Determining the Effect of PBR Cowpea in reducing the Adverse Effects of Pesticides on Soil Biological Properties and Improving Soil Fertility

FINAL PROJECT REPORT

By

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Table of Contents

INTRODUCTION

Cowpea *(Vigna unguiculata L.* Walp) is one of the most important grain and forage legumes, especially in sub-Saharan Africa, featuring prominently in many farming systems in both rural and urban areas (Boddey *et al.*, 2016; Kyel-Boahen *et al*., 2017). Nigeria is the world's leading producer of cowpea, supplying up to 40% of the daily intake of protein to the constantly increasing population (Miko and Mohammed, 2007). However, it is faced by production constrains, particularly, diseases and insect pests that needs to be protected for maximizing yield. Hence, chemical pesticides, frequently applied to agricultural fields to increase crop production and combat insect pests, however, these affect the activity and population of beneficial soil microbial communities as described by Arora and Sahni (2016). It has been established that some insecticides could be toxic to microbial populations at higher concentrations, adversely influencing the activity and diversity of biotic populations (Wesley *et al.,* 2017). Continuous application of these pesticides may result in soil pollution, threatening a number of processes mostly driven by soil microorganisms such as mineralization of organic matter, immobilization of nutrient elements, nitrogen fixation, nitrification, and denitrification, thereby, adversely affecting soil fertility (Chen *et al*., 2001; Islam and Wright, 2004; Cycon *et al*., 2006; Makarov *et al*., 2015).

Microbial biomass is also affected by pesticide application. Though it is not a measure of soil microbial activity, because it does not take into consideration differentiation between quiescent and active organisms, different classes of microorganisms (Okalebo *et al*., 2002). It comprises of less than 5% of organic matter in the soil however, it performs three critical functions in the soil and the environment (Dalal, 1998). First it is a source of available carbon, nitrogen, phosphorus and sulphur, second it is an immediate source of carbon, nitrogen, phosphorus and sulphur and thirdly an agent of nutrient transformation and pesticide degradation (Dalal, 1998). Hence, it plays a great role in a number of key functions of the soil, including nutrient release, maintenance of good soil structure and suppression of plant pathogens. Hence, measurement of total soil microbial biomass is an extremely useful tool for interpreting soil biological quality (Chen *et al*., 2001).

The microbial community structure and functions in the soil are influenced by physical and chemical properties of soils and vice versa (Dasgupta and Brahmaprakash, 2021). Pesticides enter the soil via direct application to control soil pests, through spray drift during foliage treatment, through wash off from treated foliage (Sujatha *et al.*, 2021). Hence, application of pesticides also effects both physical and chemical properties of the soil such as pH, salinity and alkalinity, leading to degradation of the soil infertility (Sarnaik *et al.*, 2006). Likewise, Abiotic controls like surrounding climate, environment, land use, nutrients, pH and rhizosphere control the composition of microbes in soil, which in turn also modify soil properties (Dasgupta and Brahmaprakash, 2021).

It is therefore, useful to study the effect the introduction of PBR cowpea, with special characteristics of resistance to pod borer insect (*Maruca vitrata*) tolerance to Striga, early maturity, drought tolerance and high yield potential in the Northern Guinea, Sudan and Sahelian regions of Nigeria (Abdullahi *et al*., 2022). It expected to influencing the effects of pesticides, through reduction in the rate of application in the main areas of cowpea production, especially as effects soil microbial population, microbial biomass and soil chemical and physical properties, influenced by the biological components. The specific research questions addressed by the study are:

1. Does PBR cowpea reduce the effect (if any) of chemical insecticides on bacterial and fungal populations in the soil?

2. Does PBR cowpea reduce the effect (if any) of chemical insecticides on soil microbial carbon, nitrogen and phosphorus?

3. Does PBR cowpea reduce the effect (if any) of chemical insecticides on physical and chemical properties as related to soil fertility?

MATERIALS AND METHODS

Study site

The study was conducted across four agroecological zones in Nigeria, Sahel, Sudan, Northern Guinea and Southern Guinea, known for cowpea production and adoption of the PBR cowpea production, along with other cowpea production ways.

Treatments and Experimental Design

The treatments used during the study were the **PBR**, **non-PBR** and **Control** fields. The PBR farmers are those that have adopted the PBR cowpea and its production practices, including only two pesticides spays being pod borer resistant, the non-PBR farmers were those who have not adopted the PBR cowpea, but grow other cowpea varieties, using their own traditional and conventional practices, including application of pesticides at least four times (or even more), while the control farmers were those who planted other cowpea varieties using their traditional cultural practices, could not afford pesticides application and mostly with poor resources, without even fertilizer application to their fields. The treatments were replicated three times in each of the agroecological zone in randomized complete block design (RCBD). This Makes nine (9) soil samples per agroecological zone (three from PBR, three from Non-PBR and three from Control plots). Hence a total of thirty six samples distributed across the four agroecological zones from the rhizosphere soils of the plants, after all the pesticide sprays have been applied, targeted for the determination of bacterial and fungal population as well as microbial biomass carbon, nitrogen and phosphorus while another thirty six soil samples taken at 0-20 cm after harvest of the crops, targeted at determination of the influence of the treatments on the soil chemical and physical properties, as related to soil fertility.

Soil Sampling and Preparation

The first set of soil samples were collected from the rhizosphere of the plants, soils attached to the roots of the plants after the application of all the pesticide prays have been applied by the farmers. Five randomly selected plants were marked in each plot, uprooted using a hand spade and the soils attached to the root composited in a clean bucket then a subsample was packaged in a polyethene plastic bag and labelled. The samples were then stored at $4^{o}C$ in the refrigerator to preserve live microbes present and microbial biomass in the samples, prior to laboratory analysis for microbial populations and microbial biomass carbon (C), nitrogen (N) and phosphorus (P). The second set of soil samples was collected after harvest of the plants at 0-20 cm depth from each of the plots using auger. Five randomly selected soil samples were collected from each plot and composited in a bucket, then a sub sample was taken into polyethene plastic bag and labelled. These samples were air dried, crushed using stainless pestle and mortar and sieved through two (2) mm sieve mesh. They were then stored safely at room temperature prior to analyses for routine soil physical and chemical properties.

Determination of the Effect of Chemical Insecticides on Bacterial and Fungal Populations.

The soil samples collected from the rhizosphere of the soil and stored at $4^{o}C$ were subjected to viable count for enumeration of pure cultures of bacteria and fungi population. The activity was conducted using Miles and Misra drop method (Surface Viable count) (Miles and Misra, 1938), as described by Xu *et al* (2014), and Anasuya *et al* (2016).

Determination of Microbial Biomass Carbon (C), Nitrogen (N) and Phosphors (P).

The rhizosphere soil samples stored in the refrigerator at 4^{o}C in the refrigerator subjected to analyses for microbial Biomass C, N, Okalebo *et al.* (2002) (equations 1 and 2) and P Anderson and Ingram (1993) (equation 3).

Soil microbial biomass C = $C_{Fumigated} - C_{unfumigated}$ ………………..Equation.....1

Soil microbial biomass N = $N_{Fumigated} - N_{unfumigated}$ ………………..Equation….2

Soil microbial biomass P = $P_{Fumigated} - P_{unfumigated}$ …………………Equation….3

Determination of Soil Physical and Chemical Properties, Related to Soil Fertility

The sample collected at 0-20 cm soil depth and store at room temperature were subjected to determination of routine soil properties; particle size distribution, pH, electrical conductivity (EC), organic carbon (OC), total nitrogen (TN), available phosphorus (AP), exchangeable Ca, Mg, K and Na, exchangeable acidity (EA), cation exchange capacity (CEC) and selected micronutrients (Zn, Mn, Cu and Fe) (Agbenin, 1995).

Statistical Analyses

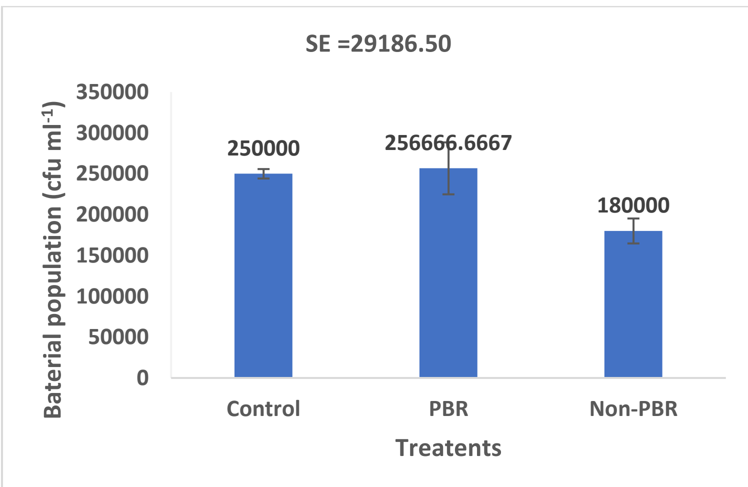
All relevant data collected were subjected to analysis of variance using IBM, SPSS, Statistics Version 23 (2015). Where F values are significant, Tukey (HSD) was used to compare the difference among the means. Data from the three locations were then pooled and analyzed to determine the variability among the three locations.

RESULTS

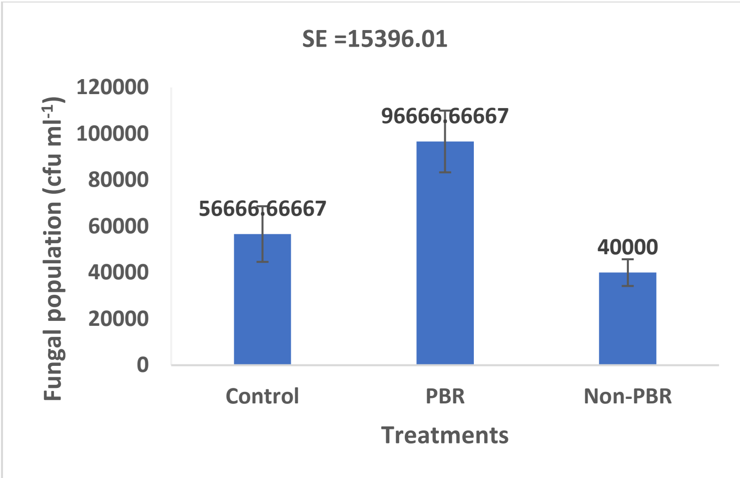
Effect of the Treatments on Bacterial and Fungal Populations

Sahel Savanna

Figure 1 shows the result of the bacterial population as influenced by the treatments in the Sahel savanna. Even though there was no significance (P > 0.05) difference among the treatments in bacterial population, there was an indication of higher bacterial population in the plots of the PBR cowpea adopters with increase of 3 and 30% over the control and Non-PBR plots, respectively. The difference in fungal population among the treatments was however, significant (P < 0.05). It was highest in the in the PBR cowpea plots, but similar between the control and the non-PBR plots (Figure 2). There was 30% higher fungal population in the PBR plots than the non-PBR plots.



Figures 1. Effect of the PBR cowpea on bacterial population relative to non-PBR and control plots in the Sahel savanna of Nigeria.



Figures 2. Effect of the PBR cowpea on fungal population relative to non-PBR and control plots in the Sahel savanna of Nigeria.

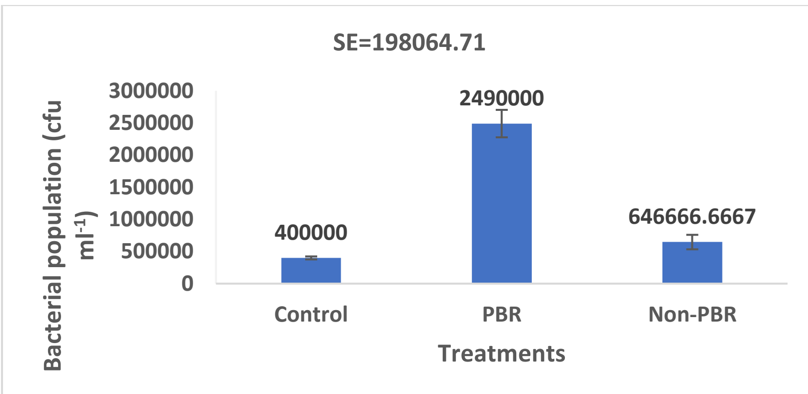
Sudan Savanna

There was significant (P< 0.01) difference in bacterial and fungal populations among the treatments in Sudan savanna (Figure 3). There was higher bacterial population in the PBR cowpea plots, compared to the non-PBR and control plots, which were statistically similar. There was 74 and 84% higher bacterial population than the non-PBR and control fields, respectively (Figure 4). The PBR cowpea plots had higher fungal population than the control plots, which was in turn higher than the non-PBR fields, with 40 and 90% higher bacterial population than the control and non-PBR farmers fields, respectively.

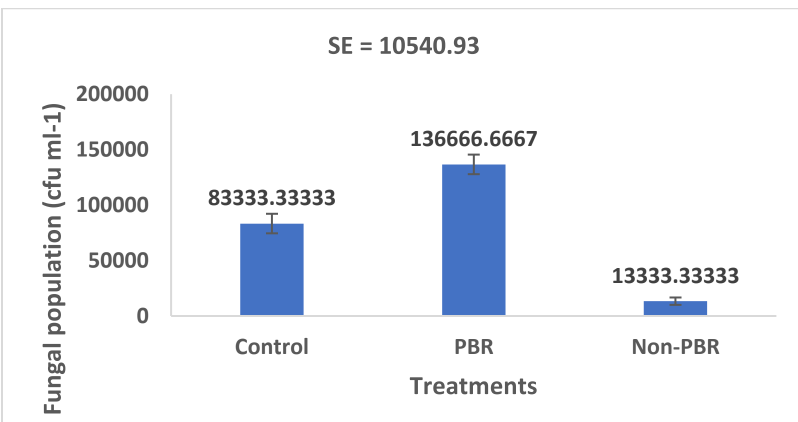
Northern Guinea Savanna

Observation of the bacterial population the Northern Guinea Savanna shows significantly (P<0.01) difference among the treatments. There was higher population in PBR cowpea, which was similar to the control plots and higher than the non-PBR plots (Figure 5). There was 62% higher bacterial population in the PBR cowpea plots than the non-PBR plots.

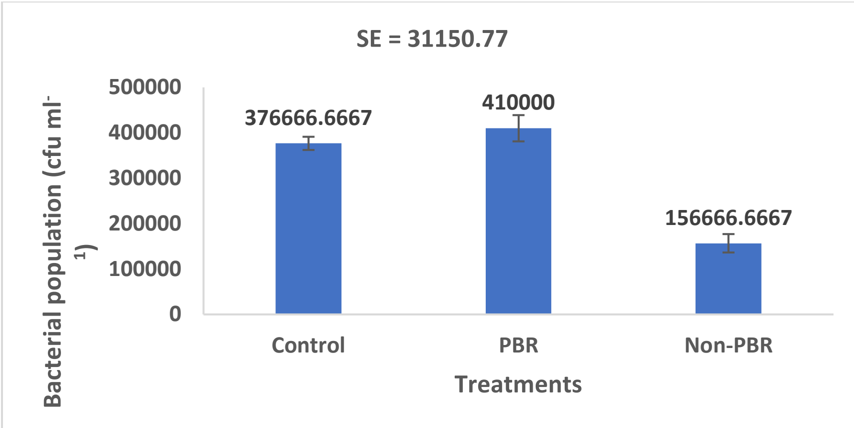
Figure 6 shows the result of the effect of the treatments on the fungal population in the Northern Guinea savanna. There was significant (P<0.01) difference was also observed among the treatments in fungal population. The PBR plots had the highest fungal population, while the control and the non-PBR plots were similar. The PBR plots had 90% higher fungal population than the non-PBR plots.



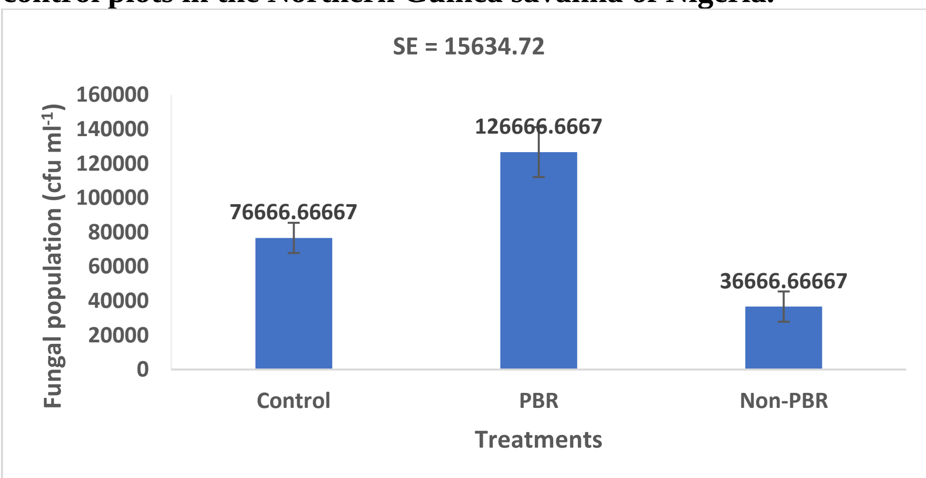
Figures 3. Effect of the PBR cowpea on bacterial population relative to non-PBR and control plots in the Sudan savanna of Nigeria.



Figures 4. Effect of the PBR cowpea on fungal population relative to non-PBR and control plots in the Sudan savanna of Nigeria.



Figures 5. Effect of the PBR cowpea on bacterial population relative to non-PBR and control plots in the Northern Guinea savanna of Nigeria.



Figures 6. Effect of the PBR cowpea on fungal population relative to non-PBR and control plots in the Northern Guinea savanna of Nigeria.

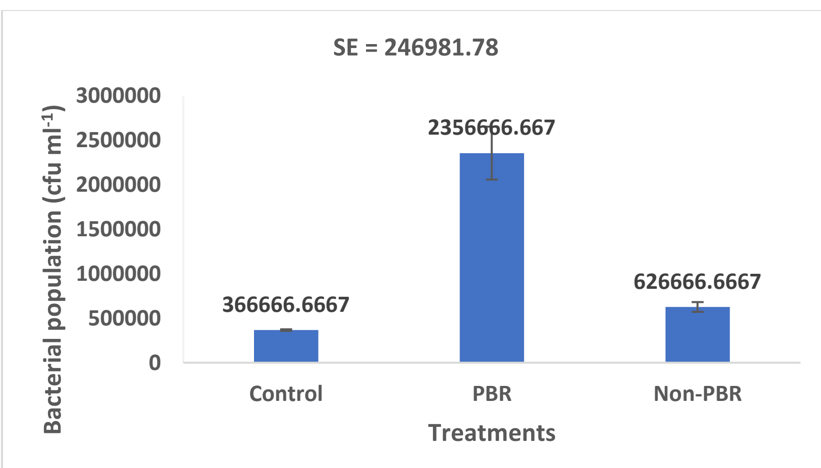
Southern Guinea Savanna

Bacterial population was significant ($P<0.01$) as affected by the treatments in the Southern Guinea Savanna (Figure 7). The PBR cowpea plots were leading, while the non-PBR and control plots were similar to each other. The Bacterial population in the PBR plots was 73% higher than the non-PBR plots. Similarly, the fungal population in the zone was significantly ($P<0.01$) different as affected by the treatments (Figure 8). The PBR plots were higher in fungal population than the control plots, which were in turn higher than the non-PBR plots. The PBR plots had 40% and 90% higher fungal population than the control and no-PBR plots, respectively.

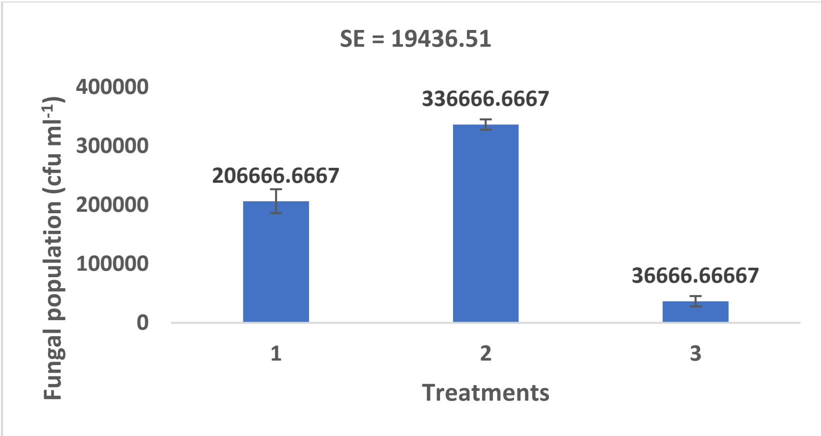
Pooled data for Bacterial and Fungal Population for the Four ecological zones (Sahel, Sudan, Northern Guinea and Southern Guinea)

Figure 9 shows the pooled data for the four ecological zones shows significant ($P<0.01$) difference among the treatments in bacterial population. The PBR cowpea plots had higher bacterial population than the non-PBR and the control plots, which were similar to each other. The PBR plots had 70% higher bacterial population than the non-PBR plots.

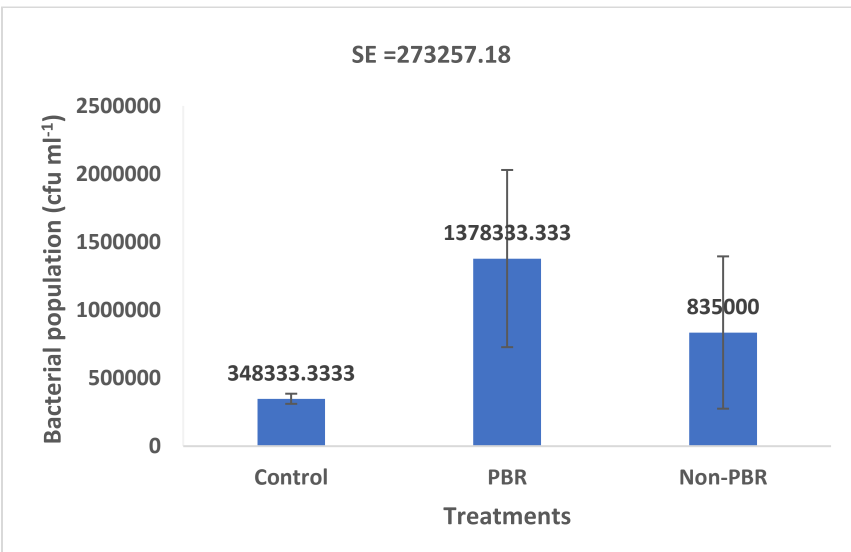
Figure 10 shows the result of the pooled data analysis for the ecological zones in bacterial population. There was also significant ($P<0.01$) difference among the treatments in fungal population, with the PBR plots and the control having similar fungal population and higher than the non-PBR plots. The PBR plots had 80% higher fungal population than the non-PBR plots.



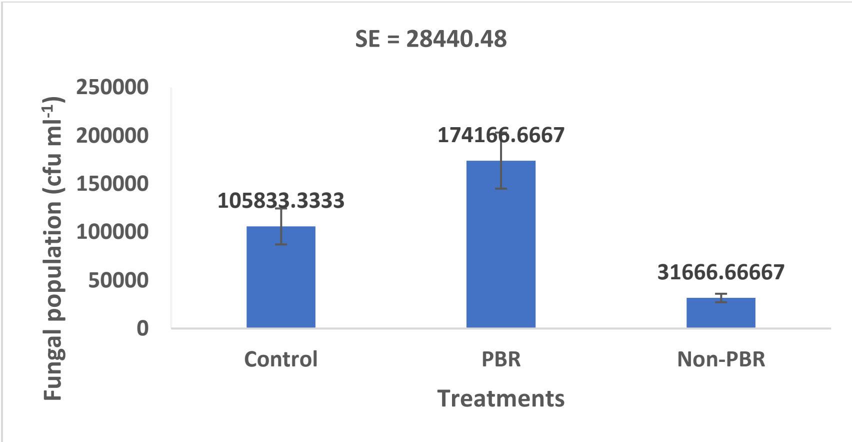
Figures 7. Effect of the PBR cowpea on bacterial population relative to non-PBR and control plots in the Southern Guinea savanna of Nigeria.



Figures 8. Effect of the PBR cowpea on fungal population relative to non-PBR and control plots in the Southern Guinea savanna of Nigeria.



Figures 9. Pooled effect of the PBR cowpea on bacterial population relative to non-PBR and control plots in the four agroecological zones of Nigeria.

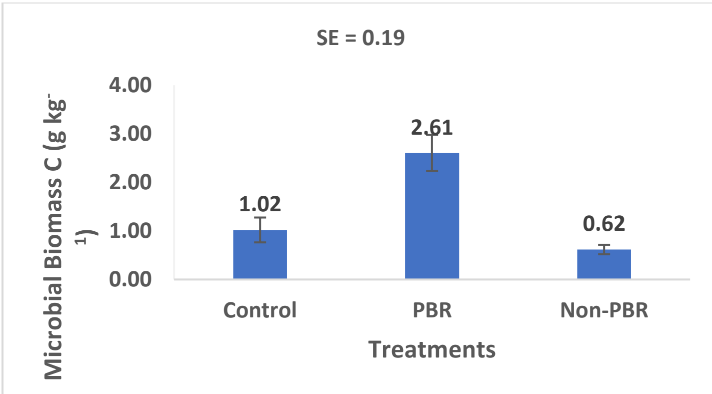


Figures 10. Pooled effect of the PBR cowpea on fungal population relative to non-PBR and control plots in the four agroecological zones of Nigeria.

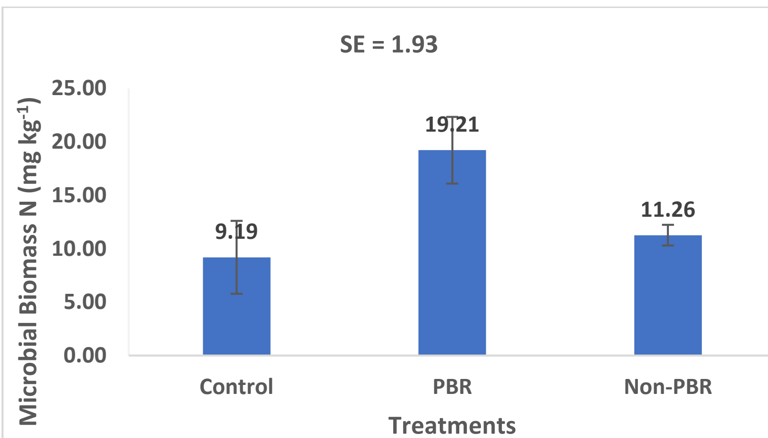
Effect of the Treatments on Microbial Biomass Carbon (MBC), Nitrogen (MBN) And Phosphorus (MBP).

Sahel Savanna

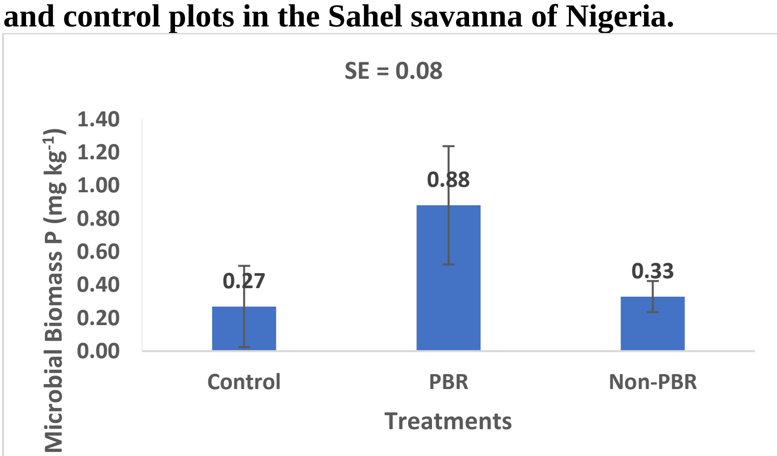
There was no significant difference among the treatments in influencing the MBC. However, the PBR cowpea plots had 70 and 60% higher MBC than the control and non-PBR fields, respectively (Figure 11). The MBN was observed to significantly ($P<0.0$) differ among the treatments as shown in Figure 12. There was higher MBN in the PBR cowpea plots than the non-PBR, which is in turn higher than the control plots. The PBR plots had 42% higher MBN and 78% higher MBC than the non-PBR and the control plots, respectively. Similarly, Figure 13 shows the effect of the treatments on MBP in the Sahel savanna. The results show significant different among the treatments in MBP. Higher MBP in the PBR cowpea was observed, which was similar to the non-PBR and higher than the control plots.



Figures 11. Effect of the PBR cowpea on microbial biomass carbon relative to non-PBR and control plots in the Sahel savanna of Nigeria.



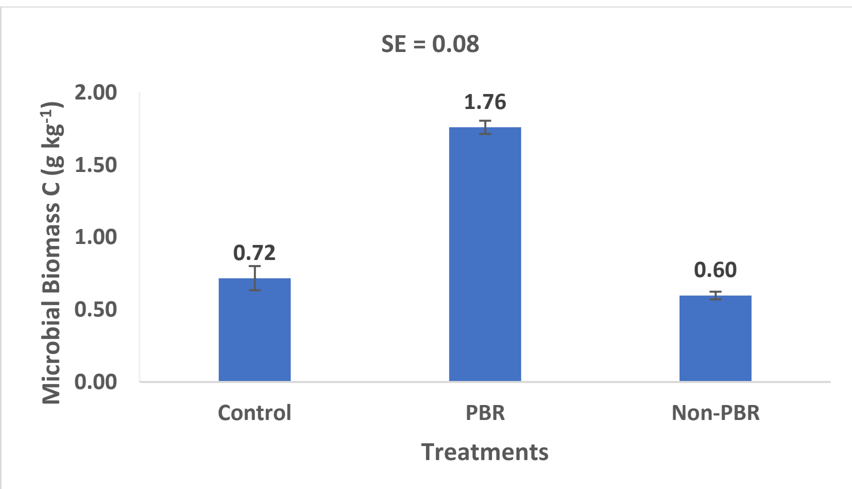
Figures 12. Effect of the PBR cowpea on microbial biomass nitrogen relative to non-PBR and control plots in the Sahel savanna of Nigeria.



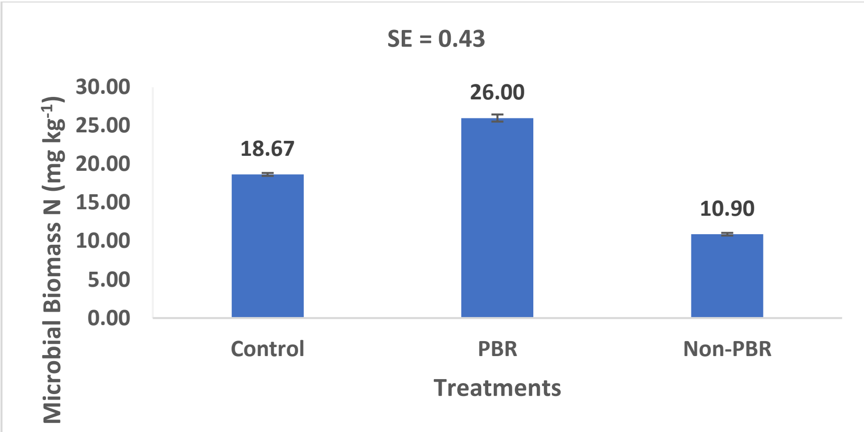
Figures 13. Effect of the PBR cowpea microbial biomass phosphorus relative to non-PBR and control plots in the Sahel savanna of Nigeria.

Sudan Savanna

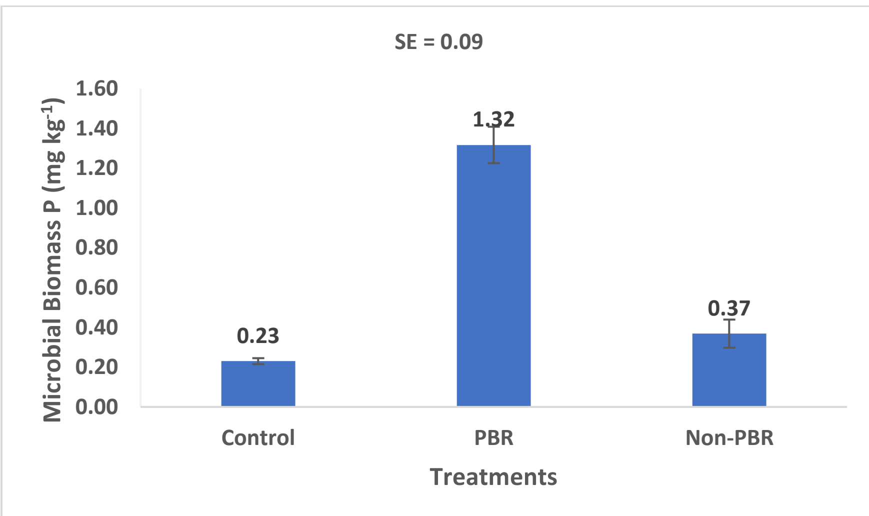
Result of the effect of the treatments on MBC in the Sudan savanna is shown in Figure 14. There was significant (P<0.01) difference among the treatments. Higher MBC wa observed in the PBR cowpea was planted, while the non-PBR and the control plots were similar. There was 66% higher MBC in the PBR plots than the non-PBR plots. Result of the effect of the treatments on MBN is shown in Figure 15. There was significant (P<0.01) difference among the treatments. PBR cowpea plots were higher than both the non-PBR plots, which were similar. The PBR plots had 58% higher MBN than the non-PBR plots. The effect of the treatments on MBP (Figure 16), also shows significant (P<0.01) difference among the treatments. The PBR cowpea plots had higher MBP than the other two treatments, but they were similar. The PBR cowpea plots exceeded the non-PBR plots in MBP by 70%.



Figures 14. Effect of the PBR cowpea microbial biomass carbon relative to non-PBR and control plots in the Sudan savanna of Nigeria.



Figures 15. Effect of the PBR cowpea microbial biomass nitrogen relative to non-PBR and control plots in the Sudan savanna of Nigeria.

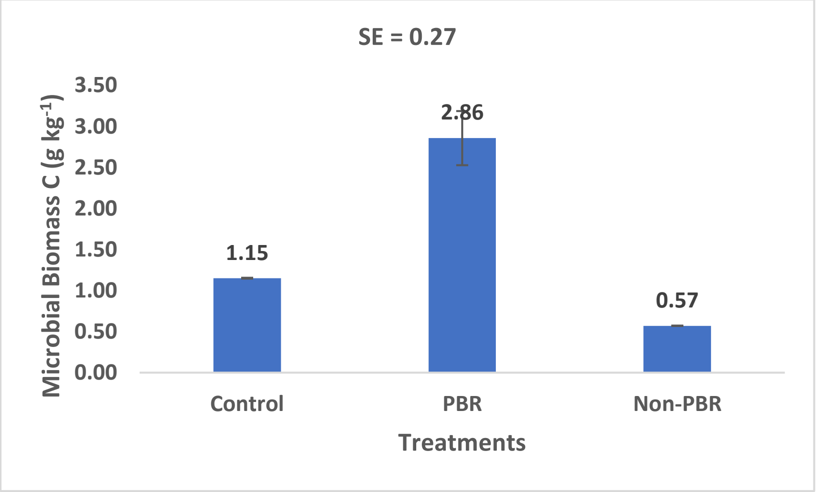


Figures 16. Effect of the PBR cowpea microbial biomass phosphorus relative to non-PBR and control plots in the Sudan savanna of Nigeria.

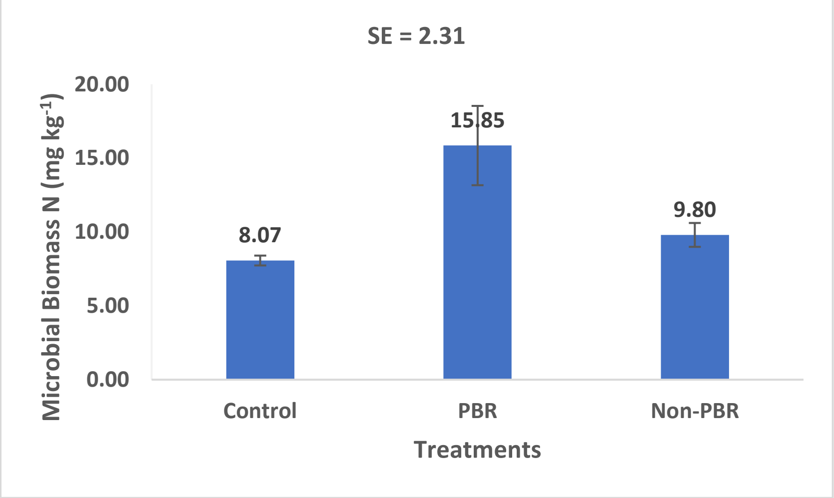
Northern Guinea savanna

The MBC was observed to be significantly ($P<0.01$) different among the treatments in the Northern Guinea savanna (Figure 17). Higher MBC was observed in the PBR plots than the control and non-PBR plots, which were similar. Up to 80% higher MBC was observed in the PBR plots relative to the non-PBR plots. There was also significant ($P<0.05$) among the treatments in MBN (Figure 18). The non-PBR and the PBR plots were however, similar and higher than the control plots in MBC.

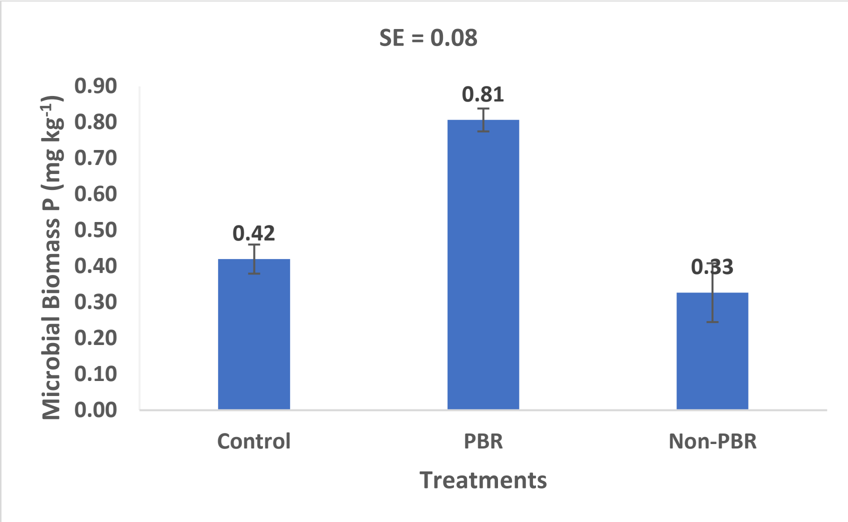
Even though, there was an indication of 38% higher MBN in the PBR plots relative to the non-PBR plots. Similarly, result of the MBP shows significant difference ($P<0.05$) among the treatments as shown in Figure 19. The PBR cowpea plots were higher in MBP then the other two treatments, which were similar. The PBR cowpea plots had 60% higher MBP than the non-PBR plots.



Figures 17. Effect of the PBR cowpea microbial biomass carbon relative to non-PBR and control plots in the Northern Guinea savanna of Nigeria.



Figures 18. Effect of the PBR cowpea microbial biomass nitrogen relative to non-PBR and control plots in the Northern Guinea savanna of Nigeria.

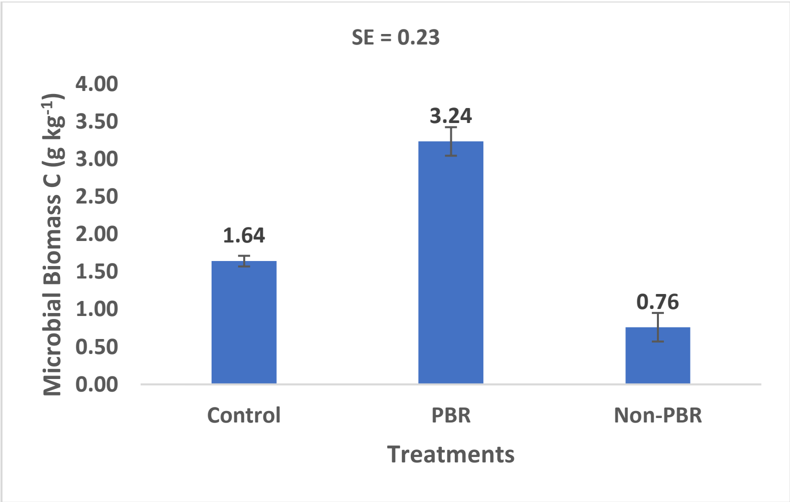


Figures 19. Effect of the PBR cowpea microbial biomass phosphorus relative to non-PBR and control plots in the Northern Guinea savanna of Nigeria.

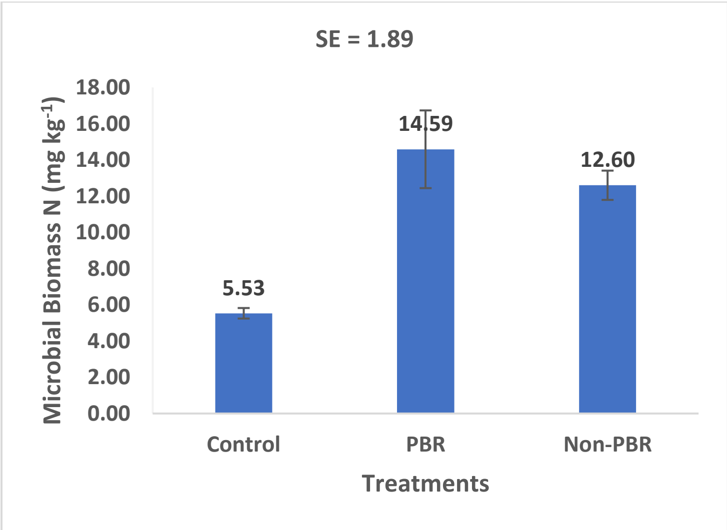
Southern Guinea Savanna

Figure 19 shows results from the southern Guinea savanna indicates MBC, which was significantly (P<0.01) different among the treatments. The PBR cowpea plots were higher in MBC than the control plots, which in turn higher than the non-PBR plots. There was 77% higher MBC in the PBR plots relative to the non-PBR plots. Significant (P<0.05) difference was also observed among the treatments in MBN (Figure 20). The PBR and non-PBR plots were similar in MBN and higher than the control plots. Even though, the PBR plots had an indication of 14% higher MBN than the non-PBR plots. The result of MBP (Figure 21) also shows significant difference among the treatments. The PBR cowpea had the highest MBP, while the other two treatments were similar to each other. The PBR cowpea plots had 47% higher MBP than the non-PBR plots.

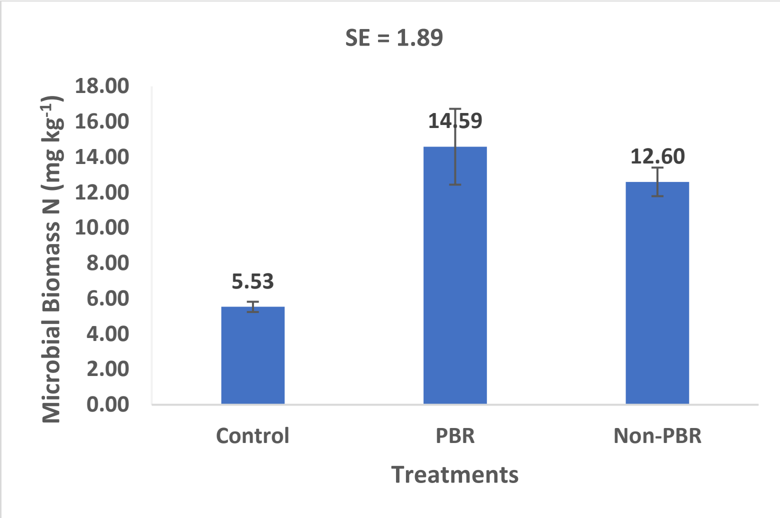
High moisture availability enhances population growth and activity of microbes leading to higher MBN. Some bacteria use pesticides as sole source of carbon and nitrogen and hence grows on the minimal medium and can be used for decontamination of pesticide polluted areas (Shinde *et al.*, 2015). Whereas significantly higher MBC and MBP were observed in PBR cowpea planted plots when compared to pesticide sprayed and control plots. This could be attributed to the production of exudates by PBR cowpea to attract more rhizosphere microbes and carbon and phosphorus inclusions as ingredients for some organic pesticides could be a reason for higher MBC and MBP in those plots.



Figures 19. Effect of the PBR cowpea microbial biomass carbon relative to non-PBR and control plots in the Southern Guinea savanna of Nigeria.



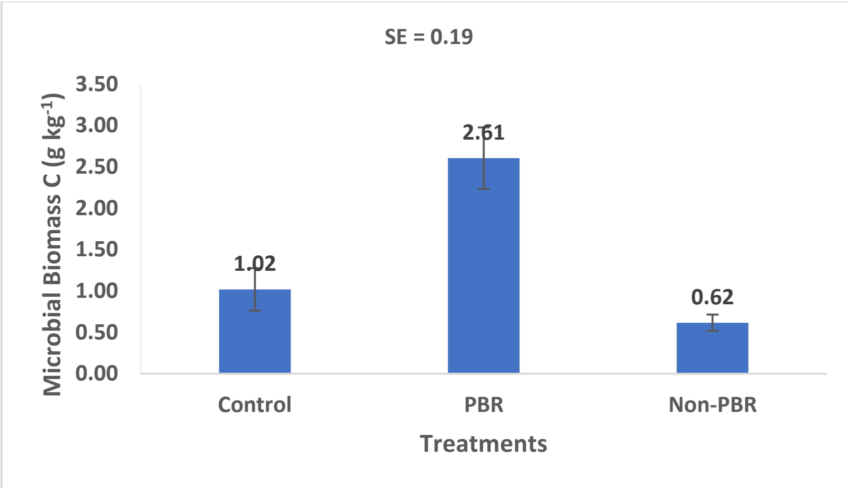
Figures 20. Effect of the PBR cowpea microbial biomass nitrogen relative to non-PBR and control plots in the Southern Guinea savanna of Nigeria.



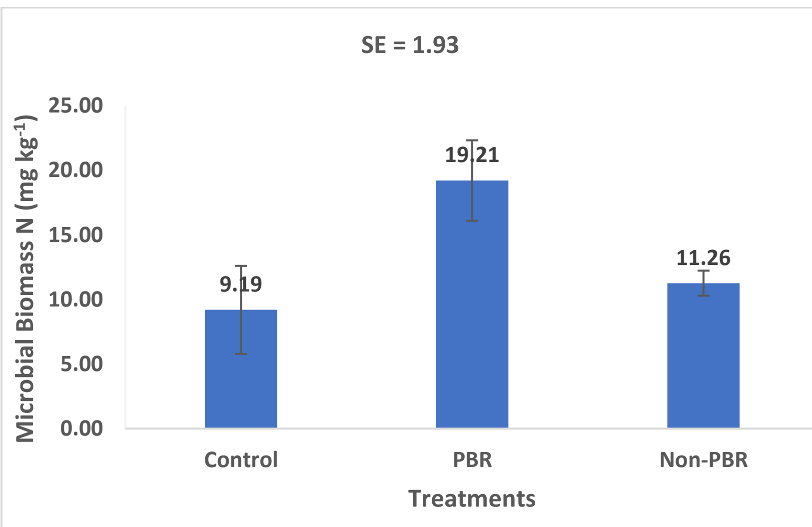
Figures 21. Effect of the PBR cowpea microbial biomass phosphorus relative to non-PBR and control plots in the Southern Guinea savanna of Nigeria.

Pooled Data for MBC, MBN and MBP for the Four Ecological Zones

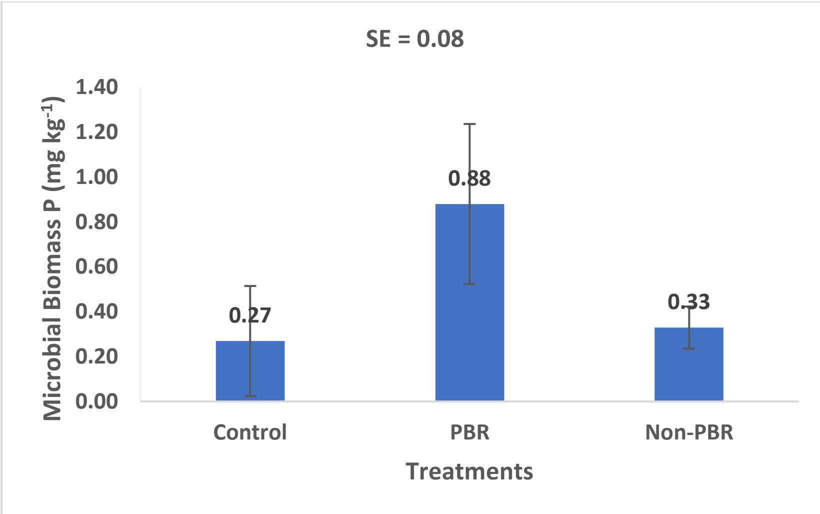
Pooled result of the MBC for the four ecological zones is shown in Figure 22. There was significant difference among the treatments in MBC. PBR cowpea plots had the highest value, while the control and non-PBR were similar. The PBR cowpea plots exceeded the non-PBR plots in MBC by 76%. Similarly, the result of MBN for the zones (Figure 23), shows significant ($P<0.01$) difference among the treatments. The PBR cowpea plots had the highest value, while the control and non-PBR plots were similar. There was 41% higher MBN in the PBR cowpea plots than the nob-PBR cowpea plots. Likewise, the MBP results as shown in Figure 24 indicates significant ($P<0.01$) difference among the treatments in MBP, with the PBR cowpea higher than the control and non-PBR that were statistically similar. Up to 62% higher MBP was observed in the PBR cowpea plots over the non-PBR plots.



Figures 22. Pooled effect of the PBR cowpea microbial biomass carbon relative to non-PBR and control plots in the four agroecological zones of Nigeria.



Figures 23. Pooled effect of the PBR cowpea microbial biomass nitrogen relative to non-PBR and control plots in the four agroecological zones of Nigeria.



Figures 24. Pooled effect of the PBR cowpea microbial biomass phosphorus relative to non-PBR and control plots in the four agroecological zones of Nigeria.

Effect of the Treatments on Soil Physical and Chemical Properties as Relates to Soil Fertility

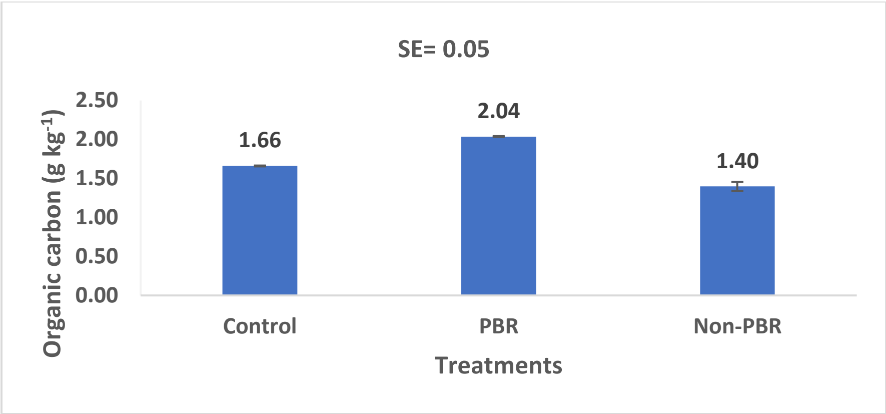
Sahel Savanna

Results of the clay content of the soils in the Sahel savanna shows no significant change in soil texture ($P > 0.05$) as a result of the treatments. Except for indications of slight differences of higher silt content of the PBR plots of 12% higher silt content than non-PBR 67% higher silt content than control. Similarly, there was no significant ($P>0.05$) differences among the treatment in soil pH. Except for indication of higher soil pH (5.94) in the non-PBR plots, than the PBR plots (5.74) and the control plots (5.70). There was also no significant difference in electrical conductivity among the treatment, except for indication of higher electrical conductivity in the non-PBR plots (1.08 dS m^{-1}) than the PBR (1.03 dS m^{-1}) and control plots (0.92 dS m^{-1}).

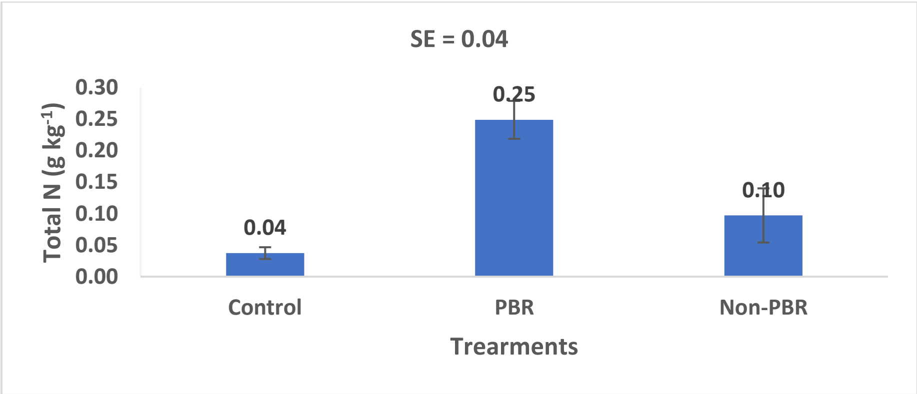
There was however, significant ($P<0.01$) difference in organic carbon among the treatments (Figure 25). The PBR cowpea plots had higher organic carbon, which higher than that of the control plots and in turn higher than the non-PBR plots. There was 19 and 30% higher organic carbon in PBR, than the control and non-PBR plots, respectively. There was also significant

(P<0.05) difference among the treatments in total N contents of the soil (Figure 26). The PBR cowpea plots had the highest total N, while the control and non-PBR plots had similar total N contents. The PBR plots exceeded the control and non-PBR plots by 84 and 61%, respectively. There was also significant (P<0.01) difference in available phosphorus as influenced by treatments (Figure 27). The PBR plots had the highest available P, while the non-PBR and the control were similar. The PBR plots had 64% and 65% higher available P than the non-PBR control plots, respectively.

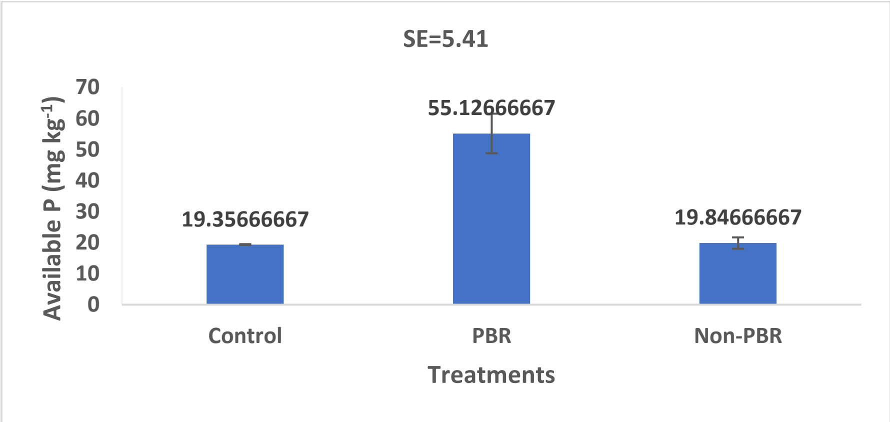
Significant (P<0.05) difference was also observed among the treatments in their influence on exchangeable calcium (Ca) (Figure 28). The PBR and non PBR cowpea plots were similar in exchangeable calcium and higher than the control. The difference among the treatments in exchangeable magnesium (Mg) was also significant (P<0.01) (Figure 29). The PBR and non-PBR cowpea plots were also similar and higher than the control plots. There was however, no significant (P>0.05) difference among the treatments in exchangeable potassium (K). However, there was an indication of 38% and 60% higher exchangeable K in the PBR than the non-PBR and control plots respectively. There was however, significant (P<0.01) difference among the treatments in exchangeable sodium (Na) (Figure 30). The PBR cowpea plots had the highest exchangeable Na contents, while the non-PBR and control plots were similar. There was no significant (P>0.05) difference in exchangeable acidity among the treatments, however, there was an indication of lowest exchangeable acidity in the PBR cowpea plots (6.00), with higher exchangeable acidity in the non-PBR (7.00) and control plots (7.33). However, there was significant (P<0.01) difference among the treatments in cation exchange capacity (CEC) (Figure 31). The PBR cowpea plots had the highest, then the non-PBR plots, while the lowest was the control plots. There was 18 and 39% higher CEC in the PBR cowpea plots than the non-PBR and control plots.



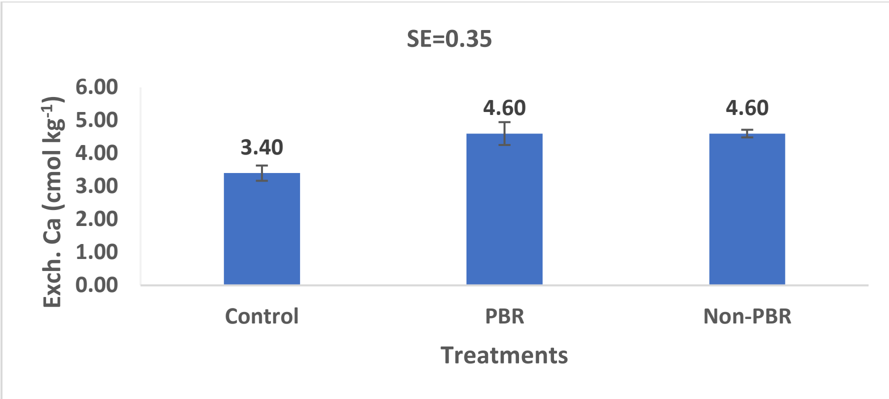
Figures 25. Effect of the PBR cowpea on organic carbon concentration relative to non-PBR and control plots in the Sahel savanna of Nigeria.



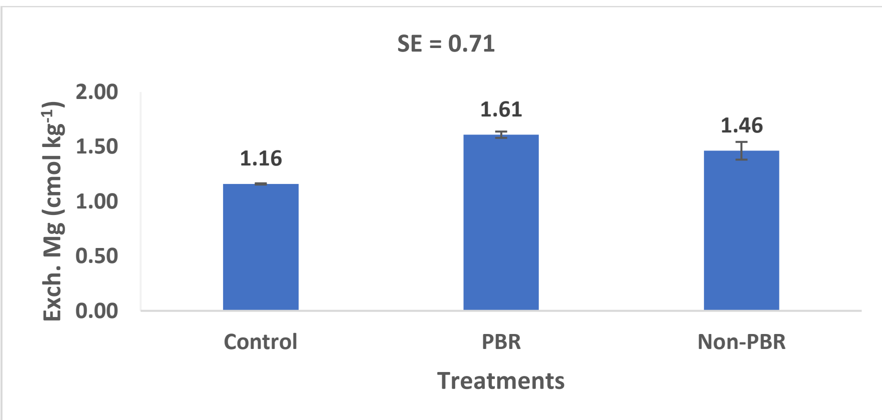
Figures 26. Effect of the PBR cowpea on total N concentration relative to non-PBR and control plots in the Sahel savanna of Nigeria.



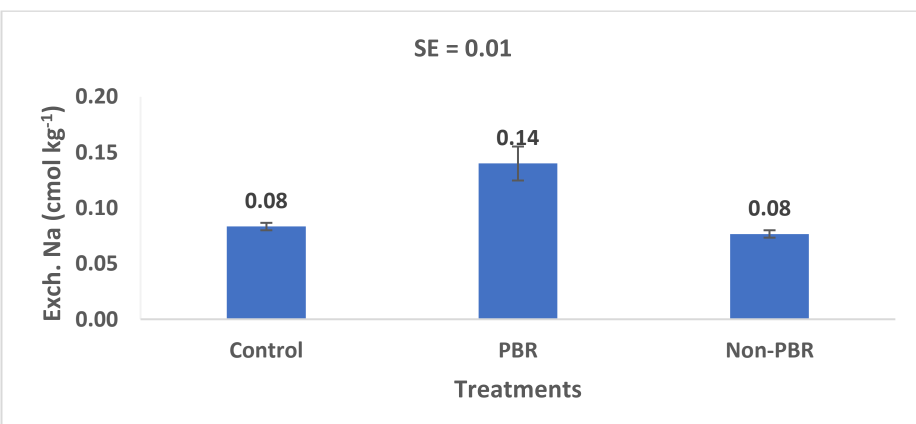
Figures 27. Effect of the PBR cowpea on available phosphorus concentration relative to non-PBR and control plots in the Sahel savanna of Nigeria.



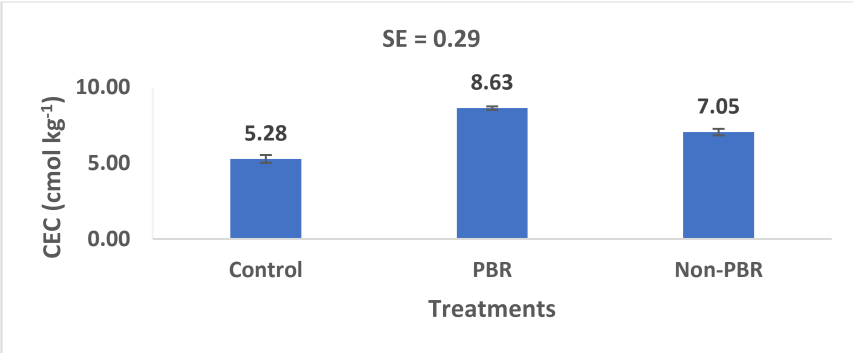
Figures 28. Effect of the PBR cowpea on exchangeable calcium concentration relative to non-PBR and control plots in the Sahel savanna of Nigeria.



Figures 29. Effect of the PBR cowpea on exchangeable magnesium concentration relative to non-PBR and control plots in the Sahel savanna of Nigeria.

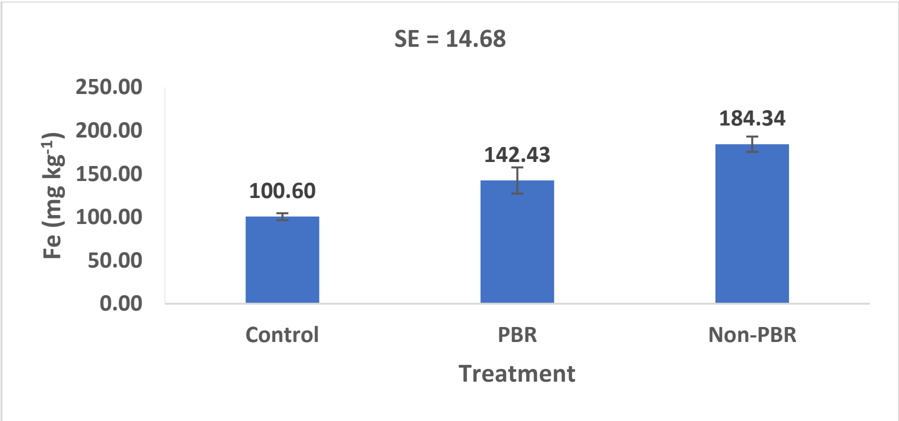


Figures 30. Effect of the PBR cowpea on exchangeable sodium concentration relative to non-PBR and control plots in the Sahel savanna of Nigeria.

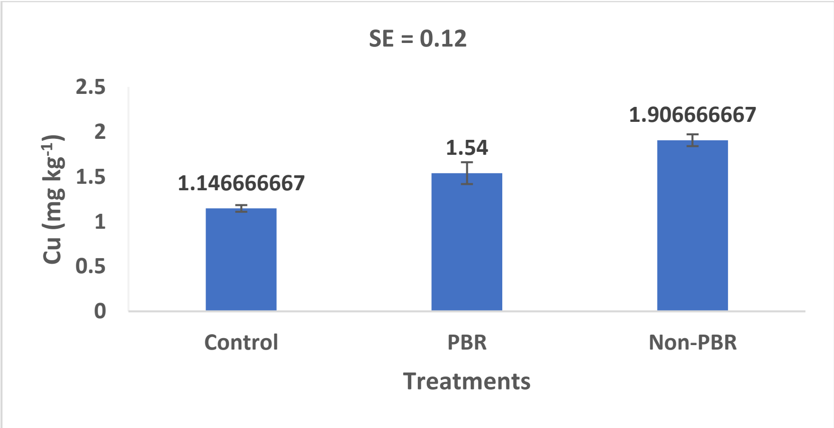


Figures 31. Effect of the PBR cowpea on soil cation exchange capacity relative to non-PBR and control plots in the Sahel savanna of Nigeria.

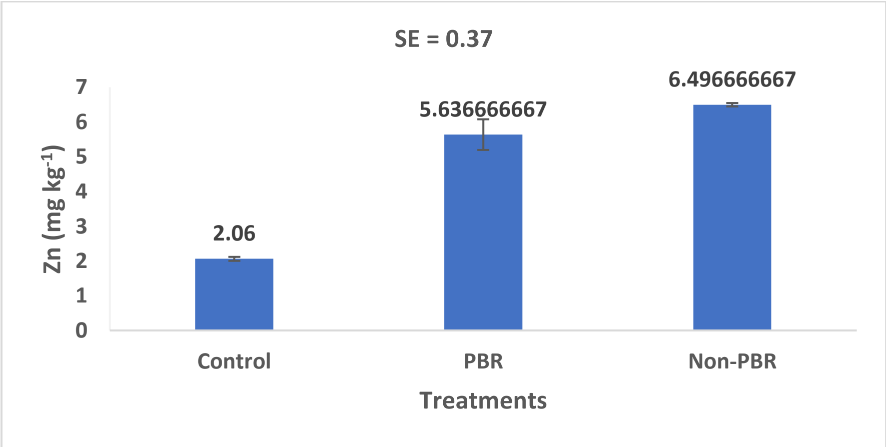
There was also significant difference among the treatments in influencing the iron (Fe) content of the soils ($P<0.01$) (Figure 32). The non-PBR and PBR cowpea plots had similar Fe content and higher than the control plots. However, there was 23% and 62% higher Fe content in the non-PBR plots relative to the PBR and control plots, respectively. There was however, no significant ($P>0.05$) difference among the treatments in manganese (Mn) content. Even though, there was an indication of 9 and 13% higher manganese content of the non-PBR over the PBR and control plots. There was also significant ($P<0.01$) difference in copper (Cu) content of the soils as influenced by the treatments (Figure 33). The non-PBR cowpea plots were higher than PBR cowpea plots, while the control plots were lowest. The Non-PBR plots had 19 and 76% higher Cu content than the PBR and the control plots, respectively. There was also significant difference among the treatments in zinc (Zn) content (Figure 34). The non PBR and PBR plots were similar in Zn content and higher the control plots. The non-PBR cowpea plots exceeded the PBR and non PBR plots in Zn content by 13 and 68%, respectively.



Figures 32. Effect of the PBR cowpea on iron concentration relative to non-PBR and control plots in the Sahel savanna of Nigeria.



Figures 33. Effect of the PBR cowpea on copper concentration relative to non-PBR and control plots in the Sahel savanna of Nigeria.

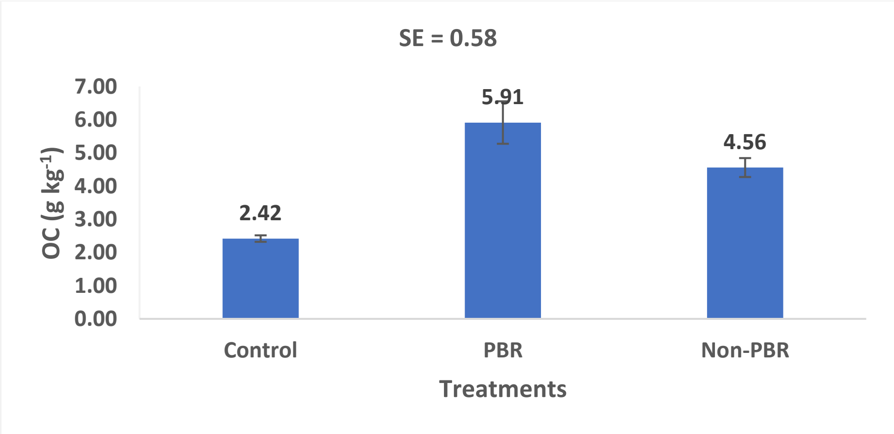


Figures 34. Effect of the PBR cowpea on zinc concentration relative to non-PBR and control plots in the Sahel savanna of Nigeria.

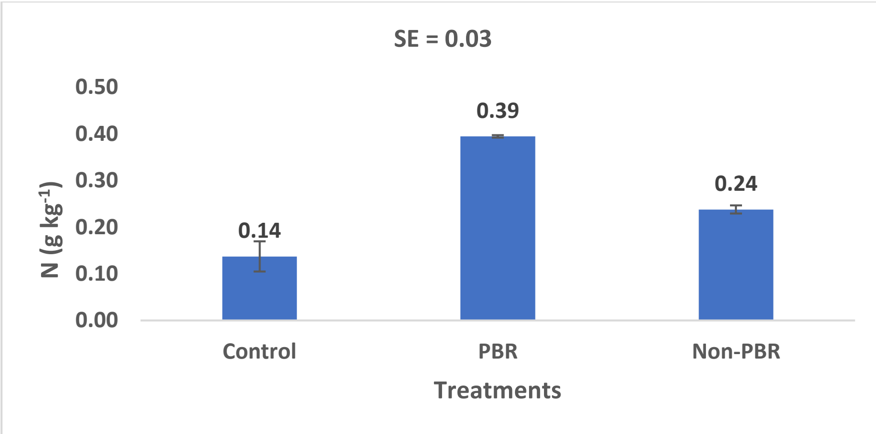
Northern Guinea Savanna

No significant (P<0.05) difference was observed among the treatments in soil texture or its fractions, soil pH and electrical conductivity in the Northern Guinea savanna soils. However, there was an indication of 19 and 25% higher clay content in control and non-PBR plots, respectively. There was also an indication of lower pH in the PBR cowpea plots (5.14) than the non-PBR (5.51) and the control plots (5.22).

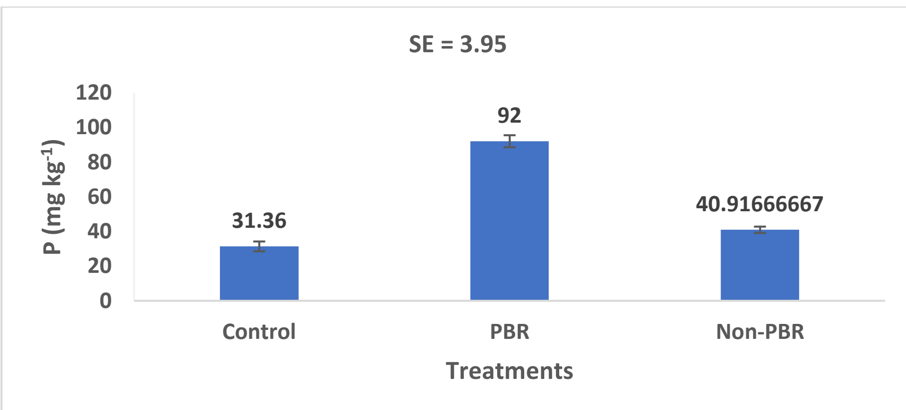
However, there significant (P<0.01) difference among the treatments in organic carbon (Figure 35). The PBR and non-PBR plots were similar and higher than the control plots. Even though, there was an indication of 23 and 59% higher organic carbon in the PBR plots relative the non PBR and control plots. There was also significant (P<0.01) difference among the treatments in total N (Figure 36). The PBR cowpea plots were higher than the non-PBR plots, while the lowest plots were the control. Up to 40 and 65% higher total N was observed in the PBR plots higher than the non-PBR and the control plots. Likewise, there was significant (P<0.01) difference among the treatments in influencing available P (Figure 37). The PBR plots were highest, while the non-PBR and the control plots were similar. There was 56 and 96% higher available P in the PBR plots than the non-PBR and control plots.



Figures 35. Effect of the PBR cowpea on organic carbon concentration relative to non-PBR and control plots in the Northern Guinea savanna of Nigeria.

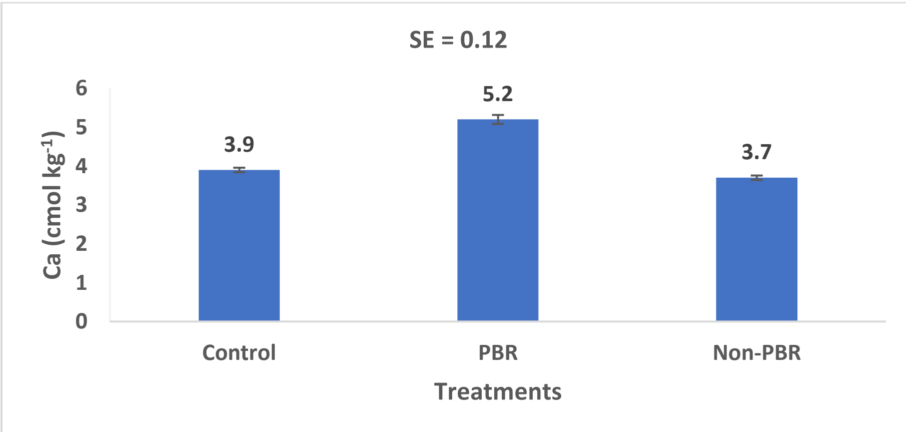


Figures 36. Effect of the PBR cowpea on total nitrogen concentration relative to non-PBR and control plots in the Northern Guinea savanna of Nigeria.

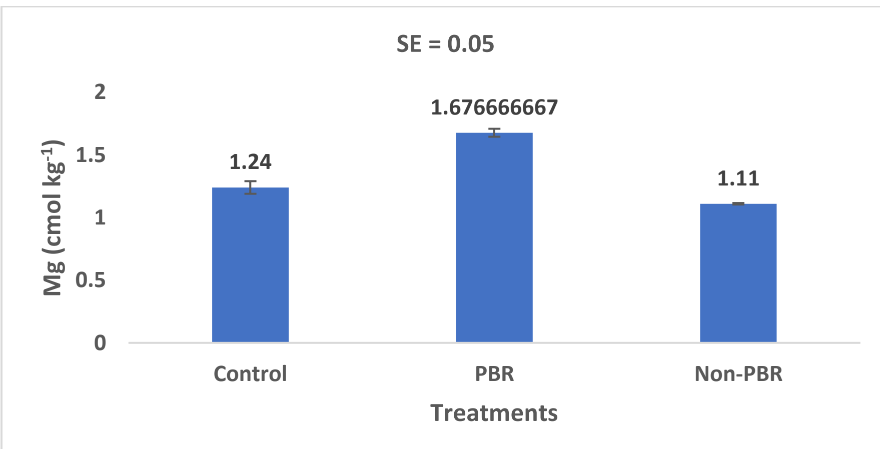


Figures 37. Effect of the PBR cowpea on available phosphorus concentration relative to non-PBR and control plots in the Northern Guinea savanna of Nigeria.

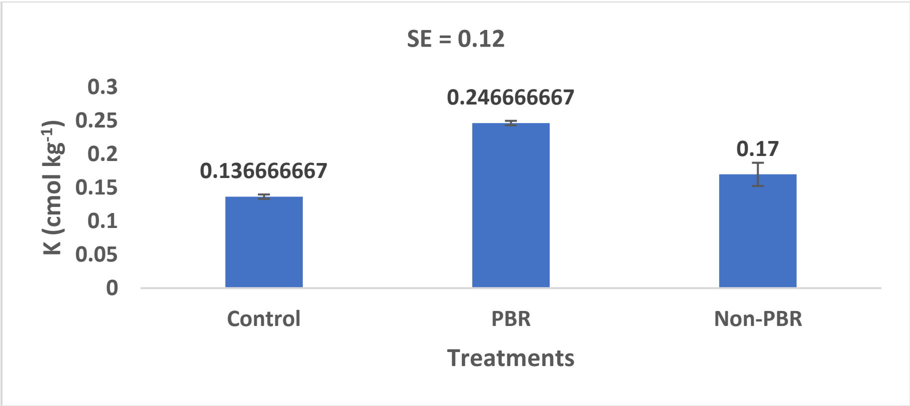
There were also significant ($P<0.01$) different levels of exchangeable Ca (Figure 38), Mg (Figure 39), K (Figure 40), Na (41) exchangeable acidity (EA) (Figure 42) and CEC (Figure 43) in the soils as influenced by the treatments. The PBR plots had the highest all the parameters, while the non-PBR and the control pots were statistically similar. The exchangeable Ca in the PBR plots was higher than the non-PBR and control plots by 25 and 30%, respectively. There was 26 and 34% higher exchangeable Mg in the PBR plots than the non-PBR and control plots, respectively. There was 31 and 45% higher exchangeable K in the PBR over the non-PBR and control plots, respectively. Sodium was 26 and 28% higher exchangeable Na in the PBR plots than the non-PBR and the control plots. The EA was 33 and 56% higher in the PBR cowpea plots than the non-PBR and the control plots. The CEC was 24 and 27% higher in the PBR than the non-PBR and control plots.



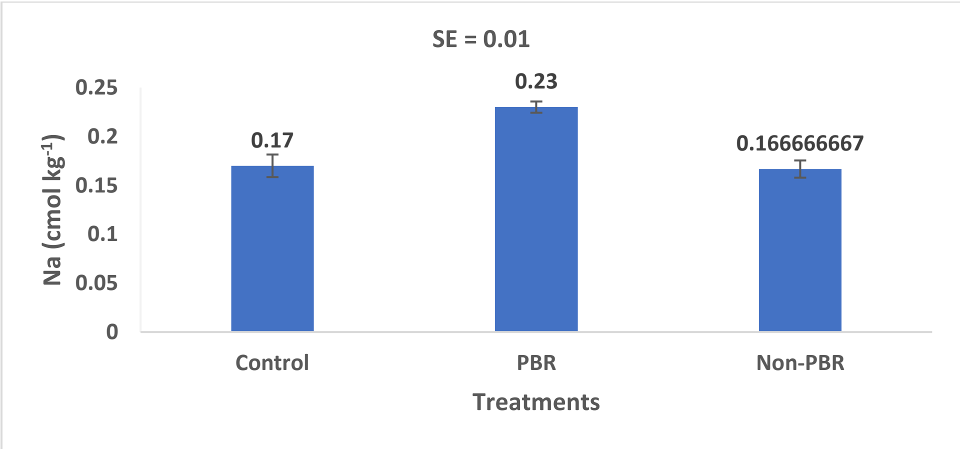
Figures 38. Effect of the PBR cowpea on calcium concentration relative to non-PBR and control plots in the Northern Guinea savanna of Nigeria.



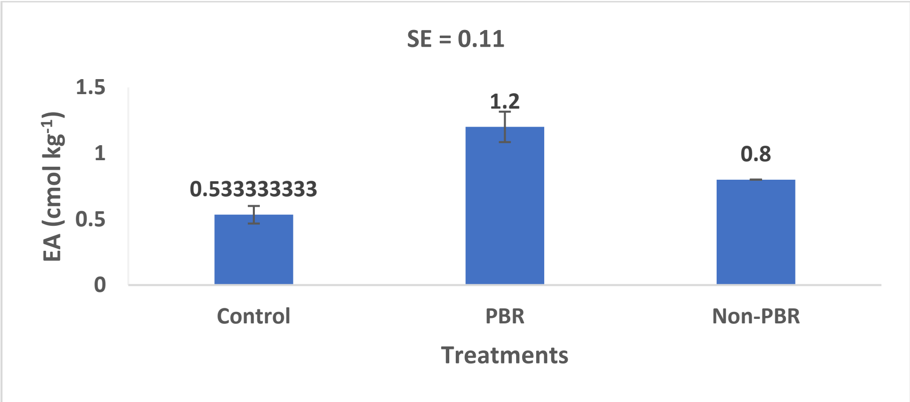
Figures 39. Effect of the PBR cowpea on magnesium concentration relative to non-PBR and control plots in the Northern Guinea savanna of Nigeria.



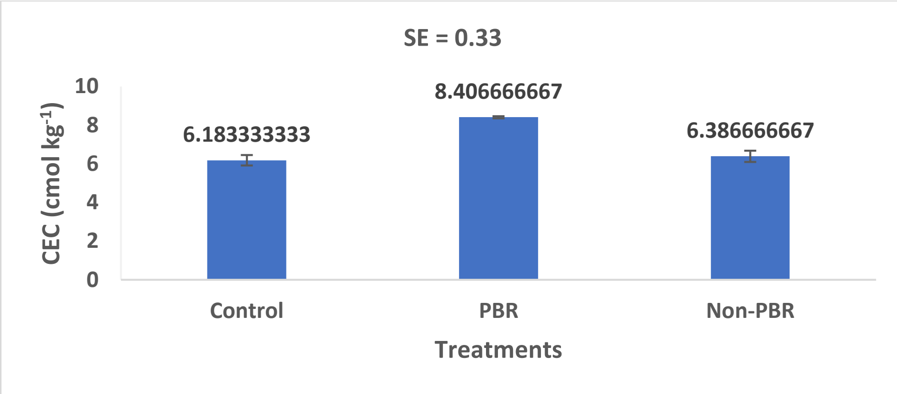
Figures 40. Effect of the PBR cowpea on potassium concentration relative to non-PBR and control plots in the Northern Guinea savanna of Nigeria.



Figures 41. Effect of the PBR cowpea on exchangeable sodium concentration relative to non-PBR and control plots in the Northern Guinea savanna of Nigeria.

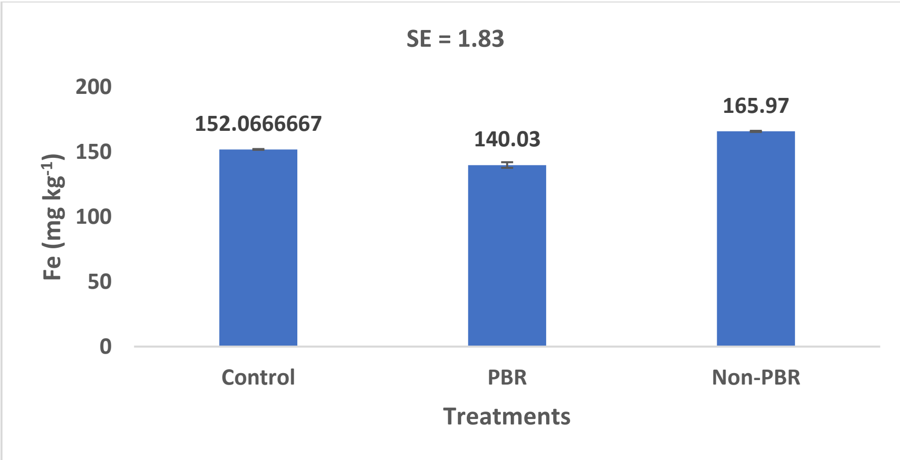


Figures 42. Effect of the PBR cowpea on soil exchangeable acidity relative to non-PBR and control plots in the Northern Guinea savanna of Nigeria.

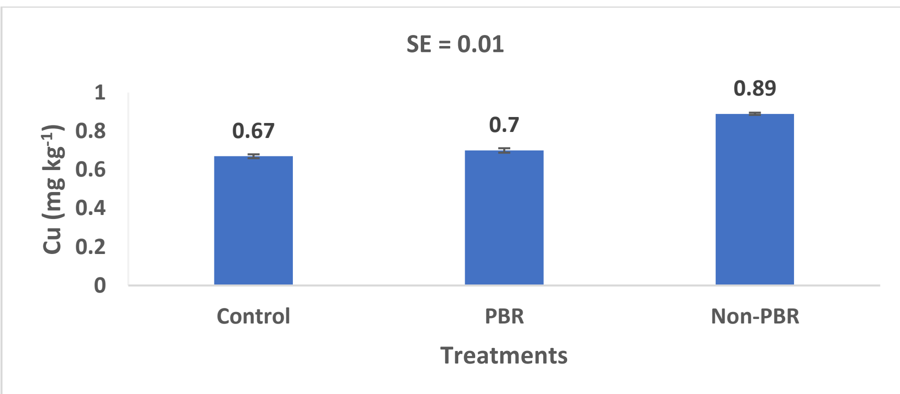


Figures 43. Effect of the PBR cowpea on soil cation exchange capacity relative to non-PBR and control plots in the Northern Guinea savanna of Nigeria.

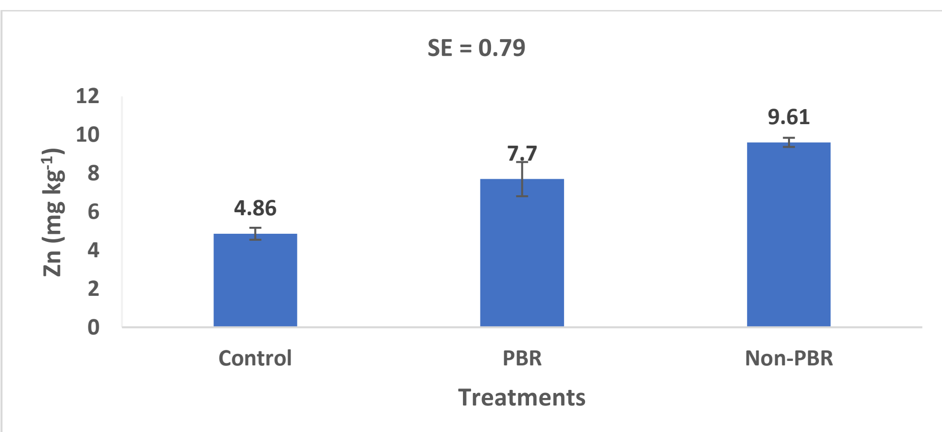
There was also significant ($P<0.01$) difference among the treatments in Fe (Figure 44), Cu (Figure 45) and Zn (Figure 46) concentrations. The non-PBR plots had the highest Fe concentration, which was higher than the control, while the PBR plots had the lowest. The non-PBR plots exceeded the control and the PBR plots in Fe concentration by 8 and 16% respectively. The Cu concentration of the non-PBR plots was the highest, while the PBR and the control plots were similar in Cu concentration. The non-PBR plots were 21 and 25% higher in Cu concentration than the PBR and control plots, respectively. The Zn concentration of the PBR and non-PBR plots were statistically similar and higher than the control plots. The non-PBR plots were however, 20 and 49% higher in Zn concentration than the PBR and control plots. Only that there was no significant ($P>0.05$) difference among the treatments in Mn concentration. Except for indication of 29 and 56% higher Mn in the non-PBR plots than the PBR and control plots, respectively.



Figures 44. Effect of the PBR cowpea on iron concentration relative to non-PBR and control plots in the Northern Guinea savanna of Nigeria.



Figures 45. Effect of the PBR cowpea on copper concentration relative to non-PBR and control plots in the Northern Guinea savanna of Nigeria.

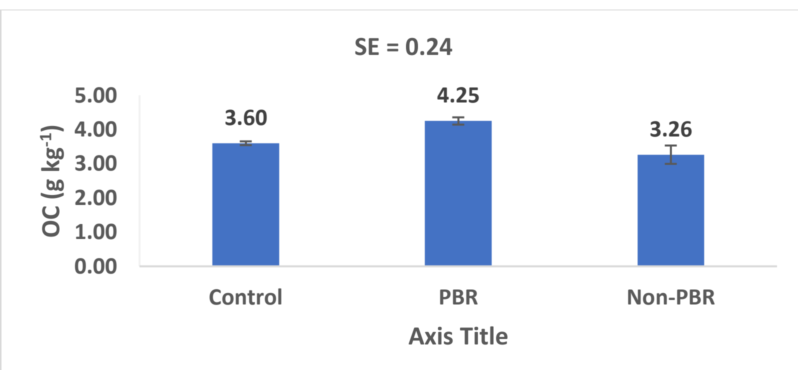


Figures 46. Effect of the PBR cowpea on zinc concentration relative to non-PBR and control plots in the Northern Guinea savanna of Nigeria.

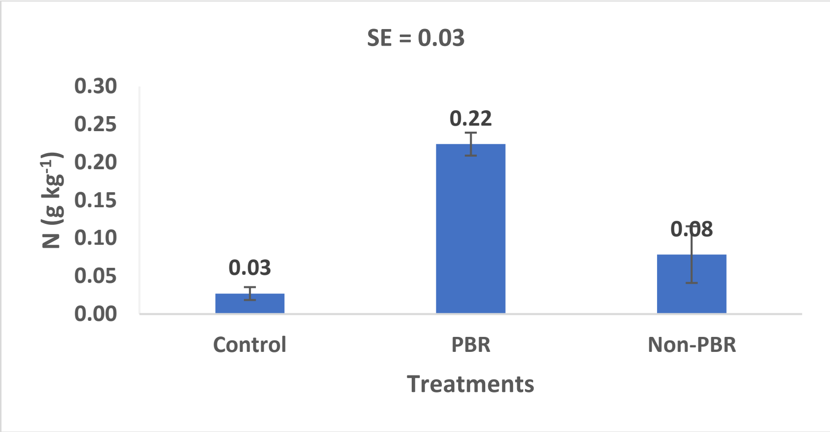
Sudan Savanna

No significant (P>0.05) difference among the treatments was observed in soil texture in the Sudan savanna as well as the soil fractions clay, silt, sand contents, pH and electrical conductivity. Except for indication of lower pH (5.51), in the PBR plots than the non-PBR (5.67) and the control plots (5.76).

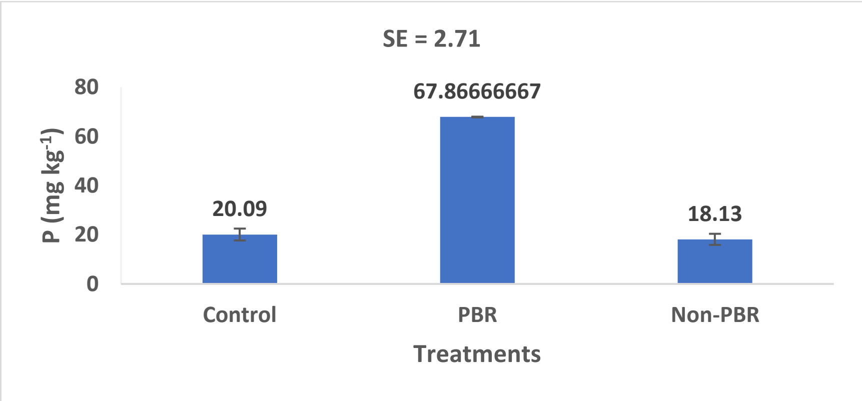
Significant (P<0.05) differences were however, observed in organic carbon as influenced by the treatments (Figure 47). The PBR cowpea and the control plots had similar organic carbon content and higher the non-PBR plots, with 15 and 23% higher organic carbon in the PBR plots than the control and non-PBR plots, respectively. There was also significant (P<0.01) difference among the treatments in influencing the total nitrogen content of the soils (Figure 48). The PBR cowpea plots had the highest total N, while the non-PBR and control plots were similar. There was also significant (P<0.01) difference in available phosphorus among the treatments (Figure 49). PBR plots had the highest values, while the non-PBR and the control had the similar values. There was 70 and 73% higher available phosphorus in the PBR plots relative to the control and non-PBR plots.



Figures 47. Effect of the PBR cowpea on organic carbon concentration relative to non-PBR and control plots in the Sudan savanna of Nigeria.



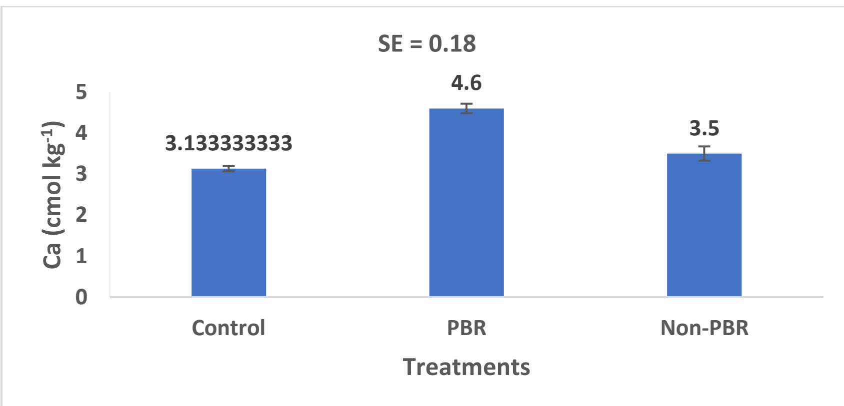
Figures 48. Effect of the PBR cowpea on total nitrogen concentration relative to non-PBR and control plots in the Sudan savanna of Nigeria.



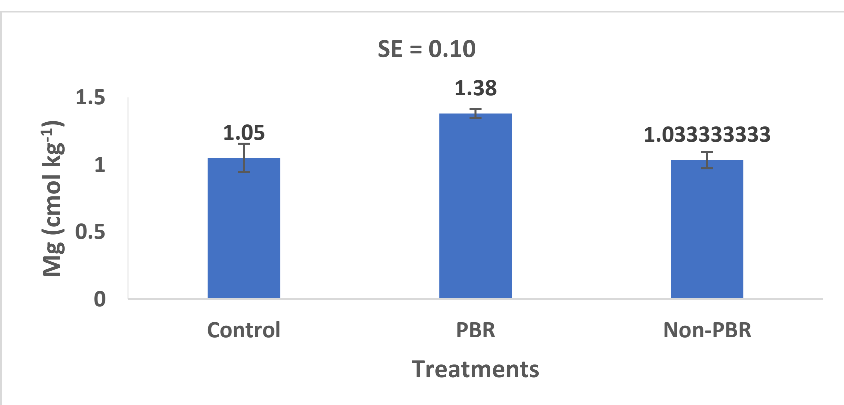
Figures 49. Effect of the PBR cowpea on available phosphorus concentration relative to non-PBR and control plots in the Sudan savanna of Nigeria.

There was also significant ($P<0.01$) calcium concentration as a result of the treatments (Figure 50). The PBR plots had the highest exchangeable calcium, while the control and non-PBR plot were similar. The PBR plots had 23 and 31% higher exchangeable calcium in the PBR plots than the control and non-PBR plots, respectively. The treatments also differ significantly ($P<0.05$) in exchangeable magnesium concentration (Figure 51) with PBR cowpea plots having the highest value while the control and the non-PBR were statistically similar. There was also significant ($P<0.05$) difference in exchangeable potassium as influenced by the treatments (Figure 52). The

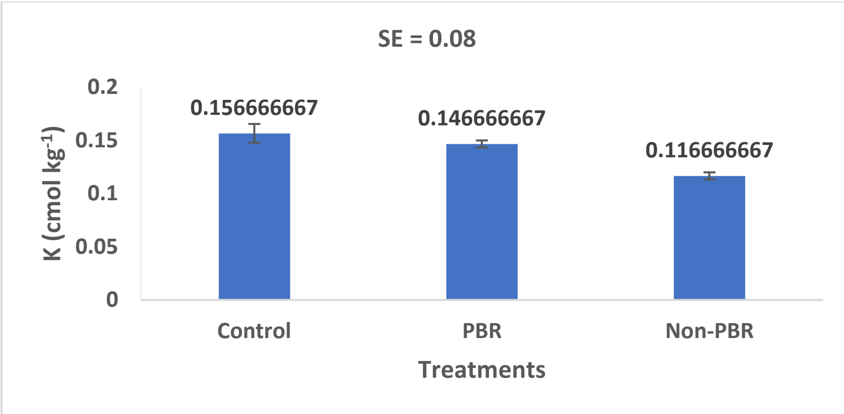
PBR and control plots were similar and higher than the non-PBR plots. The PBR plots had 21% higher exchangeable K than the non-PBR plots. Likewise, there was significant difference among the treatments in exchangeable acidity (P<0.05) (Figure 53). The non-PBR plots had he highest values of exchangeable acidity, which was similar to the control and higher than the non-PBR plots. The cation exchange capacity results also show significant (P<0.05) difference among the treatments (Figure 54). The PBR and non-PBR plots were similar and higher than the control plots. Even though, there was 19 and 23% higher CEC in the PBR plots than the non-PBR and control plots.



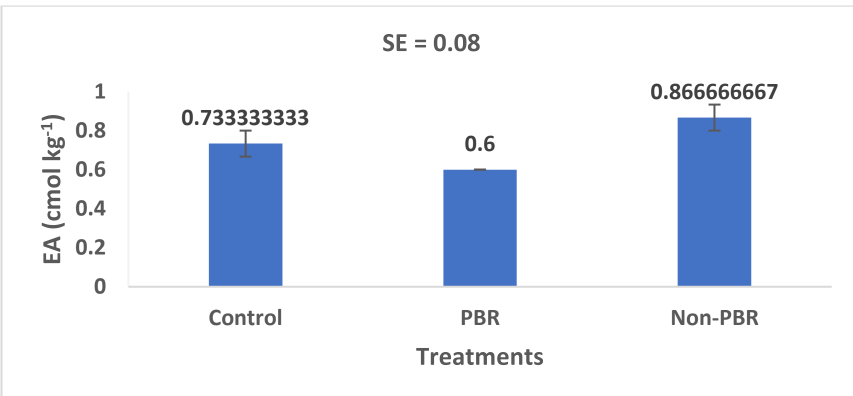
Figures 50. Effect of the PBR cowpea on exchangeable calcium concentration relative to non-PBR and control plots in the Sudan savanna of Nigeria.



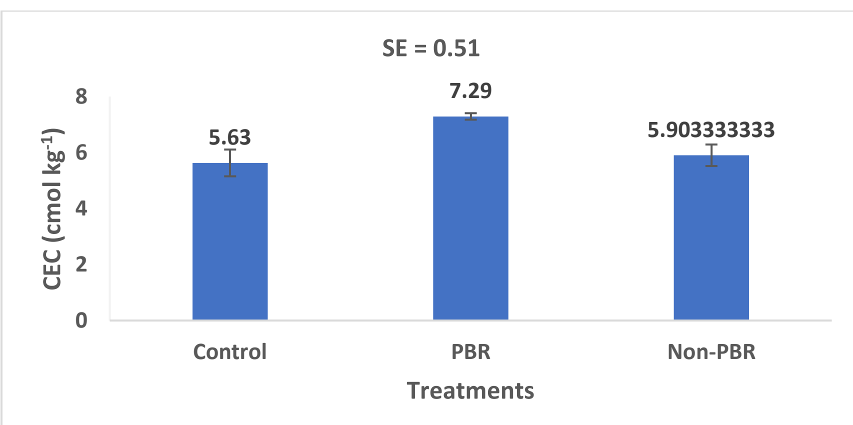
Figures 51. Effect of the PBR cowpea on exchangeable magnesium concentration relative to non-PBR and control plots in the Sudan savanna of Nigeria.



Figures 52. Effect of the PBR cowpea on exchangeable potassium concentration relative to non-PBR and control plots in the Sudan savanna of Nigeria.

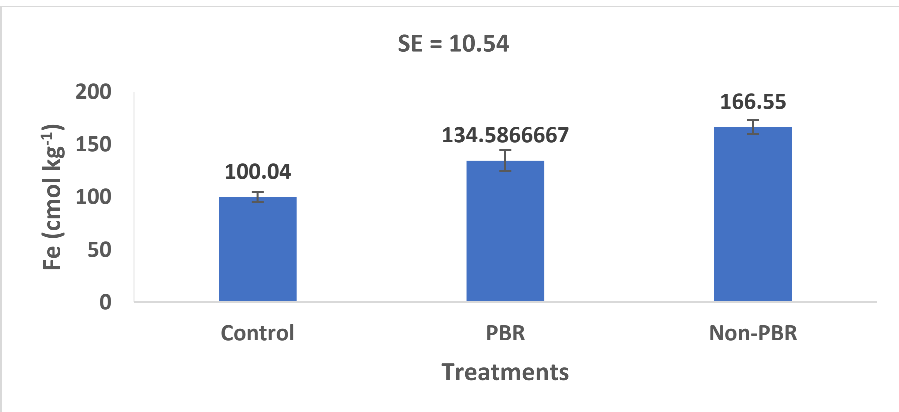


Figures 53. Effect of the PBR cowpea on exchangeable acidity concentration relative to non-PBR and control plots in the Sudan savanna of Nigeria.

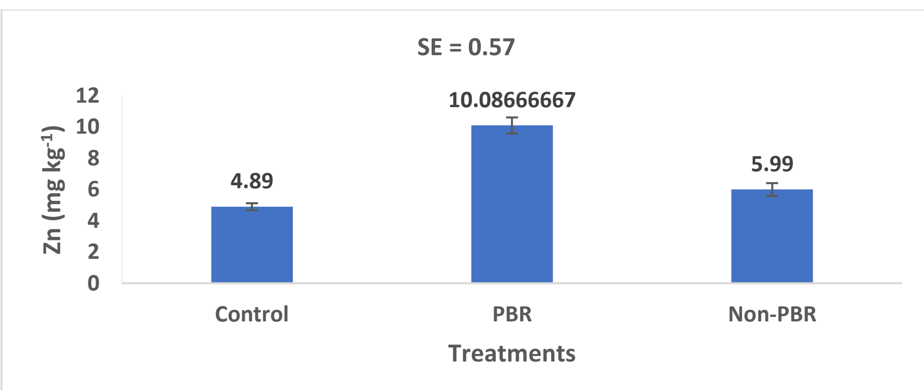


Figures 54. Effect of the PBR cowpea on soil cation exchange capacity relative to non-PBR and control plots in the Sudan savanna of Nigeria.

Significant difference was observed among the treatments in iron concentration (Figure 55). The PBR and non-PBR plots were similar in Fe concentration and higher than the control plots. The PBR plots had 19 and 40% higher Fe concentrations than the non-PBR and control plots, respectively. There was also significant ($P<0.01$) difference among the treatments in zinc concentration in the soils (Figure 56). The PBR cowpea plots had higher zinc concentrations than the non-PBR and control plots, which were similar. However, there was no significant ($P>0.05$) difference among the treatments in Mn and Cu concentrations. Except for an indication of 42 and 60% higher Cu in the non-PBR than the PBR and control respectively and 11 and 21% higher Mn in the non-PBR than the control and PBR



Figures 55. Effect of the PBR cowpea iron concentration relative to non-PBR and control plots in the Sudan savanna of Nigeria.

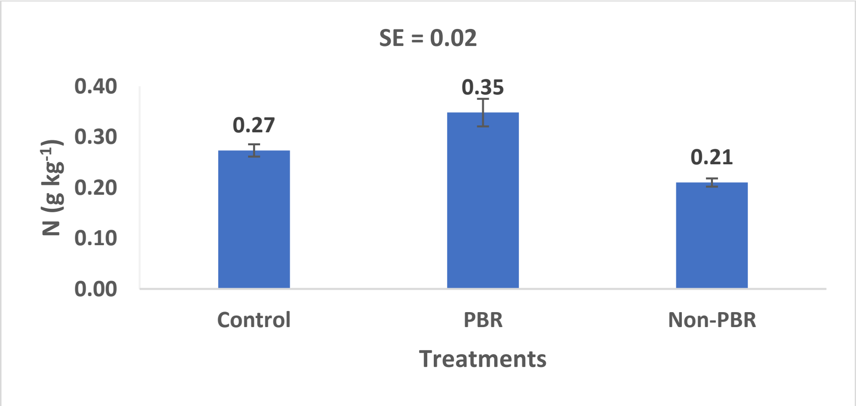


Figures 56. Effect of the PBR cowpea on zinc concentration relative to non-PBR and control plots in the Sudan savanna of Nigeria.

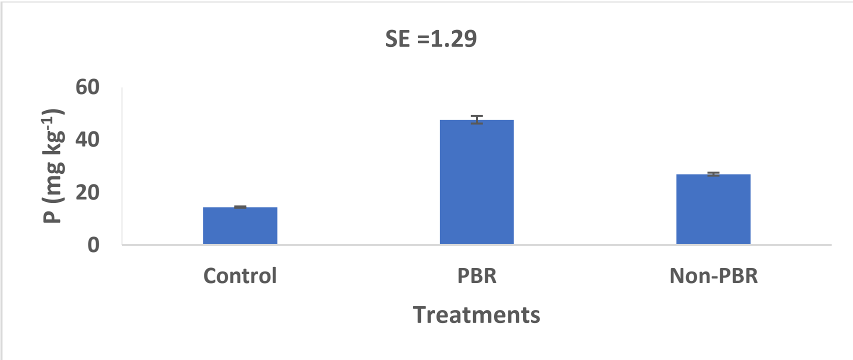
Southern Guinea Savanna

The results of the Southern Guinea savanna show no significant difference in soil texture was observed among the treatments with regards to soil texture and its components; clay, silt, sand contents, pH, electrical conductivity (EC). Except for indication of higher pH in the non-PBR cowpea plots (5.97) than the control (6.14) and the PBR plots (5.78). There was also an indication of higher electrical conductivity in the non-PBR (1.02 dS m^{-1}) than the PBR (1.00 dS m^{-1}) and the control plots (0.83 dS m^{-1}).

There was also no significant difference in organic carbon concentration among the treatments. Except of an indication of 7 and 50% higher organic carbon in the PBR plots over the non-PBR and the control plots. However, there was significant ($P<0.01$) difference among the treatments in total N (Figure 57). The PBR cowpea plots had the highest total N, while the control and the non-PBR plots were similar. The PBR plots had 23 and 40% higher total N than the control and non-PBR plots, respectively. There was also significant ($P<0.01$) difference among the treatments in available P (Figure 58). The PBR cowpea plots had the higher available P than the non-PBR plots, while the control plots had the lowest. The PBR plots had 43 and 70% higher available P then the non-PBR and control, respectively.

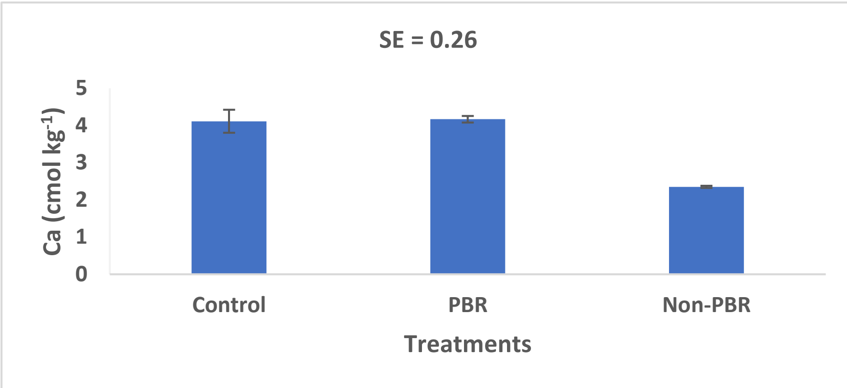


Figures 57. Effect of the PBR cowpea on total N concentration relative to non-PBR and control plots in the Southern Guinea savanna of Nigeria.

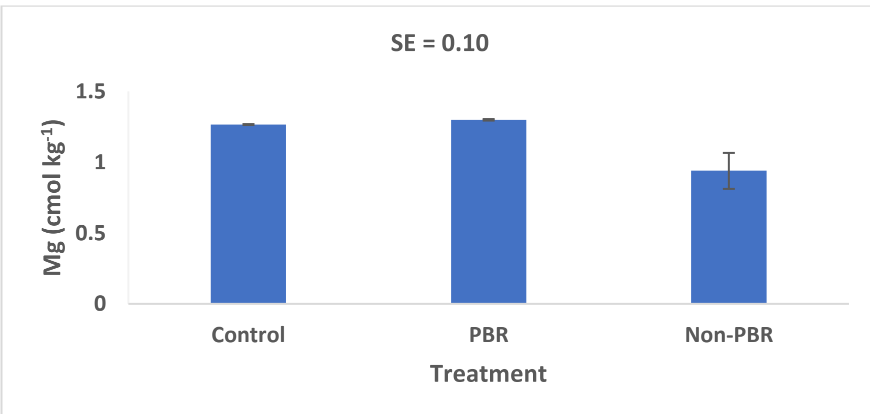


Figures 58. Effect of the PBR cowpea on available phosphorus relative to non-PBR and control plots in the Southern Guinea savanna of Nigeria.

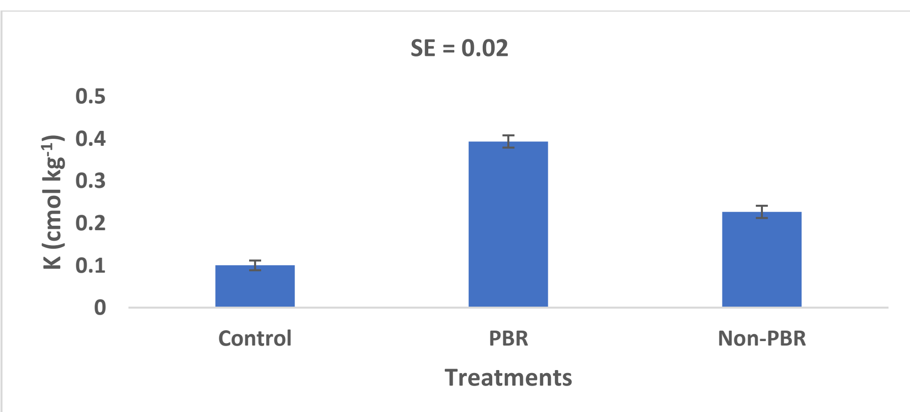
There was significant ($P<0.01$) difference observed among the treatments in Ca concentration (Figure 59). The PBR and the control plots were similar and higher than the non-PBR plots. There wa 44% higher calcium in the PBR plots, relative to the non-PBR plots. There was also significant ($P<0.05$) difference among the treatments in magnesium concentration (Figure 60). The PBR and the control plots gave highest magnesium concentration, which were similar and higher than then non-PBR plots. There was 58% higher magnesium concentration in the PBR plots over the non-PBR plots. Significant ($P<0.01$) difference was observed among the treatments in potassium (K) concentration (Figure 61). The control was higher than the PBR plots, which was higher than the PBR plots, which is in turn higher than the non-PBR plots. There were also significant ($P<0.01$) differences in the exchangeable sodium (Na). The control had higher Na concentration, the PBR and non-PBR plots, which were similar. There was also significant difference in cation exchange capacity among the treatments ($P<0.01$) (Figure 62). The control and PBR plots similar CEC and higher than the non-PBR plots. The PBR cowpea plot had 7 and 27% higher CEC than the non-PBR plots.



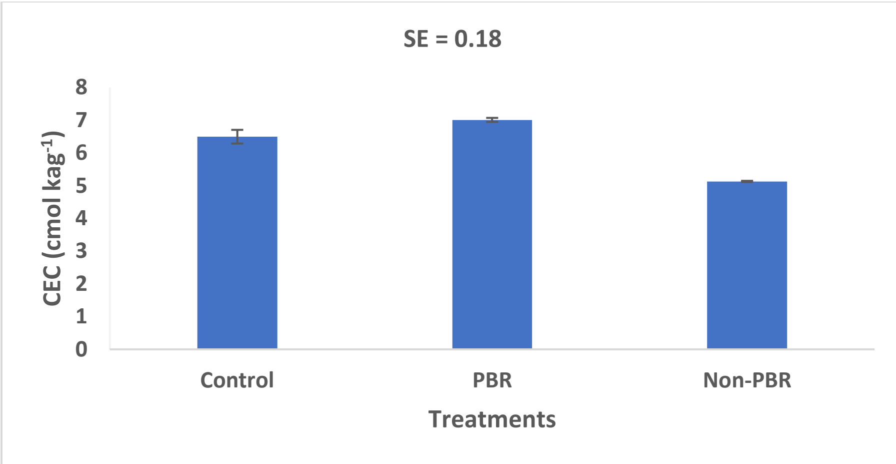
Figures 59. Effect of the PBR cowpea on exchangeable calcium relative to non-PBR and control plots in the Southern Guinea savanna of Nigeria.



Figures 60. Effect of the PBR cowpea on exchangeable magnesium relative to non-PBR and control plots in the Southern Guinea savanna of Nigeria.

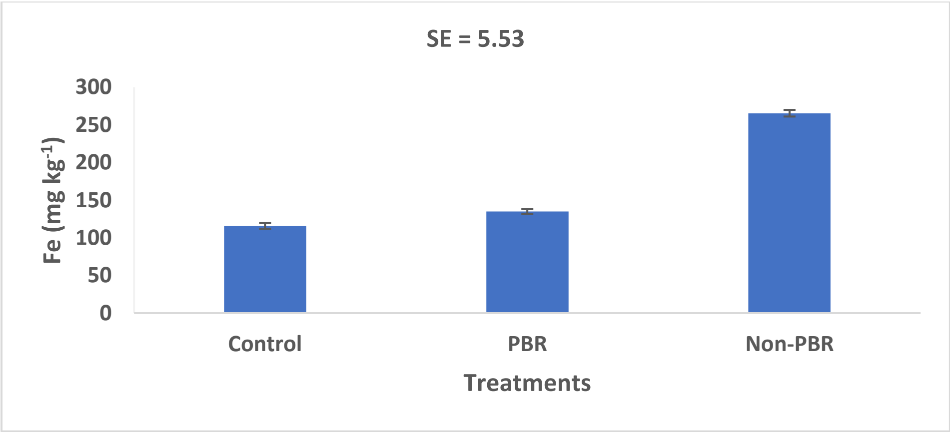


Figures 61. Effect of the PBR cowpea on exchangeable potassium relative to non-PBR and control plots in the Southern Guinea savanna of Nigeria.

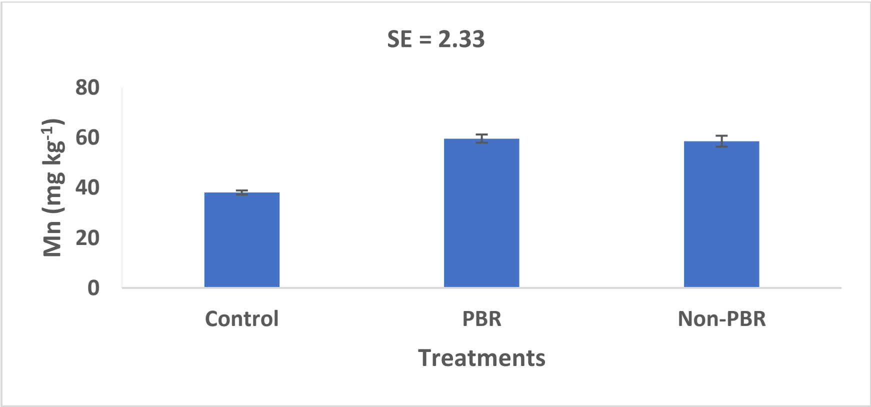


Figures 62. Effect of the PBR cowpea on cation exchange capacity relative to non-PBR and control plots in the Southern Guinea savanna of Nigeria.

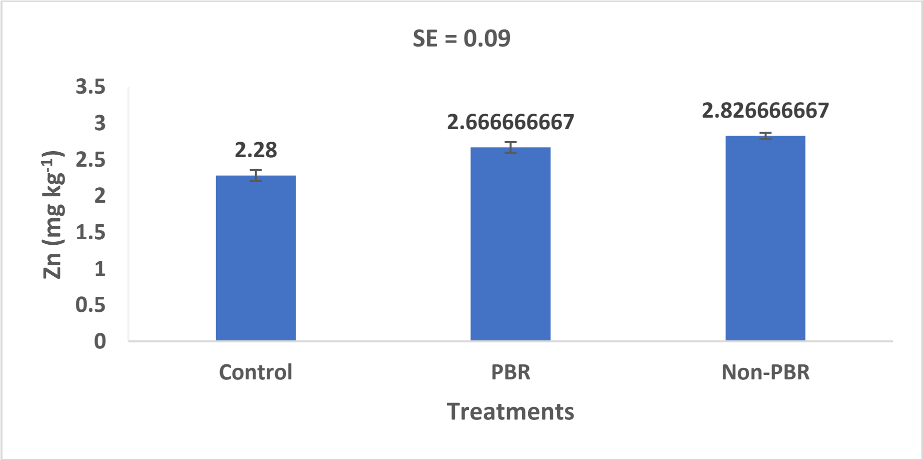
Significant ($P<0.01$) difference was observed among the treatments in Fe concentration (Figure 63). The non-PBR plots had the highest Fe concentration, the next if the PBR cowpea plots, while the lowest in Fe concentration was the control plots. There was 49 and 56% higher Fe concentration in the non-PBR than the PBR and control plots, respectively. There wa also significant ($P<0.01$) difference among the treatments in Mn concentration (Figure 64). The PBR and non-PBR plots were similar in Mn concentration. There was also significant difference in Zn concentration among the treatments (Figure 65). The non-PBR was higher in Zn concentration than the PBR and control plots, which were similar. The non-PBR plots had 37 and 54% higher zinc concentration than the PBR and control plots, respectively.



Figures 63. Effect of the PBR cowpea on iron concentration, relative to non-PBR and control plots in the Southern Guinea savanna of Nigeria.



Figures 64. Effect of the PBR cowpea on manganese concentration, relative to non-PBR and control plots in the Southern Guinea savanna of Nigeria.



Figures 65. Effect of the PBR cowpea on zinc concentration, relative to non-PBR and control plots in the Southern Guinea savanna of Nigeria.

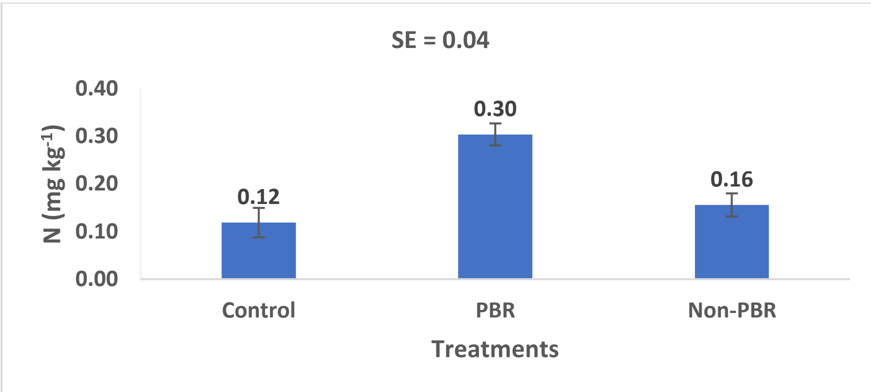
Manganese was found to be higher in PBR planted and pesticide sprayed plots when compare to control. Higher total N and available P were observed to be significantly higher in PBR planted plots when compared to pesticide sprayed and control plots. The K ion and Na were found to be significantly higher in control plots when compared to PBR planted and pesticide sprayed plots. Whereas CEC, Ca and Mg were found to be significantly higher in PBR planted and control plots when compared to pesticide sprayed plots. The Zn and Fe ions were found to be significantly higher in plots where pesticides were sprayed when compared to PBR planted and control plots. This could be linked to most pesticides have Zn and Fe as ingredients in their formulation. Some microbes like *Pseudomonas spp*. uses pesticides as sole source of carbon and hence grows on the minimal medium and can be used for decontamination of pesticide polluted areas (Shinde *et al*., 2015).

Pooled data for Soil Physical and Chemical Properties for the Four ecological zones

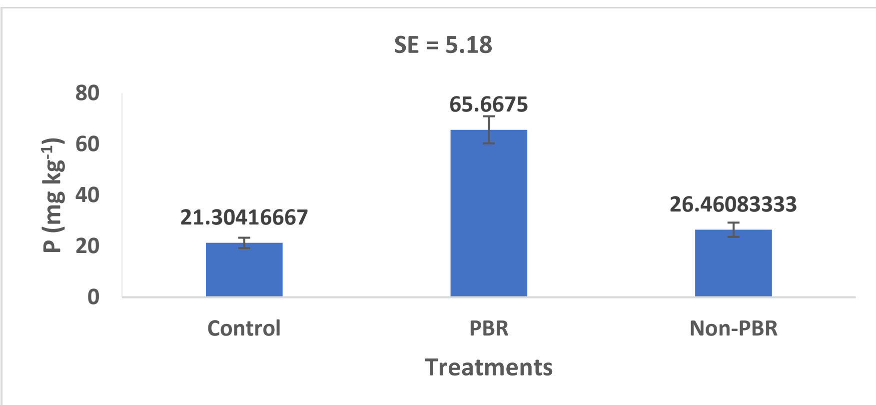
The pooled data for the agroecological zones confirms that there is no significant (P>0.05) difference in soil texture or any of its components, pH and electrical conductivity, as a result of the treatments. Except for indication of 7 and 12% higher clay in the PBR cowpea plots over the non-PBR and control plots, respectively. There was also an indication of higher pH (5.77) than the control (5.70) and the PBR plots (5.54).

There was also no significant (P>0.05) difference among the treatments in organic carbon, except for an indication of 17 and 26% higher organic carbon than the non-PBR and control plots. However, there was significant (P<0.01) difference among the treatments in influencing the total (Figure 66) nitrogen and available phosphorus (Figure 67) content of the soils. The PBR plots had the highest total N and available P, while the non-PBR and control plots had similar values. The

PBR cowpea plots exceeded the non-PBR and control plots with 49 and 61% higher total N, as well as 60 and 68% available P, respectively.

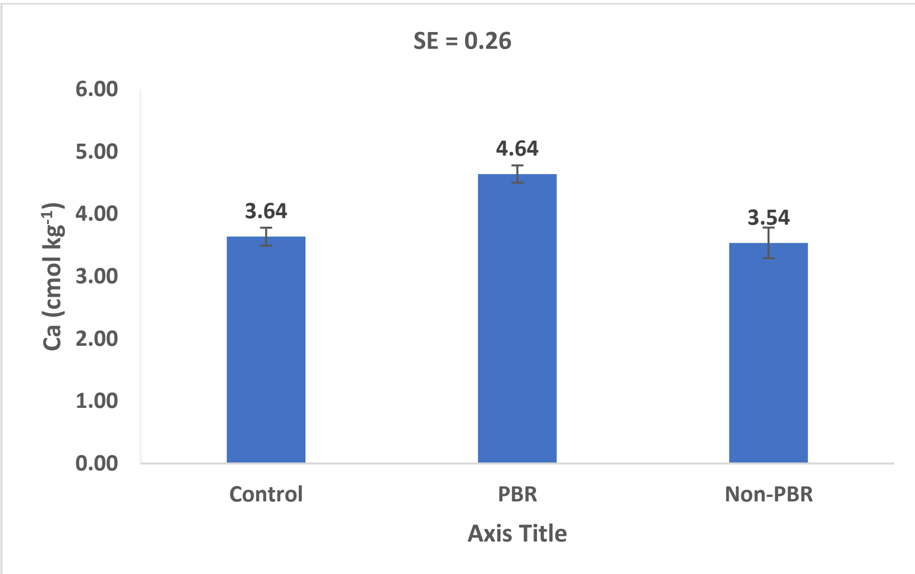


Figures 66. Pooled effect of the PBR cowpea on total concentration, relative to non-PBR and control plots in the four savanna agroecological zones of Nigeria.

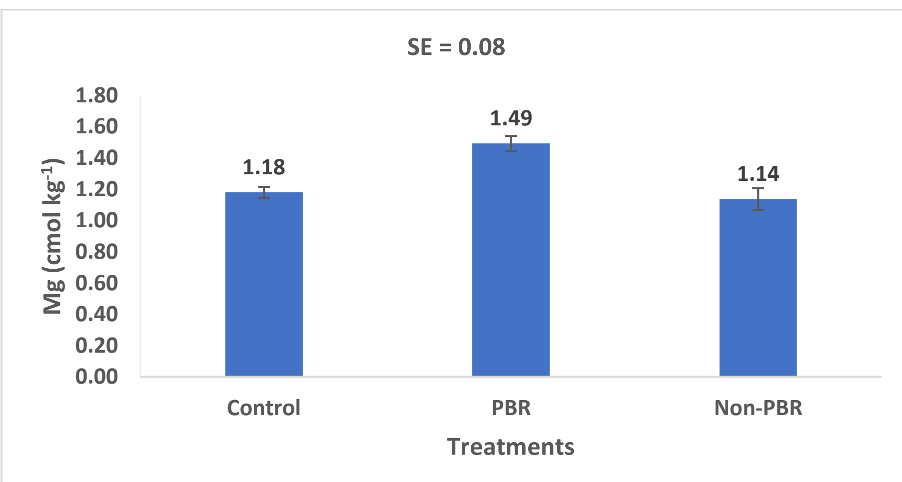


Figures 67. Pooled effect of the PBR cowpea on available phosphorus concentration, relative to non-PBR and control plots in the four savanna agroecological zones of Nigeria.

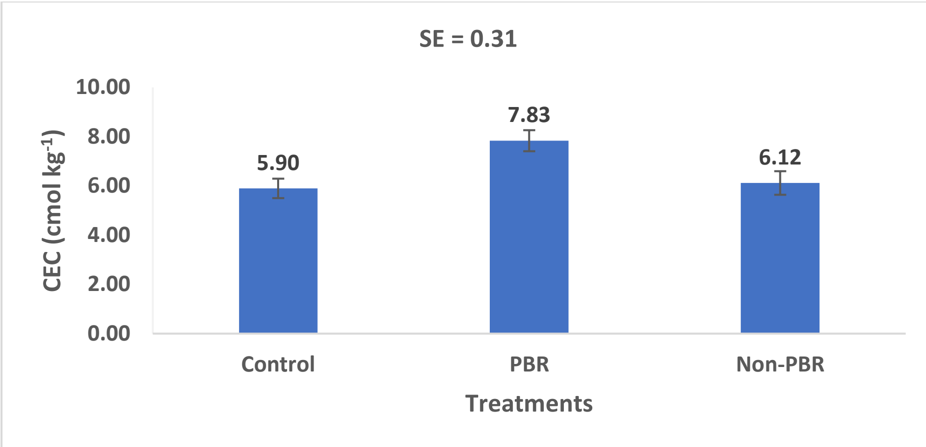
The treatments also differed significantly ($P<0.01$) in influencing exchangeable Ca (Figure 68) and Mg (Figure 69) in the soils. The PBR cowpea plots had the highest values, while the non-PBR and the control plots were lower and similar in both cases. There was 22 and 24% higher Ca as well as 21 and 24% higher Mg in the PBR plots than the control and non-PBR plots. There was however no significant ($P>0.05$) difference among the treatments in exchangeable potassium and exchangeable acidity. Even though, the PBR plots shows and indication of 62 and 67% higher exchangeable acidity than the non-PBR and control plots, respectively. However, the was significant difference among the treatments in influencing cation exchange capacity (Figure 70). The PBR cowpea plots had the highest CEC, while the rest of the treatments were similar. The PBR plots was 22 and 25% higher in CEC than the non-PBR and control plots.



Figures 68. Pooled effect of the PBR cowpea on exchangeable calcium concentration, relative to non-PBR and control plots in the four savanna agroecological zones of Nigeria.

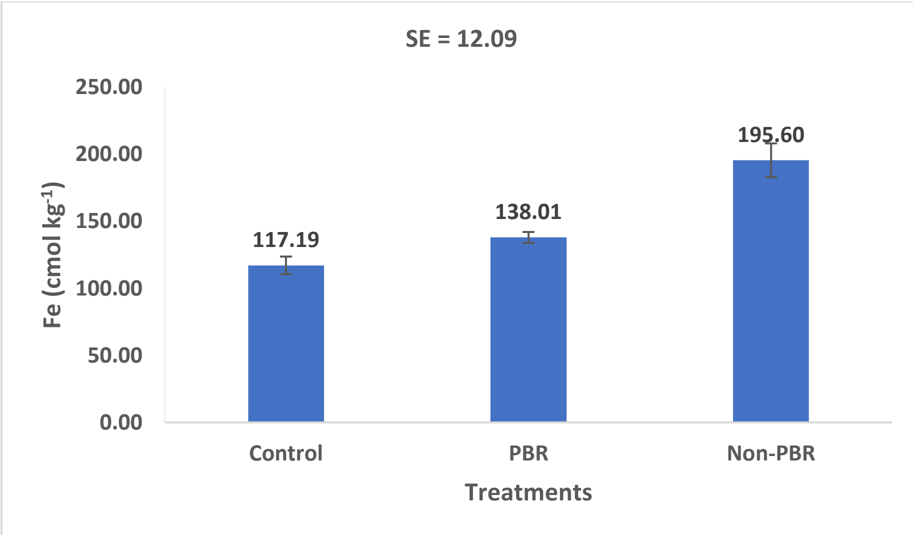


Figures 69. Pooled effect of the PBR cowpea on exchangeable calcium concentration, relative to non-PBR and control plots in the four savanna agroecological zones of Nigeria.

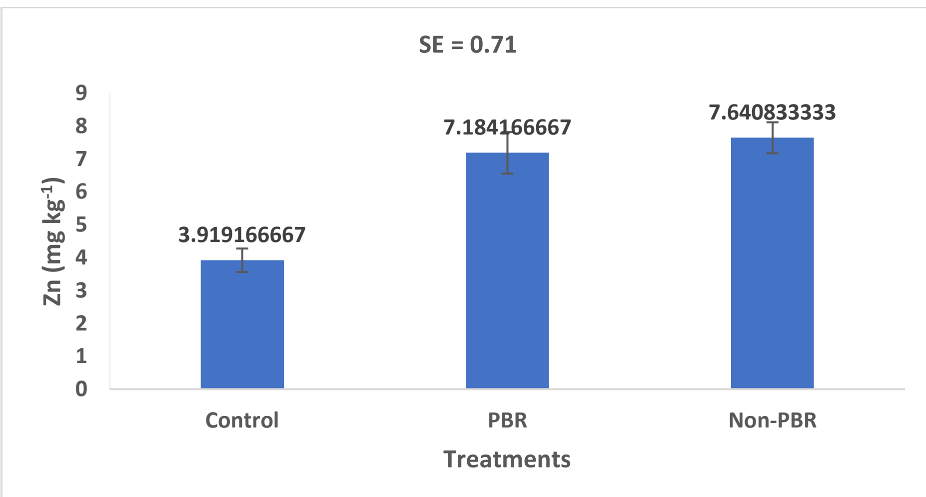


Figures 70. Pooled effect of the PBR cowpea on soil cation exchange capacity relative to non-PBR and control plots in the four savanna agroecological zones of Nigeria.

The treatments also significantly (P<0.01) influenced the Fe (Figure 71) and Zn (Figure 72) concentrations of the plots. The non-PBR plots were highest in Fe concentration, while the PBR and control plots were similar. There was 29 and 40% higher Fe in the non-PBR relative to the PBR and control plots. Likewise, the non-PBR plots and PBR plots were highest in Zn concentration and similar, while the control had the lowest Zn concentration. Up to 6 and 50% more Zn was observed in the non-PBR plots in comparison with the PBR and control plots. However, there was no significant difference among the treatments n influencing the Mn and Cu concentration of the plots. Even though, there was an indication of 14 and 24% higher Mn in the non-PBR plots as well as 9 and 17% relative to the PBR and control plots, respectively.



Figures 71. Pooled effect of the PBR cowpea on iron concentration relative to non-PBR and control plots in the four savanna agroecological zones of Nigeria.



Figures 72. Pooled effect of the PBR cowpea on zinc concentration relative to non-PBR and control plots in the four savanna agroecological zones of Nigeria.

DISCUSSION

Effect of the Treatments Bacterial and Fungal Populations in the Various Agroecological Zones

The higher population of both bacteria and fungi in the PBR plots over the non-PBR and control plots in all the ecological zones and the pooled data for all the regions may be attributed to less concentration (two sprays) and higher pesticides concentrations sprayed to the non-PBR plots, of four times and above, which is known to disturb population, diversity and activity of micro-organisms in the soil. Similar results were reported by Goswami *et al*. (2013) and Wesley *et al*. (2017) that there was a decrease in the soil microbial population, which they linked to toxic effect of pesticides. Pesticides were also reported to inhibit metabolic process organisms and leading to significant decreases in the population of bacteria (Nicoleta *et al*., 2015). Similar studies have also shown that the presence of insecticide decreased fungal population (Smith, *et al*., 2000; Walia *et al*., 2018). The results could also be explained by the ability of PBR cowpea to attract microbes through higher exudates secretion as a result of adoption of proper production practices by the farmers, including adequate nutrient input from fertilizer and manure, contrary to the poor practices in the fields used as control (Adeoye *et al*., 2011). The results show the benefit of reduced rate pesticides application two times as a result of the introduction of the PBR cowpea, along with adoption of favourable production practices in sustaining the live population of bacteria and fungi known to perform vital functions in sustaining the productivity of the ecosystem.

Effect of the Treatments Microbial biomass carbon (C), Nitrogen (N) and phosphorus (P) the Various Agroecological Zones

The result of microbial biomass in all the zones and the pooled data followed similar trend to that of the bacterial and fungal population, this may be attributed to the production of more rhizosphere exudates by PBR cowpea than the two other treatments, for its ability to attract more rhizosphere microorganisms to yield generally higher microbial biomass C, N and P, which are nutrients contained in microorganisms, either the bacteria, fungi or other nondetermined ones. Moreover, microbial biomass is an indicator of the existence of microbial organisms of different sorts, regardless of whether they are dead or alive (Okalebo *et al.*, 2002). Both are involved in mineralization or release of the nutrients immobilized in their tissues through fumigation to be read as microbial biomass CNP. The more favourable the conditions are, without extreme adverse effect of pesticides as in the case of non-PBR cowpea plots and the control plots, where inadequate fertilizer supply, without required level of pesticides and local practices without adequate agronomic practices, the better the level of microbial biomass. The PBR cowpea plots, received adequate treatment that facilitate the favourable conditions for the multiplication of these microorganism and minimal pesticide sprays to avoid adverse effect of too much application. Even though, some microorganisms utilize the pesticides and their degraded products for their growth and metabolism, at least temporarily, as reported by Arora and Sahni, 2016 that field application of glyphosate increased microbial biomass carbon by 17% and microbial biomass nitrogen by 76% in nine soils at 14 days after treatment. On the other hand, the range values for MBC and MBN are in agreement with the findings of Adeoye *et al*. (2011) with MBC of 182 to 766 mg/kg and Onweremadu *et al*. (2008) with MBN of 131 to 270 mg/kg for Nigerian soils in other land use types and terrestrial ecosystems. While it is lower than the values of 1000 to 2000 mg/kg recorded in humid tropical forest in Amazonia (Henrot and Robertson, 1994) as expected, since the conditions are drier in the savanna zones, especially the current sampling periods. Microbial biomass had been reported to comprises of less than 5% of organic matter in the soil and performs three critical functions in the soil and the environment a source of available carbon, nitrogen, phosphorus and sulphur, immediate source of carbon, nitrogen, phosphorus and an agent of nutrient transformation and pesticide degradation (Dalal, 1998). Therefore, key functions of the soil, including nutrient release, maintenance of good soil structure and suppression of plant pathogens.

Effect of PBR cowpea on soil Physical and Chemical Properties as Relate to Soil Fertility in the Various Agroecological Zones

Lack significant difference was observed among the treatments in soil texture or any of the particle sizes, clay, silt and sand could be attributed to the fact that such changes usually take place over time, one year practice is not enough to engineer such changes. Indication of higher clay and silt observed in the PBR cowpea plots shows its advantage due to attract and sustain higher microbial population and biomass whose activities and presence add to organic matter content as earlier observed, which are determiners of soil fertility and productivity of the ecosystem (Dasgupta, and Brahmaprakash, 2021).

On the other hand, significantly higher organic carbon, total N an available P, as well as significant calcium, magnesium and sometimes potassium and sodium concentrations and cation exchange capacity in the PBR plots over the non-PBRR and control plots or their indications as observed, portrays the organic matter developments from higher populations of the microorganism in the rhizosphere soils due more favourable conditions. Organic carbon is the main constituent of organic matter, which is the store house for total N and available P along with other nutrients. Its decomposition by nitrifying bacteria in a process called mineralization is responsible for the release of the nutrients from the microbial and other organisms tissues observed in the PBR cowpea plots and favours higher cation exchange capacity that in turn facilitates retention of nutrients in the soils for higher fertility and better plant growth.

However, in almost all the zones and the pooled data of the soil properties significantly higher concentrations of iron and zinc and indications of higher manganese and copper in the non-PBR cowpea plots against the PBR cowpea plots and the control plots could be attributed to the higher concentration of the pesticides applied, of up to four or more times during the growing season, whose constituents include these elements (Kanekar *et al*., 2004). Hence, limitation of the pesticides application by the PBR cowpea introduction is a welcome development that would help in saving the environment from continuous application of high concentration or rates of these pesticides to cowpea production fields.

CONCLUSION

The study indicates significant advantage of the PBR cowpea in harbouring higher population of bacteria and fungi in the rhizosphere soil relative to the non-PBR and the control, these known to perform various functions such as nitrogen fixation, nitrification, decomposition of organic matter, solubilization of soil nutrients. It also shows significantly higher ability to retain microbial biomass carbon, nitrogen and phosphorus than the other two treatments. Likewise, it shows significantly higher ability of the PBR cowpea to influence important chemical soil properties favourable to soil fertility, such as lowering of pH or acidifying the soil, higher amounts of organic carbon, total nitrogen and available phosphorus, some exchangeable cations such as calcium, magnesium and potassium and cation exchange capacity. These advantages of the PBR cowpea could be attributed to reduction the rate of pesticides application rate and improved production practices not obtainable in the other two treatments. On the other a hand, the non-PBR cowpea plots had significantly higher influence in the accumulation of Fe, and Zn, with an indication of the accumulation of Mn and Cu in the soils, relative to the other treatments. This could be attributed to the constituents of the pesticides applied in high doses, of these elements are part, hence the need for caution to avoid excess accumulation to toxic levels with time. The control plot's performance mostly lower than the two treatments, could be attributed to the poor cultural practices of the farmers, usually without any pesticides or fertilizer application, except in some places by chance.

CHALLENGES

1. The study results are indications during one season (2022 growing season), similar studies are usually conducted for three consecutive seasons before arriving at a final conclusion.

2. The study was conducted towards the end of the season, which cause limitations to obtaining vital information on root nodule bacteria, nitrifying bacteria and lower population of the general bacteria and fungal populations obtained, the sampling needs to have been earlier during the season.

3. Establishing our own experiments, would have yielded more concrete results, rather than relying on farmers practices, which they conducted on their own, only for us to interview them on what they did, at sampling point.

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