Effect of Biochar and Inorganic Fertilizer on Some Selected Soil Chemical Properties in Sokoto State, Nigeria

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Abstract

Both biochar and inorganic fertilizers have great influence on soil chemical and biological properties. This study was conducted at Biological Science Screenhouse of Usmanu Danfodiyo University, Sokoto, Nigeria to determine the effect of biochar and inorganic fertilizer (NPK) at different application rates on soil organic carbon, nitrogen, available phosphorus, exchangeable basis, CEC and exchangeable acidity. The experiment was laid out in Completely Randomized Design (CRD) consisting of two factors; biochar and inorganic fertilizer (NPK). Biochar was applied at the rate of 0, 4, and 8 t ha^{-1} while NPK was applied at the rate of 10-25-25 kg ha^{-1} (half recommended rate) and 20-50-50 kg ha^{-1} (full recommended rate) and control without biochar and NPK and replicated three times. The data on soil chemical properties were generated and subjected to analysis of variance (ANOVA) at 5% level of significance. The results from the study revealed that chemical properties of soil increased significantly with 8t ha^{-1} of biochar + 20-50-50 kg ha^{-1} NPK and 8t ha^{-1} biochar + 10-25-25 kg ha^{-1} NPK than other biochar + NPK treatments. Therefore, 8t ha^{-1} of biochar + 20-50-50 kg ha^{-1} NPK and 8t ha^{-1} biochar + 10-25-25 kg ha^{-1} NPK have the potential of improving soil pH, organic carbon, total N, available P and cation exchange capacity (CEC) and K. Similarly, all biochar + NPK treatments increased the amount of soil Na and Al when compared with control which may be detrimental, especially to plant and soil microorganisms and their activities. Therefore, biochar feedstock with higher tendency of increasing Na and Al should not be used for soil application.

Key words: Biochar, inorganic fertilizer, soil, chemical properties

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Introduction

Soil fertility can be successfully improved using both inorganic and organic fertilizers. The major drawbacks of inorganic fertilizers are their low accessibility to resource-poor farmers (Gerner and Harris 1993) and their low efficiency in highly weathered soils (Laird *et al*., 2010). Farmers often use inorganic fertilizers which are expensive and scarce, therefore, they are forced to depend on alternative nutrient sources such as organic manures (Awopegba *et al*. 2017). However, excessive use of mineral fertilizers proved to have side effects which include soil acidity, leaching of nutrients, priming effect on soil organic matter, soil structure weakening and eutrophication (Barrow, 2012). While organic amendments such as biochar improved soil physical and chemical properties (Zhang *et al*., 2015).

Biochar is derived from thermo-degradation of organic materials in an oxygen-depleted environment with physical and chemical characteristics that makes it suitable for use as a soil conditioner and carbon sequester (Shacley and Sohi 2010; Bouqbis *et al*., 2016). Studies by Bouqbis *et al*. (2016) and Ajayi and Horn (2016) reported that biochar improves soil chemical properties, decreases soil acidity, increases cation exchange capacity (CEC), improves soil aggregates, retains nutrients and helps influence water infiltration dynamics in different soil types. Furthermore, biochar has also been tested to increase soil biological community composition (Grossman *et al*., 2010) and microbial biomass by 125% (Liang *et al*., 2010). Application of biochar and inorganic fertilizer may have the potential of improving the fertility status of the soil thereby improving the soil physical and chemical properties and carbon sequestration. In the long run, biochar application increases plant nutrient availability either due to the improvement of soil properties or addition of some plant nutrients in the biochar (Sohi *et al*., 2010). Biochar and inorganic fertilizer additions through their ability to improve soil properties and increase crop yields could be used to improve soil properties most especially in arid and semi-arid regions. However, inorganic fertilizers, besides their high cost which makes them not to be affordable to resource-poor peasant farmers in the country, their continuous application without a corresponding organic input has been reported to deplete native soil organic matter (Madeley, 1990). This research aims to evaluate some soil chemical properties in response to varying biochar and inorganic fertilizer rates with a view to determining whether the integration of biochar and inorganic fertilizer will result to a better soil chemical properties than the use of either inorganic or organic fertilizer alone.

Materials and Methods

Description of the Study Area

The experiment was conducted at the Biological Science Screenhouse of Usmanu Danfodiyo University, Sokoto, Nigeria. Sokoto State is located in Northwestern Nigeria, near the confluence of the Sokoto River and the Rima River, situated between longitudes 11° 13' to 13° 50 'E and latitudes 4° and 6° N having altitude of 350 m above sea level (Sokoto State Tourist Guide, 2010).

Biochar Pyrolysis and Soil Collection

Biochar was made from rice straw using pyrolysis temperature of 350 to 400℃ (Demirbas, 2007, Crombie and Maek, 2015) and measured with the aid of metal thermometer and the pyrolysis time was 1hour 30 minutes. The biochar produced was crushed and then sieved over a 2 mm mesh sieve and was characterized for pH, total N, P, Ca, K, CEC, before incorporation in to the soil in the pots. The pots were filled with top soil collected at the University Research Farm at a depth of about 0-15 cm. Each pot was filled with 5kg of soil sample and incorporated with biochar and then N (Urea; 46%), P (SSP; 20%) and K (MOP; 60%) two weeks after incorporation of biochar for the biochar to be mineralized.

Experimental Design and Treatments

The experiment was laid out in Completely Randomized Design (CRD) and involved two factors; biochar and inorganic fertilizer (NPK). Biochar was applied at the rate of 0, 4, and 8 t ha^{-1} while NPK was applied at the rate of 10-25-25 kg ha^{-1} (half recommended rate) and 20-50-50 kg ha^{-1} (full recommended rate) and control without biochar and NPK and replicated three times.

Laboratory Analysis

Soils were sampled from each pot and used for soil chemical analysis at Soil Science Laboratory, Usmanu Danfodiyo University, Sokoto. Soil pH was determined using glass electrode pH meter (McLean, 1982). Soil organic carbon was determined by the modified Walkley-Black method as described by Nelson and Sommers (1982). Total nitrogen was determined by the Kjeldahl digestion and distillation Procedure. The phosphorus was extracted as described by Bray and Kurtz (1945) and Nelsen and Sommers (1982). Exchangeable bases were extracted with neutral 1 molar (NH_4OAc) ammonium acetate. Potassium (K) and sodium (Na) in the extract were read using flame photometer, while calcium (Ca) and magnesium (Mg) were determined by EDTA titration method. The cation exchange capacity (CEC) of the soil was determined using normal neutral ammonium acetate (Davis and Freitas, 1970). Exchangeable acidity is defined as the sum of Al + H and this was determined in 1.0 M KCl extract as described by Page *et al*. (1982).

Data Analysis

Data obtained was subjected to analysis of variance (ANOVA) using SPSS analytical software and significant differences among means were separated using LSD at 5% level of significant.

Results and Discussion

Chemical Properties of Soil and Biochar Used For the Study

The pre-sowing analyses of the soil and biochar used for this experiment were presented in Table 1. The soil pH was 6.7 and is rated slightly acidic while that of biochar was 7.41 and is rated as slightly alkaline (Enwenzor *et al.*, 1989). The available P of the soil was 0.38mg/kg, while that of the biochar was 1.20 mg/kg and were both rated as low according to Enwenzor *et al*. (1989). The organic carbon of the soil was 6.6 g/kg and is rated as low, while that of biochar was 45.9 g/kg and as such is rated as high (Enwenzor *et al*., 1989). The nitrogen of the soil was 0.28 g/kg and is rated as low, while that of biochar was 2.66 g/kg and is rated as medium (Enwenzor *et al*., 1989). The cation exchange capacity (CEC) of the soil was 2.26 cmol/kg and is rated as low while that of the biochar was 46.3 cmol/kg and is rated as high (Enwenzor *et al.,* 1989). The exchangeable bases of soil viz.; Ca was 0.50 cmol/kg and is rated as low, Mg was 0.40 cmol/kg and is rated as medium, K was 0.13 cmol/kg and is rated as low and Na was 0.13 cmol/kg and is rated as medium (Enwenzor *et al*., 1989). Similarly, the exchangeable bases of the biochar viz.; Ca, was 0.65 cmol/kg and is rated as low, Mg was 0.85 cmol/kg and is rated as medium, K was 24.62 cmol/kg and is rated as high and Na was 0.92 cmol/kg and is rated as low (Enwenzor *et al*., 1989).

Table 1: Chemical Properties of Soil and Biochar Used for the Study

Properties	Soil	Biochar
pH	5.14	7.41
P (mg/kg)	0.38	1.20
OC (g/kg)	6.6	4.59
N (g/kg)	0.28	2.66
Exchangeable bases (cmol/kg)		
Ca	0.50	0.65
Mg	0.40	0.85
K	0.13	24.62
Na	0.13	0.92
CEC	2.26	46.3

O.C= organic carbon, N= Nitrogen, P= Phosphorus, Ca= Calcium, Mg= Magnesium K= Potassium, Na= Sodium, CEC= Cation exchange capacity. Effect of Biochar and Inorganic Fertilizer on Soil pH, Organic Carbon, Total Nitrogen, and Available Phosphorus (P)

Table 2 presents the effect of biochar and NPK on soil pH, organic carbon, total N, and available phosphorus. High rates of biochar and inorganic fertilizer (8 t ha^{-1} of biochar + 20-50-50 kg ha^{-1} NPK and 8 t ha^{-1} biochar + 10-25-25 kg ha^{-1} NPK) recorded significantly ($p < 0.05$) higher soil pH of (6.65 and 6.69), organic carbon, total N, and available phosphorus than other biochar and NPK rates including the control (6.07). Although these soil properties increased with increasing rates of biochar for all the properties but in most cases the increase was more prevalent with 10-25-25 kg ha^{-1} NPK (Table 2). This indicated that biochar and NPK rates increased the soil pH when compared with the initial pH of soil (5.14) before the experiment which were within the good ranges for soil processes and microbial activities. The increase in soil pH as observed in this research was due to ash and cations presence in the biochar (Vaccari *et al*., 2011) which helped to increase the soil pH while offsetting the acidic reaction from applied NPK fertilizer (Sarma *et al*., 2017). This observation agreed with the finding of Revell *et al*. (2012) who suggested that biochar can lime the soil and also mitigate the acidity effect of inorganic fertilizer application. Similar trend of biochar and NPK rates was also observed in soil organic carbon as seen with soil pH. This could be attributed to high organic carbon content of biochar and the ability of inorganic fertilizer to provide nourishment for plant growth and soil microorganisms to carry out their activities of decomposition which increases organic carbon of soil. Zhang *et al*. (2012) reported that soil amended with biochar and NPK displayed significantly higher organic carbon compared to the control.

High rates of biochar and inorganic fertilizer (8 t ha^{-1} of biochar + 20-50-50 kg ha^{-1} NPK and 8 t ha^{-1} biochar + 10-25-25 kg ha^{-1} NPK) also recorded significantly ($p < 0.05$) higher total nitrogen (0.09 g/kg each) than 0 t ha^{-1} of biochar and NPK as well as the control (0.02 g/kg). This is because nitrogen content of the soil increases when biochar and NPK fertilizer was applied to the soil. This research also indicated that increased in total nitrogen could be due to decomposition which might have occurred when biochar was added to soil (Liang *et al*., 2006). Significant differences were also observed among biochar and NPK rates on soil available P, where addition of high rates of biochar and inorganic fertilizer (8 t ha^{-1} of biochar + 20-50-50 kg ha^{-1} NPK and 8 t ha^{-1} biochar + 10-25-25 kg ha^{-1} NPK) recorded significantly ($p < 0.05$) higher available P (0.69 mg/kg and 0.67 mg/kg) than 4 t ha^{-1} of biochar + 20-50-50 kg ha^{-1}, NPK 0 t ha^{-1} of biochar + NPK and control treatments (0.32 mg/kg). This entails that increase in available P due to biochar + NPK application could be attributed to the increase in soil pH by biochar which may help in breaking complexes of Al and Fe with the phosphorus (Verheijen *et al*., 2010).

Table 5: Cost and returns of broiler chickens as affected by the treatment diets

	Soaking Periods (Hours)			
	0	24	48	72
	Dietary Treatments			
Parameters	CONTL (1)	$APPM_1$ (2)	$APPM_2$ (3)	$APPM_3$ (4)
Cost of feed/kg(₦)	64.70	68.70	65.70	66.10
Total cost of feed consumed (₦/bird)	334.00	321.00	316.00	312.00
Cost of feed/kg weight gain (₦)	213.00	210.00	195.00	192.00
Total cost of production (₦/bird)	908.00	894.00	889.00	886.00
Income (₦/bird)	1,411.00	1,448.00	1,485.00	1,515.00
Net profit (₦/bird)	503.00	554.00	596.00	629.00

Key: $APPM_1$: Ash-soaked pigeon pea meal for 24hours, $APPM_2$: Ash-soaked pigeon pea meal for 48hours, $APPM_3$: Ash-soaked pigeon pea meal for 72hours

Effect of Biochar and Inorganic fertilizer on Soil exchangeable bases, CEC and exchangeable Acidity (Al^{+3} and H^{+})

Table 3 depicts the effect of biochar and NPK on soil exchangeable bases, CEC and exchangeable acidity (Al and H). Biochar and NPK application had shown no significant effect on Ca and Mg. all biochar and NPK rates produce significantly ($p < 0.05$) higher amount of Na when compared with control (Table 3). Increase in Na as a result of biochar and NPK application may lead to soil sodicity and therefore biochar feedstock with higher tendency of increasing Na should not be used for soil application. The 8 t ha^{-1} of biochar + 10-25-25 kg ha^{-1} NPK significantly ($p < 0.05$) recorded higher K (0.377 cmol/kg) though comparable with other biochar rates except 0 t ha^{-1} of biochar + 20-50-50 kg ha^{-1} NPK and control. Biochar and NPK addition at the rate of 8 t ha^{-1} of biochar + 20-50-50 kg ha^{-1} NPK (19.33 cmol/kg) and 8 t ha^{-1} biochar + 10-25-25 kg ha^{-1} NPK (18.83 cmol/kg) significantly ($p < 0.05$) recorded higher CEC than other biochar and NPK rates and control (2.96 cmol/kg). Hence, adding biochar and NPK to the soil may increase CEC and exchangeable cation in the amended soil, suggesting an improvement in the soil fertility and consequently soil productivity though higher Na may be detrimental. The cation exchange capacity (CEC) is an important characteristic of soil which determines nutrients adsorption and desorption and thus their availability in soil. CEC not only helps in fertilizer use efficiency by the crop during the growing season, but also improves the ability of the soil to adsorb and retain nutrients from other sources available at other times. This result agreed with that of Verheijen *et al*. (2010) and Cheng *et al*. (2006) who indicated that the CEC increased with increased carboxilation of carbon. This result also conforms with the finding of lehmann *et al*. (2003) and Chan *et al*. (2008) who reported that original nutrient in the biochar itself supplied the exchangeable cation which help to improves the status of exchangeable cation of the soil. Additionally, low oxidation in turn increase the CEC of the amended soil.

All biochar and NPK rates significantly ($p < 0.05$) recorded higher Al than 0 t ha^{-1} of biochar + 20-50-50 kg ha^{-1} NPK and control while higher H^+ was recorded with control (1.797 cmol/kg) which is significantly higher than other biochar and NPK rates. However, this increase in the soil Al might be attributed to the presence of nitrogen in the applied NPK which may cause soil acidification (Cheng *et al*., 2009).

Table 2: Soil pH, organic carbon, total nitrogen, available phosphorus (P) as affected by biochar and NPK rates

Treatment ha^{-1}	pH (H_2O)	O.C (g/kg)	TN (g/kg)	AP (mg/kg)
0 t biochar + 10-25-25 kg NPK	6.23^{bc}	2.66^{c}	0.03^{cd}	0.54^{bc}
0 t biochar + 20-50-50 kg NPK	6.19^{cd}	2.27^{c}	0.04^{c}	0.43^{cd}
4 t biochar + 10-25-25 kg NPK	6.32^{bc}	4.77^{b}	0.06^{b}	0.59^{ab}
4 t biochar + 20-50-50 kg NPK	6.35^{b}	5.36^{ab}	0.07^{b}	0.49^{bc}
8 t biochar + 10-25-25 kg NPK	6.69^{a}	7.05^{a}	0.09^{a}	0.67^{a}
8 t biochar + 20-50-50 kg NPK	6.65^{a}	7.36^{a}	0.09^{a}	0.69^{a}
Control (0 t biochar + 0-0-0 kg NPK)	6.07^{d}	0.73^{c}	0.02^{d}	0.32^{d}
LSD	0.14	2.09	0.01	0.11
Significance	*	*	*	*

Mean within the same column with the same alphabet are not significantly ($p < 0.05$) different according to LSD =Least significant difference, *=Significant at $p<0.05$, OC= Organic Carbon, TN =Total Nitrogen, AP =Available Phosphorus, 20-50-50 kg NPK = (full Recommended rate), 10-25-25 kg NPK = (half recommended rate rate), t = ton.

Conclusion

This study revealed that high rates of rice straw biochar incorporated with NPK (8t ha^{-1} of biochar + 20-50-50 kg ha^{-1} NPK and 8t ha^{-1} biochar + 10-25-25 kg ha^{-1} NPK) have the potential of improving soil pH, organic carbon, total N, available P and cation exchange capacity (CEC) and K. However, increase in Na and Al as a result of biochar and inorganic fertilizer addition may be detrimental, especially to plant and soil microorganisms. Therefore, biochar feedstock with higher tendency of increasing Na and Al should not be used for soil application.

Reference

Ajayi, A. E. and Horn, R. (2016). Modifications of chemical and hydrophysical properties of two texturally differentiated soil due to varying magnitude of added biochar. *Soil Tillage Research*, 164:34-44.

Awopegba, M. S., Oladele, S. and Awodun, M. (2017). Effect of mulch types on nutrient composition, maize (*Zea mays* L) yield and soil properties of a tropical Alfisol in southwestern Nigeria. *European Journal of Soil Science*, 6 (2):121-133.

Barrow, C. J. (2012). Biochar potential for countering land degradation and for improving Agriculture. *Applied Geography*, 34(2): 21-28.

Bougbis, N., and Weil, R. (2016). The Nature and Properties of Soils. 13th ed. Upper Saddle River, N.J., Prentice Hall, Harvard.

Bray, R. H. Kurtz, L. T. (1945). Determination of total organic carbon and available form of phosphorous in soil. *Soil science*, 13:727-742.

Chan, K. Y., Zwieten, V. L., Meszaros, I., Dowine, A. and Joseph, S. (2008) Using poultry litter biochars as soil amendments. *Australian Journal of Soil Research*, 46:437 - 444.

Cheng, C. H. and Lehmann, J. (2009). Ageing of black carbon along a temperature gradient. *Chemosphere*, 75: 1021 - 1027.

Cheng, C. H., Lehmann, J., Thies, J., Burton, S. D., Engelhard, M. H. (2006). Oxidation of black carbonby biotic and abiotic processes. O*rganic Geochem*istry, 37: 1477-1488.

Crombie, K. and O. Maek. (2015). Pyrolysis biochar systems, balance between bioenergy and carbon sequestration. GCB Bioenergy, 7: 349-361. doi:10.1111/gcbb.12137.

Demirbas, A. (2007). The influence of temperature on the yields of compounds existing in bio-oils obtained from biomass samples via pyrolysis. *Fuel Processing Technology*, 88: 591-597. doi:10.1016/j.fuproc.2007.01.010.

Davis, J. and Freites, F. (1970). Physical and chemical method of soil and water analysis. *Soil Bulletin*, 10.FOA, Rome.

Enwenzor, W. O., Udo, E .J., Usoroh, N. J., Ayotade, K. A., Adepetu, J. A., Chude, V. O and Udegbe, C. E. (1989). Fertilizer Use and Management practices for Crop in Nigeria, Series no.2 Federal Ministry of Agric Water Resources and Rural Development. Lagos. pp 163.

Gerner, H., and Harris, G. (1993). The use and supply of fertilizers in sub-Saharan Africa. In H. van Reuler and W.H. Prins (eds.), The Role of Plant Nutrients for Sustainable Food Crop Production in Sub-Saharan Africa. Leidschendam, The Netherlands: VKP (Dutch Association of Fertilizer Producers).

Grossman J. M., O'Neill, B. E., Tsai, S. M., Liang, B., Neves, E., Lehmann, J. and Thies, J. E (2010). Amazonian anthrosol support similar microbial communities that differs distinctly from those extant in adjacent, unmodified soil of the same mineralogy. *Microbial Ecology*, 60:192-205.

Laird, D. A., Fleming, P., Davis, D. D., Horton, R., Wang, B. and Karlen, D. L. (2010). Impact of biochar amendments on the quality of a typical Midwestern agricultural soil. *Geoderma*, 158: 443-449. doi:http://dx.doi.org/10.1016/j.*geoderma*.2010. 05.013.

Lehmann, J., Pereia da Silva Jr., J., Steiner, C., Nehls, T., Zech, W. and Glaser, B. (2003). Nutrient availability and leaching in an archaeological Anthrosol and a Ferralsol of the Central Amazon basin: fertilizer, manure and charcoal amendments. *Plant Soil*, 249:343 - 357.

Liang, B., Lehmann, J., Solomon, D., Kinyangi, J., Grossman, J., O'Neill, B., Skjemstad, J. O., Thies, J., Luizao, F. J., Petersen, J. and Neves, E. G. (2006). Black carbon increases cation exchange capacity in soils. *Soil Science Society of America Journal*, 70: 1719–1730.

Liang, Q., Chen, H., Gong, Y., Fan, M., Yang, H., Lal, R. and Kuzyakov, Y. (2010). Effects of 15 years of manure and inorganic fertilizers on soil organic carbon fractions in a wheat-maize system in the North China Plain, *Nutrient Cycling in Agroecosystem*, 92: 21 - 33.

Madeley, J. (1990). The organic cycle. African farming and food processing, May/June Edition. Alain Charles Publishing Ltd., London, pp. 1-22.

McLean, E. O. (1982). Soil pH and lime requirements. In page, A. L., R. H. Miller and D. R. Keeney (eds.). Method of soil analysis. Part 2- chemical and microbiological properties. (2nd Eds.). *Agronomy*, 9:199-223.

Nelson, D. W. and Sommers, L. E. (1982). Total carbon, organic carbon and organic matter. In: Page, A. L., Miller, R. H, and Keeney, D. R. (Eds.) Methods of Soil Analysis, part 2. *American Society of Agronomy*, Madison, USA, pp. 539 -579.

Page, A. L., Miller, R. H. and Keeney, D. R. (1982). Methods of soil analysis. Part 2. Chemical and microbiological properties. 2nd edition. *Agronomy series* 9, ASA, SSSA, Madison, Wis. USA.

Revell, K. T., Maguire, R. O., Agblevor, F. A. (2012). Influence of poultry litter biochar on soil properties and plant growth. *Soil Science*, 177:402–408. https://doi.

Sarma, B., Gogoi, N., Bharali, M. and Mali, P. (2017). Field evaluation of soil and wheat responses to combined application of hardwood biochar and inorganic fertilizers in acidic sandy loam soil. *Experimental Agriculture*, 114:1-13.

Shacley, S. and Soho, S. (2010). Benefit and Issue Associated with the Application of biochar to soil. Department for Environment, Food and Rural Affairs, UK Government, London.

Sohi, S., Krull, E., Lopez-Capel, E., Bol, R. (2010). A review of biochar and its use and function in soil. *Advanced Agronomy*, 105, 47–82.

Sokoto State tourist guide (2010), paper presentation in trade -fair, old airport. Sokoto State under Ministry of commerce, Sokoto State pop. 4.

Vaccari, F. P., Baronti, S., Lugato, E., Genesio, L., Castaldi, S., Fornasier, F. and Miglietta, F. (2011). Biochar as a strategy to sequester carbon and increase yield in durum wheat. *European Journal of Agronomy,* 34:231–238.

Verheijen, F., Jeffery, S., Bastos, A.C., Van der Velde, M. and Diafas, I. (2010) Biochar application to soils. A critical review of effects on soil properties, processes and functions. Institute for Environment and Sustainability, Joint Research Centre, European Commission, Italy. Pp 45.

Zhang, A., Cui, L., Pan, G., Li, L., Hussain, Q., Zhang, X., Zheng, J. and Crowley, D. (2015). Effect of biochar amendment on yield and methane and nitrous oxide emissions from a rice paddy from tai lake plain, china. *Agriculture, Ecosystems and Environment,* 2010, 139, 469–475.

Zhang, A., Liu, Y., Pan, G., Hussain, Q., Li, L. and Zheng, J. (2012). Effect of Biochar Amendment on Maize Yield and Green House Gas Emission from a soil Organic Carbon, Poor Cancerous Loamy Soil from Central China plain. *plant and Soil.* 351:263-275.