ECOLOGICAL FARMERS ASSOCIATION OF ONTARIO

DISEASE & PEST CONTROL

SOIL HEALTH

FARMER-RESEARCHERS

Ines Lacarne, Michelle Dang, and Sharene Shafie
The X Urban Farm

The Urban Farm is located in Toronto at the university formerly known as Ryerson University* on the treaty and traditional territory of many nations including the Mississaugas of the Credit, the Anishnabeg, the Chippewa, the Haudenosaunee, and the Wendat peoples and is covered by Treaty 13 with the Mississaugas of the Credit.

RESEARCH REPORT 2021

Using biochar as an amendment for engineered green roof soil blend

Listen to audio summary of this report

IN A NUTSHELL

This study aimed to find out whether adding biochar to an engineered green roof soil blend would ameliorate the soil in order to successfully grow spray-free vegetables at similar yields to the Farm's older plots with more productive soil.

- Farmers found that vegetables grew well in both the control and biochar-amended plots when compared to crops that grew poorly in the originally installed engineered soil.
- However, biochar amendment did not significantly improve crop quality, yield, or soil health during the first year of application.

This project was funded by Valerie and Andrew Pringle through the Urban Farm Living Lab; as well as by the Brian and Joannah Lawson Family Foundation and The Arrell Family Foundation through the EFAO.

MOTIVATION

Rooftop farming presents a unique opportunity to add value to underutilized urban spaces and provides many benefits for local communities and ecosystems. Many rooftop farms grow food using green roof technology, which is when layers are built up on top of a roof deck, with drainage and waterproofing elements underneath engineered soil and plants. Green roofs have a number of climate benefits, such as reducing stormwater runoff, mitigating the urban heat island effect, adding biodiversity to urban environments, and more.

The Urban Farm at X University in Toronto, Canada is a quarter acre rooftop farm that distributes roughly 10,000 pounds of food to the community each year, facilitates interdisciplinary research through a Living Lab, and offers engagement in urban farming, ecology and food justice (**Photo 1**). The rooftop farm was originally built as a passive green roof in 2004 and converted to food production in 2013/2014. Rooftop farms, such as this one, rely on green roof technology to grow plants and require engineered soil blends to be installed (**1**). While soil with a larger proportion of organic matter is optimal for food production, organic soil blends have an increased particle density and retain more water, which creates risk of weight overloading on rooftops (**2**-**5**). Green roof standards set by organizations such as the German Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau (FLL) call for use of high aggregate soil blends.

In 2009, the city of Toronto established a green roof by-law in which new buildings over 2,000 m² in gross floor area must construct green roofs (City of Toronto, 2010). As part of this regulation, the city recommends all green roofs to install soil in accordance with FLL guidelines as a best practice. Unfortunately, these soil blends are not optimal for agricultural use because of their low organic content, nutrient leaching, and shallow soil depth (**4**, **6**-**10**). These soil blends are engineered to meet FLL standards for longevity, drainage, flammability, and structural load. This leaves rooftop farmers with a dilemma when it comes to soil, balancing the need to meet safety requirements while striving for optimal soil conditions for food production.

Photo 1. Building beds at the Urban Farm.

Photo 2. Adding compost and worm castings to the entire experimental plot.

Photo 3. Charing biochar by mixing with compost and worm castings and covering with a silage tarp.

In 2020, the Urban Farm installed a new growing space on their existing rooftop farm, and a second purpose-built rooftop farm on a new campus building. Both spaces were supplied with a green roof soil blend that was higher in aggregate (i.e., crushed brick and large particle size) than the growing media on the original farm and lower in organic matter (9% versus 23% respectively). As the infrastructure of the farm was set up prior to the passing of the Toronto green roof by-law, the original soil from the older farm plots has high organic matter and no aggregate, with 17 years of biological life allowing for the development of a rich soil food web. While this soil is clearly ideal for farming, it would not meet the FLL growing media standards widely used in the green roof industry today.

In fall 2020, the farmers planted cover crops in their new plot, but unfortunately, plants had poor germination and where the cover crops did grow, they appeared deficient and stunted. Soil tests revealed that organic matter and mineral levels were suboptimal for crop production. Also, pH was significantly higher in the newer plots (pH ranging from 8.0-8.3) than in older plots on the farm (pH ranging from 7.6-7.8).

With the hope of transforming the newly installed soil to something more like the original soil, the team at the Urban Farm came up with a strategy to amend the soil while maintaining the building's structural engineering requirements for loading. In conversations with other ecological farmers and green roof professionals, the team heard about biochar — a charcoal-like substance made by burning organic material from agricultural and forestry wastes through pyrolysis (**11**). Due to its relatively high cost, they wanted to try amending one plot with biochar to see what would happen before applying biochar to the entire site.

Biochar, when applied to soil, has been observed to remediate pollutants, increase microbial activity, improve water and nutrient availability, as well as enhance crop productivity (**12**-**20**). Whether biochar enhances crop production in urban settings is largely unknown, but a growing body of research suggests biochar may be beneficial. The addition of biochar to green roof substrates has been found to create a lightweight soil blend with increased water holding capacity, higher organic matter content, and reduced bulk load density ideal for crop production (**20**, **21**). In terms of crop productivity, some studies have found biochar amendment to increase crop yields in a variety of vegetables, while in some cases reporting null effects on yield for other crops. While these studies report insignificant yields, they found significantly increased soil nutrient availability, higher soil water retention, and increased nutrition in harvested crops after biochar amendment (**22**-**25**).

With biochar's lightweight composition and potential to improve soil health and crop productivity, biochar may be part of the solution to improving engineered soil blends for food production, while still adhering to load requirements for rooftop farms. To investigate biochar's potential to improve the soil, the farmers applied biochar to a new plot and grew five different crops: Cucurbita pepo (summer squash), Raphanus raphanistrum (radish), Beta vulgaris (beets), Lactuca sativa (lettuce), and Solanum melongena (eggplant), observing and recording their growth throughout the season.

Their null hypothesis stated that the addition of biochar to the soil blend would not increase crop yield. Alternatively, the farmers hypothesized that the addition of biochar would increase crop productivity. The farmers hope the findings from this study can provide insights as to whether biochar can be a lightweight, organic, ecological solution to address the soil health concerns of rooftop farms and farmers.

METHODS

Baseline amendments

As a baseline for improving soil, farmers added compost and worm castings to the entire plot (3.5 yards of compost and 125 gallons of worm castings evenly into the top 10-20cm layer) to add fertility and introduce microbial activity (**Photo 2**).

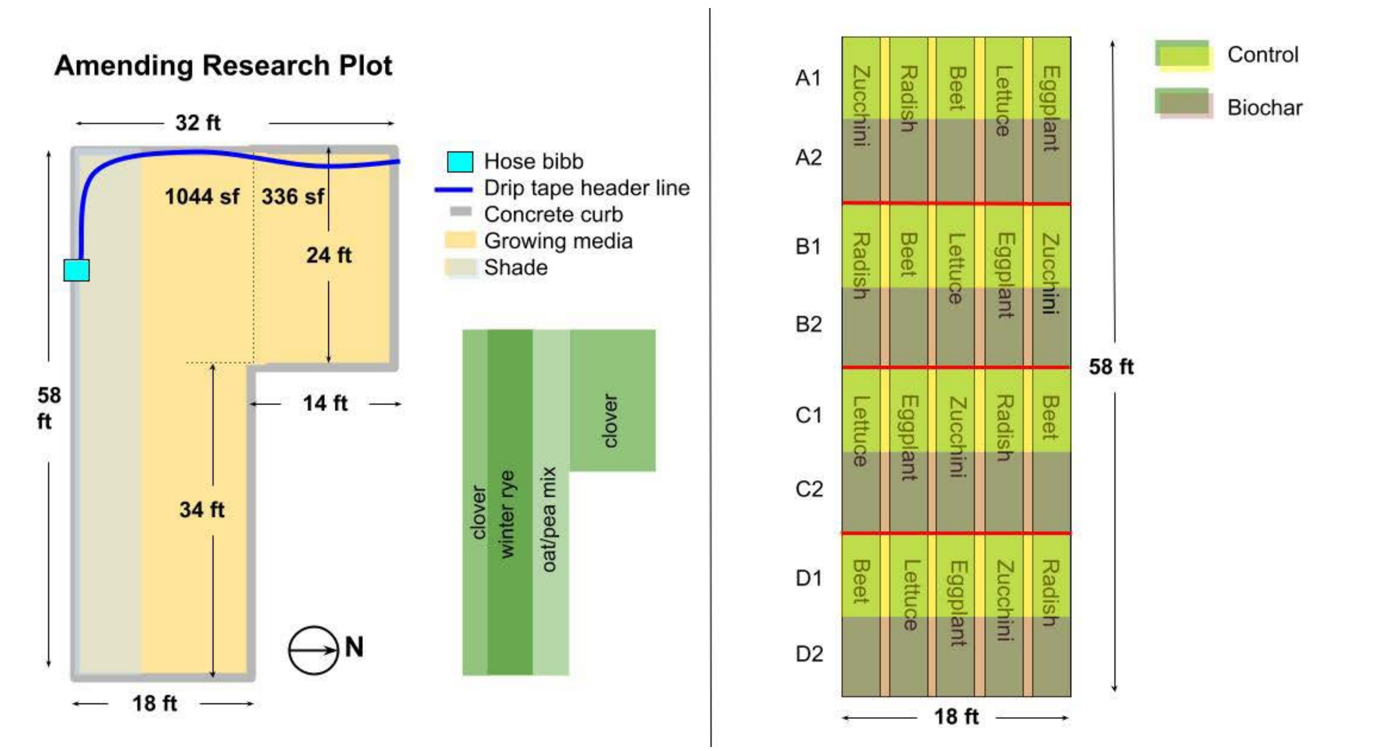


Figure 1. Site map of the Urban Farm with the randomized and replicated plot layout for the biochar amendment trial.

Before adding compost/worm castings/biochar, they followed recommendations from the growing media supplier and applied elemental sulfur (to lower pH) and two applications of a liquid bio-organic all-purpose fertilizer.

Charging the Biochar

It is generally recommended that biochar is "charged" before applying to soil. This is done to inoculate it with microbial life. Farmers used biochar produced from the 600°C pyrolysis of hardwood waste materials. To charge the biochar, they wet the biochar with all-purpose fertilizer diluted with hose water (1 tsp fertilizer/L water) until the biochar was moist enough to maintain its shape when clumped. They then mixed 100 gallons of moistened biochar with 50 gallons worm castings and 50 gallons compost, then let this mixture sit under a silage tarp for approximately one month (**Photo 3**).

Experimental Design

The experimental plot was divided into five 30-inch wide beds to establish four replicate pairs of growing media (control) and growing media + biochar (treatment) plots with their five crops randomly assigned to each experimental section (**Figure 1**). They applied biochar to experimental sections, ensuring to incorporate it into the top 10-20cm of the topsoil, at a rate of 50 gallons per 130 sq ft section (**Photo 4**).

Farmers sowed summer squash, eggplant and lettuce in the greenhouse on May 10, April 9 and May 18 respectively, placed under grow lights and watered with an overhead hose approximately every other day. On May 19, they brought all seedlings outside and left in partial sunlight to harden off. On June 9, they transplanted summer squash and eggplant seedlings directly into soil at a density of four plants in a single row at 18 inches apart per bed. They direct seeded beets in three rows, 15 seeds/ft (June 10), and radishes in four rows, 1/16 tsp of seeds/ft (June 15). Once the beet and radish seeds developed true leaves, they thinned both seedlings to four plants/ft and 15 plants/ft respectively (June 21). They also transplanted the lettuce seedlings in four rows, 6in apart. Unfortunately, some lettuce seedlings did not survive

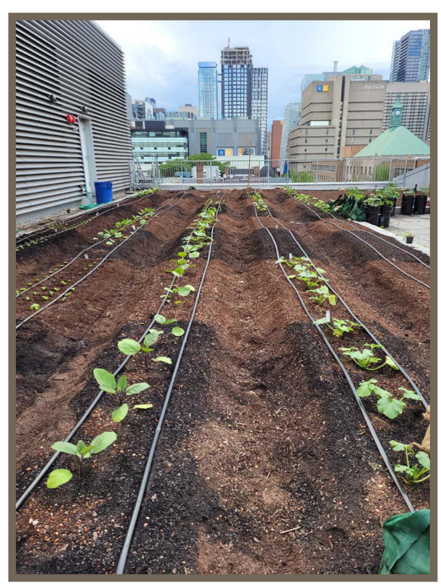


Photo 4. Biochar sections vs. control sections on June 16.

transplanting. Throughout the study, they watered seedlings and plants by natural, outdoor precipitation, or when the soil felt dry over one inch deep and precipitation was not forecasted within 1-2 days, they watered plants by a drip irrigation system that was left on for two-three days.

Overall Plant Health and Crop Quality

Farmers rated overall plant health and crop quality on a scale from one to five, the rating systems was as follows: [1] <25% plants; [2] 25-49% plants; [3] 50-74% plants; [4] 75-89% plants; and [5] 90%+ plants in plots have no issues. They took weekly observations on Wednesdays in each plot starting the week of June 23 for all crops and ending the week of July 14 for beets, July 21 for lettuce and radish, and August 18 for eggplant and squash as crops finished (**Photo 5**).

They took no overall plant health observations for crops the week of July 29 due to an altered grower schedule. Farmers documented crop quality and appearance with photos throughout the season, including capturing pest pressure and other suspected issues (such as damping off and lack of sunlight).

Marketable Weight and Quantity

For each crop and plot, farmers collected the number and weight of harvestable units on Mondays, Wednesdays, and Fridays from June 30 to August 18, 2021, although with some considerations. For root crops, they harvested vegetables when they were mature on a continuous basis. Once plants surpassed their days to maturity, they cleared the beds and separated remaining plants into marketable versus non-marketable crops based on size. They cleared radish beds on July 23, 2021, and beet beds on August 9, 2021. For the lettuce, they cleared all lettuce heads on July 29, 2021, as this was several days after they noticed that the lettuce across plots stopped growing in size. They considered lettuces harvestable if they were mature. For fruiting crops, they harvested vegetables continuously from plants when their fruit were mature. They cleared all the fruiting crop beds on August 18, 2021 as fruit production slowed down at this time. Once all field data was collected, they organized data into total units and weight of crops harvested by plant and treatment type.

Soil Health Indicators

The farmers took soil samples for soil tests to be performed before and after the study was conducted. They decided to focus on soil pH, cation exchange capacity (CEC), and organic matter percentage as indicators of overall soil health. pH is one of the main factors influencing nutritional availability, crop growth and microbial diversity. Optimal pH for plant growth ranges from 5.5 to 7.5. CEC is an indicator of the soil's sand, silt and clay content as well as an indicator of its ability to hold and exchange nutrients and prevent leaching. Last but not least, organic matter content provides structure, is an indication of soil's moisture holding capacity, and acts as a reserve for many essential nutrients, especially nitrogen (**26**).

DATA ANALYSIS

To evaluate the effect of biochar amendment on overall plant health, marketable weight, marketable quantity, and crop quality, a statistical model called analysis of variance (ANOVA) with a 90% confidence level was used to calculate the least significant difference (LSD) needed to call the treatments "statistically different".

Using a 90% confidence level means that if we measure a difference between any two treatments that is greater than the calculated LSD, we expect this difference would occur 9 times out of 10 under the same conditions. In this case, we consider the difference reliable and refer to the results as statistically significant. On the other hand, if we measure a difference between any two treatments that is less than the calculated LSD, we consider these treatments unreliably different or statistically similar. These statistical calculations were made possible because the farm's experimental design involved replication of the treatments (**Figure 1**).

FINDINGS

Overall Plant Health and Crop Quality

For overall plant health, farmers needed to see an LSD of 0.62 for radish, 0.23 for lettuce, 0.48 for beet, 0.55 for zucchini and 0.26 for eggplant between the control and biochar treatment to see a statistically significant difference. Based on these numbers, farmers found there was no statistically significant difference in overall plant health rates for any of the crops grown radish (P=0.18), lettuce (P=0.71), beet (P=0.38), zucchini (P=0.78), or eggplant (P=0.69) (**Figure 2**).

Photo 5. Weekly plant observations of the trial.

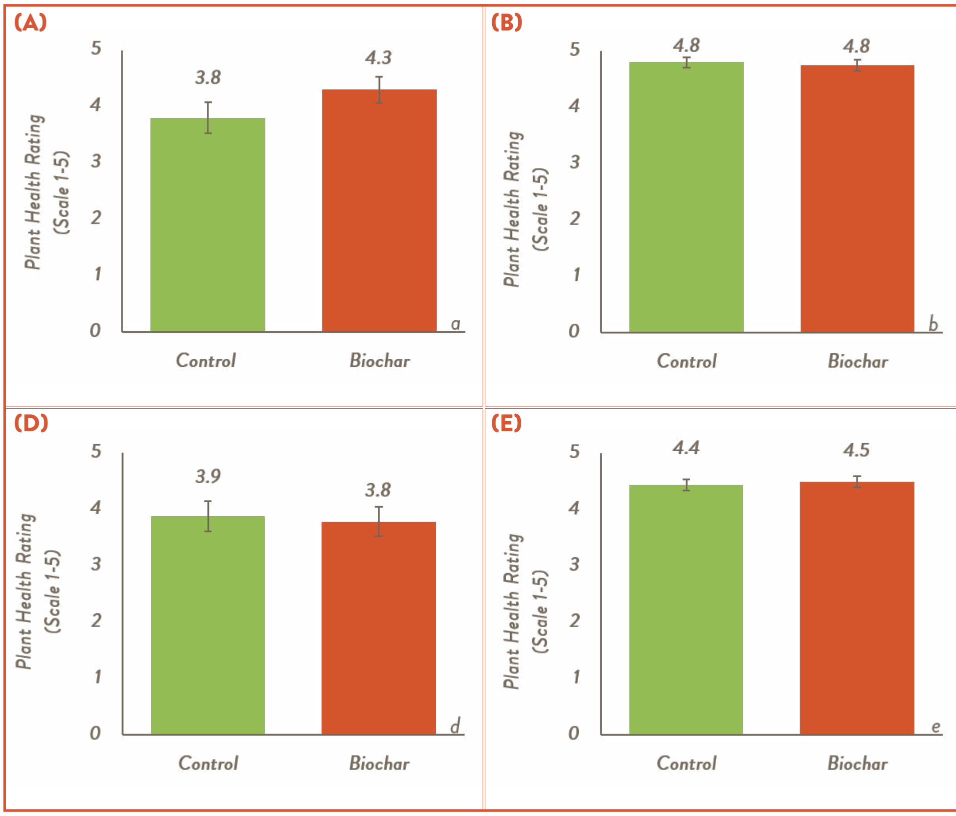


Figure 2. Mean (±SE) of overall plant health for (a) radish, (b) lettuce, (c) beet, (d) squash, (e) eggplant. For each vegetable, farmers found no significant difference between the treatments.

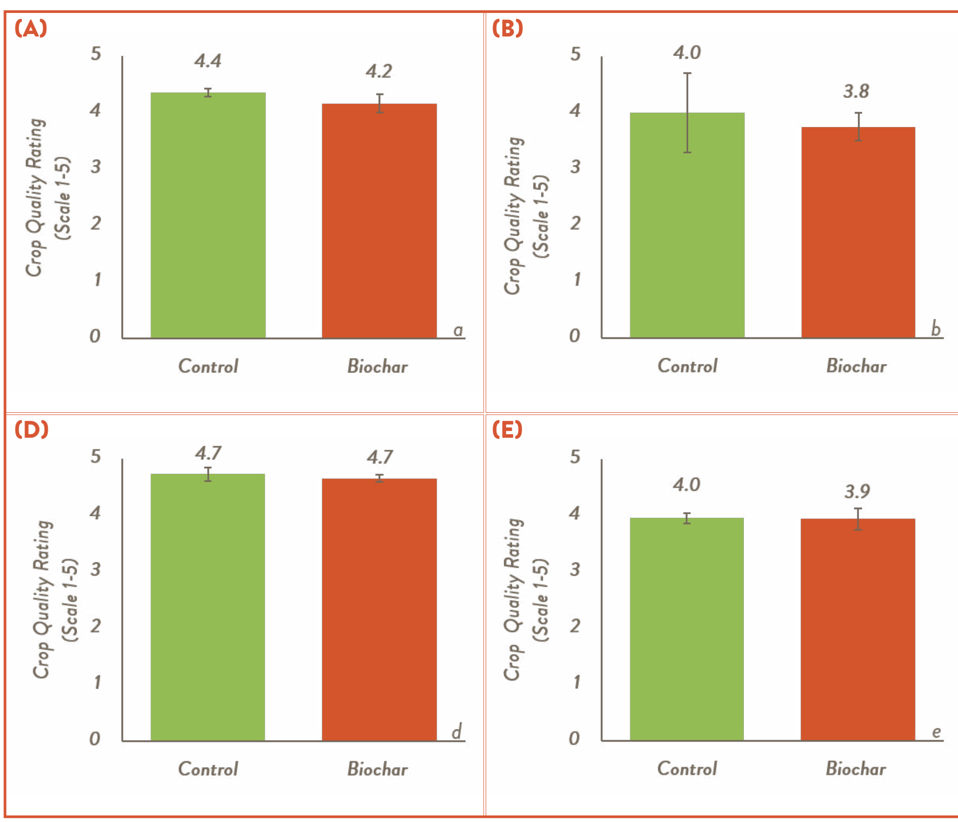
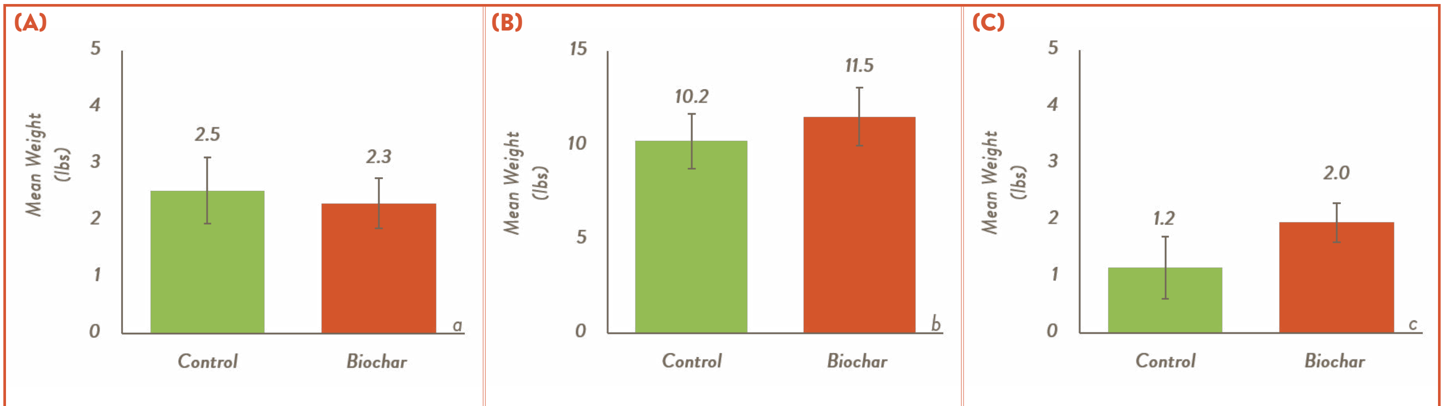


Figure 3. Mean (±SE) of crop quality for (a) radish, (b) lettuce, (c) beet, (d) squash, (e) eggplant. For each vegetable, farmers detected no significant difference between the treatments.



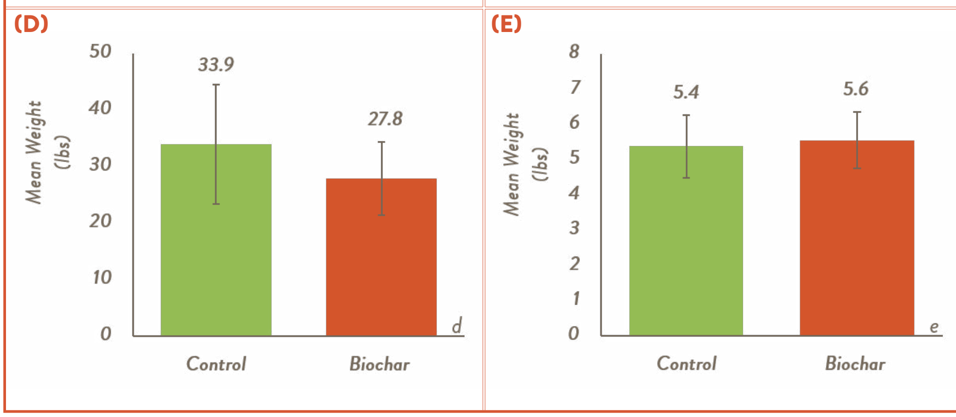
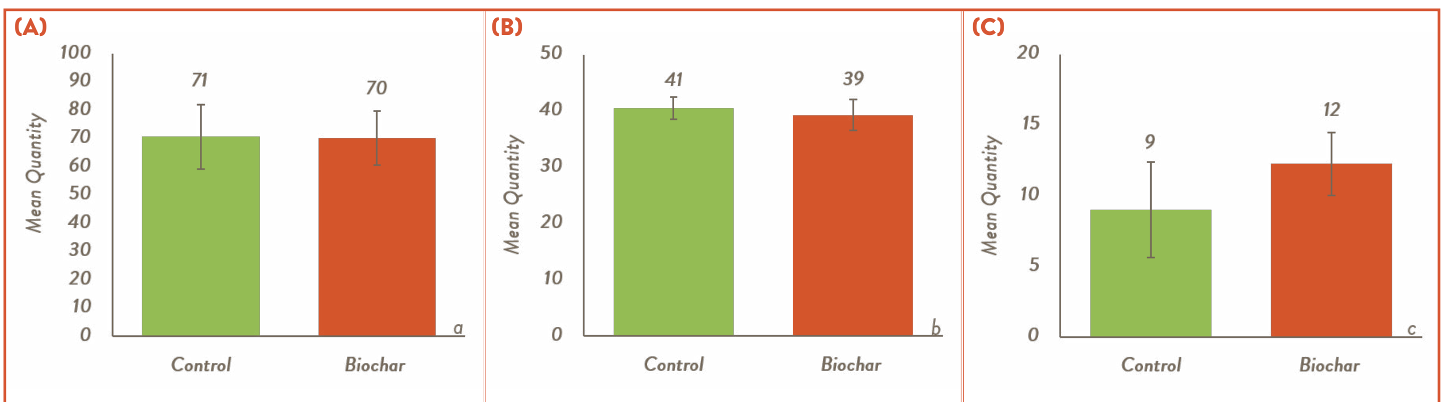


Figure 4. Mean (±SE) for marketable weight of (a) radish, (b) lettuce, (c) beet, (d) squash, (e) eggplant. For each vegetable, farmers found no significant difference between the treatments.



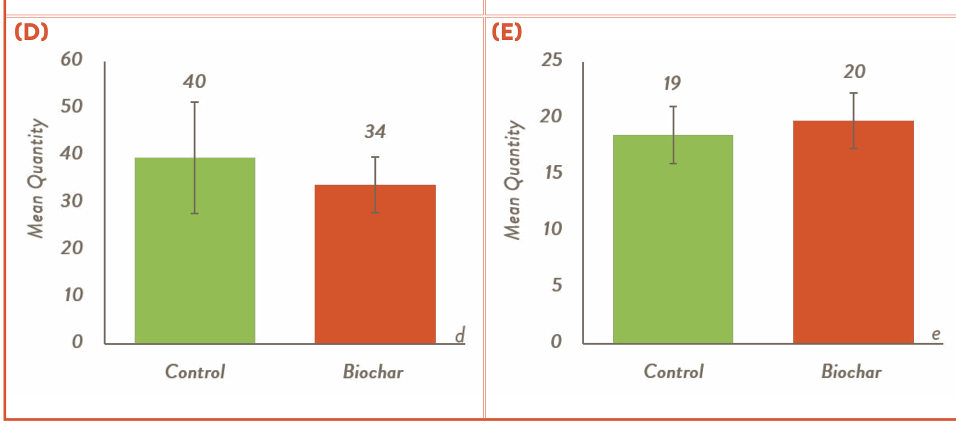


Figure 5. Mean (±SE) of marketable quantity for (a) radish, (b) lettuce, (c) beet, (d) squash, (e) eggplant. For each vegetable, farmers found no significant difference between the treatments.

Farmers did find a significant difference among replications for zucchini (P=<0.001), in which replicate A scored significantly lower overall plant health rates than all other replicates of zucchini.

For crop quality, farmers needed to see an LSD of 0.25 for radish, 1.76 for lettuce, 0.59 for beet, 0.44 for zucchini and 0.40 for eggplant between the control and biochar treatment to see a statistically significant difference. Farmers found there was no statistically significant difference in crop quality rate for any of the crops grown radish (P=0.17), lettuce (P=0.76), beet (P=0.39), zucchini (P=0.71), or eggplant (P=0.94) (**Figure 3**).

Marketable Weight and Quantity

For marketable weight, farmers needed to see an LSD of 1.3 lbs for radish, 2.9 lbs for lettuce, 1.4 lbs for beet, 13.4 lbs for zucchini and 2.2 lbs for eggplant between the control and biochar treatment to see a statistically significant difference. Farmers found there was no statistically significant difference in marketable weight for any of the crops grown radish (P=0.71), lettuce (P=0.37), beet (P=0.26), zucchini (P=0.37), or eggplant (P=0.86) (**Figure 4**). Farmers did find a significant difference among replications for zucchini (P=0.057), in which replicate A produced significantly less marketable weight than replicate C, there was no significant difference among any other replicates.

Similarly for marketable quantity, farmers needed to see an LSD of 36 units for radish, two units for lettuce, eight units for beet, 17 units for zucchini and six units for eggplant between the control and biochar treatment to see a statistically significant difference. Farmers found there was no statistically significant difference in marketable quantity for any of the crops grown: radish (P=0.97), lettuce (P=0.19), beet (P=0.40), zucchini (P=0.49), or eggplant (P=0.67) (**Figure 5**). Farmers did find a significant difference among replicates for lettuce (P=0.006), in which replicate A and B produced significantly less marketable quantity than replicate C and D (**Photo 6**), there was no significant difference between replicates A and B or C and D.

Photo 6. Lettuce growing in the experimental plots.

Soil Health Indicators

No statistical analysis was performed on soil health markers to determine whether there were significant improvements. However, as seen in **Table 1**, farmers noted that the pH went down slightly in both the control and treatment plots. They expected this outcome from the addition of elemental sulfur. Organic matter percentage also increased in the biochar plot after the growing season compared to the control crop.

CAVEATS

- Some lettuce seedlings did not survive transplanting which impacted yield. On June 23, 2021 (2 days after transplanting), the number of lettuce seedlings that appeared to survive transplant are as follows: A1-Control (n = 35), A2-Biochar (n = 35), B1-Control (n = 34), B2-Biochar (n = 37), C1-Lettuce (n = 44), C2-Biochar (n = 44), D1-Lettuce (n = 40), D2-Biochar (n = 44).
- Farmers noted that positive effects from biochar may not be apparent in the first growing season since the natural accumulation of charcoal in ancient soils occurred over very long periods of time.
- Multiple small applications of biochar over time may be more effective than a single large application.
- This field of research is nascent, which means there isn't a standard or universally recommended application rate - though that will always depend on context and many other factors.

Table 1. Comparison of soil health indicators before and after the biochar amendment study.

	NOVEMBER 2020	SEPTEMBER 2021	
	PRE-AMENDMENT	CONTROL	BIOCHAR
pH	8.3	7.8	7.8
Organic Matter (%)	10	9.9	11.4
Cation Exchange (MEQ/100g)	31.2	27.5	22.3

NEXT STEPS

Farmers will continue to monitor soil health indicators in the biochar plots over time.

A lot of the interest surrounding biochar seems to tout it as a “quick fix” to amend or remediate soil. However, farmers will not use biochar across the rest of their new growing spaces due to the fact that the results did not justify the effort and cost that was required to apply it. Moving forward, farmers will use soil amendments that are less costly, less energy intensive to produce, that are lightweight, and easier to transport than biochar - like compost, vermicompost, or pelleted fertilizers like chicken manure. They also hope to work with other farmers and community members to see how they can optimize soil blends for the purposes of rooftop farming, which might include exploring the benefits of a growing medium that has charged biochar incorporated into it.

TAKE HOME MESSAGE

Farmers did not observe in the field or statistically find any significant effect of biochar on crop quality, yield, or soil health when applied to the growing media on their new plot. However, vegetables did grow successfully in both the control and biochar-amended areas. From the farmers’ perspective, crops like eggplant, summer squash and lettuce performed better with biochar in terms of overall appearance and quality, compared to radishes and beets.

ACKNOWLEDGEMENTS

The farming team would first like to thank the EFAO for all their help and support on this experiment as this was the farm's first ever research project. The team learned so much from this collaboration and appreciate all the work the folks at the EFAO put into this. The team would also like to thank all the staff and students at X University who provided their support with conducting this experiment. We truly could not have done this without everyone involved. Lastly, the team would like to show gratitude to the land, soil, and plants that they had the privilege of working with and learning from throughout this whole process. Thank you.

*In August 2021, the university announced that it would begin a renaming process to reconcile the legacy of Egerton Ryerson for his role in designing a model for residential schools that was influential in shaping a system that amounted to cultural genocide. Hereforward, we refer to the institution as X University to cease association with the name of an individual who was instrumental in the design of the residential school system.

REFERENCES

1. Emilsson, T., & Rolf, K. (2005). Comparison of establishment methods for extensive green roofs in southern Sweden. Urban Forestry & Urban Greening, 3(2), 103-111.
2. [FLL] Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau, FLL. Guidelines for the Planning, Construction and Maintenance of Green Roofing. Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau e. V., Bonn, Germany, 119.
3. Young, T., Cameron, D. D., Sorrill, J., Edwards, T., & Phoenix, G. K. (2014). Importance of different components of green roof substrate on plant growth and physiological performance. Urban Forestry & Urban Greening, 13(3), 507-516.
4. Nagase, A., & Dunnett, N. (2011). The relationship between percentage of organic matter in substrate and plant growth in extensive green roofs. Landscape and Urban Planning, 103(2), 230-236.
5. Eksi, M., Rowe, D. B., Fernández-Cañero, R., & Cregg, B. M. (2015). Effect of substrate compost percentage on green roof vegetable production. Urban Forestry & Urban Greening, 14(2), 315-322.
6. Oberndorfer, E., Lundholm, J., Bass, B., Coffman, R. R., Doshi, H., Dunnett, N., ... & Rowe, B. (2007). Green roofs as urban ecosystems: ecological structures, functions, and services. BioScience, 57(10), 823-833.
7. Roth-Kleyer, S. (2001). Vegetationstechnische Eigenschaften mineralischer Substratkomponenten zur Herstellung von Vegetationstrag-und Dränschichten für bodenferne Begrünungen. Dach+ Grün, 10, 4-11.
8. Whittinghill, L. J., & Rowe, D. B. (2012). The role of green roof technology in urban agriculture. Renewable Agriculture and Food Systems, 27(4), 314-322.
9. Rowe, D. B., Monterusso, M. A., & Rugh, C. L. (2006). Assessment of heat-expanded slate and fertility requirements in green roof substrates. HortTechnology, 16(3), 471-477.
10. Hathaway, A. M., Hunt, W. F., & Jennings, G. D. (2008). A field study of green roof hydrologic and water quality performance. Transactions of the ASABE, 51(1), 37-44.
11. Spears, S. (2018, October 15). What is biochar? Regeneration International. Retrieved November 4, 2021, from https://regenerationinternational.org/2018/05/16/what-is-biochar/.
12. Chen, H., Du, X., Lai, M., Nazhafati, M., Li, C., & Qi, W. (2021). Biochar Improves Sustainability of Green Roofs via Regulate of Soil Microbial Communities. Agriculture, 11(7), 620.
13. Chen, H., Ma, J., Wei, J., Gong, X., Yu, X., Guo, H., & Zhao, Y. (2018). Biochar increases plant growth and alters microbial communities via regulating the moisture and temperature of green roof substrates. Science of The Total Environment, 635, 333-342.
14. Yue, Y., Cui, L., Lin, Q., Li, G., & Zhao, X. (2017). Efficiency of sewage sludge biochar in improving urban soil properties and promoting grass growth. Chemosphere, 173, 551-556.
15. Rutigliano, F. A., Romano, M., Marzaioli, R., Baglivo, I., Baronti, S., Miglietta, F., & Castaldi, S. (2014). Effect of biochar addition on soil microbial community in a wheat crop. European Journal of Soil Biology, 60, 9-15.
16. Beesley, L., Moreno-Jiménez, E., & Gomez-Eyles, J. L. (2010). Effects of biochar and greenwaste compost amendments on mobility, bioavailability and toxicity of inorganic and organic contaminants in a multi-element polluted soil. Environmental pollution, 158(6), 2282-2287.
17. Jeffery et al (2011). A quantitative review of the effects of biochar application to soils on crop productivity using meta-analysis. Agriculture, ecosystems & environment, 144(1), 175-187.
18. Oladele, S. O., Adeyemo, A. J., & Awodun, M. A. (2019). Influence of rice husk biochar and inorganic fertilizer on soil nutrients availability and rain-fed rice yield in two contrasting soils. Geoderma, 336, 1-11.
19. Gao, S., Hoffman-Krull, K., Bidwell, A. L., & DeLuca, T. H. (2016). Locally produced wood biochar increases nutrient retention and availability in agricultural soils of the San Juan Islands, USA. Agriculture, Ecosystems & Environment, 233, 43-54.
20. Cao, C. T., Farrell, C., Kristiansen, P. E., & Rayner, J. P. (2014). Biochar makes green roof substrates lighter and improves water supply to plants. Ecological Engineering, 71, 368-374.
21. Song, S., Arora, S., Laserna, A.K.C., Shen, Y., Thian, B.W., Cheong, J.C., Tan, J.K., Chiam, Z., Fong, S.L., Ghosh, S. and Ok, Y.S., 2020. Biochar for urban agriculture: Impacts on soil chemical characteristics and on Brassica rapa growth, nutrient content and metabolism over multiple growth cycles. Science of the Total Environment, 727, p.138742.
22. Steiner, Christoph, Imogen Bellwood-Howard, Volker Häring, Kwame Tonkudor, Foster Addai, Kofi Atiah, Abdul Halim Abubakari, Gordana Kranjac-Berisavljevic, Bernd Marschner, and Andreas Buerkert. "Participatory trials of on-farm biochar production and use in Tamale, Ghana." Agronomy for sustainable development 38, no. 1 (2018): 1-10.
23. Manka'abusi, D., Steiner, C., Akoto-Danso, E.K., Lompo, D.J., Haering, V., Werner, S., Marschner, B. and Buerkert, A., 2019. Biochar application and wastewater irrigation in urban vegetable production of Ouagadougou, Burkina Faso. Nutrient cycling in agroecosystems, 115(2), pp.263-279.
24. Wijitkosum, S. & Jiwnok, P. (2019). Effect of biochar on Chinese kale and carbon storage in an agricultural area on a high rise building. AIMS Agriculture and Food, 4(1), 177-193.
25. Shen, Y., Song, S., Thian, B.W.Y., Fong, S.L., Ee, A.W.L., Arora, S., Ghosh, S., Li, S.F.Y., Tan, H.T.W., Dai, Y. and Wang, C.H., 2020. Impacts of biochar concentration on the growth performance of a leafy vegetable in a tropical city and its global warming potential. Journal of Cleaner Production, 264, p.121678.
26. Understanding soil tests - A&L Canada. Retrieved November 10, 2021, from https://www.alcanada.com/pdf/Tech_Bulletins/Soil/Testing/573-Understanding_Soil_Tests.pdf.