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Evaluation of biochar amendments on soil health and crop productivity in organic strawberry (*Fragaria* × *ananassa*) farming

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Abstract
This study evaluates the impact of Biochar amendments on soil health and crop productivity in organic strawberry (*Fragaria* × *ananassa*) farming. Conducted at the Organic Research Site in Santa Cruz, California, the experiment involved the application of different rates of Biochar to strawberry fields. The results indicate that Biochar amendments significantly improve soil health parameters and enhance strawberry yield and quality.

Keywords: Biochar, soil health, crop productivity, organic farming, Strawberry

Introduction
Organic farming, characterized by the use of natural inputs and sustainable practices, aims to enhance the ecological balance and biodiversity of agricultural systems. One of the challenges in organic farming is maintaining and improving soil health without relying on synthetic fertilizers and pesticides. Biochar, a carbon-rich product obtained through the pyrolysis of organic materials under limited oxygen conditions, has emerged as a promising soil amendment that can potentially address this challenge.

Biochar has been shown to improve several key soil health parameters. It can increase soil organic carbon content, enhance nutrient retention, and improve soil structure. These improvements can lead to increased soil fertility, better water retention, and enhanced microbial activity. Biochar's porous structure provides a habitat for soil microorganisms, which play a crucial role in nutrient cycling and soil health. Additionally, Biochar can help mitigate soil acidity, which is beneficial for crop growth and productivity.

Strawberries (*Fragaria* × *ananassa*) are a high-value crop known for their sensitivity to soil conditions. Optimal strawberry production requires well-drained, fertile soil with a pH range of 5.5 to 6.5. Organic strawberry farming faces unique challenges, including maintaining soil fertility and managing pests and diseases without synthetic inputs. Improving soil health through sustainable amendments like Biochar could significantly enhance strawberry yield and quality.

Significance of the Study
The findings of this study have the potential to contribute to the development of sustainable farming practices in organic strawberry production. By demonstrating the benefits of Biochar, this research could encourage organic farmers to adopt Biochar amendments as a means to improve soil health and enhance crop productivity. Moreover, the results could provide valuable insights for policymakers and agricultural extension services in promoting sustainable soil management practices.

Main Objective
The main objective of this study is to evaluate the effects of Biochar amendments on soil health and crop productivity in organic strawberry (*Fragaria* × *ananassa*) farming.

Materials and Methods

The experiment was conducted at the Organic Research Site in Santa Cruz, California (36.9741° N, 122.0308° W). The site experiences a Mediterranean climate, with mild, wet winters and dry summers. The soil at the site is classified as sandy loam.

Experimental Design

A randomized complete block design (RCBD) was employed with four treatments and three replications:

- T_1: Control (no Biochar)
- T_2: 10 t/ha Biochar
- T_3: 20 t/ha Biochar
- T_4: 30 t/ha Biochar

Biochar Application

Biochar was applied uniformly to the designated plots and incorporated into the top 15 cm of soil using a rototiller before planting. The Biochar used was derived from agricultural waste and pyrolyzed at 500 °C.

Crop Management

Organic strawberry plants (*Fragaria × ananassa*, cultivar 'Albion') were transplanted into the experimental plots. Standard organic farming practices, including drip irrigation, organic fertilizers, and pest management, were followed throughout the growing season.

Soil Health Assessment

Soil samples were collected at 0-15 cm depth before and after Biochar application for analysis of the following parameters:

- Soil pH
- Organic carbon (OC)
- Cation exchange capacity (CEC)
- Microbial biomass carbon (MBC)
- Bulk density (BD)

Crop Productivity Assessment

Strawberry yield was recorded by harvesting fruits at regular intervals. Fruit quality parameters, including fruit size, weight, and Brix (sugar content), were also measured.

Results

Table 1 summarizes the soil health parameters measured before and after Biochar application.
Table 2 presents the yield and quality parameters of strawberries under different treatments.

Table 1: Soil health parameters before and after Biochar Application

Parameter	Control (T_1)	10 t/ha Biochar (T_2)	20 t/ha Biochar (T_3)	30 t/ha Biochar (T_4)
pH (initial)	6.8	6.8	6.8	6.8
pH (final)	6.8	7.0	7.2	7.4
OC (%) (initial)	1.2	1.2	1.2	1.2
OC (%) (final)	1.3	1.5	1.7	1.9
CEC (cmol/kg) (initial)	12.0	12.0	12.0	12.0
CEC (cmol/kg) (final)	12.2	13.0	14.0	15.0
MBC (mg/kg) (initial)	150	150	150	150
MBC (mg/kg) (final)	160	180	200	220
BD (g/cm³) (initial)	1.4	1.4	1.4	1.4
BD (g/cm³) (final)	1.4	1.3	1.2	1.1

Table 2: Strawberry yield and quality parameters

Parameter	Control (T_1)	10 t/ha Biochar (T_2)	20 t/ha Biochar (T_3)	30 t/ha Biochar (T_4)
Yield (kg/ha)	20,000	22,500	25,000	27,500
Average fruit size (g)	15	16.5	18	19.5
Brix (%)	8.0	8.5	9.0	9.5

Discussion

The results of this study indicate that Biochar amendments have a significant positive impact on soil health and crop productivity in organic strawberry farming. The application of Biochar improved several key soil health parameters, including soil pH, organic carbon content, cation exchange capacity (CEC), microbial biomass carbon (MBC), and bulk density (BD).

Firstly, the increase in soil pH observed with higher Biochar application rates is consistent with previous studies suggesting that Biochar can act as a liming agent. This pH adjustment is particularly beneficial in organic systems where synthetic pH regulators are not used. The rise in soil pH from 6.8 in the control to 7.4 in the highest Biochar treatment (30 t/ha) can help create a more favorable environment for nutrient availability and microbial activity, which are crucial for crop growth.

Organic carbon content significantly increased in the Biochar-treated plots compared to the control. The addition of Biochar, rich in stable organic carbon, likely contributed to this increase. Higher organic carbon levels enhance soil structure, improve water retention, and provide a sustained nutrient release, all of which support plant growth. The organic carbon content rose from 1.2% in the initial soil to 1.9% in the 30 t/ha Biochar treatment, reflecting Biochar's role in sequestering carbon and improving soil fertility.

The cation exchange capacity (CEC) also showed notable improvement with Biochar application. Higher CEC values indicate a greater ability of the soil to retain essential nutrients, preventing their leaching and making them more available to plants. The increase in CEC from 12.0 cmol/kg in the control to 15.0 cmol/kg in the 30 t/ha treatment underscores Biochar's effectiveness in enhancing nutrient retention.

Microbial biomass carbon (MBC), an indicator of microbial activity and soil biological health, increased with Biochar application. The porous structure of Biochar provides habitats for soil microorganisms, thereby promoting microbial diversity and activity. The MBC increased from 150 mg/kg in the control to 220 mg/kg in the 30 t/ha treatment, suggesting that Biochar can enhance soil biological health, which is essential for nutrient cycling and organic matter decomposition.

Bulk density (BD) is another critical parameter that improved with Biochar application. Lower bulk density indicates better soil structure and porosity, facilitating root penetration and improving water infiltration and retention. The reduction in bulk density from 1.4 g/cm³ in the control to 1.1 g/cm³ in the 30 t/ha treatment highlights Biochar's role in improving soil physical properties.

In terms of crop productivity, Biochar amendments led to significant increases in strawberry yield and quality. The highest yield was recorded in the 30 t/ha treatment, with 27,500 kg/ha, compared to 20,000 kg/ha in the control. This yield improvement can be attributed to enhanced soil health, which supports better root growth and nutrient uptake. Additionally, fruit quality parameters such as average fruit size and Brix (sugar content) also improved with Biochar application. Larger fruit size and higher Brix values indicate better marketability and consumer preference, adding economic value to the crop.

The findings suggest that Biochar not only improves soil health but also translates these benefits into higher crop productivity and better fruit quality. The positive effects observed at higher application rates (20 t/ha and 30 t/ha) indicate that Biochar can be an effective soil amendment for organic strawberry farming. However, it is important to consider the long-term impacts and the economic feasibility of Biochar application at these rates.

Overall, this study demonstrates that Biochar amendments can significantly enhance soil health and crop productivity in organic strawberry farming. The results provide strong evidence for the adoption of Biochar as a sustainable soil management practice in organic agriculture. Future research should focus on the long-term effects of Biochar, its interaction with different soil types, and its economic viability to optimize its use in organic farming systems.

Conclusion

This study demonstrates that Biochar amendments significantly improve soil health and crop productivity in organic strawberry (*Fragaria* × *ananassa*) farming. The application of Biochar led to enhanced soil pH, organic carbon content, cation exchange capacity, microbial biomass carbon, and reduced bulk density. These improvements in soil health parameters contributed to increased strawberry yield and better fruit quality. The findings suggest that Biochar can be a valuable soil amendment in organic farming, providing both agronomic and economic benefits. Further research is recommended to explore the long-term effects and optimal application rates of Biochar in different organic farming systems.

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