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IMPACT OF SOIL APPLIED PHOSPHORUS AND BORON FERTILIZERS ON VERTISOLS OF PALAKKAD DISTRICT, INDIA WITH RESPECT TO GROUNDNUT

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ABSTRACT

Increasing costs of chemical fertilizers, environmental concerns in their application and demand for protein foods, placed an extensive interest in growing of legume crops for human nutrition, and soil fertility replenishment. This study was conducted during year 2021 to investigate the effects of phosphorus (P) and boron (B) fertilizers on soil nutrient availability and plant nutrient uptake (N, P, K, Ca, Mg, B), growth performance (Plant height and number of leaves), yield components (Number of pods plant^{-1} and yield of groundnut) and seed protein content of groundnut in the black cotton soils of Palakkad district in India. Four levels of P (0, 60, 75 and 90 kg ha^{-1}) and four levels of B (0, 5, 10 and 15 kg ha^{-1}) were set in factorial randomized block design (FRBD) with three replications. Soil nutrient status and plant nutrient uptake were influenced by individual P and B application and interaction of P and B. Results showed that P had negative interaction with K and B, whereas P showed positive interaction with N, Ca and Mg in soil. Application of P at 90 kg ha^{-1} increased plant height and number of leaves plant^{-1}. Applications of P at 90 and B at 10 kg ha^{-1} resulted in the highest number of pods plant^{-1}. But application of P at 90 kg ha^{-1} and B at 5 kg ha^{-1} resulted in highest pod yield ha^{-1}.

(Key words: Phosphorus fertilizers, boron fertilizers, black cotton soil, groundnut)

INTRODUCTION

A balanced supply of nutrients is crucial for optimizing crop yield. However, nutrients applied to soil are not always readily available for plant uptake, as their availability is influenced by interactions among various nutrients. When the presence of one nutrient impacts the absorption and effectiveness of another, these nutrients are said to interact. Such interactions in the soil can significantly affect crop performance overall. Nutrient interactions can be either positive or negative. A positive interaction, or synergism, occurs when the combined effect of nutrients exceeds their individual effects. In contrast, a negative interaction, or antagonism, occurs when the combination results in a weaker response than expected from individual nutrients alone.

Black cotton soils in Kerala are located in Chitturtaluk of Palakkad district, spanning around 2,000 hectares (Jayakrishnan *et al*., 2022). These soils are distinguished by their dark colour, calcareous properties, and neutral to alkaline pH (between 7.0 and 8.5). They are also high in clay content and possess a high cation exchange capacity (CEC). The soil texture ranges from clay loam to clay. Although the total nitrogen content is sufficient, only a minimal amount of phosphorus is available for plant uptake (less than 1%) due to phosphorus fixation, influenced by high pH, free calcium carbonate, and clay content.

Although these soils are fertile, nutrient imbalances and suboptimal physical conditions can negatively impact crop yields (Sarangi *et al*., 2022). With the exception of available phosphorus (P) and boron (B), most other soil nutrients are present at either medium or adequate levels. In alkaline soils, the availability of phosphorus for plant uptake and use is limited due to the formation of calcium phosphate minerals, which are poorly soluble.

The groundnut (*Arachis hypogaea* L.), a member of the legume family, originated in South America, specifically in the region of southern Bolivia and northwest Argentina, with cultivation dating back to 1000 B.C. Groundnut is a significant oilseed crop, with approximately two-thirds of global production devoted to oil extraction. The kernel is a valuable source of edible oil, containing 36 to 54% oil and 25 to 32% protein. Although groundnut can thrive in soils with marginal fertility, the application of appropriate fertilizers is essential to realize the crop's full yield potential. Groundnut also has the unique ability to utilize soil nutrients that are less accessible to other crops, making it well-suited to benefit from residual soil fertility.

Phosphorus is the second most limiting nutrient in crop production (Mallikarjuna *et al.,* 2003). In most Indian

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soils, available phosphorus levels range from low to medium. Phosphorus plays a key role in pod formation, reduces the number of unfilled pods (pops), and accelerates crop maturity. It also improves nitrogen use efficiency in plants. As it is essential for energy storage and transfer, phosphorus is often referred to as the "energy currency" of living systems.

Boron is the most critical micronutrient limiting groundnut production due to its importance in kernel quality and flavour (Singh *et al*., 2007). Deficiency in boron leads to "hollow-heart" in groundnut kernels, where the inner cotyledon surfaces become darkened and sunken, resulting in kernels being classified as damaged. This happens because a deficiency in boron impairs the development of conducting tissues like phloem and xylem, which hampers the transport of carbohydrates from leaves to fruits (Li *et al*., 2017). Moreover, insufficient boron adversely impacts root growth, early root growth inhibition, relative to shoot growth, increases the shoot-to-root ratio, potentially making plants more vulnerable to environmental stresses such as nutrient deficiencies and soil moisture shortages (Kohli *et al*., 2023). Recent studies indicate that the optimal boron level in soils for cultivating groundnut is 1.25 mg kg^{-1} (Kumar *et al*., 2023). Soil parent material and texture are key factors linked to the occurrence of boron deficiency, which can be effectively managed and corrected through soil or foliar applications (Songsriin *et al*., 2023).

The objective of this study was to evaluate the effect of different levels of applied P and B on the growth, concentration and uptake of minerals in groundnut grown on a black cotton soil.

MATERIALS AND METHODS

Study site and experimental design

Field experiment was carried out during year 2021 on black cotton soils in Chittur, Palakkad. Geographically, the field is located on the eastern side of Palakkad at 10°38'03.88" N latitude and 76°44'53.90" E longitude, with an elevation of 129 meters above mean sea level. Soil samples were gathered from various locations in the area, and the experiment was conducted in a field identified as having deficiencies in both phosphorus (P) and boron (B) (Table 1).

The experimental site was designed as a factorial randomized block design with seventeen treatment combinations and four replications, for a total of 68 plots. Each single 4 m x 2 m plot was separated from the next by a 1 m buffer zone to avoid interference by different treatments. Treatment combinations were made with four levels of P and four levels of B with soil test-based recommendation as control. N and K levels were kept same based on POP recommendations of KAU (Anonymous, 2016) for all treatments except for the first treatment where soil test-based recommendations were given. P0- 0 kg ha^{-1}, P1-60 kg ha^{-1}, P2-75 kg ha^{-1} and P3- 90 kg ha^{-1} were the four levels of P and B0- 0 kg ha^{-1}, B1-5 kg ha^{-1}, B2- 10 kg ha^{-1} and B3- 15 kg ha^{-1} were the four levels of borax. Single super phosphate was used as source of P and borax was used as source of B.

Soil sampling and chemical analysis

Soil samples were taken from a depth of 0-15 cm to analyse their chemical properties before and after the crop. The major nutrients like N, P and K, secondary nutrients like Ca and Mg and micronutrient B were analysed. The available nitrogen was analyzed by the alkaline permanganate method (Subbiah and Asija, 1956), using a 0.32% $KMnO_4$ solution and 2.5% NaOH. Released ammonia was absorbed in 5% boric acid with a mixed indicator and titrated against 0.02 N H_2SO_4.

Available phosphorus was determined through Olsen's method (Watanabe and Olsen, 1965). For the measurement of soil exchangeable cations (Ca²z , Mg²z and Kz) 1 M ammonium acetate (pH 7.0) was used as extractant, available K was measured with flame photometer and Ca and Mg measured with atomic absorption spectrophotometer (Sims and Johnson, 1991). Available boron (B) was extracted using hot water and measured with ICP-OES (Perkin Elmer Optima-8000) (Carter and Gregorich, 2007).

Leaf sampling and analysis

The plant samples collected after harvest were washed with tap water to remove any soil or dirt, followed by rinsing in single and double-distilled water. After washing, the samples were shade-dried for one week. Once shade-dried, they were placed in an oven at 60°C until dry, and their dry weights were recorded. The dried samples were then powdered and stored in polythene bags for analysis. The powdered samples were analyzed for major nutrients (N, P, K), secondary nutrients (Ca, Mg) and micronutrient (B). Nutrient uptake for major, secondary, and micronutrients was calculated using a specified formula.

Uptake of major, secondary, and minor nutrients were calculated by using the formula,

$$\text{Uptake of nutrient (kg ha}^{-1}\text{)} = \frac{\text{Nutrient concentration (\%) X biomass (kg ha}^{-1}\text{)}}{100}$$

Yield and yield attributes

Yield attributes recorded for groundnut crop were plant height (cm), number of leaves plant^{-1}, protein content (g) and the yield parameters recorded were the number of pods plant $^{-1}$and fresh weights of pods (kg ha^{-1}).

RESULTS AND DISCUSSION

Soil responses to P and B fertilization

The application of phosphorus (P) and boron (B) significantly influenced the available nitrogen (N) levels in the soil (Table 2). Soil N availability increased with higher doses of P application with mean values increased from 254.02 kg ha^{-1}, as P positively interacted with N and supported plant development (Jiang *et al*., 2019). This increase in available N may be attributed to enhance N fixation, as P improved N use efficiency and aids in nodule formation and N fixation. Zeng *et al*. (2024) reported that higher P concentrations result in greater N fixation. Conversely, available N decreased with the increasing doses of B and the P-B interaction had no significant effect on available N.

Soil available phosphorus (P) significantly increased under all P fertilized treatments (Table 2) with the lowest levels observed in treatments without P and the highest levels in those with high P doses. The treatment P3 B0 (90 kg P ha^{-1} and 0 kg B ha^{-1}) showed the highest available P level (51.31 kg ha^{-1}). Except the treatments P0B1 and P0B2 all other treatments were significantly superior over the control. Rising levels of phosphorus (P) fertilization led to an increase in soil P content (Hynst *et al*., 2024). Boron application also influenced the soil available P, which decreased as B application levels increased, indicating an antagonistic relationship between P and B (Long and Peng, 2023).

P and B addition significantly influenced available K content in soil (Table 2). Treatment P1B3 (P 60 kg ha^{-1} and B 15 kg ha^{-1}) showed highest K content (454.72 kg ha $^{-1}$). Compared to initial status, available K in all treatments was increased, which might be due to application of K fertilizer. All the treatments were significantly higher over control. Generally, soil with high pH had high value for Mg which decreased the K content in soil. In calcareous soil K availability is limited by high pH and high concentrations of Ca and Mg (Najafi-Ghiri *et al*. (2020)). This might be due to increased competition between Ca, Mg and K for exchangeable sites. Available K status of soil was affected by B content rather than P. Treatment which had highest B showed higher value for K. The simultaneous increase in available potassium can be attributed to the synergistic interaction between boron and the primary nutrients in the soil, potentially enhancing the availability of plant nutrients (Bhupenchandraa *et al*., 2021).

Usually, Ca and P have an antagonistic effect due to precipitation of P into less soluble Ca phosphate**.** In the current experiment there was an increase in available Ca with increased dose of P application (Table 2). This might be due to the presence of Ca in SSP. Highest available calcium was in treatment that received P at 0 kg ha^{-1} and B at 15 kg ha^{-1} (4,975.31 mg kg^{-1}). An increase in Ca was observed with higher doses of B application, which can be attributed to a positive interaction between Ca and B. The lowest value was obtained for the control and all other treatments were significantly higher than the control.

The data regarding influence of application of different levels of P and B on available Mg are given in the Table 2. Data showed that available Mg content in soil significantly varied among different treatments by both main and interaction effects of P and B. Mg showed positive interaction with P application. Since it is a calcareous soil, field was high in Mg. Treatment P3 B2 (P 90 kg ha^{-1} and B 10 kg ha^{-1}) had highest available Mg (730.56 mg kg^{-1}). The increase in available Mg with increased doses of P might be due to the formation of sparingly soluble compound with phosphorus which is less prone to precipitation. Hence, losses of Mg could be reduced (Manimel Wadu *et al*., 2013).

Data showed that water soluble B in soil significantly varied due to application of different levels of P and B in the soil (Table 2). A significant positive decrease in available B was noticed in treatment having high P. Highest B (0.80 mg kg^{-1}) was noted in treatment T5 (P0B3 – P 0 kg ha^{-1} and B 15 kg ha^{-1}) and lowest (0.49 mg kg^{-1}) was in treatment T14 (P3B0- P 90 kg ha^{-1}and B 0 kg ha^{-1}). There was antagonistic interaction between B and P. Phosphate and borate share the same absorption and transport system, which leads to a competitive relationship between these two elements (Kaya *et al*., 2009).

Effect of application of P and B on plant nutrient uptake

The nutrient uptake in groundnut is closely linked to the plant metabolic processes, which rely on nutrient ion concentration and distribution within the plant system (Manasa *et al*., 2015). Phosphorus (P) and boron (B) applications significantly influenced nutrient uptake at harvesting stage (Table 3). Higher N uptake was seen in treatments with higher P levels (68.70 %), likely due to N fixation facilitated by P, which supports better root development and, consequently, greater N absorption from the soil and enhanced metabolic activities (Xia *et al*., 2023).

Phosphorus uptake also peaked in the treatment P3B0 (90 kg P ha^{-1}, 0 kg B ha^{-1}) i.e. 11.93 %, with higher P doses resulting in greater nutrient availability. Results are consistent with the findings of Chandrakanth (2015). The highest potassium (K) uptake was recorded in treatment T13 (P2 B3), which received medium P dose (75 kg ha^{-1}). The Treatment received highest amount of magnesium (Mg) and calcium (Ca) had lowest value for K uptake due to competitive interactions among K, Ca, and Mg, where addition of one nutrient reduces the uptake rates of other nutrients. The interaction between boron (B) and potassium (K) may be influenced by the effects of boron on cell membrane permeability, which in turn affects potassium uptake or distribution within plant tissues.

The uptake of Ca, Mg and B increased with P fertilizer application, whereas B fertilizers did not show much effect on it (Table 3). The highest uptake of Ca was in the treatment that received P at 90 kg ha^{-1} and B at 5 kg ha^{-1} and that of Mg was in the treatment received P at 90 kg ha^{-1} and B at 0 kg ha^{-1}. Research suggests that P fertilization can enhanced the uptake of Ca, Mg and B by plants. When sufficient phosphorus is available, plants are better able to absorb other nutrients, such as calcium and magnesium, resulting in increased concentrations of these elements in plant tissues. Aboyeji *et al*. (2020) reported that increasing the amounts of phosphorus fertilizer up to 80 kg P ha^{-1} significantly increased the groundnut seed concentration of Ca and Mg.

Growth and yield parameters of groundnut

Plant height and number of leaves plant^{-1}

Plant height and the number of leaves plant^{-1} during the flowering, pegging, pod development, and harvest stages were significantly influenced by the application of varying levels of phosphorus (P) and boron (B) fertilizers (Figure 1and 2). The treatment that received phosphorus at 90 kg ha^{-1} and boron at 0 kg ha^{-1} resulted highest plant height and number of leaves during the flowering (15.42 and 39.64 cm respectively), pegging (24.21 and 60.58 cm respectively), and pod development stages (32.99 and 81.53 cm respectively). Lro *et al*. (2019) and Hinduja *et al*. (2020) also reported that applying phosphorus fertilizer significantly enhanced the growth parameters of groundnut. These findings suggest that phosphorus fertilizer supports vigorous and healthy plant growth, improving yield and its components (Tekulu *et al*., 2020). Optimum phosphorus level is crucial for root development, root formation, and nitrogen fixation (Khan *et al*., 2023). The application of soluble phosphorus could increase the availability of soluble phosphate, promoting root development, which in turn enhance the nutrient uptake and finally improve overall plant growth.

Protein content in seeds

The data regarding seed protein content of groundnut treated with varying individual and combined levels of P and B fertilizers are presented in Table 4. The application of P and B fertilizers had a significant impact on grain protein content. The highest protein content, 24.41 g was observed in plots treated with 75 kg P ha^{-1} without B application. The study showed that seed protein content ranged from 21.09 to 24.41 g across the different treatments, with a general trend of increasing protein levels as P fertilizer rates increased. Control treatment was significantly lower than the treatments received T2, T6, T9, T10, T11, T14, T15, T16 and T17. Groundnut production is gaining importance in developing countries as a source of income, food, and protein, particularly where animal-based protein is less accessible to the community. Phosphorus plays a crucial role in protein biosynthesis within plant tissues. Numerous studies have demonstrated a positive response in grain or leaf protein content to P application, especially in soils deficient in phosphorus (Souri and Aslani, 2018). Integrated fertilizer application and improved soil management have been shown to enhance groundnut protein content. Additionally, inoculating Rhizobium and applying P fertilizers increased crude protein levels in cowpea seeds (Kyei-Boahen *et al*., 2017).

Number of pods plant^{-1} and yield ha^{-1}

There was significant difference in number of pods due to application of various levels of fertilizers (Table 5). Treatment that received P at 90 kg ha^{-1} and B at 10 kg ha^{-1} produced maximum number of pods. Kabir *et al*. (2013) and Jeetarwal *et al*. (2014) also averred that increasing the level of phosphorus could increase the number of pods in groundnut. The yield data revealed that application of 90 kg P ha^{-1}along with 5 kg B ha^{-1} recorded the highest groundnut yield (3,66 t ha^{-1}) (Table 6). The lowest for both the number of pods and yield was in the treatment received 0 kg P ha^{-1} along with 15 kg B ha^{-1} which was significantly lower than all other treatments including control. P stimulates setting of pods, decreases the number of unfilled pods (pops) and hastens the maturity of the crop. The improvement in groundnut yield could be attributed to better partitioning of assimilates and an adequate supply and translocation of metabolites and nutrients to reproductive structures, meeting their growth and development demands (Manan and Sharma, 2018). The combination of phosphorus and boron proved beneficial for carbohydrate transport and pollen tube growth, positively impacting fruit setting and yield (Hapuarachchi *et al*., 2022).

Soil nutrient status and nutrient uptake by the groundnut crop were influenced by the interaction of phosphorus and boron. Soil nutrient levels and plant nutrient absorption were influenced by both the main and interaction effects of phosphorus (P) and boron (B). The findings indicated that P interacted negatively with potassium (K) and B, while it had a positive interaction with nitrogen (N), calcium (Ca), and magnesium (Mg) in the soil. Applying P at a rate of 90 kg ha^{-1} enhanced plant height and leaf count plant^{-1}. The combination of P at 90 kg ha^{-1} and B at 10 kg ha^{-1} led to the highest number of pods, whereas the application of P at 90 kg ha^{-1} along with B at 5 kg ha^{-1} resulted in the greatest pod yield ha^{-1}.

Table 1. Initial properties of soil in the experimental site

Parameters	Value
pH	7.83
Electrical conductivity (dS m^{-1})	0.242
Organic carbon (%)	1.40
Available nitrogen (kg ha^{-1})	288.50
Available phosphorus (kg ha^{-1})	8.7
Available potassium (kg ha^{-1})	284.48
Available calcium (mg kg^{-1})	4154.5
Available magnesium (mg kg^{-1})	812.54
Available boron (ppm)	0.31

Table 2. Effect of P and B application on available N, P, K, Ca, Mg and B

Treatments	Treatment combinations	N (kg ha^{-1})	P (kg ha^{-1})	K (kg ha^{-1})	Ca (mg kg^{-1})	Mg (mg kg^{-1})	B (mg kg^{-1})
T1	Control	254.02	14.75	308.0	4125.31	687.46	0.57
T2	P0B0	260.29	18.93	409.36	4773.44	715.84	0.64
T3	P0B1	257.15	15.66	445.48	4774.69	694.28	0.66
T4	P0B2	257.15	15.10	438.76	4815.31	681.56	0.74
T5	P0B3	250.88	12.75	442.96	4975.31	697.78	0.80
T6	P1B0	260.29	32.89	448.28	4314.44	663.25	0.61
T7	P1B1	257.15	29.68	447.44	4396.25	675.47	0.62
T8	P1B2	254.02	28.40	369.6	4464.06	720.00	0.62
T9	P1B3	254.02	23.90	454.72	4555.94	646.41	0.62
T10	P2B0	285.38	40.98	428.12	4399.06	702.16	0.55
T11	P2B1	282.24	36.53	451.08	4540.00	650.72	0.56
T12	P2B2	279.10	36.29	306.88	4523.44	718.56	0.57
T13	P2B3	266.56	28.08	321.72	4554.38	726.22	0.62
T14	P3B0	291.65	51.31	319.2	4447.81	728.06	0.49
T15	P3B1	288.51	50.36	365.96	4640.00	725.59	0.51
T16	P3B2	285.38	38.15	372.4	4650.00	730.56	0.56
GT17	P3B3	282.24	35.36	427.56	4705.00	711.75	0.59
	SE(m)±	4.054	0.556	2.631	23.759	4.509	0.017
	CD (5%) (P×B)	-	1.588	7.518	67.897	12.887	0.049

Table 3. Effect of P and B application on N, P, K, Ca, Mg and B uptake in plant samples at harvest

Treatments	Treatment combinations	N(%)	P(%)	K(%)	Ca(%)	Mg(%)	B(%)
T1	Control	49.15	7.79	45.40	13.89	25.34	33.59
T2	P0B0	52.73	5.93	43.44	29.85	36.07	35.65
T3	P0B1	47.32	4.95	46.24	27.53	29.98	33.48
T4	P0B2	44.84	4.19	38.02	29.56	25.31	32.86
T5	P0B3	44.27	3.45	42.80	29.66	25.02	33.61
T6	P1B0	54.76	6.35	57.99	16.38	26.37	34.66
T7	P1B1	48.74	5.82	50.49	17.96	29.91	31.62
T8	P1B2	47.4	5.81	49.33	19.90	26.62	31.29
T9	P1B3	48.49	6.11	54.04	22.35	28.13	32.60
T10	P2B0	67.48	9.91	69.87	25.37	33.24	34.07
T11	P2B1	60.79	9.05	60.48	27.45	32.88	35.16
T12	P2B2	46.24	6.53	50.99	20.28	25.17	28.02
T13	P2B3	43.95	5.62	45.99	21.04	27.69	30.30
T14	P3B0	79.43	11.93	61.15	29.31	42.79	38.35
T15	P3B1	68.70	10.43	51.49	31.78	38.94	31.84
T16	P3B2	59.21	9.48	56.53	29.91	33.11	31.96
T17	P3B3	55.51	9.52	56.68	29.93	28.93	32.98
	SE(m)±	0.709	0.184	0.935	0.802	0.609	0.534
	CD (5%) (P×B)	2.025	0.525	2.672	2.293	1.826	1.527

Table 4. Effect of application of P and B on seed protein content (g)

	B_0	B_1	B_2	B_3	Mean P
P_0	22.50	21.28	21.09	20.91	**21.45**
P_1	22.88	21.91	21.78	22.28	**22.21**
P_2	24.28	23.84	21.31	21.19	**22.66**
P_3	24.41	24.16	23.59	23.19	**23.84**
Mean B	**23.52**	**22.80**	**21.95**	**21.89**	

SE(m)± P 0.018 SE(m)± B 0.018 SE(m)± PXB 0.036

CD (5%) P 0.054 CD (5%) B 0.054 CD (5%) PXB 0.108

Table 5. Effect of application of P and B on number of pods plant -1

	B_0	B_1	B_2	B_3	Mean P
P_0	13.33	13.25	12.93	12.38	**12.97**
P_1	15.35	15.08	14.48	14.30	**14.80**
P_2	19.48	19.08	18.53	18.23	**18.83**
P_3	21.53	22.35	23.33	21.38	**22.14**
Mean B	**17.42**	**17.44**	**17.31**	**16.57**	

SE(m)± P 0.036 **SE(m)± B 0.036** **SE(m)± PXB 0.072**

CD (5%) P 0.103 **CD (5%) B 0.103** **CD (5%) PxB 0.207**

Table 6. Effect of application of P and B on pod yield (t ha-1)

	B_0	B_1	B_2	B_3	Mean P
P_0	3.28	3.22	3.17	3.02	**3.17**
P_1	3.34	3.33	3.30	3.40	**3.34**
P_2	3.45	3.52	3.52	3.43	**3.48**
P_3	3.57	3.66	3.64	3.54	**3.60**
Mean B	**3.41**	**3.43**	**3.41**	**3.35**	

SE(m)± P 0.020 **SE(m)± B 0.020** **SE(m)± PXB 0.039**

CD (5%) P 0.056 **CD (5%) B 0.056** **CD (5%) PxB 0.113**

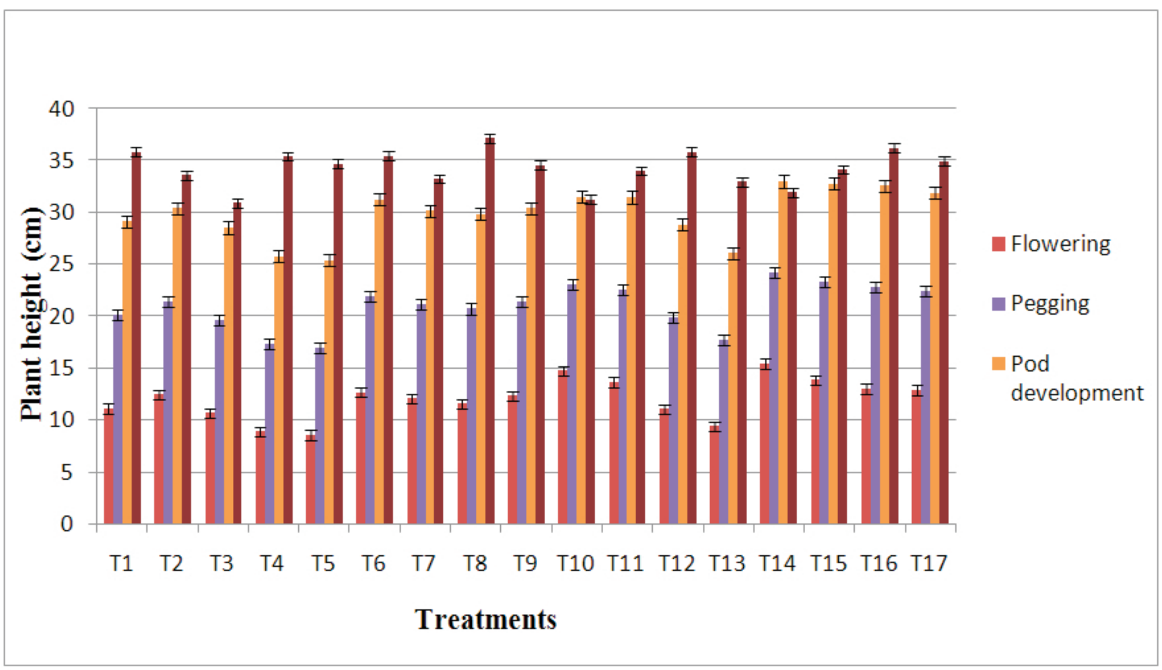

Figure 1. Effect of P and B application on plant height (cm)

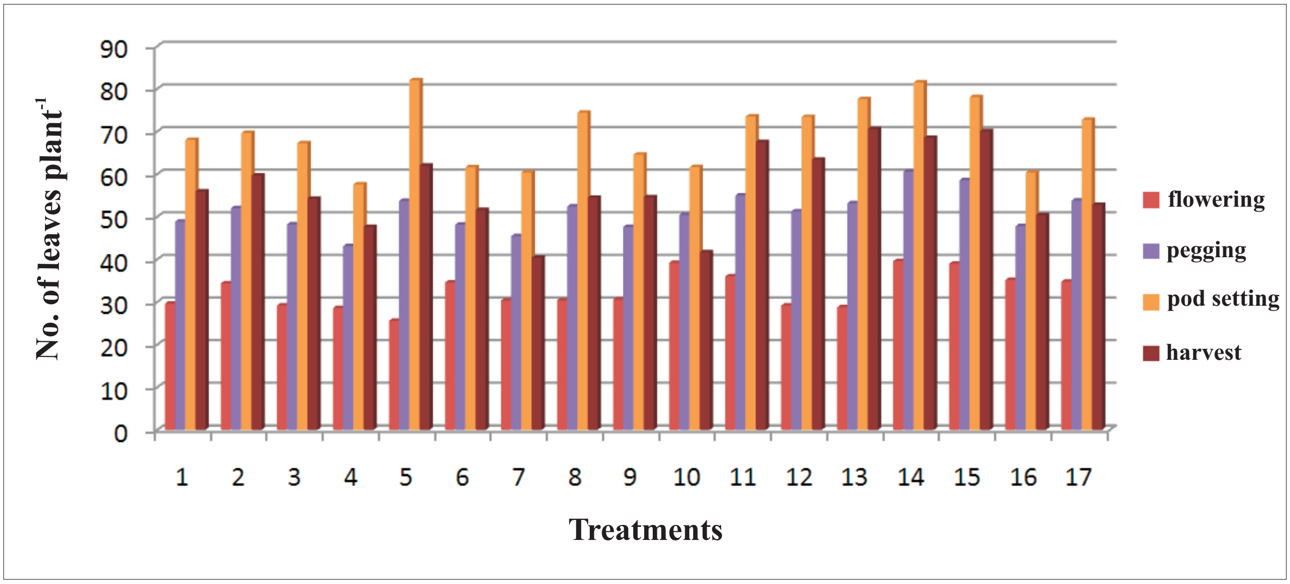

Figure 2. Effect of application of P and B on number of leaves plant^{-1}

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