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Improving Groundnut Productivity in Coastal Soils with Different Textures Through Application of Nanophosphorus and Microbial Inoculants

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ABSTRACT

To improve yield of groundnut in coastal areas through application of nanophosphorus and microbial inoculants, two field experiments were conducted at farmers' field in sandy clay loam texture of North Pichavaram village, Parangipettai block and sandy texture of Vanagiri village, Sirkali block during *Rabi* of 2022- 2023. The experimental treatments encompassed six levels of nanophosphorus (0, 200, 400, 600, 800 and 1000 ppm) and two types of microbial inoculants (Phosphorus Solubilizing Bacteria @ 5 Kg ha^{-1} (PSB) and Arbuscular Mycorrhiza (AM) @ 5 Kg ha^{-1}). These treatments were laid in factorial randomized block design yielding eighteen treatment combinations with three replications. The yield parameters namely number of pods per plants, hundred seed weight and shelling percentage and yield of pod, kernel and haulm yield were recorded. The outcome of the field experiments showed that nanophosphorus or microbial inoculants or both caused significant increase in yield parameters and yield over control. In the case of nanophosphorus levels, the highest pod yield (2839 and 2497 kg ha^{-1}), kernel yield (2208 and 1909 kgha^{-1}), and haulm yield (3010 and 2629 kg ha^{-1}) were achieved with nanophosphorus @ 1000 ppm in sandy clay loam and sandy soils, respectively. With microbial inoculants, Arbuscular Mycorrhiza (AM) @ 5 kg ha^{-1} resulted in the highest yield of 2732 and 2395 kg ha^{-1}by pod, 2098 and 1784 kg ha^{-1} by kernel and 2984 kg ha^{-1} and 2531 kg ha^{-1} by haulm in both textured soils, respectively. The most favorable outcomes were observed when AM was combined with nanophosphorus at 1000 ppm, leading to the highest pod yield (2921 and 2537 kg ha^{-1}), kernel yield (2297 and 1969 kg ha^{-1}), and haulm yield (3037 and 2651 kg ha^{-1}) in both sandy clay loam and sandy-textured soils, respectively. In summary, the research indicates that the synergistic use of nanophosphorus at a concentration of 1000 ppm along with Arbuscular Mycorrhiza (AM) fungi @ 5 kg ha^{-1} could be more effective approach for enhancing higher yield of groudnut in coastal regions.

Key words: *Groundnut, Coastal soil, Yield, Nanophosphorus, Microbial inoculants,*

Introduction

Agriculture plays a pivotal role in ensuring global food security and economic sustainability. As the global population continues to burgeon, the demand for food crops intensifies, necessitating innovative strategies to enhance crop productivity. Groundnut (*Arachis hypogaea* L.), commonly known as peanut, is a vital oilseed crop worldwide due to its high protein and oil content. India is second largest producer of groundnut in world next to china contributes 22% to the world production. Majority of groundnut production in India lies in the coastal area in which Saurashtra of Gujarat shares the major portion. Coastal soils, characterized by their unique physico-chemical properties of sandy texture, poor water and nutrient holding capacity, salinity, deficiency of nutrients and environmental challenges, often pose limitations to crop growth and yield (Arulmathi and Porkodi, 2020). However, the convergence of modern agricultural advancements, such as nanotechnology and microbial inoculants, presents an exciting avenue to address these challenges and boost groundnut production in coastal regions.

Nanotechnology has revolutionized various sectors, including agriculture, by offering novel tools and materials for crop improvement. One such innovation is nanophosphorus, which involves the utilization of nano-sized particles of phosphorus to enhance nutrient uptake, improve soil structure, and promote overall plant growth (Mikhak *et al.,* 2017). Coastal soils, typically low in essential nutrients like phosphorus, can greatly benefit from the precise and efficient delivery of nutrients provided by nanophosphorus. The application of nanophosphorus in groundnut cultivation holds promise as a sustainable means to counteract nutrient deficiencies and increase yields in coastal regions (Hagab *et al.,* 2018).

Furthermore, microbial inoculants, consisting of beneficial microorganisms like bacteria and fungi, have garnered attention for their ability to form symbiotic relationships with plants, aiding in nutrient acquisition, disease resistance and stress tolerance. Coastal soils, often prone to salinity and other adverse conditions, can be rejuvenated by the introduction of these microbial allies. When combined with nanophosphorus, microbial inoculants offer a synergistic approach to optimize groundnut growth by improving soil health, nutrient availability, and plant-microbe interactions. The objective of this research is to examine how the application of nanophosphorus and microbial inoculation can positively influence groundnut yield in coastal saline soils. Our working hypothesis is that these bio-inoculants, in combination, can enhance groundnut growth and productivity by mitigating the adverse impacts of soil salinity.

Materials and Methods

Field experiments were conducted during the Rabi season of 2022-2023 in two different farmers' fields, one in North Pichavaram village of Parangipettai block in sandy clay loam and the other in Vanagiri village of Sirkali block in sandy textures. The experimental soil characteristics were as follows: pH levels of 7.99 and 8.39, electrical conductivity (EC) of 2.15 and 4.01 dSm^{-1}, organic carbon content of 2.30 and 1.40 g kg^{-1}, available nitrogen content of 156.32 and 135.56 kg ha^{-1}, available phosphorus content of 9.32 and 7.75 kg ha^{-1}, available potassium content of 173.74 and 156.48 kg ha^{-1}, and available sulphur content of 6.15 and 5.95 mg kg^{-1}, respectively at parangipettai and sirkali block soils.The experiments were carried out using a randomized block design with factorial concept and included the following treatments: six different levels of nanophosphorus (0, 200, 400, 600, 800, and 1000 ppm) and three types of microbial inoculants (control, PSB applied at 5 kg ha^{-1}, and AM applied at 5 kg ha^{-1}). These treatments were replicated three times, and groundnut variety CG7 was chosen as the test crop. All treatment plots received the recommended dose of fertilizer, consisting of 17:54 kg of N and K_2O per hectare, except for the control plot. The fertilizer application was carried out as follows: the full dose of potassium, PSB at 5 kg ha^{-1}, and half of the nitrogen dose were applied as a basal application. The remaining nitrogen dose was top-dressed at the flowering and pegging stages. AM at 5 kg ha^{-1} was applied by mixing it with enriched farmyard manure (FYM) after seedling emergence around the root surface. Nanophosphorus was applied as a foliar spray at both the pre-flowering and flowering stages of groundnut.After harvest, various yield parameters, including the number of pods $plant^{-1}$, hundred-kernel weight, shelling percentage, and the yield of pods, kernels, and haulm, were recorded. Statistical analysis was performed following the procedure described by Sheoran *et al.* (1998) at a significance level of 5%.

Results and Discussion

Yield parameters

The application of nanophosphorus and microbial inoculants, in conjunction with the recommended nitrogen and potassium doses, had a significant impact on yield parameters such as shelling percentage and number of pods per plant in both sandy clay loam and sandy textured soils, as shown in Table 1.

Meanwhile hundred kernel weight was not influenced by treatments (Table 1). Yield parameters displayed a linear increase with the increasing dose of nanophosphorus. The maximum shelling percentage (77.76 and 76.44%) and number of pods plant^{-1} (21.95 and 18.88) were achieved when foliar spraying was done using 1000 ppm of nanophosphorus applied twice in both sandy clay loam and sandy texture soils, respectively. This performance was comparable to using 800 ppm nanophosphorus but significantly better than all other nanophosphorus levels. Regarding microbial inoculants, applying AM fungi @ 5 kg ha^{-1} led to the highest shelling percentage (76.71 and 74.31%) and number of pods per plants (20.51 and 17.69) in sandy clay loam and sandy soils, respectively. This result was significantly superior to using PSB @ 5 kg ha^{-1}. With considering the interaction effect between nanophosphorus and microbial inoculants, it was evident that the number of pods per plant and shelling percentage showed a significant response. The combination of applying nanophosphorus at 1000 ppm and AM fungi at 5 kg ha^{-1} resulted in the highest number of pods plant^{-1}, with values of 22.98 in sandy clay loam and 19.38 in sandy soil and shelling percentage of 78.64% in sandy clay loam and 77.62% in sandy soils. These results were statistically comparable to the combinations of 800 ppm nanophosphorus and AM fungi at 5 kg ha^{-1} in both type of soil textures.

The foliar application of nutrients provides a swift and efficient means of facilitating the rapid uptake of essential elements during periods of fast plant growth (Niu *et al.*, 2021). Nanoparticles with a size of less than 10nm, when applied to the leaves, can penetrate through the plant's cuticle and follow the symplastic route to access cellular levels via the phloem. They tend to accumulate in various parts of the plant, including roots, stems, fruits, and young leaves (Peìrez-de-Luque, 2017). Furthermore, when nanoparticles are coated onto the leaf surface following foliar application, they have a positive impact on photosynthetic activity. This results in an increased production of carbohydrates, ultimately enhancing various yield parameters of the plants, as demonstrated by Smita *et al.,* 2012. Phosphorus, a crucial element in this process, plays a pivotal role in root development. Nanophosphorus promotes the formation of robust and extensive root systems, improving the plant's ability to access water and nutrients more efficiently. This enhanced root growth fa-

Table 1. Effect of nanophosphorus and microbial inoculants on yieldparameters of groundnut

	No.of pods per plant								Hundred seed weight (g)								Shelling percentage (%)							
	Sandy clay loam				Sandy				Sandy clay loam				Sandy				Sandy clay loam				Sandy			
	Control	PSB	AM	Mean	Control	PSB	AM	Mean	Control	PSB	AM	Mean	Control	PSB	AM	Mean	Control	PSB	AM	Mean	Control	PSB	AM	Mean
NP_0	10.01	13.91	16.94	13.62	9.55	12.09	14.73	12.12	45.04	45.60	45.75	45.46	45.04	45.60	45.75	45.46	62.48	71.52	73.26	69.09	62.02	67.63	70.01	66.55
NP_{200}	14.60	16.85	18.74	16.73	12.70	14.65	16.30	14.55	45.49	45.71	46.17	45.79	45.49	45.71	46.17	45.79	71.40	73.12	75.53	73.35	68.09	70.10	71.59	69.93
NP_{400}	15.62	17.74	20.44	17.93	13.58	15.42	17.77	15.59	45.68	46.08	46.65	46.12	45.68	46.08	46.65	46.12	72.78	74.80	75.95	74.51	70.43	71.94	73.67	72.02
NP_{600}	18.66	20.16	21.49	20.11	16.23	17.53	18.69	17.48	46.04	46.48	47.48	46.67	46.04	46.48	47.48	46.67	74.58	75.52	78.48	76.20	72.47	73.57	76.24	74.09
NP_{800}	20.12	21.24	22.45	21.27	17.31	18.27	19.28	18.29	46.57	47.40	47.64	47.21	46.57	47.40	47.64	47.21	75.53	77.41	78.40	77.11	75.01	76.07	76.74	75.94
NP_{1000}	20.91	21.96	22.98	21.95	18.18	19.10	19.38	18.88	47.29	47.46	47.84	47.53	47.29	47.46	47.84	47.53	76.97	77.67	78.64	77.76	75.15	76.56	77.62	76.44
Mean	16.65	18.64	20.51		14.59	16.18	17.69		46.02	46.45	46.92		46.02	46.45	46.92		72.29	75.01	76.71		70.52	72.65	74.31	
Factors	SE(m)		C.D.		SE(m)		C.D.		SE(m)		C.D.		SE(m)		C.D.		SE(m)		C.D.		SE(m)		C.D.	
A	0.25		0.72		0.22		0.62		0.57		NS		0.56		NS		0.18		0.51		0.25		0.73	
B	0.18		0.51		0.15		0.44		0.40		NS		0.39		NS		0.12		0.36		0.18		0.52	
A X B	0.43		1.24		0.37		1.08		0.98		NS		0.96		NS		0.31		0.88		0.44		1.26	

cilitates more effective water and nutrient uptake, thereby supporting comprehensive crop development and ultimately resulting in higher yields (Yadav *et al.*, 2023). Furthermore, during the reproductive phase of plant growth, phosphorus is instrumental in influencing flower formation and pod development in groundnut crops. The application of nanophosphorus encourages more prolific flowering and enhances pod formation, ultimately leading to a significant increase in overall crop yields.

The observed increase in yield parameters can be attributed to the ability of Vesicular Arbuscular Mycorrhizae (VAM) to thrive in salinity-stressed conditions and their capacity to accumulate osmolytes, such as proline and sugars. These osmolytes play a crucial role in maintaining cellular water content (Kumar *et al.*, 2017). Moreover, VAM fungi stimulate root growth and development by enhancing phosphorus uptake, leading to the establishment of a more extensive and efficient root system. This well-developed root system enables plants to explore a larger soil volume for nutrients and water, ultimately resulting in improved yield parameters (Begum *et al.,* 2019). Additionally, the extension of VAM hyphae in the soil binds soil particles together, improving soil structure. This enhanced soil structure has several benefits, including better water infiltration, improved soil aeration, and increased nutrient availability (Lehmann *et al.*, 2017). The improved soil structure, facilitated by VAM hyphae, contributes to overall soil health and can positively impact groundnut crop yield parameters.

Yield (kg ha^{-1})

The individual and combined application of different levels of nanophosphorus and microbial inoculation exerted a significant influence on pod, kernel and haulm yields of groundnut in both sandy clay loam and sandy texture (Table 2). Among the different levels of nanophosphorus, foliar application of nanophosphorus @ 1000 ppm recorded the highest pod(2839 and 2497 kg ha^{-1}), kernel (2208 and 1909 kg ha^{-1}) and haulm (3010 and 2629 kg ha^{-1}) yield at sandy clay loam and sandysoils, respectively, however it was at par with 800 ppm nanophosphorus application. Application of nanophosphorus level @ 1000 ppm resulted in mean increase of pod yield of 26.68 and 22.10%, kernel yield of 41.63 and 39.75% and haulm yield of 25.62% and 25.61% over control in sandy clay loam and sandy textured soils. Nano

Table 2. Effect of nanophosphorus and microbial inoculants on yield of groundnut (kg ha^{-1})

	Pod yield (kg ha^{-1})							
	Sandy clay loam				Sandy			
	Control	PSB	AM	Mean	Control	PSB	AM	Mean
NP_0	1908	2340	2475	2241	1854	2092	2190	2045
NP_{200}	2338	2474	2600	2471	2087	2181	2285	2185
NP_{400}	2471	2597	2725	2598	2178	2272	2398	2283
NP_{600}	2585	2714	2799	2699	2263	2354	2440	2352
NP_{800}	2710	2782	2872	2788	2387	2449	2522	2453
NP_{1000}	2756	2839	2921	2839	2448	2504	2537	2497
Mean	2461	2625	2732		2203	2309	2395	
Factors	SE(m)		C.D.		SE(m)		C.D.	
A	18.05		52.64		16.44		47.93	
B	12.77		37.22		11.63		33.89	
A X B	31.27		91.17		28.48		83.02	

	Kernel yield (kg ha^{-1})							
	Sandy clay loam				Sandy			
	Control	PSB	AM	Mean	Control	PSB	AM	Mean
NP_0	1192	1673	1813	1559	1150	1415	1533	1366
NP_{200}	1669	1809	1963	1814	1421	1530	1636	1529
NP_{400}	1798	1942	2070	1937	1534	1635	1767	1646
NP_{600}	1928	2049	2196	2058	1640	1732	1861	1744
NP_{800}	2047	2153	2252	2151	1790	1863	1935	1862
NP_{1000}	2121	2205	2297	2208	1840	1918	1969	1909
Mean	1727	1972	2098		1562	1681	1784	
Factors	SE(m)		C.D.		SE(m)		C.D.	
A	22.24		64.20		16.39		44.47	
B	15.73		45.40		11.59		31.44	
A X B	38.53		111.20		28.39		77.02	

	Haulm yield (kg ha^{-1})							
	Sandy clay loam				Sandy			
	Control	PSB	AM	Mean	Control	PSB	AM	Mean
NP_0	2180	2411	2598	2396	1897	2110	2273	2093
NP_{200}	2307	2618	2796	2574	2019	2290	2446	2252
NP_{400}	2554	2791	2899	2748	2234	2442	2537	2405
NP_{600}	2824	2910	3011	2915	2464	2544	2635	2547
NP_{800}	2907	2965	3025	2966	2543	2594	2647	2595
NP_{1000}	2978	3014	3037	3010	2602	2634	2651	2629
Mean	2625	2785	2894		2293	2436	2531	
Factors	SE(m)		C.D.		SE(m)		C.D.	
A	16.81		49.02		15.25		44.47	
B	11.89		34.66		10.79		31.44	
A X B	29.12		84.91		26.42		77.02	

Where, NP_0- Nano Phosphorus – 0 ppm, NP_{200}- Nano Phosphorus – 200 ppm, NP_{400}- Nano Phosphorus – 400 ppm, NP_{600}- Nano Phosphorus – 600 ppm, NP_{800}- Nano Phosphorus – 800 ppm, NP_{1000}-Nano Phosphorus – 1000 ppm fertilzers or nano-encapsulated nutrients have the properties that are effective to crops, release the nutrients on-demand, controlled release of chemicals fertilizers that regulate plant growth and enhanced target activity (DeRosa *et al.,* 2010). In a study by Drostkar *et al.* (2016), it was found that applying NPK fertilizers through foliar application led to an increase in chickpea seed yield under rainfed conditions. Additionally, Hagab *et al.* (2018) reported that the utilization of nanophosphorus improved phosphorus efficiency in sandy soils. This improvement was attributed to better phosphorus interception, absorption, and utilization throughout the plant's growth cycle. As a result, groundnut plants exhibited a higher photosynthetic rate and ultimately accumulated more biomass yield. This is relevant with findings of Dhoke *et al.,* (2013) and Hasaneen *et al.* (2016).

Among microbial inoculants, application of AM fungi @ 5 kg ha^{-1} recorded significantly the highest pod yield (2732 kg ha^{-1} at sandy clay loam and 2395 kg ha^{-1} at sandy soils), kernel yield (2098 kg ha^{-1} at sandy clay loam and 1784 kg ha^{-1} at sandy) and haulm yield (2984 kg ha^{-1} at sandy clay loam and 2531 kg ha^{-1} at sandy soils),which is significantly superior to PSB @ 5 kg ha^{-1} inoculated treatments. The result showed that application of microbial inoculants had increased the pod yield of 11.01% and 8.71%, kernel yield of 21.48 and 14.21% and haulm yield of 10.25% and 10.37% by AM fungi compared to soil without microbial inoculant at both textured soils, respectively. The research findings indicate that VAM (vesicular-arbuscular mycorrhizae) has proven to be more effective than PSB (phosphate-solubilizing bacteria) in enhancing crop yields, and this improvement was observed in both types of soils. PSB's positive impact on yield can be attributed to its ability to convert insoluble phosphorus into a soluble form, as well as its capacity to enhance root activity and nutrient uptake in plants (Cheng *et al.,* 2023). On the other hand, VAM inoculation is known to expand its hyphal network within the soil, effectively mobilizing nutrients that might be unevenly distributed, thus making them more available to plants (Huey *et al.,* 2020). Furthermore, when microbial inoculants are applied to groundnut plants, they exhibit a robust mechanism for managing salt ions like sodium and chloride. This mechanism involves limiting the uptake of these ions by plants and sequestering them within fungal structures. Studies conducted by Abdel-Fattah and Asrar (2012) and Selvakumar *et al.* (2014) have shown that this strategy reduces the detrimental effects of salinity on groundnut plants, allowing them to grow more effectively and yield higher harvests. These findings are in line with the research by Wahane *et al.* (2022), who also reported increased groundnut yields in coastal regions of Maharashtra through the inoculation of both PSB and VAM.

In combined effect, the maximum pod yield of 2921 kg ha^{-1} and 2537 kg ha^{-1}, kernel yield of 2297 and 1969 kg ha^{-1} and haulm yield of 3037 kg ha^{-1} and 2651 kg ha^{-1}in sandy clay loam and sand soils was recorded with application of nanophosphorus @ 1000ppm along with AM fungi @ 5 kg ha^{-1}, respectively. It was at par with nanophosphorus @ 800ppm along with AM fungi @ 5 kg ha^{-1}. When nanophosphorus and AM (arbuscular mycorrhizal) fungi are combined, they act as an immediate nutrient source for groundnut plants, facilitating more efficient nutrient acquisition. The synergistic interaction between nanophosphorus and VAM shows promise in improving nutrient availability, root development, and stress tolerance, which could potentially lead to increased flowering, improved pod formation, and enhanced pod retention in groundnut plants (Ingle *et al.,* 2017; Mahawar and Prasanna, 2018).

It's worth noting that sandy clay loam soil, characterized by a balanced mixture of sand, silt, and clay particles, offers superior water retention, aeration, and nutrient-holding capacity compared to sandy soil, all of which are crucial for optimal plant growth. In sandy clay loam soil, mycorrhizal fungi extend their hyphae more effectively compared to sandy soil, enhancing nutrient uptake, especially phosphorus. Additionally, foliar application of phosphorus can enhance its uptake by groundnut plants directly through their leaves, which is particularly advantageous in sandy soils that typically have poor phosphorus retention.

Conclusion

The adoption of nanofertilizers and microbial inoculants holds significant promise for enhancing both productivity and sustainability in agriculture. These approaches excel in delivering nutrients efficiently while minimizing losses, thereby contributing to a reduction in environmental pollution compared to conventional fertilizers. Additionally, they assist in mitigating the detrimental effects associated with traditional fertilizer use and offer the prospect of long-term cost savings. Based on the outcomes of our experiment, it is evident that the combination of nanophosphorus at a concentration of 1000 ppm and AM fungi represents the optimal choice for fertilizing groundnut crops in coastal soil. This approach carries the potential to generate highly productive groundnut harvests even in the challenging conditions of coastal soil.

Conflict of Interest- None

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