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Synergistic Effect of Phosphatic Fertilizer and Biofertilizers on Soil Enzyme Activity and Yield of Finger Millet (*Eleusine coracana* L.)

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ABSTRACT: A field experiment was carried out at the Agricultural Research Station in Perumalapalle, Tirupati, Andhra Pradesh, India, during the *kharif* season of 2018. The main objective of the experiment was to investigate the effects of phosphorus fertilizer, Phosphorus Solubilizing Bacteria (PSB), and Vesicular Arbuscular Mycorrhiza (VAM) on soil enzyme activity in finger millet. The experiment was structured using a randomized block design, with nine different treatments comprising varying combinations of phosphorus fertilizer, PSB, and VAM. Each treatment was replicated three times, and the study was conducted in sandy loam soil. The investigation involved the collection of soil samples at two key growth stages: flowering and harvest. The analysis focused on assessing soil enzyme activity, specifically targeting acid phosphatase, alkaline phosphatase, and arylsulfatase activities. Additionally, the grain yield was recorded at the harvest stage. The results highlighted the substantial impact of combinedly applying PSB and VAM along with phosphorus fertilizer on both soil enzyme activity and grain yield. Among the diverse treatment options, the combination involving 75% of the recommended dose of phosphorus (RDP) + PSB at 750 ml/ha + VAM at 12.5 kg/ha (T9) showcased the highest acid phosphatase activity during the harvest period. Similarly, the treatment comprising 100% RDP + PSB at 750 ml/ha + VAM at 12.5 kg/ha (T6) exhibited the most elevated alkaline phosphatase activity at both growth stages. Moreover, for arylsulfatase activity during the flowering phase, the treatment sequence of 75% RDP + PSB at 750 ml/ha + VAM at 12.5 kg/ha (T9), followed by 100% RDP + PSB at 750 ml/ha + VAM at 12.5 kg/ha (T6), produced the most pronounced results. In contrast, the absence of phosphorus (T1) led to significantly lower levels of acid and alkaline phosphatase, arylsulfatase activity, and grain yield. Certainly, here's a paraphrased version of the sentence. Some of the challenges in this study is potential benefits of applying phosphorus fertilizer along with biofertilizers (PSB and VAM) are a highly effective method for managing phosphorus in finger millet cultivation, with the aim of enhancing plant growth, increasing crop yield and stimulating enzyme activity over application of phosphorus fertilizers alone. Hence it is best option for realizing higher productivity in finger millet.

Keywords: Enzyme activity, finger millet, grain yield, Phosphorus fertilizer, PSB and VAM.

INTRODUCTION

Finger millet (*Eleusine coracana* L.) holds a significant position as a staple food crop in the semi-arid regions of Asia and Africa, contributing to the dryland farming systems. In India, it is commonly referred to as Ragi and is recognized for its nutritional excellence, earning the title of "nutritious millet." This grain surpasses many cereals in terms of nutritional value, boasting substantial protein, fiber, calcium, and other minerals. Apart from its nutritional richness, finger millet exhibits drought resistance and resilience against diseases, enabling it to thrive across various climatic conditions. Phosphorus stands out as a pivotal macronutrient essential for fostering biological growth and facilitating proper plant development. It serves as a building block for cellular membranes, chloroplasts, and mitochondria. Additionally, it plays a role in energy production through compounds like ADP and ATP, while also contributing to nucleic acids (DNA and RNA), nucleic proteins, purines, pyrimidines, nucleotides, and various coenzymes. A significant portion of phosphorus, around 93-99 percent, remains insoluble, thereby rendering it inaccessible to plants directly. However, introducing phosphorus-solubilizing microorganisms into the rhizosphere and soil enhances the availability of phosphorus from otherwise insoluble phosphate sources. This process involves the desorption of fixed phosphates and an improved efficiency of phosphatic fertilizers, aided by the secretion of acidic substances. The mutualistic relationship between plant roots and specific soil fungi, such as Vesicular Arbuscular Mycorrhiza (VAM), plays a pivotal role in the phosphorus cycle and its uptake by plants. These symbiotic microorganisms establish a network of mycelia that enhances enzyme activity in the soil (Kumar *et al.*, 2017). With these considerations in mind, a comprehensive investigation was designed to explore the collective impact of phosphatic fertilizer and biofertilizers (PSB and VAM) in enhancing soil enzyme activity and the grain yield of finger millet.

MATERIAL AND METHODS

An experiment was conducted in the kharif season of 2018 at the Agricultural Research Station in Perumallapalli, Tirupati, Andhra Pradesh, India. The experimental design was a randomized block design, with each treatment being replicated three times, resulting in nine distinct treatments. The treatments were as follows: T1 - No Phosphorus, T2 - 100% RDP, T3 - 125% RDP, T4 - 100% RDP + Phosphorus Solubilizing Bacteria @ 750 ml ha-1 (PSB), T5 - 100% RDP + Vesicular Arbuscular Mycorrhizae @ 12.5 kg ha-1 (VAM), T6 - 100% RDP + PSB + VAM, T7 - 75% RDP + PSB, T8 - 75% RDP + VAM, and T9 - 75% RDP + PSB + VAM. Before transplanting the crop, an initial soil sample was collected from the 0-15 cm depth range. These samples were collected in a random manner, thoroughly mixed, dried under shade, sieved through a 2 mm mesh, and appropriately labeled. Soil samples from the 0-15 cm depth were also gathered from each treatment plot both at the flowering stage and post-harvest, and then subjected to analysis. The processed soil samples underwent analysis for biological properties using standard procedures. The methods outlined by Tabatabai and Bremner (1969) ; Evazi and Tabatabai (1977) were followed for assessing acid and alkaline phosphatase activities, respectively. Additionally, the method devised by Tabatabai and Bremner (1970) was employed to measure arylsulfatase activity. The quantification of enzyme activities was based on the liberated p-nitrophenol, expressed as µg of p-nitrophenol released per gram of soil per hour. At physiological maturity, the earheads from each plot were harvested and the resulting grain yield was recorded.

Statistical Analysis. The data on various soil properties and yield were subjected to statistical scrutiny by following the analysis of variance for randomized block design as outlined by Panse and Sukhatme (1985). Statistical significance was tested with ‘F’ test at 5 per cent and 1 per cent level of probability. Further multiple comparison tests have been done using duncan’s multiple range test (DMRT) to identify the homogenous groups of treatments using SPSS-20.

RESULTS AND DISCUSSION

Acid phosphatase activity. The data pertaining to enzyme activity at flowering and harvesting was presented in Table 2.

The acid phosphatase activity showed an increase during the flowering stage compared to the initial stage, followed by a decrease from flowering to the harvest stage. During flowering, no significant impact on acid phosphatase activity in the soil was noticed across various treatments. The acid phosphatase activity ranged from 70.63 µg p-nitrophenol g^{-1} soil h^{-1} in the absence of phosphorus (T1) to 80.97 µg p-nitrophenol g^{-1} soil h^{-1} achieved by applying 75% RDP + PSB @ 750 ml ha^{-1} (T7). By harvest time, both phosphatic fertilizer and biofertilizers significantly influenced the acid phosphatase activity. The highest acid phosphatase activity (54.32 µg p-nitrophenol g-^{1}soil h^{-1}) was recorded with 75% RDP + PSB @ 750 ml ha^{-1} + VAM @ 12.5 kg ha-^{1} (T9), which was comparable to 100% RDP + PSB @ 750 ml ha^{-1} + VAM @ 12.5 kg ha^{-1} (T6). The lowest activity (44.80 µg p-nitrophenol g^{-1} soil h^{-1}) was observed in the absence of phosphorus (T1).

The highest acid phosphatase activity observed with 75% RDP + PSB @ 750 ml ha^{-1} + VAM @ 12.5 kg ha^{-1} could be attributed to an increased microorganism population due to available substrate, consequently leading to the release of these extracellular enzymes. These findings align with the research conducted by Ramakrishnaiah and Vijaya (2013); Vajantha *et al.* (2013).

Alkaline phosphatase activity. The alkaline phosphatase activity experiences a decline as the crop advances in age from the flowering stage to harvest. Both at the flowering and harvest stages, phosphorus management practices significantly impact the alkaline phosphatase activity. During flowering, the highest alkaline phosphatase activity (104 µg p-nitrophenol g^{-1} soil h^{-1}) was observed with the application of 100% RDP + PSB @ 750 ml ha^{-1} + VAM @ 12.5 kg ha^{-1} (T6), followed by 75% RDP + PSB @ 750 ml ha^{-1} (T9) and 125% RDP (T3). The lowest activity (89.83 µg p-nitrophenol g-1 soil h-1) was recorded in the absence of phosphorus (T1). By harvest, the highest alkaline phosphatase activity (79.5 µg p-nitrophenol g^{-1} soil h^{-1}) was found with 100% RDP + PSB @ 750 ml ha^{-1} + VAM @ 12.5 kg ha^{-1} (T6), which was comparable to 125% RDP (T3). The lowest activity (66.50 µg p-nitrophenol g^{-1} soil h^{-1}) was observed without phosphorus (T1).

The increased alkaline phosphatase activity observed with the application of 100% RDP + PSB @ 750 ml ha^{-1} + VAM @ 12.5 kg ha^{-1} could be attributed to the combined usage of PSB and VAM with RDP, leading to enhanced soil microflora and subsequently higher soil enzyme activity (Kaur *et al*., 2017). Furthermore, higher amounts of inorganic phosphorus led to an augmentation in alkaline phosphatase activity. These findings align with the research of Venkatarao *et al*. (2017); Vajantha *et al*. (2013).

Arylsulfatase activity. Arylsulfatase activity has decreased with advancement in age of crop from flowering to harvest. During the flowering stage, various treatments demonstrate a noticeable impact on the arylsulfatase activity in the soil. During flowering, various treatments showed a significant impact on arylsulfatase activity in the soil. The highest arylsulfatase activity (68.5 µg p-nitrophenol g^{-1} soil h^{-1}) was observed with the application of 75% RDP + PSB @ 750 ml ha^{-1} + VAM @ 12.5 kg ha^{-1} (T9), followed by 100% RDP + PSB @ 750 ml ha^{-1} + VAM @ 12.5 kg ha^{-1} (T6). The lowest activity (57.54 µg p-nitrophenol g^{-1} soil h^{-1}) was recorded without phosphorus (T1). At harvest, the differences in arylsulfatase activity among treatments were not statistically significant. Arylsulfatase activity in the soil ranged from 40.70 to 48.32 µg p-nitrophenol g^{-1} soil h^{-1}, with the highest value observed for 125% RDP (T3), while the lowest was associated with no phosphorus (T1).

The highest arylsulfatase activity was recorded with the application of 75% RDP + Liquid PSB @ 750 ml ha^{-1} + VAM @ 12.5 kg ha^{-1}, potentially due to the inclusion of biofertilizers alongside inorganic phosphorus, resulting in an increased microorganism population due to enhanced substrate availability. This, in turn, aids in the release of extracellular enzymes. The increased enzyme activity during the flowering stage might be attributed to heightened root activity and the release of extracellular enzymes into the soil solution during the active growth phase. These findings closely correlate with the research conducted by Vajantha *et al*. (2013).

Grain Yield. Data presented in Table 3 on grain yield revealed that phosphorus management practices showed a greater impact on grain yield of finger millet.

The grain yield of finger millet was significantly affected by both phosphatic fertilizer and biofertilizers. The highest grain yield (4328 kg ha-1) was achieved with the application of 100% RDP + PSB @ 750 ml ha^{-1} + VAM @ 12.5 kg ha^{-1} (T6), followed by 75% RDP + PSB @ 750 ml ha^{-1} + VAM @ 12.5 kg ha^{-1} (T9), both of which are statistically significant. The lowest grain yield (3692 kg ha-1) was associated with the absence of phosphorus (T1).

The increased grain yield from the application of 100% RDP + PSB @ 750 ml ha^{-1} + VAM @ 12.5 kg ha^{-1} can be attributed to a more favorable nutrient supply coupled with an optimal physical environment. This combination encourages enhanced root activity and improved nutrient absorption, resulting in greater overall plant growth and superior yield attributes. The incorporation of biofertilizers (PSB and VAM) enhances the efficiency of chemical fertilizers due to the controlled release of nutrients in the soil through microbial activity, thereby promoting better crop growth. These findings align with the research outcomes of Abbasi and Yousra (2012); Acharya *et al*. (2012); Roy *et al*. (2018); Kejiya *et al*. (2022).

Table 1: Initial soil properties of the experimental field.

Particulars	Value
A. Physical characteristics	
Sand (%)	68.26
Silt (%)	20.50
Clay (%)	11.24
Textural class	Sandy loam
B. Biological characteristics	
Acid phosphatase (µg *p*-nitrophenol g^{-1} soil h^{-1})	42.29
Alkaline phosphatase (µg *p*-nitrophenol g^{-1} soil h^{-1})	64.39
Arylsulfatase (µg *p*-nitrophenol g^{-1} soil h^{-1})	40.73

Table 2: Soil enzyme activity of soil at different stages of finger millet as influenced by phosphatic fertilizer and biofertilizers.

Treatments	Acid phosphatase (µg *p*-nitrophenol g^{-1}soil h^{-1})		Alkaline phosphatase (µg *p*-nitrophenol g^{-1}soil h^{-1})		Arylsulfatase (µg *p*-nitrophenol g^{-1}soil h^{-1})	
	Flowering	Harvest	Flowering	Harvest	Flowering	Harvest
T_1	70.63	44.80^{c}	89.83^{d}	66.50^{d}	57.54^{d}	40.70
T_2	73.73	45.13^{bc}	92.43^{cd}	74.50^{abc}	63.79^{bc}	47.34
T_3	80.13	47.59^{bc}	99.30^{ab}	79.23^{a}	65.24^{bc}	48.32
T_4	73.05	51.67^{ab}	97.00^{bc}	74.91^{abc}	62.87^{bc}	44.55
T_5	71.17	50.00^{ab}	93.70^{bcd}	69.00^{bcd}	64.14^{bc}	44.44
T_6	73.87	53.73^{a}	104.00^{a}	79.52^{a}	65.81^{ab}	42.63
T_7	80.97	48.85^{bc}	92.63^{cd}	68.66^{cd}	61.93^{c}	45.80
T_8	74.60	50.17^{ab}	95.07^{bcd}	73.76^{abc}	64.02^{bc}	44.97
T_9	72.64	54.32^{a}	99.57^{ab}	75.33^{ab}	68.51^{a}	44.51
F value	1.93	5.55**	5.07**	5.28**	8.36**	1.35
p-value	0.125	0.002	0.003	0.002	0.000	0.289

* Significant at p=0.05 level ** Significant at p=0.01 level

Note: Same set of alphabets indicates no significant difference or at par with each other (DMRT)

Table 3: Grain yield (kg ha^{-1}) of finger millet as influenced by phosphatic fertilizer and biofertilizers.

Treatments	Grain yield
T_1	3692^{d}
T_2	3846^{bc}
T_3	4083^{abc}
T_4	3946^{bc}
T_5	3858^{bc}
T_6	4328^{a}
T_7	3783^{cd}
T_8	3942^{bc}
T_9	4157^{ab}
F value	3.54*
p-value	0.015
* Significant at p=0.05 level ** Significant at p=0.01 level Note: Same set of alphabets indicates no significant difference or at par with each other (DMRT)	

CONCLUSIONS

The current study's findings lead to the concluded that the combined utilization of 75% RDP + PSB @ 750 ml ha^{-1} + VAM @ 12.5 kg ha^{-1} (T9) has demonstrated its superiority in enhancing soil enzyme activity. The highest grain yield was achieved with the application of 100% RDP + PSB @ 750 ml ha^{-1} + VAM @ 12.5 kg ha^{-1} (T6), establishing it as the most effective phosphorus management approach compared to the application of phosphorus fertilizer alone.

FUTURE SCOPE

This study' findings highlight the potential for exploited the combined application of phosphorus fertilizer and biofertilizers as the most efficient approach to phosphorus management for promoting growth, yield, and enzyme activity in finger millet.

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Conflict of Interest. None.

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