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Original Article

Combined Effect of Woodchips and Biochar for Sweet Corn (*Zea mays*) Production: Productivity and Economic Efficiency of Sustainable Agriculture

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ABSTRACT

Biochar addition in soil has already been recognized as a promising technology as it contributes to improve the soil quality, crop yield, and mitigate climate change. This study intended to evaluate the combined effects of woodchips and biochar on soil quality, crop productivity, and economics of sweet corn production. The experiment was conducted in the experimental field of Shimane University, Matsue, Shimane, Japan during the period from 9th May 2019 to 24th July 2019. The experiment was laid out in a randomized block design with three replications and it consisted of six treatments namely, T_1 – woodchips +Organic fertilizer (OF), T_2 – woodchips + OF + Arbuscular mycorrhizal fungi (AMF) + Gliocladium fungi (GF), T_3 – woodchips + biochar + OF, T_4 – woodchips + biochar + OF + AMF + GF, T_5 – biochar + OF, and C (control) – OF. Results revealed that combined application of woodchips, biochar, and OF at teatment (T_3) obtained the highest corn yield (0.796 kg/m^2), stalk length (130 cm), water holding capacity (52%), gross margin (56.03%), and benefit-cost ratio (1.81) whereas the lowest yield (0.026 kg/m^2), stalk length (51cm), water holding capacity (21.66%), gross margin (-908%), and benefit-cost ratio (0.07) were obtained at control. Soil mineral concentrations of N (33.49 mg/100g), P (14.40 mg/100g), K (21.33 mg/100g), and Ca (49.33 mg/100g) were highest in T_4 where as the second highest values was recorded in T_3. Another notable significant result is that the sweet corn grown in all treatments contained small amount of nitrate (6.66 mg/L) as compared to conventional practice (83.33 mg/L). Furthermore, this new approach is able to achieve significant crop yield on existing land without using any pesticides, fertilizers, or other agricultural chemicals consequently has no adverse environmental impact and thus could be a sustainable approach. Therefore, it can be concluded that combined application of woodchips, and biochar appears as a suitable combination in terms of soil quality, crop productivity, and economics of sweet corn production.

Introduction

Worldwide haphazard use of chemical fertilizers and pesticides increases agricultural productivity since the green revolution of 1960s, with the cost of the environment and society. Therefore, high-level researches are essential to figure out innovative, alternative, environment friendly, sustainable options to decrease the use of costly and non-environmentally friendly chemical fertilizers. The present day agriculture is challenged to fulfill twin objectives of achieving food security for rapidly growing population as well as sustainability with emphasis on restoring soil resources, improving water quality, mitigating climate change, and preserving soil and natural resources for long-term use. Recently, a sustainable agricultural approach for utilizing wood wastes without any fertilizers and pesticides has been reported that application of wood waste with arbuscular mycorrhizal fungi (AMF) and gliocladium fungi (GF) achieved approximately 400 times higher yield than untreated soil (Islam and Katoh, 2017). Another promising agricultural approach for utilizing wood wastes has been reported that application of a high C: N ratio organic material without additional nitrogen fertilizer achieved 4 times higher productivity than that of conventional farms (Oda et al., 2014). Therefore, wood waste or woodchips can be a good agricultural material to enhance sustainability as they are rich in carbon and can be a good source of organic materials in the soil

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because they decompose slowly and add nutrients to the soil over time also loosen compacted soil, keep soil moisture levels up (Wollenberg et al., 2012). Woodchips are coarser, have a wider C/N ratio and also add to the nitrogen content of soil, thus provide more nutrients for growing plants (Bryant and Gary, 2014). Woodchips also act as a medium of various fungi. Fungi decompose woodchips along with bacteria and convert it into nutrients, which benefit the plants (Palvis, 2017). Therefore, woodchips could be an effective and sustainable natural material that has agricultural value for crop production. Application of biochar as a soil amendment has already been proved and accepted as a sustainable and promising approach to improve soil quality and remove heavy metals pollutants from the soil (Lahori et al., 2017). Biochar can improve soil properties because of its large surface area, porous nature, presence of plant nutrients and ash, and the ability to act as a medium for microorganisms (Nigussie et al., 2012). Several researchers have revealed that sweet corn yield increased by 98–150% as a result of biochar (Uzoma et al., 2011), and application of biochar enhances plant growth, retains nutrients, improves soil physical and biological properties (Downie et al., 2009), and biochar could release large amount of N (23–635 mg/kg), P (46–1664 mg/kg), K (711 mg/kg), and Ca (5880 mg/ kg) in soil (Mukherjee and Zimmerman, 2013). AMF form a symbiotic association with more than 80% of land plant families and benefit the host plant by improving nutrient availability in the soil and enhancing resistance to soil-borne pests, disease and drought (Gosling et al., 2006). Organic fertilizers (OF) are derived from animal matter, human excreta or vegetable matter (compost, manure) and have the ability to improve soil structure, texture and aeration, increasing water retention abilities of the soil and stimulating healthy root development (Sisay, 2019). Based on the criteria of these agricultural materials it was hypothesized that without using any fertilizer and pesticide, incorporation of woodchips, biochar, AMF, GF, and OF may achieve high yield and good quality of crop as well as with the improvement of soil health and sustainability. Therefore, the study was conducted to find out the effects of woodchips along with biochar, OF, AMF and GF as a new sustainable approach towards improving agricultural soil qualities, crop yield, crop quality as well as economic profitability.

Materials and Methods

Site description, soils and experimental design

The experiment was carried out in the experimental field of Shimane University, Shimane, Japan during the period from 9th May 2019 to 24th July 2019. Geographically, the site was located between 35˚28'27''N and 133˚3'11''E. The average monthly temperature, precipitation (rainfall), and relative humidity from April to November were 12.5°C to 26.5°C, 140 mm to 280 mm, and 70% - 80%, respectively. Initially the soil of the experimental site was clay (Fine-textured gley soils, Ham) (Shimane Prefecture,1974) with soil pH of 5.0. The experimental field was cleared, ploughed, and partitioned into the unit plots. The present experiment consists of 6 treatment plots, with 18 m^2 areas. 5 treated and 1 control plots were prepared namely, T_1 - woodchips + OF, T_2 - woodchips + OF + AMF + GF, T_3 - woodchips + biochar + OF, T_4 - woodchips + biochar + OF + AMF + GF, T_5 -biochar + OF, and C (control) - OF. Each plot site contained 1 ridge (1 ridge = 500 cm length × 40 cm width × 20 cm height) and 2 furrows (1 furrow = 500 cm length × 10 cm width × 60 cm depth). Conifer woodchips *(Cryptomeria japonica)*, biochar (Yamamoto funtankogyo, Shimane, Japan, raw material: mainly oak species, pyrolysis temperature: 800°C to 1000°C), OF (Tosho, Tokyo, Japan, NPK= 4:4:1.5), AMF (Idemitsu, Tokyo, Japan, Arbuscular mycorrhizal fungi are soil borne microorganisms that form a mutualistic symbiotic association with most land plants.) and GF (Idemitsu, Tokyo, Japan, Gliocladium is a mitosporic filamentous fungus which is widely distributed in soil and decaying vegetation) were used as agricultural materials. The experimental design was laid out in a randomized block design (RBD) with three replications. Woodchips, biochar, OF, AMF and GF were directly used in the furrows and ridges for the experimental investigation (Table 1). Sweet corn was considered as plant material. Commercially available seedlings (canberra 86, takii) were used for the experimental observation, 25 plants were transplanted in each treatment on 9th May 2019, plant to plant distance (spacing) was maintained 20cm. Irrigation was continued only for two weeks from the transplanting day during the whole life cycle of sweet corn.

Plant height, yield and mineral analyses

Plant height was measured 2 times after transplanting at 49th and 77th days respectively. At harvest, sweet corns per treatment were manually graded to get marketable corn ears. Marketable corn ears were then weighed and converted the average yield into kg/m^2. Area of each treatment was 3 m^2consisting of one furrow (0.5 m^2) at right side + one ridge (2 m^2) + one furrow (0.5 m^2) at left side. NO_3^- (mg/L) concentration of sweet corns was measured by Quantofix (MACHEREY-NAGEL, Düren, Germany), K^+ (mg/L) and Ca^{2+} (mg/L) were measured by LAQUA twin B-731(HORIBA, Kyoto, Japan), and LAQUA twin B-751(HORIBA, Kyoto, Japan). Sugar (Brix %) was measured by pocket refractometer PAL-S (Atago, Tokyo, Japan). Brix % was converted into g/100 ml. Conventionally grown sweet corns were collected from

3 different retail stores, and used for mineral analysis and comparative study with experimental sweet corns.

Table 1. Experimental treatment overview

Treatment	Furrow		Ridge		
	Conifer woodchips (kg/furrow)	Biochar (kg/furrow)	Biochar (g/m^2)	Organic fertilizer (g/m^2/2weeks)	AMF and GF (g/m^2)
C	0	0	0	25	0
T_1	24	0	0	25	0
T_2	24	0	0	25	60
T_3	24	10	350	25	0
T_4	24	10	350	25	60
T_5	0	0	3000	25	0

Here, **C** (control) – OF, **T_1** - woodchips + OF, **T_2** - woodchips + OF + AMF + GF, **T_3** - woodchips + biochar + OF, **T_4** - woodchips + biochar + OF + AMF + GF, and **T_5** - biochar + OF.

Soil analysis

To evaluate soil mineral concentration, soil samples were collected four times in the beginning, mid, and end of the season. The LAQUA twin B-742 (HORIBA, Kyoto, Japan) was used to measure NO_3^- concentration of soil. RQ flex plus 10 (Merck KGaA, Darmstadt, Germany) was used to measure PO_4^{3-} concentration of soil. LAQUA twin B-731(HORIBA, Kyoto, Japan), and LAQUA twin B-751(HORIBA, Kyoto, Japan) were used to measure K^+ and Ca^{2+} concentrations of soil. Soil pH was measured by SHINWA digital soil acidity meter72716 (Shinwa Rules Co. Ltd., Niigata, Japan). Soil water holding capacity was measured by the following formula, i) Volume of water retained = Volume of water poured - Volume of water collected in cylinder ii) Water holding capacity = [(volume of water retained/ volume of water required) × 100].

Economic evaluation

Profitability analysis

To estimate the profitability of sweet corn production, gross return, gross margin, net return and benefit cost ratio were calculated. Rent of land and depreciation of agricultural equipments were considered as fixed cost. The cost of agricultural materials, labor, and seedlings were considered as the variable cost of sweet corn production.

To estimate the cost of sweet corn production, the following equations were used:

$VC = \sum X_i P_i$, and $TC = FC + VC$

Where, VC = Variable cost (yen/ha), Xi = Quantity of inputs (kg/ha), Pi = Price of inputs (yen/kg) used for sweet corn production, TC = Total cost of sweet corn production (yen/ha), FC = Fixed cost (yen/ha)

To estimate the profitability of sweet corn production, the following equations were used to calculate gross return, gross margin and net return:

$GR = \sum Y_i P_i$ (Gross return: The output and price of sweet corn were taken into consideration in estimating gross return), Gross margin, GM = (GR-TVC)/GR x 100 [Gross return (yen/ha) - Total variable cost (yen/ha)]/Gross return (yen/ha) x 100) and Net return, NR = GR-TC [Gross return (yen/ha) - Total cost (yen/ha)] (Gittinger, 1982; CIMMYT, 1988).

Benefit Cost Ratio (BCR)

To estimate the BCR, the following equation was used.
BCR = Gross return (yen/ha)/Total cost (yen/ha) (Jones, 1982).

If the BCR is higher than the cost, the investment is considered as a profitable investment.

Statistical analysis

The experiment was conducted for six treatments with three replications. Data were conveyed as mean ± standard error (SE). Statistical analyses of the data were carried out using SPSS for Windows, Version 20.0. NY. The level of significance was calculated from the F value of ANOVA. Mean comparison was achieved by Tukey-test ($P \leq 0.05$).

Results

Yield of sweet corn and stalk length

Yield of sweet corn was influenced by the treatments (Figure 1) and was significantly ($p \leq 0.05$) greater in all the treatments compared to the control. Average marketable yield (kg/m^2) of sweet corn was recorded in the order as follows: T_3 (0.796) > T_4 (0.526) > T_2 (0.386) > T_5 (0.226), T_1 (0.226) > C (0.026). The highest yield of sweet corn was obtained at T_3 with a significantly higher value compared to T_1, T_2, T_4, T_5, and control. On average, different types of treatments were able to increase the yield of sweet corn 1561.54% over the control. The application of woodchips, biochar, and OF at T_3 treatment resulted the highest yield (0.796 kg/m^2) which was approximately 31 times higher than the control (C). Different types of treatments had significantly improved the growth of sweet corn plants throughout the study. Average stalk length of sweet corn (cm) was in the order as follows: T_3 (130) > T_2 (116) > T_4 (110) > T_5 (108) > T_1 (107) > C (51) (Figure 2). On average, plants grown in the treatments were 123.92 %

taller than plants of the control plot. The highest stalk length of sweet corn (130 cm) was observed at T_3 and the lowest (51 cm) was observed at C, even if no significant ($p \leq 0.05$) differences were observed among T_1, T_2, T_3, T_4 and T_5.

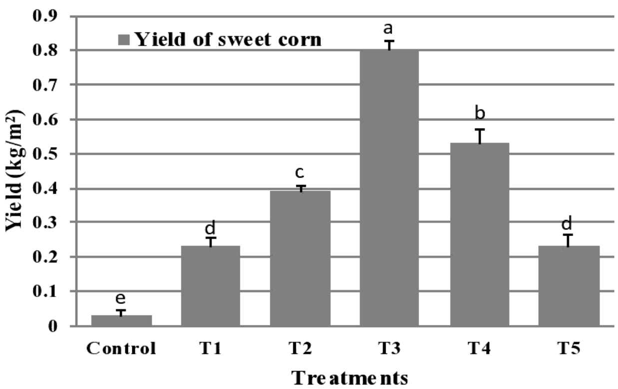

Figure 1. The effect of different treatments on the yield (kg/m²) of sweet corn, different letters indicate significant differences ($p \leq 0.05$), and bars indicate mean value ± SE (Standard Error).

Here, Control – OF, T_1 - woodchips + OF, T_2 - woodchips + OF + AMF + GF, T_3 - woodchips + biochar + OF, T_4 - woodchips + biochar + OF + AMF + GF, and T_5 - biochar + OF.

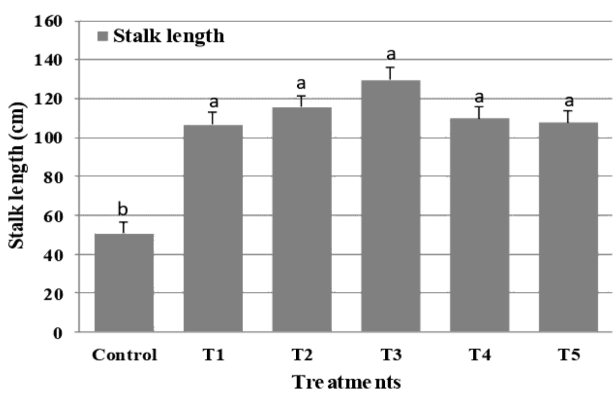

Figure 2. The effect of different treatments on the stalk length (cm) of sweet corn, different letters indicate significant differences ($p \leq 0.05$), and bars indicate mean value ± SE (Standard Error).

Here, Control – OF, T_1 - woodchips + OF, T_2 - woodchips + OF + AMF + GF, T_3 - woodchips + biochar + OF, T_4 - woodchips + biochar + OF + AMF + GF, and T_5 - biochar + OF.

Minerals and sugar of sweet corn

In this study, NO_3^- concentration was the most important contributing parameter, which was significantly marked in conventionally grown sweet corn and treatments. NO_3^- concentration (mg/L) of sweet corn was recorded in the order: Conventional (83.33) > C (6.66), T_1 (6.66), T_2 (6.66), T_3 (6.66), T_4 (6.66), T_5 (6.66) (Figure 3). The highest NO_3^- concentration of sweet corn(83.33) was obtained in conventionally grown sweet corn with a significantly higher value compared to the treatments and control. The concentration of NO_3^- of all treatments was approximately 13 times lower than the conventionally (chemical based farming) grown sweet corn. However, no significant ($p \leq 0.05$) differences were observed among C, T_1, T_2, T_3, T_4, and T_5. The highest potassium concentration (3066.66 mg/L) of sweet corn was observed at treatment T_1 and T_4, closely followed (2966.66 mg/L) by treatment T_5 and the lowest (1966.66 mg/L) was observed in conventionally grown sweet corn (Figure 4). Significant differences ($p \leq 0.05$) were found among control, treatments, and conventional. Ca^{2+} concentration (mg/L) of sweet corn was recorded in the order: T_4 (15.66) > T_3 (14.66) > T_1 (13.66) > T_2 (11.66) > T_5 (9.66), C (9.66) > Conventional (5.66) (Figure 5). The highest Ca^{2+} concentration of sweet corn (15.66) was observed at T_4 and the lowest (5.66) was observed in conventionally grown sweet corn. Ca^{2+} concentration of sweet corn was significantly ($p \leq 0.05$) higher in all treatments and control compared to the conventionally grown sweet corn. Sugar concentration (g/100 mL) of sweet corn was recorded in the order: T_3 (17.66) > C (17.16) > T_2 (16.66) > T_4 (15.66) > T_1 (15.26) > T_5 (14.40) > Conventional (7.66) (Figure 6). The highest sugar concentration of sweet corn (17.66) was observed at T_3, and the lowest (7.66) was observed in conventionally grown sweet corn but no significant differences were observed among C, T_2, and T_3, significant differences ($p \leq 0.05$) were observed when compared to the conventional.

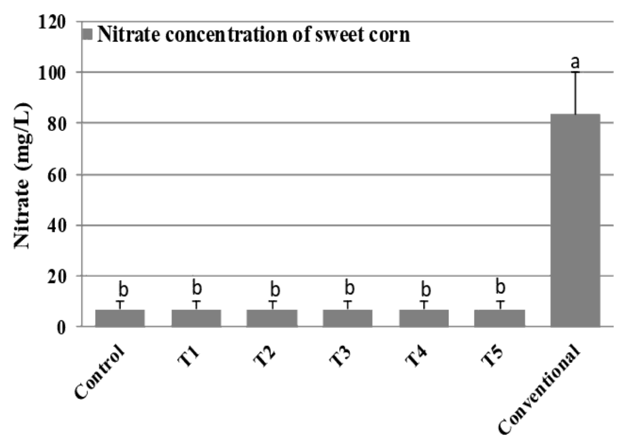

Figure 3. The effect of different treatments on the NO_3^- (mg/L) concentration of sweet corn, different letters indicate significant differences ($p \leq 0.05$), and bars indicate mean value ± SE (Standard Error).

Here, Control – OF, T_1 - woodchips + OF, T_2 - woodchips + OF + AMF + GF, T_3 - woodchips + biochar + OF, T_4 - woodchips + biochar + OF + AMF + GF, and T_5 - biochar + OF.

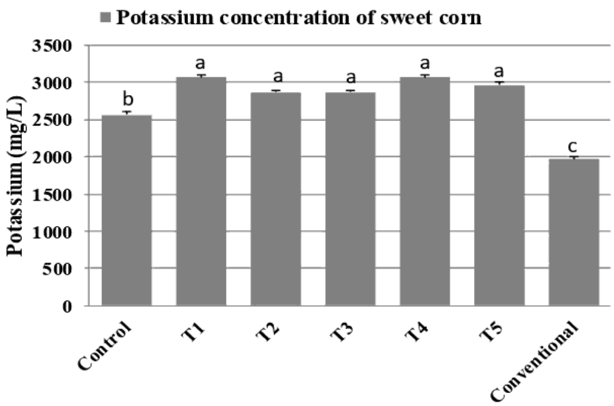

Figure 4. The effect of different treatments on the K^+ (mg/L) concentration of sweet corn, different letters indicate significant differences ($p \leq 0.05$), and bars indicate mean value ± SE (Standard Error).

Here, Control – OF, T_1 - woodchips + OF, T_2 - woodchips + OF + AMF + GF, T_3 - woodchips + biochar + OF, T_4 - woodchips + biochar + OF + AMF + GF, and T_5 - biochar + OF.

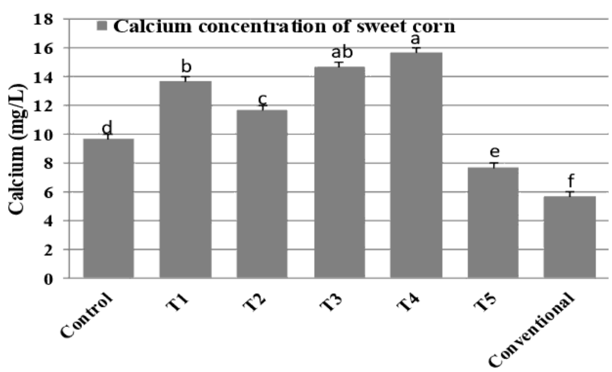

Figure 5. The effect of different treatments on the Ca^{2+} (mg/L) concentration of sweet corn, different letters indicate significant differences ($p \leq 0.05$), and bars indicate mean value ± SE (Standard Error).

Here, Control – OF, T_1 - woodchips + OF, T_2 - woodchips + OF + AMF + GF, T_3 - woodchips + biochar + OF, T_4 - woodchips + biochar + OF + AMF + GF, and T_5 - biochar + OF.

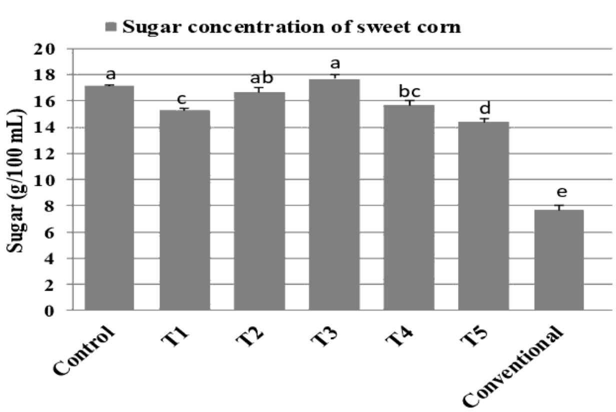

Figure 6. The effect of different treatments on the sugar (g/100 ml) concentration of sweet corn, different letters indicate significant differences ($p \leq 0.05$), and bars indicate mean value ± SE (Standard Error).

Here, Control – OF, T_1 - woodchips + OF, T_2 - woodchips + OF + AMF + GF, T_3 - woodchips + biochar + OF, T_4 - woodchips + biochar + OF + AMF + GF, and T_5 - biochar + OF.

Soil mineral concentrations

The mineral concentrations of soil were improved by the application of woodchips, biochar, OF, AMF and GF. N, P, K, and Ca (mg/100g) concentrations of soil of the treatments and control were recorded 4 times, and average levels were calculated. N (mg/100g) concentration of soil was recorded in the order: T_4 (33.49) > T_3 (26.34) > T_5 (22.43) > T_2 (20.59) > T_1 (9.87) > C (4.48) (Figure 7). The highest N concentration of soil (33.49) was observed at T_4, and the lowest (4.48) was observed at C but no significant differences ($p \leq 0.05$) were observed among T_2, T_3, T_4, and T_5. P (mg/100g) concentration of soil was recorded in the order: T_4 (14.40) > T_3 (12.16) > T_5 (12.06) > T_2 (11.73) > T_1 (8.83) > C (3.93) (Figure 7). The highest P concentration of soil (14.40) was observed at T_4, and the lowest (3.93) was observed at C. No significant differences were observed among T_2, T_3, T_4, and T_5 but significant differences ($p \leq 0.05$) were observed when compared to the control. K (mg/100g) concentration of soil was recorded in the order: T_4 (21.33) > T_3 (20.33) > T_5 (15.00) > T_2 (14.00) > T_1 (12.00) > C (5.00) (Figure 7). The highest K concentration of soil (21.33) was observed at T_4, and the lowest (5.00) was observed at C but no significant differences ($p \leq 0.05$) were observed among T_1, T_2, T_3, T_4, and T_5. Ca (mg/100g) concentration of soil was recorded in the order: T_4 (49.33) > T_3 (42.66) > T_2 (35.00) > T_5 (33.33) > T_1 (28.00) > C (24.00) (Figure 7). The highest Ca concentration of soil (49.33) was observed at T_4, and the lowest (24.00) was observed at C but no significant differences ($p \leq 0.05$) were observed among T_1, T_2, T_3, T_4, T_5, and C. The mineral concentrations of soil were improved by the incorporation of woodchips, biochar, OF, AMF and GF. Concentration of N, P, K, and Ca (mg/100g) of all treatments were increased which is shown in Figure 4 and the highest concentration of N, P, K, and Ca was obtained in the soil of treatment T_4 where woodchips, biochar, OF, AMF and GF were used as soil amendment. The lowest concentration of N, P, K, and Ca was observed at control.

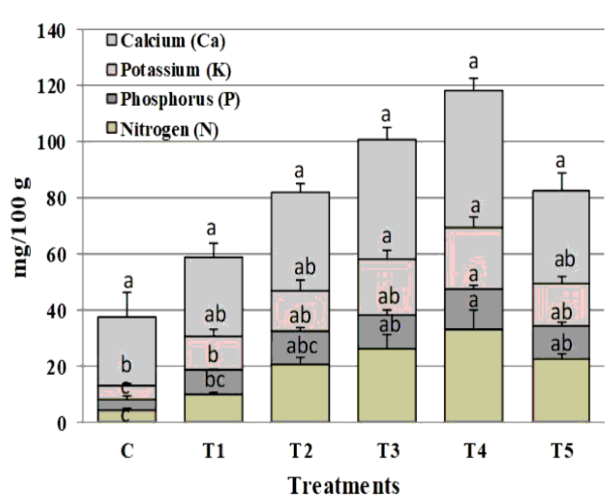

Figure 7. Effect of different treatments on N, P, K, and Ca concentrations of soil, different letters indicate significant differences ($p \leq 0.05$), and bars indicate mean value ± SE (Standard Error).

Here, Control – OF, T_1 - woodchips + OF, T_2 - woodchips + OF + AMF + GF, T_3 - woodchips + biochar + OF, T_4 - woodchips + biochar + OF + AMF + GF, and T_5 - biochar + OF.

Soil pH and water holding capacity

Initially, in the untreated soil of the experimental site, soil pH was recorded 5.0 that was acidic, and then soil pH slightly increased in the treated soil that was in the order: T_3 (5.8), T_4 (5.8) > T_2 (5.3) > T_1 (5.2), C (5.2) > T_5 (4.0) (Figure 8). The highest soil pH (5.8) was observed at T_3 and T_4, but no significant differences ($p \leq 0.05$) were observed among T_1, T_2, T_3, T_4, and C. The lowest soil pH (4.0) was observed at T_5. Water holding capacity (%) of soil was recorded in the order: T_3 (52.00) > T_4 (40.00) > T_2 (33.00) > T_5 (32.00) > T_1 (31.00) > C (21.66) (Figure 9). The highest water holding capacity of soil (52.00) was observed at T_3, but no significant differences ($p \leq 0.05$) were observed among T_1, T_2, T_4, and T_5. Significant differences were observed when compared T_3 with others.

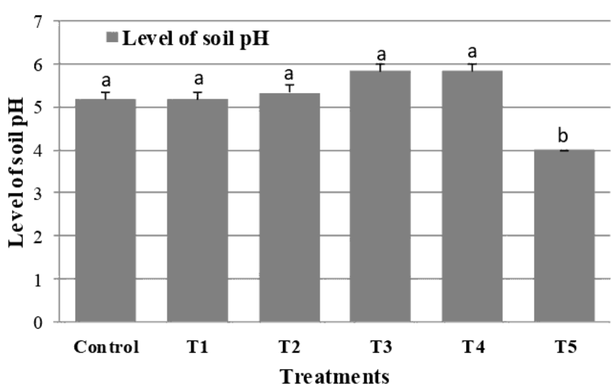

Figure 8. The effect of different treatments on the pH of soil, different letters indicate significant differences ($p \leq 0.05$), and bars indicate mean value ± SE (Standard Error).

Here, Control – OF, T_1 - woodchips + OF, T_2 - woodchips + OF + AMF + GF, T_3 - woodchips + biochar + OF, T_4 - woodchips + biochar + OF + AMF + GF, and T_5 - biochar + OF.

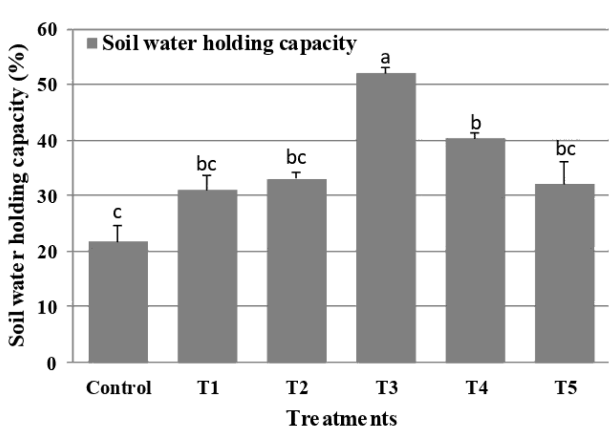

Figure 9. The effect of different treatments on the water holding capacity of soil, different letters indicate significant differences ($p \leq 0.05$), and bars indicate mean value ± SE (Standard Error).

Here, Control – OF, T_1 - woodchips + OF, T_2 - woodchips + OF + AMF + GF, T_3 - woodchips + biochar + OF, T_4 - woodchips + biochar + OF + AMF + GF, and T_5 - biochar + OF.

Economic evaluation of sweet corn production

Yield, gross return, net return, gross margin, total cost, total fixed cost, total variable cost and benefit cost ratio were shown in Table 2. The price of organic sweet corn was approximately 1400 yen/kg in the local market of Matsue- Shi, Shimane prefecture, Japan. The highest gross margin was obtained at treatment T_3 (56.03%) with the application of woodchips, biochar, and OF, followed by treatment T_4 (27.08%) with the application of woodchips, biochar, OF, AMF and GF. All the treatments recorded higher gross margin over the control. A similar trend was observed in case of net return. The result revealed that addition of woodchips along with biochar can reduce the cost of using only biochar as soil amendment and also can increase the profit level that will benefit the farmers. The highest total cost was recorded at treatment T_4 with the application of woodchips, biochar, OF, AMF and GF. The benefit-cost ratio was highest (1.81) at treatment T_3 with the application of woodchips, biochar, and OF, while the lowest benefit-cost ratio was obtained at control (0.07), the benefits in terms of quality, nutritional values due to addition of natural agricultural materials should not be over looked. In case of variable costs, seedling cost and labor cost were similar among all treatments, total variable cost varied due to the variation in the cost of agricultural materials of different treatments. Cost of woodchips was not taken into consideration as any type of carbon rich source can be used, for example wood wastes, bamboo wastes. Fixed costs were also similar among all treatments. Irrigation cost was zero as irrigation was fully dependent on rain. For experimental purpose, we used organic fertilizer but farmers can use any type of organic source, in that case, production cost will be decreased and net return will be increased. However, our ground of economic assessment of sweet corn production is a traditional economic evaluation, but when we also start to calculate natural capital values, it will become the clear winner for long-term profitability.

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Table 2. Economics of sweet corn production as influenced by different treatments

Treatment	Yield (kg/ha) 2	Gross return ($\times10^3$yen/ha) 3	Total cost ($\times10^3$yen/ha) 4=(5+6)	Total variable cost ($\times10^3$yen/ha) 5	Total fixed cost ($\times10^3$yen/ha) 6	Net return ($\times10^3$yen/ha) 7 = (3–4)	Gross margin(%) ×100	Benefit cost ratio 9(3/4)
Control	260	364	4920	3670	1250	-4556	-908%	0.07
T_1	2260	3164	4920	3670	1250	-1756	-15.99%	0.64
T_2	3860	5404	5380	4130	1250	24	23.58%	1
T_3	7960	11144	6150	4900	1250	4994	56.03%	1.81
T_4	5260	7364	6620	5370	1250	744	27.08%	1.11
T_5	2260	3164	5450	4200	1250	-2286	-32.74%	0.58

Here, Control - OF, $\mathbf{T_1}$ - woodchips + OF, $\mathbf{T_2}$ - woodchips + OF + AMF + GF, $\mathbf{T_3}$ - woodchips + biochar + OF, $\mathbf{T_4}$ - woodchips + biochar + OF + AMF + GF, and $\mathbf{T_5}$ -biochar + OF.

Discussion

Our experimental results revealed that the combined application of woodchips and biochar (T_3, and T_4) had positive effects on the yield of sweet corn, plant height, and soil minerals. We got the highest sweet corn yield and plant height at T_3, and the second highest at T_4. We found the highest level of soil minerals (N, P, K, and Ca) at T_4, and second highest was at T_3. So, the combined application of woodchips, and biochar played a key role on the height, yield of sweet corn and soil minerals at T_3 and T_4. Alternatively, when woodchips and biochar were applied separately, then yields and minerals were lower than yields and minerals of combined applications of these materials. The application of biochar improves soil fertility through two mechanisms: adding nutrients to the soil or retaining nutrients from other sources (Downie et al., 2009; Viger et al., 2015). In this case, woodchips contribute to biochar to retain nutrients from soil and microbes because woodchips are high C: N ratio organic material, woodchips added to the soil can supply high amount of carbon to various fungi and also add nutrients to the soil slowly when decompose. Various fungi and microbes grow and perform important functions in the soil in relation to nutrient cycling, disease suppression, water dynamics, and create biodiversity (Islam and Katoh, 2016). That is probably the reason of higher yield and soil minerals at T_3 and T_4 treatment. On the other hand, at T_5 treatment, only biochar effect was involved, that is why yield was comparatively lower than T_3 and T_4. We observed highest level of soil minerals (N, P, K, and Ca) at T_4. The yield, however, was lower than that of T_3. This result indicates that mycorrhizal fungi might not work as the mutualistic partner for sweet corn cultivation at T_4. Under nutrient-rich conditions, mycorrhizal fungi sometimes show a negative effect on host plants because mycorrhizal fungi deprive carbohydrates from host plants (Treseder, 2004). Thus, it is deduced that T_3 treatment (in absence of AMF and GF) showed highest corn yield. At the same time, variation in the yield and the stalk length of sweet corn was found between T_1 (woodchips) and T_2 (woodchips, and AMF and GF). The higher yield and the stalk length were observed at T_2 than at T_1. Here, the effect of fungal sources was observed. The highest level of soil pH was measured at T_3 and T_4, and the highest level of water holding capacity (WHC) was observed at T_3. Combined application of biochar and woodchips influenced Soil pH and WHC at T_3 and T_4. Several researchers have reported that biochar works better for elevating the pH of soils (Zaccheo *et al*., 2014), and biochar amendment in soil can increase WHC of soil (Laird *et al*., 2010). In this study, integrated application of woodchips and biochar increased the level of soil minerals (N, P, K, and Ca), soil pH, and WHC at T_3 and T_4. Thus, the soil properties were improved significantly at T_3 and T_4 than the other treatments that might be related to the highest sweet corn yield and plant height at T_3, and the second highest at T_4. The application materials (woodchips, biochar, OF, AMF, and GF) of different treatments had significant effects on the nutritional status of the sweet corn. NO_3^- level of experimental sweet corn (T_1, T_2, T_3, T_4, T_5) was extremely lower than that of conventionally grown sweet corn. Several researchers have revealed that the cultivating edible crops with high nitrate content may lead to poisonous for human health (Mensinga *et al*., 2003). However, higher level of K^+, Ca^{2+}, and sugar were found in the sweet corn of all treatments and the lowest was found in conventionally grown sweet corn. Several researchers have reported that cultivating edible crops with high K^+ and Ca^{2+} content is beneficial for human health (D'Elia *et al*., 2011). Economic analysis of sweet corn production essentially entails the evaluation of costs and benefits. We observed the highest BCR at T_3, and the lowest at control. High yield of sweet corn at T_3 treatment is the main reason for this achievement.

Conclusion

In this field experiment, we found that combined application of woodchips, and biochar have substantial impacts on crop physiology, yield, nutritional status, soil quality and economics of sweet corn production. Furthermore, this approach is an environment friendly method and has no adverse effects on soil, water, biodiversity, surrounding or downstream resources also both woodchips and biochar persist in the soil for long time and gradually improve soil quality thus could be effective for sustainability purpose. Overall findings of this study suggest that combined application of woodchips and biochar have a potential to be innovative agricultural materials. To the best of our knowledge, this is a very new report to study the combined effect of woodchips and biochar. The results of this study may provide useful information to farmers and policymakers. However, subsequent field studies are planned to be carried out in future, especially long-term experiments.

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