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Research Article

Preparation of water hyacinth-based phosphocompost and its evaluation against certain phosphorus fertilizers along with phosphate solubilizing bacteria on P availability, uptake and rice productivity

Vignesh. D
Department of Soil Science and Agricultural Chemistry, Faculty of Agriculture, Annamalai University, Annamalainagar-608002 (Tamil Nadu), India
P. Senthilvalavan*
Department of Soil Science and Agricultural Chemistry, Faculty of Agriculture, Annamalai University, Annamalainagar-608002 (Tamil Nadu), India
M. V. Sriramachandrasekharan
Department of Soil Science and Agricultural Chemistry, Faculty of Agriculture, Annamalai University, Annamalainagar-608002 (Tamil Nadu), India
R. Manivannan
Department of Soil Science and Agricultural Chemistry, Faculty of Agriculture, Annamalai University, Annamalainagar-608002 (Tamil Nadu), India
C. Ravikumar
Department of Agronomy, Faculty of Agriculture, Annamalai University, Annamalainagar-608002 (Tamil Nadu), India

*Corresponding author. Email: senvalavan_m2002@yahoo.co.in

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Abstract

Phosphorus (P) deficiency in soil limits crop yields and can be managed by P fertilizers. But mere applying P fertilizers alone may not be effective in justifying its bioavailability. At present global P reserves are declining in an increasing way which urges us to find out alternatives. Thus, the present work was taken to prepare phosphocompost using water hyacinth *(Eichhornia crassipes*) as feedstock, termite, and normal soil as bulking agents cum decomposers and enriched with single super phosphate. The effect of phosphocompost on rice(var.ADT-43) productivity, P availability and uptake was evaluated by comparing various P fertilizers (single super phosphate, rock phosphate, di-ammonium phosphate, nano phosphate) combined with or without phosphate solubilizing bacteria (PSB). The experiment was laid out in a completely randomized design with seven treatments including absolute control and replicated thrice. Phosphocompost produced with water hyacinth and termite soil microbes come with superior quality and early maturity compared to normal soil. Pot culture study results revealed that rice growth, yield, P availability and uptake were significantly ($p<0.05$) higher with SSP + PSB, and Nano phosphate +PSB treated plants, followed by Phosphocompost + PSB. The cost of P fertilizer (Rs/ha) related to yield (kg/ha) was found to be significantly low with phosphocompost (Rs.1132/-) than SSP (Rs.1530/-) and Nano P (Rs.2518/-). Further, phosphocompost combined PSB helps in optimizing the P availability in a long run through P solubilization thus sustained the P uptake. The present investigation brings light to the valorization of water hyacinth as compost will be an effective and economically viable alternative for P fertilizers.

Keywords: Nano phosphate, Phosphocompost, Phosphorus solubilizing bacteria, Rice productivity, Single super phosphate, Termite soil microbes, Water hyacinth

INTRODUCTION

Crop plants struggle with growth and development and cannot achieve their full potential when nutrients are limited, especially phosphorus (P). P limitation represents the relative yield gap (Licker,2010; Mueller,2012), attributable to limited P availability for crops. P management is crucial to sustainable development goals (SDGs). Insight of the limited world phosphate rock reserves, the global P requirement over the coming century has become a major concern (Mogollon *et al*.,2018). Besides, the extensive use of P fertilizers is a threat to SDG 6 (clean water and sanitation) and SDG14 (life below water) due to P losses from agricultural fields through surface runoff and resulting eutrophication of freshwaters (Tiessen,1995). Though, the supply of P is crucial to food security (Koning,2008). Future P management will then play a vital role in achieving SDG 2 (zero hunger). Attaining this goal is vital as the global populace is expected to grow from 7.3 billion in 2015 to perhaps more than 10 billion population in 2050 (Samir and Lutz,2017). On the other hand, global food security and agricultural sustainability are being threatened as a consequence of the activities of human beings on earth.

Composting is one of the key management strategies frequently used for safe clearance of the remarkable amount of wastes continuously generated globally through anthropogenic activities. However, the significance of composting as a waste management choice covers copious benefits such as the greening of wastes, environmental friendliness, and its potential to guarantee a safe and sustainable future (United Nations Environment Program,2011). The use of composts as plant nutrient sources or as soil conditioners proved an age-long practice (Tognetti*et al*., 2011; Pan *et al*.,2012). Thus, it is regarded as one of the important low-cost inputs used for meeting nutrient requirements for plant growth and yield (Zameer*et al*., 2010). Compelled by global economic growth and development, bioconversions of agricultural, industrial, and aquatic wastes into useful value-added products have steadily increased. Recently scientists have shifted attention to investigating aquatic macrophytes as an alternative resource to be employed to solve societal problems. Water hyacinth is a fast-growing perennial aquatic plant found in freshwater bodies and wetlands which prefers nutrient-enriched water (Sakthika and Sornalakshmi,2019; Ayanda *et al*.,2020; Jain *et al*., 2019). It can cause infestations over large water surface areas and lead to problems in certain ecosystems. Therefore, the possibility of producing organic fertilizers from water hyacinth, an invasive aquatic weed (*Eichhornia crassipes*), is being considered globally. However, researchers are yet to fully explore *E. crassipes* as a resource (waste) with immense potential and to consider it being recycled or converted back into agriculture as a value-added product.

The amount of phosphorus available from composts is not the same. It varies with the percentage of total P available in the feedstock. Its release rate is influenced by compost maturity and stability, i.e. slow and less than 25 % of the total P content (Prasad,2009;Lanno*et al*.,2021). The maturity and stability of compost by maintaining the mineralizing ratio of carbon to other macronutrients like CN/CP/CS is a must concern. However, the widespread P-deficiency problem in the world soils due to the less native soil P is exacerbated by crop removal and deprived practices like using organic manures alone applied at low to suboptimal levels (Kutu,2012;Withers *et al*.,2015; Ramadhani*et al*.,2018). Thus, it is often required that substantial external P addition to satisfy crop demand and warranting the maximum yield. Regrettably, the problems of availability of P fertilizers (Food and Agricultural Organization, 2005) leads to a considerable decline in their use by farmers (Bationo*et al*.,2006;Nesme*et al*.,2011), creating a situation of huge yield losses and yield gaps eliciting food insecurity. So, there is a need to urgently identify and offer viable alternatives to the current costly inorganic P fertilizers used for crop production. Phospho-composting has been reported to offer the environmental advantage of the safe disposal of organic wastes (Hellal*et al*.,2013; Singh and Manna,2018). Single superphosphate (SSP) is the most widely used P fertilizer and its usage is increased tremendously for realizing the yield in different crops(Allen,2019). Hence, there shall be constraints on availing SSP by the farmers. So, enriching weed-based compost with SSP may be a crucial and viable option for reducing SSP use. Further, compost quality depends on feedstock, co-composting materials like bulking materials, and additives to enrich their quality and nutrient content.

Traditionally, rice has been a very stable food for two-thirds of the world's population. It necessitates the sustainability of much more intensive forms of rice cultivation and the associated potential changes in soil, water, and environment (Loko *et al*.,2022). More recently, concerns about climate change have reiterated the need to understand better the long-term consequences of cultivating rice throughout the world (Liu *et al*.,2021). Besides productivity, depletion and use efficiency macronutrients, especially phosphorus being a key nutrient element next to nitrogen in rice crop productivity(Khan *et al*.,2018), needs special care. Hence, assessing potential changes in the sustainability of P reserve in the soil is a must concern (Bindraban *et al*.,2020), and the availability and use of P fertilizers to rice producers for realizing the full-scale yield potential of rice under different soils. However, several researchers have reported composting water hyacinth with different co-composting materials and processes (Ogutu,2019; Roman *et al*.,2020). But studies on the composting of water hyacinth enriched single super phosphate and termite mound soil (naturally rich in microbes) as bulking material and decomposing agents are scanty. Therefore, the present study has been undertaken to develop phospho-compost using water hyacinth with single super phosphate and termite mound soil and compare different P fertilizer sources along with phosphate solubilizing bacteria (PSB) on the rice(Var. ADT-43) productivity in deep clay soil.

MATERIALS AND METHODS

Preparation of phosphocompost and a pot experiment was carried out at the pot culture yard of the Department of Soil Science and Agricultural Chemistry, Faculty of Agriculture, Annamalai University. The methodology followed in the experiment is presented as follows.

Preparation of water hyacinth compost (WHC)

Composting was carried out by pit and heap method at Department of Soil Science and Agricultural Chemistry, Faculty of Agriculture Annamalai University. Water hyacinth weeds were collected from Uppanar canal (11.38 N and 79.71 E), Annamalai University and dumped at the department backyard in pits and heaps for decomposition. Two different bulking materials, i.e. termite mound soil and normal field soil were added to the feedstock (air-dried, chopped water hyacinth material) to identify the time of the composting process. After composting, samples were analyzed for the most important physical and chemical parameters such as pH (Sanchez-Monedero*et al*., 2001)), C: N (Tandon,2005), moisture content (Richard *et al*.,2002), organic carbon (Yeomans and Bremner,1988), cation exchange capacity and electrical conductivity (Jean *et al*.,2004) and other parametersviz., macro and micro nutrient contents were inspected with standard methods.

Enrichment of WHC

The homogenous compost was combined with single super phosphate at 25 kg P_2O_5 ha^{-1} with 750 kg ha^{-1} WHC to produce phospho-compost. The phospho-compost obtained was used for further experiments (Table 2) and analyzed for total P using Spectrophotometer.

Response of various P fertilizer sources and phosphate solubilizing bacteria (PSB) on rice productivity, P availability and uptake

The pot culture experiment was carried out to evaluate the effect of various P sources along with phosphorus solubilizing bacteria (PSB) using rice as a test crop in

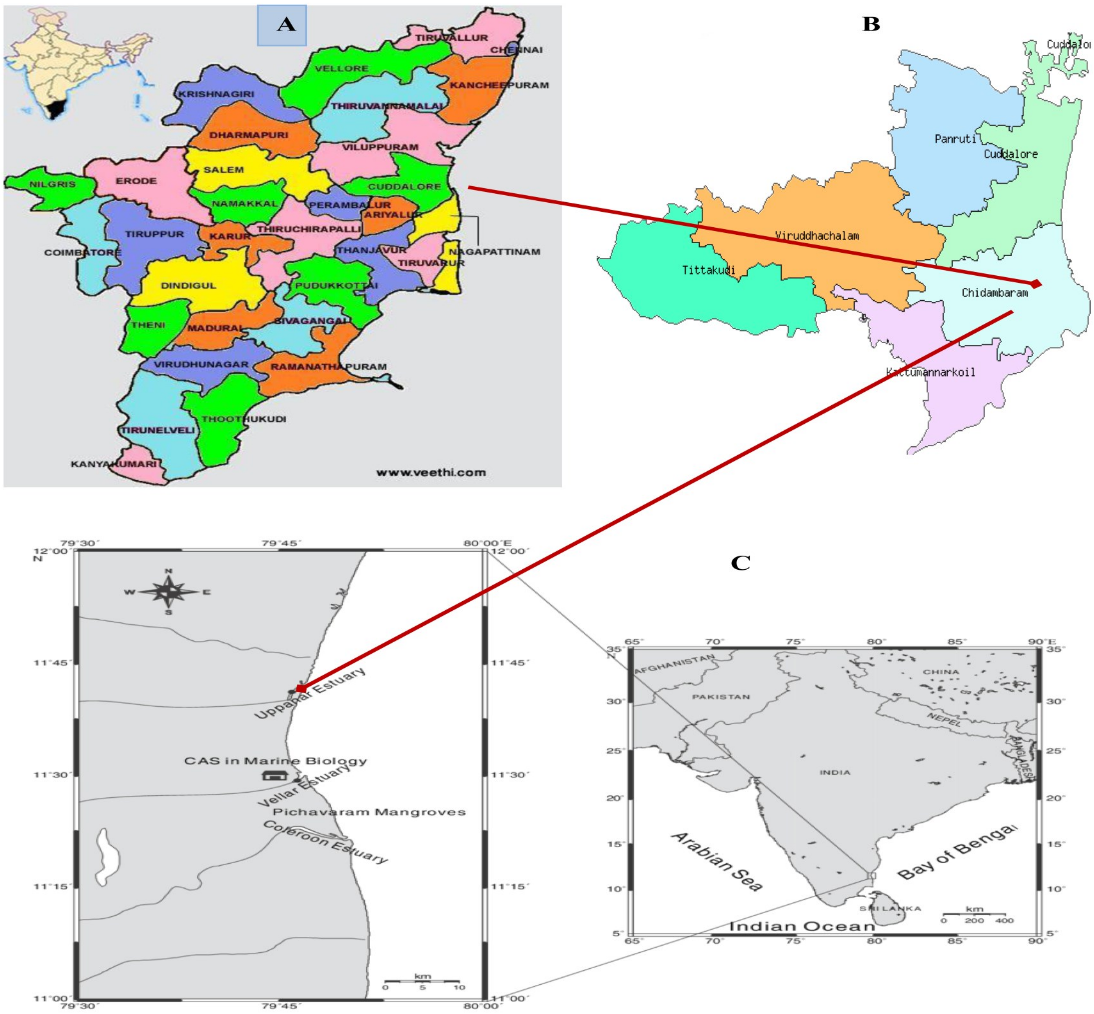

Fig.1. *Details of the experimental location maps, A).Location of the experimental site in Tamil Nadu (Cuddalore District) B).Location of the, experimental soil, and termite soil collection, C).Location of the aquatic weed (water hyacinth) collection [Uppanar location map adapted from Mondal et al.(2010)]*

Table 1. Physico-chemical and biological properties of soil and irrigation water characteristics of the experimental soil

Particulars	Details
Site location	Experimental Farm, AU
Soil series (Taxonomical)	*Typic Haplusterts*
Soil characteristics	
A. Physical properties (Mechanical analysis)	
Clay %	46.3
Silt %	22.2
Coarse sand %	14.2
Fine sand %	16.4
Texture	Clay
Bulk density (Mg m^{-3})	1.51
Particle density (Mg m^{-3})	2.30
Pore space (%)	34.35
Water holding capacity (%)	54.6 (56 ml/100 g of soil)
Chemical properties	
pH	7.46
EC (dSm^{-1})	0.51
Cation exchange capacity (cmol (P^+) kg $^{-1}$)	13.04
Organic carbon (%)	0.61
Available nitrogen (kg ha^{-1})	194
Available phosphorus (kg ha^{-1})	17.04
Available potassium (kg ha^{-1})	152

clay soil at pot culture yard in the Department of Soil Science and Agricultural Chemistry, Faculty of Agriculture, Annamalai University, Annamalainagar during June to September 2018.The climatic conditions of the study locations wereas the mean annual temperature varied from 22°C to 32°C. The mean summer (April–June) temperature varied from 32°C to 40°C, rising to a maximum of 42°C in May, and the mean winter (December–February) temperature varied from 15°C to 23°C. The mean annual rainfall varied from 450 to 950 mm covering 42–45% of the mean annual potential evapotranspiration (PET) ranging between 1300 and 1600 mm.Soil was collected from the experimental farm of the Faculty of Agriculture, Annamalai University and physicochemical properties of the experimental soil are presented in Table 1. Twenty-four kg of soil was taken in cement pot of 45 cm in height and45 cmin diameter. Before planting, soil in the pots was a well puddle and the calculated quantity of NPK fertilizers @ 150:50:50 kg $ha^{-1}$was applied on a dry weight basis. P sources (organic and inorganic) selected for the study were applied as per the treatment schedule (Table1). 1-2 seedlings of 8-10 days old were planted pot^{-1}. The soil in the pots was kept at 60 percent moisture by maintaining the water level through proper irrigation scheduling. Growth (plant height, dry matter production, number of $tillers^{-1}$,root length and root volume) parameterswere recorded at three distinct physiological stages of rice: Active tillering (AT), Panicle initiation (PI) and Harvest (H), yield parameters (number productive tillers $hill^{-1}$, panicle length, filled grains $panicle^{-1}$ and 1000 grain weight) and grain and straw yield were recorded at harvest and expressed as g pot^{-1}. The initial soil samples were analysed for both mechanical and chemical compositions (Table 1) following standard methods viz., soil pH was measured in the suspension of (1:2.5 soil: water) using pH meter, conductivity was measured in the same suspension using a conductivity meter and the cation exchange capacity was determined by Neutral normal ammonium acetate method (Jackson, 1973). The organic carbon content was determined by modified Chromic acid wet digestion titration method (Walkley and Black,1934). The available nitrogen (K) was determined by alkaline permanganate method (Subbiah and Asija, 1956). Available phosphorus (P) (using 0.5 M $NaHCO_3$ of pH 8.5) was quantified by the spectrophotometer method (Olsen *et al.*,1954). Available potassium (K) (using neutral normal ammonium acetate extract) was determined by Flame photometric method (Standford and English,1949).P content of plant in the digest was determined by Spectrophotometer and P uptake was computed by multiplying the grain and straw yield with respective P concentration. Location map of water hyacinth weed collection, experimental soil, and termite soil collection is given in Fig.1.

Table.2. Details of the treatments and experimental design

Treatments	Fertilizer doses	Statistical Design	: CRD
T_1	Absolute Control	Treatments	: 7
T_2	NK 100 % RDF + PSB	Replications	: 3
T_3	NK 100 % RDF + SSP + PSB	Number of pots	: 21
T_4	NK 100 % RDF + RP + PSB	Weight of soil pot^{-1}	: 24 kg
T_5	NK 100 % RDF + DAP + PSB	Duration of experiment	: 110 days
T_6	NK 100 % RDF + Nano P + PSB	RDF :150:50:50 kg NPK ha^{-1} Phospho compost @ 6.25 t ha^{-1}	
T_7	NK 100 % RDF + Phospho compost + PSB	$ZnSO_4$ @ 25kg ha^{-1} (applied to all the treatments except control).	

Statistical analysis

The data collected were statistically analyzed using SPSS statistical package version 11.0.All the parameters were analyzed by one-way ANOVA. The Duncan's multiple range test was used to segregate the significance of difference among the mean values obtained for observed parameters. The interpretation of treatment effects was made on the basis of critical difference at 5 % probability level.

RESULTS AND DISCUSSION

Properties of water hyacinth compost

Water hyacinth compost(WHC) prepared with bulking materials of normal soil and termite mound soil showed a significant difference(p=0.05) in nutrient content. Compared to normal soil, the termite mound soil added compost has shown higher nutrient contents. As indicated in Table 3, the data showed that the pH, EC was 7.2 and 6.9; 0.46 and 0.36 ds/m, respectively in normal soil (NS) in termite mound soil (TMS). The changes in pH and electric conductivity (EC) might be due to the microbial population and the nature of the soil (Rashad Ferial *et al*., 2010). Higher organic carbon, N,P, K and S content and Zn, Fe, Mn and Cu of the compost were significantly attributed by the use of TMS, which may consist of body fluids and excretion of mound construction and accumulated biomass as food reserves by termitorium compared to NS used compost.Further, the increase in nutrient contents during composting was caused by the decrease of substrate carbon resulting from the loss of CO_2 i.e. the decomposition of the organic matter (from water hyacinth), which is chemically bound with nutrient elements (Semhi*et al*.,2008).Further, quick decomposition occurred in TMS-treated FS and attained higher levels of ripeness and constancy much faster than NS. TMS addition significantly reduced the composting cycle to less than a month attributed dueto higher activity of microbial decomposers (Bacteria, fungi, actinomycetes) in TMS over NS. Time reduction in composting of WH with TMS might be due to quicker mineralization of FS materials into fully ripened compost caused by the type, nature and species of different microorganisms present in the termite mound soil.

Response of rice growth parameters to P sources

The pot experiment results of different treatments in rice revealed significant responses on growth attributes viz., plant height (PH), dry matter production (DMP) at panicle initiation (PI), active tillering(AT) and at harvest stages and a number of tillers at active tillering stage (AI). Among the different treatments T_3 (NK 100 % RDF + SSP + PSB) and T_6 (NK 100 % RDF + Nano P + PSB) were found to be superior and followed by T_7(NK 100 % RDF + Phospho compost + PSB) effective in increasing growth parameters over control and other treatments respectively (Table 4). The required bio availability of phosphorus from SSP and the added advantage of solubilizing native soil P by PSB might have enhanced rice growth (Zeng *et al*.,2009). And the similar effect was realized in the nano P added pots i.e. the enhanced bio-availability of P from added protein- lacto-gluconatednano P fertilizer for a longer duration along with the beneficial effects of PSB with its native P solubilization (Valojai*et al*., 2021). However, the nutrient contents, microbial consortia containing water hyacinth-based phospho-compost, phosphate solubilizing bacteria treated pot, proved to be the next best treatment in this experiment and the results are in conformity with the earlier findings of Benzon*et al*. (2015); Senthilvalavan and Ravichandran,(2016); and Senthilvalavan (2019).

Root parameters and P availability and uptake

Root length (cm) and root volume (cc hill^{-1})

Root length was significantly influenced by P sources along with PSB. In general, root length steadily increased from active tillering to panicle initiation stage and then slightly declined at harvest. Data related to root length are presented in Table 10. Among treatments, NK100 % RDF + SSP + PSB (T_3) recorded higher root lengths of 9.6,17.20,16.89 cm and it was on par with 100 % RDF + Nano P + PSB (T_6) followed by T_7 >T_5, T_4 (being on par with each other) and T_2 and the

Table 3. Pre and post compost properties of water hyacinth (*Eichhornia crassipes*)

Properties	pH	EC	C/N	OC	N	P	K	Ca	Mg	S	Zn	Mn	Fe	Cu
		ds/m		g /kg	%	%	%	%	%	%	mg/kg	mg/kg	mg/kg	mg/kg
WH Feed stock	6.2	0.32	-	0.18	1.29	0.28	0.86	0.61	0.49	0.4	20	9	84	1.4
Compost 1 (WH+NS)	7.2	0.46	18/1	0.59	0.66	0.81	1.14	2.3	1.0	0.9	34	12	122	3.1
Compost 2 (WH + TMS)	6.9	0.36	12/1	0.72	0.78	0.97	1.72	1.9	1.2	1.1	51	24	221	7.6

BM: bulking material, EC: Electrical conductivity, FS: Feed stock, OC: organic carbon, NS: Normal soil , TMS: Termite Mound Soil, WH: Water hyacinth lower root length was registered in T$_1$ (absolute control) (6.85,14.02,13.7 cm) at all stages, respectively. Similar trend was followed in root volume (Fig.2). Among treatments, NK100 % RDF + SSP + PSB (T$_3$) recorded maximum root volume of 17.90,27.80,29.03 cc hill^{-1} and it was on par with 100 % RDF + Nano P + PSB (T$_6$) followed by T$_7$ >T$_5$, T$_4$ (being on par with each other) and T$_2$ and the minimum root volume was registered in T$_1$ (absolute control) (12.93,19.84,21.43 cc hill^{-1}) at all stages, respectively. Roots are the absorbing part of plants; their growth is evident by plant vigor index and productivity. Root characters (length, distribution and especially root volume) help in revealing the crop water use and nutrient uptake pattern.

In general, root characters *viz.*, root length and root volume\gradually increase up to panicle initiation and decline later. In the present study AT, PI and at harvest stages, root characters like root length and root volume assessed were significantly improved by the application of P sources over control (Fig.2). This might be due to inoculation of PSB with P sources that helps in providing soil P for the plant growth especially root growth compared to non-inoculated one (Panhwar*et al.*,2010). Application of NK 100 %RDF +SSP or Nano P +PSB showed higher values of root characteristics than other P sources used in the experiment. Similar results have been reported by Banerjee and Pramanik (2009) and Bhattacharya *et al*. (2013)in rice tested with various P sources and levels. Other P sources plus PSB following in the order of phosphocompost> DAP >RP >PSB alone > absolute control at all the stages. These results are in conformity with those of Walpola and Yoon (2012), Sathya *et al*. (2013), Singh and Singh (2016)in rice with organic manures and fertilizer P sources.

Response of rice yield parameters and yield to P sources

Data on the number of productive tillers hill^{-1}, panicle length, filled grains panicle^{-1} and 1000 grain weight (g) are furnished in Table 5. Concrete variation among

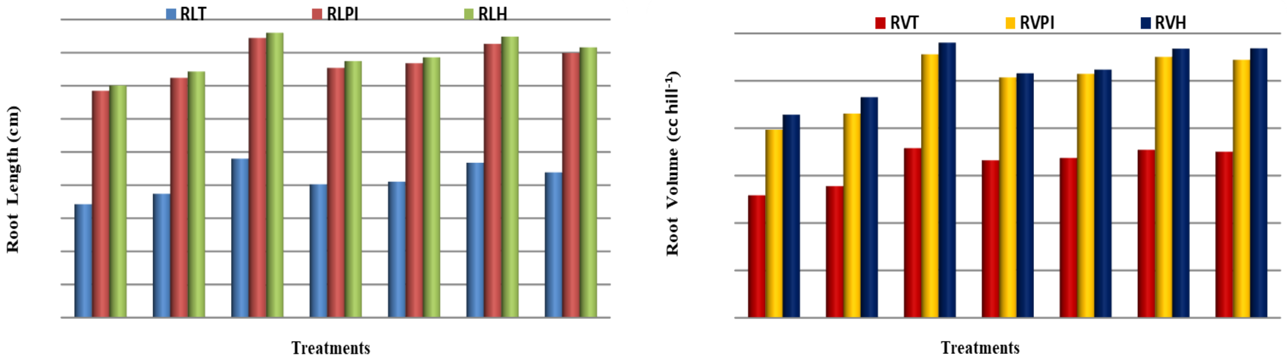

Fig .2.*Comparative increase of root characters at different crop growth stages of rice A). Root length B). Root volume ; RLT- Root length at tillering ; RLPI-Root length at panicle initiation; RLH-Root length at harvest ;RVT-Root volume at tillering; RVPI- Root volume at panicle initiation ;RVH-Root volume at harvest (significant difference at the P < 0.05 level)*

Table 4. Effect of various phosphorus sources and PSB on growth parameters of rice

Crop growth stages	**AT**	**PI**	**Harvest**	**AT**	**PI**	**Harvest**	**AT**
Treatments / Parameters	**Plant height(cm)**			**Dry matter production(g/pot)**			**No. of tillers**
T$_1$	41.0e	67.6e	69.9d	4.38e	17.4e	29.3e	14.7e
T$_2$	45.9d	75.7d	78.1c	5.87d	19.6d	33.6d	17.2d
T$_3$	63.9a	105.8a	108.3a	9.27a	29.6a	49.0a	25.5a
T$_4$	50.8c	83.8c	86.2c	6.98c	22.9c	37.8c	19.7c
T$_5$	51.5c	86.1c	88.5b	7.36c	23.9c	39.9c	19.8c
T$_6$	61.2a	101.8a	104.8a	8.96a	28.5a	47.4a	24.5a
T$_7$	56.4b	93.9b	96.6b	8.21b	26.1b	43.6b	22.1b
SEm±	2.21	3.67	3.78	0.31	1.02	1.69	0.87
CD (P=0.05)	4.75	7.88	8.10	0.67	2.19	3.63	1.87

AT: Active tillering, PI: Panicle initiation. Mean (±standard deviation, n =3) with the same letters are not significantlydifferent at $p < 0.05$; p values were determined by ANOVA.

Table 5. Effect of various phosphorus sources and PSB yield parameters and yield of rice

Parameters Treatments	**No. of productive tillers**	**Panicle length (cm)**	**No. of filled grains**	**1000 grain weight (g)**	**Grain yield (g/pot)**	**Straw yield (g/pot)**	**Harvest index**
T_1	15.9e	15.0e	77.6b	15.6	15.4e	16.9e	47.6b
T_2	16.7d	16.8d	82.4b	15.7	17.6d	19.0d	48.1a
T_3	19.8a	23.1a	108.0a	15.7	25.3a	27.2a	48.2a
T_4	17.5c	18.6c	87.5a	15.7	19.8c	21.2c	48.4a
T_5	17.7c	18.8c	89.3a	15.7	20.1c	22.1c	47.7b
T_6	19.6a	22.4a	105.6a	15.7	24.3a	26.3a	48.1a
T_7	18.5b	20.6b	98.4a	15.7	22.3b	24.2b	48.0a
SEm±	0.33	0.81	11.6	0.02	0.87	0.94	0.22
CD (P=0.05)	0.73	1.73	24.9	NS	1.87	2.02	0.46

Mean (±standard deviation, n =3) with the same letters are not significantly different at $p < 0.05$; p values were determined by ANOVA

treatments was witnessed with respect to the number of productive tillers hill^{-1}, panicle length, and filled grains per panicle except for 1000 grain weight. A relatively maximum number of productive tillers hill^{-1} was recorded in NK100 % RDF + SSP + PSB (T_3) applied treatment (19.8 hill^{-1}) and it was on par with 100 % RDF + Nano P + PSB (T_6) followed by T_7 (18.5) >T_5, T_4 (being on par with each other), T_2 and T_1 which recorded the minimum number of productive tillers (15.9 hill^{-1}). The highest panicle length was registered by NK100 % RDF + SSP + PSB (T_3) applied treatment (23.1 cm) and it was on par with 100 % RDF + Nano P + PSB (T_6) followed by T_7 (22.4) >T_5, T_4 (being on par with each other), T_2 and T_1 which registered the lowest panicle length (15.0 cm). And maximum number of filled grains per panicle (108.0) was found with T_3 (NK100 % RDF + SSP + PSB) and it was on par with 100 % RDF + Nano P + PSB (T_6) followed by T_7 (98.4) >T_5, T_4 (being on par with each other), T_2 and T_1 which registered the minimum number of filled grains per panicle (77.6). Effects of various P sources along with PSB in rice did not significantly impact the test weight (g). Finally, the improved yield parameters in the present study proved that the application of single super phosphate or nano P fertilizer along with PSB played a vital role in nutrient uptake by rice. As P release from SSP or Nano P were realized with longer bioavailability of P in soil. Further, PSB could have helped in solubilizing soil fixed P conveniently; thus, its uptake was enhanced in rice (Singh and Singh,2016; Meena *et al.*,2017).

Concerning grain and straw yield, the application of NK100 % RDF + SSP + PSB (T_3) registered higher grain and straw yield of 25.3 and 27.2 g plant^{-1}, respectively and it was on par with T_6 (100 % RDF + Nano P + PSB) followed by T_7 (100 % RDF + Nano P + PSB) >T_5, T_4 (being on par with each other), T_2 and T_1 which registered the lower grain and straw yield of 15.4 and 16.9 g plant^{-1}, respectively as the same trend was realized with yield parameters and these results are in conformity with those of Valojai*et al*. (2021); Meena *et al*. (2014); Erfani*et al*. (2020)asthey used nano and conventional fertilizers,bio-organic sources and chemical,organic and biofertilizers in rice, respectively.They opined that applying NPK nano-fertilizer can improve rice yield and quality and maintain fertiliser efficiency compared to conventional fertilizers.

P availability

Considerably higher available P of 0.28, 0.26, and 0.23 g pot^{-1} at AT,PI stages and at harvest, respectively, observed in SSP + PSB applied treatment (T_3) and it was on par with T_6 (Nano P + PSB) followed by T_7 (Phosphocompost + PSB) >T_5, T_4 (being on par with each other), T_2 and T_1 which register the lower values of soil available P (0.14, 0.12,and 0.10 g pot^{-1}) at AT,PI and at harvest, respectively. The present investigation showed that concentrations of the P in rhizosphere soil decreased from panicle initiation to maturity stage irrespective of inoculation of PSB and P application (Fig.3,4,5). The dilution effect decreased nutrient concentrations at the later stage of crop growth. Availability of nutrients is the capacity of soils to be productive and depends on more than just plant nutrients. The physical, biological and chemical attributes of soil decide the nutrient available to plants to produce more. The present study assessed available P in rhizosphere soil at active tillering (AT), panicle initiation (PI) stages, and harvest. Among the P sources, SSP plus PSB registered higher values of available P than the other sources tried at all the crop growth stages. This might be attributed to greater mobilization of inorganic Pand mineralization of organic P through PSB inoculation, which increases soil P (Najafi and Towfigi, 2008) other than PSB alone and absolute control treatment. Sharma *et al*. (2009) reported similar findings that an increase in P application generally increased the available P content in soil. The capability of water soluble fertilizers and microorganisms under rice rhizosphere might have influenced by soil physicochemical properties and enzyme activities which in turn enhanced the soil availability of P throughout the crop growth (Fageria*et al.*, 2011).

Nano P + PSB applied pots were on par with SSP+ PSB application in available P content. Release of P in soil solution from nano fertilizer may have occurred through microbial-mediated enzymatic disintegration of linkages within Nano P. Hence, a relatively higher P content across different crop growth stages may be explained by the slow release of P from Nano P, thereby making its interaction in ionic form with positively charged particles which otherwise make complex with solution P resulting lower availability. Similar reports were given by Mandal (2014) and Mandal *et al*.(2015). Nano P increases P content in soil may be by two fold action (i) slow release of P into solution and (ii) release of compatible ion concomitantly in solution interacting with native or applied P present therein. Nano P acts as rhizosphere controlled release fertilizer (Sarkar *et al*., 2013; Mandal, 2014). Effective releasing of P from nano fertilizers might caused by conditioning (structuring) the soil; improvement of its physico-chemical properties (creating favorable air and water regime close to the plant root system); increased cation -exchange capacity of soil; regular and rational plant nutrition by having more surface area (Tarafdar*et al*.2012c).Subramanian *et al.,* (2015) reported that nano-fertilizers and nanocomposites could be used to control the release of nutrients from the fertilizer granules so as to improve the nutrient use efficiency while preventing the nutrient ions from either getting fixed or lost to the environment, which might have enhanced the nutrient availability in soil solution. Sharmila Rahale (2011) has monitored the nutrient release pattern of nano fertilizers carrying nitrogen [nano-clay based fertilizer formulations (zeolite and montmorillonite with a dimension of 30-40 nm] are capable of releasing the N for a longer period (> 1000 hrs) than conventional fertilizers (< 500 hrs). Furthermore, Nano materials hold the material more strongly due to higher surface tension than conventional surfaces (Solanki *et al*., 2015; Subramanian *et al*. 2015) which helps in more nutrient availability that holds by. Finally, the treatment received PSB which might have enhanced the biochemical substances *viz*., organic acids, poly phenols, amino acids and polysaccharides and enhanced synergetic nutrient interaction, which stimulated the solubility, transport and availability of essential nutrients (Senthilvalavan,2019). This is in conformity with those of Banik and Sharma (2008); Hossain *et al*. ()2008; Senthilvalavan and Ravichanderan (2016) and Senthilvalavan, 2018. Next to Nano P, the other P sources used were showed the decreasing order of P availability as phosphocompost> DAP > RP > PSB alone and absolute control (T_1). T_1Which recorded the lowest Olsen P. This would indicate that the role of P sources and bio-fertilizers (PSB) enhanced P release in soil. This is in conformity with those of Ramalakshmi*et al*. (2013) reported that organic acid contents increased with the addition of organics/ biofertilizers, which enhanced the microbial properties of soil and available nutrients over control.

P uptake

Significantly higher uptake of N, P, K and Zn uptake (0.50.09,0.89 g pot^{-1} and 0.64 mg pot^{-1}; 0.78,0.12,1.22 g pot^{-1}and 0.99 mg pot^{-1}; 0.51,0.60,0.16 g pot^{-1} and 0.37 mg pot^{-1} and 0.34,0.44,1.08 g pot^{-1} and 0.89 mg pot^{-1} at AT,PI stages and grain and straw at harvest, respectively) was registered by the treatment received NK100 % RDF + SSP + PSB (T_3) and it was on par with T_6 (100 % RDF + Nano P + PSB) followed by T_7 (100 % RDF + Nano P + PSB) >$T_{5,}$ T_4 (being on par with each other), T_2 and T_1 which registered the lower values of NPK and Zn uptake (0.25,0.02,0.59 g pot^{-1} and 0.35 mg pot^{-1}; 0.50,0.33,0.70 g pot^{-1}and 0.68 mg pot^{-1}; 0.29,0.36,0.05 g pot^{-1} and 0.16 mg pot^{-1} and 0.23,0.20,0.68 g pot^{-1} and 0.59 mg pot^{-1}) at AT, PI and grain and straw at harvest, respectively. Uptake, a function of nutrient concentration and dry matter production, increased with the age of the crop. Favorable soil conditions well-developed and strong root structure plays an important role in the uptake and translocation of nutrients from soil solution (Kumar *et al*., 2016 and

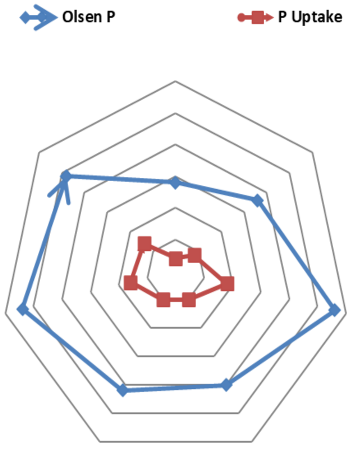

Fig. 3. *Olsen P and P uptake at Tillering stage*

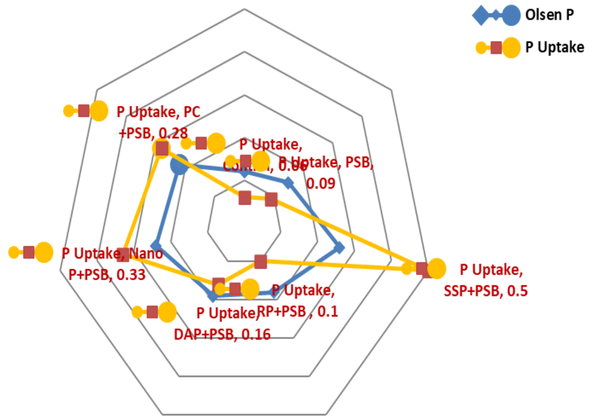

Fig.4. *Olsen P and P uptake at panicle initiation stage*

Bommayasami*et al*., 2010). Phosphorus uptake in rice plants facilitated through the application of NK 100 % RDF + P sources combined with PSB significantly influenced all the stages (active tillering, panicle initiation and harvest (grain and straw) of rice in the present experiment (Fig. 3,4,5) over absolute control. Among the P sources, SSP and Nano P plus PSB significantly recorded higher values of P uptake at respective stages and plant parts compared to other P sources. Next to these treatments, phosphocompost application showed higher nutrient uptake. Nutrient contents in rice were considerably affected by the advancement of crop age and growth. From active tillering to harvest, nutrient contents decreased due to the dilution effect, caused by higher dry matter production compared to absorption and mobilization of these nutrients towards the sink (Das *et al*., 2010).

Further, Radha Kumari and Reddy (2011) also opined that initial quick availability of nutrient from inorganic sources and later from soil organic pool for a longer period, led to overall higher uptake of nutrients through increased mineralization by microbial population and enhanced enzymatic activities in the rhizosphere. The significance of PSB in increasing the P availability through solubilizing insoluble forms of phosphorous into simple soluble forms that plants can take up has been reported by Panhwar and Othman.(2011); Panhwar*et al.* (2013) and Senthilvalavan and Ravichandran, (2016). The PSB application with mineral P increased the efficiency of P fertilizer and would decrease about 25% of the required P to plants (Attia *et al.,* 2009). Afzal *and* Bano (2008) reported that 30-40% more efficiency of PSB strains with P fertilizer for improving grain yield of cereals and dual inoculation of microorganisms without P fertilizer improved grain yield by 20%. The results in the present study may be explained with P-dissolution capabilities of PSB, while PSB may solubilize inorganic P due to excretion of organic acids and have significant interaction with other microbial populations, which influenced the P availability in the rice rhizosphere which in turn enhanced the uptake of P at all the crop growth stages and at harvest (grain). These results are in conformity with the findings of Bahadur*et al*. (2012) and Sharma *et al*. (2013).Whereas, the lower P uptake was observed under absolute control at all crop growth stages. This may be due to unfavorable soil environment brought up by various physicochemical and biological properties and it turns nothing or meager with regards to nutrient availability and uptake throughout the crop growth.

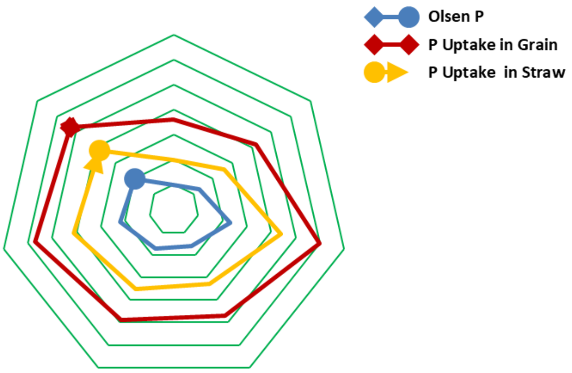

Fig. 5. *Olsen P and P uptake at harvest*

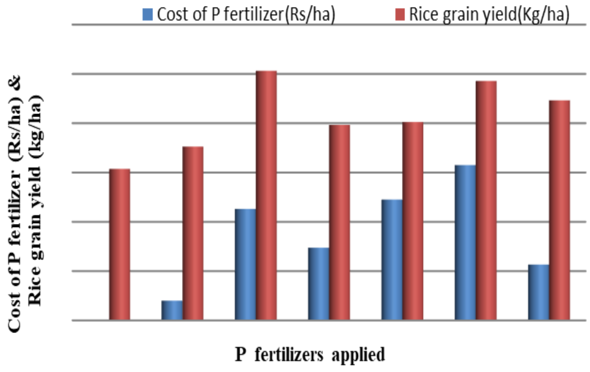

Fig. 6. *Cost of different P fertilizers applied and rice grain yield per hectare (yield was computed from g/pot to kg/ha)*

The price of phosphorus fertilizers used in the experiment was calculated using Tamil Nadu Govt. rates and materials from certain production companies. Phospho -compost production cost was calculated by actual money spent. SSP – Rs.7.24/kg ; RP- Rs.1.50/kg ; DAP- Rs.22.5/ kg ; Nano P – Rs.105/kg ; PSB- Rs.200/ litre ; Water hyacinth compost – no cost except SSP enrichment. To justify the effect of P fertilizers on rice yield, the cost of P fertilizers and grain yields were converted to per hectare (Figure. 1). Both Cost and grain yield difference were calculated by comparing with phosphocompost to SSP+PSB, Nano P +PSB the best performed treatments. There was a 19.47 % and 12.8 % increase in yield observed under SSP and Nano P applied pots over phosphocompost, respectively. Regarding the cost of P fertilizer Rs/ha related to yield kg/ha, SSP + PSB have Rs.1530/- and Nano P+PSB have Rs.2518/- more compared to phosphocompost that cost only Rs.1132/-. From these results, it was found that application of water hyacinth-based phosphocompost could be a viable option for augmenting rice productivity economically. Also, the use of chemical fertilizer can be reduced by this novel approach of utilizing underutilized weeds towards cleaner production and environmental and ecosystem management.

Conclusion

Steady release of P from water hyacinth-based phospho-compost and its interventions with soil biotic environment helps to sustain higher rice production in a coastal clay soil. Preparation of phosphocompost using water hyacinth as feedstock and termite soil as bulking agent cum decomposer brought the compost with superior quality and complete maturity in a short period compared to normal soil. Also, termite soil with more active microbes combined with PSB might have helped to enhance rice plants' P availability sustainably. P supplementation via single super phosphate and nano phosphate along with PSB to rice performed well compared to other P sources, as they are in the form of quick and slow availability, respectively. However, P supply through phosphocompost proved its stable performance on rice productivity with lower cost. Hence, an alternative way of P supply via phosphocompost underpins the necessity of conserving global P resources as it is declining substantially and saving them for future concern. Supplementing P through various P fertilizers may yield high but when input cost matters, where recycling of weed (water hyacinth) based wastes into P sources might be a vital source for achieving yield required to keep pace with the growing global demand for rice and reducing inorganic P fertilizer use.

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Conflict of interest

The authors declare that they have no conflict of interest.

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