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BIOCHAR FOR IMPROVING CROP PRODUCTION IN NEPAL

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ABSTRACT

Improving soil fertility and crop productivity is crucial to reduce food insecurity and poverty in Nepal. Biochar as a soil amendment has been found effective in increasing crop production. Here, we reviewed various biochar studies carried out in Nepal by different organizations and assessed future potential of biochar as an effective soil amendment. In this review, we have included the biochar pretreated (enriched) with nutrient or added separately in soil. We found that good quality biochar could be produced using the novel flame curtain metal and soil pit "*Kontik*" kiln with slow pyrolysis technology. Biochar produced from Kontiki found having high pH (9.8), organic carbon (OC, 72%), surface area (215 m^2g^{-1}) and cation exchange capacity (CEC, 72 cmol kg^{-1}). Further, biochar application improved soil chemical properties (pH, OC, CEC, base cations) and nutrient availability such as available phosphorous (P) and potassium (K). Similarly, biochar addition increased crop yield significantly compared with non-biochar plots. Higher crop yield was achieved when biochar was enriched or charged with cattle urine. Thus, from this study, we suggest that biochar should be prioritized in government programs as a potential soil amendment and scale up or increase its use at farm level.

Keyword: Biochar, Kontiki, Urine charged biochar.

INTRODUCTION

Soil is the dynamic living integument of the planet, Earth. It is responsible for various biogeochemical process such as nitrogen and carbon cycling in the biosphere influencing both agricultural production system and the environment. Moreover, soil is the habitat for all living things (flora and fauna) in the biosphere, thus plays an important role in conserving the biodiversity and delivering ecosystem functions (Adhikari and Hartemink, 2015). Ninety five percent of our food comes from soil and 99% of all the freshwater passes through soil (FAO and ITPS 2015). Therefore,

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maintenance of soil fertility is critical for producing more food and functioning ecosystem services. This is important to achieve sustainable development goals and meet the global food demand that needs to be increased by 70% to feed extra 2.5 billion population by 2050 (FAO 2009). However, in many areas, adoption of soil conservation and management measures is poor leading to lower productivity.

In recent years, many studies have focused in assessing various soil management strategies including the use of biochar as a soil amendment to improve soil fertility and condition vis-a-vis crop productivity. Biochar is a fine-grained charcoal produced through the thermal decomposition of organic feedstock (pyrolysis) at low temperature in absence or limited supply of oxygen (Lehmann, et al., 2006). Biochar enhances the soils physical and chemical properties such as bulk density, porosity, surface area, nutrient content, soil aggregation, cation exchange capacity (CEC), pH, and soil organic carbon content (Pandit et al., 2018 and Schmidt et al., 2015). Worldwide, most of the studies have shown positive effects of biochar amendment on increasing soil fertility and crop yield. However, some studies have reported non-significant or even negative effects, mainly in a fertile soil and temperate region (Jeffery et al., 2011). Similarly, biochar can play an important role in climate change mitigation as a result of reduced harmful greenhouse gases (GHGs) emissions such as CH_4, CO_2, and N_2O from the soil (Zhang et al., 2019). Biochar is recalcitrant in nature (highly resistant to decomposition) and can remain stable for thousands of years in the soil, thus, can be a potential mean of carbon sequestration to mitigate the global warming potential (Woolf, 2008).

In Nepal, the majority of soils range from low to medium category for organic matter (OM), total nitrogen, available phosphorus (P) and potassium (K) including more than 55% soils, acidic in the nature (Bajracharya et al., 2009). In mid-hills, Nepal, large amounts of soil nutrients are lost through erosion, drainage and run off resulting in down streams and tropospheric pollution through greenhouse gas (GHGs) emissions (Raut et al., 2010). As a result, soil fertility and nutrient status is depleted attributing to lower crop productivity resulting poor connectivity with soil due to migration. Soil has been continuously mined without supplying adequate nutrients taken up by crops, which rendered loss of soil's capacity and condition to function properly. Therefore, the conservation and sustainable management of soil is critical to increase crop productivity and feed the growing population successfully.

Towards this end, biochar as a soil amendment holds the potential to address most of the soil's fertility challenges in Nepal (Dahal et al., 2016 and Vista et al., 2017). Therefore, Nepal Agricultural Research Council (NARC) in association with Nepal Academy of Science and Technology (NAST), Landell Mills,United kingdom, and Ministry of Agriculture and Livestock Development initiated a research on biochar at various locations taking more than 20 crops for testing this technology. Beside these, other research has been carried out on biochar by Agriculture and Forestry University, Kathmandu University, Nepal Agroforestry Foundation (partnership with

Norwegian Geo-technical Institute, Norway) and other I/NGOs. The main objective of the research was to test the potential of biochar as a soil amendment to improve crop productivity in a low fertile Nepalese soil. This paper highlights some of the suitable research findings adaptable in Nepalese context.

Production of Biochar

Various feedstocks and kilns (pyrolysis technologies) were used to produce a biochar. At Matatirtha, Nepal, biochar was produced with *Eupatorium* spp (Banmara) from different kilns, i.e., flame curtain *"Kontiki"* kilns (four sub types: deep-cone metal kiln, steel-shielded soil pit, conical soil pit and steel small cone kiln), brick-made traditional kilns, traditional earth-mound kilns, and top lit up draft (TLUD) kilns and were tested for its physical and chemical properties (Pandit et al 2017). Chemical properties of biochar produced from these kilns including four sub-types of flame curtain meets the premium quality of the European Biochar Certificate (EBC). Furthermore, among these kilns, flame curtain *"Kontiki"* was found environmentally (low GHG's emissions during production process) and economically viable (conical soil pit) for small holders' farmers (Cornelissen et al., 2016 and Schmidt et al., 2015).

In NARC research stations, biochar was produced by using a low cost, novel flame curtain "*Kontiki"* originally developed by Schmidt et al., 2014. Conical soil pit "*Kontiki*" was dug in the farmers field to produce biochar according to the availability of raw materials available at the site. Agriculture residues, maize stalk and cobs, weeds, twigs of *Banmara* (*Lantana camera)*, saw dust, rice husk, bamboo, etc., were used as feedstocks for preparing biochar. In some areas, where firewood is not limited, they were also used as a feedstock. Pyrolysis of biomass is carried out following the principle outlined in Schmidt et al., 2014 and 2015. The process of biochar preparation is quite similar to that of *yajna*, *(*a Hindus tradition where fire is lit with the help of *Shorea robusta* wood and gradually a mixture of ghee, rice, and grains were added which in turn converted to charred materials called *'Charu'),* generally done during any ritual and cultural ceremony (Fig. 1).

Figure 1: Production of Biochar

The whole layer of the feedstock is piled near the conical pit and initially, some hardy woods are kept below the piled layer in storied structure so that enough aeration is possible. At the top, easily combustible materials are kept and lit the fire, wait for certain time till all the feedstock catches fire. This will form first layer of burning feed stock at the bottom. Then, feed stock layers are added gradually in the burning flame without letting them to burn completely. Below the burning flame, carbonization of the feedstock occur (pyrolysis process) as the oxygen is consumed above the flame. Similarly, all the feedstock is pyrolysed and it is quenched either with water or cattle urine available at the site. However, we recommend quenching with cattle urine so that urine charged biochar is prepared. For conical soil pit biochar, pyrolyzed layers can also be covered with the soil (spreading soil uniformly at the top) to stop further burning and kept overnight to cool down. After cooling, the biochar is harvested the next day morning and stored for further usage.

Processing of Biochar

Biochar can be applied in soil with or without crushing. However, it is advised to crush the biochar into fine particles so that the surface area is increased by many folds (Fig.2). The moisture content should be low or dried before crushing. Dried biochar is easy to crush and forms fine powder. Farmers generally used local mortar and pestle for crushing. Paddle driven portable crushing machine is also available. Those farmers who can afford it, used crushing machine to make the biochar into fine powder. After crushing, the powdered biochar is charged or quenched with cattle urine or mineral nutrients. Nutrient enriched biochar with chemical fertilizers or urine can be stored in the sacks in dark room and can be used when needed. The storability of the biochar is high but generally, it is recommended to apply fresh biochar in the field.

Figure 2: Crushing of Biochar locally

Properties of biochar

Various types of feed stocks and pyrolysis technologies used during biochar production process may affect the physicochemical properties of biochar (Cornelissen et al., 2016). In general, intrinsic properties of biochar produced with *Eupatorium* feedstock (*Banmara*) was alkaline in nature (pH ranging from 9.3 to 10.2) and contains higher amount of organic carbon (ranging from 70 to 76%), surface area (215 m^2/g) and CEC (72 cmol/kg) (Pandit et al., 2017, Cornelissen et al., 2016, Schmidt et al., 2015). The results focused improvement in soil condition through reclaiming acidity by the use of biochar. The cumulative effect of applied biochar would retain soil moisture for longer period thereby improving its capability. Biochar also contains pollutant such as polyaromatic hydrocarbons and the value was ranged from 2.3 to 4.9 mg kg^{-1}, which was within the threshold level to meet the premium quality outlined in European biochar certificate (EBC). Thus, biochar produced from *Eupatorium* feed stock with flame curtain "*Kontiki"* was of good quality that meets the premium quality of EBC.

Charging of Biochar with cattle urine

Biochar per se is not a source of nutrients, but is a good soil conditioner, which can improve soil fertility thereby increasing water and nutrient use efficiencies in soil. Due to porous structure of biochar, it has almost 600% of the water absorption capacity along with high nutrient absorptivity. So that most of the nutrients in cattle urine absorbed by biochar and supply to crops slowly as per plant demand.

When biochar is enriched with cattle urine, the biochar serves as a carrier material, holding the nutrients in its highly porous structure, which in turn, may slow down leaching of mobile nutrients, particularly in sandy soil where the water retentions are low and leaching is very high. The quantity of cattle urine for charging depends on the quantity of biochar and cattle urine available. Higher the quantity of cattle urine used for charging, more will be the nutrients in the Urine Charged Biochar (UCB). After charging the biochar with nutrients, it is ready for application in the field (Fig.3).

Figure 3: Urine Charged Biochar

UCB application in the field

Application of UCB in the soil depends on the type of the crops to be grown. In general, our research has shown better results when it is applied in the root zone (15 to 20 cm depth). In crops that require transplanting, it is better to place the UCB in the dibbled hole and slightly covered with some soil and transplant over it. Care should be taken that the roots of the newly transplanted seedlings do not directly touch the UCB, which may affect the tender roots. However, in case of line sowing, UCB applied in line and covered by a thin soil layer, and over it, sowing or transplanting should be done. Even, broadcasting can be done but UCB should be incorporated immediately into the soil after it is broadcasted (Fig.4).

Figure 4: Application of UCB in the field

Dose of application of Biochar

Numerous studies carried out in different parts of the world with varying biochar rates have shown different levels of crop production at different rates. The dose of biochar varies with the types of soil and crops to be grown. Pandit et al. (2018) investigated six different biochar dosages (0, 5, 10, 15, 25 and 40 t ha^{-1}) in multi-season field trials with maize-mustard cropping system in Rasuwa, Nepal and reported 15 t ha^{-1} biochar as the optimum dose for maize production. Biochar dose was calculated taking agronomical, economic and environmental effect of biochar into considerations. In another study conducted by Gautam et al. (2017), biochar applied at 5 and 20 t ha^{-1} increased coffee and vegetables (radish, chilli, soyabean and garlic) production significantly compared with control. Taking into account the soil health and biological activities, 30 tha^{-1} is recommended for Khumaltar condition by NARC (Vista et al., 2017). Some researchers found that with increased rates of biochar application, the soil properties have been improved significantly thereby increasing the crop productivity. Upadhyaya, et al. (2020) found that the application of biochar enhanced potato yield, however, the research could not determine the exact dose of biochar for potato. Vista and Khadka, (2017) observed that the appropriate biochar dose based on the earthworm persistence, was 30 t ha^{-1}. It is suggested that the application of biochar at 30 tha^{-1} may not be economical to the farmers. Therefore, it should be added in a closed cycle in each crop and in each cropping system till 30 tha^{-1} is reached. With proper application technology, even small amounts of biochar can provide multifaceted benefits to soil and crops. Schmidt et al. (2015) reported increased pumpkin yield in Dhading with the use of 1 t ha^{-1} biochar when it is urine enriched and applied at the root zone. Hence, continuous application of biochar in small quantity adopting appropriate technology is recommended for the farmers in Nepal.

Changes in soil properties due to Biochar application

The effects of biochar on soil properties depend on several factors, such as feedstock type, pyrolytic condition, application rate, and environmental condition. Biochar application had considerable influence on pH of the soil (Vista and Khadka, 2017). The increase in soil pH was seen to be directly proportional to the amount of biochar (pH 10.2) applied to the soil (pH 4.9). It is evident that the application of biochar can remediate soil acidity problems in most acid soil as it increased the soil pH from 4.9 to 5.6 when 50 ton of biochar was applied to the soil. Soil pH was increased from 4.6 to 5.0 with the use of 15 tha^{-1} biochar in a moderately acidic soil (Pandit et al., 2018). Improved soil pH suits most of the preferable crops grown by farmers. This indicates that most of the crop's problems due to acute acidity are minimized and thereby preventing outmigration resulting intact soil connectivity. Soil organic carbon content and available potassium content were found to be increased in the soil treated with biochar indicating greater increment with higher dose of biochar. Results further revealed that application of biochar has no effect on the dynamics of phosphorous availability. This may be due to acidic soil condition where P remains unavailable. However, in the study conducted by Pandit et al. (2018), soil available P was increased with biochar amendment (15 t/ha) which could be due to a confounding effect of pH (biochar increases pH and makes more P available). Similarly, in another study by Gautam et al. (2017), available P was increased with biochar and farmyard manure addition (5 and 20 t/ha, respectively). The effect of biochar on available P may vary, depending on the rate of biochar, soil type and soil acidic conditions. Timilsina et al. (2017) reported significantly higher soil pH, including other soil properties such as soil organic matter, total nitrogen, available phosphorus, and available potassium with the addition of biochar. Furthermore, Jaishi, 2020 found that application of UCB improved soil chemical properties. Soil pH, EC, CEC, SOC stock, total N and available P and K content in soil were found higher with the treatment UCB 100%. Similarly, the plot treated with higher rate of UCB had decreased the leaching of NO_3^-.

The bulk density of the soil decreased with the application of 20 ton per hectare of biochar (Timilsina et al., 2017). The bulk density and porosity of soil was significantly affected by application of UCB (Jaishi, 2020). The lowest soil bulk density (1.00±0.02 g cm^{-3}) and the highest (56.46±0.53 %) porosity was obtained from UCB 100% application, indicating that UCB improves the soil physical properties. A similar increasing trend was obtained for soil moisture content upon biochar application. The soil treated with UCB 100% had the highest soil moisture content (13.52±1.12 %) and water holding capacity (33.68 ± 0.94 %) compared to other treatments adopted for the experiment by Jaishi, 2020. The highest infiltration rate (0.2169 mm/sec) was found in UCB 75 % + Recommended dose of NPK 25 % followed by UCB 100% which showed that UCB or application of biochar has a great influence in improving soil physical and chemical properties.

Effect of biochar on crop production and productivity

According to Vista et al. (2016), research carried out at various sites of Nepal, fields treated with biochar showed significantly higher yield of vegetables (cauliflower, cabbage, pumpkin, chilly, potato, tomato, etc) compared with fields without biochar indicating necessity of mass awareness about biochar promotion at local level. However, in this study, significant increase on yield was not observed in rice, barley and ginger. Similarly, Jaishi, 2020 reported significantly higher yield of cauliflower by the combined effect of UCB and chemical fertilizers than their sole application. Both curd and biological yield of cauliflower was significantly increased by the application of UCB. Moreover, Upadhyaya et al. (2020), found significantly higher yield of potato with the application of biochar. The application of biochar significantly increased the biomass, root, and shoot yields of radish (Timilsina et al., 2017).

In the multiyear field trials conducted by Pandit et al. (2018) over three years period with maize-mustard in Rasuwa, biochar addition showed significantly higher yield of both maize and mustard compared with control treatment (without biochar). In this study, biochar addition increased soil chemical properties (pH, SOC and CEC) and available P, which in turn, increased crop productivity. The results indicate that biochar addition significantly reduce crop nutrient stress and increase the crop production in moderately acidic Nepalese soil. Result from field trials was further confirmed with mechanistic study performed under controlled greenhouse conditions using the same soil where biochar addition increased available nutrients and increased maize growth significantly. Similarly, another study conducted by Gautam et al. (2017) in Bhaktapur, biochar addition significantly increased production of coffee and vegetables (chilly, garlic, radish and soyabean).

Biochar effect on crop yield was observed to be higher when biochar was enriched with mineral or organic fertilizers than applying biochar and nutrient separately in soil. Pandit et al. (2017) reported increased maize biomass production ($p<0.05$) when biochar was enriched with mineral NPK fertilizers compared with fertilized control and separate application of biochar and NPK. In this study, enriched biochar increased maize biomass production by 108% compared with fertilized control (only NPK). Similarly, biochar enriched with cattle urine produced significantly higher pumpkin yield compared with only urine and NPK treatments in Dhading, Nepal (Schmidt et al., 2015). Furthermore, Schmidt et al. (2017) conducted multi-location field trials (21 field trials) with 13 different crop species across Nepal and found significantly higher crop yield with nutrient (organic) enriched biochar compared with fertilized control receiving the same amount of nutrient inputs. In this study, average yield was increased by 20 ± 5·1% with NPK-charged biochar compared with only NPK treatment. Yields significantly increased when biochar was enriched with organic fertilizers (urine/manures), an average yield increase of 123 ± 76·7% compared with organic fertilizers alone. In this study, organic-enriched biochar outcompeted NPK-charged biochar in three primary and one village trial with three different crops showing an average yield increase of 103 ± 12·4%. The comparatively low but highly significant yield increases in the NPK-biochar treatments compared with NPK ranged from 15 ± 8·7% in potato trial, 16 ± 7·8% in onion trial, 22± 17·1% in maize trial, and 28 ± 14·6% in tea trial (Schmidt et al., 2017).

Synthesis of Biochar research findings in Nepal

Biochar improves soil physical, chemical and biological properties, thereby, increasing production of most crops and vegetables. Introducing biochar as soil amendment could sustain production and productivity of major crops thereby leading towards better utilization of ecosystem services and sustainable use of natural resources. Biochar performs well in acidic and/or sandy soil and best fit for river basin farming. This indicates better connectivity of ethnic people living nearby river basins with soils. However, it is less effective under waterlogged/submerged soil conditions. Biochar needs to be enriched with mineral or organic nutrients to improve soil fertility and condition, and crop production. UCB can be a viable option as organic based fertilizer in countries like Nepal. Since, Nepal does not have its own chemical fertilizer plant, the efficiency of nutrients can be increased when blended with biochar. Hence, biochar is a potential soil amendment which can improve overall soil properties thus improving the crop productivity with multitude environmental benefits. This multidimensional benefits about biochar should be formally introduced in educational curricula and hence, regulations focusing massive utilization of biochar should be formulated at local level.

Prospects of UCB to substitute Chemical Fertilizer

There is a good prospect for preparation of UCB in Nepal as large numbers of cattle are reared by farmers. According to the data of MOALD, 2076, Nepal has 795,530 cows and 1,372,905 buffaloes totaling 2,168,435 cattle. On an average, a cow urinates 13.2 liters per day that is equivalent to 4,818 liters of urine per year. 100 liters of cattle urine contain 1.5 kg of nitrogen, 0.5 kg of phosphorus and 2 kg of potassium along with oligo elements and more than 4,000 metabolites. Considering these values, it can be estimated that a farmer with a single cow can prepare UCB that can substitute 100 kg of urea using the cattle urine. If all the cattle urine in the country is collected and utilized, it could substitute 217,000 tons of urea, which is more than the amount of urea imported in Nepal during 2075/76 (215,733 t It has a good potentiality as Nepal has abundant raw materials for preparation of biochar and also for collection of cattle urines. The preparation method and handling are easy and suitable for farmers of Nepal. There is a great scope of establishment of biochar based organic fertilizer plant and sale of UCB in Nepal. Therefore, UCB is a viable option to substitute fertilizers in the period of shortage of chemical fertilizer in the country.

It is always preferable to use biochar continuously before sowing every crop around 1 ton tha^{-1} $year^{-1}$ to reach 30 tha^{-1}. Research carried out in NARC showed that the cost of production per kg of biochar is around NRs 13.0 but amplifies the benefit after the use. A farmer using 1-ton of biochar can reduce atmospheric CO_2 or sequester 2-3 ton C per year. A farmer could earn extra amount of about NRs 8,000 (8.8 USD per ton of CO_2 sequestration and it is estimated that 4 ton of biochar/ha can sequester 8 ton of C) or even higher when traded in voluntary market, per year by sequestering carbon in the soil.

CONCLUSION

In general, application of biochar along with cattle urine increased the production of most crops by more than 20%. The rate of biochar application varies with the quality of biochar, soil types and environment. However, it is recommended to apply biochar up to 30 tha^{-1} but not necessary to apply full dose at a time. A household with single cattle can prepare UCB and substitute 100 kg urea, 120 kg MOP and 100 kg of SSP in a year besides improving soil health. Under such circumstances, the government should encourage farmers to prepare biochar-based fertilizer by diverting a small portion of fertilizer subsidy so that a sustainable production system is initiated. Farmers will be further incentivized if carbon trading is legalized in agriculture. Therefore, it would be a win-win situation for all, if the policy of carbon trading is legalized in the agriculture sector too.

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