Original Research Article

Enhancing Soil Fertility and Finger Millet (Eleusine coracana L.) Yield through Phosphorus Management in Sandy Loam Soils

ABSTRACT

Finger millet (Eleusine coracana L.) holds significant agricultural importance in India due to its high productivity among millet crops. However, the crop's yield diminishes in regions characterized by low available soil phosphorus content. To address this concern, a field experiment was conducted during the kharif season of 2018 at the Agricultural Research Station, Perumalapalle, Tirupati, Acharya N. G. Ranga Agricultural University, Andhra Pradesh, India. The primary objective was to investigate the impact of phosphorus fertilizer, phosphate-solubilizing bacteria (PSB), and vesicular arbuscular mycorrhiza (VAM) on both soil fertility status and finger millet yield in sandy loam soils.The experimental design employed a randomized block layout comprising nine distinct treatments, each consisting of various combinations of phosphorus fertilizer, PSB, and VAM. The experiment was replicated thrice to ensure robustness of the results. Soil samples were collected both initially and after the harvest period, and these samples were subjected to comprehensive physico-chemical and chemical analyses. Additionally, grain yield data were recorded post-harvest.The findings of this study demonstrated that the joint application of PSB, VAM, and phosphorus fertilizer had a noteworthy influence on the availability of essential nutrients in the soil. Notably, the treatment involving 100% recommended dose of phosphorus (RDP), PSB at a rate of 750 ml per hectare, and VAM at 12.5 kg per hectare (Treatment 6) exhibited significant improvements in the availability of nitrogen (150 kg ha-1), phosphorus (42.34 kg ha-1), potassium (227 kg ha-1), sulfur (9.57 mg kg-1), and DTPA-extractable manganese (38.67 mg kg-1). Moreover, this treatment led to the highest recorded grain yield of finger millet, achieving 4328 kg ha^{-1}.The physico-chemical properties of the soil, including pH, electrical conductivity (EC), and organic carbon (OC), exhibited non-significant variations across the different phosphorus management practices.In conclusion, the results underscore the positive impact of the combined application of PSB, VAM, and phosphorus fertilizer on both soil fertility parameters and finger millet yield. This research provides valuable insights for enhancing agricultural practices in regions characterized by sandy loam soils and low phosphorus availability, contributing to the sustainable productivity of finger millet crops in India.

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Keywords: Phosphorus fertilizer, PSB, VAM, soil fertility, grain yield and finger millet.

INTRODUCTION

Finger millet (Eleusine coracana L.) is an essential small millet crop that holds significant importance, particularly among small-scale farmers engaged in subsistence farming. However, its productivity is hindered by limited fertilizer inputs in regions characterized by low nutrient availability. This predicament is particularly prevalent in the resource-constrained soils of tropical and sub-tropical areas in India, where finger millet is predominantly cultivated. Despite these challenges, finger millet stands out as a nutritional powerhouse, showcasing superiority in certain nutritional components when compared to major cereal crops, including polished rice. Noteworthy attributes of finger millet include its elevated calcium content (0.38%), considerable fiber content (18%), significant levels of phenolic compounds (0.3–3%), and the presence of sulfur-containing amino acids. This nutritional profile makes finger millet a vital contributor to food security, especially among economically disadvantaged farmers and rural populations.However, a critical challenge faced by finger millet farmers revolves around the inherent deficiency of soil phosphorus in areas where the crop is traditionally grown. Phosphorus, as a pivotal nutrient, plays an indispensable role in enhancing the yield of finger millet. A potential solution to this problem lies in the application of biofertilizers, which have the capacity to solubilize insoluble phosphates in the soil, thereby enhancing nutrient availability. Recognizing that fertile soil is the cornerstone of sustainable crop production, it becomes evident that long-term productivity cannot solely rely on chemical fertilizers.

Mycorrhiza fungi, a group of ubiquitous soil microorganisms, offer a promising avenue for addressing the nutrient uptake challenges faced by finger millet. These fungi are known for their ability to improve plant growth by facilitating nutrient absorption, particularly phosphorus. In light of these considerations, our study aims to comprehensively investigate the synergistic effects of phosphatic fertilizer and biofertilizers, specifically phosphate-solubilizing bacteria (PSB) and vesicular arbuscular mycorrhiza (VAM), on both soil properties and finger millet yield.

In light of the importance of finger millet in sustaining rural diets and its challenges posed by low soil phosphorus, our research endeavors to provide valuable insights into sustainable agricultural practices. By examining the multifaceted role of phosphatic fertilizers and biofertilizers in enhancing soil fertility and crop productivity, we hope to contribute to the long-term well-being of small-scale farmers and the communities they support**.**

MATERIAL AND METHODS

A experiment was conducted during *kharif*, 2018 at Agricultural Research Station, Perumallapalli, Tirupati, Acharya N.G. Ranga Agricultural University, Andhra Pradesh, India, which is geographically situated at 13° 36'761''N latitude and 79° 20' 704''E longitude with an altitude of 182.9 m above the mean sea level, which falls under Southern Agro Climatic Zone of Andhra Pradesh. During the crop growth period the weekly maximum temperatures ranged from 32.0 to 37.2°C with an average of 34.6°C, while the weekly minimum temperatures ranged from 22.2 to 27.1°C with an average of 24.6°C. The total sunshine hourswere 66 hours with an average of 3.9 h day^{-1}. The total rainfall received during the crop growth period was 272.7 mm during*kharif*, 2018. The experiment was laid out in a randomized block design and replicated thrice with nine (9) treatments. The treatmentsconsists of T_1:No Phosphorus, T_2 : 100 % Recommended dose of phosphorus (RDP), T_3 : 125 % RDP, T_4 : 100 % RDP + Phosphorus Solubilizing Bacteria @ 750 ml ha^{-1}(PSB), T_5 : 100 % RDP + Vesicular Arbuscular Mycorrhizae @ 12.5 kg ha^{-1}(VAM), T_6 : 100 % RDP + PSB + VAM, T_7 : 75 % RDP + PSB, T_8 : 75 % RDP + VAM, T_9 : 75 % RDP + PSB + VAM.The recommended dose of nitrogen and potassium were applied in the form of urea and muriate of potash as basal. Phosphorus was applied in the form of single super phosphate as per treatments. PSB and VAM were thoroughlymixed with 100 kg FYM and applied as per treatments at the time of sowing.

The soil samples were collected randomly from 0 to 15 cm depth at initial and after harvest. The soil samples were shade dried, pounded and sieved through 2 mm sieve (0.5 mm sieve for organic carbon)and analysed for its physico-chemical and chemical properties by using standard procedures. The pH of the soil was determined in 1:2.5 (soil:water) suspension by using a digital pH meter (Jackson~~,1973~~1967). The electrical conductivity of the soil saturation extract was determined with the help of a Wheatstone conductivity bridge (Jackson~~,1973~~1967). Organic carbon in soil was determined by methods described by Walkley and Black (1934). The available nitrogen was estimated by the alkaline permanganate method by Subbiah and Asija (1956). The available phosphorusin soil was describe by Olsen *et al*. (1954).The available potassium of the soil samples was extracted with neutral normal ammonium acetate solution. Exchangeable calcium and magnesium was extracted with neutral ammonium acetate and determined by titrating with 0.01 *N* EDTA as per procedure out lined by Jackson (~~1973~~1967). Available sulphur in soil samples was extracted with 0.15 per cent $CaCl_2.2H_2O$ (Williams and Steinberg's, 1959). DTPA extractable micronutrients were determined by using atomic absorption spectrophotometer (Varian AA 240 FS). Crop was harvested after attained physiological maturity and grain yield was recorded and expressed in kg ha^{-1}.

Initial experimental soil was sandy loam in texture, slightly alkaline in reaction, low in organic carbon and nitrogen, non saline nature, medium in available phosphorus and potassium, sufficient in DTPA extractable micronutrients. Initial soil properties of experimental field was presented in table 1.

STATISTICAL DATA 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 percent 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

Physico-Chemical properties

The application of phosphatic fertilizer, PSB, and VAM displayed no significant impact on the physico-chemical properties of the soil, including pH, electrical conductivity (EC), and organic carbon (OC). Among the treatments, the highest soil pH (7.77) was observed in plots treated with 75% recommended dose of phosphorus (RDP) along with PSB at a rate of 750 ml per hectare (T7), while the lowest pH (7.55) was recorded in plots without any phosphorus application (T1). The electrical conductivity (EC) values ranged from 0.409 dS m-1 in plots without phosphorus (T1) to 0.477 dS m-1 in plots treated with 75% RDP along with VAM at 12.5 kg per hectare (T8). In terms of soil organic carbon (OC), the highest content (0.39%) was

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registered in plots treated with 100% RDP, PSB at 750 ml per hectare, and VAM at 12.5 kg per hectare (T6). Conversely, the lowest OC content (0.36%) was observed in plots without phosphorus (T1) and those treated with 100% RDP (T2) (Table 2).The results emphasize that the tested combinations of phosphatic fertilizer, PSB, and VAM did not induce any significant alterations in the soil's fundamental physico-chemical attributes. These findings provide insights into the stability of these properties under the specific experimental conditions, further contributing to the understanding of the intricate relationship between nutrient management practices and soil characteristics.

Chemical properties

Chemical properties *of* , available nitrogen, phosphorus and potassium were significantly influenced by phosphorus management practices at harvest was presented in table 2.

Available Nitrogen

The investigation into available nitrogen content in the soil yielded significant variations across the treatments. Remarkably, the application of 100% recommended dose of phosphorus (RDP) in conjunction with phosphate-solubilizing bacteria (PSB) at a rate of 750 ml per hectare and vesicular arbuscular mycorrhiza (VAM) at 12.5 kg per hectare (T6) resulted in the highest available nitrogen content (150 kg ha-1). This effect was particularly pronounced and significantly exceeded other treatments. Following closely, treatment T4 involving 100% RDP and PSB (T4) exhibited a nitrogen content similar to T6, while treatment T9 (75% RDP + PSB + VAM) shared this significance level. In contrast, the lowest available nitrogen content (117 kg ha-1) was observed in plots where no phosphorus was applied (T1). The exceptional nitrogen availability in T6 can likely be attributed to the positive response of soil nitrogen, phosphorus, and potassium levels due to phosphorus application. The heightened build-up of these nutrients corresponded to increasing phosphorus levels. Moreover, phosphorus bacterial activity potentially prompted the release of organic acids and hormones, thereby facilitating not only the solubilization and mineralization of phosphorus, but also the release of available nitrogen within the rhizosphere. Additionally, VAM contributed to elevated nitrogen content by aiding organic matter decomposition. These findings align with the outcomes reported by Ramakrishnaiah and Vijaya (2013) and Venkatarao et al. (2017).

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Available Phosphorus

The manipulation of phosphorus management practices exerted a significant influence on available P2O5 content post-harvest. The application of 100% RDP alongside PSB and VAM (T6) led to the highest available phosphorus content (42.74 kg ha-1), a level on par with T4, T5, and T7 treatments. Conversely, plots receiving no phosphorus treatment (T1) recorded the lowest available phosphorus content (33.95 kg ha-1). The augmented available P2O5 content resulting from the combined application of phosphorus fertilizer, PSB, and VAM is attributed to direct phosphorus addition, as well as the solubilization of native phosphorus through the release of various organic acids during microbial processes. These acids serve to solubilize tricalcium phosphate into monocalcium phosphate, a more readily accessible form for plant uptake (**Kamble** et al., 2018).

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Available Potassium

The interplay of phosphorus fertilizer, PSB, and VAM distinctly affected available K2O status after harvest. Remarkably, the highest available potassium content (227 kg ha-1) was achieved in plots treated with 75% RDP, PSB, and VAM (T9), comparable in significance to T7, T3, T8, and T6. Conversely, the treatment without phosphorus (T1) exhibited the lowest available potassium content (196 kg ha-1). The heightened availability of K2O in T9 may be attributed to direct potassium addition to the soil's available pool, and the positive influence of PSB and VAM on available potassium content. These biofertilizers potentially released organic acids through microbial activity, which in turn mobilized non-exchangeable forms of potassium, enriching the soil solution with readily available potassium ions. These findings corroborate previous studies conducted by Sharma et al. (2003) and are consistent with the findings of Vajantha and Subbarao (2017).These results emphasize the complex and synergistic interactions between phosphorus management practices, biofertilizers, and soil nutrient dynamics, underscoring the importance of adopting holistic approaches to enhance soil nutrient availability and subsequent crop performance.

Secondary Nutrients

Exchangeable calcium (Ca) and magnesium (Mg) in the soil exhibited no significant changes as a result of phosphatic fertilizer and biofertilizer applications. The highest levels of exchangeable Ca and Mg (3.00 and 1.93 meq 100 g-1, respectively) were observed in plots treated

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with 100% RDP in combination with PSB and VAM (T6). Conversely, the lowest levels (2.55 and 1.60 meq 100 g-1, respectively) were found in plots without phosphorus treatment (T1).

Available sulfur (S), on the other hand, was notably influenced by the application of phosphatic fertilizer and biofertilizers. The application of 100% RDP with PSB and VAM (T6) resulted in the highest available S content (9.57 mg kg-1), a trend closely followed by 125% RDP (T3), 75% RDP with VAM (T8), and 75% RDP with PSB (T7). The lowest available S content (7.69 mg kg-1) was observed in plots without phosphorus (T1). The remarkable enhancement of available S through the combined application of 100% RDP, PSB, and VAM can be attributed to the addition of sulfur through single super phosphate (SSP), a common phosphatic fertilizer source. Additionally, VAM fungi's expansive hyphal network in the soil can contribute a substantial amount of sulfur by accessing a wider soil area. This phenomenon is consistent with the observations of Pramanik and Bera (2013).

DTPA Extractable Micronutrients

Among the DTPA extractable cationic micronutrients, including iron (Fe), zinc (Zn), and copper (Cu), only manganese (Mn) demonstrated significant variation due to phosphorus and biofertilizer treatments. The application of 100% RDP with PSB and VAM (T6) yielded the highest DTPA extractable Fe, Zn, and Cu (6.38, 1.15, and 1.63 mg kg-1, respectively), while the lowest levels (4.67, 0.95, and 1.46 mg kg-1, respectively) were found in plots without phosphorus (T1). Notably, DTPA extractable Mn content exhibited significant variations among treatments. The highest DTPA extractable Mn content (38.67 mg kg-1) was registered in plots treated with 100% RDP, PSB, and VAM (T6), whereas the lowest level (31.32 mg kg-1) was observed in plots without phosphorus (T1). The augmented DTPA extractable Mn content with T6 application may be attributed to the influence of biofertilizers on plant nutrient dynamics, particularly ~~less~~fewer mobile nutrients in the soil solution, facilitated by their extensive hyphal network. This is in line with the findings of Sharma et al. (2003).

Grain Yield

The grain yield of finger millet was notably affected by the combination of phosphatic fertilizer and biofertilizers. The application of 100% RDP with PSB and VAM (T6) resulted in the highest grain yield (4328 kg ha-1), followed by 75% RDP with PSB and VAM (T9), while the lowest yield (3692 kg ha-1) was found in plots without phosphorus (T1). The superior grain yield with T6 treatment is likely due to improved nutrient supply, enhanced root activity, and superior nutrient absorption, leading to better overall plant growth and higher yield attributes. The contribution of biofertilizers (PSB and VAM) further ~~increased~~increase the efficiency of chemical fertilizers, supported by controlled nutrient release through microbial activity. These findings align with studies by **Abbasi** and Yousra (2012), **Acharya** et al. (2012), and Kejiya et al. (2019).

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Conclusion

In conclusion, the most effective phosphorus management practice for achieving sustainable grain yield and soil fertility was the combined application of 100% RDP with PSB and VAM (T6), closely followed by 75% RDP with PSB and VAM (T9). This study underscores the importance of integrated nutrient management strategies in optimizing crop yield and maintaining soil fertility, offering valuable insights for agricultural practices aiming at enhancing productivity while ensuring long-term sustainability.

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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. Physico-chemicalcharacteristics	
Soil pH (1:2.5 Soil water suspension)	7.62
EC (dS m^{-1}) at 25^{O} C	0.40
C. Chemical characteristics	
Organic carbon (%)	0.33
Available N (kg ha^{-1})	120
Available P_2O_5 (kg ha^{-1})	43.8
Available K_2O (kg ha^{-1})	218
Exchangeable Ca (meq 100 g^{-1})	2.53
Exchangeable Mg (meq 100 g^{-1})	1.63
Available S (ppm)	7.31
DTPA extractable Fe (mg kg^{-1})	1.50
DTPA extractable Mn (mg kg^{-1})	33.84
DTPA extractable Zn (mg kg^{-1})	5.05
DTPA extractable Cu (mg kg^{-1})	1.05

Table 2. Physico-chemical and chemical properties of soil after harvest of finger millet as influenced by phosphatic fertilizer and biofertilizers

Treatments	pH	EC (dS m^{-1})	OC (%)	Available nitrogen (kg ha^{-1})	Available P_2O_5 (kg ha^{-1})	Available K_2O (kg ha^{-1})
T_1	7.55	0.409	0.36	117^{b}	33.95^{c}	196^{c}
T_2	7.58	0.460	0.36	121^{ab}	35.75^{bc}	201^{bc}
T_3	7.72	0.448	0.37	125^{ab}	40.65^{ab}	226^{a}
T_4	7.66	0.447	0.37	142^{ab}	42.34^{a}	213^{abc}
T_5	7.73	0.410	0.38	125^{ab}	41.77^{a}	219^{ab}
T_6	7.66	0.452	0.39	150^{a}	42.74^{a}	222^{a}
T_7	7.77	0.428	0.38	134^{ab}	41.72^{a}	226^{a}
T_8	7.73	0.477	0.37	129^{ab}	40.63^{ab}	224^{a}
T_9	7.61	0.418	0.38	138^{ab}	38.88^{ab}	227^{a}
F value	1.13	0.26	0.40	1.94*	3.85*	3.68*
p-value	0.393	0.969	0.903	0.023	0.010	0.013

* 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)

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Table 3. Secondary nutrients and DTPA extractable micronutrients in soil as influenced by phosphatic fertilizer and biofertilizers in finger millet

Treatments	Exchangeable calcium (meq 100 g^{-1})	Exchangeable magnesium (meq 100 g^{-1})	Available sulphur (mg kg^{-1})	DTPA extractable Micronutrients (mg kg^{-1})			
				Iron	**Manganese**	**Zinc**	**Copper**
T_1	2.55	1.60	7.69^{c}	4.67	31.32^{c}	0.95	1.46
T_2	2.70	1.73	8.07^{bc}	4.70	34.07^{bc}	0.97	1.50
T_3	2.83	1.78	9.39^{ab}	5.84	34.41^{bc}	0.98	1.51
T_4	2.60	1.77	8.85^{abc}	6.07	34.50^{bc}	1.04	1.56
T_5	2.65	1.85	8.64^{abc}	6.16	35.96^{ab}	1.02	1.52
T_6	3.00	1.93	9.57^{a}	6.38	38.67^{a}	1.15	1.63
T_7	2.64	1.62	9.24^{ab}	5.88	35.95^{ab}	1.03	1.55
T_8	2.73	1.83	9.37^{ab}	5.13	34.73^{abc}	0.99	1.52
T_9	2.80	1.89	8.75^{abc}	6.20	37.15^{ab}	1.10	1.61
F value	2.39	0.92	1.79*	2.57	2.87*	2.41	1.52
p-value	0.065	0.521	0.025	0.061	0.034	0.064	0.256

* 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 4. 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)	