Letters in Applied NanoBioScience
Open-Access Journal (ISSN: 2284-6808)

Article
Volume 12, Issue 1, 2023, 2
https://doi.org/10.33263/LIANBS121.002

Synthesis and Characterization of Biochar Based Nanoscale Phosphorus and its Effect on Yield and Nutrient Uptake of Groundnut (Arachis hypogaea L.)

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Received: 13.09.2021; Accepted: 14.10.2021; Published: 8.01.2022

Abstract: The utilization of agricultural waste is of great concern to all and a challenging research area that needs special attention from the scientific community. The present study was carried out to synthesize the biochar-based nanoscale phosphorous and evaluate its effect on the growth and yield of groundnut (Arachis hypogaeaL.) under a pot culture experiment. Nano phosphorus particles were prepared using Stevia leaf extract as a reducing and stabilizing agent. Biochar-based phosphorus (BBP) and biochar-based nano phosphorus (BBNP) were prepared by loading the respective chemicals. Transmission electron microscopic micrographs showed relatively spherical-shaped particles with a size less than 100 nm. BBP and BBNP were tested in 26 different combinations with the recommended dose of phosphorus on the growth and yield components of groundnut. Among all treatments, 100% RDP+ soil application BBNPF @ 4 kg ha^{-1} and 100% RDP+ soil application BBPF @ 10 kg ha^{-1} showed significant plant growth, nutrient uptake, and yield. Thus, biochar-based nanoscale phosphorous significantly influences the growth, uptake, and yield of groundnut. The present study paves the way to utilize the biochar in developing nanotechnology-based fertilizers for soil application.

Keywords: biochar; phosphorus; nano phosphorus; groundnut; yield.

1. Introduction

Biochar, an inert carbonaceous material, has proven potential usage in agricultural systems due to multiple benefits in improving soil fertility, crop productivity [1-4], and the porous physical structure of biochar induces a greater sorption capacity to conserve soil moisture and nutrients [4-6]. Recent reports highlighted the beneficial agricultural applications of fortified biochar as a soil amendment, including organic manure, to host a variety of plant nutrients and soil amendment [7-9] to enhance the soil's physical properties and improve the soil quality [10-12]. However, biochar does not contain enough nutrients for crop growth [13]. Grain yield of rice decreased significantly when only biochar was applied [14]. This might be due to the poor nutrient supply capacity of biochar. Thus, supplementing biochar with certain nutrients renders biochar materials are more suitable for enhancing plant growth. It has been reported [15,16] that conjunctive application of organic and inorganic fertilizers and the biochar significantly increased the contents of available nitrogen, phosphorus, and potassium compared to the application of chemical fertilizers alone due to the agricultural and environmental advantages. The slow-release effect of biochar-based fertilizers has been reported by many researchers [17].

In tropical and sub-tropical regions, groundnut (*Arachis hypogaea L*) is widely grown and used as a high protein meal, food, and edible oil extraction and feed to the animals. [18-20]. Moreover, groundnut is a crop with a relatively high return on a limited land area, and it is well adapted to hot semiarid conditions [21,22].

In groundnut production, phosphorus plays a pivotal role in increasing root growth, nutrient utilization, water use efficiency, and enhancing yield [23]. P requirement in nodulating legumes is higher than non-nodulating crops as it plays a significant role in nodule formation and fixation of atmospheric nitrogen [24]. Phosphorus (P) is a primary macronutrient required in large quantities to fertilize crops, especially in tropical soils. It has been estimated that up to 90% of the soluble P applied in these soils rapidly assumes insoluble forms due to the fixation reactions of phosphate [25,26]. Therefore, the increase in agricultural production has resulted in high demand for phosphate fertilizers. However, depletion in available phosphorus is an emerging problem and affects food grain production and may lead to global food insecurity. In agriculture, phosphorous was used as a major nutrient extracted from a non-renewable source called rock phosphate. India is the largest importer of fertilizers of which, phosphorous alone accounts for 4.3 million tonnes (28 percent of total imported fertilizers) (https://www.thehindubusinessline.com). The demand for phosphorus may outpace the supply by 2035. This would urge immediate attention to reduce the usage of phosphatic fertilizers without declining agricultural productivity.

Nanotechnology deals with the matter at the nanoscale (1-99 nm) in at least one dimension. The development of nanomaterials could open up new applications in agriculture and allied sciences [27,28]. The materials, when reduced to the nanoscale, show unique properties which are different from what they exhibit on a macro scale, enabling them to use in diverse applications in agriculture, including the development of nanoscale pesticides, nanoscale fertilizers, nanoscale sensors for moisture, soil conditioners and nanoscale delivery systems for targeted delivery of genes [28-30].

However, reducing the particle size of phosphorus to nanosize, i.e., smaller than 100 nm, can further improve its properties, especially the absorption and utilization by plants, which may reduce the applied doses [31,32]. Therefore, there is a dire need to search for new nanoscale materials applicable in agriculture to enhance crop productivity. Considering this, it is proposed to study the effect of biochar-based phosphorus and biochar-based nano phosphorus on the growth and yield of groundnut. Perhaps, it is the first report on this kind of material and its application.

2. Materials and Methods

Synthesis and characterization of biochar based phosphorus (BBP) and biochar based nano phosphorus (BBNP)

Nanoscale phosphorus particles will be prepared using Stevia leaf extract to reduce and stabilize agents. Take 10 g of dried Stevia leaf powder to add 100 ml of distilled water into it.

Then heat the content at 600 degrees centigrade for one hour. Then, we filtered the content with Wattman filter paper 40. After that, we prepared a 10 molar rock phosphate solution (422 g of rock phosphate dissolved in 1000 ml distilled water). We took100 ml of stevia leaf extract and mixed it with 100 ml rock phosphate solution. We left it for 2 days. Then, we centrifuged the content at 6000 rpm for 15 min. After centrifugation, we discarded the supernatant solution and dried the solid portion (shade dry). After drying, we made it into powder with the help of a pestle and mortar.

Biochar surface modification was done through the acid wash (nitric acid), and gum acacia powder was used for binding/loading of nano-phosphorous and phosphorus particles. The transmission electron microscopy (TEM) technique was used to characterize the biochar-based phosphorus and nano phosphorus.

2.1. Transmission electron microscopy (TEM).

The morphology and shape of the prepared nano phosphorous particles were studied using transmission electron microscopy (HT7700, 40-120 kV, 100 V step variable, Hitachi Ltd., Japan). The sample was prepared by drop-casting on TEM grids and allowed to dry in air and imaged within 24 h.

2.2 Pot culture experiment.

The experiment was conducted during Rabi, 2019-20 (Groundnut crop var. Dharani) at S. V. Agricultural College Farm, Tirupati, Acharya N.G. Ranga Agricultural University is geographically situated at 13.5°N latitude and 79.5°E longitude, with an altitude of 182.9 m above the mean sea level in the Southern Agro-Climatic Zone of Andhra Pradesh.

2.3. Basic properties of soil at the beginning of the experiment.

Soil Reaction (pH) of the soil samples was 7.63 (neutral) determined in saturated paste (1:2.5 soil to water ratio) using Systronics pH system 361 Glass electrode pH meter [33].The electrical conductivity of the soil samples was (0.67 dSm^{-1}) determined in saturated paste (1:2.5 soil to water ratio) using Systronics conductivity meter 306 [33]. The organic carbon content of the 0.5 mm sieved soil samples was (0.41%) estimated by Walkley and Black's wet oxidation method [33]. Available N was (63 kg ha^{-1}) determined by alkaline permanganate method Alkaline potassium permanganate [34]. The available P was (22 kg ha^{-1}) extracted with the 0.5 M $NaHCO_3$ extractant and determined by using ascorbic acid as a reducing agent (Olsen's method [35] and the available K in the soils was (207 kg ha^{-1}) extracted by employing Neutral normal ammonium acetate and determined by aspirating the extract into the flame photometer [33]. In contrast, available micronutrients in soil samples were extracted using a DTPA extractant of pH 7.3 [36], and the extract was aspirated to an atomic absorption spectrophotometer (VARIAN AA240FS). The available micronutrients content Zn, Cu, Fe, and Mn were 1.01, 0.53, 1.04, and 4.58 mg kg^{-1} soil. The oven-dried samples of plants material were ground in a Willey mill and analyzed for P contents. First, the total phosphorus content in the plant sample was estimated with the diacid digestion method by Jackson6. Then, phosphorus uptake was calculated by multiplying the nutrient content of the plant sample with corresponding total dry matter and expressed in kg ha^{-1}.

The experiment was laid out in randomized block design with three replications and twenty five treatments viz., T1- 100 % RDF; T2-100% RDP + Soil application of BBPF @ 4

Kg ha^{-1} ; T3- 75% RDP + Soil application of BBPF @ 4 Kg ha^{-1}; T4-50% RDP + Soil application of BBPF @ 4 Kg ha^{-1}; T5- 100 % RDP + Soil application of BBPF @ 6 Kg ha^{-1}; T6- 75 % RDP + Soil application of BBPF @ 6 Kg ha^{-1}; T7- 50 % RDP + Soil application of BBPF @ 6 Kg ha^{-1}; T8- 100 % RDP + Soil application of BBPF @ 8 Kg ha^{-1}; T9- 75 % RDP + Soil application of BBPF @ 8 Kg ha^{-1}; T10- 50 % RDP + Soil application of BBPF @ 8 Kg ha-1; T11- 100 % RDP + Soil application of BBPF @ 10 Kg ha^{-1}; T12- 75 % RDP + Soil application of BBPF @ 10 Kg ha^{-1}; T13- 50 % RDP + Soil application of BBPF @ 10 Kg ha^{-1}; T14-100% RDP + Soil application of BBNPF @ 4 Kg ha^{-1} ; T15 - 75% RDP + Soil application of BBNPF @ 4 Kg ha^{-1}; T16-50% RDP + Soil application of BBNPF @ 4 Kg ha^{-1}; T17- 100 % RDP + Soil application of BBNPF @ 6 Kg ha^{-1}; T18- 75 % RDP + Soil application of BBNPF @ 6 Kg ha^{-1}; T19- 50 % RDP + Soil application of BBNPF @ 6 Kg ha^{-1}; T20- 100 % RDP + Soil application of BBNPF @ 8 Kg ha^{-1}; T21- 75 % RDP + Soil application of BBNPF @ 8 Kg ha^{-1}; T22- 50 % RDP + Soil application of BBNPF @ 8 Kg ha^{-1}; T23- 100 % RDP + Soil application of BBNPF @ 10 Kg ha^{-1}; T24- 75 % RDP + Soil application of BBNPF @ 10 Kg ha^{-1}; T25- 50 % RDP + Soil application of BBNPF @ 10 Kg ha^{-1}. (Recommended Fertilizer Dose (RDF): 30 - 40 - 50 kg N, P2O5 and K2O ha^{-1}).

3. Results and Discussion

3.1. Characterization of BBNP, BBP, and NP.

Micrographs (Figure 1)of transmission electron microscopy clearly showed the monodispersed and relatively spherical-shaped particles. Agglomeration of the particles was not seen supports the claim that the particles are highly dispersed in nature.

3.2. Yield and yield attributes.

3.2.1. Number of pods per plant.

A higher number of pods plant-1 was recorded with the soil application of 100 % RDP + BBPF @ 10 kg ha^{-1} followed by 75 % RDP + BBPF @ 10 kg ha^{-1}, 100 % RDP + BBPF @ 8kg ha^{-1}which is on par with75 % RDP + BBPF @ 8kg ha^{-1}.

Among the biochar based nano-phosphorus fertilizers combinations, soil application of 100 % RDP + BBNPF @ 4kg ha^{-1} resulted higher number of pods plant-1 followed by 75 % RDP + BBNPF @ 4 kg ha^{-1}, 100 % RDP + BBNPF @ 6 kg ha^{-1} and 75 % RDP + BBNPF @ 6 kg ha^{-1} in the order of decent. The lowest number of pods per plant was noticed with control (No application) (Table 1, Figure 2). Leguminous crops require more phosphorus than other crops to attain optimum growth and productivity [37]. Therefore, the application of phosphorus has a dramatic effect on legumes when it is applied to soils low in phosphorus. Phosphorus helps leguminous plants in root-nodulation, efficient use of nutrients, nitrogen fixation, and efficient partitioning of photosynthates from vegetative to reproductive parts. Studies [38, 39] suggested that nanoparticles have high reactivity because of the large surface area, more density of the reactive area, and increases the reactivity of this area on the particles' surface. There features their absorption in plants [40]. As indicated by the main effects of biochar-based nanophosphorous and BBPF gave the highest values of pod per plant.

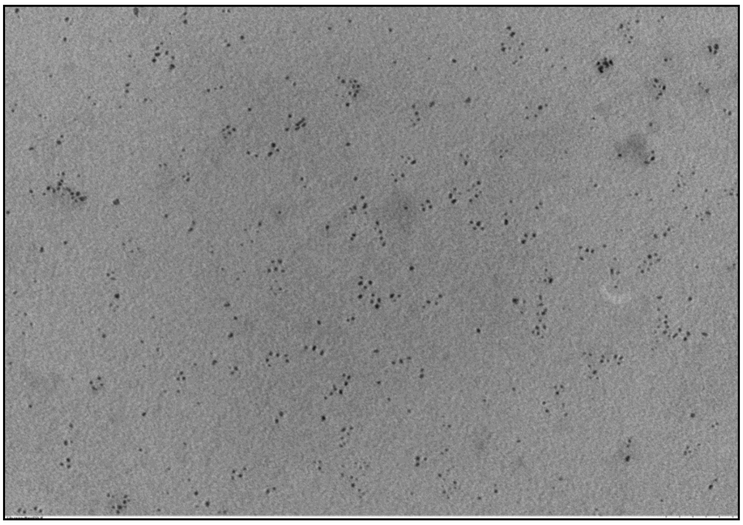

Figure 1. TEM image of highly dispersed Nano-phosphorus particles (bar scale 100 nm).

3.2.2. Number of seeds per plant.

Among the different combinations of biochar based phosphorus, soil application of 100 % RDP + BBPF @ 10 kg ha^{-1} was recorded the maximum number of seeds plant- 1 75 % RDP + BBPF @ 10 kg ha^{-1}, 100 % RDP + BBPF @ 8kg ha^{-1}which is on par with75 % RDP + BBPF @ 8kg ha^{-1}(Table 1, Figure 3).

Higher number of seeds plant- 1 were found with soil application of 100 % RDP + BBNPF @ 4kg ha^{-1} which was significantly superior to rest of the concentrations tried. The next best treatments were 75 % RDP + BBNPF @ 4 kg ha^{-1}, 100 % RDP + BBNPF @ 6 kg ha^{-1} and 75 % RDP + BBNPF @ 6 kg ha-1. Control recorded lowest number of seeds plant- 1 during the experimentation (Table 1, Fig.3).

3.2.3. Seed weight per plant.

Soil application of 100 % RDP + BBPF @ 10 kg ha^{-1} was recorded the higher number of seed weight plant- 1, among different biochar based phosphorus concentrations tried. The next best treatments were75 % RDP + BBPF @ 10 kg ha^{-1}, 100 % RDP + BBPF @ 8kg ha^{-1}which is on par with75 % RDP + BBPF @ 8kg ha^{-1}.

With respect to biochar based nano-phosphorus, soil application of 100 % RDP + BBNPF @ 4kg ha^{-1} recorded significantly higher seed weight plant- 1, followed by 75 % RDP + BBNPF @ 4 kg ha^{-1}, 100 % RDP + BBNPF @ 6 kg ha^{-1} and 75 % RDP + BBNPF @ 6 kg ha-1, in order of descent. The lowest value was noticed with control (Table 1, Figure 4). The beneficial effect of the application of nano nutrients resulted in increased photosynthesis and production of more photosynthates leads to an improved source-sink relationship, with efficient translocation of photosynthates to the grains subsequently reflected in the improved seed weight, and these results were in accordance with results obtained by [41,42].

3.3. Phosphorus content.

Phosphorus content of pot cultured groundnut plants measured at peak flowering and harvest stages during the crop period was presented in Table 2. From the data obtained, it has been observed that the phosphorus content at peak flowering and harvest significantly differed among the treatments. At both the sampling stages, the effect of biochar-based phosphorus and biochar-based nano-phosphorus on phosphorus content was significant.

Among the biochar based phosphorus fertilizers combinations the maximum phosphorus content was associated with soil apllication of 100% RDP + BBPF @10 kg ha^{-1} followed by 75 % RDP + BBPF @ 10 kg ha^{-1} and 100 % RDP + BBPF @ 8kg ha^{-1} which is on par with75 % RDP + BBPF @ 8kg ha^{-1}(Figure 5).

Table 1. Effect of Biochar-based phosphorus and biochar-based nano-phosphorus on no. of pods, seeds, and seed weight per groundnut plant (pot culture experiment).

Treatments	No of Pods plant^{-1}	No of Seeds plant^{-1}	Seed weight plant^{-1}(g)
Biochar based phosphorus			
T_1- control (No application)	4.5	8.5	2.37
T_2-100% RDP + Soil application of BBPF @ 4 Kg ha^{-1}	5.5	9.0	2.47
T_3-75% RDP + Soil application of BBPF @ 4 Kg ha^{-1}	4.5	8.5	4.29
T_4-50% RDP + Soil application of BBPF @ 4 Kg ha^{-1}	4.5	10.5	3.97
T_5-100% RDP + Soil application of BBPF @ 6 Kg ha^{-1}	5.0	11.5	2.66
T_6-75% RDP + Soil application of BBPF @ 6 Kg ha^{-1}	5.5	11.0	2.48
T_7-50% RDP + Soil application of BBPF @ 6Kg ha^{-1}	5.5	10.0	4.64
T_8-100% RDP + Soil application of BBPF @ 8 Kg ha^{-1}	8.5	15.5	7.31
T_9-75% RDP + Soil application of BBPF @ 8 Kg ha^{-1}	8.5	14.5	6.60
T_{10}-50% RDP + Soil application of BBPF @ 8 Kg ha^{-1}	7.5	13.5	6.10
T_{11}-100% RDP + Soil application of BBPF @ 10 Kg ha^{-1}	9.5	19.0	8.92
T_{12}-75% RDP + Soil application of BBPF @ 10 Kg ha^{-1}	9.0	17.5	8.46
T_{13}-50% RDP + Soil application of BBPF @ 10 Kg ha^{-1}	7.5	14.5	6.44
SEm±	0.460	0.797	0.408
C.D	1.420	2.459	1.261
Biochar based Nano-phosphorus			
T_1- control(No application)	4.5	8.5	2.37
T_2-100% RDP + Soil application of BBNPF @ 4 Kg ha^{-1}	10.0	17.5	8.52
T_3-75% RDP + Soil application of BBNPF @ 4 Kg ha^{-1}	7.5	15.5	7.31
T_4-50% RDP +S oil application of BBNPF @ 4 Kg ha^{-1}	5.5	12.5	4.91
T_5-100% RDP + Soil application of BBNPF @ 6 Kg ha^{-1}	7.0	14.0	6.21
T_6-75% RDP + Soil application of BBPNF @ 6 Kg ha^{-1}	6.0	11.0	5.83
T_7-50 % RDP + Soil application of BBPNF @ 6Kg ha^{-1}	5.5	10.5	4.06
T_8-100% RDP + Soil application of BBPNF @ 8 Kg ha^{-1}	5.0	11.0	4.26
T_9-75% RDP + Soil application of BBPNF @ 8 Kg ha^{-1}	4.5	9.5	3.88
T_{10}-50 % RDP + Soil application of BBPNF @ 8 Kg ha^{-1}	7.0	10.5	4.43
T_{11}-100 % RDP + Soil application of BBPNF @ 10 Kg ha^{-1}	4.5	11.5	3.03
T_{12}-75% RDP + Soil application of BBPNF @ 10 Kg ha^{-1}	5.0	9.5	3.65
T_{13}-50 % RDP + Soil application of BBPNF @ 10 Kg ha^{-1}	4.5	9.5	4.07
SEm±	0.537	0.519	0.378
C.D	1.658	1.602	1.165

Table 2. Effect of Biochar based phosphorus and biochar-based nano-phosphorus on phosphorus content and uptake of groundnut (pot culture experiment).

	Phosphorus content (%)		Phosphorus uptake (Kg ha^{-1})	
Treatments	**Peak flowering stage**	**Harvesting stage**	**Peak flowering stage**	**Harvesting stage**
Biochar based phosphorus				
T_1- control (No application)	0.15	0.05	1.99	15.48
T_2-100% RDP + Soil application of BBPF @ 4 Kg ha^{-1}	0.19	0.10	2.17	15.92
T_3-75% RDP + Soil application of BBPF @ 4 Kg ha^{-1}	0.17	0.11	2.99	17.03
T_4-50% RDP + Soil application of BBPF @ 4 Kg ha^{-1}	0.14	0.11	2.18	13.89

Treatments	Phosphorus content (%)		Phosphorus uptake (Kg ha^{-1})	
	Peak flowering stage	Harvesting stage	Peak flowering stage	Harvesting stage
T_5-100% RDP + Soil application of BBPF @ 6 Kg ha^{-1}	0.19	0.14	2.40	16.10
T_6-75% RDP + Soil application of BBPF @ 6 Kg ha^{-1}	0.17	0.14	2.26	16.37
T_7-50% RDP + Soil application of BBPF @ 6Kg ha^{-1}	0.17	0.12	2.59	20.15
T_8-100% RDP + Soil application of BBPF @ 8 Kg ha^{-1}	0.23	0.16	3.56	30.14
T_9-75% RDP + Soil application of BBPF @ 8 Kg ha^{-1}	0.21	0.14	3.23	30.10
T_{10}-50% RDP + Soil application of BBPF @ 8 Kg ha^{-1}	0.19	0.14	3.06	21.99
T_{11}-100% RDP + Soil application of BBPF @ 10 Kg ha^{-1}	0.28	0.20	4.03	30.79
T_{12}-75% RDP + Soil application of BBPF @ 10 Kg ha^{-1}	0.26	0.17	3.70	30.46
T_{13}-50% RDP + Soil application of BBPF @ 10 Kg ha^{-1}	0.16	0.15	2.94	16.27
SEm±	0.006	0.007	0.260	1.137
C.D	0.019	0.021	0.802	3.510
Biochar based Nano-phosphorus				
T_1- control(No application)	0.15	0.05	1.99	15.48
T_2-100% RDP + Soil application of BBNPF @ 4 Kg ha^{-1}	0.27	0.20	4.93	30.66
T_3-75% RDP + Soil application of BBNPF @ 4 Kg ha^{-1}	0.26	0.20	4.07	29.55
T_4-50% RDP +S oil application of BBNPF @ 4 Kg ha^{-1}	0.19	0.14	2.36	27.08
T_5-100% RDP + Soil application of BBNPF @ 6 Kg ha^{-1}	0.24	0.19	3.89	27.75
T_6-75% RDP + Soil application of BBPNF @ 6 Kg ha^{-1}	0.23	0.18	3.84	20.44
T_7-50 % RDP + Soil application of BBPNF @ 6Kg ha^{-1}	0.18	0.15	2.59	16.35
T_8-100% RDP + Soil application of BBPNF @ 8 Kg ha^{-1}	0.19	0.10	2.89	17.32
T_9-75% RDP + Soil application of BBPNF @ 8 Kg ha^{-1}	0.16	0.13	2.77	20.92
T_{10}-50 % RDP + Soil application of BBPNF @ 8 Kg ha^{-1}	0.18	0.08	2.39	18.30
T_{11}-100 % RDP + Soil application of BBPNF @ 10 Kg ha^{-1}	0.18	0.14	3.21	24.00
T_{12}-75% RDP + Soil application of BBPNF @ 10 Kg ha^{-1}	0.18	0.15	2.54	23.08
T_{13}-50 % RDP + Soil application of BBPNF @ 10 Kg ha^{-1}	0.18	0.17	2.57	17.26
SEm±	0.020	0.006	0.298	1.043
C.D	0.061	0.017	0.920	3.221

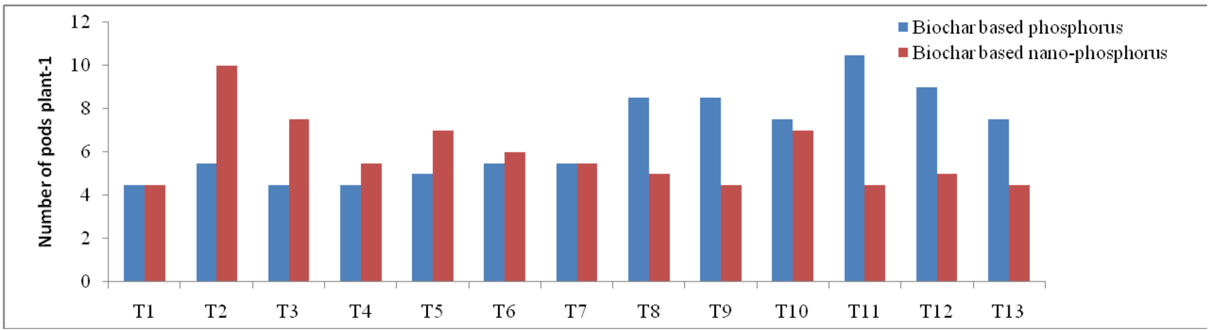

Figure 2. Effect of Biochar-based phosphorus and biochar-based nano-phosphorus on no. of pods per plant (groundnut).

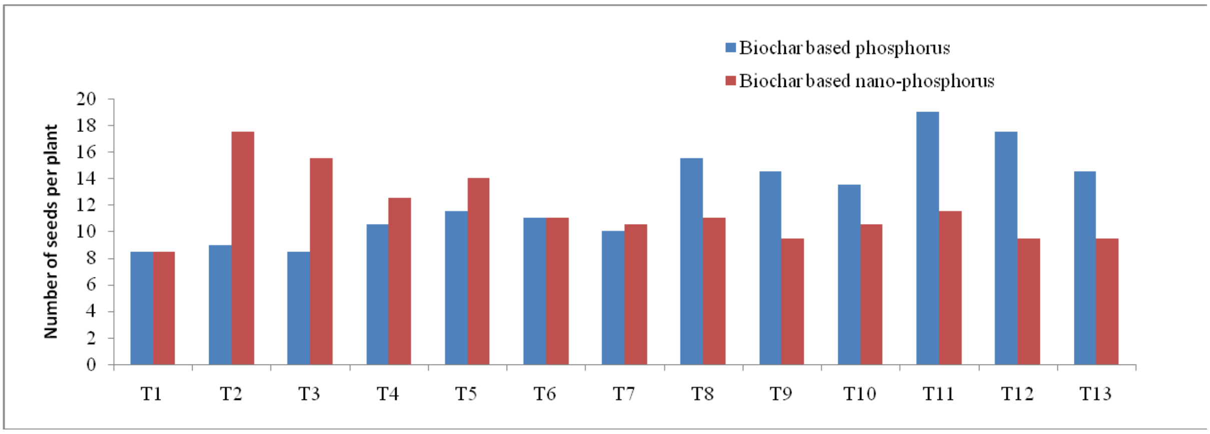

Figure 3. Effect of Biochar-based phosphorus and biochar-based nano-phosphorus on no. of seeds per plant (groundnut).

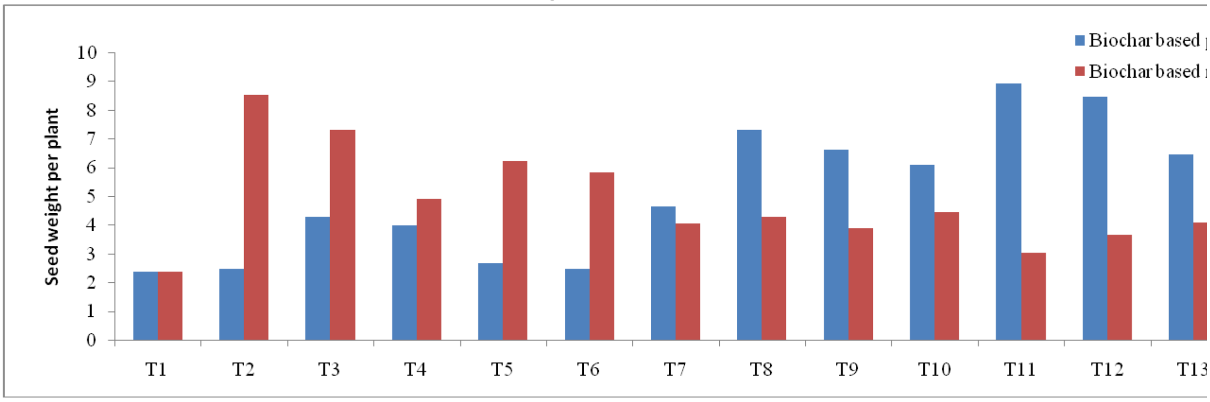

Figure 4. Influence of application of Biochar-based phosphorus and biochar-based nano-phosphorus on seed weight per plant (groundnut).

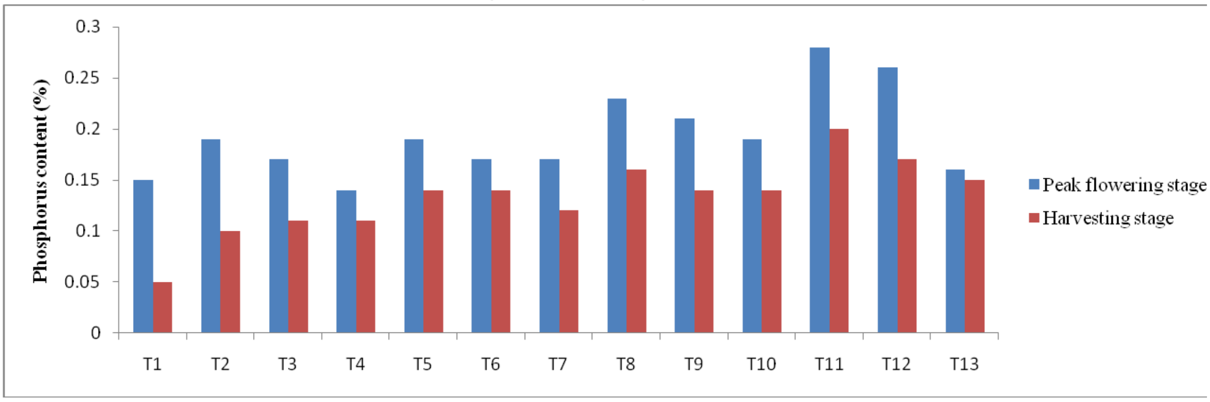

Figure 5. Effect of Biochar-based phosphorus on phosphorus content of groundnut.

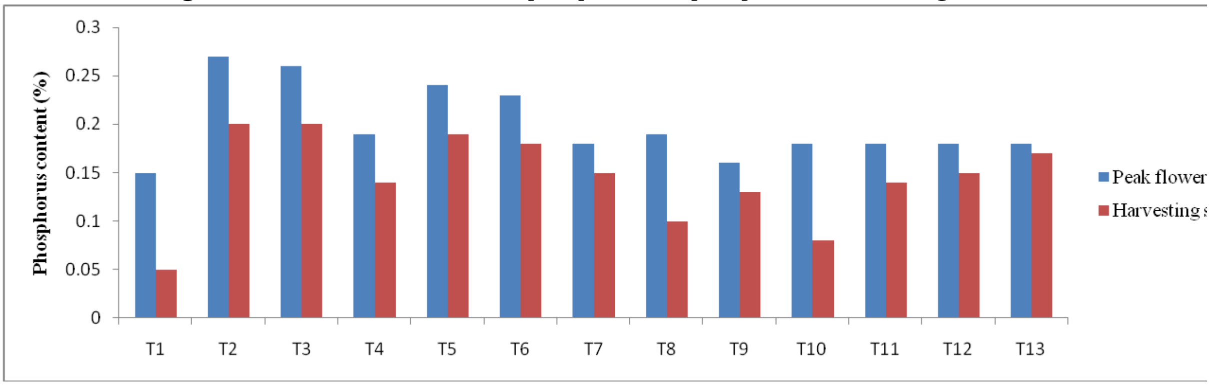

Figure 6. Effect of Biochar-based nano-phosphorus on phosphorus content of groundnut.

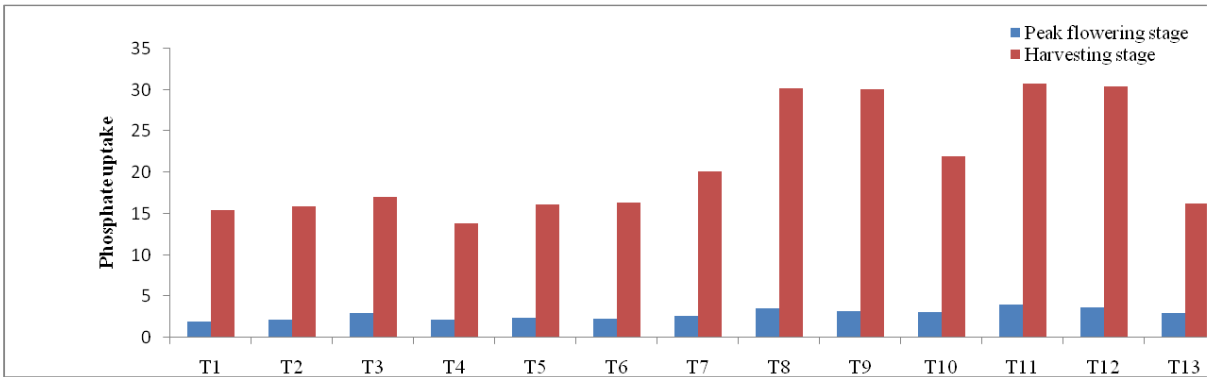

Figure 7. Effect of Biochar-based phosphorus on phosphorus uptake of groundnut.

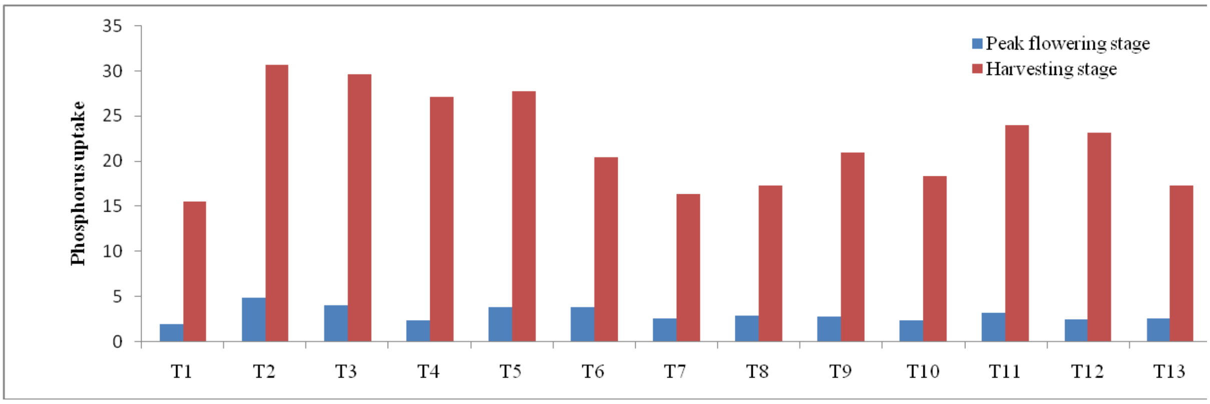

Figure 8. Effect of Biochar-based nano-phosphorus on phosphorus uptake of groundnut.

Among the biochar based nano-phosphorus fertilizers combinations, soil application 100 % RDP + BBNPF @ 4kg ha^{-1} resulted in higher phosphorus content followed by 75 % RDP + BBNPF @ 4 kg ha-1 and 100 % RDP + BBNPF @ 6 kg ha-1 and 75 % RDP + BBNPF @ 6 kg ha-1 in the order of decent. Minimum phosphorus content was noticed with control (No application) during the investigation (Fig.6).

The beneficial effect of phosphorus in the fruiting of plants ascribed this beneficial effect to better translocation of desired metabolite uptake and translocation of nanoparticles as in the yield attributing parts of plants. A significant increase in phosphorus content with biochar application was also supported by [42]. Furthermore, biochar application leads to an increase in the availability of phosphorus by reducing sorption and leaching, which increases its absorption by the groundnut plant tissues [43,44].

3.4. Phosphorus uptake.

Groundnut crop has significantly differed with the phosphorus uptake due to soil application of different combinations of biochar-based phosphorus and biochar-based nano-phosphorus fertilizers during the study (Table 2).

Among the different combinations of biochar based phosphorus, soil application of 100 % RDP + BBPF @ 10 kg ha^{-1} was recorded the maximum phosphorus uptakefollowed by 75 % RDP + BBPF @ 10 kg ha^{-1}, 100 % RDP + BBPF @ 8kg ha^{-1}which is on par with75 % RDP + BBPF @ 8kg ha^{-1}(Figure 7).

Higher phosphorus uptake was found with soil application of 100 % RDP + BBNPF @ 4kg ha^{-1}, which was significantly superior to the rest of the concentrations tried. The next best treatments were 75 % RDP + BBNPF @ 4 kg ha^{-1} and 100 % RDP + BBNPF @ 6 kg ha^{-1}. Control recorded the lowest phosphorus uptake during the experimentation (Fig.8).

A significant increase in phosphorus uptake with the biochar addition was also supported by [45] and reported that priming effects, competitive sorption processes, or improvement of root growth might have contributed to the increased P recovery and its uptake by the plant. [43] noticed that higher phosphorus uptake by the groundnut plant indicates that the biochar treated soil maintained a higher concentration of these nutrients in the soil solution due to the reduced leaching [46].

4. Conclusions

In the present investigation, we have successfully synthesized the nanophosphorous using the leaf extract of Stevia. Further, the prepared nano phosphorous particles were loaded onto the biochar to develop biochar-based nano phosphorous fertilizers. Without a doubt, experimentally, it has been proved that the application of biochar-based nano phosphorous fertilizer can improve peanut yield, phosphorus content, and phosphorus uptake, leading to an increase in groundnut productivity in a sustainable manner.

Funding

The research received no external funding.

Acknowledgments

The authors are thankful to the authorities of Acharya N.G. Ranga Agricultural University, for research facilities provided at Institute of Frontier Technology, Regional Agricultural Research Station, Tirupati to carry out this research work.

Conflicts of Interest

The authors declare no conflict of interest.

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