. Further, within the same level of boron, increasing phosphorus doses increased the dry weight of nodules, but significantly highest dry weight of nodules was found at $P_{50}B_{0.5}$ at 30 and 60 DAS as 25.92 and 27.88 mg plant^{-1} whereas at maturity at $P_{50}B_1$ as 26.71 mg plant^{-1}. Similarly, with same level of phosphorus, increasing boron doses increased the dry weight of nodules but the significant highest number of nodules was observed at $P_{75}B_{0.5}$ as 26.35, 28.60 mg plant^{-1} at 30 and 60 DAS whereas at maturity at $P_{75}B_1$ as 27.89 mg plant^{-1}. The per cent increase in $P_{50}B_{0.5}$ at 30 and 60 DAS over control was 43.43 and 44.77 per cent whereas at maturity, the increase in the dry weight of nodules in $P_{50}B_1$ was 56.58 per cent. The dry weight of nodules increased in $P_{75}B_{0.5}$ at 30 and 60 DAS over control was 45.78, 48.48 per cent, respectively whereas at maturity, it was 63.51 per cent in $P_{75}B_1$. The increase in number of nodules per plant in black gram (*Vigna mungo* L.) was also reported by Parashar *et al.* (2020) which is attributed to better root biomass with increasing applications of the essential nutrients, especially phosphorus, being the constituent of nucleic acid and different forms of proteins, which might have stimulated cell division resulting in increased growth of plants and thereby nodulations.

CONCLUSION

The soil available phosphorus showed significant increment with succeeding application over control, despite this, it showed declining trend with advancement of crop development/time. The addition of boron had significant impact on available phosphorus content in soil. Similarly, the soil available boron showed significant increment with consecutive addition of B besides control and it showed declining trend with time. The addition of P has significant impact on available boron content in soil. The number of nodules and their dry weight increased significantly with increase in phosphorus and boron doses and optimum values for number of nodules were recorded with combined application of 50 kg P_2O_5 ha^{-1} and 1.0 kg B ha^{-1}, whereas for dry weight of nodules with 50 kg P_2O_5 ha^{-1} and 0.5 kg B ha^{-1}.

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Conflict of interest: None.

REFERENCES

Berger, K.C. and Troug, E. (1939). Boron Determination in Soils and Plants. Industrial and Engineering Chemical Analysis. 11th ed. pp. 540-544.

Bray, R.H. and Kurtz, L.T. (1945). Determination of total organic and available forms of phosphorus in soils. Soil Science. 59: 39-45.

Choudhury, B.U., Das, A., Ngachan, S.V., Shong, A., Bordoloi, L.J. and Chowdhury, P. (2012). Trend analysis of long term weather variables in mid altitude, Meghalaya, North-East. Indian Journal of Agricultural Physics. 12(1): 12-22.

Dhakal, D., Shah, S.C., Gautam, D.M. and Yadav, R.N. (2009). Response of cauliflower (*Brassica oleracea* var. Botrytis) to the application of boron and phosphorus in the soils of Rupandehi district. Nepal Agricultural Research Journal. 9: 56-66.

Gomez, K.A. and Gomez, A.A. (1984). Statistical Procedures for Agricultural Research. A Wiley Inter Sci. Publication, John Wiley and Sons, New York.

Gupta, U. and Solanki, H. (2013). Impact of boron deficiency on plant growth. International Journal of Bioassays. 2: 1048-1050.

Hellsten, A. and Huss-Danell, K. (2000). Interaction effects of nitrogen and phosphorus on nodulation in red clover (*Trifolium pratense* L.). Acta Agriculturae Scandinavica, Section B, Plant Soil Science. 50: 135-142.

Huang, Y.F., Huang, L.B., Yan, X.L. and Lia, H. (2012). Effects of phosphorus and boron coupled deficiency on soybean growth, phosphorus, boron uptake and their genetic variations. Journal of South China Agricultural University. 33: 129-134.

Kamboj, N., Malik, R.S. and Deepika (2018). Residual effect of applied zinc, boron and phosphorus on post harvest nutrient availability status of soils. International Journal of Chemical Studies. 6(2): 1443-1446.

Kaya, C., Tuna, A.L., Dikilitas, M., Ashraf, M., Koskeroglu, S. and Guneri, M. (2009). Supplementary phosphorus can alleviate boron toxicity in tomato. Scientia Horticulturae. 121: 284-288.

Kumpawat, B.S. (2010). Integrated nutrient management in black gram *(Vigna mungo)* and its residual effect on succeeding mustard *(Brassica juncea)* crop. Indian Journal of Agricultural Sciences. 80(1): 76-79.

Laltanmawia, L., Singh, A.K. and Sharma, S.K. (2005). Effect of phosphorus and molybdenum nutrition on growth, yield and nutrient content of soybean in an acid Alfisol of Nagaland. Annals of Agricultural Research. 26(4): 591-595.

Marschner, P. (2012). Marschner's Mineral Nutrition of Higher Plants. Academic Press, New York, USA. pp. 672.

Oyinlola, E.Y. (2007). Effect of boron fertilizer on yield and oil content of three sunflower cultivars in the Nigerian Savanna. Journal of Agronomy. 6(3): 421-426.

Parashar, A., Jain, M. and Tripathi, L. (2020). Effect of phosphorus and sulphur on the growth and yield of black gram (*Vigna mungo* L.). Journal of Pharmacognosy and Phytochemistry. 9(5): 2585-2588.

Phogat, M., Rai, A.P., Kumar, S. and Angmo, P. (2021). Effect of phosphorus and sulphur application on their dynamics and nodulation in soil under black gram [*Vigna mungo* (L.) Hepper] crop. Legume Research. 44(3): 315-321.

Razaq, M., Zhang, P. and Shen H-l, S. (2017). Influence of nitrogen and phosphorus on the growth and root morphology of Acer mono. PLoS One. 12(2): e0171321.

Takkar, P.N. (1996). Micronutrients research and sustainable crop production in India. Journal of Plant Physiology. 3: 237-239.

Tamang, B. and Sanjay-Swami (2017). Effect of Phosphorus and Sulphur on Nutrient Uptake of Black gram [*Vigna mungo* (L.) Hepper] in Acid Inceptisol. In: Natural Resource Management for Climate Smart Sustainable Agriculture, [(eds.) Sanjay Arora, Sanjay-Swami and Suraj Bhan,] Soil Conservation Society of India, New Delhi, pp. 298-309. ISBN: 978-81-909228-8-3.

Tamang, B. and Sanjay-Swami (2021). Temporal availability of phosphorus and sulphur in acid Inceptisol as influenced by graded application of P and S under black gram [*Vigna mungo* (L.) Hepper] production. Legume Research. 44(5): 608-612.

Yu Fan, H., LongBin, H., XiaoLong, Y. and Hong, L. (2012). Effects of phosphorus and boron coupled deficiency on soybean growth, phosphorus, boron uptake and the genetic variations. Journal of South China Agricultural University. 3(3): 129-134.