Journal of Materials and Environmental Sciences
ISSN : 2028-2508
CODEN : JMESCN

J. Mater. Environ. Sci., 2020, Volume 11, Issue 2, Page 220-229

http://www.jmaterenvironsci.com

Soil properties and groundnut (*Arachis hypogea* L.) responses to intercropping with *Eucalyptus camaldulensis* Dehn and amendment with its biochar

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Received 31 Oct 2019,
Revised 29 Dec 2019,
Accepted 01 Jan 2020

Keywords
- ✓ *Eucalyptus,*
- ✓ groundnut,
- ✓ biochar,
- ✓ soil properties,
- ✓ yield.

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Abstract
In the South of Senegal, *Eucalyptus camaldulensis* is being intercropped with groundnut as an effort to avoid further deforestation. Introducing *E. camaldulensis* in agroforestry systems may have mitigated effects on soil and crop yield. This study was conducted to evaluate the effect of *E. camaldulensis* intercropping and its biochar amendment on groundnut yield. A factorial block design was set up in three sites (Boucotte Diembering, Boukitingho, Oussouye) in South Senegal in year1 with three treatments: *E. camaldulensis* intercropped with groundnut (Eucal+GrdNut), groundnut amended with *E. camaldulensis* biochar (Bioch+GrdNut), and groundnut cultivated alone (control). The study was repeated in two years. In biochar-amended plots, soil became significantly less acid in the site of Oussouye only ($p<0.05$). For all sites, there was also a significant increase in Ca^{2+} content and C/N compared to other treatments. Pod, seed, and biomass yield were significantly higher for biochar amended plots in Oussouye and Boucotte Diembering during both year1 and year2 ($p<0.05$). In Boukitingho also, pod yield was higher for biochar treatment for year1. When *E. camaldulensis* is intercropped with leguminous crop: groundnut, there was at least a decrease of 35% in seed yield ($p<0.001$). However, no effect was found for the soil physico-chemical properties when *E camaldulensis* was intercropped for two years. Introduction of *E. camaldulensis* to agroforestry system may be beneficial only through the use of its biochar

1. Introduction
Groundnut is one of the most economically important crops in Senegal contributing up to 60% of agricultural GDP [1]. Groundnut cultivation requires space for farmers to clear up, transforming the forest then into arable land, this scour forest resources. To limit this deforestation, *Eucalyptus camaldulensis* is being intercropped with a leguminous crop: groundnut in an agroforestry system in the South of Senegal. Although *E. camaldulensis* releases a significant amount of litter into the soil, some authors have highlighted its high demand for water and mineral nutrients [2]. *E. camaldulensis* litter is difficult to mineralize due to its high C/N ratio, and the leaves have antibiotic properties with adverse effects on soil microorganisms [3]. *E. camaldulensis* may reduce available P, K, Ca and Mg soil stocks. Its negative influence on nitrogen availability is much greater [4]. Intercropping with *Eucalyptus* generates interactions whose nature depends on crop species, cultural techniques, and soil available mineral nutrients. The effects of *E. camaldulensis* on crops may be either beneficial because of mineral nutrients recycling which improve soil fertility or adverse due to competition for limited resources, toxins production… [5-6]. Intercropping *Eucalyptus* with crops is hampered by competition for soil nutrients and allelopathy [7]. The type of root system is also very important in countering the negative effects of *E. camaldulensis*. If the species

intercropped with *E. camaldulensis* are leguminous, this could help reduce or eliminate some of the negative effects of *Eucalyptus* and improve soil fertility [8-9]. Moreover, the same authors showed also that, in mixed plantations of *Acacia mangium* and *Eucalyptus grandis* in Brazil, *Eucalyptus* was subjected to strong competition in shallow horizons. Positive interactions of *Eucalyptus* trees and crops are possible, although edge-effect interactions between trees and crops appear to affect crop yields [10-11-12]. Associating *E. camaldulensis* with a leguminous with a shallow root system could counteract the negative aspect of *E. camaldulensis* and enrich the soil with litter. Besides, *E. camaldulensis*, through its biochar, could also be used to restore degraded soil. Biochar would reduce soil density by increasing soil porosity [13]. Biochar contributes to an increase in water holding capacity of soils [14]. Biochar also promotes the reduction of nutrient loss through leaching in temperate soils as well as in highly degraded tropical soils [15-16-17]. Intercropping *E. camaldulensis* with groundnut could, therefore, improve soil fertility. The effect of *E. camaldulensis* and its biochar on leguminous such as groundnuts remains however poorly investigated. The objective of this study was to characterize the effect of *E. camaldulensis* in an intercropping system and its biochar on the physico-chemical properties of the soil and groundnut yield. We hypothesize that intercropping *E. camaldulensis* with a leguminous plant and its biochar amendment will increase soil nutrient content and improve groundnut yield.

2. Material and Methods

2.1. Presentation of the study area

The work was carried out in the fields of the farmers of Boukitingho, Boucotte Diembering and Oussouye. These sites are located in the Ziguinchor region at 12° 47′ north, 16° 13′ west, Latitude, 12.783333 N. Longitude, -16.216667 W in southern Senegal (Figure 1). *E. camaldulensis* plantations were 8 years old with an average density of 1,500 trees per hectare. The distance between trees was 2 m on the line and 8 m between lines. The climate of the area is of southern Sudanese coastal type with a dry season of 8 months from October to May. The average annual rainfall is 1500 mm. The average rainfall in 2017 is 1500 mmm while the average rainfall in 2018 is 1310 mm. Average temperatures vary from 20°C at night to 35°C during the day. The soil is of tropical ferruginous type with a sandy-silty texture. Groundnuts are the main crop in the highlands while rice is mainly grown in the lowlands.

Figure 1: Situation map of the Study Area

2.2. Experimental Design

A factorial block design was set up in year1 (2017) with the factor site with three localities (Oussouye, Boukitingho, and Boucotte Diembéring), the factor cropping systems with three treatments (*E. camaldulensis* intercropped with groundnut (Eucal+GrdNut), groundnut amended with biochar (Bioch+GrdNut), and groundnut cultivated alone (control). At each site, three elementary plots of 20m x 20m = 400 m^2 were set up for each treatment for a total of 3x3 = 9 elementary plots per site. The entire study was repeated in year2 (2018) at the same sites.

2.3. Conduct and follow-up of the experiment

The variety of groundnut "Boulkousse" which has a 90-day cycle was cropped. The biochar was obtained from the pyrolysis of *E. camaldulensis* stems. Biochar was added to soil in the quantity of 0.75 $kg.m^{-2}$. Groundnut was sown after the first rain with one seed per pocket. The space between pockets was 20 cm on the same line and 60 cm between the lines.

2.4. Data Collection

2.4.1. Soil sampling

In each elementary plot, 10 soil samples were randomly collected at the 0-10 cm horizon. Samples were then mixed and combined by three for a total of 3 x 9 = 27 samples for all sites. Subsequently, soil samples were air-dried and stored for analysis. Physicochemical analyses were carried out at the Senegalese National Institute of Pedology laboratory (INP).

2.4.2. Agronomic Parameters

Agronomic data were collected at 90 days after sowing (DAS). Following the diagonals, one (1) meter square was defined in a step of 4 m. In total, fourteen (14) squares were defined in each 400m² plot. A total of 14 x 9 = 126 squares were defined for each year. All groundnut plants in each square were collected, wrapped in a cardboard envelope and then oven-dried at 65 °C for 72 hours. These plants were used for the determination of biomass, pod and seed yield.

2.5. Statistical data processing

The R software version 3.4.2 was used for data analysis. Site, treatment and year effects were analyzed using ANOVA. Data were further ordinated using .principal component analysis (PCA) with the software PCord V5. ANOVA was used to analyze scores from axes1 and 2 for differences in means. A correlation matrix of different parameters was also established.

3. Results and discussion

3.1. Effect of intercropping with *E. camaldulensis* and its biochar on soil physical and chemical properties

There was no significant variation in pH, sodium (Na^+) and potassium (K^+) content in Boukitingho and Boucotte Diembering for all treatments. It was only in Oussouye, where the pH was significantly higher ($p < 0.05$) for the Eucal+GrdNut and Bioch+GrdNut treatments compared to the control (Table 1). The same is observed for Na^+, which is statistically much higher for the control compared to other treatments, ($p < 0.05$). In Oussouye also, K^+ was significantly higher for the treatment where *E. camaldulensis* was intercropped with groundnut ($p < 0.01$). For carbon (C), organic matter (OM), nitrogen (N), phosphorus (P), CEC and clay content, there was also no significant difference among treatments and among sites ($p > 0.05$). Soil nutrient content was relatively low with values ranging respectively from 0.26 to 0.46% for C, from 0.45 to 0.79% for OM, 0.02 to 0.04% for N, 3.03 to 5.5 ppm for P. As for the C/N ratio, it was statistically higher in the biochar amended plots in Boucotte Diembéring and Boukitingho ($p<0.001$); no significant difference was noted among in Oussouye ($p>0.05$). Calcium content range from 0.02 to 2.57 $meq.100g^{-1}$ for all treatments in all three sites. And, in all sites also, Ca^{2+} content was statistically higher ($p<0.05$) in the biochar amended plots compared to control ($p>0.05$). In this study, soils from all sites had very low organic matter content; since the biochar is mainly composed of carbon, its addition to soil would increase soil C primarily. A C/N of 13 to 14 is still a very good indicator of nutrient availability and microorganism activities. As for the Ca2+ content, its increase in biochar amended soil may be linked to the origin of the biochar but also to its release in soil due to the slight increase in pH. The increase in pH although not significant with the exception of the site of Oussouye, contributed to reducing the acidity of soils. This may have triggered a release of more nutrients from the biochar and the soil. Biochar is a direct source of nutrients [18].

Table 1. Physico-chemical characteristics of soils sampled under different treatments in three experimental sites

	pH water	C %	MO %	N %	C/N	Ca meq/100g	Na meq/100g	K meq/100g	P ppm	CEC meq/100g	Argile%
Boucotte Diembering											
Eucal+GrdNut	5.9(0.1)a*	0.3(0.08)a	0.51(0.14)a	0.03(0.01)a	10(0.2)b	1.8(0.3)a	0.31(0.02)a	0.21(0.06)a	5.5(0.06)a	24(3.2)a	8.6(0.7)a
Bioch+GrdNut	6.1(0.2)a	0.27(0.05)a	0.47(0.08)a	0.02(0.004)a	13.5(0.3)a	1.6(0.3)a	0.21(0.05)a	0.13(0.03)a	4.6(0.03)a	21.75(1.5)a	11.2(0.62)a
GrdNut	5.8(0.37)a	0.26(0.06)a	0.45(0.1)a	0.023(0.004)a	11.3(0.9)b	0.02(0.7)b	0.31(0.04)a	0.16(0.04)a	4.7(0.04)a	26.3(0.9)a	9.2(0.45)a
Boukitingho											
Eucal+GrdNut	6.02(0.1)a	0.46(0.1)a	0.79(0.25)a	0.04(0.01)a	11.6(0.15)b	2.23(0.34)ab	0.25(0.04)a	0.15(0.04)a	5.1(0.04)a	22.3(0.9)a	9.9(015)a
Bioch+GrdNut	5.9(0.09)a	0.38(0.07)a	0.56(0.13)a	0.026(0.01)a	14.6(0.06)a	2.57(0.68)a	0.21(0.01)a	0.11(0.04)a	5.2(0.04)a	22(0.9) a	10.3(2.1)a
GrdNut	5.8(0.4)a	0.35(0.09)a	0.61(0.2)a	0.03(0.01)a	11.7(0.7)b	1.29(1.1)b	0.23(0.01)a	0.19(0.02)a	3.03(0.02)a	24(3.8)a	6(0.25)a
Oussouye											
Eucal+GrdNut	5.9(0.37)a	0.33(0.1)a	0.56(0.3)a	0.028(0.01)a	11.8(0.2)a	1.33(0.3)b	0.22(0.04)b	0.1(0.01)a	3.87(0.01)a	23.8(0.5) a	12.8(0.24)a
Bioch+GrdNut	5.9(0.2)a	0.38(0.08)a	0.66(0.1)a	0.026(0.01)a	14.6(0.3)a	2.36(0.2)a	0.15(0.1)b	0.11(0.01)a	3.95(0.01)a	22.8(0.8) a	13.7(1.6)a
GrdNut	5.6(0.5)b	0.33(0.05)a	0.57(0.2)a	0.028(0.01)a	11.8(1.4)a	1.4(0.7)b	0.28(0.01)a	0.17(0.01)a	4.35(0.01)a	23.8(0.4)a	13.7(0.26)a

*Values in the same column followed by the same letter are not significantly different (SNK test, $p < 0.05$).

Eucal+GrdNut: *E. camaldulensis* intercropped with groundnut, Bioch+GrdNut: groundnut amended with biochar, GrdNut: Control

3.2. Effect of intercropping with *E. camaldulensis* and its biochar on groundnut yield

Plots amended with biochar had higher pod yield compared to other treatments in Oussouye and Boucotte Diembering for year1 and year2, with a highly significant difference ($p<0.001$, Figure 2). In Boukitingho, pod yield was statistically higher for plots amended with biochar and control plots ($p<0.0001$) for both years. Overall, pod yield was significantly higher in biochar-amended plots regardless of site and year ($p<0.01$). The average pod yield, therefore, varied depending on the treatments, the sites and the year of experimentation (Figure 2). In all sites, intercropping with *E. camaldulensis* significantly reduce pod yield in year2 ($p<0.05$).

For the seed yield, it was higher with biochar amended plots and control plots in Oussouye and Boucotte Diembering for year2 ($p<0.001$, Figure 3). In year2, however, in Boukitingho, seed yield was significantly higher for the control plots ($p<0.05$). In year1, there was no significant difference for all treatments in Oussouye and Boukitingho ($p>0.05$). Average seed yield varied with sites, treatments, and years ($p<0.001$, Figure 3). In all sites intercropping with *E. camaldulensis* significantly reduce seed yield by at least 35% compared to control in year2 ($p<0.001$).

The average dry biomass yield was significantly higher in Boucotte Diembering for both years ($p<0.05$). In Oussouye, the yield was significantly higher for biochar amended plots compared to the treatment Eucal+GrdNut for year1 and year2 ($p<0.05$, Figure 4). In Boukitingho and Boucotte Diembering, there was no difference among treatments in year1. However, in year2, in Boukitingho, yields were statistically higher for the control compared to other treatments ($p<0.001$). The same trend was observed in Boucotte Diembering for year2 where yields were statistically higher ($p<0.001$) for both the control and the biochar amended plots. Pod yield varied according to treatment, site and year of experimentation ($p<0.01$).

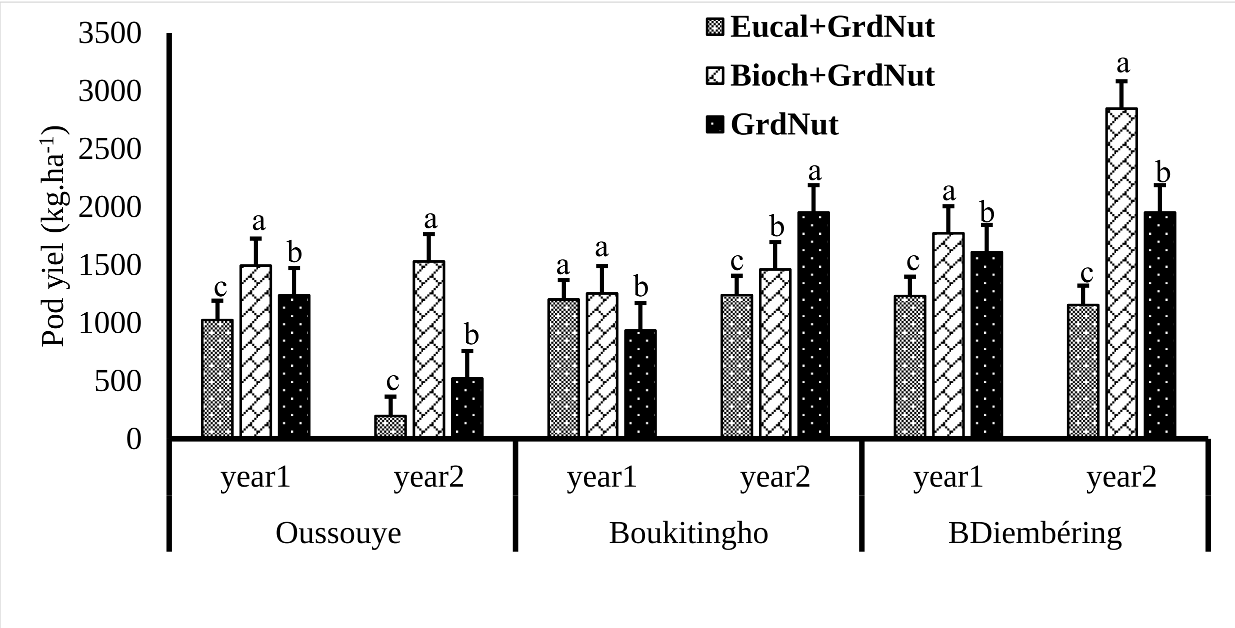

Figure 2: Pod yield under three different treatments (Eucal+GrdNut, Bioch+GrdNut, and GrdNut) in tree sites during year1 and year2.

Eucal+GrdNut: *E. camaldulensis* intercropped with groundnut, Bioch+GrdNut: groundnut amended with biochar, GrdNut: Control

Although there were globally no differences for soil nutrients content among treatments, there was a significant difference in yields among plots amended with biochar, plots where *E. camaldulensis* is intercropped with groundnut and the control plots. Yields were lower when *E. camaldulensis* is intercropped with peanut. [19] found a reduction in the germination rate of sorghum and inhibition of maize dry matter grown under the shading of *Eucalyptus tereticornis*. In another study, [20] showed that *Stercula setigera* has a depressive effect on millet, groundnuts, and sorghum yield.

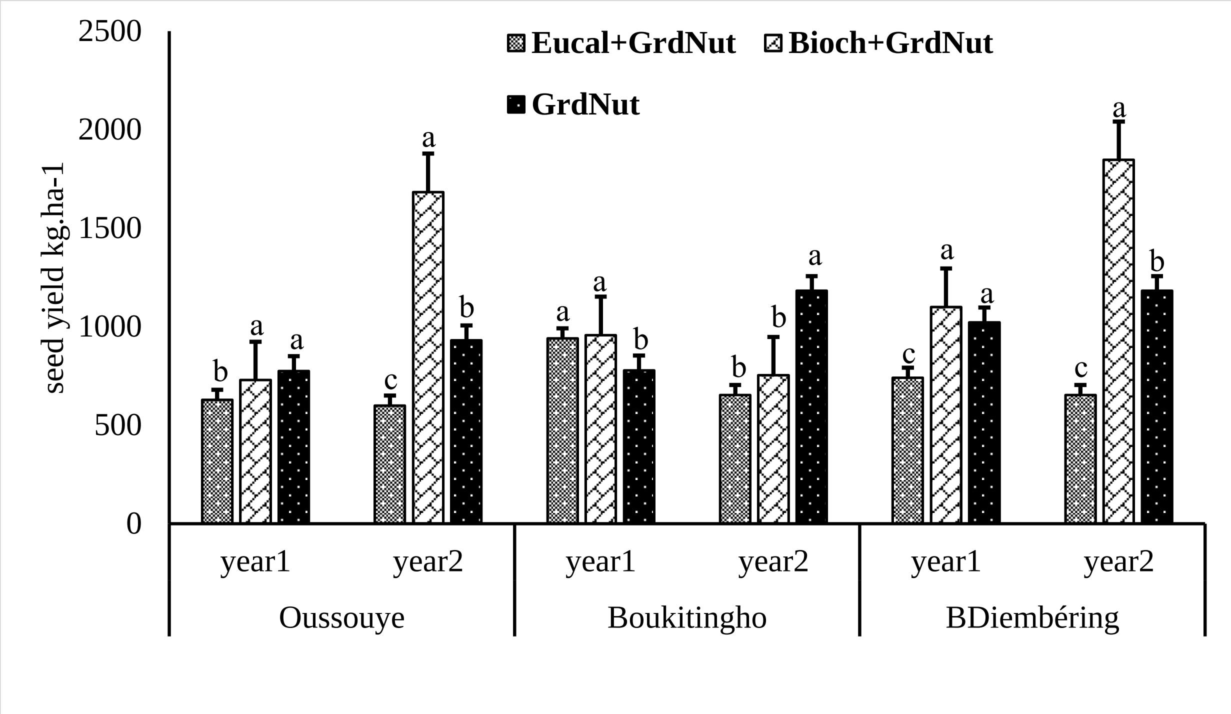

Figure 3: Seed yield under three different treatments (Eucal+GrdNut, Bioch+GrdNut, and GrdNut) in tree sites during year1 and year2.

Eucal+GrdNut: *E. camaldulensis* intercropped with groundnut, Bioch+GrdNut: groundnut amended with biochar, GrdNut: Control

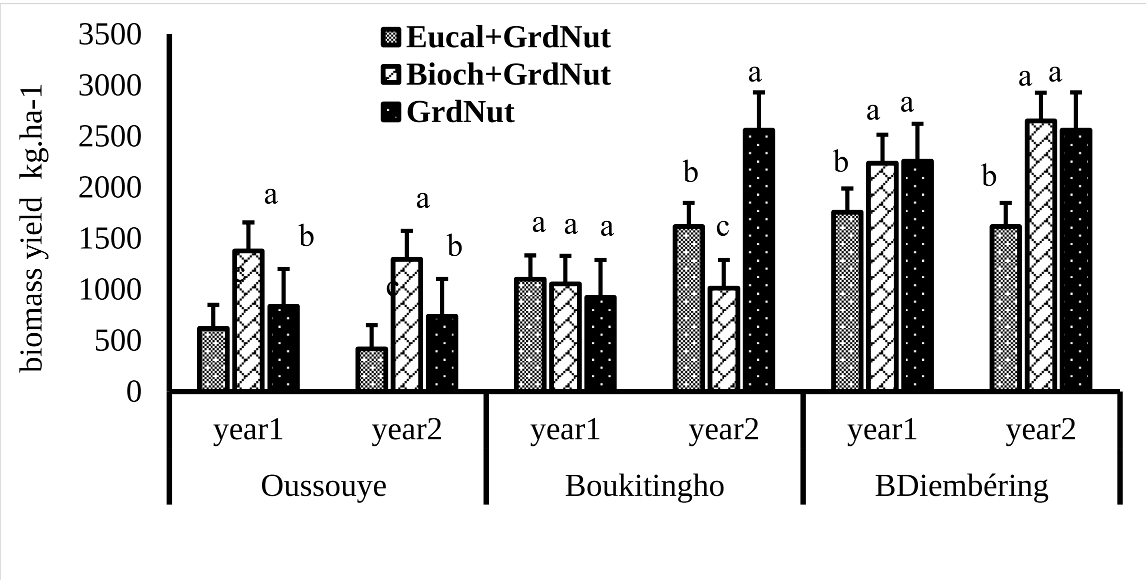

Figure 4: Biomass yield under three different treatments (Eucal+GrdNut, Bioch+GrdNut and GrdNut) in tree sites during year1 and year2.

Eucal+GrdNut: *E. camaldulensis* intercropped with groundnut, Bioch+GrdNut: groundnut amended with biochar, GrdNut: Control

The low yield when *E. camaldulensis* is intercropped may be explained by competition for light and soil nutrients which may exist between *Eucalyptus* plants and crops [21-22]. The association of *E. camaldulensis* and crops can be harmful due to the production of toxins and the reduction of solar energy [6]. In addition, *E. camaldulensis* may not have returned enough litter to the soil; plants were young with 8 years of age. This may have contributed to the low nutrient available in soil [23]. In opposite, [24] found no *Eucalyptus* effect when intercropped with groundnut in systems where crop sewing lines are sufficiently distant.

3.3. Principal Component Analysis (PCA) and Correlation among yields and soil chemical characteristics

Analysis of all data from all treatments for both years and in all sites using PCA explained a total of 64.7% for the first two axes respectively 41.5% for axis 1 and 23.2% for axis 2. Samples separated primarily based on the site (Figure 5). There was a strong site effect ($p<0.0001$) with data from all sites strongly different among them. Data from the site of Oussouye highly separated from Boucotte Diembering data.

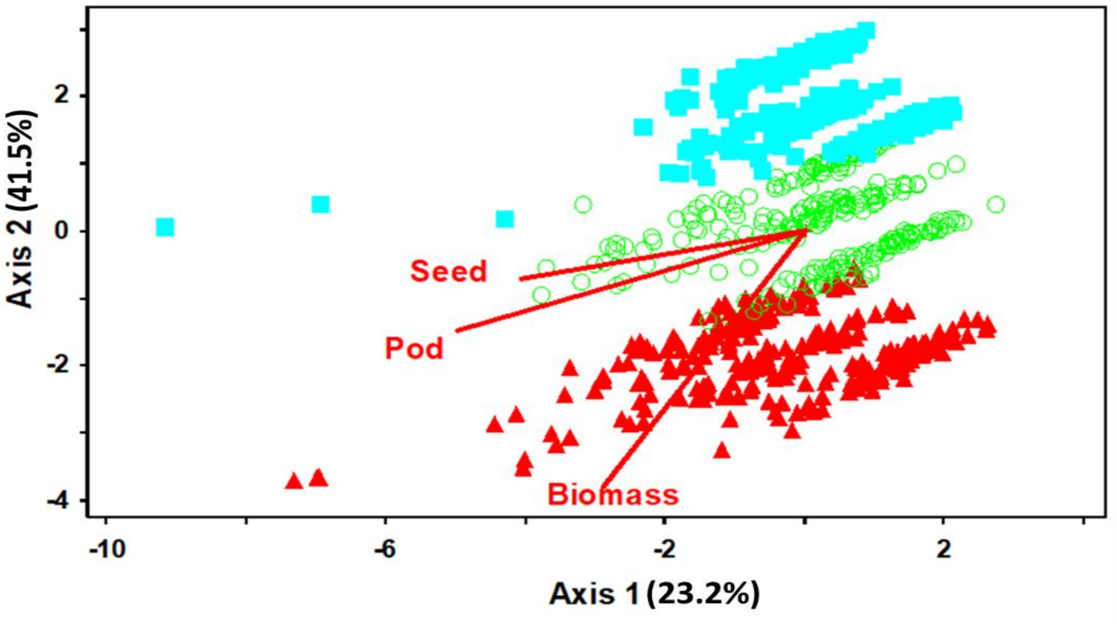

Figure 5: PCA based on soil samples and groundnut data collected in tree sites, Boucotte Diembering (triangles), Boukitingho (rounds) and Oussouye (squares) for all treatments during year1 and year2.

Within each site, samples separated according to the treatment. Samples where *E. camaldulensis* was intercropped strongly separated from biochar and control treatments (Figure 6).

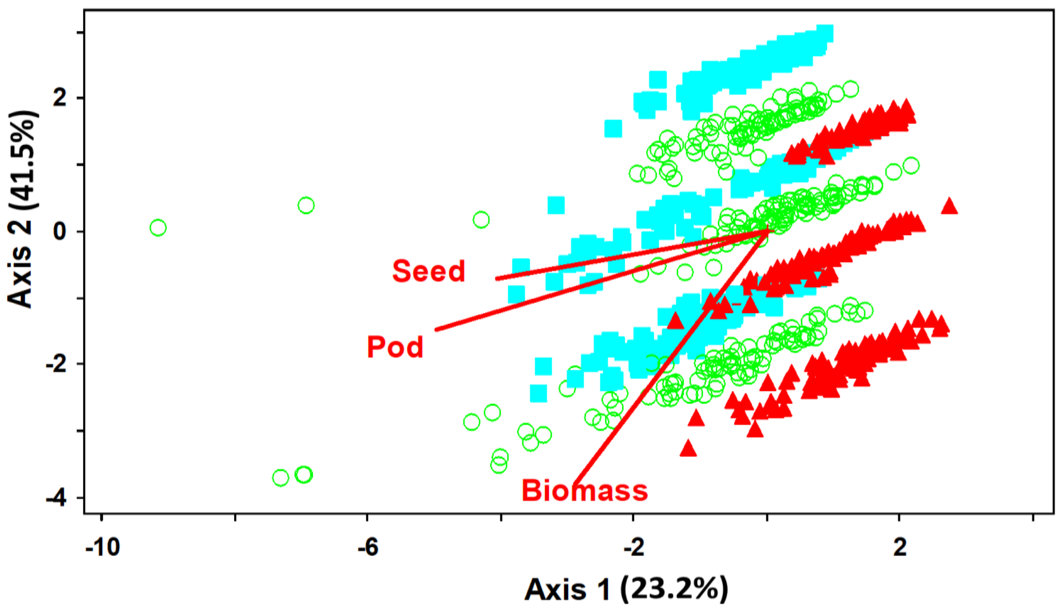

Figure 6: PCA based on soil samples and groundnut data collected in tree sites in year1 and year2 for all three treatments: Eucl+GrdNut (triangles), Bioch+GrdNut (rounds) and Control (squares)

Year effect was significant but not as strong as the treatment effect nor the site effect (Figure 7). Positive interaction existed among sites, treatments and years ($p < 0.001$).

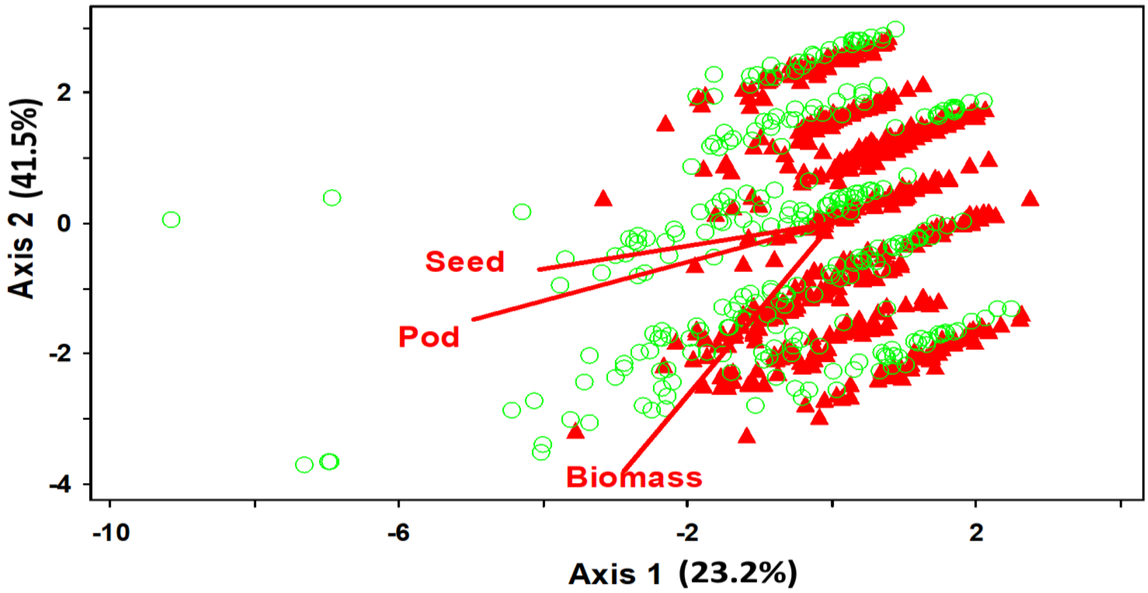

Figure 7: PCA based on soil samples and groundnut data collected in tree sites for all treatments in year1 (triangles) and year2 (rounds)

PCA biplot showed that pod and seed yield were highly correlated among them as well as with the C/N ratio (Figure 8). These parameters were also correlated with the biochar amended plots. The treatment biochar+GrdNut was influential for groundnut seed yield as well as for the C/N ratio of the soil. These parameters were crucial for this treatment compared to others.

Chemical characteristics such as N and P were more correlated with the treatment of *E. camaldulensis* intercropped with groundnut. The control treatment also influenced yield in biomass as well as K^+.

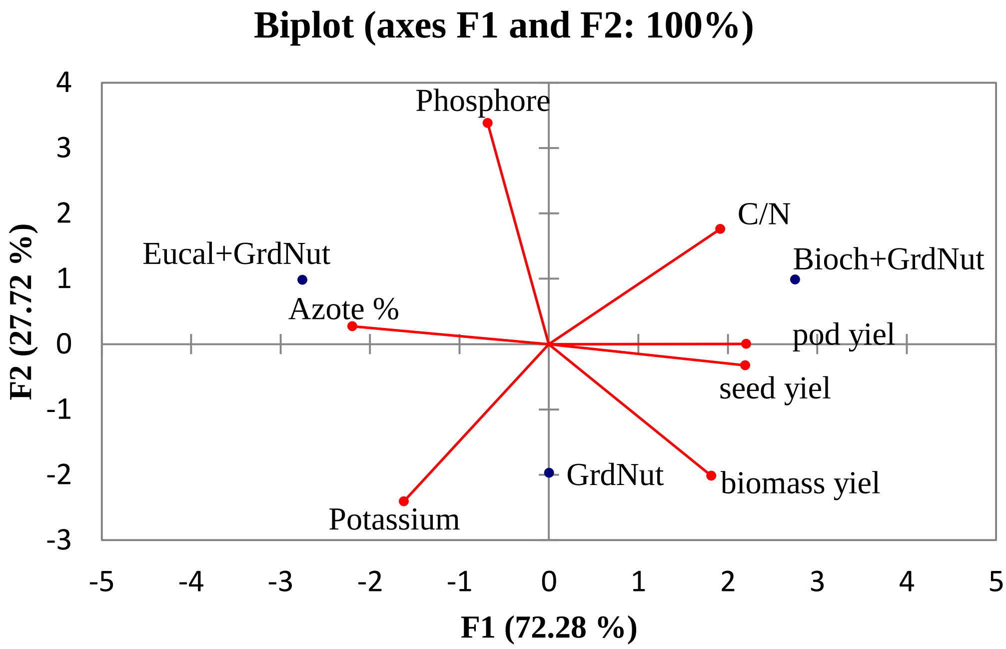

Figure 7. Correlation among yields, soil chemical properties, and different treatments

Higher yield in biochar amended plots may be due to the fact that biochar improves soil physical and chemical properties, and generates higher mineral concentrations (NO_3^-, K^+, Fe^{2+}, Mn^{2+} and Zn^{2+}) [25-26]. Biochar retains nutrients in soil and promotes biological activities crucial for mineralization, which increases nutrient availability for crops while reducing losses by leaching [27-28]. Moreover, [29] found an increase in N content, water retention, and a better CEC for biochar-amended soils; this favored the retention of cations such as NH_4^+ and reduced NO_3^- leaching in soil by 25% [30]. Biochar amended soil contributes to improve productivity and consequently crop yield [31]. [32] argued also that the effect of biochar in the soil may be stronger than that of earthworms. The surface and porosity of biochar determine both their water-holding capacity, their absorptive capacity, and their CEC. In our study, all plots amended with biochar presented higher yield compared to plots where *E. camaldulensis* was intercropped.

Conclusion

Management of *E camaldulensis* in farmers' field resulted in the lowest yield of seed, pod or biomass when *E. camaldulensis* is intercropped with groundnut compared to other treatments including the control. Intercropping decrease yield by at least 35% compared to the control. When plots are amended with biochar, C/N ratio increased from 10 to at least 13, there was also an increase in Ca^{2+}. Soil also became less acid in biochar-amended plots. Biochar amendment increased also pod, seed, and biomass yield. In our study, there was no negative or positive effect on the nutrient content when *E. camaldulensis* is intercropped with groundnut for two years, but groundnut yield did decrease. Better management of *E. camaldulensis* in an agroforestry system maybe through its biochar amendment in farmers' fields.

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(2020) ; http://www.jmaterenvironsci.com