PRODUCTION, CHARACTERISATION AND QUALITY ASSESSMENT OF BIOCHAR

by

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THESIS

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DECLARATION

I hereby declare that this thesis entitled **"PRODUCTION, CHARACTERISATION AND QUALITY ASSESSMENT OF BIOCHAR"** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma associateship fellowship or other similar title, of any other University or Society

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Ammu Punnoose

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ABBREVIATIONS

BD - Bulk Density
CEC Cation Exchange Capacity
CRD - Completely Randomised Desigin
DAT - Days after Transplanting
FYM - Farm Yard Manure
GHG - Green House Gas
IARI - Indian Agricultural Research Institute
KAU - Kerala Agricultural University
MSL - Mean Sea Level
NS - Non Significant
OC - Organic Carbon
PC - Pine Chip
PL Poultry Litter
POP Package of Practices
PPNMU - Plant Protection and Nursery Management Unit
Sig - Significant
WHC -Water Holding Capacity

INTRODUCTION

1. INTRODUCTION

Crop residue management is one of the emerging problems in agriculture sector Crop residues in fields can cause considerable crop management problems as they accumulate in surplus Estimated total amount of crop residues in India is 91 141 Mt (IARI 2012) Composting is a viable option for crop residue management Composting of plant twigs and woody plant residues becomes difficult as it takes longer time for decomposition In such cases farmers do crop residue burning Residue burning traditionally provides a faster way to clear the agricultural field for land preparation and planting However in addition to loss of valuable biomass and nutrients biomass burning leads to release of toxic gases including GHGs like carbon dioxide and methane Efficient use of biomass by converting it as a useful source of soil amendment/nutrients is one way to manage soil health and fertility

Conversion of crop residue biomass into biochar and using the char as a soil amendment is a nascent approach and suggested as an alternative to composting and crop residue burning (Srinivasarao *et al* 2013) Biochar is produced by controlled burning of biomass with little or no oxygen which is known as pyrolysis Biochar holds 50 per cent of the biomass' carbon When biochar is applied to soil it can increase the soil's carbon content permanently and would establish a carbon sink for atmospheric CO_2 and that carbon is sequestered for centuries Thus biochar reduces the overall atmospheric CO_2 by removing carbon from the active cycle and sequestering it Biochar also enhances plant growth which takes more CO_2 out of the atmosphere Overall, these benefits make the biochar carbon negative as long as biomass production is managed sustainably In Indian conditions there is an immense scope for converting millions of tonnes of crop residues which are not used as fodder or fuel into biochar and use the same for enriching soil carbon (Srinivasarao *et al* 2013)

Biochar has been shown to be very beneficial in highly weathered tropical soils, soils with low pH, or soils with low cation exchange capacity The properties of biochar depend on the agricultural feedstock that is being pyrolized just as compost properties depend heavily on the original material being composted Biochar has the potential to increase the conventional agricultural productivity by stabilizing soil organic matter The use of biochar as soil amendment is proposed as a new approach to mitigate man-induced climate change along with improving soil productivity The central quality of biochar that makes it attractive as a soil amendment is its highly porous structure, potentially responsible for improved water retention with increased soil surface area (Srinivasarao *et al*, 2013)

Research information on the use of biochar in Indian agriculture is scanty Very few reports are available on production, characterization and use of bio char as a soil amendment The present study is proposed against this backdrop with the broad aim to produce biochar from crop residue and to study the effect of bio char on the performance of crops If it proves to be successful, the widespread use of biochar to improve soil fertility or to reduce carbon emissions could have a dramatic impact on our society and on agriculture world wide Taking all these into account the present study was planned with the following objectives

(1) To produce biochar from crop residues and to assess its characteristics

(2) To study the effects of biochar on crop growth

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

Biochar application has received a growing interest as a sustainable technology to improve highly weathered or degraded tropical soils (Lehmann and Rondon 2006) In India, about 435 98 million tons of agro residues are producing every year out of which 313 62 million tons are surplus These residues are either partially utilized or un-utilized due to various constraints (Murali *et al*, 2010) and can be effectively utilised through biochar production Numerous recent studies have shown that biochar application can enhance soil C stock, soil fertility, and crop yields (Kimetu *et al*, 2008, Major *et al*, 2010, Van Zwieten *et al*, 2010) According to Laird (2008), the pyrolysis-biochar platform was fundamentally a vision for simultaneous production of renewable bioenergy, sequestration of large amounts of C in soils, and the enhancement of soil quality, water quality and agricultural productivity Research results available on biochar production, its characteristics and its effect on crop performance are reviewed in this chapter

2 1 PRODUCTION OF BIOCHAR

Charcoal is created both naturally as a result of vegetation fires and intentionally by humans in burn pits and hand made structures When charcoal is made for the purpose of adding it to soil as an amendment it's called biochar Biochar is a carbon rich product obtained when organic biomass is heated under limited or without oxygen conditions (Lehmann, 2007) Despite the good things that biochar can do for soils, making charcoal in the traditional method is not an environmentally friendly practice Archaeological evidence suggests that ancient people piled and covered wood in earthern pits, then burned it slowly with limited air This method, still used today in developing countries, creates considerable smoke and releases half the carbon dioxide (CO_2) in the original biomass along with other greenhouse gasses (GHG's) This practice is neither healthy for people nor the atmosphere above all, the entire heat energy is wasted

The process of carbonization was as old as civilization itself (Brown 1917) As long as human history had been recorded, heating or carbonizing wood for the purpose of manufacturing biochar had been practiced (Emrich, 1985) Klark (1925) reported that according to the writings of Theophrastus the Macedonians obtained wood tar from burning biochar in pits Ponamperuma (1982) observed that the use of rice straw and rice husk as feedstock for biochar has been practiced for a long time

According to Bridgwater (1994) pyrolysis referred to the process of thermo chemical decomposition of organic material at elevated temperatures in the absence of oxygen Biomass derived black carbon or biochar, was produced through burning at 300 to 500^0C under partial exclusion of oxygen (Antal and Gronli 2003) The result was a highly aromatic organic material with carbon concentrations of about 70 to 80 percent (Lehmann *et al* 2002) Today, biochar is produced using pyrolysis that is, biomass is super heated in the absence of oxygen at high temperatures (350-700°C) in specially designed furnaces Madison (2010) reported that among production methods slow pyrolysis appears to be the optimal process for maximizing biochar output Demirbas (2004) defined pyrolysis as the temperature driven chemical decomposition of biomass without combustion and also noted that in commercial biochar pyrolysis systems, the process occurs in three steps first, moisture and some volatiles are lost, second unreacted residues are converted to volatiles, gasses and biochar and third there was a slow chemical rearrangement of the biochar Graetz and Skjemstad (2003) observed that at the instant of burning, the biomass carbon exposed to fire has three possible fates The first, and least possible fate of biomass exposed to fire is that it remains un burnt The other two possible fates are that it is either volatized to carbon dioxide or numerous other minor gas species, or it is pyrolysed to biochar There are many ways to achieve this result A sustainable model of biochar production primarily uses waste biomass such as greenwaste from municipal landscaping forestry or agriculture (for example bagasse) McClellan *et al* (2007) reported that analysis of several such charcoals revealed variation in quantities of undesirable tars, resins and polycyclic aromatic hydrocarbons (PAH) and typically, lower adsorption capacities, thus lessening their ability to improve soil quality The pyrolysis platform had been proposed as a potentially sustainable means for processing cellulosic biomass to produce renewable energy products (Lehmann, 2007, Laird 2008) According to Madison (2010) large production systems uniform feedstocks and tightly controlled application regimes were apt to be more reliable from a monitoring and verification standpoint Though there has been a great deal of interest in small biochar production systems stemming from long standing efforts to introduce more efficient cook stoves in the developing world smaller, dispersed systems will be much more difficult to characterize and monitor and monitoring and verification challenges will be difficult to overcome As a result, small systems should likely not be thought of as frontline tools to combat climate change

2 1.1. Effect of temperature

Maximum heating temperature and heating rate have a strong influence on the retention of nutrients as does the original composition of the feedstock Stability of biochar critically depends on the production procedure Kawamoto *et al* (2005) found greater stability of charcoal produced at 400° C than 1000° C Surface of biochars produced under high temperature were less hydrophilic (Cornelissen *et al* 2005) Effect of temperature had led to suggestions that biochar created at low temperature may be suitable for controlling the release of fertilizer nutrients (Day *et al*, 2005) while high temperatures would lead to a material analogous to activated carbon (Ogawa *et al* 2006) The optimum temperature for biochar production was around 500°C (Lehmann, 2007) Gaskin *et al* (2008) found that feedstock nutrients (P K Ca, Mg) were concentrated in the biochar and were significantly higher in the biochars produced at 500°C Unlike the carbon found in most organic matter biochar carbon was chemically altered during the heating process and form into benzene type ring structure that are very resistant to attack by microorganisms

(Karve *et al,* 2011) Ahmad *et al* (2012) found out that rice husk biochar produced under temperatures between 500 and 600^0C showed a noticeable increment in Si, Ca K and Mg content

2.1.2. Recovery of biochar

Biochar could be produced at scales ranging from large industrial facilities down to the individual farm (Lehmann and Joseph 2009) and even at the domestic level (Whitman and Lehmann, 2009), making it applicable to a variety of socioeconomic situations Biochar produced from technologies including gasification and pyrolysis which yield between 2 and 35 per cent by weight of the biomass In a modified method, char production was done by pyrolysis kiln (Venkatesh *et al* 2010) Kammen and Lew (2005) reported that biochar yield was different for different kilns and pit method yield 12 5-30 per cent, mound yield 2-42 per cent and brick kiln yield 12 5 33 per cent of feedstock Current biochar production yield a mere 20 per cent of the original biomass it can be estimated that more than 220 million tons of biomass was processed to produce the world s supply of biochar annually (Baker 1985) By tapping into the vast waste reserve of the world enhanced biochar reserve technology with high grade energy recovery system can find a new application and the biochar industry can make one of the most important contributions to mankind by helping to provide for the energy needs of the future while helping to sequester carbon (Levine, 2010)

2 2 CHARACTERISATION OF BIOCHAR

Biochar had been widely accepted as a potential alternative which currently being suggested to overcome soil infertility problems (Woolf *et al* 2010) Several techniques are used for characterisation of biochar The properties of biochar are governed by its physical and chemical constituents According to (Ahmad *et al*, 2014 , Uchimiya *et al* 2012) the properties of biochars depends on the feedstock type, pyrolysis temperature and residence time Biochars could be produced from a range of organic materials and under different conditions resulting in products of varying properties (Baldock and Smernik, 2002 Nguyen *et al* 2004, Guerrero *et al*, 2005) Sohi *et al* (2010) observed that the form and size of the feedstock and pyrolysis product may affect the quality and potential uses of biochar and also reported that biogeochemical characterization of biochar helps in determining the agronomic importance as well as impact on soil process Some workers have reported seven key properties for the evaluation of biochar *ie* pH content of volatile compounds ash content, water-holding capacity bulk density, pore volume, and specific surface area (Okimori *et al*, 2003, Sohi *et al*, 2010) More studies have shown that biochar could improve nutrient retention and cation exchange capacity, decreasing soil acidity, improved soil structure, and increase crop yield Size of biochar particles and how it is produced, affect performance when first applied Adsorption capacity of biochar is an important factor in determining how biochar will perform The strong resistance of biochar to microbial decomposition and hence its continued persistence in the soil ensure that the benefits of biochar application would be long term Bornermann *et al* (2007) claimed that the surface area, porosity, nutrient content and charge density all change in relation to the temperature of biochar formation Rajapaksha *et al* (2014) reported that biochar had been applied to improve soil quality, enhance C sequestration and immobilize contaminants

2.2.1. Physical characterization

2.2.1.1. *Surface area and porosity*

Physical structure of biochar is generally characterised by scanning electron microscopy (SEM) Sohi *et al* (2010) reported that the macroporous structure (pores of approximately 1 mm diameter) of biochar produced from cellulosic plant material inherits the architecture of the feedstock and was potentially important to water holding and adsorption capacity of soil (Day *et al* 2005) Pyrolysis temperature is the main regulating factor which governs surface area of biochar Day *et al* (2005) also reported that increase in temperature from 400 to 900^0C increased surface area of biochar from 120 to 460 m^2/g Increasing the porosity of soil to water incident at the surface biochar can reduce the runoff of agriculture inputs such as nitrates as well as suppressing N_2O and CH_4 emission from the soil to atmosphere (singh *et al*, 2010) The improvements in crop productivity were related to increased soil water permeability and plant water availability due to porous structure of biochar (Asai *et al* 2009) Warnock *et al* (2007) proposed that the physical structure of the feedstock mainly its pore size which greatly determines surface area water retention, and biological utilization of the biochar produced, was essentially locked into form during 'thermal modification' While a greater proportion of micro-pores may yield a higher surface area, and thus greater nutrient retention capability, many soil microorganisms are too large to utilize such small spaces and benefit from some amount of larger pore sizes The Biochar of *Prosopis* had a pore space of about 48 per cent (Shenbagavalli and Mahimairaja 2012) In terms of increasing plant growth biochar with various pore sizes may be best suited to enhance the physical chemical and biological characteristics of soils Yu *et al* (2006) had suggested that the porous structure of biochar can explain its impact on soil water holding and adsorption capacity

2 2.1.2. *Water holding capacity*

Studies state that there are several possibilities for improved irrigation efficiency (Wallace, 2000) however, there are concerns that in the decades ahead water withdrawals for irrigation cannot be significantly increased because of water stresses and that the lack of water available for irrigation will impede growth in global food production (Oki and Kanae, 2006) Novak *et al* (2009) observed that biochar addition to soil in non irrigated regions might increase moisture available for crops reducing the chances for water stress between rainfall events Major *et al* (2009) hypothesized that biochar addition would increase water holding capacity (WHC), since organic amendments generally increase WHC and biochar has a high capacity to retain water due to high amount of small pores If this enhanced WHC increased water availability to plants it could also have beneficial effect on crop yields Biochar had high total porosity and it can both retain water in small pores and thus increase WHC and let the water flow through the larger pores after heavy rain from topsoil to deeper soil layers (Asai *et al* 2009) Mulcahy *et al* (2009) noticed that due to its porous structure biochar contained water up to 4 5 times its initial dry weight and Brockhoff *et al* (2010) reported that as a consequence when a large fraction of biochar was incorporated into the soil the overall water holding capacity was expected to increase Purakayastha *et al* (2013) found that the water holding capacity of wheat biochar was the highest (561%) followed by maize biochar (456%) Karhu *et al* (2010) in their study found that application of biochar in agricultural soils increased soil water holding capacity by 11 per cent The Biochar of *Prosopis* had high water holding capacity of 131 per cent (Shenbagavalli and Mahimairaja 2012) Southavong *et al* (2012), observed an improvement in water holding capacity from 27 4 % to 39% when biochar applied as soil amender Borchard *et al* (2014) reported that the slow-pyrolysis charcoal increased the water holding capacity of the soil by about 20 per cent Olmo *et al* (2014) during the experiment, noticed the highest soil moisture in biochar-treated plots from 8 to 40 per cent higher than the control plots Jha *et al* (2010) showed that the water holding capacity varies with material used for the biochar production

2.2.1.3. *Bulk density*

According to Ueckert *et al* (1978), bulk density was one of the most important site characteristic affecting rainfall infiltration and Oguntunde *et al* (2008) found a decrease in soil bulk density after biochar additions Decreased soil bulk density increased soil porosity and soil aeration and then had a positive effect on root and microbial respiration Rogovska *et al* (2011) and Laird *et al* (2010) reported that biochar was a low density material that reduced soil bulk density and thereby increased water infiltration root penetration and soil aeration Purakayastha *et al* (2013) observed that the bulk density of rice and wheat biochar prepared at 400°C was comparatively lower than the maize and pearl millet biochar Pastor Villegas *et al* (2006) found that the bulk densities of biochars made from different types of woods processed in different types of traditional kilns ranged from 0 30 gcm ^{3} to 0 43gcm ^{3} The biochar of *Prosopis* had a bulk density of 0 45 Mgm^{3} (Shenbagavalli and Mahimairaja 2012) Lower bulk density in biochar treated plots had the potential to reduce the tensile strength of mineral soils eventually leading to reduced tillage costs

2.2 2. Chemical characterisation

Brockhoff *et al* (2010) found that biochar additions to soil had been shown to add nutrients and influence nutrient leaching and availability Lakaria *et al* (2012) observed variations in nutrient composition of biochars formed under varying pyrolitic temperature and duration Nutrient properties and their availability after the biochar is incorporated into the soil, however were greatly influenced by feedstocks and pyrolysis parameters used for the production of the biochar (Amonette and Joseph 2010)

2.2.2.1. *pH of biochar*

Novak *et al* (2009) claimed that biochar was commonly alkaline, and thus could be used as a soil amendment to neutralize soil acidity and increase soil pH The pH values of biochar at different pyrolysis temperature ranged from 9 2 to 10 4 and increased with pyrolysis temperatures (Feng *et al*, 2012) Southavong *et al* (2012) observed an increase in Soil pH from 4 7 to 6 6 due to addition of biochar Topoliantz *et al* (2002) found that pH frequently increased through soil applications of biochar by one pH unit Alkaline biochar can improve acidic tropical soils and thereby improve biomass yields (Chan *et al* 2008) Biochar produced from different feedstock had pH ranged from 8 2- 13 0 (Jha *et al*, 2010) Zhang *et al* (2010) found that the wheat straw biochar had a pH (H_2O) of 10 4 Sukartono *et al* (2011) characterised the coconut shell biochar and noted that it had a pH of 9 9 Kuwagaki and Tamura (1990) observed a corresponding impact on the pH of the biochar from 7 6 at 310°C to 9 7 at 850°C

2.2.2.2 *Cation exchange capacity*

According to Xie *et al* (2015) the cation exchange capacity (CEC) of most biochars was relatively high, in part due to their negative surface charge and resultant affinity for soil cations including most heavy metals (e g Pb^{2+}, Cr^{3+}) Cheng *et al* (2006) observed that as biochar surfaces are oxidized on contact with air and water, the effective cation exchange capacity (ECEC) of biochar increases with time after being incorporated into the soil CEC varies significantly between terrestrial derived biomass from different feedstocks ranging from 4 5 to 40 cmol/kg (Bird *et al*, 2011) Gaskin *et al* (2008) noticed that the cation exchange capacity was significantly higher in biochar produced at lower temperature CEC frequently increased through soil applications by up to 40 per cent of initial CEC (Mikan and Abrams, 1996 , Topoliantz *et al* 2002) Masulili and Utomo (2010) reported the characteristics of rice husk biochar and noted a CEC of 17 57c mol kg^{1} The improvements in crop productivity were related to increased soil CEC (Steiner *et al*, 2007) Sukartono *et al* (2011) characterised the coconut shell biochar and noted that it had a CEC of 11 78 cmol kg^{1} According to McLaughlin *et al* (2009) the most important measures of biochar quality appear to be high adsorption and cation exchange capacities and low levels of mobile matter (tars resins, and other short lived compounds) Cheng *et al* (2008) observed that over time adsorption capacity of biochar decreases, whereas its cation exchange capacity increases In a key multiparameter study, Cheng *et al* (2008) showed that properties that become enhanced over time are CEC and pH, as a result of gradual surface oxidation The CEC of biochar amended soil was strongly dependent on the age and surface functional properties and charge of the applied char (Kookana *et al*, 2011)

2.2.2 3. *Total carbon*

Total carbon content in biochar materials produced from different feedstock varied from 33 0 to 82 4 per cent (Jha *et al* 2010) According to Srinivasarao *et al* (2013) invariably, total carbon content of biochar increased with the increase in pyrolysis temperature Gaskin *et al* (2008) reported that the C content of the biochar ranged from 40 per cent in the poultry litter (PL) biochar to 78 per cent in the pine chip (PC) biochar Purakayastha *et al* (2012) found that increase in pyrolysis temperature from 400°C to 600°C decreased the volatile and N component of biochar, while it increased ash and fixed carbon content One exception to this trend was observed in corn stalk-derived biochar Its total carbon content decreased with pyrolysis temperature, from 56 8 per cent at 300^{0}C to 48 4 per cent at 500^{0}C reported by Feng *et al* (2012) Zhang *et al* (2010) found that the wheat straw biochar had 46 7 per cent C Masulili and Utomo (2010) reported the characteristics of rice husk biochar and noted a carbon content of 18 72 per cent Sukartono *et al* (2011) characterised the coconut shell biochar and noted that it had a carbon content of 80 59 per cent

2 2.2.4. *Elemental composition in biochar*

Masek (2009)found that biochar was not a pure carbon but rather mix of carbon (C), hydrogen (H) oxygen (O) nitrogen (N) sulphur (S) and ash in different proportions Chan *et al* (2007) reported that biochars could be produced from wide range of feedstocks such as animal manure coconut shell rice husk, and other crops waste Biochars from plant materials were often low in nutrient content, particularly N According to Chan *et al* (2008) the biochar was alkaline in nature, high in total C but low in total N (1 3 g/kg) with C/N ratio 200 1 and extremely low in mineral nitrogen (<0 5 mg/kg) According to Laird *et al* (2010) the biochar amendments significantly increased total N (up to 7%) organic C (up to 69%), and Mehlich III extractable P, K Mg and Ca Biochar contained appreciable quantity of Ca, Mg, K and P Due to its high pH and appreciable amount of Ca and Mg, biochar acts as liming material in acid soils Zhang *et al* (2010) found that the wheat straw biochar contained N (0 59%), Ca (1 %), Mg (0 6%), Fe (0 4%) and K (2 6%) Masulili and Utomo (2010) reported the nutrient contents of rice husk biochar as K (0 20%), Ca (0 41%) Mg (0 62%) and Na (1 40%) DeLuca *et al* 2009 reported that N and S compound tends to volatize at a temperature above 200 and 375°C respectively So, biochar produced at higher temperature showed depletion of N and S whereas, K and P volatilized between 700 and 800°C DeLuca *et al*, 2009 also noted that high temperature biochars (800°C) tended to had a higher pH electrical conductivity (EC) and extractable NO^{3} while low-temperature biochars (350°C) had greater amounts of extractable P, ammoniacal N and phenols Shenbagavalli and Mahimairaja (2012) found that the NPK contents of Biochars varied from 8 5 to 1 12 g kg^{1}, 0 6 to 3 2 g kg^{1} and 2 4 to 29 g kg^{1} respectively Sukartono *et al* (2011) characterised the Coconut Shell Biochar and noted that it contained N (0 34%), P(0 10%) K (0 84%) Ca (0 04%), Na (0 12%), and Mg (0 06%)

2 3 EFFECT ON CROP PRODUCTION

Beneficial effects of biochar in terms of increased crop yield and improved soil quality had been reported Ability of many biochars to retain nutrients develops over time so it was possible to not saw any differences in the first cropping season after application (Cheng *et al* 2006 2008, Major *et al* 2010) Similarly, a single biochar application had been observed to provide benefits for crop nutrition for several years after an initial neutral year Major *et al* (2010) showed that maize increased to about 140 per cent during the fourth year of biochar application and this was attributed to increased pH and nutrient retention in soil Olmo *et al* (2014) reported that in wheat the plants in biochar treated plots showed higher relative growth and net assimilation rates, above ground biomass and yield than those in control plots Anderson (2011) observed a 39 per cent increase in tomato yield and 27 per cent stalk width increase compared to control

Haefele *et al* (2011) reported that on a poor soil where the crop also suffered from water stress application of carbonized rice husks increased yields by 16 to 35 per cent over the control

Yield increases had frequently been reported that were directly attributable to the addition of bio char over a control without bio-char (Lehmann *et al* 2003) Yilangai *et al* (2014) observed that tomato yield from beds treated with charcoal and covering was 76 per cent higher than the yield from beds without charcoal and covering Rogovska *et al* (2014) observed that maize grain and biomass yields were increased by 11 to 55 per cent in response to biochar amendments during the first year after biochar application on soil following very high stover application rates presumably because biochar mitigated adverse effects of allelochemicals released from the decomposing maize residue

The effect of bio char on plant productivity depended on the amount added According to Lehmann and Rodon (2006) progressive growth improvement with greater bio char applications was seen with comparatively low application rates of 0 4 to 8 t C ha^{1} Significant improvements in productivity could be observed, ranging from 20 to 220 per cent (biomass production equal to 120 to 320 per cent of the control) Liu *et al* (2014) observed that when the amount of biochar was 40 t ha^{-1}, rapeseed and sweet potato yields were increased by 36 02 and 53 77 per cent respectively Experiments proved that rates between 5 50 t/ha (0 5-5 kg/m^{2}) had often been used successfully While there was no recommended application rates for biochar biochar should be applied in moderate amounts to soil According to Major (2013) rates around 1% by weight or less had been used successfully so far in field crops Winsley (2007) reported that even low rates of biochar application could significantly increase crop productivity assuming biochar was rich in nutrients Lehmann and Rondon (2006) recorded that the application of higher amounts of biochar increased the carbon credit benefit, but, in nitrogen-limiting soils it could fail to assist crop productivity as a high C/N ratio leads to low N availability According to srinivasarao *et al* (2012) crop productivity benefits of higher biochar application rates could be maximized only if the soil is rich in nitrogen or if the crops were nitrogen-fixing legumes

Therefore, application of biochar to soils in a legume based (e g peanut and maize) rotational cropping system clovers and lucernes is more beneficial Several workers had reported that biochar applications to soils had shown positive responses for net primary crop production, grain yield and dry matter (Chan and Xu 2009 , Spokas et al 2009) Purakayastha (2010) reported that application of biochar prepared from wheat straw at 1 9 t/ha along with recommended doses of NPK (NPK 180 80 80) significantly increased the yield of maize in Inceptisol of IARI farm and this treatment was superior to either crop residue incorporation (CRI) or crop residue burning (CRB) In the case of pearl millet and rice, the yields with biochar were on par with those obtained either with CRI or CRB fertilizer

Most of the results of deliberate bio char additions to soil showed increasing crop yields with increasing additions up to very high loadings of 140Mg C ha^{-1} (Lehmann and Rondon 2006) Some experiments showed decreased biomass production and crop yields at high concentrations For example, beans (*Phaseolus vulgaris* L) grown with bio char additions of 60Mg C ha^{-1} exhibit yields similar to control plants without biochar additions (Rondon *et al*, 2004) Lehmann and Rondon (2005) also reported significant improvements of crop growth that with relatively small amounts of 2–5Mg C ha^{-1} of bio char

Studies in both tropical and temperate climates had demonstrated biochar's ability to increase plant growth reduce leaching of nutrients increase water retention, and increase microbial activity In a study done on a Colombian Oxisol (a soil type also found extensively in Hawai), total above-ground plant biomass increased by 189 per cent when biochar was applied at a rate of 23 2 tons per hectare (Major *et al*, 2005) Research indicated that both biological nitrogen fixation and beneficial mycorrhizal relationships in common beans (*Phaseolus vulgaris*) were enhanced by biochar applications (Warnock *et al*, 2007) Major *et al* (2005) reported that in Brazil occurrence of native plant species increased by 63 percent in areas where biochar was applied Studies had also shown that the characteristics of biochar most important to plant growth could improve over time after its incorporation into soil (Cheng *et al* 2006) Sun *et al* (2014) noticed that crop yields (oat) were not significantly different in the first year after biochar application, but in the second year, total yields of spring barley increased by 11 per cent Matsubara *et al* (2002) noted that biochar might a positive impact on plant resistance to disease due to its suppressive effect on soil pathogens, therefore indirectly increased crop productivity Rondon *et al* (2004) showed that carrots and beans grown on steep slopes and on soils with a soil reaction of less than pH 5 2 yielded significantly high by bio-char additions Southavong *et al* (2012) observed an increase in foliage yield of the water spinach after biochar addition

The economic optimum after biochar application could be gained through a gain in crop yield at the current or possibly higher rate of application in which case the net result would be higher per hectare yields

2 4 SOIL FERTILITY CHANGES

Biochar potentially influenced the soil-forming processes that governed the accumulation, transformation and translocation of soil constituents and hence in the long term, it modified soil pedogenic activity morphology and productivity (Richter, 2007) Sohi *et al* (2010) noticed that for biochar to serve a beneficial role in revitalizing nutrient impoverished soils, there should be a noted increase in the quantity of plant available nutrients and its nutrition retention capacity Atkinson *et al* (2010) found out that adding biochar to soils produced immediate effects on properties such as soil nutrition, water retention, or microbial activity, although these effects vary depending on soil type (Tryon 1948)

Lehmann and Rondon (2005) noticed that biological immobilization of inorganic N also aided in retaining N and in decreasing ammonia volatilization, due to the low N concentrations and high C/N ratios of biochars Further bio chars were very efficient adsorbers for dissolved NH_4^+ (Lehmann *et al*, 2002) NO^2 (Mizuta *et al*, 2004), PO_4^{3} (Beaton *et al* 1960), and other ionic solutes (Radovic *et al*, 2001) Additions of bio char to soil showed definite increase in the availability of major cations and P as well as in total N concentrations

(Lehmann *et al* 2003) The improvements in crop productivity was related to enhanced cycling of P and S (DeLuca *et al* 2009), and neutralization of phyto toxic compounds in the soil (Steiner *et al*, 2007) Longer-term benefits for nutrient availability included a greater stabilization of organic matter, concurrent slower nutrient release from added organic matter, and better retention of all cations due to a greater cation exchange capacity Higher nutrient availability for plants was the result of both the direct nutrient additions by the bio char and greater nutrient retention (Lehmann *et al* 2003)

2 5 BIOCHAR AND FERTILIZERS

Glaser *et al* (2001) reviewed a number of early studies conducted during the 1980s and 1990s These tended to show marked impacts of low charcoal additions (0 5 t/ha) on various plant species Higher rates seemed to inhibit plant growth In later experiments combination of higher biochar application rates alongside NPK fertilizer increased crop yield on tropical Amazonian soils (Steiner *et al*, 2007) and semi-arid soils in Australia (Ogawa *et al*, 2006) Yilangai *et al* (2014) noticed that application of biochar together with nitrogen fertilizer probably enhanced biochar effect on crop growth and yield This might be because biochar served as a carrier substrate for N which increases the effectiveness of biochar by retaining and preventing the leaching of N beyond the reach of plants Chan *et al* (2007) found that plant yield decreased when biochar was applied at 10 t/ha but increased when the biochar was applied with N fertilizer Chan *et al* (2008) also reported a 96 per cent increase in radish yield by application of biochar in a greenhouse experiment and suggested that this increased yield was largely due to the ability of biochar to increase N availability Studies by Tenenbaum (2009) found that a combination of biochar and fertilizer resulted in productivity increase of 60 per cent over fertilizer alone Experiment by Huang *et al* (2008) in rice showed that biochar application resulted in 23–27 per cent increase in fertilizer N uptake by rice plants and consequently

8–10 per cent increase in grain yield The increased N uptake was associated with a reduced fertilizer N loss by 9–10 per cent under biochar application

Charcoal acted as an adsorber and reduced N leaching in pot experiments (Lehmann *et al*, 2002, 2003) Steiner *et al* (2007) found that charcoal additions proved to sustain fertility if an additional nutrient source was given in a field trial Charcoal plus fertilizer improved plant growth and doubled grain production in comparison to the fertilizer without charcoal (Steiner *et al* 2008) Gunther (2007) explained that when the inner area of the charcoal was full of nutrients and soil micro-organisms, it would work as a sponge for nutrients, readily available to interact with the plant roots, keeping the nutrients away from leakage Therefore, the inner surface of the charcoal should be saturated with nutrients before or during its addition to the soil He further added that this could be done by mixing the charcoal, manure, urine or nitrogen fixed by leguminous plants before or during the addition to the soil

Application of synthetic N and P fertilizer on the biochar amended soils, by contrast, brought a significant yield response which was attributed to reduced leaching and hence more efficient use of applied nutrients was reported by Asai *et al* (2009) Several other studies reported similar positive interactions between biochar and fertilizers additions (Kimetu *et al* 2008 , Van Zwieten *et al* 2010) Asai *et al* (2009) showed that Char application for upland rice as amendment resulted in higher grain yields at sites with low P availability and improved the response to N and NP chemical fertilizer treatments

2 6 BIOCHAR AS AMENDMENT

Much of the interest on using biochar as soil amendment comes from studies of Amazonian soils where the presence of charcoal has led to significant improvements in soil quality and increases in crop yields These changes persisted for hundreds, if not thousands of years (Lehmann and Joseph, 2009) If the biochar is used as a soil amendment then the impact of biochar on soil quality, the ability of soils to retain plant available nutrients water holding capacity, crop yields, and C sequestration are just a few of the potential factors that will influence biochar quality

Characterization of any amendment is the first step to understand the mechanism of action Ameloot *et al* (2015) found that biochar amendment led to a lowered or equalized soil microbial activity and abundance Biochar would function as a substrate after 1 4 years of incorporation in the field Like any other organic amendments biochar could be applied to soil by different methods including broadcasting band application, spot placement deep banding etc Mixing of biochar with composts and manures reduced odors, and improved nutrient performance over time due to slower leaching rates Line trenching and backfilling lended itself to high biochar application rates in soil for carbon sequestration with increased agronomic performance of soils Though labor and carbon intensive, the combination of high saturation rates and improved agronomic productivity made the practice viable Biochar could enhance plant growth by improving soil chemical characteristics (i e , nutrient retention, nutrient availability) soil physical characteristics (i e , bulk density water holding capacity, permeability), and soil biological properties, all contributing to an increased crop productivity (Lehmann and Rondon, 2006 Yamato et al 2006) Glaser *et al* (2002) noticed that crop yields could be enhanced even more compared to control soils if charcoal amendments are applied together with inorganic or organic fertilizers

The results of the study conducted by Zhu *et al* (2014) implied that the liming effect of biochar improved plant growth through alleviating Al toxicity and P deficiency, especially in poor acidic red soils According to Lehmann *et al* (2003) the particle size of the bio-char appeared to play a minor role in its effect on soil fertility and crop production which simplified the application of the technology Mbagwu and Piccolo (1997) proposed that the application of charcoal can increase soil pH and decrease the Al concentration of acid soils which were the limitations to growth in tropical soils Charcoal had been shown to be a soil conditioner in many tropical and subtropical soils increasing exchangeable bases cation exchange capacity larger specific surface areas and nutrient availability, decreased soil bulk density and improved water holding capacity (Laird *et al*, 2010) Biochar amendments to agricultural soils had been shown to reduce nutrient leaching and to had positive effects on soil physical, chemical and microbiological properties (Lehmann *et al*, 2003)

Organic amendments such as cover crops mulches, compost or manure additions had been used successfully, but were short lived especially in the tropics, since decomposition rates were high therefore had to be applied each year to sustain soil productivity, according to Warnock *et al* (2007) compared biochar to other soil amendments The high surface area and porosity of biochar enabled it to adsorb or retain nutrients and water and also to provide a habitat for beneficial microorganisms to flourish

Biochar had been shown to benefit crop growth and yield and proved as promising material for use in agriculture However, as in the case for any soil amendment, its efficacy must be shown in a variety of cropping systems and optimal application rates have yet to be determined

2 7 NEGATIVE EFFECTS OF BIOCHAR

McClellan *et al* (2007) proposed that in most cases of decreased plant growth due to biochar application could be attributed to temporary levels of pH, volatile or mobile matter and/or nutrient imbalances associated with fresh biochar Biochar often had an initially high (alkaline) pH, which was desirable when used with acidic, degraded soils however if soil pH was too alkaline plants might suffer nutrient deficiencies "Mobile matter referred to tars resins and other short lived substances that remained on the biochar surface immediately after production and could inhibit plant growth (McLaughlin *et al* 2009) According to Hunt *et al* (2010), good production practices could decrease the amount of mobile matter in the biochar Microbial activity could decompose and transform the carbon rich mobile matter into nutrients for plants, however in the process, the microorganisms would require nitrogen and other soil elements rendering them temporarily unavailable for uptake by plants These transitional imbalances were corrected as mobile matter decomposers pH neutralizers and unavailable nutrients were released Borchard *et al* (2014) observed that increased application rate of biochar resulted in decreased plant biomass in the second and third year of the experiment, likely as a result of nutrient imbalances and N immobilization Kammann *et al* (2011) found that the large application rate of 200 t ha^{-1} biochar did not improve plant growth compared to 100 t ha^{-1}

Though several studies have reported significant increases in crop yield with biochar, a few studies reported negative or neutral effects of biochar on crop yield Results of studies from Schultz *et al* (2014) showed a negative effect on growth and yield of oat plant with application of biochar on soil Graber *et al* (2010) in their study in tomato noticed that biochar treatments positively enhanced plant height and leaf size, but had no effect on flower and fruit yield also yield decreases was observed in lettuce and corn (Deenik *et al* 2010) Asai *et al* (2009) observed that application of biochar without additional N fertilization resulted in both reduced plant uptake of N and a decreased in rice grain yield The authors speculated that a portion of the C in the applied biochar was available for microbial decomposition and this resulted in limited N immobilization in soils However growth depressions had been found in some instances (Mikan and Abrams 1996) The combination of returning biochars with high C/N ratios and abiotic buffering of mineral N might in some situations lead to low N availability to crops (Lehmann and Rondon, 2006)

In soils that already had a high organic matter content biochar showed little improvements in crop yield for the first year Biochar applied to cold climate soils takes longer to work Lehmann *et al* (2002) argued that char application might even limit soil N availability in N deficient soils due to the high C/N ratio specific to biochar and, therefore, it might reduce crop productivity at least temporarily

The production, transport and application of biochar had some safety concerns of which users should be aware, however if precautions were taken The primary concern for human and environmental was risk was the particulate matter

(PM), biochar dust and vapour fall as per the U S A Environmental Protection Agency (EPA) air quality standards (USEPA 2006)

The current application of biochar to soil was modelled after the Amazonian Terra Preta soils, which had higher soil fertility that to resulted from intentional biochar additions from 'slash and char" agricultural practices (Mann, 2005) However, biochar additions to soils had not uniformly resulted in soil fertility improvements Charcoal spots (historical charcoal production sites) in Zambian forests possessed slower plant regeneration rates than surrounding areas without biochar remnants (Chidumayo, 1988)

2 8 OTHER EFFECTS OF BIOCHAR ADDITION IN SOIL

In recent years, biochar attracted extensive attentions from environmental researchers due to its prominent benefit in contaminants elimination (Sun *et al*, 2011) Biochar played a great potential in the remediation, revegetation and restoration of contaminated soils (Freddo *et al* 2012) Due to the high specific area and several of functional groups (e g , amino carboxyl, and hydroxyl groups) (Liu *et al*, 2011) Mohan *et al* (2007) proposed that biochar could be used as a low cost adsorbent for organic pollutants and heavy metal removal from water Hence these properties could be used effectively to address some of the most urgent environmental problems including soil degradation and water pollution from agro-chemicals and climate change (Laird, 2008) Yang *et al* (2014) studied that biochar from *Alternanthera philoxeroides* had maximum adsorption capacity for Pb(II) was 257 12 mg/g which was 5 3 times of that of the activated charcoal Biochar acted as an additive for reducing the bioavailability and mobility of toxic trace metals (Uchimiya *et al* 2011) and as a contaminant mitigation agent (Beesley *et al*, 2010)

Because of its high surface area and high surface charge density (Liang *et al* 2006), biochar increased the ability of soils to retain nutrients and plant available water and reduced the leaching of nutrients and agricultural chemicals (Laird *et al*, 2010, Lehmann *et al*, 2003) and so biochar applications to soils had been shown to enhance soil and water quality Laird *et al* (2010) found that the plots receiving swine manure, the 20 g kg ^{1} biochar treatments reduced leaching of total N and total dissolved P by 11 and 69 per cent, respectively

In addition, biochars might alleviate the ramifications of removing crop residues (Lehmann *et al*, 2003) Laird (2008) also reported that it contained most of the nutrients that were in the biomass could release them slowly and was a liming agent

Biochars were very efficient adsorbers for hydrophobic organic pollutants (Accardi-Dey and Gschwend, 2002) Moresover biochar was a porous material showing good sorption properties for inorganic and organic pollutants Because of this, biochar could be applied for environmental remediation

Microbial diversity was altered in response to organic amendments (Khodadad *et al*, 2011) and some studies had reported increased microbial activity in soils enriched with biochar (Steiner *et al*, 2008) Ogawa (1994) reported that upon addition of biochar to soil for the first time mineralisation might be stimulated by the presence of an active fraction and associated soluble nutrients or labile carbon fractions It was noted that the physical structure of typical biochar products provided a secure environment for microbial colonies Already small amounts (7 9 t C ha $^{1)}$ of bio char in a highly weathered soil in the tropics significantly enhanced microbial growth rates when nutrients were supplied by fertilizer (Steiner *et al*, 2004) Apparently, bio char provided a suitable habitat for a large and diverse group of soil microorganisms Bio char was also able to serve as a habitat for extra radical fungal hyphae that sporulated in their micropores due to lower competition from saprophytes and it could therefore act as an inoculum for arbuscular mycorrhizal fungi (Saito and Marumoto, 2002) Woods *et al* (2008) reported to increase nitrogen uptake of the soil by up to 400% as a result of increased microbial activity after biochar addition

Biochar as a component of compost had synergistic benefits Biochar could increase microbial activity and reduce nutrient losses during composting (Dias *et al*, 2010) In the process, the biochar charged with nutrients covered with microbes, and reaction balanced, and its mobile matter content was decomposed into plant nutrients

Biochar had the potential to increase conventional agricultural productivity and enhanced the ability of farmers to participate in carbon markets beyond the traditional approach by directly applying carbon into the soil (McHenry 2009) Biochar could be applied along with other amendments like compost, manures or crop residues and it did not need to be applied when each new crop was established to provide benefits over time Biochar would be applied for agricultural profitability and/or carbon sequestration Thus, applying the material must not increase costs and/or CO_2 emissions beyond acceptable levels The benefits of adding charcoal to already fertile soils just were not great enough to justify the expense and effort of applying the charcoal As pointed out by Day *et al* (2004) biochar sequestered carbon in agricultural land as a way to combat climate change if the sequestered C had beneficial soil amendment and/or fertiliser values

Soil biochar applications offer the potential to stabilize some of the carbon fixed by terrestrial vegetation through photosynthesis and appeared to be a promising strategy for large scale, low cost carbon sequestration (Roberts *et al* 2010)

Little research has been published elucidating the mechanisms responsible for the reported benefits of the biochars on crop growth production, and soil quality Such understanding is essential for development of agricultural markets for biochars and for the future development of technology for the production of biochar products with improved quality and value

MATERIALS AND METHODS

3. MATERIALS AND METHODS

The present investigation entitled "Production, Characterization and Quality Assessment of Biochar" was conducted to produce biochar from crop residues, to assess its characteristics and to study its effect on crop growth. The details of materials and methods adopted for the study are briefly described below.

3.1 GENERAL DETAILS

3.1.1. Location

The experiment was conducted at PPNMU, Vellanikkara, Thrissur. The station is geographically located at 10° 31'N latitude and 76°13'E longitude. The experimental site lies at an altitude of 40 m above MSL. It is located 10Km away from Thrissur on the northern side of NH-47.

3.1.2. Weather and Climate

The area enjoys a typical humid tropical climate. The meteorological data prevailed during the investigation are given in Fig 1 and 2.

The weather prevailed during the cropping period were normal. The maximum and minimum temperature recorded during the cropping period were and 32.7 and 22.9^{0}C respectively. Relative humidity of 60.2 per cent was recorded. Rainfall of about 600, 215, 225, 85 and 9.6 mm was distributed during the month of August, September, October, November and December respectively. No rainfall was received during the months of January and February 2015.

3.1.3. Season

Biochar production using heap and drum method were carried out from August 2014 to December 2014. Effect of biochar on crop performance was studied from December 2014 to February 2015.

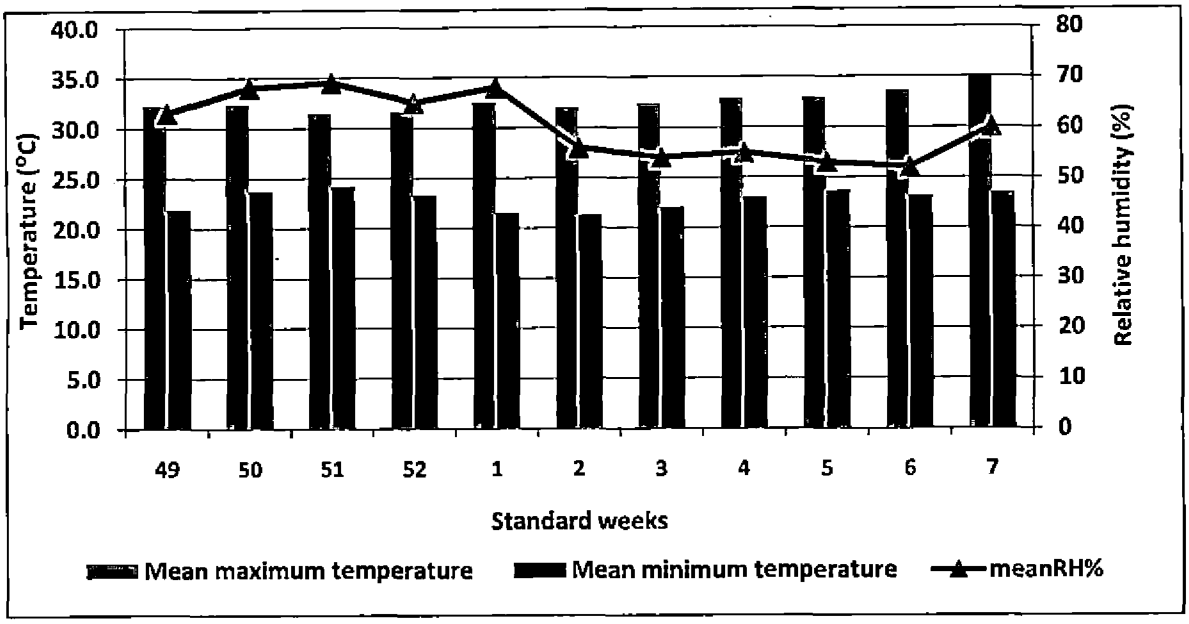

Fig.1 Mean weekly weather data of atmospheric temperature and relative humidity during crop period

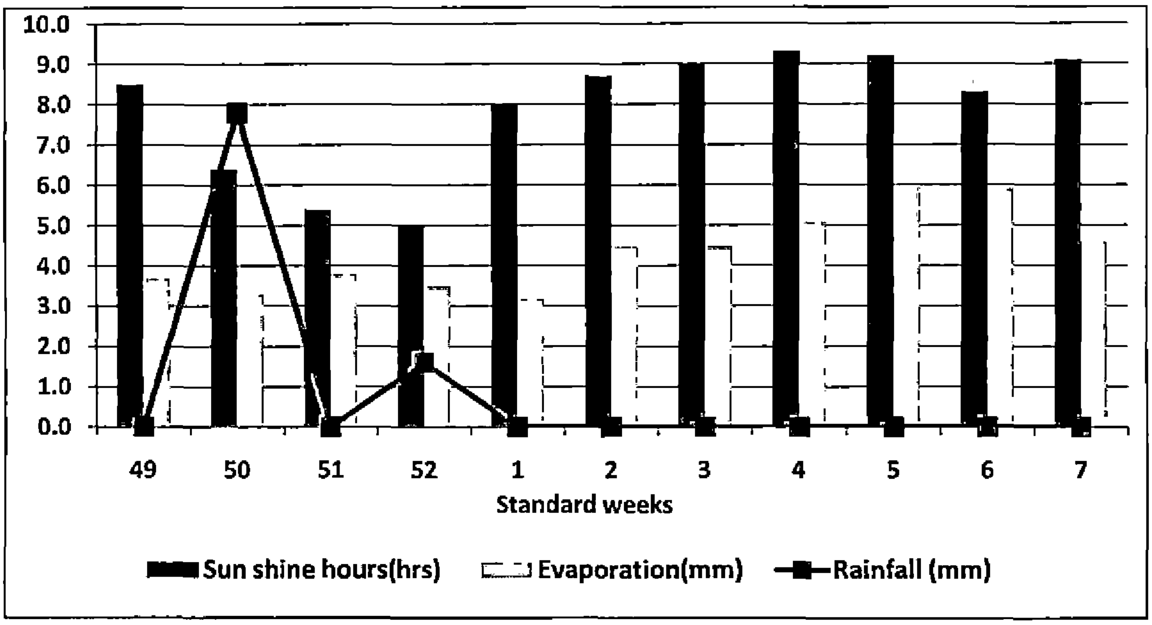

Fig.2 Mean weekly weather data of sunshine hours, evaporation and rain fall during crop period

3.2. MATERIALS USED

Experiment -1

3.2.1. Production of biochar

Woody wild growth, coconut petiole and herbal waste residue were the feedstock materials used for the biochar production (Plates. 1a-1c).

Woody wild growth

Woody wild growth was collected from Coconut Development Farm, which includes the undecomposable hard stems of *Gliricidia maculata, Citrus aurantium* (Kattu neeroli), *Macaranga peltata, Artocarpus heterophyllus* (Jack), *Caesalpinia sappan, Ficus hispida.* All these were cut into pieces of similar size and shade dried to facilitate uniform burning.

Coconut petiole

Coconut petiole of matured leaves were collected from the Coconut Development Farm and cut into small pieces and shade dried.

Herbal waste residue

Undecomposed waste left after the composting of herbal waste obtained from the Oushadi, Thrissur. Materials of similar size were sorted out and used for the biochar production.

The mineral nutrient content (%) of raw materials (biomass) are included in the table.1

Table 1. NPK content of materials used for biochar production

Materials	Mineral nutrients		
	N (%)	P (%)	K (%)
Woody wild growth	0.35	0.06	0.44
Coconut petiole	0.35	0.14	1.06
Herbal waste	0.52	0.23	0.14

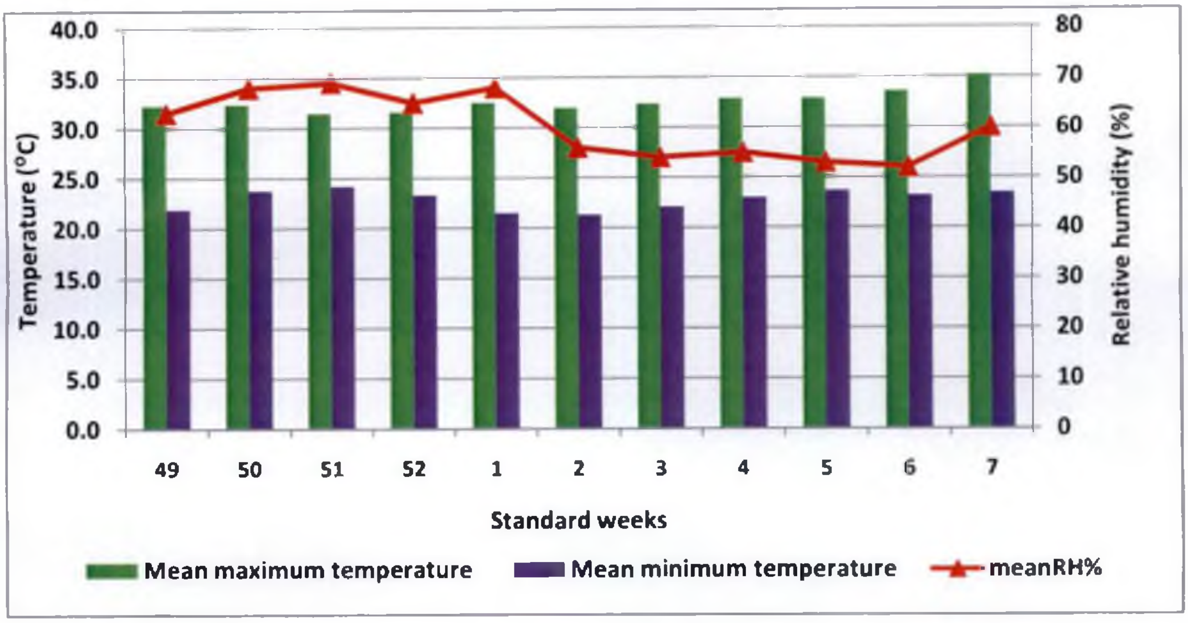

Fig.1 Mean weekly weather data of atmospheric temperature and relative humidity during crop period

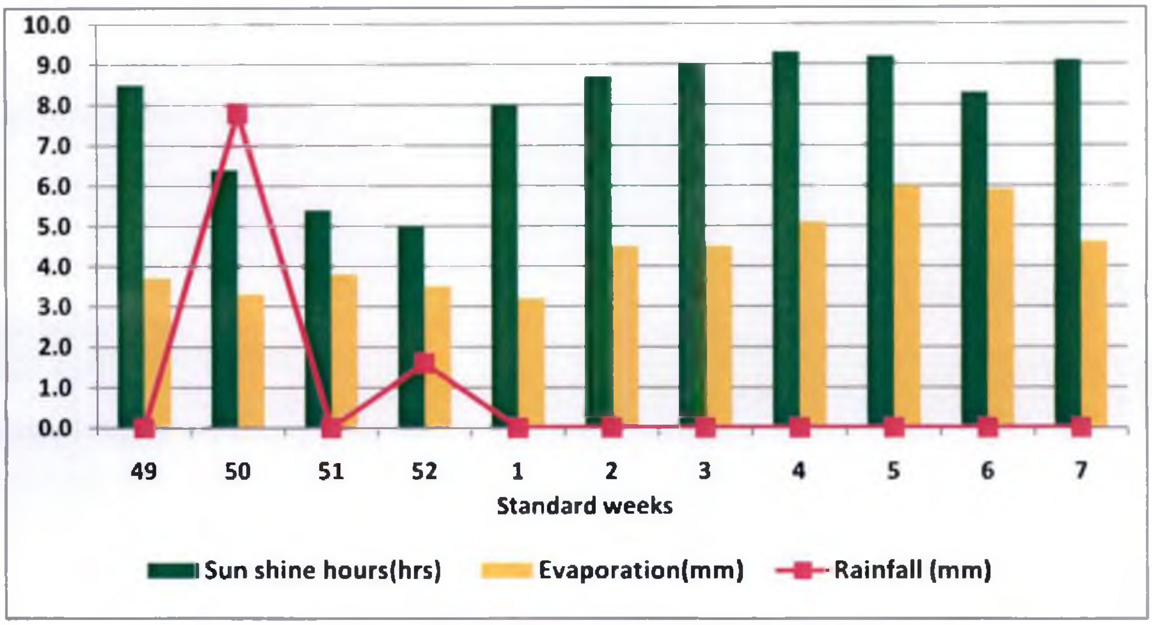

Fig.2 Mean weekly weather data of sunshine hours, evaporation and rain fall during crop period

Plates 1a-1c: Materials used for biochar production

Plate 1a. Woody wild growth

Plate 1b. Coconut petiole

Plate 1c. Herbal waste residue

Biochar production methods

Biochar was produced using two methods

1. Heap method

A kiln was fabricated for the heap method of biochar production. A pit of size 110"x 60"x 24" was taken. The pit was brick lined to get an inner dimension of 86"x 36" x 24". The pit was then divided in to two compartments of equal size using bricks for easy handling. The floor and top edge portion of the pit was cemented. A hole each of one brick size was given on the four sided of the top portion of the two compartments for easy escape of smoke. A door made of 4 mm iron sheet with 1"x1/4" ankler lining was fitted on the top of each compartments. The door was fixed in such a way that after igniting the materials filled in the pit, the closing of door facilitate anaerobic condition inside the pit. (Plates 2a -2f)

2. Drum method

In this method small metal drums of size 17"x 11" and large metal drums of size 36"x 21" were used to burn the biomass. (Plates 3a-3d)

Fuel materials used

Coconut husk, coconut shell, dried fronds, coconut spathe were used as the fuel materials for the production of biochar in drum method.

Experiment -2

3.2.2. *Effect of biochar on crop performance*

Crop and variety

Amaranth variety Arun was used for the study. Arun is a multi-cut, high yielding, red leaves and photo insensitive variety released by KAU .

Plates 2a-2f: Steps involved in the fabrication of kiln for heap method of biochar production

Plate 2a

Plate 2b

Plate 2c

Plate 2d

Plate 2e

Plate 2f

Plates 3a-3d: Materials used for drum method of biochar production

Plate 3a – Large drum

Plate 3b- Holes at the bottom

Plate 3c- Fuel materials

Plate 3d – Small drum

Materials used in potting mixture

In biochar applied treatments, pots were filled using soil and biochar in the ratio 1:1. For control treatment, ordinary potting mixture with soil, sand and FYM in 1:1:1 ratio was used.

Nutrient content in soil and FYM used in the potting mixture are presented in the tables 2 and 3 respectively.

Table 2. Nutrient content in soil used for potting mixture

Particulars	contents
OC %	1.06
Available N (mg/kg)	78.45
Available P (mg/kg)	2.7
Available K (mg/kg)	90
pH	5.1

Table 3. Nutrient contents in FYM

Particulars	Contents
N %	1.75
P%	1.40
K%	0.430

Fertilizers

Urea, Rajphos and Muriate of Potash were used as the sources for different nutrients. The nutrient content of the fertilizer is given in Table 4.

Table 4. Nutrient contents of the fertilizer

Nutrients	Fertilizer	Nutrient content (%)
Nitrogen	Urea	46
Phosphorus	Rajphos	18
Potassium	Muriate of potash	60

3.3. METHOD

Experiment- 1

3.3.1. *Production of biochar*

Heap method

Biomass were put inside the kiln as a heap. After heaping the materials inside the kiln, fire was put and the lid was closed after spreading the fire to provide anaerobic burning. Smoke was allowed to escape through the vents. After the escape of the smoke, the vents were closed and the sides of the lid were plastered using mud. Here there was a direct burning of materials at 300^0C. The lid was opened on the next day to collect biochar. (Plates 4a-4e)

Drum method

In drum method, two different sized drum, one large and other small drum were used. The materials were filled in the small drum and kept it upside down inside the large drum to prevent the entry of air. Because of the size difference there was a gap between the two drums. Fuel materials were filled in the gap were fired and burned for an hour. Here there was indirect burning *ie,* the biochar was produced by the heat received by burning the fuel materials and here the temperature involved was 400^0C. Biochar was collected on the next day. (Plates 5a-5e)

Experiment- 2

3.3.2. Design and layout

The experiment was conducted in poly bags of size 15"x15". The experiment consisted of 18+1 treatments replicated thrice and laid out in factorial CRD.

Plates 4a-4e: Steps involved in heap method of biochar production

Plate 4a

Plate 4b

Plate 4c

Plate 4d

Plate 4e

Plates 5a-5e: Steps involved in drum method of biochar production

Plate 5a

Plate 5b

Plate 5c

Plate 5d

Plate 5e

Treatments:

A . Biochar - 6 Nos. (2 production method x 3 materials used)

B1 - Biochar of woody wild growth by heap method

B2 - Biochar of woody wild growth by drum method

B3- Biochar of coconut petiole by heap method

B4- Biochar of coconut petiole by drum method

B5 - Biochar of herbal waste residue by heap method

B6 - Biochar of herbal waste residue by drum method

B . Nutrient levels – 3

N1- 100% POP recommendation

N2- 75% POP recommendation

N3- Absolute control

C .Control- Ordinary Potting mixture – soil: sand : FYM (1:1:1) + 100% POP recommendation

3.3.3. *Nursery preparation*

Amaranth seedlings were raised on the seed beds prepared in the field of PPNMU on 7th of December 2014.

3.3.4. *Transplanting*

One month old seedlings were transplanted on 7th of January. One seedling per poly bag was planted at the centre of the poly bag.

3.3.5. *Manure and fertilizer application*

Half dose of N, full dose of P and K were applied as basal and another half dose of N was applied as topdressing. Recommended fertilizer application and scheduled application of fertilizer are given in table 5. Quantity of fertilizer applied for each plant according to the fertilizer levels are given in the table 6

Table 5. Recommended dose of fertilizer and schedule of fertilizer application

Recommendation (kg ha^{-1})			Schedule of fertilizer application
N	**P**	**K**	
50	50	50	Half N, Full P, Full K.
50	-	-	Half N one month after transplanting

Table 6. Quantity of fertilizer applied for each plant

Nutrient level	Quantity (g plant^{-1})		
	N	**P**	**K**
N_1- 100% POP	0.652	1.66	0.499
N_2- 75% POP	0.489	1.245	0.374
N_3- 0% POP	0	0	0

3.3.6. *Weeding*

Weeds were controlled by hand weeding as and when required.

3.3.7. *Irrigation*

Irrigation was provided twice daily up to the harvest for control and once in three days for rest of the treatments containing biochar.

3.3.8. *Incidence of pest and diseases*

Pseudomonas fluorescens spray was given thrice in a month at the rate of 10g/litre to control damping off by *pythium* and leaf blight by *Rhizoctonia solani.*

3.3.9. *Harvesting*

Harvesting was started from the 30th day onwards from the transplanted plants in poly bags and subsequent harvest was done at an interval of one week. A total of three harvests were taken. Harvesting was done by cutting the above ground portion using knife, leaving the basal node of the plant.

3.3.10. Raising a residual crop

A residual crop of amaranth was raised in the same poly bags after the harvest of the first main crop and harvest was done as in the case of first crop.

3.4. OBSERVATIONS

3.4.1. Recovery percentage of biochar

Heap method

Weight of the biomass added to the kiln was taken before burning and the biochar obtained after burning was weighed. The weight of biochar produced to the weight of biomass used, multiplied with hundred, gave the recovery percentage in heap method and was expressed in percentage.

Drum method

After filling the small drum with biomass, the weight was taken. Difference in weight between biomass filled small drum and empty small drum gave the weight of biomass used for burning. The weight difference between the biochar in the filled small drum and empty small drum gave the weight of biochar. The ratio of the weight of biochar to the weight of biomass used, multiplied with hundred gave the recovery percentage in drum method and was expressed in percentage.

3.4.2. Characterisation of biochar

Biochar samples collected after the production were analysed for physical and chemical parameters according to the standard procedure. The details are depicted in Table.7

Table 7. Physico-chemical characteristics of biochar

No.	Particulars	Method	Reference
		Physical	
1	Bulk density	Tapping method	FCO, 1985
2	Water holding capacity	Keen Racksawski method	Keen and Racksawski, 1921
3	Porosity	Keen Racksawski method	
		Chemical	
1	pH	pH meter 1:10 suspension (Organic waste :water)	FCO, 1985
2	Cation exchange capacity	Extraction of cations by $BaCl_2$ and filtration. Determination by Atomic absorption spectrophotometer and Flame Photometer.	Hendershot and Duquette (1986)
3	Total Carbon	Ashing	FCO,1985
4	Total nitrogen	Microkjeldahl digestion and distillation	Jackson, 1958
5	Total phosphorus	Extraction using diacid (2:1) and estimation by spectrophotometry	FCO,1985
6	Total potassium	Extraction using diacid (2:1) and estimation by flamephotometry	

3.4.3. Biometric observations and yield

3.4.3.1. *Plant height (cm)*

Plant height was measured from the base of the plant to the tip of the growing point at 15 days after transplanting and at harvest and expressed in cm.

3.4.3.2. *Number of leaves plant^{-1}*

Number of fully opened leaves produced per plant was taken at 15 days after transplanting and at harvest.

3.4.3.3. *Number of branches plant^{-1}*

Number of branches produced were taken at 15 days after transplanting and at harvest.

3.4.3.4. *Yield plant^{-1}*

Total yield obtained from all the harvest were summed up to get the yield of the crop. The yield of residual crop was taken by adding the yield of different harvest.

3.4.4. Plant analysis

The plant samples were collected from each pot at harvest and was shade dried and thereafter oven dried at 80 ± 5°C, powdered and estimated the contents of total NPK of crop at harvest as per standard procedure given in Table.8.

Table 8. NPK analysis of plants

No.	Nutrients	Method &	Reference
1	N	Microkjeldahl digestion and distillation method	Jackson, 1958
2	P	Diacid digestion of leaf sample followed by filtration. Vandadomolybdate phosphoric yellow colour in nitric acid system	Piper, 1966
3	K	Diacid extract using Perkin-Elmer Atomic Absorption Spectrophotometer	Piper, 1966

Uptake of major nutrients

Uptake of N, P and K were calculated by multiplying the respective values of N, P and K with total dry weight of the plant at harvest. The values were expressed in g plant $^{-1}$.

3.4.5. Soil analysis

Soil samples were analyzed before and after the experiment. Samples were collected from the potting mixture prepared for the pre soil analysis and samples from the pots were also collected after the harvest of the crop for the post nutrient analysis. Soil samples were dried, powdered and passed through 2 mm sieve, the samples were used for analyzing chemical characteristics of the soil. The various methods used for the analysis are given in Table 9.

Table 9. Pre and post experimental status on soil parameters

No.	Particulars	Method	Reference
1	Soil reaction (pH)	Soil water suspension of 1:2.5 and read in pH meter	Jackson,1958
2	Organic carbon	Walkley and Black method	Walkley and Black, 1934
6	Available N	Alkaline permanganate method	Subbiah and Asija, 1956
7	Available P_2O_5	Ascorbic acid reduced molybdophosphoric blue colour method	Bray and Kurtz, 1945; Wattanabe and Olsen, 1965
8	Available K_2O	Neutral normal ammonium acetate extract using flame photometer	Jackson, 1958

3.4.6. Economics

Cost involved in the production of biochar using different methods and the B: C ratio for the production of biochar were worked out.

3.4.7. Statistical analysis

The data were analysed statistically applying the techniques of analysis of variance using the statistical package 'MSTAT-c' (Freed, 1986).

Plates 6a- 6d. Effect of different biochar and ordinary potting mixture on crop performance

Plate 6a-Woody wild growth biochar

Plate 6b- Coconut petiole biochar

Plate 6c- Herbal waste residue biochar

Plate 6d-Ordinary potting mixture

Plates 7a- 7f. Effect of different biochar (6 types) on crop performance

Plate 7a- Heap – Woody wild growth biochar

Plate 7b- Drum – Woody wild growth biochar

Plate 7c- Heap –Coconut petiole biochar

Plate 7d- Drum –Coconut petiole biochar

Plate 7e- Heap – Herbal waste residue biochar

Plate 7f- Drum – Herbal waste residue biochar

RESULTS

4. RESULTS

An experiment was conducted to produce biochar from crop residues, to assess its characteristics and to study its effect on crop growth at Plant Propagation and Nursery Management Unit, Vellanikkara, Thrissur during August 2014 to February, 2015. The data obtained from the experiment are described here with appropriate tables after statistical analysis.

4.1 CHARACTERIZATION OF BIOCHAR

4.1.1. Physical characteristics

4.1.1.1. Recovery percentage

Recovery percentage of biochar produced by different production technique is presented in Table 10. The result indicated that recovery percentage was significantly higher for drum method (27.0%) compared to the heap method (22.4%). Among the different materials used for the biochar production, herbal waste gave higher recovery of about 25.50 per cent. Wild growth and coconut petiole reported a recovery of 24.24 and 24.42 per cent respectively. Biochar produced from coconut petiole using drum method showed higher recovery (28.32%) and it produced using heap method resulted in lower recovery (20.52%).

4.1.1.2. *Bulk density (BD)*

The data on bulk density are given in Table 10. Bulk density of biochar was significantly influenced by method of production and materials used. Drum method showed significantly higher BD (0.55 g/cc) than heap method(0.49 g/cc). BD was found to be significantly higher in herbal waste (0.74 g/cc) and lower in wild growth (0.34 g/cc). Herbal waste produced by heap method(0.81 g/cc) showed higher BD and wild growth produced by heap method(0.30 g/cc) showed lower BD.

4.1.1.3. *Porosity*

Results on porosity of different biochar materials are provided in Table 10. Different methods of production had significant influence in porosity. Drum method (56.2%) recorded significantly higher porosity than heap method (51.1%). Among the different materials, wild growth (62.9%) resulted in higher porosity and herbal waste (35.8%) recorded lower porosity. Significantly higher pore space was noted in wild growth by drum method (67.4%) and lower pore space was shown by herbal waste produced by heap method (27.8%).

4.1.1.4. *Water holding capacity* (WHC)

Data on WHC are presented in Table 10. All the biochar materials recorded a higher WHC. Drum method (239.5%) of biochar production resulted in significantly higher WHC than heap method (232.1%). Biochar from wild growth showed significantly higher WHC (363.9%) and herbal waste (109.2%) showed minimum WHC among different materials used for biochar production. Higher WHC was observed for wild growth biochar produced by drum method (377.2%) and lower was for herbal waste produced through heap method (92.7%).

4.1.2. Chemical characteristics

4.1.2.1. *pH*

Data on pH of different biochar produced are shown in Table 11. All the biochar materials are alkaline in nature. Drum method (9.1) recorded more pH compared to heap method (8.8). Biochar from coconut petiole (10.0) showed significantly higher pH than the other two materials and herbal waste recorded lower pH (8.3).The pH was higher for coconut petiole produced by heap method (10.2) and was lower for herbal waste produced by heap method (8.0).

Table 10. Physical characteristics of biochar as influenced by production method and feedstock materials

Treatments	Recovery (%)	Bulk density (gcm $^{-3}$)	Porosity (%)	Water holding capacity (%)
Method of production				
Heap	22.4	0.49	51.1	232.1
Drum	27.0	0.55	56.2	239.5
CD(0.05)	0.141	0.005	0.397	0.211
Materials				
Woody wild growth	24.2	0.34	62.9	363.9
Coconut petiole	24.4	0.49	62.3	234.3
Herbal waste residue	25.5	0.74	35.8	109.2
CD(0.05)	0.173	0.006	0.486	0.258
Interaction	Sig	Sig	Sig	Sig
Interaction - Method x Material				
Heap-wild growth	21.8	0.30	58.4	350.7
Drum-wild growth	26.7	0.38	67.4	377.2
Heap-coconut petiole	20.5	0.38	67.0	252.8
Drum-coconut petiole	28.3	0.59	57.5	215.8
Heap-herbal waste	24.9	0.81	27.8	92.7
Drum-herbal waste	26.1	0.67	43.7	125.6
CD(0.05)	0.245	0.008	0.687	0.365

4.1.2.2. *Cation Exchange Capacity (CEC)*

CEC of different biochar are presented in Table 11. Method of production was insignificant in case of CEC of biochar materials. There was significant influence for the materials used and CEC was higher for the coconut petiole biochar (10.37 cmols kg $^{-1}$) followed by wild growth (8.17 cmols $^{-1}$kg) and the least CEC was recorded by herbal waste residue (6.19 cmols kg $^{-1}$). Interaction between method of production and materials used was significantly higher for heap- coconut petiole (10.48 cmols kg $^{-1}$) which was on par with drum-coconut petiole (10.26 cmols kg $^{-1}$). The least interaction was noticed for heap- herbal waste (5.8 cmols kg $^{-1}$).

4.1.2.3. *Total carbon*

Data on total carbon content in the different biochar is presented in Table 11. Carbon content of biochar was significantly higher in heap method (47.7%) compared to drum method (45.85%). Among the different materials, biochar produced from wild growth showed significantly higher carbon content (50.98%) than the other two. Carbon content was lower in biochar produced from coconut petiole (44.1%). The interaction between materials used and method of production exerted significant influence on carbon content of biochar. Higher carbon content of 52.6 per cent was recorded for wild growth produced through heap method and lower carbon content of 44.1 per cent was recorded for the three materials, coconut petiole and herbal waste biochar from drum method and coconut petiole biochar from heap method.

4.1.2.4. *Total nitrogen*

Total nitrogen content of different biochar materials are given in Table 11. Nitrogen content in the biochar materials got increased when compared to the feed stock materials except for coconut petiole in which the nitrogen content remains constant. Comparing the production methods total nitrogen content was higher for heap method (0.64%) than drum method (0.55%). Herbal waste biochar showed higher (0.831%) and coconut petiole showed lower (0.35%) N content. Significant interaction was noticed in nitrogen content of biochar and was significantly higher for herbal waste produced through heap method (0.88%). Both the method of production of biochar from coconut petiole recorded lower nitrogen content of 0.35 per cent.

4.1.2.5. *Total phosphorus*

Total phosphorus content of different biochar materials is presented in Table 11. The results showed that phosphorus content of the final product (biochar) got increased when compared with the raw materials except for coconut petiole in which the total phosphorus content showed a decreasing trend. Biochar produced by heap method (0.18%) showed higher phosphorus content than drum method(0.18%). Among the different materials wild growth recorded significantly higher P content (0.22%) compared to herbal waste and coconut petiole recorded the lowest P content (0.12%). Wild growth biochar produced through drum method showed significantly higher Phosphorus content (0.23%) compared to others. Coconut petiole biochar produced through heap method recorded the lowest (0.11%) phosphorus content.

4.1.2.6. *Total potassium*

Data on total potassium content of different biochar materials are presented in Table 11. An increasing trend of potassium content was observed in the biochar materials except for the coconut petiole biochar when compared with the raw materials. In case of coconut petiole biochar, total potassium content got decreased compared to raw material. Even then the K content of biochar from coconut petiole was the highest among the other material (0.63%) and the lowest was noted for herbal waste (0.48%). Heap method (0.56%) resulted in more potassium content than drum method (0.54%). Significant interaction was noticed between production method and materials used with respect to K content. The highest K content was for coconut petiole produced by heap method (0.67%) and lowest was for herbal waste produced by heap method (0.47%).

Table 11. Effect of production methods and materials used on the chemical characteristics of biochar

Treatments	pH	Total carbon (%)	Total N (%)	Total P (%)	Total K (%)	CEC (cmols kg ^{1})
Method of production						
Heap	8.8	47.70	0.64	0.18	0.56	8.16
Drum	9.1	45.85	0.55	0.18	0.54	8.33
CD(0.05)	0.092	0.831	0.025	NS	0.007	NS
Material						
Woody wild growth	8.6	50.9	0.61	0.22	0.53	8.17
Coconut petiole	10.0	44.1	0.35	0.12	0.63	10.37
Herbal waste residue	8.3	45.2	0.83	0.20	0.48	6.19
CD(0.05)	0.113	1.018	0.031	0.006	0.008	0.306
Interaction	Sig	Sig	Sig	Sig	Sig	Sig
Interaction - Method x Material						
Heap-wild growth	8.4	52.6	0.70	0.22	0.54	8.20
Drum-wild growth	8.9	49.3	0.52	0.23	0.53	8.15
Heap- coconut petiole	10.2	44.1	0.35	0.11	0.67	10.48
Drum coconut petiole	9.8	44.1	0.35	0.12	0.59	10.26
Heap herbal waste	8	46.4	0.88	0.22	0.47	5.80
Drum herbal waste	8.6	44.1	0.79	0.18	0.48	6.59
CD(0.05)	0.159	1.439	0.044	0.008	0.011	0.432

4.2. Growth and yield parameters of crop

4.2.1. *Plant height*

The effect of various treatments on height of plants at 15DAT and at harvest are given in Table 12. Ordinary potting mixture receiving 100 per cent RDF produced the tallest plants at 15DAT (29.8 cm) and at harvest (36.4 cm). Production methods of biochar had no significant influence on the plant height. Significant variation was noticed between materials used for biochar production. Wild growth resulted significantly higher plant height than herbal waste and coconut petiole which showed lower height in both stages. Fertilizer levels also influenced the plant height significantly with 100 per cent NPK showed higher height and absolute control showed lower height at both the stages.

Significant interaction (Table 13) was noticed between production methods and materials used with respect to plant height at both stages. Drum-herbal waste biochar (11.88 cm) showed highest plant height which is on par with heap-wild growth biochar (11.87 cm) at 15DAT. Heap-wild growth recorded higher values (27.39 cm). Shorter plants were shown by drum-coconut petiole at 15 DAT (8.23cm) and at harvest (14.72 cm).

There was no significant interaction between production methods and fertilizer levels on plant height.

Significant interaction between material and fertilizer level was there at 15 DAT but not in harvest stage. The height was found to significantly higher for wild growth at 100 per cent NPK (13.16 cm) and lower height was recorded for coconut petiole at absolute control (7.79 cm) at 15 DAT.

Significant interaction was noticed between production method, materials used and fertilizer levels (Table 14) at 15 DAT but not in harvest stage with respect to plant height. Heap-wild growth at 100 per cent NPK (15.16 cm) showed taller plants and the shorter plants were reported in heap-herbal waste at 75 per cent NPK (7.58 cm) which are on par with the treatments heap- coconut petiole at absolute control (7.77cm), drum- coconut petiole at 75 per cent of NPK (7.61cm) and drum-coconut petiole biochar at absolute control (7.8cm) at 15 DAT.

Table 12. Plant height of amaranth as affected by method of production, materials used and fertilizer levels

	Height (cm)	
Treatment	15 DAT	At harvest
Method of production		
Heap	9.76	19.92
Drum	10.27	21.47
CD(0.05)	NS	NS
Materials		
Wild growth	11.29	25.57
Coconut	8.49	14.85
Herbal	10.28	21.68
CD(0.05)	0.995	1.974
Fertilizer levels		
100%	11.52	22.24
75%	9.61	20.57
0%	8.92	19.29
CD(0.05)	0.995	1.974
Ordinary potting mixture	29.83	36.40
Method x Materials	Sig	Sig
Method x Fertilizer	NS	NS
Material x Fertilizer	Sig	NS
Method x Material x Fertilizer	Sig	NS

4.2.2 *Number of leaves*

The data regarding the effects of treatments on number of leaves per plant at 15 DAT and at harvest are presented in Table 15. Number of leaves at 15 DAT (84.22) and at harvest (171.0) was significantly higher for the treatment of ordinary potting mixture receiving 100 per cent NPK. There was no significant difference between production methods with respect to number of leaves at 15 DAT. At harvest significant variation was noticed between the two production methods. Drum method showed more number of leaves (58.24) than heap method (51.44) at harvest. Significant variation was recorded among the different materials used at both stages of observation. Wild growth biochar resulted higher and coconut petiole biochar recorded the lower number of leaves at both the stages. Higher leaf number was recorded by 100 per cent NPK and absolute control showed lower leaf number at both the stages.

Significant interaction (Table 16) was noticed between production methods and materials used with respect to number of leaves per plant at both stages. Higher number of leaves per plant was recorded in heap-wild growth biochar (34.389) at 15 DAT and drum-herbal waste biochar (81.96) at harvest. The number of leaf was least in drum-coconut petiole biochar at 15 DAT (10.76) and for heap-coconut petiole (31.09) at harvest.

Significant Interaction was noticed between production method and fertilizer level at harvest but not in 15 DAT. At harvest the higher number of leaf was recorded in drum method at RDF (61.44) and the least was for heap method at 75 percent (45.87).The interaction between materials and fertilizer levels had significant influence on the number of leaves at both stages. The higher leaf number was for wild growth at 100 per cent NPK (39.62) at 15 DAT and at harvest (78.78). Least was for coconut petiole at absolute control (9.88) at 15 DAT and at harvest (29.11).

There was significant interaction between method of production, materials used and fertilizer levels at both stages (Table 17, 18) with respect to number of leaves. Heap-wild growth at 100 percent NPK showed higher number of leaves at 15 DAT (45.83) and drum- herbal waste at absolute control (89.66) at harvest. Lower leaf number was observed in the treatments drum- coconut petiole at 75 per cent NPK (7.88) at the stage of 15 DAT and heap-coconut petiole at 75 per cent NPK (27.83) at the stage of harvest.

Table 15. Number of leaves per plant of amaranth as affected by method of production, materials used and fertilizer levels

	No. of leaves/plant	
Treatment	15 DAT	At harvest
Production method		
Heap	23.05	51.44
Drum	23.95	58.24
CD(0.05)	NS	2.988
Materials		
Wild growth	30.84	68.49
Coconut	11.68	31.49
Herbal	27.98	64.53
CD(0.05)	2.526	3.659
Fertilizer levels		
100%	27.20	60.24
75%	23.09	53.22
0%	20.21	51.06
CD(0.05)	2.526	3.659
Ordinary potting mixture	84.22	171
Method x Materials	Sig	Sig
Method x Fertilizer	NS	Sig
Material x Fertilizer	Sig	Sig
Method x Material x Fertilizer	Sig	Sig

Table 16. Two way interaction effects on number of leaves per plant at 15 DAT and at harvest

Interactions	**No. of leaves/plant**	
	At 15DAT	At harvest
Production method x material		
Heap-wild growth	34.39	76.14
Heap-coconut petiole	12.59	31.09
Heap-herbal waste	22.17	47.11
Drum-wild growth	27.29	60.84
Drum coconut petiole	10.76	31.91
Drum- herbal waste	33.79	81.96
CD(0.05)	3.572	5.175
Production method x fertilizer		
Heap-100% NPK	NS	59.04
Heap-75% NPK		45.87
Heap-0% NPK		49.43
Drum-100% NPK		61.44
Drum-75% NPK		60.57
Drum-0% NPK		52.69
CD(0.05)		5.175
Material x fertilizer		
Wild growth-100% NPK	39.62	78.78
Wild growth-75% NPK	34.12	69.53
Wild growth-0% NPK	18.78	57.16
Coconut petiole-100% NPK	13.54	35.55
Coconut petiole-75% NPK	11.61	29.83
Coconut petiole-0% NPK	9.88	29.11
Herbal waste-100% NPK	28.43	66.39
Herbal waste-75% NPK	23.54	60.29
Herbal waste-0% NPK	31.97	66.92
CD(0.05)	6.187	6.338

Table 17. Interaction effect of production method, materials used and nutrient levels on number of leaves per plant at 15DAT

Nutrient levels	Materials used					
	Woody wild growth		Coconut petiole		Herbal waste residue	
	Production method					
	Heap	Drum	Heap	Drum	Heap	Drum
100% NPK	45.83	33.42	13.17	13.92	19.92	36.94
75% NPK	35.08	33.17	15.33	7.89	16.42	30.66
0% NPK	22.25	15.30	9.29	10.47	30.17	33.77
CD(0.05)	6.187					

Table 18. Interaction effect of production method, materials used and nutrient levels on number of leaves per plant at harvest

Nutrient levels	Materials used					
	Woody wild growth		Coconut petiole		Herbal waste residue	
	Production method					
	Heap	Drum	Heap	Drum	Heap	Drum
100% NPK	86.33	71.22	37.22	33.88	53.55	79.22
75% NPK	66.17	72.89	27.83	31.83	43.60	76.99
0% NPK	75.91	38.42	28.22	30.00	44.17	89.66
CD(0.05)	8.963					

4.2.3 *Number of branches*

The data on number of branches are given in Table 19. Higher number of branches was observed in the treatment of ordinary potting mixture receiving 100 per cent NPK at 15 DAT (8.33) and at harvest (12.33) respectively.

Methods of production behaved similarly in case of number of branches at both stages of observation. There was significant variation among different materials used for biochar production on number of branches. Wild growth biochar resulted significantly higher number of branches than biochar from other materials and coconut petiole recorded lower branch number at both the stages. There was significant difference in three fertilizer levels at harvest stage but not in 15 DAT. higher number of branch per plant was shown by100 per cent NPK and absolute control recorded least number of branches at harvest stage.

Interaction (Table 20) was significant between production method and materials used at both stages of observation. Heap -wild growth (5.18) at 15DAT and drum- herbal waste (7.65), which was on par with heap -wild growth biochar (7.19) at harvest, showed higher number of branches. The least number of branches was shown by drum -coconut petiole biochar (1.78) at 15 DAT and (3.28) at harvest.

Interaction between production method and fertilizer levels was not significant on number of branches at both stages of observations. The interaction between material and fertilizer level was significant at 15 DAT but not in harvest. Higher number of branches was noticed for wild growth biochar at 75 per cent NPK at 15 DAT (5.55). Coconut petiole at 100 per cent NPK in 15 DAT (1.83) recorded lower number of branches per plant.

There was no significant interaction between production method, materials used and fertilizer levels at both stages of observations.

Table 19 Number of branches per plant of amaranth as affected by method of production, materials used and fertilizer levels

	No. of branches/plant	
Treatment	At 15 DAT	At harvest
Production method		
Heap	3.19	5.14
Drum	3.59	5.59
CD(0.05)	NS	NS
Materials used		
Wild growth	4.69	6.53
Coconut	1.92	3.59
Herbal	3.56	5.98
CD(0.05)	0.715	0.876
Fertilizer levels		
100%	3.71	6.32
75%	3.46	5.28
0%	3.01	4.49
CD(0.05)	NS	0.876
Ordinary potting mixture	8.33	12.33
Method x Materials	Sig	Sig
Method x Fertilizer	NS	NS
Material X Fertilizer	Sig	NS
Method x Material x Fertilizer	NS	NS

Table 20. Two way interaction effects on number of branches per plant

	No. of branches/plant	
	At 15DAT	At harvest
Production method x material		
Heap-wild growth	5.18	7.19
Heap-coconut petiole	2.07	3.91
Heap-herbal waste	2.33	4.31
Drum-wild growth	4.22	5.86
Drum coconut petiole	1.78	3.28
Drum- herbal waste	4.78	7.65
CD(0.05)	1.011	1.239
Material x fertilizer		
Wild growth-100% NPK	5.46	NS
Wild growth-75% NPK	5.56	
Wild growth-0% NPK	3.08	
Coconut petiole-100% NPK	1.83	
Coconut petiole-75% NPK	2.00	
Coconut petiole-0% NPK	1.93	
Herbal waste-100% NPK	3.83	
Herbal waste-75% NPK	2.83	
Herbal waste-0% NPK	4.00	
CD(0.05)	1.238	

4.2.4 *Leaf: Stem ratio*

Result (Table 21) showed that leaf stem ratio from heap method (2.31) was significantly higher than drum method (2.11). Materials used had significant influence on the leaf: stem ratio. Biochar from coconut petiole resulted in significantly higher (2.42) and wild growth resulted in lower (2.09) leaf: stem ratio. 100 per cent NPK recorded significantly higher leaf: stem ratio and the plants received absolute control recorded the least. Interaction (Table 22) was insignificant between production method and materials used.

Also the interaction among production method and fertilizer level did not significantly influence the leaf: stem ratio. Significant interaction was noticed between materials used and fertilizer levels. Biochar from coconut petiole received 100 per cent NPK recorded the higher (2.68) and herbal waste biochar at absolute control recorded the lower (1.59) leaf: stem ratio. Interaction among production method, materials used and fertilizer levels (Table 23) had significant variation in leaf: stem ratio. The higher leaf: stem ratio was noticed in the plant received the drum- coconut petiole biochar at 100 per cent NPK (2.86) and the lower was noticed in the treatment heap -herbal waste at absolute control (1.38).

4.2.5 *Main crop yield*

The effects of various treatments on yield are shown in Table 21. The treatment which received 100 per cent NPK in ordinary potting mixture produced the higher yield of 243.4 g plant $^{-1}$. Different methods of production had significant influence on yield of amaranth. Higher yield was recorded in drum method (49.203g plant^{-1}) than heap method (42.78 g plant $^{-1}$). There was significant difference between materials used with respect to yield. Wild growth (65.29 g plant $^{-1}$) recorded the higher and coconut petiole biochar (17.20 g plant $^{-1}$) recorded the lower yield. Significant variation was also noticed among fertilizer levels on yield. 100 per cent NPK recorded the higher (52.71 g plant $^{-1}$) yield and absolute control (40.16 g plant $^{-1}$) recorded the lower yield.

Significant interaction (Table 22) was noticed between biochar production method and materials used on yield. Heap-wild growth biochar reported higher yield (80.70 g plant $^{-1}$) which was on par with drum- herbal waste(80.32 g plant $^{-1}$) and heap -coconut petiole (16.99 g plant $^{-1}$) showed lower yield.

Interaction between production method and fertilizer level had influence on yield of amaranth. Drum method at 100 per cent NPK (54.76 g plant $^{-1}$) recorded higher yield and lower was for heap method at 75 per cent NPK (37.69 g plant $^{-1}$).

There was significant yield difference in interaction between material and fertilizer levels. The higher yield was noticed for wild growth at 100 per cent NPK (79.00 g plant $^{-1}$) and the least was for coconut petiole biochar without fertilizer (14.02 g plant $^{-1}$).

Significant interaction was noticed among the production method, materials used and fertilizer levels (Table 24). Heap -wild growth biochar at 100 per cent NPK resulted in higher yield of 92.89 g plant $^{-1}$. Drum - coconut petiole biochar without fertilizer resulted in the lower yield of about 13.56 g plant $^{-1}$.

4.2.6. *Residual crop yield*

A residual crop was raised in the same pots and recorded the yield of that crop. Biochar treated pots recorded higher yield than ordinary potting mixture from the second crop. With respect to different methods of production, heap method (76.18 g plant $^{-1}$) resulted significantly higher yield than drum method (55.41 g plant $^{-1}$). Significant variation was noticed in yield among various materials used. Wild growth recorded higher yield (130.89 g plant $^{-1}$) and coconut petiole recorded lower yield (18.22 g plant $^{-1}$). Significant difference was noticed in fertilizer levels with respect to yield. 100 per cent NPK recorded the higher yield (80.31 g plant $^{-1}$) and absolute control recorded the lower yield (45.5g plant $^{-1}$) (Table 21).

Significant difference was noticed in the residual crop yield due to interaction (Table 22) between the production method and material used. Heap-wild growth biochar resulted in higher (156.39 g plant $^{-1}$) yield. Heap- coconut petiole biochar reported the lower yield (17.78 g plant $^{-1}$) which is on par with the drum -coconut petiole biochar (18.67 g plant $^{-1}$).

Interaction between biochar production method and fertilizer levels was significantly different on yield data. Heap method at 100 per cent NPK recorded the higher yield (92.11 g plant $^{-1}$). Drum method at absolute control (42.67 g plant $^{-1}$) recorded the lower yield. Significant interaction was noticed between materials and fertilizer levels with respect to yield. Wild growth biochar at 100 per cent NPK had the higher yield (162.25 g plant $^{-1}$) and the lower yield was for the coconut petiole biochar without fertilizer (16.00 g plant $^{-1}$).

There was significant interaction between production method, materials used and fertilizer levels (Table 25) on yield of residual crop. Significantly higher yield was reported by the treatment heap-wild growth biochar at 100 per cent NPK (192.33g plant $^{-1}$) which was on par with heap -wild growth biochar at 75per cent NPK (189.33 g plant $^{-1}$).

Table 21. Leaf : Stem ratio, yield from main crop and yield from the residual crop of amaranth as affected by method of production, materials used and fertilizer levels

Treatment	**Leaf:stem ratio**	**Main crop yield (g /plant)**	**Residual crop yield (g/plant)**
Method of production			
Heap	2.31	42.78	76.18
Drum	2.11	49.20	55.41
CD(0.05)	0.122	2.509	1.581
Materials used			
Wild growth	2.09	65.29	130.89
Coconut	2.42	17.19	18.22
Herbal	2.10	55.49	48.28
CD(0.05)	0.149	3.072	1.936
Fertilizer levels			
100%	2.32	52.71	80.31
75%	2.25	45.11	71.58
0%	2.05	40.16	45.50
CD(0.05)	0.149	3.072	1.936
Ordinary potting mixture	2.04	243.4	173.0
Method x Materials	NS	Sig	Sig
Method x Fertilizer	NS	Sig	Sig
Material x Fertilizer	Sig	Sig	Sig
Method x Material x Fertilizer	sig	Sig	Sig

Table 22. Two way interaction effects on leaf: stem ratio, main crop yield and residual crop yield

Interactions	Leaf : stem ratio	Main crop yield (g plant $^{-1}$)	Residual crop yield (g plant $^{-1}$)
Production method x material			
Heap-wild growth	NS	80.70	156.39
Heap-coconut petiole		16.99	17.78
Heap-herbal waste		30.66	54.39
Drum-wild growth		49.89	105.39
Drum- coconut petiole		17.40	18.67
Drum- herbal waste		80.32	42.17
CD(0.05)		4.345	2.738
Production method x fertilizer			
Heap-100% NPK	NS	50.67	92.11
Heap-75% NPK		37.69	88.11
Heap-0% NPK		39.99	48.33
Drum-100% NPK		54.76	68.50
Drum-75% NPK		52.53	55.06
Drum-0% NPK		40.32	42.67
CD(0.05)		4.345	2.738
Material x fertilizer			
Wild growth-100% NPK	1.92	79.00	162.25
Wild growth-75% NPK	2.04	67.97	146.33
Wild growth-0% NPK	2.32	48.91	84.08
Coconut petiole-100% NPK	2.68	21.83	20.83
Coconut petiole-75% NPK	2.35	15.74	17.83
Coconut petiole-0% NPK	2.24	14.02	16.00
Herbal waste-100% NPK	2.37	57.31	57.83
Herbal waste-75% NPK	2.35	51.63	50.58
Herbal waste-0% NPK	1.59	57.54	36.42
CD(0.05)	0.259	5.322	3.354

Table 23. Interaction effect of production method, materials used and nutrient levels on leaf: stem ratio

Nutrient levels	Materials used					
	Woody wild growth		Coconut petiole		Herbal waste residue	
	Production method					
	Heap	Drum	Heap	Drum	Heap	Drum
100% NPK	2.02	1.81	2.51	2.86	2.82	1.92
75% NPK	1.95	2.14	2.29	2.42	2.62	2.08
0% NPK	2.48	2.15	2.70	1.79	1.38	1.79
CD(0.05)	0.366					

Table 24. Interaction effect of production method, materials used and nutrient levels on main crop yield (g plant $^{-1}$)

Nutrient levels	Materials used					
	Woody wild growth		Coconut petiole		Herbal waste residue	
	Production method					
	Heap	Drum	Heap	Drum	Heap	Drum
100% NPK	92.90	65.11	21.96	21.70	37.15	77.46
75% NPK	73.30	62.64	14.54	16.93	25.22	78.03
0% NPK	75.91	21.92	14.47	13.57	29.61	85.47
CD(0.05)	7.526					

Table 25. Interaction effect of production method, materials used and nutrient levels on residual crop yield (g plant $^{-1}$)

Nutrient levels	Materials used					
	Woody wild growth		Coconut petiole		Herbal waste residue	
	Production method					
	Heap	Drum	Heap	Drum	Heap	Drum
100% NPK	192.33	132.17	20.33	21.33	63.67	52.00
75% NPK	189.33	103.33	17.17	18.50	57.83	43.33
0% NPK	87.50	80.67	15.83	16.17	41.67	31.17
CD(0.05)	4.743					

4.3. Nutrient uptake

4.3.1. *Nitrogen*

The data pertaining to nitrogen uptake by the crop at harvest is shown in Table 26. Treatment which received ordinary potting mixture with 100 per cent NPK showed significantly higher N uptake by plants (0.23 g plant $^{-1}$). Method of production had noticed significant variation in N uptake. Drum method showed significantly greater N uptake (0.11 g plant $^{-1}$) than heap method (0.09 g plant $^{-1}$). Among the different materials used herbal waste recorded significantly higher (0.14 g plant $^{-1}$) and coconut petiole recorded lower (0.05 g plant $^{-1}$) N uptake by plants. The higher N uptake was observed in 100 per cent NPK (0.14 g plant $^{-1}$) and the lower N uptake was in absolute control (0.06 g plant $^{-1}$) among the different fertilizer levels.

Significant interaction (Table 27) was noticed between production methods and materials used with respect to N uptake by amaranth. N uptake was higher in herbal waste biochar produced by drum method (0.18 g plant $^{-1}$) and lower in coconut petiole biochar in drum method (0.04 g plant $^{-1}$). Interaction between production method and fertilizer levels had significant influence on the N uptake by plants. Higher N uptake by plants were observed in heap method at 100 per cent NPK (0.14 g plant $^{-1}$) which was on par with drum method at 100 per cent NPK (0.13 g plant $^{-1}$) .The least N uptake was noticed in control treatment of heap method (0.06 g plant $^{-1}$) which was on par with the absolute control of drum method (0.06 g plant $^{-1}$). Interaction between materials used and fertilizer levels showed significant influence on N uptake by plants. Herbal waste at 100 percent NPK recorded significantly higher (0.17 g plant $^{-1}$) and coconut petiole at absolute control recorded lowest (0.03 g plant $^{-1}$) N uptake. Interaction between production method, materials used and fertilizer levels (Table 28) had significant influence on N uptake. Higher N uptake was recorded by drum- herbal waste biochar at 75 per cent (0.21 g plant $^{-1}$). Lower N uptake in plants was recorded in heap-coconut petiole biochar without fertilizers (0.02 g plant $^{-1}$) which was on par with absolute control of drum -coconut petiole (0.03 g plant $^{-1}$).

4.3.2. *Phosphorus*

The effect of various treatments on P uptake by the crop is presented in Table 26. Ordinary potting mixture received 100 per cent NPK recorded significantly higher P uptake in plants (0.051 g plant $^{-1}$). Method of production had noticed significant influence on P uptake by plants. Drum method was recorded significantly higher (0.018 g plant $^{-1}$) P uptake than the heap method (0.016 g plant $^{-1}$). Significant variation in P uptake was noticed among the different materials and was higher in herbal waste (0.026 g plant $^{-1}$) followed by wild growth(0.018 g plant $^{-1}$) and lower in coconut petiole(0.008 g plant $^{-1}$). Significant variation was noticed in the P uptake among fertilizer levels. Higher uptake was noticed in the 100 per cent NPK (0.022g plant $^{-1}$) and least was noticed in the absolute control (0.014g plant $^{-1}$).

Significant interaction (Table 27) was noted between production method and materials used on P uptake by plant. The higher P uptake was noticed in herbal waste biochar produced by drum method (0.033 g plant $^{-1}$) and the lower in coconut petiole in drum method (0.007 g plant $^{-1}$). Significant interaction was noticed between production method and fertilizer used. Drum method at 100 per cent NPK recorded significantly higher P uptake (0.024 g plant $^{-1}$) and heap method at absolute control recorded lower P uptake (0.012 g plant $^{-1}$). Interaction between materials used and fertilizer levels significantly influenced the P uptake in plants. Herbal waste at 100 per cent NPK observed higher P uptake (0.032 g plant $^{-1}$) and coconut petiole at 75 per cent NPK observed lower P uptake (0.005 g plant $^{-1}$) by crops. Significant interaction was noticed among production methods, materials used and fertilizer levels (Table 29) on P uptake. Higher P uptake was noted for drum- herbal waste at 100 per cent NPK (0.042 g plant $^{-1}$) The P uptake was lowest in the treatment heap-coconut petiole (0.01 g/plant) and drum- coconut petiole (0.005g plant $^{-1}$) at 75 per cent NPK.

4.3.3. *Potassium*

The effects of treatments on K uptake by the crop are shown in Table 26. The K uptake by plant was significantly higher in ordinary potting mixture received 100 per cent NPK (0.249g plant $^{-1}$). Potassium uptake by plants was higher in drum method (0.143g plant $^{-1}$), than in heap method (0.111g plant $^{-1}$) of production. Significant difference was also noticed in K uptake among the materials used. The treatments which received biochar of wild growth showed the higher K uptake (0.167g plant $^{-1}$), followed by herbal waste(0.133g plant $^{-1}$) and the least by coconut petiole(0.081g plant $^{-1}$). Among the different fertilizer levels, 100 per cent NPK reported significantly higher uptake (0.151g plant $^{-1}$) and treatment without fertilizer showed least uptake of K (0.090g plant $^{-1}$).

Interaction (Table 27) between production method and materials had significant influence in K uptake. The higher K uptake was noticed by the plants received herbal waste in drum method (0.189g plant $^{-1}$) and the lower uptake was noticed in coconut petiole in drum method (0.075g plant $^{-1}$). Other interactions had no significant influence on the K uptake by plants.

Table 26. NPK uptake by amaranth plants at harvest as affected by method of production, materials used and fertilizer levels (g plant $^{-1}$)

	Nutrient uptake		
Treatment	N (g plant $^{-1}$)	P (g plant $^{-1}$)	K (g plant $^{-1}$)
Production method			
Heap	0.09	0.016	0.11
Drum	0.11	0.018	0.14
CD(0.05)	0.007	0.001	0.026
Materials used			
Wild growth	0.10	0.018	0.17
Coconut	0.05	0.008	0.08
Herbal	0.14	0.026	0.13
CD(0.05)	0.008	0.001	0.031
Fertilizer levels			
100%	0.14	0.022	0.15
75%	0.10	0.016	0.14
0%	0.06	0.014	0.09
CD(0.05)	0.008	0.001	0.03
Ordinary potting mixture	0.231	0.051	0.249
Method x Materials	Sig	Sig	sig
Method x Fertilizer	Sig	Sig	NS
Materialx Fertilizer	Sig	Sig	NS
Method x Material x Fertilizer	Sig	Sig	NS

Table 27. Two way interaction effects on NPK uptake by amaranth plants at harvest

Interactions	**N(g plant $^{-1}$)**	**P (g plant $^{-1}$)**	**K(g plant $^{-1}$)**
Production method x material			
Heap-wild growth	0.11	0.022	0.17
Heap-coconut petiole	0.07	0.008	0.09
Heap-herbal waste	0.11	0.019	0.08
Drum-wild growth	0.10	0.014	0.16
Drum coconut petiole	0.04	0.007	0.08
Drum- herbal waste	0.18	0.033	0.19
CD(0.05)	0.011	0.001	0.044
Prodution method x fertilizer			
Heap-100% NPK	0.14	0.020	NS
Heap-75% NPK	0.08	0.017	
Heap-0% NPK	0.06	0.012	
Drum-100% NPK	0.13	0.024	
Drum-75% NPK	0.12	0.016	
Drum-0% NPK	0.06	0.015	
CD(0.05)	0.011	0.001	
Material x fertilizer			
Wild growth-100% NPK	0.14	0.023	NS
Wild growth-75% NPK	0.11	0.019	
Wild growth-0% NPK	0.06	0.013	
Coconut petiole-100% NPK	0.09	0.011	
Coconut petiole-75% NPK	0.04	0.005	
Coconut petiole-0% NPK	0.03	0.007	
Herbal waste-100% NPK	0.17	0.032	
Herbal waste-75% NPK	0.15	0.025	
Herbal waste-0% NPK	0.11	0.021	
CD(0.05)	0.014	0.001	

Table 28. Interaction effect of production method, materials used and nutrient levels on N uptake (g plant $^{-1}$)

Nutrient levels	Materials used					
	Woody wild growth		Coconut petiole		Herbal waste residue	
	Production method					
	Heap	Drum	Heap	Drum	Heap	Drum
100% NPK	0.14	0.15	0.12	0.07	0.15	0.19
75% NPK	0.10	0.11	0.05	0.03	0.10	0.21
0% NPK	0.10	0.04	0.02	0.03	0.08	0.13
CD(0.05)	0.020					

Table 29 Interaction effect of production method, materials used and nutrient levels on P uptake (g plant $^{-1}$)

Nutrient levels	Materials used					
	Woody wild growth		Coconut petiole		Herbal waste residue	
	Production method					
	Heap	Drum	Heap	Drum	Heap	Drum
100% NPK	0.026	0.019	0.011	0.010	0.022	0.042
75% NPK	0.025	0.013	0.005	0.005	0.020	0.030
0% NPK	0.016	0.009	0.007	0.007	0.014	0.028
CD(0.05)	0.002					

4.4. Post soil characteristics

4.4.1. *pH*

The effect of various treatments on pH of soil after harvest is given in Table 30. The pH of potting mixture after harvesting of crop was increased compared to the initial value in all the treatments. All the treatments recorded an alkaline pH except for the ordinary potting mixture received 100 per cent NPK. pH of the soil was significantly affected by the method of production. Drum method resulted in more pH (8.1) than heap method (7.8). pH was significantly higher in the coconut petiole biochar (8.5) treated soils followed by wild growth (7.7)and the least was observed in herbal waste residue biochar (7.5). Treatments of absolute control noticed significantly higher pH (8.1) and 100 per cent NPK reported the lowest pH (7.9) among the fertilizer levels.

Significant interactions (Table 31) were noticed between production method and materials used on soil reaction. Coconut petiole biochar produced through heap method recorded significantly higher pH (8.6) and herbal waste through heap method recorded lower pH (7.3). Other interactions did not influence the pH of post experiment soil.

4.4.2 *Organic carbon*

The organic carbon content of soil after harvesting of crop is given in Table 30. The organic carbon content of soil after harvesting of the crop got increased compared to the initial content. Method of production did not show any significant influence in OC content. The content of OC was significantly influenced by the materials used. Coconut petiole biochar showed higher OC content (2.36%) and wild growth biochar showed the lower (1.76%) OC content in soil after harvest. Treatment received 100 per cent NPK recorded the higher (2.18 %) and absolute control recorded the lower (2.03%) OC content.

Significant interaction (Table 31) was noticed between production method and materials used. The OC content in treatment received coconut petiole biochar produced by drum method was significantly higher (2.42%) and wild growth biochar from drum method was lower (1.74 %) among treatments. There was significant interaction between production methods and fertilizer levels. Higher OC content was shown by heap method at 100 per cent NPK (2.25%) and lower OC content was shown by the treatment in heap method at absolute control (2.02%). Interaction between materials and fertilizer levels had significant influence on OC content. Treatment received coconut petiole at 75 per cent NPK recorded the higher (2.44%) and wild growth at absolute control recorded lower (1.52%) OC content. The interaction between all the three factors (Table 32) had also significantly influenced OC content. The treatment drum -coconut petiole at 75 per cent NPK recorded the higher OC after harvest (2.58 %). It was on par with drum- coconut petiole at absolute control (2.52%) and heap- herbal waste at 100 per cent NPK (2.5%). Lower OC content (1.44%) was recorded by the treatment drum -wild growth at absolute control.

4.4.3 *Available nitrogen*

The data pertaining to available nitrogen content in the media after harvest is shown in Table 33. All the factors had significant influence in available N content in the potting media after harvest. Heap method showed significantly greater N content (70.96 mg/kg) than drum method (69.73 mg/kg). Herbal waste biochar recorded significantly higher (79.38 mg/kg) and coconut petiole biochar recorded lower (59.77 mg/kg) available N content in media. Significantly higher available N content was observed in 100 per cent NPK treated pots (81.26 mg/kg) and lower was in absolute control (61.62 mg/kg).

All the interactions (Table 34) had significant influence on the available N content in the media after harvest. Interaction between production methods and materials was significantly higher in herbal waste biochar produced by drum method (84.06 mg/kg) and lower was in coconut petiole in drum method (50.43 mg/kg).

Table 30. pH and organic carbon content of soil after harvest as affected by method of production, materials used and fertilizer levels

Treatment	pH	Organic carbon %
Production method		
Heap	7.8	2.10
Drum	8.1	2.11
CD(0.05)	0.119	NS
Materials used		
Wild growth	7.7	1.76
Coconut	8.6	2.36
Herbal	7.5	2.20
CD(0.05)	0.145	0.031
Fertilizer levels		
100%	7.8	2.18
75%	7.9	2.11
0%	8.1	2.03
CD(0.05)	0.145	0.031
Ordinary potting mixture	6.6	1.89
Method x Materials	Sig	Sig
Method x Fertilizer	NS	Sig
Material X Fertilizer	NS	Sig
Method x Material x Fertilizer	NS	Sig

Table 31. Two way interaction effect on pH and organic carbon content (%) in the soil after harvest

Interactions	pH	Organic carbon %
Production method x material		
Heap-wild growth	7.4	1.78
Heap-coconut petiole	8.6	2.31
Heap-herbal waste	7.3	2.21
Drum-wild growth	8.0	1.74
Drum coconut petiole	8.5	2.42
Drum- herbal waste	7.7	2.19
CD(0.05)	0.206	0.044
Production method x fertilizer		
Heap-100% NPK	NS	2.25
Heap-75% NPK		2.04
Heap-0% NPK		2.02
Drum-100% NPK		2.11
Drum-75% NPK		2.19
Drum-0% NPK		2.05
CD(0.05)		0.04
Material x fertilizer		
Wild growth-100% NPK	NS	1.96
Wild growth-75% NPK		1.81
Wild growth-0% NPK		1.52
Coconut petiole-100% NPK		2.24
Coconut petiole-75% NPK		2.44
Coconut petiole-0% NPK		2.42
Herbal waste-100% NPK		2.36
Herbal waste-75% NPK		2.09
Herbal waste-0% NPK		2.16
CD(0.05)		0.054

Table 32. Interaction effect of production method, materials used and nutrient levels on organic carbon (%)

Nutrient levels	Materials used					
	Woody wild growth		Coconut petiole		Herbal waste residue	
	Production method					
	Heap	Drum	Heap	Drum	Heap	Drum
100% NPK	1.95	1.97	2.31	2.16	2.50	2.21
75% NPK	1.80	1.81	2.31	2.58	2.01	2.18
0% NPK	1.60	1.44	2.32	2.52	2.13	2.19
CD(0.05)	0.076					

The higher N content in media was observed in drum method at 100 per cent NPK (82.19 mg/kg) and the least available N content was noticed in absolute control treatment of heap method (59.74 mg/kg). The N content in herbal waste biochar at 100 per cent NPK treated media was significantly higher (95.26 mg/kg) and coconut petiole biochar at absolute control was lower (44.83 mg/kg) among the effect on interaction between materials used for biochar production and fertilizer levels. Interaction among production method, materials used and fertilizer levels was significant (Table 35).Treatment which received drum- herbal waste biochar with 100 per cent recorded significantly higher available N content (112.08 mg/kg). The lower available N content was recorded in the control treatment of heap -coconut petiole and drum -coconut petiole (44.83 mg/kg) biochar treated soils.

4.4.4 *Available phosphorus*

The effects of various treatments on available P content in the potting media after harvest are presented in Table 33. Ordinary potting mixture containing 100 per cent NPK recorded higher available P content (16.38 mg/kg). Available P content in potting media containing biochar produced by heap method (8.72 mg/kg) was significantly higher than the drum method (6.20 mg/kg). Significant variation was noticed among the different materials and was higher in wild growth (9.9 mg/kg) followed by coconut petiole (7.41 mg/kg) biochar and the lowest in herbal waste biochar (5.04 mg/kg). Significant variation was noticed in the P content among fertilizer levels also. Higher available P content was noticed in the 100 per cent NPK (10.04 mg/kg) and the lower was recorded by the treatment without fertilizers (5.08 mg/kg).

Significant interaction (Table 34) was noticed between production method and materials used with respect to P content in potting media after harvest. Significantly higher available P was noted in wild growth biochar produced by heap method (12.09 mg/kg) and the lowest in herbal waste produced using drum method (4.3 mg/kg). There was significant interaction among production method and fertilizer used. Heap method in 100 per cent recorded significantly higher available P content (13.09mg/kg) and drum method at absolute control recorded lower P content (5.07 mg/kg). Available P content was significantly affected by the interaction between materials used and fertilizer levels. Wild growth at 100 per cent NPK recorded significantly higher P content (12.46 mg/kg) and herbal waste at absolute control observed the least available P content (3.19 mg/kg) after harvest. Interaction among all the three factors (table 36) was also found significant. Significantly higher available P was noticed in heap - wild growth biochar at 100 per cent NPK (16.01 mg/kg). The P content was lower in the treatment (2.72 mg/kg) of heap -herbal waste at absolute control.

4.4.5 *Available potassium*

The available K content in the various treatments after harvest of crop is shown in the Table 33. The treatment containing ordinary potting mixture received 100 per cent recorded least available K content (95.79 mg/kg). Significantly higher available K content in potting media was noticed in drum method (225.86 mg/kg), than in heap method (214.41 mg/kg). The treatments which received biochar of coconut petiole recorded significantly higher available K content (310.47 mg/kg), followed by wild growth (198.67 mg/kg) and the least in herbal waste (151.27 mg/kg). Different fertilizer levels also significantly influenced the available K content in potting media after harvest. RDF reported highest content (247.83 mg/kg) and control treatment showed least content of K (193.86 mg/kg).

All the interactions (Table 34) found to be significant with respect to available K content in post harvest media. Significantly higher K content was noticed in the coconut petiole biochar in drum method (314.867mg/kg) and lower content was noticed in herbal waste biochar in heap method (129.633mg/kg). Interaction between production method and fertilizer levels was significantly higher in drum method at 100 per cent (254.933mg/kg). The least was noticed in the heap method in absolute control (185.967mg/kg). Interaction between material and fertilizer levels was significantly higher in coconut petiole biochar at 100 per cent (330.95 mg/kg) and herbal waste biochar at absolute control recorded lower available K content of 142.13 mg/kg. Interaction between production method, materials used and fertilizer levels (Table 37) found significant and was significantly higher in pots received drum -coconut petiole biochar at 100 per cent NPK (333.4 mg/kg) and lower was noticed in heap herbal waste biochar without fertilizer (120.1 mg/kg).

Table 33. Available NPK content of soil after harvest as affected by method of production, materials used and fertilizer levels (mg/kg)

	Available nutrient status (mg/kg)		
Treatment	N	P	K
Production method			
Heap	70.97	8.72	214.41
Drum	69.73	6.20	225.86
CD(0.05)	0.755	0.299	1.509
Materials used			
Wild growth	71.89	9.94	198.67
Coconut	59.77	7.41	310.47
Herbal	79.38	5.04	151.27
CD(0.05)	0.924	0.367	1.848
Fertilizer levels			
100%	81.25	10.04	247.83
75%	68.17	7.26	218.71
0%	61.62	5.09	193.86
CD(0.05)	0.924	0.367	1.848
Ordinary potting mixture	95.26	16.38	95.79
Method xMaterials	Sig	Sig	sig
Method xFertilizer	Sig	Sig	Sig
Material xFertilizer	Sig	Sig	Sig
Method x Material x Fertilizer	Sig	Sig	Sig

Table 34. Two way interaction effects on available NPK content in the soil after harvest

	Available nutrient status (mg/kg)		
Interactions	N	P	K
Production method x material			
Heap-wild growth	69.08	12.09	207.53
Heap-coconut petiole	69.11	8.31	306.07
Heap-herbal waste	74.70	5.77	129.63
Drum-wild growth	74.70	7.80	189.80
Drum coconut petiole	50.43	6.50	314.87
Drum- herbal waste	84.06	4.30	172.90
CD(0.05)	1.307	0.519	2.614
Production method x fertilizer			
Heap-100% NPK	80.32	13.09	240.73
Heap-75% NPK	72.83	7.98	216.53
Heap-0% NPK	59.74	5.11	185.97
Drum-100% NPK	82.19	6.99	254.93
Drum-75% NPK	63.51	6.54	220.88
Drum-0% NPK	63.49	5.07	201.75
CD(0.05)	1.307	0.519	2.614
Material x fertilizer			
Wild growth-100% NPK	75.65	12.46	250.70
Wild growth-75% NPK	72.82	10.44	195.85
Wild growth-0% NPK	67.20	6.92	149.45
Coconut petiole-100% NPK	72.85	11.00	330.95
Coconut petiole-75% NPK	61.64	6.08	310.45
Coconut petiole-0% NPK	44.83	5.14	290.00
Herbal waste-100% NPK	95.26	6.66	161.85
Herbal waste-75% NPK	70.04	5.24	149.82
Herbal waste-0% NPK	72.82	3.19	142.13
CD(0.05)	1.601	0.635	3.201

Table 35 Interaction effect of production method, materials used and nutrient levels on available N after harvest (mg/kg)

Nutrient levels	Materials used					
	Woody wild growth		Coconut petiole		Herbal waste residue	
	Production method					
	Heap	Drum	Heap	Drum	Heap	Drum
100% NPK	72.85	78.45	89.66	56.04	78.45	112.08
75% NPK	67.20	78.45	72.85	50.43	78.45	61.64
0% NPK	67.20	67.20	44.83	44.83	67.20	78.45
CD(0.05)	2.264					

Table 36. Interaction effect of production method, materials used and nutrient levels on available P after harvest (mg/kg)

Nutrient levels	Materials used					
	Woody wild growth		Coconut petiole		Herbal waste residue	
	Production method					
	Heap	Drum	Heap	Drum	Heap	Drum
100% NPK	16.01	8.92	14.86	7.14	8.40	4.93
75% NPK	12.07	8.82	5.67	6.50	6.19	4.30
0% NPK	8.19	5.66	4.41	5.87	2.72	3.67
CD(0.05)	0.898					

Table 37. Interaction effect of production method, materials used and nutrient levels on available K after harvest (mg/kg)

Nutrient levels	**Materials used**					
	Woody wild growth		Coconut petiole		Herbal waste residue	
	Production method					
	Heap	Drum	Heap	Drum	Heap	Drum
100% NPK	253.40	248.00	328.50	333.40	140.30	183.40
75% NPK	213.60	178.10	307.50	313.40	128.50	171.15
0% NPK	155.600	143.30	282.20	297.80	120.10	164.16
CD(0.05)	4.527					

DISCUSSION

5. DISCUSSION

An investigation entitled "Production characterisation and quality assessment of biochar "was conducted to produce biochar from crop residues, to assess its characteristics and to study its effect on crop growth. Important results of the experiment are discussed in this chapter under the following major section.

1. Production and characterisation of biochar
2. Effect of biochar on the performance of amaranth

5.1. PRODUCTION AND CHARACTERISATION OF BIOCHAR

Large quantity of crop residues that are unsuitable for composting or the undecomposed portion left after the composting can effectively converted into biochar. With the objective of producing biochar from various crop residues and to study its agronomic suitability in crop production, the first experiment has been undertaken.

Biochar was produced from three crop residues *viz.* Woody wild growth, coconut petiole and herbal waste residue under two methods of production *viz.* heap and drum method. In heap method direct burning of biochar was done at a temperature of 300^0C but in drum method, biochar was produced by indirect burning and the temperature went up to 400^0C. The experiment on production of biochar revealed that the biochar recovery (Fig. 3) varied with the production method and materials used. Drum method has led to an increased recovery of 27 per cent compared to heap method. Biochar recovery also varied with production method. Srinivasarao *et al.* (2013) reported that biochar yield decreased with increase in time of partial combustion and this may be due to increased exposure to oxygen supply which might have contributed to volatilization of carbon. It was observed that biochar recovery varied with the materials used in this experiment. The recovery percentage was more in herbal waste. The thermal degradation of different materials are different and is based on the lignin and recalcitrant carbon content in the source materials. The amount of biochar produced from a given amount of biomass will be higher for lingo cellulosic (wood derived) biomass and the thermal degradation of cellulosic and hemicellulosic content occurs first (Xie *et al* 2015). It may assumed that the herbal waste residue left after the composting contains high lignin content and produced highest yield of biochar. Coconut petiole biochar in drum method recorded highest recovery. Temperature and feedstock played a major role in the recovery of biochar. Usually the biochar produced from technologies including gasification and pyrolysis which yield between 2 and 35 percentage by weight of biomass.

5.1.1. Physical characteristics

Physical characteristics such as bulk density, porosity and water holding capacity were observed (Table 10). Bulk density of biochar (Fig. 4) was significantly influenced by method of production and materials used and found that heap method recorded low bulk density compared to drum method. This may be due to the low carbon content of biochar in drum method. Brewer (2012) reported that biochar bulk density is low ie, around 0.2-0.5 g/cm3, but this can vary with feedstock and process of biochar production. Feedstocks or processes that result in low char carbon contents will have significantly higher densities due to the contribution of different minerals. Herbal waste showed significantly higher bulk density (0.74 g/cc). This may be due to the low porosity and low carbon content in herbal waste.

Porosity (Fig. 5) is an important character determining the water holding capacity of the materials. It was observed that production method and materials used had significant influence on porosity and water holding capacity (Fig. 6). Drum method of production showed highest porosity (56.2%). Among the materials, wild growth biochar had higher porosity (62.9%) and there by more water holding capacity (363.9%). According to Asai *et al.* (2009) biochar usually has high total porosity and it can retain water in pores and thus retain water balance resulting in better nutrient availability. Higher porosity was recorded in the drum method of production confirming the result of Bagreev *et al.* (2001), who detected significant increase in porosity with increase in temperature. The

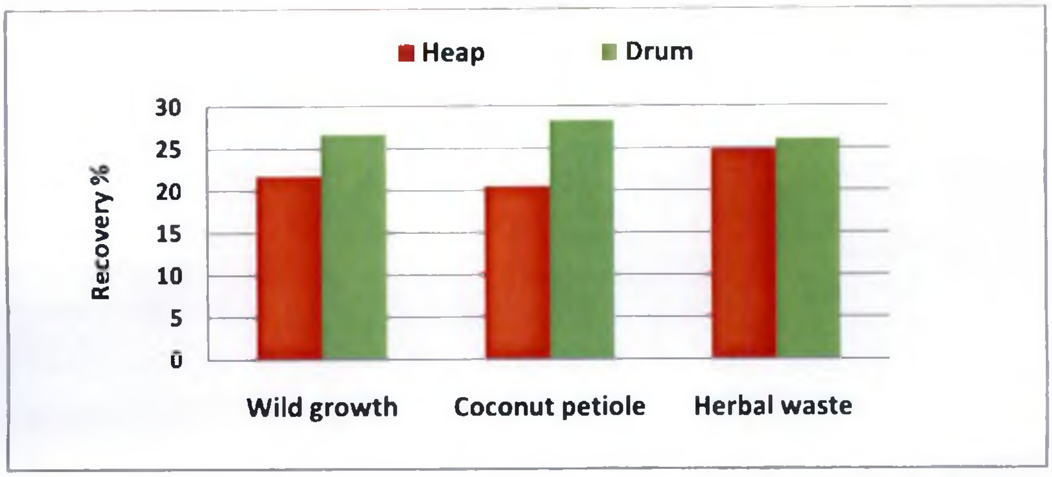

Fig. 3. Recovery % of biochar as influenced by production methods and materials

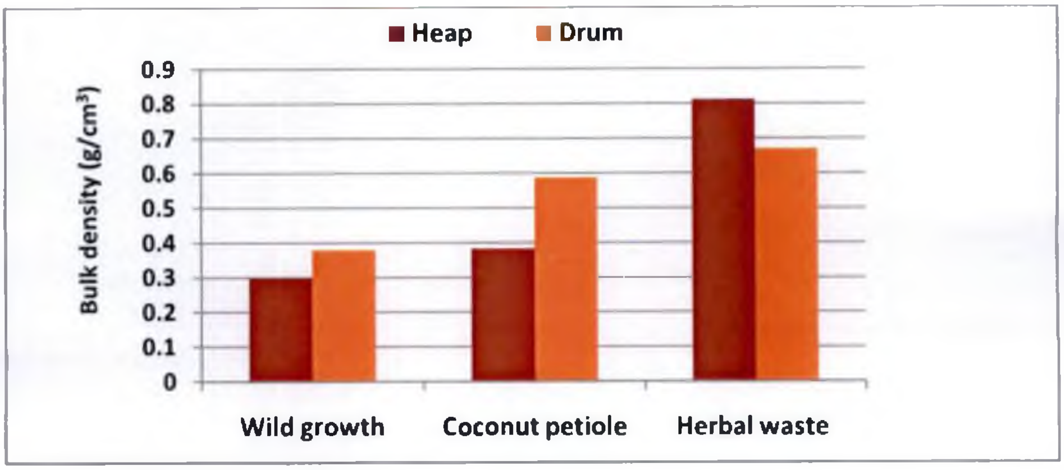

Fig. 4. Bulk density of biochar as influenced by production methods and materials

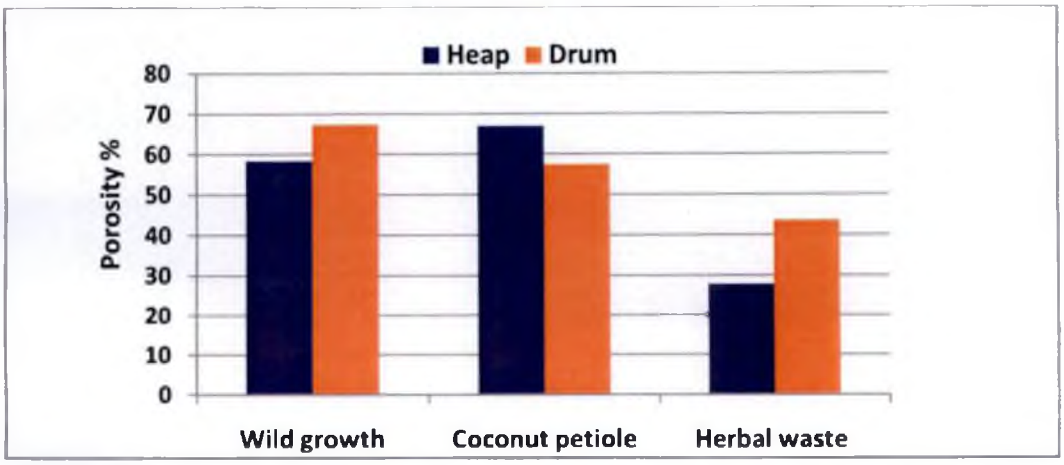

Fig. 5. Porosity of biochar as influenced by production methods and materials used

highest porosity in drum method and wild growth biochar resulted in significantly higher water holding capacity. Surface of high temperature biochar is hydrophilic in nature water holding capacity was highest in the wild growth produced from the drum method (377.19%) which showed maximum porosity(67.44%). Purakayastha *et al.* (2013) found that the water holding capacity of wheat biochar was highest (561%) followed by maize biochar (456%). The increase in porosity resulted in three fold increase in surface area resulted in increasing the water holding capacity of biochar materials.

5.1.2. Chemical characterization

Chemical characteristics such as pH, CEC, total C and total NPK were observed (Table 11). Production method as well as materials used showed significant difference in pH (Fig. 7). All the biochars recorded an alkaline pH. The resultant pH of biochar materials produced in drum method is significantly higher due to comparatively higher temperature in drum method (9.1). High temperature biochar resulted in higher pH which was noted by Gundale and DeLuca (2006). Coconut petiole biochar exhibited higher pH (10.0) among the different biochar materials and this may be due to higher concentration of alkaline metals present in the coconut petiole.

Cation exchange capacity (CEC) (Fig.8) gave an idea of nutrient holding capacity of biochar. The CEC of biochar varied from 5 to 10 cmols kg $^{-1}$. The highest CEC was noticed in coconut petiole biochar (10.37 cmols kg $^{-1}$) may be due to an increased concentration of alkaline metals (Ca, Mg, and K) and their oxides in the biochar. No variation was observed in CEC due to method of production. Cation exchange capacity of most biochar is relatively high, in part due to their negative surface charge and resultant affinity for soil cations including most heavy metals(Xie *et al.*, 2015). The CEC was not affected by the method of production because CEC varies significantly between terrestrial-derived biomass

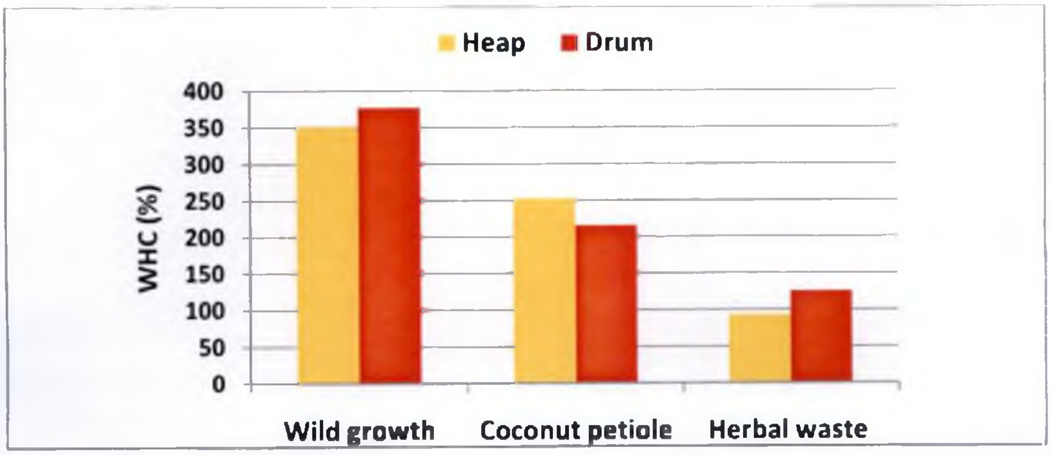

Fig. 6. Water holding capacity of biochar as influenced by production methods and materials used

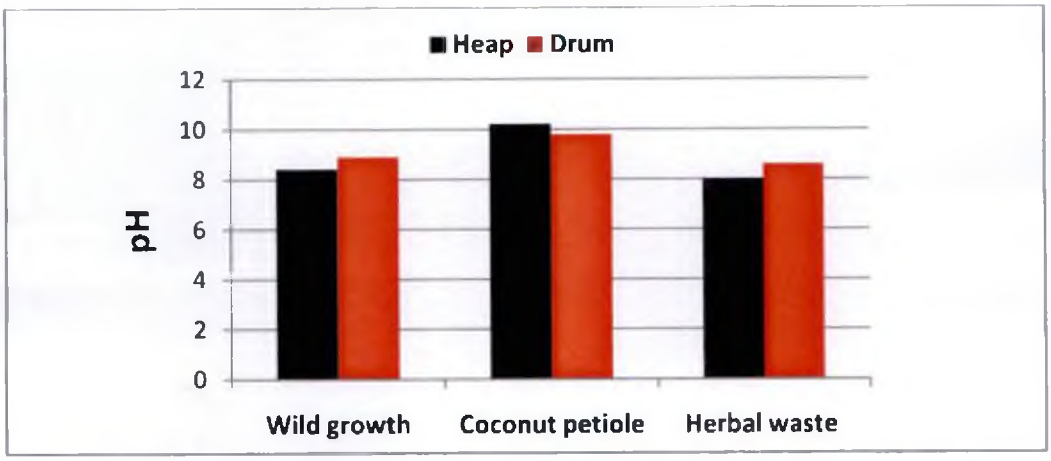

Fig. 7. pH of biochar as influenced by production methods and materials used

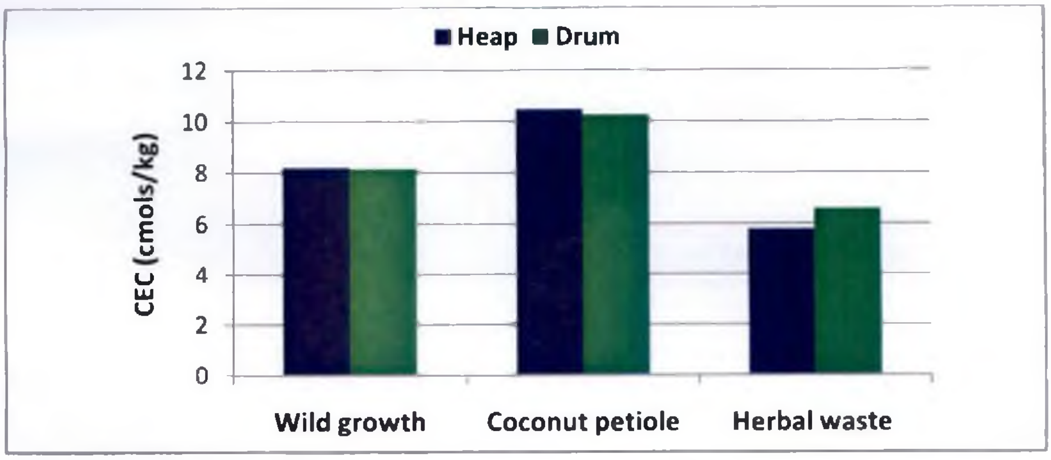

Fig. 8. Cation exchange capacity of biochar as influenced by production methods and materials used

from different feed stocks, ranging from 4.5 to 40 cmol kg $^{-1}$ (Uzoma *et al.*, 2011). High porosity also resulted in high CEC of the biochar materials.

Carbon content (Fig. 9) of biochar varied with production method and materials used for the production of biochar. Heap method of production recorded the highest carbon content (47.7%). According to Chun *et al.* (2004), with an increase in pyrolytic temperature, the carbon content increases while the oxygen and hydrogen content decreases indicating an increasing degree of carbonization of chars. As an exception to this general criteria, the total carbon content of heap method is significantly higher than drum method (more temperature). Feng *et al.* (2012) noted a similar result in the corn stock biochar with its total carbon content decreases with increase in pyrolysis temperature from 56.8% at 300^0C to 48.4% at 500^0C. Wild growth which had the lower recovery percentage had the highest presence of carbon. A similar result was obtained for the corncob biochar which had the lower yield with the higher presence of carbon (Stoyle, 2011).

Nitrogen content of the biochar (Fig. 10) varied with method of production and materials used. Total nitrogen content in the biochar materials was higher in the heap method (0.64%) than drum method (0.55%). De Luca *et al.* (2009) reported that biochar produced at higher temperature showed nutrient depletion due to volatalization. This may be the reason for decreased N content in drum method. Also N content in biochar generally decreases with pyrolysis temperature (Feng *et al.*, 2012).

The content of N was relatively stable for wood biochars like in case of coconut petiole biochar comparing with the N content in feedstock. In case of other biochars like wild growth and herbal waste an increase in N content was observed when compared with feedstock material (Table 1). This increase in N content can be explained by the enrichment of nitrogen containing compounds during pyrolysis (Keiluweit *et al.*, 2010). Even in some studies, N content was concentrated with charring temperature and duration, ranging from 0.97 to 1.73(Peng *et al.*, 2011).

Production method did not influence P content. Biochar materials showed variation in P content (Fig. 11). Biochar from woody wild growth recorded high P content (0.22%). P content in the biochar materials got decreased when compared to feedstock materials except in case of wild growth in which the P content increased. Usually in case of P, the content increases with pyrolysis as the P volatilise only at a temperature of 700^0 to 800^0 C but in certain cases during pyrolysis temperature increases and there will be loss of elements such as N, P and cations through volatilization which is accompanied by complex changes in the structural forms of carbon and microporosity of biochar materials (Chun *et al.*, 2004).

Potassium content of biochar (Fig. 12) produced from heap method was higher than drum method. This may be due to the higher temperature during pyrolysis in drum method. Biochar K content was higher than its feedstock except for coconut petiole. Exceptionally high K content of the coconut petiole was got reduced as a result of pyrolysis. Even then, coconut petiole biochar recorded the highest K content (0.63%). This may be due to the high initial K content in coconut petiole. Biochar produced through heap method recorded the highest K content (0.56%). The reduced K content in drum method may be due to elemental decomposition as a result of higher temperature. Similar to our result Sukartono *et al.* (2011) characterised the coconut shell biochar and noted that it contains 0.84 per cent K.

From the different characteristics studied the beneficial effects noted were high porosity,water holding capacity, carbon content and pH. High porosity and water holding capacity shows the water conservation effect of biochar. The high pH and alkaline nature of biochar increases its efficiency as a soil amendment in acidic soils. High carbon content may leads to increased C/N ratio and immobilisation of nutrients. Hence there may be less benefit to the crop

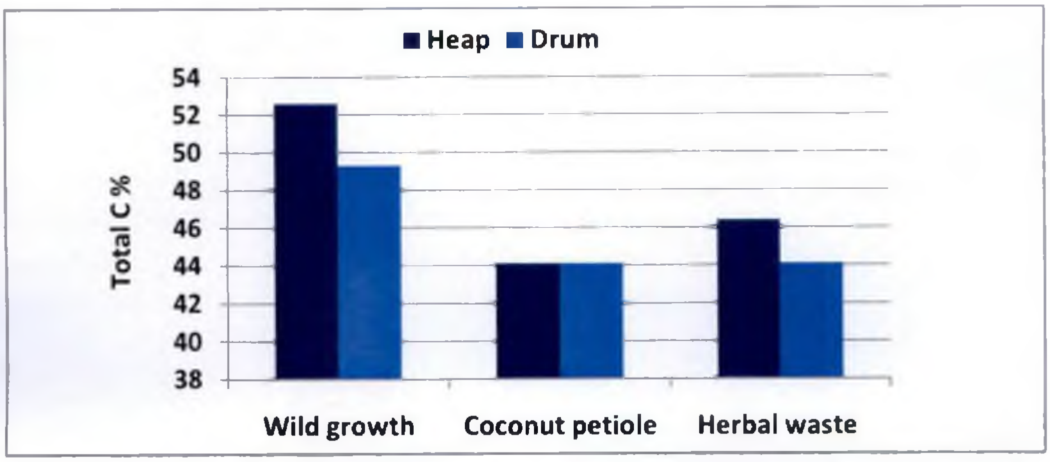

Fig. 9. Total C of biochar as influenced by production methods and materials used

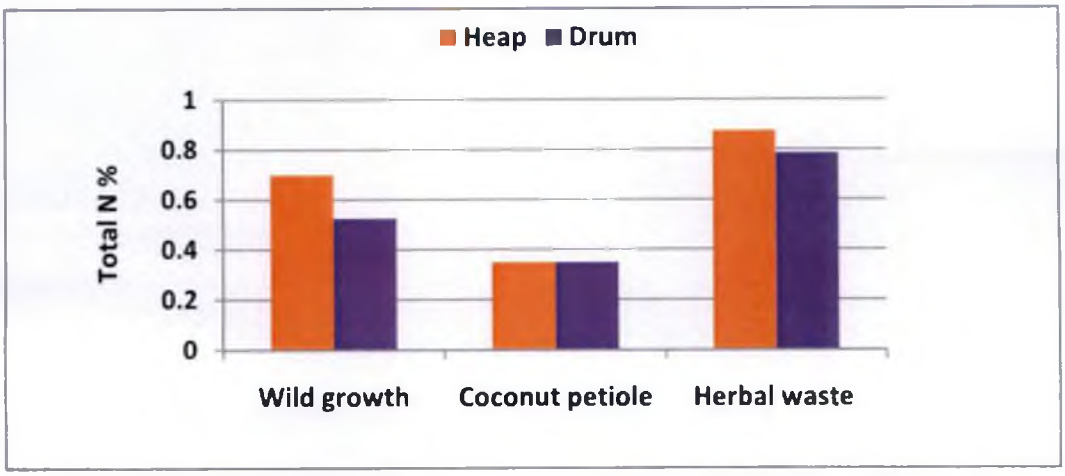

Fig. 10. Total N of biochar as influenced by production methods and materials used

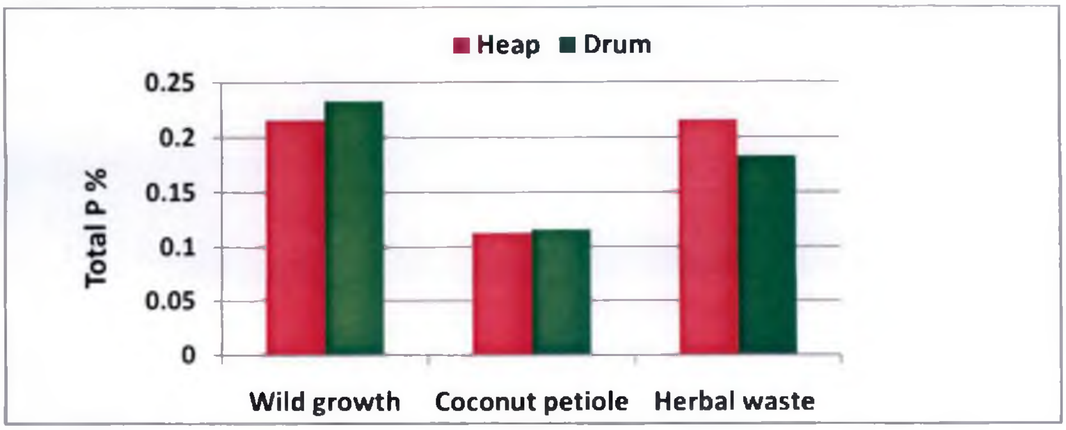

Fig. 11. Total P of biochar as influenced by production methods and materials used

immediately on addition of biochar but it has CEC, high carbon content and high macro nutrient content make biochar a better soil amendment.

5.2 EFFECT OF BIOCHAR ON CROP PERFORMANCE

The experiment to study the effect of biochar in the growth and yield performance of amaranth was conducted by raising amaranth crop in biochar produced by two methods of production and three materials with three levels of nutrients (100% NPK, 75% NPK and 0% NPK as per the recommendation). These were compared with ordinary potting mixture (sand, soil and FYM @ 1:1:1) receiving 100 per cent NPK. In the biochar treatments the potting media was prepared by mixing soil and biochar in 1:1 ratio. Results of the study revealed that the yield (Fig.13 ; Table 21)) and growth performance of amaranth was significantly higher in treatments receiving FYM and 100 per cent NPK recommendation (243.4 g plant $^{-1}$) as compared to all other biochar applied treatment. The increasing yield in potting mixture was may be due to the presence of cowdung which is a great source of essential nutrients for the plant growth. Easy availability of nutrients from cowdung due to the presence of organic matter content in the ordinary potting mixture resulted in increased NPK uptake and this resulted increased growth and the yield parameters of amaranth grown in ordinary potting mixture with 100% NPK. In biochar applied treatments organic matter was very low and because of the high carbon content the nutrients may be immobilized and prevented the immediate availability of nutrients to growth of the plant. The reduction in yield for the first crop was due to higher C/N ratio and high pH which reduced the availability of nutrients to the plants. Similarly, N immobilization after addition of fresh biochar has been observed by Bridle and Pritchard (2004), which decreased N availability and further resulted in growth depression.

Among the biochar applied treatments, the production method of biochar, materials used for biochar production and nutrient levels showed significant difference in growth and yield parameters. Drum method of biochar production

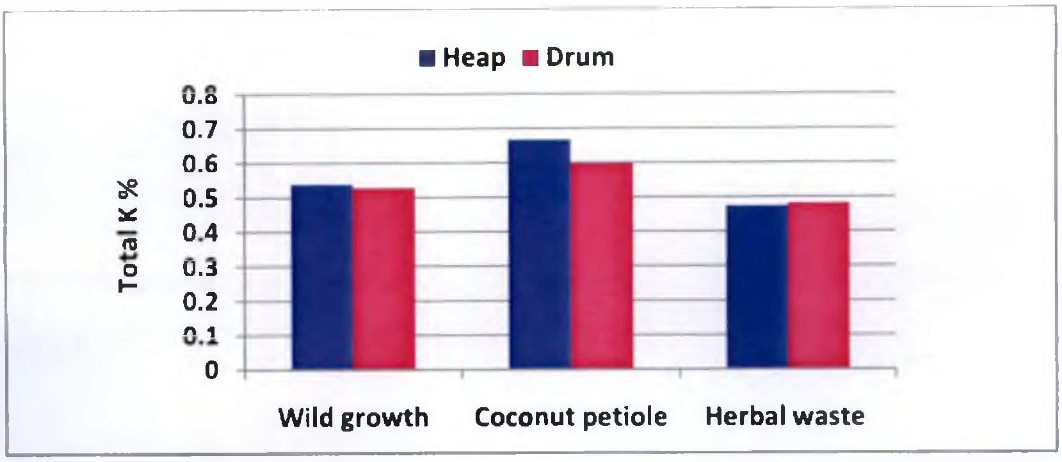

Fig. 12. Total K of biochar as influenced by production methods and materials used

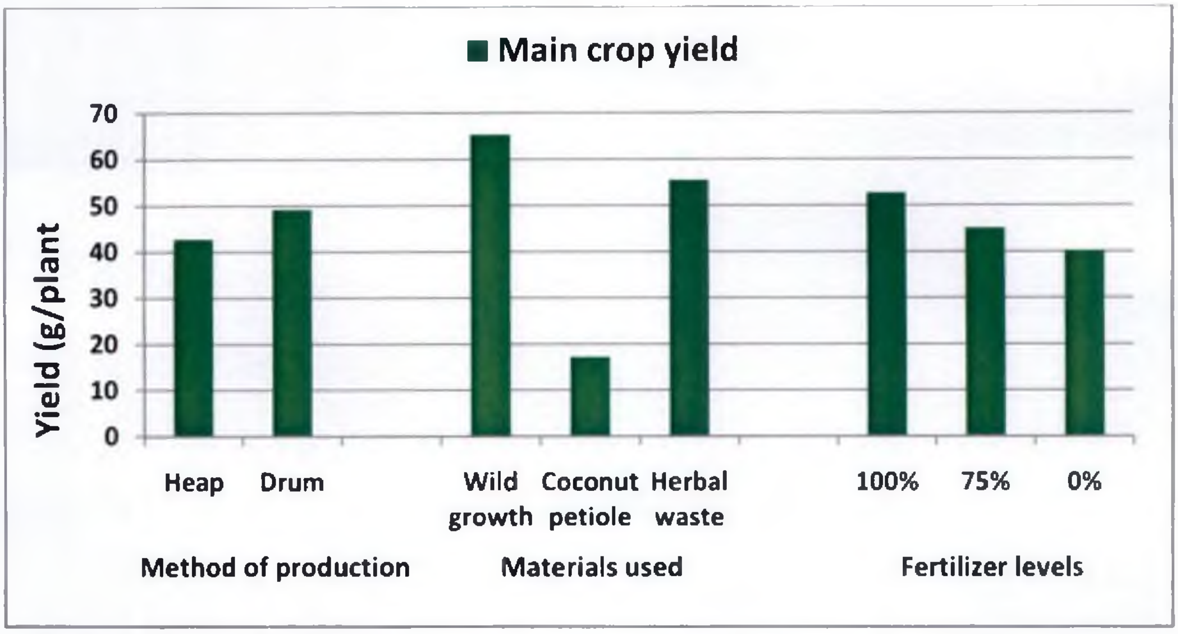

Fig. 13. Yield of main crop as influenced by production method, materials used and fertilizer levels

resulted in higher yield (49.2 g $plant^{-1}$) compared to heap method (42.7 g plant $^{-1}$). The yield increase of amaranth in the drum method may be due to the higher uptake of NPK compared to heap method. Growth parameters along with better nutrient uptake resulted in higher yield. Among the different materials used for the production of biochar, the yield was significantly higher in woody wild growth biochar(65.29 g plant $^{-1}$) may be due to the better development of growth parameters like plant height, number of leaves and number of branches. The better performance in woody wild growth biochar may be due to the better characteristics like high carbon content, low bulk density, high porosity and water holding capacity. The reduced growth and yield, for the coconut petiole biochar treated plants, were due to its reduced nutrient availability as a result of highly alkaline pH resulted in reduced NPK uptake. Biochar, along with 100 per cent NPK, resulted in higher yield (52.7 g plant $^{-1}$) and growth parameters. Biochar containing high carbon increased addition of nutrients which resulted in better nutrient uptake and in the better development plant growth parameters and this resulted in higher yield in the treatments which received 100 per cent NPK. Significantly strong (fertilizer x biochar) interaction was noticed in yield and resulted in higher productivity for the combination of biochar and fertilizer which showed a 60% increase over fertilizer alone (Tenenbaum, 2009). Growth and yield of the plant was significantly higher for the 100 per cent NPK along with biochar followed by 75 percent NPK and the least was for absolute control. Steiner *et al.* (2007) reported a doubling of maize grain yield on plots using a combination of NPK fertilizer with charcoal compared to use of NPK fertilizer alone. Similarly, Purakayastha (2010) also reported that application of biochar prepared from wheat straw at 1.9 t/ha along with recommended doses of NPK (NPK::180:80:80) significantly increased the yield of maize.

Poor growth and yield performance of amaranth in the biochar treatments without any nutrients revealed that biochar alone is not sufficient for meeting the nutrient requirement of crop. The nutrient content of biochar compared to FYM and other organic manures was less and because of high carbon content in biochar the plant availability of nutrient was significantly less in biochar treatments, with no addition of nutrients. The nutrient value of biochar alone was less compared to organic manures. Hence it cannot be considered as a substitution for organic manures in crop production.

After the harvest of the crop a residual crop of amaranthus was raised in the same pots to study the long term benefits of biochar on crop production. Compared to the yield of first crop, the increased yield of residual crop (Fig. 14 ; Table 21) was noticed in wild growth biochar. The yield of residual crop obtained from the wild growth biochar (130.8 g plant $^{-1}$) was even higher than the yield obtained from the ordinary potting mixture which received 100 per cent NPK. The yield obtained from other biochar applied treatments was also more or equal to that of previous crop. This indicated the long term effect of biochar. This also depends on the materials used for the production of biochar. This shows that biochar application to soil can provide increasing benefits over time. According to Glaser *et al.* (2002), the trend of sustained positive effects on plant growth could be related to a higher nutrient-retention capacity through elevated total organic carbon and biochar content. The results further confirm that biochar as a soil amendment can efficiently utilize the nutrients by holding ammonium ions in soils and inhibiting nitrogen fertilizer nitrification (Spokas *et al.*, 2009). It also has been hypothesized that the long term effect of biochar on nutrient availability was due to an increase in surface oxidation and CEC (Liang *et al.*, 2006).

The uptake (Fig. 15 ; Table 26) of N (0.14 g plant $^{-1}$) and P (0.026 g plant $^{-1}$) was higher for the plants in the herbal waste biochar due to its higher P content and relatively higher N content in plants that received the herbal waste biochar. The uptake of K was higher for the wild growth (0.17 g plant $^{-1}$) treated plants followed by herbal waste and least was for coconut petiole. The increase in K uptake in biochar amended soils might be attributed to the richness of K in the biochar. The uptake of N, P and K by the plants in the coconut petiole biochar was least and reduced yield might be the reason for that. The uptake of N, P and K by the plants in drum method was higher due to the higher growth of

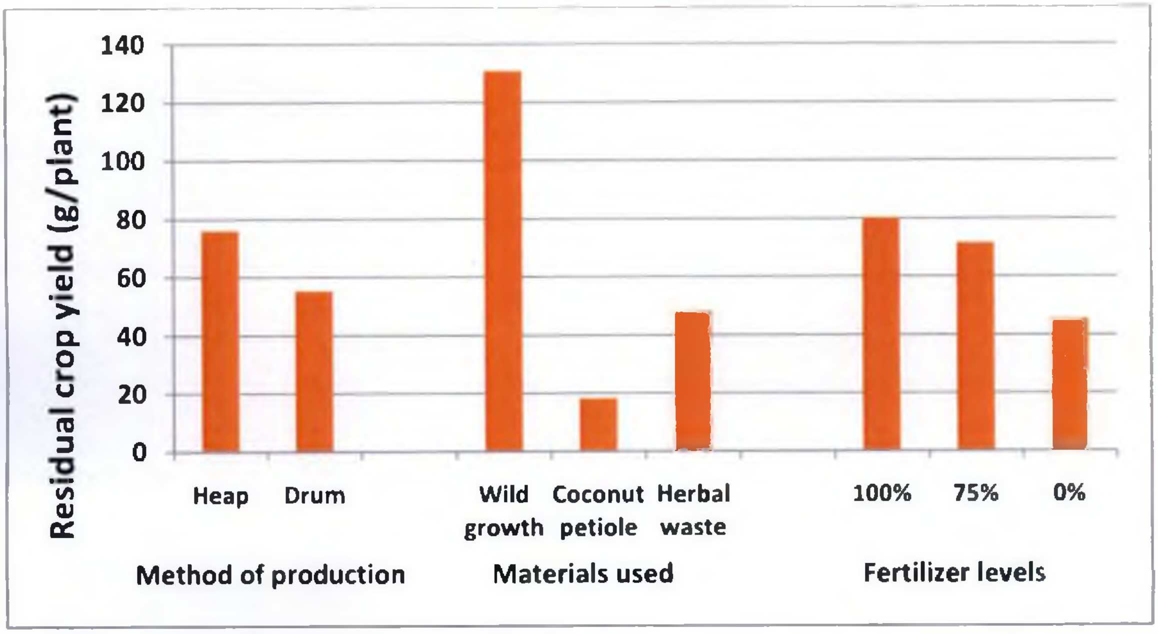

Fig. 14. Yield of residual crop as influenced by production method, materials used and fertilizer levels

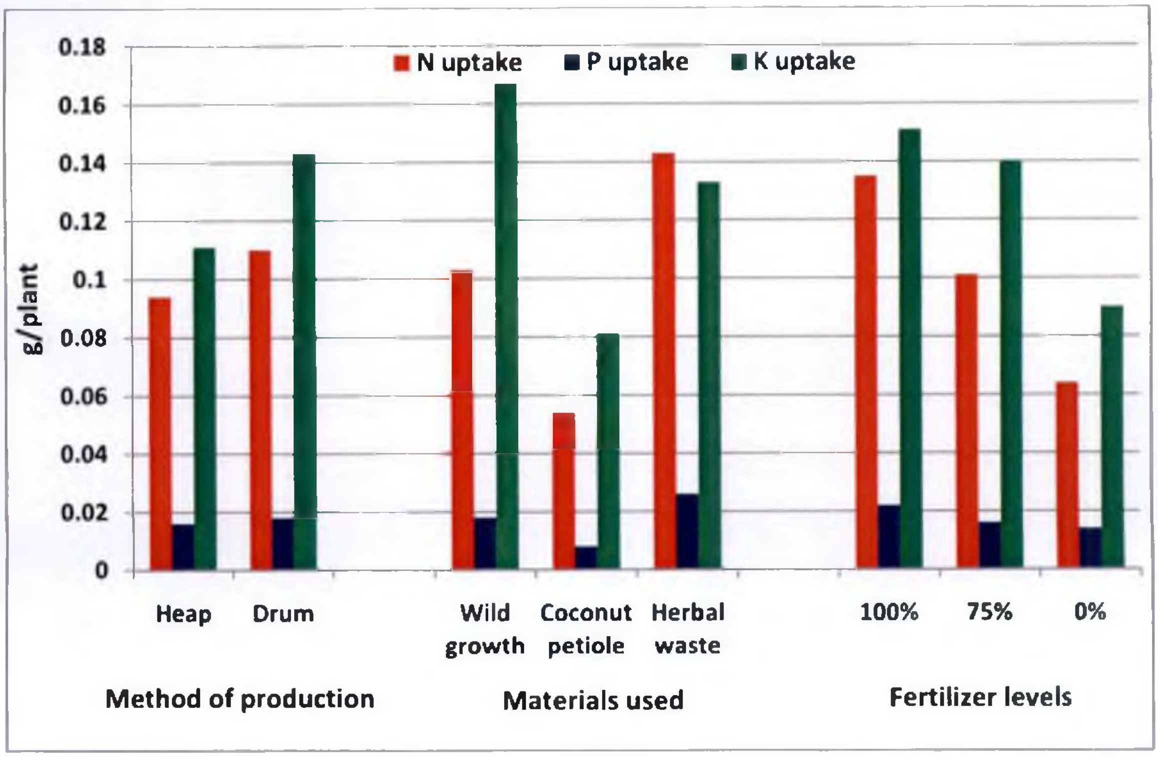

Fig. 15. NPK uptake of amaranth as influenced by production method, materials used and fertilizer levels

plants. The uptake of N, P and K was significantly higher for 100 per cent NPK followed by 75 percentage and the least was for zero per cent (absolute control). Higher nutrient content along with biochar increased the nutrient availability which may be the reason for the same. Combination of biochar along with fertilizers is the most promising means of management for good crop performance. The uptake of major nutrients was higher for the plants in the ordinary potting mixture when compared with biochar treated plants due to significantly higher yield than biochar treated plants. Glaser *et al.* (2002) concluded that crop growth and agronomic performance depended on biochar characteristics and its nutrient concentration as well as the soil and plant type. They concluded that the positive effects of biochar on yield were most marked in highly weathered and infertile tropical soils. While the yield fell over the course of four cropping cycles on all of the plots, the rate of decline in yield was significantly lower on charcoal amended plots than on those which received only mineral fertiliser (Glaser, 2001), which confirms the results of this study.

5.2.1. Effect on soil properties

The biochar treated plots showed the highest soil moisture during the experiment than the ordinary potting mixture. This can be attributed to the high water retention capacity of biochar due to high porosity and high specific surface area. Because of the high water holding capacity, irrigation was given once in three days compared to irrigating twice daily in ordinary potting mixture. From this it was clear that biochar can efficiently used for water conservation. Addition of biochar significantly influenced the pH of the soil (Fig.16). The soil pH got increased as a result of biochar addition. This increase in pH was associated with increased base cation concentration in the soil. Khanna *et al.* (1994) also reported the capacity of the ash material to neutralize the acidic soil. Jeffery *et al.* (2011) noticed a soil pH increase of 0.1 to 2 units after the application of biochar to soil that have a wide range of pH values. Alteration of soil pH has implications on nutrient availability (especially phosphorus) and mineralization. The higher pH was recorded for the soil treated with biochar in drum method (8.1) since it was resulted from high temperature. Usually high temperature biochar has high porosity and so high surface area. Porous nature of biochar increases the cation exchange capacity (CEC) with retention of more basic cations with higher pH in drum method. Coconut petiole biochar treated soil (8.5) recorded significantly higher pH because of the higher pH of coconut petiole biochar itself. Absolute control treatment recorded relatively higher pH may be due to the absence of application of acid forming fertilizers. High pH soils resulted in low yield due to the reduced nutrient availability in highly alkaline pH. The ordinary potting mixture remained in acidic to neutral pH which resulted in the high nutrient availability and yield. Increase in pH of the soil by the application of biochar leads to the possibility of using biochar as a soil ameliorant in acidic soils.

Addition of biochar resulted in increased organic carbon content (Fig. 17) of the soil except in the case of wild growth biochar which reported a similar organic carbon content as that of ordinary potting mixture. Higher organic carbon content could be resulted from the presence of high amount of carbon in the biochar. Reduced organic carbon content of soil in wild growth biochar applied treatments (1.76%) may be due to the increased decomposition of carbon of wild growth biochar compared to coconut petiole biochar. The high organic carbon content of coconut petiole biochar applied treatments (2.36%) may be due to the reduced decomposition as a result of the more stable carbon in the coconut petiole compared to other biochars. Organic carbon was found high in biochar treatments receiving 100 per cent NPK. This may be attributed to the reduced decomposition of organic carbon in high nitrogen receiving treatments.

Increased nutrient content of the soil in biochar applied treatments may be due to the increased retention of nutrients in biochar when compared to FYM. This revealed the nutrient retention capacity of the biochar and its sustainable nature in increasing the soil productivity.

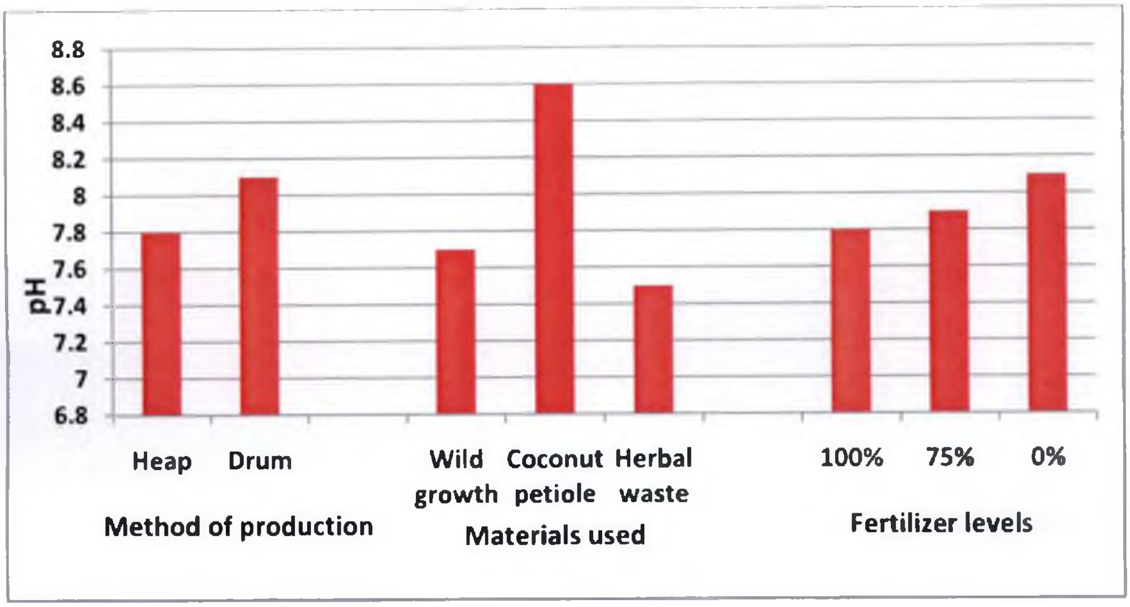

Fig. 16. pH of the soil after harvest as influenced by production method, materials used and fertilizer levels

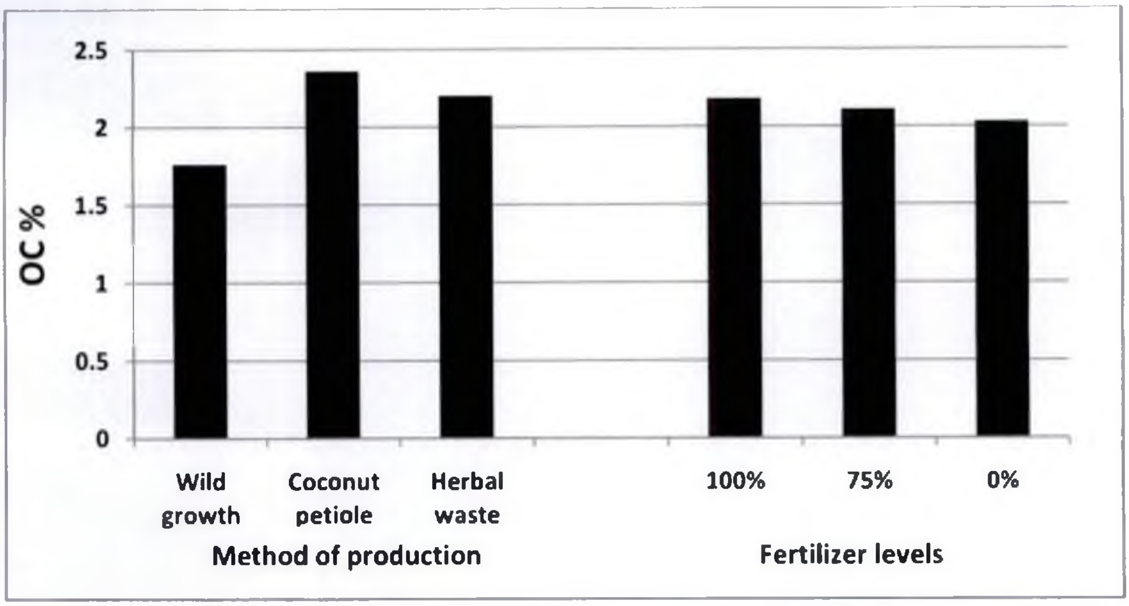

Fig. 17. Organic carbon content of the soil after harvest as influenced by materials used and fertilizer levels

Based on the growth and yield performance of the first crop and residual crop, wild growth biochar was proved to be more beneficial. The performance of crop grown in biochar was found to be better with the addition of required nutrients. Because of the high pH, it can be used to correct the pH in acidic soils. Due to the high water holding capacity biochar application helps to reduce the water requirement of the crops.

Available N (Fig. 18) and P (Fig. 19) were significantly higher in the treatment receiving ordinary potting mixture at 100 per cent NPK after the harvest of the first crop (95.26 mg/kg). This may be due to the presence of FYM and its mineralisation. Even though the plants in the ordinary potting mixture showed a reduced yield than the biochar treated plants during the residual crop may be partly due to the loss of nutrients in the potting mixture during the gap period of first and residual crop. The higher pH in the biochar treated soils reduced the P availability in soils. Variation in soil nutrient retention was noticed in the production methods and for the materials used in the production of biochar. Also the study by Schulz and Glaser (2012), reported that the biochar amendment had no significant influence on P retention. Highest available K (Fig. 20) was also noted in biochar amended pots compared to potting mixture as biochar itself is a source of potassium (Table 33). The reduced yield in biochar treated pots may be due to the N immobilization as stated for biochar in earlier studies (Lehmann *et al.*, 2003; Rondon *et al.*, 2007) resulted due to high C/N ratio. Available N was significantly higher for the heap method due to the fact that Nitrogen is the most sensitive of all macronutrients to heating; thus, the N content of high-temperature biochar is extremely low (Tyron, 1948). Available N was higher in the herbal waste biochar containing soil, after harvest because herbal waste biochar noticed higher total N content among the biochar produced. Available P was significantly higher for the wild growth biochar (9.94 mg/kg) among the biochar treated soils may be due to comparatively lower P uptake by the first crop. Due to the enormous quantity K in the coconut petiole biochar, plant available K was maximum in the coconut petiole biochar treated soils (310.47 mg/kg) after

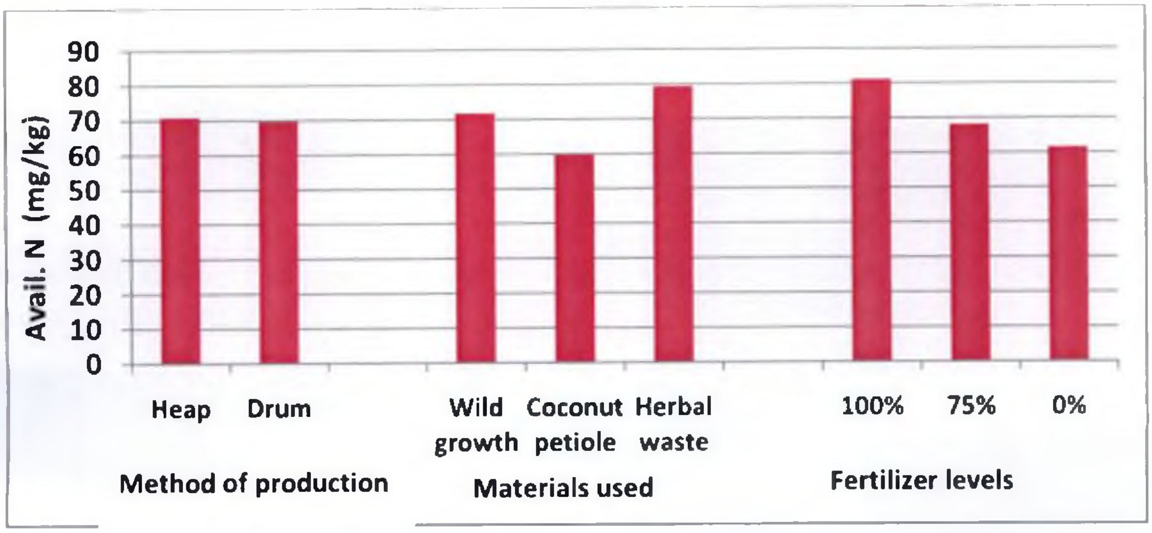

Fig. 18. Available N content of the soil after harvest as influenced by production method, materials used and fertilizer levels

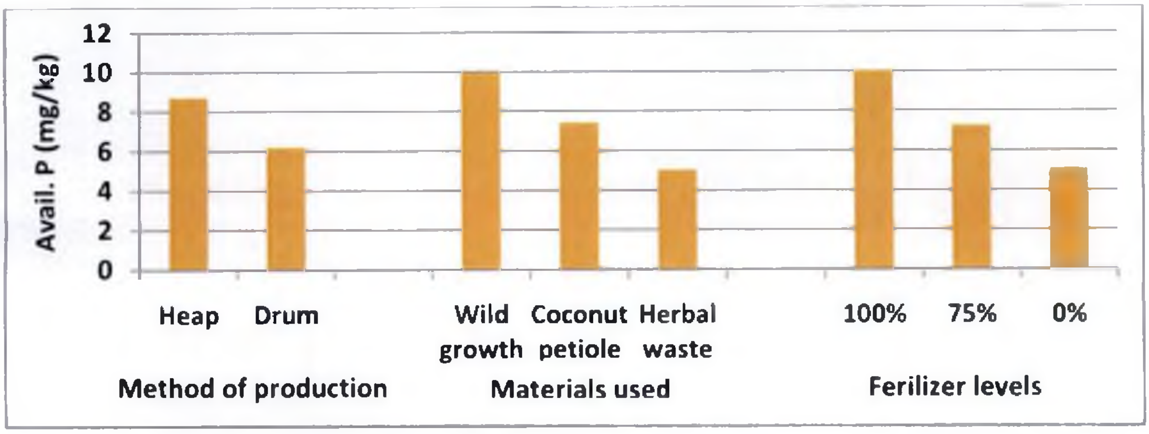

Fig. 19. Available P content of the soil after harvest as influenced by production method, materials used and fertilizer levels

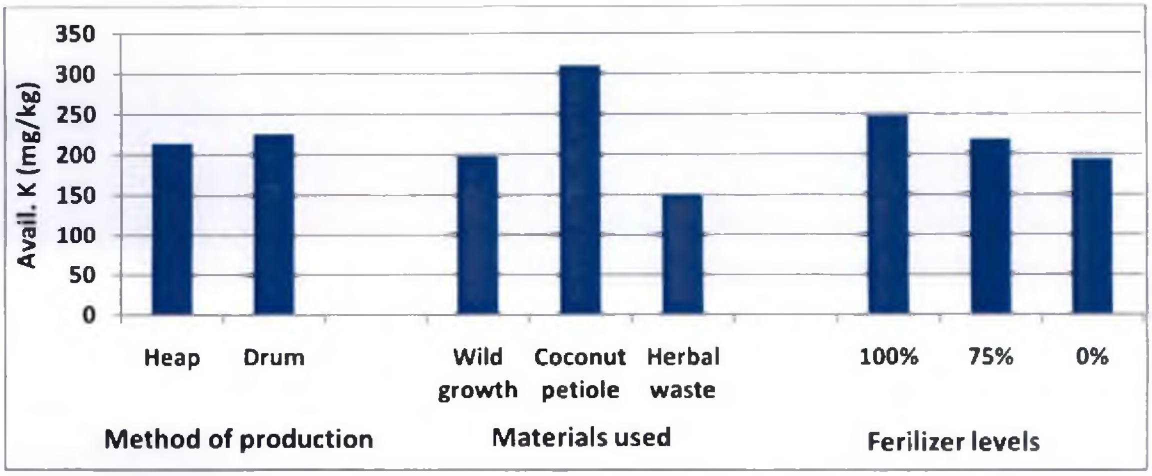

Fig. 20. Available K content of the soil after harvest as influenced by production method, materials used and fertilizer levels

harvest. Treatments received 100 percent NPK showed significantly higher quantity of available NPK after harvest followed by 75 percent and the least release of NPK was for absolute control. This confirms the fact that biochar is likely more important as a soil conditioner and driver of nutrient transformations and less so as a primary source of nutrients (Lehmann *et al.*, 2003).

FUTURE LINE OF WORK

- Standardisation of rate of application of biochar
- Studies to find out the long term effect of biochar
- Effect of biochar on crop growth while integrating with organic manures
- Effect of biochar on physical and chemical properties of soil
- Possibility of using biochar for conserving water and as an ameliorant
- Role of biochar in carbon sequestration

SUMMARY

6. SUMMARY

The present study entitled 'Production characterisation and quality assessment of biochar', was conducted at PPNMU, Vellanikkara, Thrissur during August 2014 to February 2015. The objective of the study was to produce biochar using different methods from different feed stocks, to study the characteristics of biochar and to assess the effect of biochar on crop production. The salient findings of the study are summarised below.

Biochar was produced using two different methods, heap and drum. The materials used were woody wild growth, coconut petiole and herbal waste residue. Recovery of biochar was significantly higher for drum method compared to the heap method of production. Among the different materials used for the biochar production, herbal waste gave higher recovery. The physical and chemical characteristics of biochar varied with the feedstock materials and the production process. Physical characteristics like bulk density, porosity and water holding capacity were recorded. pH, CEC, total carbon and total NPK were the chemical properties evaluated. Biochar produced using drum method recorded higher porosity and WHC than heap method. Woody wild growth biochar recorded lower bulk density, higher porosity and there by higher WHC compared to coconut petiole biochar and herbal waste biochar. Physical properties of biochar *viz.* low bulk density, high porosity and WHC may be useful in water and nutrient retention and make biochar a suitable material for water and nutrient management. Increased WHC of biochar helped to reduce the irrigation requirement.

All the biochar materials were alkaline in nature. Biochar produced using drum method recorded more pH compared to heap method. Biochar from coconut petiole was found highly alkaline compared to other materials used. CEC of coconut petiole biochar was higher due to the presence of Na, K, Ca, and Mg. Carbon content of biochar was significantly higher in heap method of production and for biochar produced from wild growth. Elemental composition (NPK) of biochar varied with materials used for production. NPK content of biochar produced showed an increasing trend compared to the feedstock NPK of woody wild growth and herbal waste. But N content of coconut petiole biochar remains constant as that of initial N of coconut petiole. In coconut petiole biochar, P and K content showed a decreasing trend compared to coconut petiole even then the K content of coconut petiole was the highest among the biochar produced from different materials.

Biochar produced by two methods *viz.* heap and drum using three materials (woody wild growth, coconut petiole, herbal waste residue) along with three levels of fertilizers (100%, 75% and 0% recommended NPK) were tested for its performance on growth and yield of amaranth. These treatments were compared with ordinary potting mixture receiving 100 per cent NPK. A residual crop was also raised in the same pots after the harvest of the first crop. The growth and yield performance of the first crop of amaranth was significantly higher when grown in ordinary potting mixture receiving 100 per cent NPK compared to biochar applied treatments. Production method of biochar showed no significant variation in the growth and yield of amaranth. Materials used for the biochar production and levels of nutrients added recorded variation in the growth and yield performance. Among the materials used, woody wild growth and among the nutrient levels, 100 per cent resulted in significantly higher yield. Crop performance under coconut petiole biochar was very poor due to high pH of coconut petiole biochar leading to non availability of nutrients.

For the residual crop, all the biochar treatments produced more or similar yield that of the previous crop. But for ordinary potting mixture, yield of residual crop was less. This showed the long term benefit of biochar in crop performance. With respect to different methods of production, heap method recorded significantly higher yield than drum method. Significant variation was noticed in yield among various materials used. Wild growth recorded higher yield and coconut petiole recorded lower yield. Significant difference was noticed in fertilizer levels with respect to yield. 100 per cent NPK recorded the higher yield and absolute control recorded the lower yield. Wild growth biochar produced by heap method received 100 per cent and 75 per cent NPK produced more yield than ordinary potting mixture received 100 per cent NPK.

Method of production, materials used and fertilizer levels had noticed significant variation in NPK uptake. Drum method of production and 100 per cent NPK application showed significant increase in NPK uptake. NPK uptake varied with materials used for production. N and P uptake was high in herbal waste biochar and K uptake was higher for wild growth biochar.

pH of the soil in biochar treatments were showed an increase of one to two units compared to initial pH. Hence biochar can be used as a soil amendment in acidic soils. Biochar from drum method of production, coconut petiole and biochar without NPK recorded higher pH. The yield reduction in coconut petiole biochar was due to higher pH which caused the nutrient unavailable to plants.

The organic carbon content of soil after harvesting of the crop got increased compared to the initial content. Coconut petiole showed the higher OC content and wild growth showed lower OC content in soil after harvest. Available nutrient content increased with biochar addition. Higher nutrient retention in biochar applied treatments showed the long term benefits of biochar in crop production.

This study confirms the fact that biochar may effectively used as a soil conditioner for the acidic soils of Kerala. The high water holding capacity of biochar may used for water constraints. The long term effect of biochar material in soil is to be highlighted in further researches.

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APPENDIX

APPENDIX

Economics of biochar production for a period of one month

	HEAP METHOD	DRUM METHOD
Fixed cost (Rs.)		
Fixed cost of tank for 100 Kg	1000	6000
Life period	10 years	6 months
Depreciation (10%)	1000	1000
Repair and Maintenance(2%)	200	
Total	1200	1000
Variable cost for 1 month (1.5 t crop residue) (Rs.)		
Cost of fuel materials		1110
Cost of kerosene	375	375
Labour cost	8250	12375
Interest on WC (7.5%p.a.)	54	87
Total variable cost	8679	13947
Total cost (Rs.)	9879	14947
Return from biochar (Rs.50/kg)	16875	21250
B:C ratio	**1.7**	**1.4**

PRODUCTION, CHARACTERISATION AND QUALITY ASSESSMENT OF BIOCHAR

by

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ABSTRACT OF THE THESIS

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ABSTRACT

Crop residues in fields can cause considerable crop management problems if they accumulate. Composting is a viable option for crop residue management. However composting of plant twigs and woody plant residues is difficult as they take longer time for decomposition. Conversion of crop residue biomass into biochar and using it as a soil amendment is a nascent approach and then suggested as an alternative to composting and crop residue burning. Biochar is produced by controlled burning of biomass with little or no oxygen, known as pyrolysis. Research information on biochar in agricultural use in India is scanty. Very few reports are available on production, characterization and use of biochar as soil amendment. The present study was proposed against this backdrop to produce biochar from crop residues and to study the effect of biochar on the performance of crops.

The investigation entitled 'Production characterisation and quality assessment of biochar' was conducted to assess the effect of production methods and materials used on the character of biochar and to study its suitability as soil amendment for amaranth. Woody wild growth, coconut petiole and herbal waste residues left after composting were the three materials used for biochar production. Biochar was produced using heap and drum methods. Biochar was characterised by percentage mass recovery and by physical and chemical distinctiveness. Methods of production and materials used had significant influence on the characteristics of biochar. Drum method gave higher biochar recovery compared to heap method. Porosity, water holding capacity and carbon content were higher in biochar produced from woody wild growth. All biochars showed alkaline pH with the highest pH in coconut petiole biochar. An increase in NPK content was noticed in biochar compared to the materials used.

A pot culture experiment was conducted to study the soil amendment effect of biochar on crop performance. The treatments consisted of six biochars produced from three materials using two methods of production, along with three levels of fertilizers *ie*, 100 per cent recommended NPK, 75 per cent NPK and absolute control(without any fertilizers). Biochar materials were mixed at a 1:1 ratio on volume basis with soil and assessed their effect on the growth and yield of amaranth. They were also compared with treatment of ordinary potting mixture receiving FYM and 100 per cent NPK. A residual crop was raised in the same pot after the experiment and the yield of the crop was noted.

For the first crop, the highest yield was obtained in the ordinary potting mixture which received 100 per cent NPK when compared with the biochar treatments. For the second crop, the highest yield was observed in the woody wild growth biochar receiving 100 per cent NPK. This indicated the nutrient retention property of biochar and its long term benefit. Biochar from woody wild growth recorded the highest carbon content, porosity and water holding capacity and produced better yields, among the different biochar materials. Biochar along with 100 per cent NPK recorded the highest yield compared to biochar treatments without fertilizers. Because of the high water holding capacity of biochar, irrigation could be given to the crops once in three days for the biochar applied treatments instead of twice daily as was done in ordinary potting mixture. Increase in pH of the soil was noticed after the experiment indicating its efficiency as a soil amendment in acidic soil. Beneficial properties of biochar like high carbon content, alkaline pH and high water and nutrient holding capacity revealed the suitability of biochar as a soil amendment.