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Biochar and Animal Manures Increased Yield of Three Varieties of Turnips

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Abstract: Biochar, a product of incineration of biomass is proposed for use as a soil amendment (SA) to enhance soil water holding capacity, increase soil microbial community, and plant nutrients availability. We studied the effect of six SA (sewage sludge SS, horse manure HM, chicken manure CM, vermicompost Vermi, commercial inorganic fertilizer (19N-19P-19K), commercial organic fertilizer (Nature Safe 10N-2P-8K), and biochar added to SA on the root, shoot, and plant weight of three varieties of field-grown turnips (Purple Top White Globe PTWG, Scarlet Queen Red SQR, and Tokyo Cross TC. Regardless of SA type used in this investigation, results revealed that varieties grown in soil treated with biochar had significantly greater root, shoot, and plant weight compared to similar varieties grown in SA not treated with biochhar. SQR significantly increased turnip yield compared to PTWG and TC varieties Overall turnip shoot, root, and plant weight obtained from CM amended soil not treated with biochar was significantly greater (295.9, 524.4, and 820.3 g, respectively) compared to yield obtained from the no-amendment (NM) control treatments (147.3, 242.5, and 389.8 g, respectively). Biochar added to SS, Org, Vermi, and HM significantly increased plant weight from 522.3, 482.5, 476.5, and 450.2 g to 737.5, 701.9, 673.3, and 640.8 g, respectively. This increase represents 41, 46, 41, and 42% increase in plant weight, respectively due to the addition of biochar. Regardless of biochar application to growing plants, variety SQR is recommend for growing turnips in CM amended soil. Substitution of inorganic fertilizer by animal manure mixed with biochar may help limited-resource farmers in growing turnips at affordable costs.

Keywords: *Brassica rapa*, Chicken Manure, Sewage Sludge, Organic Fertilizer, Vermicompost, Horse Manure

1. Introduction

Many economic horticultural crops are included in the Brassicacea family. Turnip, *Brassica rapa* edible parts (leaves, stems, and roots) are commonly consumed fresh [1] due to their high content of antioxidants, since synthetic antioxidants are being questioned regarding their safety as food additives [2]. Turnip is rich in fiber, vitamins (A, B, and C), minerals (Mg, K, P, Mn, Fe, Ca, and Cu), omega-3 fatty acids, and proteins [3].

Due to the continuous increase in synthetic fertilizer prices, limited resource farmers may reduce fertilizers application rates or find alternative sources. Organic amendments proposed as alternatives to synthetic fertilizers provide organic matter and plant nutrients needed to improve both the physicochemical and biological properties of the soil environment [4]. Soil biology and fertility are dependent on soil microorganisms that promote crop yield by increasing soil enzymatic activity, organic matter decay, and nutrient availability to growing plants. Animal manures improve soil fertility due to their microbial composition. Due to declining of fossil fuel resources and increasing demand for energy, interest in renewable energy resources, such as animal manures as alternative to inorganic fertilizers has increased.

Biochar as a soil amendment used in agricultural production systems is gaining attention for improving crop yield as well as for carbon sequestration. Biochar is formed by burning biomass in the absence of air. Biochar produced by incinerating wood, as a soil amendment was proposed to enhance plant nutrients availability, soil electrical conductivity (EC), and soil organic matter [5], retention of soil water content, and constructive impact on soil microorganism population, and plant yield [6, 7]. Studies have indicated that soil biotic properties are associated with the application of biochar and soil C maintenance, microbial populations, and enzymatic activities [8, 9]. Biochar is a recalcitrant C that degrades slowly in the soil and can take several years to degrade [10, 11]. Recalcitrant C usually refers to the component of soil organic C that is resistant to microbial decomposition [12]. Biochar provides shelters for soil microorganisms, improves soil structure, and increases plants absorption of macronutrients (NPK), plant growth and yield [13, 14]. Biochar also reduces soil bulk density by increasing soil porosity, which positively affects the soil microbial community and nutrient cycling [11, 15]. Adding biochar to animal manures used in agricultural production systems reduces NH_3 emissions from compost due to biochar pore spaces and acid groups that can trap NH_4^+ NH_3, preventing their volatilization and undesirable fragrance [16, 17]. The biochar production process is unique because it takes more C out of the atmosphere than it releases during incineration. In addition, biochar provides suitable habitat for soil microbes to allow them to decompose soil organic matter [18]. The process of converting biomass into biochar produces renewable energy (synthetic gas and bio-oil) and decreases the content of CO_2 in the air [19]. Animal manures and its microbial content that breakdown complex forms of organic matter have a significant role in refining the soil fertility and plant development [20].

The increasingly petition of chicken meat has driven the need for more poultry farming operations resulting in subsequent increase in organic wastes production that can be explored as organic fertilizer [21]. The moisture content, chicken age, age of CM, type and amount of bedding material, and length of CM storage period, all control the composition of CM. Approximately one ton of CM contains 2.2 kg N, 0.2 kg P and 1.9 kg K [22]. Due to the high NPK composition of CM compared to other types of animal manures, CM has passed the use of other types of animal manure [23, 24]. SS obtained from wastewater treatment plants recovered after municipal water proper treatment [25] enhances soil properties like soil pH, organic matter and availability of plant inorganic and organic nutrients [26]. The application of SS increases soil C, H, and O structural nutrients and macronutrients (N, P, K, Ca, S, and Mg) coupled with balance of micronutrients [27]. In addition, application of SS compost to agricultural soil reduces the environmental threats of N and P leaching as well as soil heavy metal accumulation [28]. The NPK elemental content and C/N ratio of Vermi publicized its agronomic value as an organic soil conditioner. Many investigators reported that Vermi has important benefits that can be implemented to convert organic wastes into a product rich in plant nutrients [29-33]. The composition of HM (feces, urine, and various bedding materials, such as peat, wood shavings and pelleted straw), as well as valuable plant nutrients, such as P and N and humus-forming substances can enrich the soil as a useful biofertilizer in agricultural land [34]. However, being a lignocellulosic material, spontaneous degradation of HM is slow.

The current investigation has two main objectives: 1)- assess the impact of six soil amendments (SA): sewage sludge SS, horse manure HM, chicken manure CM, vermicompost Vermi, commercial organic fertilizer (Org), inorganic fertilizer Inorg) and no-mulch (NM) native soil on turnip root, shoot, and plant weight. 2)- assess the impact of biochar on the root, shoot, and plant weight of three varieties of turnips, *Brassica rapa* (Purple Top White Globe, Scarlet Queen Red and Tokyo Cross) grown under field conditions.

2. Materials and Methods

The experimental study at the University of Kentucky Horticultural Research Farm (Fayette County, KY, USA) included a randomized complete block design (RCBD). Sixty-three field plots (3 turnip varieties × 7 treatments × 3 replicates) of 4 ft. (1.22 m) length and 3 ft. (0.91 m) width each were used for biochar treatments and similar 63 plots used for no-biochar treatments for comparison purposes. The seven soil treatments included sewage sludge (SS), horse manure (HM), chicken manure (CM), vermicompost (Vermi or worm castings), commercial inorganic fertilizer (19N-19P-19K), commercial organic fertilizer (Nature Safe 10N-2P-8K), and no-amendment (NM native soil) used as control treatment. Prior to planting, biochar obtained from Wakefield Agricultural Carbon (Columbia, MO) was added to each SA at the rate of 10% (w/w). The native soil in the experimental plots was a Bluegrass-Maury Silty Loam (2.2% organic matter, pH 6.2) and the soil has an average of 56% silt, 38% clay, and 6% sand.

Soil amendments used in this investigation also were mixed with native soil at 5% nitrogen (N) on dry weight basis prior to planting to eliminate variations among soil treatments due to their variability in N content. SS was purchased from the Metropolitan Sewer District (Louisville, KY, USA) and CM was purchased from the Department of Animal and Food Sciences, University of Kentucky (Lexington, KY, USA). HM was obtained from the Kentucky horse park (Lexington, KY, USA) and Vermi was obtained from Worm Power (Montpelier, Vermont, USA), whereas Org and Inorg commercial fertilizers were purchased from the Southern States Cooperative Stores (Lexington, KY, USA). Three varieties of turnip (*Brassica rapa* var. Purple Top White Globe (PTWG), var. Scarlet Queen Red (SQR), and var. Tokyo Cross (TC) were planted from seeds on May 15, 2019. Each amendment was added to native soil and rototilled to a depth of 15 cm (~ 0.5 ft.) topsoil. Seeds of turnip, *Brassica rapa* were planted in a freshly tilled soil at 18-in (45.7 cm) in-row spacing, and drip irrigated as needed. Weeding and other agricultural operations were carried out during the growing season regularly as needed. The plants were sprayed with a mixture of two pyrethroid insecticides esfenvalerate (Asana XL) and Baythroide XL (β-cyfluthrin) three times during the growing season at the recommended rate of application [35]. At maturity (71 d old plants), three turnip varieties (PTWG, SQR, and TC) were removed from the soil, cleaned with water, and their shoots and roots were separated with a sharp knife, and their weights were recorded.

Data containing root, shoot, and plant weight of each variety grown under the different soil treatments were statistically analyzed using analysis of variance (ANOVA) and the means were compared using Duncan's multiple range test [36].

3. Results and Discussion

Figure 1 shows a comparison among turnip varieties grown in soil treated with biochar and similar varieties grown in soil not treated with biochar, regardless of soil amendments. Results revealed that varieties grown in soil treated with biochar had significantly (*P*<0.05) greater root, shoot, and plant weight compared to similar varieties grown in soil not treated with biochhar. It could be concluded that the use of biochar in growing turnips and its storage in soils have two advantages, lessening climate change by sequestering carbon (C) and increasing turnip yields. This increase in crop yield due to addition of biochar might support the observation and investigators findings that biochar helps in providing suitable habitat for soil microbes to decompose soil organic matter and release the nutrients needed for growing plants. Biochar increased soils ability and improved microbial growth in the plant rhizosphere area around root zone and increased soil water holding capacity. It can reduce availability of toxic metals and acidity to plants due to its high pH value. In addition, potential benefits of biochar are decreased emissions of CO_2, NO_2 and CH_4 [37, 38]. Demisie and Zhang [39] reported that biochar could improve soil fertility, which enhance the soil microbial community and enzymes activity. Accordingly, farmers can improve the quality of acidic soil by adding biochar with high pH values [40].

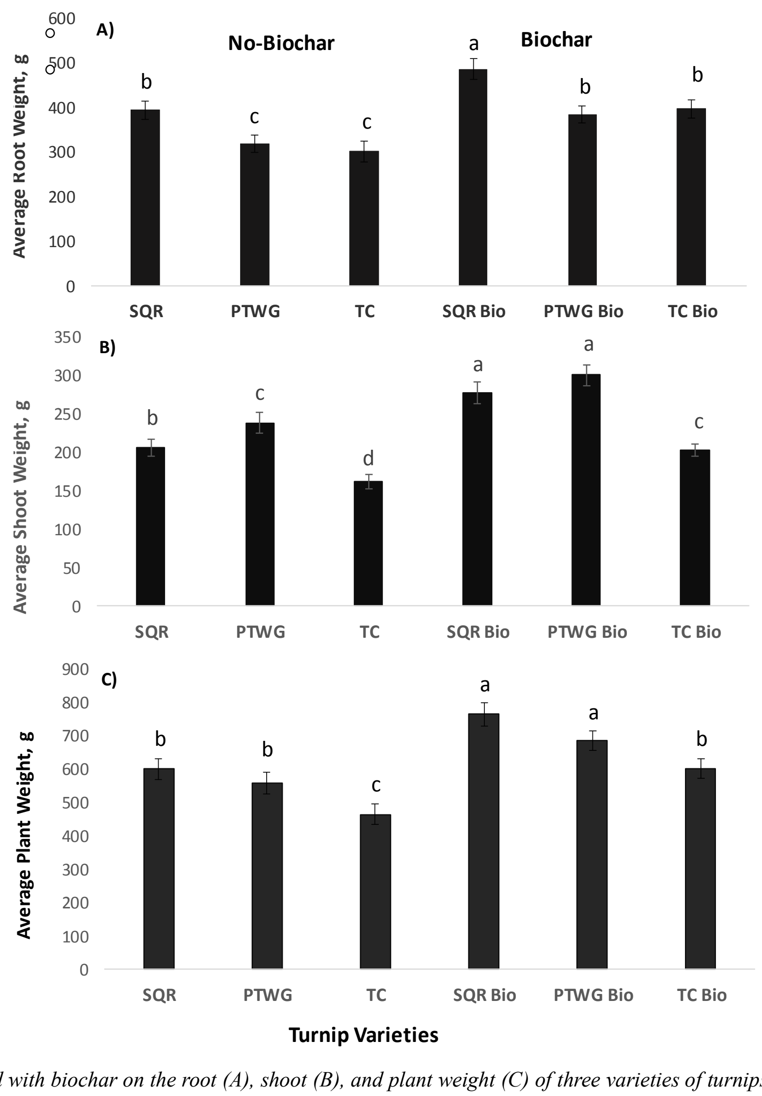


Figure 1. *Effect of soil not treated with biochar on the root (A), shoot (B), and plant weight (C) of three varieties of turnips: Scarlet Queen Red (SQR), Purple Top White Globe (PTWG), and Tokyo Cross (TC) and soil treated with biochar on A, B, and C of similar varieties, regardless of soil amendments. Statistical comparisons were accomplished among varieties for each plant part, or total plant weight. Bars accompanied by different letter indicate significant differences (P<0.05) using Duncan's multiple range test [36].*

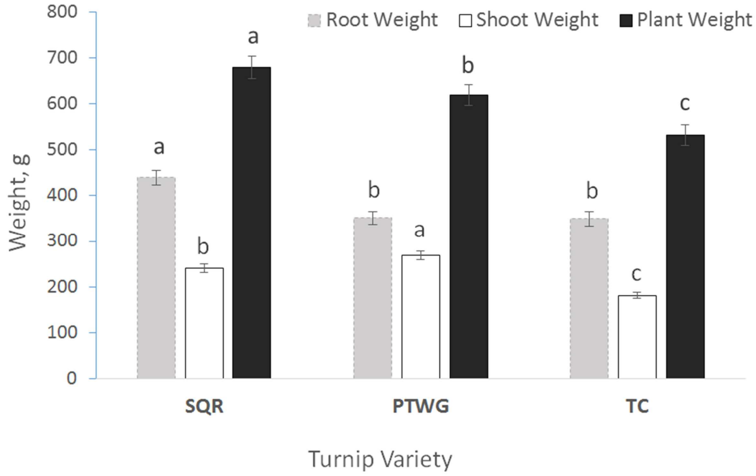
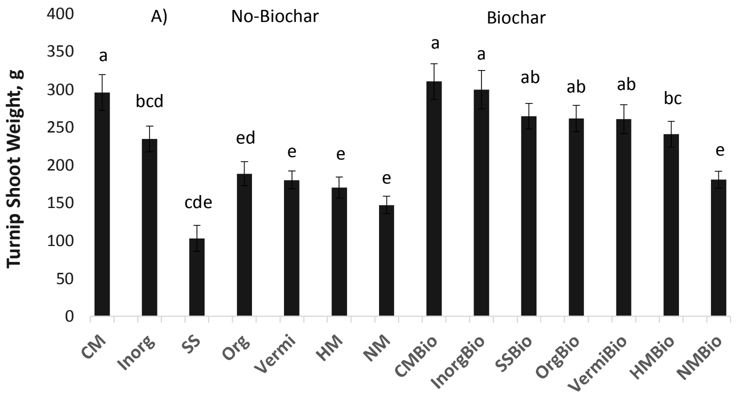


Figure 2. *Variability of three varieties of turnips: Scarlet Queen Red (SQR), Purple Top White Globe (PTWG), and Tokyo Cross (TC) in root, shoot, and plant weights, regardless of biochar treatments. Statistical comparisons were accomplished among varieties for each plant part, or total plant weight. Bars accompanied by different letter indicate significant differences (P<0.05) using Duncan's multiple range test [36].*

Regardless of soil amendments type, variety SQR significantly increased turnip root yield compared to the PTWG and TC varieties (Figure 2), whereas, variety PTWG had the greatest shoot weight compared to SQR and TC. Accordingly, SQR can be a recommended variety for greater turnip yield. As a result, turnip varieties can be arranged based on their yield in a descending order as follows: SQR>PTWG>TC. Worldwide turnip can be consumed as shoot or root vegetable. Usually the young roots are used in salads, whereas the green shoots are consumed cooked. Turnip greens (tops and leaves) are more beneficial to human health in comparison to the roots [41].



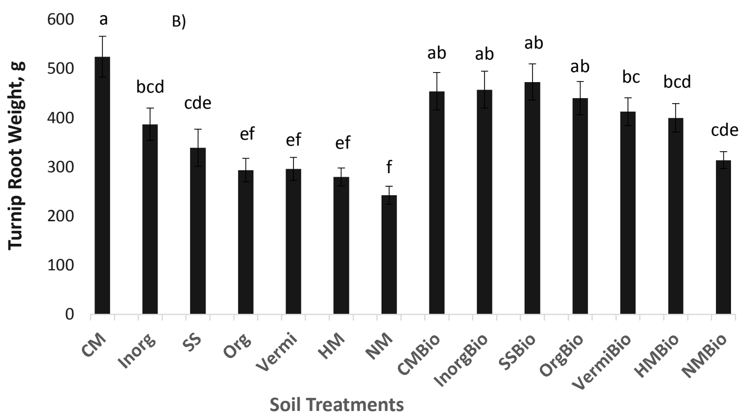


Figure 3. *Average weight (n=3) ± standard deviation of turnip shoot (A) and root (B) of plants grown under seven soil treatments not amended with biochar and seven treatments amended with biochar. Note that chicken manure CM, inorganic fertilizer Inorg, sewage sludge SS, organic fertilizer Org, vermicompost Vermi, horse manure HM, and no-mulch NM) are not treated with biochar, whereas CMBio, InorgBio, SSBio, OrgBio, VermiBio, HMBio, and NMBio) are treated with biochar, regardless of turnip cultivar. Statistical comparisons were accomplished among 14 soil treatments of each plant part. Bars accompanied by different letter (s) indicate significant differences (P<0.05) using Duncan's multiple range test [36].*

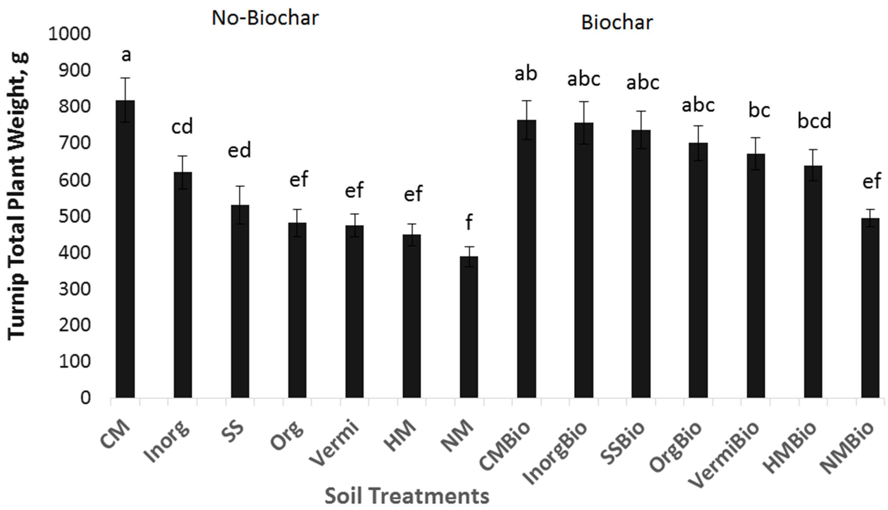


Figure 4. *Average weight (n=3) ± standard deviation of turnip plants grown under seven soil treatments not amended with biochar (chicken manure CM, inorganic fertilizer Inorg, sewage sludge SS, organic fertilizer Org, vermicompost Vermi, horse manure HM, and no-mulch NM), and seven soil treatments amended with biochar (CMBio, InorgBio, SSBio, OrgBio, VermiBio, HMBio, and NMBio), regardless of turnip cultivar. Statistical comparisons were accomplished among 14 soil treatments. Bars accompanied by different letter (s) indicate significant differences (P<0.05) using Duncan's multiple range test [36].*

Overall turnip shoot, root, and total plant weight obtained from CM amended soil not treated with biochar was significantly ($P<0.05$) greater (295.9, 524.4, and 820.3 g, respectively) compared to yield obtained from NM control treatment (147.3, 242.5, and 389.8 gm, respectively), regardless of turnip variety (Figures 3 and 4). Biochar added to SS, Org, Vermi, and HM significantly increased turnip plant weight from 522.3, 482.5, 476.5, and 450.2 g to 737.5, 701.9, 673.3, and 640.8 g, respectively (Figure 4). Investigators reported that biochar increased soil fertility and improved microbial growth in the plant rhizosphere area around roots due to increased soil water holding capacity. Biochar can reduce availability of toxic metals and acidity to plants due to its high pH value. In addition, farmers can improve the quality of acidic soil by adding biochar that has high pH values [40].

Regardless of biochar application, variety SQR is recommended for growing turnips in CM amended soil. CM is a complex mixture of bedding materials (sawdust wood shavings, grass cuttings, leaves or rice hulls.) and raw poultry manure. This blend is available at law cost to replace the use of inorganic fertilizer (Inorg). Our results indicated an increase in turnip yield due to addition of biochar to SS, Org, Vermi, and HM. However, manure application rates to agricultural soils and soil properties (not investigated in the present investigation) may increase NH_4, NO_3, and CH_4 emissions. In addition, some studies have indicated changeable results related to full substitution of synthetic fertilizers by animal manure. Some investigators show increases in crop yield [42] and others show significant decreases in crop yield [43]. Our future plan will include mixing more than one type of animal manures and investigate the various rates of manure application on the release of NH_4 and NO_3 in soil and their accumulation in turnips shoots and roots at harvest.

4. Conclusion

Traditional farming systems in limited-resource farmers became unaffordable due to the increased cost of inorganic fertilizers. Most small farmers employ crop residues, minimum tillage, and any vegetative materials as organic amendments to add plant nutrients and keep soil productivity as alternatives to the use of inorganic fertilizers and develop more sustainable farming system. Animal manure is an affordable source of organic fertilizers. We investigated the impact of animal manures (sewage sludge SS, horse manure HM, chicken manure CM, vermicompost Vermi), and commercial inorganic fertilizer (19N-19P-19K), commercial organic fertilizer (Nature Safe 10N-2P-8K), and animal manures mixed with biochar on the root, shoot, and plant weight of three varieties of field-grown turnips (Purple Top White Globe PTWG, Scarlet Queen Red SQR, and Tokyo Cross TC. Regardless of biochar application, results revealed that soil amended with CM had passed the use of other types animal manures. CM not mixed with biochar significantly ($P<0.05$) improved turnip plant weight compared to other manures tested. Biochar added to SS, Org, Vermi, and HM significantly increased turnip plant weight by 41, 46, 41, and 42%, respectively. On the other hand, regardless of soil amendments used in this investigation, variety SQR significantly increased turnip root yield compared to the PTWG and TC varieties, whereas variety PTWG had the greatest shoot weight compared to SQR and TC.

Authors Contributions

G. FA. designed the study, conducted the laboratory work, and wrote the manuscript. E. T. T. and R. B. T. conducted the field experiment and M. H. D. conducted the statistical analysis.

Conflicts of Interest

The authors declare that they have no conflict of interest.

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