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Production and Characterization of Compost Manure and Biochar from Cocoa Pod Husks

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Abstract
Cocoa farms loss lots of nutrients through pod harvest which are not replaced through fertilizer application. Thus the soils are much depleted in nutrients leading to low yields. Inorganic fertilizers are expensive and above the reach of most small scale farmers. There is thus the need for cheap sources of soil amendments. Biochar was produced from cocoa pod husks at 3 different pyrolysis temperatures (300 °C for 2 hours, 350 °C for 3 hours and 400 °C for 2 hours). Compost manure was also produced using cocoa pod husk, poultry litter and Pureria. The samples produced were characterized for pH, and total elements. The biochar and compost manure produced from cocoa pod husks were found to possess alkaline properties. Most elements increased in quantity with pyrolysis temperature. Compost manure presented the highest nutrient values compared to the different biochars however, both compost and biochar presented properties that made them suitable as soil amendments.
Keywords: *Biochar, Compost, Cocoa pod husk, pH*

1. Introduction

Cocoa based small scale agriculture is an important income source for many families in the humid zone of West and Central Africa, in which forest trees provide shade and other environmental services as well as marketable products (Duguma et al., 2001). Cocoa yields are usually low (Baah et al., 2011) due to low soil fertility and disease (Adejumo, 2005). This results in food insecurity, hunger and extreme poverty among smallholder farmers who depend on agriculture to make a living and feed their families. Nutrients are being 'mined' through pod harvest without replacement in the form of fertilizer application. Chemical fertilizers are scarce, costly and beyond the reach of small scale farmers.

In cocoa fruits only about 10 % of cocoa pod is currently valuable as this is the percentage occupied by the bean (Amos and Thompson, 2015). Each ton of dry beans produced results in the production of 10 tons of cocoa pod husk (Khanahmadi et al., 2014). When these cocoa pod husks are left in farms, they act as a source of inoculum for the Phytophthora which is the causal agent for the black pod disease (Barazarte et al., 2008; Donkoh et al., 1991; Figueira et al., 1993; Kalvatchev et al., 1998). Black pod disease can reduce cocoa yields up to 90 % if left untreated. In a study carried out on the effect of heat on fungi (Michailides et al., 1988), it was found that fungi are sensitive to extreme temperatures as heat can be lethal to their survival.

Crop wastes such as spent grain and cocoa husk combined with poultry, cow and goat manures were effective in increasing nitrogen and potassium concentrations, growth and fruit yield of tomato significantly (Ojeniyi, 2007). It has been advised that the cocoa pod husk be burnt to serve as farm sanitation and reduce the incidence of Phytophtora which is the causal agent of blackpod disease of cocoa. Burning of cocoa husk also reduces its C/N ratio and therefore enhances its early mineralization. Cocoa pod ash is rich in K and Ca (Ayeni, 2008). Cocoa pod husks can be used as a compost or mulch if left to rot in the fields on cocoa farms where they recycle nutrients back into the soil as manure and also serve as a breeding ground for midges.

Cocoa pod husk can be converted to biochar which is the carbonaceous solid residue obtained upon heating biomass under oxygen-deficient conditions. It has a potential as a nutrient recycler, soil conditioner, income generator, waste management system, and agent for long-term, safe and economical carbon sequestration (Brewer, 2012). Biochar has been used as soil amendment to improve soil structures and fertility qualities (Glaser et al., 2002; Atkinson et al., 2010).

Converting cocoa pod husk into compost manure and biochar will disinfect the husk during production at high temperatures (Nde, 2015) thus reducing the inoculum levels of the pathogen in the fields as well as provide a source of nutrient for the plants.

The objective of this work was to produce compost manure and biochar from cocoa pod husk and characterize these products for potential application.

2. Materials and methods

Materials: Cocoa pod husk, poultry manure and grasses were used for the preparation of the compost manure and biochar was made from only cocoa pod husk. A kiln made of a metallic drum was used for biochar production.

2.1 Preparation of biochar from cocoa pod husks

Cocoa pod husk were collected from farmers` fields and dried. The production of biochar from cocoa pod husks was carried out at the Institute of Agricultural Research for Development (IRAD) Ekona in Cameroon using a muffle furnace. The dried cocoa pod husks were placed in the muffle furnace for burning in the presence of limited oxygen (the vent of the muffle furnace was closed). The first set was pyrolysed at 300 °C for 2 hours (300/2hrs), the second at 350 °C for 3 hours (350/3hrs) and the third, at 400 °C for 2 hours (400/2hrs).

2.2 Production of compost manure from cocoa pod husk

Pureria phaseoids and cocoa pod husk were shredded into tiny pieces. Using a balance, the shredded cocoa pod husk, chopped grass and poultry droppings were weighed in the ratio 2:2:1 respectively. The various weighed components were mixed thoroughly and mounted into a heap. A hand full of wood ash was sprinkled over the heap. The heap was covered with polythene sheets. The temperature of the heap was monitored using a thermometer and the heap was turned every two weeks using a spade. The compost was ready after twelve weeks and the well-decomposed compost was spread on concrete floor and allowed to dry prior to analysis.

2.3 Characterization of biochar and compost manure produced from cocoa pod husks

The pyrolysed cocoa pod husks and compost manure were characterized at the University of Florida in the Agricultural and Biological Engineering laboratory for pH, Cation Exchange Capacity (CEC), surface area (only for biochar) and elemental composition.

2.3.1 pH

The pH was measured using a pH meter (Accumet Basic AB 15/15+), a shaker, a deionizer, an electronic balance, test tubes and water. 1g of each sample was put in different test tubes and 200 ml of deionized water was added into the plastic test tubes containing the samples. The test tubes were firmly closed and placed on a shaker (New Brunswick Scientific shaker) for 1 hour. After shaking, they were allowed to settle for 45 minutes and the pH was read from the supernatant.

2.3.2 Elemental analysis

The inductively coupled plasma optical emission spectroscopy was used for the determination of the elemental composition of the samples. For the determination of the total amounts of each micro- and macro- element in the samples, the samples were completely charred at 550 °C for 5 hours. Each sample was measured, making sure that the mass was in the interval of 0.1 g to 0.2 g. 1 ml of concentrated hydrochloric acid (HCl) was added and left to dissolve. To these, 19 ml of deionized water was added and then filtered to remove all the particles present. Each sample was then ionized with inductively coupled plasma and then a mass spectrometer was used to separate and quantify those ions.

For the determination of carbon (C) and nitrogen (N), a TruSpec CHN (Manufacturer Leco) was used. The sample was pre-dried, crushed and placed into a tin capsule. The capsule was then closed and put into the TruSpec CHN for measurement.

3. Results and discussion

3.1 pH

The pH values for biochar and compost manure revealed an alkaline property with pH ranging from 9.54 to 9.80 and 8.65 respectively. This was observed to be a common property for thermally produced biochars (Lehmann and Joseph, 2009). These high pH values are also in accordance with findings made in a study (Mukherjee et al., 2014) which explained that newly made biochars at high temperatures have high pH values. Increasing the pyrolysis temperature from 300 °C to 400 °C for 2 hours resulted in an increase in the pH value of biochar as seen in Table 1. This was in accordance with another finding (Wang et al., 2015) where it was explained that this pH rise is due to the fact that pyrolysis temperatures can result in the increase of the percentage of alkaline cations such as Ca2+, Mg2+, and K+. Another explanation to this rise in pH could be the fact that, at high temperatures the ash content of biochar is increased. The ash content of biochar has been found to be directly proportional to its pH due to the fact that at higher pyrolysis temperatures the carboxyl groups are reduced and/or the acidic groups become deprotonated to the conjugate bases resulting in a more alkaline pH of the biochar (Ronsse, 2013). The increase in the pH of biochar with temperature was also attributed to the dissociation of Alkaline and Alkali Earth Metallic (AAEM) species and the formation and deposition of alkaline carbonates on char surfaces (McKendry, 2002). This rise in pH with pyrolysis temperature was also explained as being the result of the continuous rearrangement of functional compounds released under lower temperatures that scissor the carbonyl group thus deactivating organic acids and increasing the pH values of the biochar (Twidell, 1998). The pH value however dropped at higher pyrolysis residence time (350 °C for 3 hours), contrary to other findings made (Ronsse et al., 2011) in which the pH of biochar was found to increase with increasing pyrolysis temperature and residence time.

Table 1 : pH of samples

Sample code	pH
300/2hr	9.62
350/3hr	9.54
400/2hr	9.80
Compost	8.65

The pH of the compost manure was within the alkaline range (table 1). The high pH values for the studied samples showed that they could be very useful for liming of acidic soils. Using biochar and compost manure produced from cocoa pod husks to lime the soils could result in increased microbial activities in the soil resulting in increased fertilization due to the decomposition of Soil Organic Matter (SOM) by these microbes (McElligott, 2011).
Biochars with high pH are useful in immobilizing metals, especially in acid soils where they have been found to be generally more soluble (Novak et al., 2009) thus useful in soil remediation. The high CEC of biochar produced from cocoa pod husks makes it useful in the remediation of heavy metals through the exchange of these heavy metals with the cations associated to the biochar (Lu et al., 2012; Uchimiya et al., 2011c). Biochar remove heavy metals from soils through the formation of complexes with the metal ions on their surfaces (Beesley et al., 2011)

4 Elemental Composition

4.1 Macro-elements

The biochar produced was found to have high amounts of primary macro-elements with a K content ranging from 341.54 mg/L to 1497.75mg/L, Mg content ranging from 25.38 mg/L to 80.07mg/L and Ca content ranging from 28.34 mg/L to 82.50 mg/L. The concentrations of Ca, Na, K, P and Mg were found to increase with pyrolysis temperature as seen in table 3 below. This was in accordance with previous findings (Wenchuan et al., 2014). The increase in the concentrations of Ca, Na, K and Mg was explained as being a result of the accumulation of alkaline salts during pyrolysis (Ding et al., 2014). Increasing the pyrolysis temperature from 300 °C to 350 °C as well as the pyrolysis residence time from 2 hours to 3 hours, resulted in an increase in the concentrations of Ca, Na, K, P and Mg. The K and Mg concentrations were found to be higher at 350 °C for 3 hours than at 400 °C for 2 hours.
For the produced compost manure, the macro elements were far higher than for biochar (Table 2). This is attributed to the fact that in addition to the cocoa pod husk, poultry litter and pureria grass were added for the production of the compost manure thus making it much richer. This was similar to an observation made in comparing sunflower compost (richer than) sunflower biochar (Adejumo et al., 2015).

Table 2 : Macro-elements in biochar and compost manure

Sample code	Ca (mg/L)	Mg (mg/L)	K (mg/L)	P (mg/L)
300/2hrs	28.34	25.38	341.54	26.89
350/3hrs	82.50	80.07	1453.51	70.93
400/2hrs	74.80	79.61	1497.75	80.10
Compost	608.54	463.15	2581.91	1286.52

4.2 Micro-elements

The elemental analysis revealed that at the same pyrolysis residence time, all the micro-elements in the samples increased with pyrolysis temperature. The increase in the Fe content observed was in accordance with previous findings (Wenchuan et al., 2014) and was explained as being a result of accumulation of alkaline salts during pyrolysis (Ding et al., 2014). The highest increase was observed in Cu which went from 1.66 mg/L to 5.26 mg/L. as seen in Table 3. In a whole, the micro elements in compost were by far higher than those in the biochar.

Table 3 : Micro-elements in biochar

Sample code	Al (mg/L)	Fe (mg/L)	Mn (mg/L)	Zn (mg/L)	Cu (mg/L)	B (mg/L)
300/2hrs	1.29	1.32	1.04	0.63	1.66	1.02
350/3hrs	2.94	2.52	2.55	1.08	0.93	1.58
400/2hrs	1.34	1.38	3.09	0.99	5.26	1.15
Compost	27.35	10.34	185.80	7.15	0.71	1.31

4.3 Carbon (C) and nitrogen (N)

The CN analysis indicated that the biochar samples prepared in this work are carbon rich with the carbon ranging from 39.95 % to 57.89 %. However, the N was found to be in low concentrations, ranging from 0.66 % to 1.03 % (table 4) in conformity with other findings (Uchimya et al., 2011). Pyrolysis temperature during biochar production showed little effects on the C and N variations as their concentrations remained almost unchanged. Contrarily to other findings (Sun et al., 2014), when the pyrolysis temperature increased from 300 °C to 400 °C, the C content of the biochar was found to decrease from 57.89 % to 52.27 %. The decrease in C content with increasing pyrolysis temperatures could be explained by an accelerated biomass decomposition and organic volatilization, as higher temperature biochars contain more non-volatile elements than the low temperature ones (Garcia et al., 2014). The nitrogen content in cocoa pod husk compost manure was high but its carbon content was low (21.23%).

Table 4 : C and N in cocoa pod husk biochar and manure

Sample code	N %	C %
300/2hrs	1.03	57.89
400/2hrs	0.95	52.27
350/3hrs	0.66	39.95
Compost	2.10	21.23

5. Conclusion

Generally, the biochar produced from cocoa pod husks was found to have characteristics which were affected by pyrolysis conditions, namely, pyrolysis temperature as well as the residence time. The biochar and compost were found to be alkaline in nature thus making them very suitable as a soil amendment especially in acidic tropical soils. Their high micro and macro nutrient levels make them suitable for crop fertilization. Above all it is a very cheap source of manure and the technique is not difficult for farmers to understand.

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References

[1] Adejumo, Owolabi and Odesola, Agro-physiologic effects of compost and biochar produced at different temperatures on growth, photosynthetic pigment and micronutrients uptake of maize crop. African Journal of Agricultural Research, Vol. 11 (Issue 8): Page No 661- Page No 673, (2016)

[2] Agusalim, Rice Husk Biochar for Rice Based Cropping System in Acid Soil. The Characteristics of rice husk biochar and its influence on the properties of acid sulfate soils and rice growth in West Kalimantan, Indonesia, Journal of Agricultural science. Vol. 2 (Issue 1): Page 39 – Page 43, (2010)

[3] Ahmad and Masood, Affordable filtration technology of safe drinking water for rural Newfoundland and Labrador. St. John's,NL:

Master thesis, Memorial University of Newfoundland. Page No. 122-139. (2013)

[4] American Society of Agronomy, Crop Science Society of America, Soil Science Society of America, In: Publication handbook and style manual. ASA, CSSA, SSSA. Madison, WI (1998)

[5] Amos T. T. and O. A. Thompson, Climate Change and the Cocoa Production in the Tropical Rain Forest Ecological Zone of Ondo State, Nigeria. Journal of Environmental Science. Vol. 5 (Issue 1): Page No. 2224- Page No 3216, (2015)

[6] ASTM C1069-09. Standard Test Method for Specific Surface Area of Alumina or Quartz by Nitrogen Adsorption, ASTM International, West Conshohocken, Page No. 2, (2014)

[7] Barazarte, Sangronis, & Unai,. La cáscara de cacao (Theobroma cacao L.): Una posible fuente comercial de pectinas.Archivos Latinoamericanos de Nutrición, Vol. 58 (Issue 1) : Page No. 64 – Page No. 70. (2008)

[8] Beesley, Moreno-Jiménez, Jose, Gomez-Eyles, Harris, Robinson and Sizmur. A review of biochars' potential role in the remediation, revegetation and restoration of contaminated soils. Environmental Pollution Vol. 159 (Issue 12), Page No. 3269 - Page No. 3282, (2011)

[9] Brewer, Biochar characterization and engineering Iowa State University Graduate Theses and Dissertations. Page No. 12 – Page No. 97, (2012).

[10] Cao, Ma, Gao, and Harris, Dairy-manure derived biochar effectively sorbs lead and atrazine, Environment science and technology. Vol. 50 (Issue 43): Page No. 3285 – Page No. 3291, (2009)

[11] Chan, Van, Meszaros, Downie and Joseph. Agronomic values of green waste biochar as a soil amendment. Australian Journal of Soil Research, Vol. 27 (Issue 45): Page No. 629 – Page No. 634, (2007)

[12] Choppala, Bolan, Megharaj, Chen, and Naidu, The influence of biochar and black carbon on reduction and bioavailability of chromate in soils. Journal of Environmental Quality. Vol. 41 (Issue 4): Page No. 1175 – Page No. 1184, (2012)

[13] Deutsches Institut Fur Normung E.V (German National Standard). CHN according to DIN 51732: Testing of solid mineral fuels- Determination of total carbon, hydrogen and nitrogen- Instrumental methods, Page No. 11 (2007)

[14] Ding, Dong, Ime, Gao, Len, Pyrolytic temperatures impact lead sorption mechanisms by bagasse biochars. Chemosphere , Vol. 105, Page No. 68 – Page No. 74, (2014)

[15] Ding, Huang, Sun, Jiang and Chen, Decomposition of Organic Carbon in Fine Soil Particles Is Likely More Sensitive to Warming than in Coarse Particles: An Incubation Study with Temperate Grassland and Forest Soils in Northern China. PLOS ONE Vol. 9 (Issue 4): Page No. 95348, (2014)

[16] Donkoh, Atuahene, Wilson and Adomako, Chemical composition of cocoa pod husk and its effect on growth and food efficiency in broiler chicks. Animal Feed Science and Technology, Vol. 35, (Issues 1 – 2): Page No. 161- Page No. 169, (1991)

[17] Figueira, Janick, and BeMiller. New products from Theobroma cacao: Seed pulp and podgum. In: J. Janick and J.E. Simon (eds.), New crops. Wiley, New York. Page No. 475 – Page No. 478. (1993)

[18] Garcia-Perez, Lewis, Kruger, Literature Review of Pyrolysis Reactors, Methods for Producing Biochar and Advanced Biofuels in Washington State. Department of Biological Systems Engineering and the Center for Sustaining Agriculture and Natural Resources, Washington State University, Pullman, WA, (2010)

[19] Kalvatchev, Garzaro and Cedezo, Theobroma cacao L.: un nuevo enfoque para nutrición y salud. Agroalimentaria, Vol. 6, Page No. 23 – Page No. 25, (1998)

[20] Khanahmadi, Soofia, Yusof, Faridah, Amid, Azura, Mahmod, Safa, Senan, Mahat and Khairizal, Optimized preparation and characterization of CLEA-lipase from cocoa pod husk. Journal of Biotechnology. Vol. 202, Page No. 153 – Page No. 161, (2015)

[21] Lehmann, Silva, Steiner, Nehls, Zech, and Glaser. Nutrient availability and leaching in an archaeological Anthrosol and a Ferralsol of the Central Amazon basin: Fertilizer, manure and charcoal amendments. Plant Soil, (Issue 249): Page No. 343 – Page No. 357, (2003b)

[22] Lehmann and Joseph, Biochar for environmental management: an introduction. Science and Technology, Earthscan, London. Page No. 1 – Page No. 12, (2009)

[23] Lehmann, Rilling, Thies, Masiello, Hockaday, and Crowley, "Biochar effects on soil biotan- A review," Soil Biology and Biochemistry, Vol. 43 (Issue 9): Page No. 1812 – Page No.1836, (2011)

[24] Lu, Wang, Qin, Wang, Han, and Zhang, Multivariate and geostatistical analyses of the spatial distribution and origin of heavy metals in the agricultural soils in Shunyi, Beijing, China. Science of The Total Environment, Vol. 425 (Issue 0): Page No. 66 – Page No. 74, (2012)

[25] McElligott. Biochar amendments to forest soils: effects on soil properties and tree growth. University of Idaho, Page No. 1 – Page No. 94, (2011)

[26] McKendry. Energy production from biomass part 1: overview of biomass. Bioresource Technology, Vol. 83 (Issue 1), Page No. 55 – Page No. 63, (2002)

[27] Michailides, Ogawa, and Ferguson,

Investigations on the correlation of fig endosepsis on Calimyrna fig with caprifig infestations by Fusarium moniliforme. Annual Fig Research Reports. Carlifornia Fig Institute, Fresno. Vol. 25, (1988)

[28] Mukherjee, Zimmerman, Hamdan, and Cooper: Physicochemical changes in pyrogenic organic matter (biochar) after 15 months of field aging, Solid Earth, Vol. 5, Page No. 693 – Page No.704, (2014)

[29] Nde Divine Bup. Class course on sustainable and renewable energy resources. (2015)

[30] Nigussie, Kissi, Misganaw and Ambaw, Effect of biochar application on soil properties and nutrient uptake of lettuces grown in chromium polluted soils, American-Eurasian Journal of Agricultural and Environmental Science Vol. 12 (Issue 3): Page No. 369 – Page No. 376 (2012)

[31] Novak. Characterization of designer biochar produced at different temperatures and their effects on a loamy sand. Annals of Environmental Science Vol 3, Page No. 195 – Page No. 206 (2009)

[32] Nyasse, Lima, Xing, Gaskin, Steiner, Das, Ahmedna,

[33] Rehrah, Watts, Busscher and Schomberg. Etude de la diversite de Phytophthora megakarya et caracterisation de la resistance du cacaoyer (Theobroma cacao L.) a cet agent pathogene. PhD thesis, Institut National Polytechnique of Toulouse France. Page No. 173 – Page No.177 (1997)

[34] Paz-Ferreiro, Lu1, Fu1, Méndez, and Gasco. Use of phytoremediation and biochar to remediate heavy metal polluted soils. Solid Earth, Vol. 5, Page No. 65 – Page No. 75, (2014)

[35] Ronsse, Hecke, Dickinson, Prins, Production and characterization of slow pyrolysis biochar: influence of feedstock type and pyrolysis conditions. Global Change Biology and Bioenergy, Vol. 5, Page No. 104 – Page No. 115, (2013)

[36] Ronsse, Puttemans, Coxon, Goble, Wagemans, Wenderoth, Swinnen. Motor learning with augmented feedback: modality-dependent behavioral and neural consequences. Cerebral Cortex , Vol. 21 (Issue 6): Page No. 1283 – Page No.1294 (2011)

[37] Simon, Meggyes, and Tünnermeier. Groundwater remediation using active and passive processes. Advanced groundwater remediation: Active and passive technologies. Federal Institute for Materials Research and Testing (BAM), Unter den Eichen, Page No. 283 – Page No. 302. (2015)

[38] Steinbeiss, Gleixner, Antonietti, Effect of biochar amendment on soil carbon balance and soil microbial activity. Soil Biology and Biochemistry Vol. 41, Page 1301 – Page 1310, (2009)

[39] Teixido, Pignatello, Beltran, Granados, Peccia, Speciation of the ionizable antibiotic sulfamethazine on black carbon (biochar). Environmental Science Technology. Vol. 45 (Issue 23): Page No. 10020 – Page No. 10027, (2011)

[40] Tighe, Lockwood, and Wilson, Adsorption of antimony (V) by floodplain soils, amorphous iron (III) hydroxide and humic acid. Journal of Environmental Monitoring, Vol. 7 (Issue 12): Page No. 1177 – Page No. 1185, (2005)

[41] Uchimiya, Wartelle, Klasson, Fortier, Lima, Influence of pyrolysis temperature on biochar property and function as a heavy metal sorbent in soil. Journal of Agricultural and Food Chemistry. Vol. 59 (Issue 6): Page No. 2501 – Page No. 2510, (2011)

[42] Uchimiya, Chang, and Klasson Screening biochars for heavy metal retention in soil: Role of oxygen functional groups. Journal of Hazardous Material, 2011c. Vol. 190 (Issues 1-3), Page 432 – Page No. 444, (2011c)

[43] Vriesmann, Teófilo, and de Oliveira Petkowicz, Extraction and characterization of pectin from cacao pod husks (Theobroma cacao L.) with citric acid, LWT. Food Science and Technology, Vol. 49 (Issue 1): Page No. 108 – Page No. 116, (2011)

[44] Wang, Gao, Zimmerman, Yuncong, Lena, Willie, Physicochemical and sorptive properties of biochars derived from woody and herbaceous biomass. Chemosphere, Vol. 134, Page No. 257 – Page No. 262, (2015)

[45] Warnock, Lehmann, Kuyper and Rillig, Mycorrhizal responses to biochar in soil - Concepts and mechanisms. Plant and Soil. Vol. 300 (Issues 1-2): Page No. 9 – Page No. 20 (2007)

[46] Warren, Alloway, Lepp, Singh, Bochereau, and Penny, Field trials to assess the uptake of arsenic by vegetables from contaminated soils and soil remediation with iron oxides. Science of the Total Environment, Vol. 311 (Issue 1): Page No. 19 – Page No. 33, (2003)

[47] Xu, Lou, Luo, Cao, Duan, Chen, Effect of bamboo biochar on pentachlorophenol leachability and bioavailability in agricultural soil. Science of the Total Environment. Vol. 414, Page No. 727 – Page No. 731, (2012)