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Effect of PSB and VAM with graded levels of Phosphorus on growth and yield of Litchi (*Litchi chinensis* Sonn.) cv. Muzaffarpur under foothills of Arunachal Pradesh

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Abstract
The experiment was conducted to assess the effect of Phosphorus Solubilising Bacteria (PSB) and Vesicular Arbuscular Mycorrhizae (VAM) with graded levels of Phosphorus on growth and yield of Litchi (*Litchi chinensis* Sonn.). The design of experiment was three Factorial Randomized Block Design with 12 treatments and replicated thrice. Experimental results showed significant increase in growth parameters of litchi trees *viz.*, increase in plant height (8.43 cm), increase in canopy spread (E-W) (17.41 cm) and yield parameters *viz.*, fruit weight (22.74 g), aril weight (14.16 g), maximum juice content (10.26 ml), fruit yield (20.38 kg/tree) were recorded the highest with the application of 600g P + 100g of PSB + 100g of VAM/ tree. Treatment applied with 400g of P + 100g of PSB + 100g of VAM (T_8) showed significant increase in stem girth (6.73 cm), took minimum days from flowering to harvesting of fruits (76.92) and gave maximum peel weight (4.46 g).

Keywords: Phosphorus, PSB, VAM, litchi, growth, yield

1. Introduction
Litchi (*Litchi chinensis*), a member of sapindaceae family with distinct chromosomal number 2n=30, was known to be originated in Southern China. It was introduced to India in 18th century. It is is the most environmentally sensitive crop commonly grown in warm sub-tropical climate with short, dry, frost-free winters, long, hot summers, and high rainfall and humidity (Pathak and Mitra, 2008) [11]. At 30 °C, it blooms profusely and it is accessible in India primarily around the first week of May and lasts through the last week of July. The widespread production of litchi fruit is limited by high sensitivity to soil and climatic conditions and short post-harvest life. Both in low and high temperatures, nutrients and irrigation may result in undesirable yield losses or decreased fruit quality (Menzel and Simpson, 1988) [9]. It is a single seeded nut with attractive red rind/cover has high juice content and a good source of minerals, vitamins, and antioxidant that helps protect against free radical damage. It is a good source of Vitamin C comprising of 40.0-90mg/100g. Depending upon its variety and climatic condition, it contains 60% of juice, 19% of seed, 13% of skin and 8% of rag (Nath *et al*., 2015) [10]. The major litchi producing states in India are Bihar, West Bengal, Jharkhand, Assam, Uttar Pradesh, Chhattisgarh, Uttarakhand, Punjab, Himachal Pradesh, Haryana, Odisha and Tripura. During 2019-2020, the total coverage under litchi in India is 93,000 ha area with a production around 7,28,000 metric tonnes. (Anon., 2019-20) [1]. Phosphorus availability in Indian soils is poor to medium, however application of adequate amount of phosphorus has been recorded for higher formation of good quality nodules led to enhances growth and yield (Sammauria *et al*., 2009) [15]. Phosphate is made available to plants by biofertilizers such as Phosphate Solubilizing Bacteria and Vesicular Arbuscular Mycorrhiza (VAM fungus), which aid in phosphorous mobilisation through their biological activity.

Biofertilizers are used with an objective to increase the microbial population in the rhizosphere which in turn enhances the availability of nutrients for easy assimilation by plants (Sudhakar and Ranganathan, 2020) [16]. Application of soil with Phosphate Solubilizing. Bacteria in the rhizosphere of the crop solubilizes unavailable soil phosphorus and make available to plants. Vesicular arbuscular mycorrhiza (VAM) fungi improve plant growth through phosphorus nutrition. VAM is different from phosphate Solubilizer as it does not solubilize the unavailable or insoluble phosphorus but assimilate phosphorus, zinc and other nutrient and translocate them into the host root along with their own need (Pandey *et al*., 2014) [12]. Since, a major amount of the phosphorus in soil is insoluble; it is unavailable to plants directly. PSB uses organic acids, acidification, chelating, and exchange processes to convert insoluble phosphate into soluble forms. Similarly, VAM produces hyphae that extend into the phosphorus-available zone, which is positioned far from the roots, so expanding the absorption surface. Arunachal Pradesh is emerging as a potential region for litchi cultivation due to high phosphorous fixing capacity of acid soils, there is a deficient of P in this region (Raghavan, *et al.*, 2018) [20]. Hence, keeping in view with all above mentioned aspects, present study was formulated to access the most suitable combination of biofertilizers and phosphorus for enhancing the growth and yield parameters of litchi.

2. Materials and Methods

A field experiment was carried out during 2019-2020 at Litchi orchard, Fruit Research Farm, Department of Fruit Science, College of Horticulture and Forestry, Central Agricultural University, Pasighat, Arunachal Pradesh to assess the effect of biofertilizers like PSB and VAM with graded levels of phosphorus on growth parameters and yield of Litchi. The soil of experimental site was sandy loam in texture with high available nitrogen (589.5 kg/ha), medium available phosphorus (20.48 kg/ha) and medium available potassium (190.4 kg/ha). The experimental location is situated at an altitude of 155 m above mean sea level with a latitude of 28.07°North and a longitude of 95.33° East. The average annual temperature is 22.8°C / 73.1°F to be 23.96°C / 75.13°F with sub-tropical and humid climatic condition.

The experiment was laid out in three Factorial Randomized Block Design consisting of 12 treatment combinations each replicated thrice *viz.*, three levels of phosphorus (0, 400 & 600 g per tree), two levels of PSB (0 & 100 g per tree), two levels of VAM (0 & 100 g per tree) along with control. The combination of treatments was as given below:

$T_1 = P_0S_0V_0$ (Control)
$T_2 = P_0S_0V_1$ (0g P + 0g of PSB + 100g of VAM)
$T_3 = P_0S_1V_0$ (0g P + 100g of PSB + 0g of VAM)
$T_4 = P_0S_1V_1$ (0g P + 100g of PSB + 100g of VAM)
$T_5 = P_1S_0V_0$ (400g P + 0g of PSB + 0g of VAM)
$T_6 = P_1S_0V_1$ (400g P + 0g of PSB + 100g of VAM)
$T_7 = P_1S_1V_0$ (400g P + 100g of PSB + 0g of VAM)
$T_8 = P_1S_1V_1$ (400g P + 100g of PSB + 100g of VAM)
$T_9 = P_2S_0V_0$ (600g P + 0g of PSB+ 0g of VAM)
$T_{10} = P_2S_0V_1$ (600g P + 0g of PSB + 100g of VAM)
$T_{11} = P_2S_1V_0$ (600g P + 100g of PSB + 0g of VAM)
$T_{12} = P_2S_1V_1$ (600g P + 100g of PSB + 100g of VAM)

The plats were planted at a spacing of 8 × 8m. According to the treatment, the full dose of Phosphorus was applied through SSP and after ten days of phosphorus application, biofertilizer like PSB and VAM is applied to the soil respectively. The data were recorded for morphological parameters of litchi *viz*., increase in plant height (cm), increase in stem girth (cm), increase in canopy spread (N-S) (E-W) (cm), flowering parameters of tree (days from flowering to harvest), and physical parameters of fruit and yield parameters *viz*., fruit weight, peel weight, aril weight, juice content, seed weight and fruit yield. Observations recorded during field experiment and data obtained were subjected to the statistical analysis of variance for FRBD. Significance and non-significance of the variance due to different treatments were determined by calculating the respective F values according to the method described by Gomez and Gomez, 2010 [6].

3. Results and Discussion

3.1 Effect of PSB and VAM with graded levels of Phosphorus on Morphological Parameters of Litchi

The interaction effect of Phosphorus and bio-fertilizer application was significantly affected the growth parameters of litchi. The maximum increase in plant height (8.43cm) was recorded in T_{12} (600g of P + 100g of PSB + 100g of VAM) which is at par with $P_1S_1V_1$ (7.53cm) (T_8) as well as maximum increase in canopy spread in E-W direction (17.41 cm) was recorded in T_{12} (600g of P + 100g of PSB + 100g of VAM) which was at par with the treatment combinations of $P_0S_0V_1$ (T_2) (13.44cm), $P_1S_1V_1$ (T_8) (13.23cm), $P_2S_0V_0$ (T_9) (12.77cm), $P_1S_0V_0$ (T_5) (12.70cm), $P_1S_1V_0$ (T_7) (12.68cm), $P_1S_0V_1$ (T_6) (11.38cm), $P_2S_1V_0$ (T_{11}) (11.13cm) (Table 1) than the control. The interaction impact of phosphorus and bio-fertilizer was found to be non-significant in Canopy spread in (N-S) direction. The main interaction effect of phosphorus and bio-fertilizer was discovered to be significantly influencing the stem girth (Table 1). $P_1S_1V_1$ (T_8) (6.73cm) had the greatest increase in stem girth, which was at par with $P_2S_1V_1$ (T_{12}) (6.67cm), $P_2S_0V_0$ (6.40 cm) (T_9), and $P_1S_1V_0$ (T_7) (5.80 cm). $P_0S_0V_0$, the control treatment, had the lowest reading of 2.50 cm.

This could be attributed due to the PSB's phosphate solubilizing action and the VAM fungi's phosphorus mobilising effect resulted in greater uptake and transfer of plant nutrients to litchi plants, resulting in an increase in plant height and canopy spread. Another reason might be due to the action of PSB and VAM which improved in plant growth by converting insoluble form of phosphate to soluble form by producing organic acids and also increase in the growth parameters might be due to slow but steady effect of biofertilizers which fixes and makes the nutrients available to the plant. Similar findings of growth improvements under different grades of phosphorus were also observed in papaya by Suresh *et al.* (2008) [17].

3.2 Effect of PSB and VAM with graded levels of Phosphorus on Flowering Parameters of Litchi

From the experimental result, the days from flowering up to the days of harvesting showed significant influence of flowering in litchi. The minimum time taken for number of days from flowering to harvest was taken in treatment T_8 with $P_1S_1V_1$ at 76.92 days. It was statistically at par with combination of $P_2S_1V_1$ in T_{12} at 77.84 days. The highest number of days was observed in control $P_0S_0V_0$ at 86.25 days. It was presented in Table 1. This could be attributed due to the effect of phosphorus, which is an important factor for the commencement of blooming and the stimulation of early maturity.

Early flowering was noticed due to application of increased phosphorus level and biofertilizer inoculation was studied by Suresh *et al.*, (2008) [17] in papaya. In sapota, this result is identical to Manjare *et al*. (2018) [7]. This could be owing to the abundant amount of phosphorus, which is a crucial element for blooming initiation and was made available by PSB and VAM. The findings are consistent with previous research in mango (Madhavi *et al*., 2008) [8], which found that phosphorus stimulated flowering.

3.3 Effect of PSB and VAM with graded levels of Phosphorus on Physical and Yield attributing Parameters of Litchi

The use of phosphorus with PSB and VAM had a considerable impact on the majority of physical and yield metrics. It was apparent that the different treatment application showed significantly influenced the fruit weight. T_{12} i.e. 600g P+100g PSB+100g VAM had the highest in average fruit weight (22.74 g), it was followed by the treatment combinations of $P_2S_0V_1$ (T_{10}) as 21.03g, $P_0S_1V_1$ (T_4) as 20.93g, $P_2S_1V_0$ (T_{11}) as 20.54g, while the lowest was observed in the control treatment $P_0S_0V_0$ (T_1) weighing as 17.21g. In aril weight highest was observed in T_{12} combination (14.16 g) and in the control treatment $P_0S_0V_0$ (T_1), the lowest aril weight was observed as 9.38g. It was statistically at par with the treatment combination of $P_1S_0V_0$ (T_5), which had a 14.09g value, $P_2S_0V_1$ (T_{10}) measured 13.76g, $P_1S_1V_1$ (T_8) measured 13.69g and $P_1S_0V_1$ (T_6) measuring 13.49g (Table.2). This may be due to the faster mobility of photosynthates from source to sink as influenced by growth hormones, released or synthesised owing to organic sources of nutrition, resulted in an increase in average fruit weight. Suresh *et al*., (2008) [17] found similar findings in papaya, showing that various quantities of phosphorus and biofertilizers influenced yield per plant.

In juice content, the highest was measured in treatment (T_{12}) $P_2S_1V_1$ as 10.26ml which is statistically at par with treatment (T_8), $P_1S_1V_1$ as 9.36ml, $P_2S_0V_1$ (T_{10}) measuring as 9.26ml, $P_2S_0V_0$ (T_9) recorded as 9.06ml. The lowest juice content was measured in the control treatment (T_1) $P_0S_0V_0$ as 5.34ml (Table.2). It could be owing to a larger canopy, which increases photosynthetic activity and so glucose buildup. Larger carbohydrate content could have accelerated fruit growth and, as a result, increased fruit weight. This matched the findings of Chezhigen *et al*., (1999) [2] in the banana and Verma and Chauhan (2013) [19] in the apple. The probable reason might also be to render insoluble and unavailable phosphorus into available form by the synergistic action of these two biofertilizer i.e. PSB+VAM.

T_8, on the other hand, had the highest peel weight (4.46 g) when combined with 400g P+100g PSB+100g VAM (Table.2). The interaction impact of phosphorus and bio-fertilizer was found to be non-significant in seed weight. Pathak and Mithra (2008) [11] discovered that increasing the phosphorus level in the plant increases the aril weight of the fruit. In sapota, Manjare *et al*. (2018) [7] found that using PSB in combination with a full dose of chemical fertilisers resulted in the number of fruits per tree, and yield per tree.

As indicated in Table 2, T_{12} (400g P+100g PSB+100g VAM) was found to considerably enhancing the fruit yield (20.38 kg/ tree) which had the highest number of fruits per tree of all the treatment combinations. It was followed by the $P_1S_1V_1$ (T_8) treatment combination, which had a 17.77kg/tree value. In the control treatment $P_0S_0V_0$ (T_1), the lowest fruit yield was 7.39kg/tree. The use of phosphorus resulted in a significant increase in litchi production was reported by Dey *et al*., (2010) [3]. It also resembles the litchi findings of Dutta *et al*., (2010) [5] and Rathore *et al*., (2013) [14]. This could be attributed to organic sources of organic matter and nutrients, as well as the solubilization of insoluble phosphate and fixed potassium by organic acids released from biofertilizers and manures as they decompose. Many grape experts claim that optimal phosphorus promotes grape yield by having a favourable influence in 'Anab-e-shahi' (Shikhamany and Satyanarayana, (1972) [18] and 'Perlette' grapes (Dhillon *et al*., 1998) [4].

4. Conclusion

Long-term use of biofertilizer will not only minimize the demand for chemical fertilizer, but it will also increase the farmer's yield and profit. Based on the findings, it can be stated that using 100g Phosphate Solubilizing Bacteria and 100g Vesicular Arbuscular Mycorrhiza per tree in combination with 600g phosphorus per tree is more desirable for achieving higher growth parameters, physical attributes, and yield attributes in litchi. Thus, litchi grown with application of Phosphate Solubilizing Bacteria, Vesicular Arbuscular Mycorrhiza, and phosphatic fertilizer in the foothills of Arunachal Pradesh may be recommended to expect increased yields.

Table 1: Effect of PSB and VAM with different grades of phosphorus on growth parameters of Litchi

Treatments	Increase in Plant height (cm)	Increase in Stem Girth (cm)	Increase in Canopy Spread		Maturity (Days from Flowering to harvest)
			(N-S) (cm)	(E-W) (cm)	
$P_0S_0V_0$	4.11	2.50	6.44	5.74	86.25
$P_0S_0V_1$	4.98	3.43	13.15	13.44	84.35
$P_0S_1V_0$	6.20	3.67	9.21	10.25	83.81
$P_0S_1V_1$	5.53	4.43	8.10	9.21	80.47
$P_1S_0V_0$	6.53	4.72	12.03	12.70	80.01
$P_1S_0V_1$	6.63	3.54	14.17	11.38	81.21
$P_1S_1V_0$	4.75	5.80	10.97	12.68	81.83
$P_1S_1V_1$	7.53	6.73	11.43	13.23	76.92
$P_2S_0V_0$	5.40	6.40	14.46	12.77	78.26
$P_0S_0V_0$	6.77	3.67	15.14	9.62	80.22
$P_0S_0V_1$	7.19	5.63	12.63	11.13	80.56
$P_0S_1V_0$	8.43	6.67	13.66	17.41	77.84
SE (m)±	0.40	0.35	1.22	0.83	0.47
CD @ 5%	1.17	1.01	NS	2.44	1.37

Table 2: Effect of PSB and VAM with different grades of phosphorus on yield parameters of Litchi

Treatments	Fruit weight (g)	Peel weight (g)	Aril weight (g)	Juice content (ml)	Seed weight (g)	Fruit yield (kg/tree)
$P_0S_0V_0$	17.21	2.67	9.38	5.34	2.40	7.39
$P_0S_0V_1$	19.35	3.62	10.56	6.67	3.09	14.78
$P_0S_1V_0$	18.45	2.97	12.12	7.90	2.69	8.88
$P_0S_1V_1$	20.93	3.46	12.75	8.16	3.35	12.99
$P_1S_0V_0$	17.26	3.64	14.09	6.08	2.82	13.45
$P_1S_0V_1$	18.55	3.28	13.49	6.21	2.92	13.38
$P_1S_1V_0$	18.30	2.69	11.59	7.62	2.87	12.36
$P_1S_1V_1$	19.36	4.46	13.69	9.36	3.62	17.77
$P_2S_0V_0$	18.07	3.57	10.51	9.06	3.17	12.48
$P_0S_0V_0$	21.03	3.02	13.76	9.26	3.01	15.53
$P_0S_0V_1$	20.54	3.06	12.02	8.32	2.75	16.09
$P_0S_1V_0$	22.74	4.33	14.16	10.26	3.07	20.38
SE (m)±	0.57	0.27	0.48	0.62	0.30	0.43
CD @ 5%	1.18	0.55	0.99	1.28	NS	1.27

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