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Influence of Biochar Based Nano-phosphorus on Phosphorus Uptake and Yield Performance of Groundnut (*Arachis hypogaea* L.) Grown in Sandy Loam Soils

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ABSTRACT

An experiment was conducted during 2020 and 2021 at S.V. Agricultural college, Tirupati to improve phosphorus availability by application of biochar-based nano-phosphorus fertilizer in order to improve the phosphorus uptake and groundnut productivity in sustainable manner. Nanoscale phosphorus particles were prepared by the biological method by using *Stevia* leaf extract as reducing and stabilizing agent. Surface modification of biochar was done through acid wash and gum acacia was used as a binding agent for loading of nano-phosphorous particles and the techniques such as, UV-VIS spectroscopy, Fourier transform infrared spectroscopy (FTIR), Dynamic light scattering (DLS), Transmission electron microscopy (TEM) and X-ray diffraction (XRD) were used to characterize the biochar-based phosphorus fertilizer (BBPF), biochar-based nano-phosphorus fertilizer (BBNPF) and nano phosphorous (NP). The synthesized BBPF, BBNPF and NP mean size was 110.8, 87.6 and 53.7 nm, respectively. The experiments were conducted during two seasons *viz.*, *kharif*-2020 (June–September) and *rabi* 2020–21 (November–March) with commercial groundnut variety Dharani. The experiment was laid out in a randomized complete block design contain ten treatments with three replications. The phosphorus content and phosphorus uptake were higher with the soil application of 100% RDP+BBNPF @ 4 kg ha^{-1}. The higher pod yield and haulm yield was recorded with the application of 100% RDP+BBNPF @ 4 kg ha^{-1}. Loading of nano-phosphorus with biochar and the consequent application to the soil enhance the phosphorus availability with an extended period of time.

KEYWORDS: Biochar, nanophosphorus, UVVIS, XRD, FTIR, TEM, particle size

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1. INTRODUCTION

Biochar, a pyrolysis product of plant biomass has unique characteristics like high porous nature, relatively increased surface area and the presence of a variety of functional groups on the surface inducing a greater sorption capacity to conserve soil moisture and nutrients which improves soil fertility and crop productivity (Liu et al., 2012; Novak et al., 2012). The slow-release nature of biochar-based fertilizers has been reported by many researchers (Khan et al., 2008 and Gao et al., 2012). However, loading the biochar with certain nutrients makes them more suitable for replacing conventional fertilizers and subsequently useful to enhance plant growth and productivity. Recent reports highlighted the beneficial effects of fortified biochar as an organic manure (to host a variety of plant nutrients) and also as soil amendment (Ngulube et al., 2018) for enhancing the soil physical properties and thereby improving the soil quality (Cornelissen et al., 2013, Martinsen et al., 2014 and Xu et al., 2015).

The conjunctive use of inorganic fertilizers with biochar effectively increased the content of total nitrogen and potassium, available nitrogen, potassium and phosphorus (Mengyu et al., 2017, Zang et al., 2016, Liu et al., 2017 and Liu et al., 2018).

Phosphorus is extracted from phosphate rock, a non-renewable resource that is used almost exclusively in agriculture. India is the largest importer of fertilizers and of which, phosphorous alone accounts for 4.3 mt (28% 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. Therefore, the increase in agricultural production has resulted in high demand for phosphatic fertilizers and the depletion in available phosphorus in soils affects food grain production and may lead to the global food insecurity.

The development of nano materials could open up new applications in agriculture and allied sciences (Mukhopadhyay, 2014). The materials when reduced to the nanoscale show unique properties which were different from what they exhibit on a macro scale, enabling them to use in diverse applications in agriculture including the development of nanoscale fertilizers (Prasad et al., 2012), nanoscale pesticides (Ghormade et al., 2011), nano-sensors (Rai et al., 2013), soil conditioners (Dixit et al., 2015) and nanoscale delivery systems for targeted delivery of genes (Riley and Vermerris, 2017).

Groundnut (*Arachis hypogaea* L.) is widely grown in tropical and sub-tropical regions and used as a high protein meal, food, and edible oil extraction and feed to the animals. (Bekele et al., 2019; Taru et al., 2010). Phosphorus (P) is a primary macronutrient, required in large quantities in fertilization of crops, especially in tropical soils. It has been estimated that up to 90% of the soluble P applied in these soils (tropical) rapidly converts into insoluble forms due to the fixation of phosphate through chemical reactions (Broggi et al., 2010; Behera et al., 2014). Groundnut is a crop with a relatively high return on a limited land area, and it is well adapted to hot semiarid conditions (Sinare et al., 2021). In groundnut, phosphorus plays a pivotal role in increasing root growth, nutrient utilization and water use efficiency apart from enhancing the yield. The requirement of P in nodulating legumes is higher as compared to non-nodulating crops as it plays a significant role in nodule formation and fixation of atmospheric nitrogen (Brady and Well, 2002). 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.

2. MATERIALS AND METHODS

2.1. Location and experimental details

The experiment was conducted during two seasons *viz.*, *kharif*, 2020–21 and *rabi*, 2020–21 at College Farm, S.V. Agricultural College, Tirupati, which 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. The soil of the experimental field was neutral (7.63) determined in saturated paste (1:2.5 soil to water ratio) using Systronics pH system 361 Glass electrode pH meter (Jackson, 1973) The electrical conductivity of the soil samples was (0.02 dS m^{-1}) determined in saturated paste (1:2.5 soil to water ratio) using Systronics conductivity meter 306 (Jackson, 1973). The organic carbon content of the 0.5 mm sieved soil samples was (0.41%) estimated by Walkley and Black's wet oxidation method (Jackson, 1973). Available N was (63 kg ha^{-1}) determined by the alkaline permanganate method Alkaline potassium permanganate (Subbaiah and Asija, 1956). 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 (Olsen et al., 1954) 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 (Jackson, 1973). In contrast, available micronutrients in soil samples were extracted using a DTPA extractant of pH 7.3 (Lindsey and Norvell, 1978) and the extract was aspirated to an atomic absorption spectrophotometer (VARIAN AA240FS). The available micronutrients content of Zn, Cu, Fe, and Mn were 1.01, 0.53, 1.04, and 4.58 mg kg^{-1} soil. The experiments were laid out in randomized block design (RBD) with three replications and ten treatments (with groundnut cultivar 'Dharani') viz T_1: Control (No application),T_2: 100% RDF, T_3: 100% RDP+@ 1 t ha^{-1}, T_4: 75% RDP+BBPF @ 8 kg ha^{-1}, T_5: 75% RDP+BBPF @ 10 kg ha^{-1}, T_6: 100% RDP+BBPF @ 10 kg ha^{-1}, T_7: 100% RDP+BBNPF @ 4 kg ha^{-1}, T_8: 75% RDP+BBNPF @ 4 kg ha^{-1}, T_9: 100% RDP+BBNPF @ 6 kg ha^{-1} and T_{10}: NP @ 4 kg ha^{-1}. Concentrations of BBPF and BBNPF were applied (soil application) as per the treatments, while nitrogen and potassium was applied common to all the treatments and gypsum was applied (just before the flowering stage) @ 500 kg ha^{-1}. 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 Jackson. 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}.

2.2. 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 to 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 took 100 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. (Kavitha et al., 2021) The techniques such as size, UV VIS, DLS, XRD, FTIR, and TEM used to characterize the biochar-based phosphorus and nano phosphorus (Kavitha et al., 2021)

2.3. UV-VIS Spectroscopic analysis

UV-visible spectrophotometer (UV-2450, SHIMADZU) is used to record the characteristic absorbance biochar based phosphorus and nano phosphorus. The sample was prepared by suspending 1mg of the nanoparticles in 5 ml of water and then spectra of this solution were recorded by scanning the sample from 200 to 800 nm.

2.4. Fourier transform infrared spectroscopic analysis (FT-IR)

FTIR is particularly useful for the identification of organic molecular groups and compounds due to the range of functional groups, side chains and cross-links involved, all of which will have characteristic vibration frequencies in the infra-red range. The FTIR spectrum has taken in the mid-IR region of 400–4000 cm^{-1}. The spectrum was recorded using ATR (Attenuated Total Reflectance) technique. A small amount of sample was mixed with KBr (1: 200) crystal and finely grounded and then, that mixture was pressed to get a homogeneous and transparent film and the spectrum was recorded in the transmittance mode (Tensor 27, BRUKER).

2.5. Dynamic light scattering (DLS)

The aqueous suspension of the synthesized nanoparticles was filtered through a 0.22 μm syringe filter unit and the size and zeta potential of the distributed nanoparticle were measured by using the principle of Dynamic Light Scattering (DLS) using Nanopartica (HORIBA, SZ-100) compact scattering spectrometer. This information is useful to know the hydrodynamic diameter (size), dispersity of nanoparticles and stability of nanoparticles.

2.6. TEM analysis

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.

3. RESULTS AND DISCUSSION

3.1. Characterization of BBP, BBNP, NP

The synthesized BBP (biochar-based phosphorus), BBNP (biochar based nano-phosphorus) and NP (Nano-phosphorus) was 110.8, 87.6 and 53.7 nm in size, respectively and this was confirmed by X-ray powder diffraction (XRD). Further, the zeta potential of synthesized BBP, BBNP and NP was -30.1 mV, 9.2 mV and -22.0 respectively.

3.2. Phosphorus content

Phosphorus content of groundnut plants measured at different growth stages during the crop period *viz.*, 30, 60, 90 DAS and harvest significantly differed among the treatments during both seasons of study (Table 1 and 2). During *kharif* at all stages of observation, the highest phosphorus content (at harvest, 0.290%) was recorded with the treatment 100% RDP+Soil application of BBNPF @ 4 kg ha^{-1} (T_7) which was significantly superior to other treatments. During *rabi*, soil application of 100% RDP+BBNPF @ 4 kg ha^{-1} (T_7) gave the highest phosphorus content (at harvest, 0.271%) which was on par with 75% RDP+BBNPF @ 4 kg ha^{-1} (T_8) and 100% RDP+BBPF @ 10 kg ha^{-1} (T_6). Lower phosphorus content of groundnut was reported with control (T_1) at all growth stages. The beneficial effects of availability of the phosphorus at the fruiting stage of plants and could

Table 1: Effect of biochar based phosphorus and biochar based nano-phosphorus on phosphorus content and phosphorus uptake of *kharif* groundnut at different stages

Treatments	Phosphorus content (%)				Phosphorus uptake (kg ha^{-1})			
	30 DAS	60 DAS	90 DAS	Harvest	30 DAS	60 DAS	90 DAS	Harvest
T_1	0.278	0.086	0.026	0.188	2.49	3.03	1.58	8.37
T_2	0.321	0.117	0.038	0.212	2.64	4.40	2.36	9.92
T_3	0.334	0.137	0.053	0.225	2.78	5.53	3.31	11.13
T_4	0.313	0.102	0.052	0.228	2.86	3.46	3.37	10.89
T_5	0.332	0.150	0.062	0.217	3.59	5.62	4.08	10.89
T_6	0.351	0.178	0.091	0.256	3.86	5.55	6.28	13.64
T_7	0.371	0.190	0.109	0.290	4.59	8.52	8.14	16.49
T_8	0.341	0.175	0.084	0.243	3.94	6.90	6.02	12.81
T_9	0.341	0.158	0.084	0.237	3.78	5.68	5.75	12.30
T_{10}	0.294	0.142	0.074	0.219	3.43	6.64	4.95	11.39
SEm±	0.014	0.010	0.005	0.007	0.331	0.492	0.369	0.415
CD (p=0.05)	0.044	0.032	0.016	0.024	1.060	1.574	1.180	1.330

Table 2: Effect of biochar based phosphorus and biochar based nano-phosphorus on phosphorus content and phosphorus uptake of *rabi* groundnut at different stages

Treatments	Phosphorus content (%)				Phosphorus uptake (kg ha^{-1})			
	30 DAS	60 DAS	90 DAS	Harvest	30 DAS	60 DAS	90 DAS	Harvest
T_1	0.347	0.114	0.067	0.180	3.29	4.40	4.98	10.28
T_2	0.393	0.121	0.080	0.203	4.55	5.53	6.37	12.80
T_3	0.415	0.123	0.082	0.205	5.25	6.10	7.31	14.17
T_4	0.414	0.125	0.085	0.209	5.73	6.55	7.80	13.86
T_5	0.410	0.125	0.093	0.215	5.99	7.55	8.40	18.99
T_6	0.428	0.134	0.100	0.243	6.06	7.64	9.41	20.49
T_7	0.473	0.138	0.102	0.271	7.43	9.07	10.41	25.10
T_8	0.435	0.136	0.097	0.244	6.64	8.31	9.66	21.01
T_9	0.421	0.129	0.094	0.236	5.84	6.58	8.16	17.98
T_{10}	0.410	0.129	0.088	0.193	5.82	5.81	7.71	15.12
SEm±	0.016	0.001	0.016	0.006	0.236	0.272	0.553	0.846
CD (p=0.05)	0.051	0.004	0.005	0.020	0.756	0.872	1.769	2.707

be ascribed this beneficial effect to better translocation of desired metabolites to different parts of plants Devi et al. (2012) and Nguyen et al. (2012). Application of Biochar/biochar-based nanocomposite materials application leads to an increase in the availability of phosphorus by reducing sorption and leaching which increases its absorption by the groundnut plant tissues (Agegnehu et al., 2015).

3.3. *Phosphorus uptake*

Phosphorus uptake by the crop was significantly influenced by soil application of biochar-based phosphorus and nano-phosphorus levels at all stages of sampling *viz.*, 30, 60, 90 DAS during both the seasons of study (Table 1 and 2). During both seasons at all stages, soil application of 100% RDP+Soil application of biochar based nano phosphorus fertilizer @ 4 kg ha^{-1} (T_7) recorded higher phosphorus uptake (at harvest, 16.49 kg ha^{-1}) which was significantly superior among the other treatments. The next best treatments were 75% RDP+Soil application of biochar-based nano-phosphorus fertilizer @ 4 kg ha^{-1} (T_8). However, lower phosphorus uptake (at 30 DAS, 3.29 kg ha^{-1}) of groundnut was noticed with control (T_1). This might be due to the better nutrient release pattern biochar-based nano-phosphorus in to the soil there by availability to the crop, which in turn enhanced the dry matter production, ultimately leading to increased uptake of phosphorus by the crop. A significant increase in phosphorus uptake with the biochar addition was supported by Supriyadi et al. (2012) and they also 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. In addition, nano fertilizers combined with nano devices were useful for synchronizing nutrient release with the uptake by crops and thereby preventing undesirable nutrient losses. Agegnehu et al. (2015) 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 reduced leaching with extended periods of availability.

3.4. Yield attributes and yield

3.4.1. Number of pods plant^{-1}

The number of pods plant^{-1} was significantly influenced by the treatments and the obtained results were presented in Tables 3 and 4. During *kharif*, the maximum number of pods plant^{-1} (18.0) was obtained with the incorporation of 100% RDP+BBNPF @ 4 kg ha^{-1} (T_7) which was significantly superior to 75% RDP+BBNPF @ 4 kg ha^{-1} (T_8) which is on a par with 100% RDP+BBPF @ 10 kg ha^{-1} (T_6). During *rabi*, the recorded data indicated that the number of pods per plant increased with the application of 100% RDP+BBNPF @ 4 kg ha^{-1} (18.1) which was significantly superior to 75% RDP+BBNPF @ 4 kg ha^{-1} (T_8) and which is on par with 100% RDP+BBPF @ 10 kg ha^{-1} (T_6). The lower number of pods of plant^{-1} production of groundnut was recorded with control (T_1) during both seasons. These results were in good agreement with Heba et al. (2016). Phosphorus uptake leads to increased net CO_2 fixation with the increased rate of photosynthesis and thereby more photosynthates to develop a greater number of pods per plant (Badsra and Chaudhary, 2001). Dhoke et al. (2012) suggested that nano particles have high reactivity because of their large surface area which increases their absorption in plants (Zheng et al., 2005). The application of biochar based nano-phosphorus resulted in the highest number of pods per plant due to their rapid absorption compared to the application of conventional phosphorus.

3.4.2. 100 pod weight

During *kharif*, maximum 100 pod weight (118.30 g) was obtained with the soil application of 100% RDP+BBNPF @ 4 kg ha^{-1} (T_7) which was significantly superior to 75% RDP+BBNPF @ 4 kg ha^{-1} (T_8) which is on a par with 100% RDP+BBPF @ 10 kg ha^{-1} (T_6) Lower 100 pod weight (103.12 g) of groundnut reported with control (T_1). During *rabi* season, soil application of 100% RDP+BBNPF @ 4 kg ha^{-1} (T_7) recorded a maximum 100 pod weight (134.8 g). A lower 100 pod weight (114.3 g) reported with control (T_1). The higher 100 pod weight was due to better filling and greater utilization of assimilates of pods which ultimately increased the pod and kernel weight of groundnut and could be attributed to the enhanced synthesis of carbohydrates,

Table 3: Effect of biochar based phosphorus and biochar based nano-phosphorus on yield parameters on *kharif* groundnut

Treatments	No. of pods plant^{-1}	100 pod weight (g)	100 kernel weight (g)	Shelling percentage (%)
T_1	10.6	103.12	49.22	64.8
T_2	13.6	109.69	51.81	70.0
T_3	12.4	107.90	51.66	72.2
T_4	12.5	112.09	51.34	72.7
T_5	11.7	111.20	52.77	74.5
T_6	15.0	113.50	53.75	74.5
T_7	18.0	118.30	56.45	77.6
T_8	15.5	113.79	54.44	75.8
T_9	13.6	113.01	52.61	72.9
T_{10}	12.8	110.76	53.98	71.5
SEm±	0.811	1.675	0.561	4.555
CD (p=0.05)	2.59	5.30	1.79	1.52

Table 4: Effect of biochar based phosphorus and biochar based nano-phosphorus on yield parameters of *rabi* groundnut

Treatments	No. of pods plant^{-1}	100 pod weight (g)	100 kernel weight (g)	Shelling percentage (%)
T_1	13.4	114.3	50.7	61.1
T_2	14.8	119.7	51.8	65.8
T_3	15.9	121.1	52.6	65.5
T_4	16.1	123.1	52.9	65.6
T_5	14.7	124.6	52.0	69.9
T_6	17.2	126.5	53.3	70.5
T_7	18.1	134.8	55.3	71.4
T_8	17.7	129.4	53.3	70.4
T_9	16.2	124.5	53.0	69.8
T_{10}	15.0	123.3	51.7	66.4
SEm±	0.626	3.386	0.940	1.731
CD (p=0.05)	2.00	10.80	3.00	0.57

fats, proteins and building phospholipids and nucleic acid constituting the kernels. Similar findings were reported by Hasan and Ismail (2016).

3.4.3. 100 kernel weight

The 100 kernel weight results are represented in Tables 3 and 4. During *kharif*, the highest 100 kernel weight (56.45 g) was recorded with soil application of 100% RDP+BBNPF @ 4 kg ha^{-1} (T_7) which was significantly superior to other treatments. Next numerically higher 100 kernel weight was recorded with 75% RDP+BBNPF @ 4 kg ha^{-1} (T_8). Lower 100 kernel weight (49.22 g) of groundnut was reported with control (T_1). During *rabi*, soil application of 100% RDP+BBNPF @ 4 kg ha^{-1} (T_7) gave the highest 100 kernel weight (55.3 g) which was on par with 75% RDP+BBNPF @ 4 kg ha^{-1} (T_8) followed by 100% RDP+BBPF @ 10 kg ha^{-1} (T_6) Lower 100 kernel weight (50.7 g) of groundnut reported with control (T_1). The reasons for the increased kernel weight may be due to the beneficial effects of the application of nano nutrients resulted in increased photosynthesis and production of more photosynthates leading to improved source sink relationship, with efficient translocation of photosynthates to the grains subsequently reflected in the improved kernel weight and these results were in accordance with results obtained by Kumari et al., (2017) and Prasad et al. (2012).

3.4.4. Shelling percentage

During *kharif*, the highest shelling percentage (77.6%) was recorded with soil application of 100% RDP+BBNPF @ 4 kg ha^{-1} (T_7) which was significantly superior to 75% RDP+BBNPF @ 4 kg ha^{-1} (T_8) and Lower 100 shelling percentage (64.8%) of groundnut reported with control (T_1). During *rabi*, soil application of 100% RDP+BBNPF @ 4 kg ha^{-1} (T_7) gave the highest shelling percentage (71.4%) which was significantly superior to other treatments. Next numerically higher shelling percentage was recorded with 75% RDP+BBNPF @ 4 kg ha^{-1} (T_8) and a Lower 100 shelling percentage (61.1%) of groundnut reported with control (T_1) (Table 3 and 4). These results are in good agreement with Kumari et al. (2017).

3.4.5. Pod yield

During *kharif*, the maximum pod yield was (2746.7 kg ha^{-1}) recorded with 100% RDP+Soil application of BBNPF @ 4 kg ha^{-1} (T_7) which was significantly superior over other treatments. The next best treatment was 100% RDP + Soil application of BBPF @ 10 kg ha^{-1} (T_6) which was on a par with 75% RDP+Soil application of BBNPF @ 4 kg ha^{-1} (T_8) and 100% RDP+Soil application of BBNPF @ 6 kg ha^{-1}. Lower pod yield (1206.7 kg ha^{-1}) was noticed with application of no application of fertilizers (T_1) During *rabi*, soil application of 100% RDP+BBNPF @ 4 kg ha^{-1} (T_7) gave highest pod yield (3721.9 kg ha^{-1}) which was significantly superior to 100% RDP+Soil application of BBNPF @ 6 kg ha^{-1} (T_9), followed by 100% RDP+Soil application of BBPF @ 10 kg ha^{-1} (T_6). Lower pod yield (1742.0 kg ha^{-1}) production of groundnut was reported with control (T_1) (Table 5 and 6). Phosphorus might have promoted the growth of roots and efficient functioning of nodule bacteria for fixation of nitrogen to be utilized by plants during the pod development stage, as well as functional activity resulting in higher extraction of nutrients from the soil environment to aerial plant parts which led to increase in pod yield. Results endorse the findings of Salve and Gunjal (2011), Mouri et al. (2018) and Madhuridevi et al. (2019).

3.4.6. Haulm yield

From Tables 5 and 6 it was observed that during *kharif*, the maximum haulm yield (2349.3 kg ha^{-1}) was recorded in the treatment 100% RDP+Soil application of BBNPF @ 4 kg ha^{-1} (T_7) which on par with 75% RDP+Soil application of BBNPF @ 4 kg ha^{-1} (T_8). Lower haulm yield (1732.3 kg ha^{-1}) was noticed with the application of no application of fertilizers (T_1), followed by 100% RDF (T_2), 100% RDP + Soil application of biochar @ 1 t ha^{-1} (T_3) in order ascent during the investigation. During *rabi*, soil application of 100% RDP+BBNPF @ 4 kg ha^{-1} gave the highest haulm yield (2953.3 kg ha^{-1}) which was on par with 75% RDP+Soil application of BBNPF @ 4 kg ha^{-1} (T_8) and Lower haulm yield (2361.1 kg ha^{-1}) of groundnut reported with control (T_1). It is evident that high dry matter accumulation ultimately in turn increases the haulm yield. The results are in good agreement with the earlier reports of Salve and Gunjal (2011) and Yadav et al. (2015).

Table 5: Effect of biochar based phosphorus and biochar based nano phosphorus on pod yield and haulm yield of *kharif* groundnut

Treatments	Pod yield (kg ha^{-1})	Haulm yield (kg ha^{-1})
T_1	1206.7	1732.3
T_2	1577.7	1880.3
T_3	2045.7	1967.7
T_4	2264.7	2164.7
T_5	2306.7	2076.0
T_6	2530.7	2137.7
T_7	2746.7	2349.3
T_8	2529.0	2200.3
T_9	2452.7	2178.7
T_{10}	2155.3	1804.7
SEm±	46.43	29.94
CD (p=0.05)	148.5	95.7

Table 6: Effect of biochar based phosphorus and biochar based nano-phosphorus on pod and haulm yield of *rabi* groundnut

Treatments	Pod yield (kg ha^{-1})	Haulm yield (kg ha^{-1})
T_1	1742.0	2361.1
T_2	2144.7	2483.9
T_3	2780.6	2616.7
T_4	3191.1	2730.6
T_5	3127.8	2661.1
T_6	3455.3	2780.6
T_7	3721.9	2953.3
T_8	3424.4	2784.7
T_9	3550.3	2719.4
T_{10}	3210.6	2526.4
SEm±	49.13	82.661
CD (p=0.05)	157.1	264.43

4. CONCLUSION

The results indicated that the application of 100% RDP+biochar-based nano-phosphorus fertilizer @ 4 kg ha^{-1} recorded higher pod yield as well as haulm yield of groundnut. The application of biochar-based nano-phosphorus enhanced the phosphorus availability and uptake, which led to an increase in groundnut productivity in a sustainable manner. The soil application of BBNPF and BBPF availability of the phosphorous increased with the reduced losses and was available in the soil for extended periods of time.

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