Analyze the Effects of Soil Management Practice on Water Holding Capacity of Soil to Reduce Water Application and Increase Crop Yield Using Precision Agriculture Technology

Introduction

Background:

- According to Environmental Protection Agency (2017), due to climate change, the western part of the United States is getting less precipitation and that leads to less availability of fresh water, one of the most valuable natural resources in our planet.
- Per World Bank, agriculture uses about 70% of all available fresh water worldwide (World Bank, 2020).
- These facts direct to the question- is there any way to optimize water use for agriculture by improving soil's ability to hold more water?
- To answer this question, this experiment was designed including biochar soil amendment and soil moisture sensor-based irrigation together with a home-made pump controller on a Raspberry Pi to minimize water use for winter spinach (*Spinacia oleracea*).
- This experiment can demonstrate that it is possible to prevent waste of our valuable and limited water resources for agricultural use and can also help improve crop yield.

Problem Statement:

This project is designed to examine if biochar can help improve soil water holding capacity and nutrient retention together with a pump controller to optimize water use for vegetable production.

Hypothesis:

Biochar and controlled irrigation system together can help to improve soil water holding capacity and nutrient retention in soil to grow vegetable better with less water.

Literature Review

- Biochar is a charcoal like material that is rich in carbon. It is created from plant materials like grass or agricultural waste or other biological waste that are decomposed in high temperature. It is highly porous, fine-grained and capable of improving soil water holding capacity (Jahromi et. al. 2019).
- By adding biochar, the available water in soil can be improved up to 45% for coarse textured soil, 21% for medium textured soil and 14% for fine textured soil (Razzaghi et. al. 2020).
- Biochar can help to improve crop productivity by reducing fertilizer drainage as it helps to increases water retention (Li et. al. 2021).
- In general, spinach needs 1 inch of water per week for their best growth, however if temperature increases the water requirement can go up to 1.5 inch per week (Spencer 2023).
- Spinach is a winter season vegetable that has shallow roots and requires frequent but short duration of irrigation (Koike et. al. 2011).
- For managing the irrigation in spinach, soil moisture monitoring is helpful so that water is always available for plants and the plants do not face water stress (Drost et. al. 2019).
- Out of 16 different nutrients that are required for plant growth, Nitrogen(N), Potassium (K) and Phosphorus (P) are very important (Penas et. al. 1990).
- Soil pH is another important factor for vegetable growth and a range between 5.5 to 7.5 is suitable for most vegetables (Penas et. al. 1990).

Materials

- Winter Spinach Seeds
- Three soil moisture sensors (ACEIRMC)
- An area inside the home garden to accommodate three 2ft*10ft size experiment and control plots
- Biochar & garden soil
- Soil testing kit
- A data collection laptop (Field Computer)
- Raspberry Pi, Ribbon Cable, 40 pin breakout board , Breadboard, Relay Module
- Jumper Wires
- HDMI Monitor
- Two Mini Pumps, & Small Reservoir
- Irrigation System Setup (irrigation pipe, drip emitters)

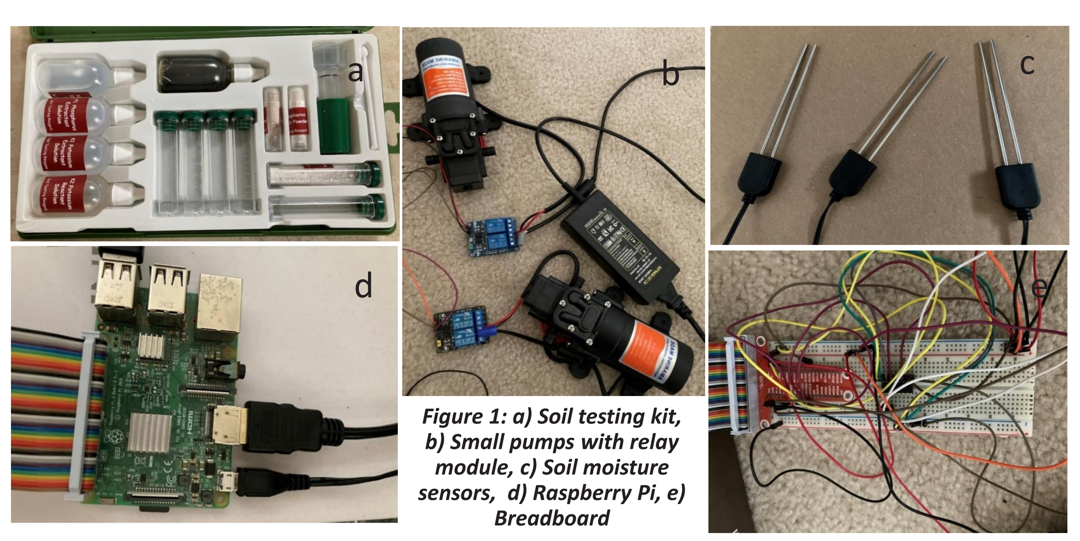

Figure 1: a) Soil testing kit, b) Small pumps with relay module, c) Soil moisture sensors, d) Raspberry Pi, e) Breadboard

*All photos, images, and charts are taken and created by Kinnoree Pasha

Methodology

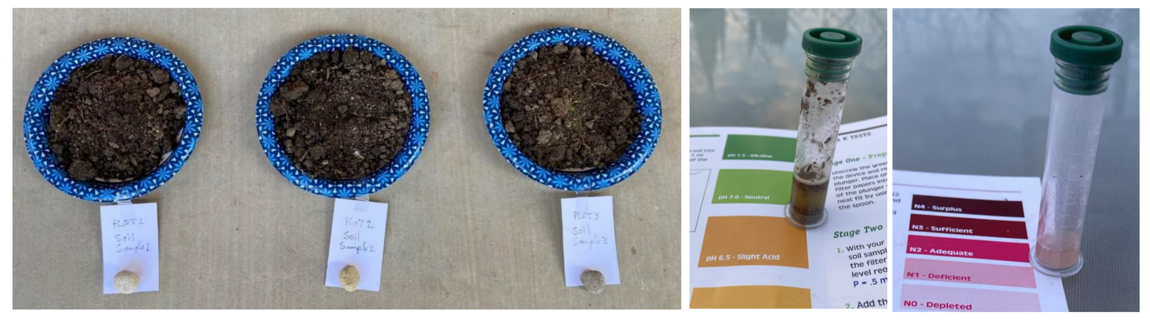

Figure 2: Soil sampling and testing before experiment

Figure 4: Sensor calibration

Calibration Equation:

$$SM_{wp}\ (\%) = \frac{(760 - Pulse)}{(760 - 360)}\ x\ 100$$

SM_{wp}(%) = soil moisture content in percent,
Pulse = soil moisture pulse reading

Figure 3: Experimental setup in the garden

1) Three research plots: one for control and two for experiment (experiment plot 1 and experiment plot 2) were established in the backyard home garden. All three plots were same size (2 ft. x 10 ft.) (Figure 3).

2) Soil sample were collected from all three plots before any soil amendment were made and were tested with soil testing kit for soil pH and major nutrient content (N, P, & K) (Figure 2).

3) Biochar was applied to the experiment plot 2 soil.

4) Literature review was conducted to get an idea on the overall water demand for winter spinach plants

5) Then a low-pressure drip irrigation system was installed in the experiment plots. The control plot was left to be irrigated manually.

6) One soil moisture sensor and one small pump with a small water reservoir was installed in each of the experiment plots. Sensors were calibrated before installing (Figure 4).

7) One soil moisture sensor was also installed in the control plot for monitoring the soil moisture, but no pump was added for the control plot.

8) A control system was developed using Python programming language on Raspberry Pi to gather soil moisture data using the sensors and then based on a logic turn the pump on or off for irrigation in both the experiment plots (Figure 5, 6).

Figure 5: Irrigation control system with soil moisture sensor and pumps at the experiment plots

Figure 6: Python Code to automatically turn on and off the pumps based on soil moisture reading

9) Two threshold soil moisture values were used in the control system to automatically start and stop the pump.

10) For the control plot, manual irrigation was scheduled based on the theoretical water need for the plant per literature review.

11) Soil sample was collected at the end of the experiment from each plot and tested with soil testing kit again for soil pH and nutrients (N, P & K) (Figure 7).

12) Plant growth and development was monitored by taking measurements of plant height, width (diameter at the top of the plant), and number of leaves etc.

13) Statistical analysis was done to observe the differences between experiment plots & control plot. Graphs and tables were prepared to summarize and visualize the results.

Figure 7: Soil sampling & testing after experiment

Results and Discussion

Soil Test

- Soil test results show that the application of biochar increases all the nutrients including pH (Table 1).
- While increase of nutrients are good for the plant growth, the pH increase may not always be good for the plant but in this case the pH was in the range (6.0 – 7.5) for the optimum growth of spinach.

Table 1: Soil test result before and after soil amendment

Parameter	Before Amendment			After Amendment: (Applied to Experiment Plot 2 only)		
	Test Results			Test Result		
	Control	Experiment 1	Experiment 2	Control	Experiment1	Experiment2
Soil pH	6.5	6.5	6.5	6.5	6.5	7.5
Nitrogen (N)	Adequate	Adequate	Adequate	Adequate	Adequate	Sufficient
Phosphorus (P)	Adequate	Adequate	Adequate	Adequate	Adequate	Sufficient
Potassium (K)	Adequate	Adequate	Adequate	Adequate	Adequate	Sufficient

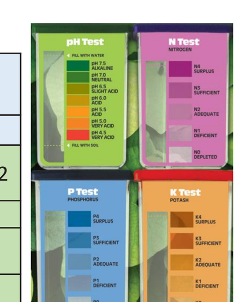

Figure 8: Soil test reading

Weather:

- Figure 9 shows the weather during the planting season from January 1 to March 2, 2023. Except last week of January and two weeks in mid-February there was precipitation.
- A continuous irrigation data set was thus found in mid-February.

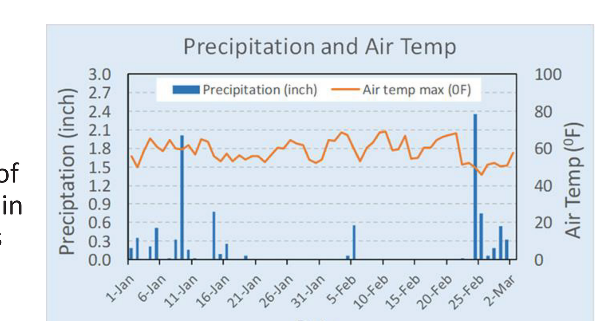

Figure 9: Weather during planting season

Results and Discussion (*Continued*)

Irrigation:

- Control Plot: no-biochar & no-pump (base condition), soil moisture was monitored.
- A set irrigation of 1.0 inch/week (i.e., 25.4 mm/week) based on theoretical water requirement (Spencer 2023) for spinach was applied on every Sunday, Tuesday, and Friday to the control plot.
- Experiment Plot 1: no-biochar & with-pump (to test effect of pump controller).
- Experiment Plot 2: with-biochar and with-pump (to test effect of biochar).
- In the experiment plots, the controller was set such that the soil moisture level does not go below 40%.
- Pump starts at moisture level below 40% and turn it off when moisture level is at 48% or above.
- While the range between the maximum and minimum moisture levels at the control plot is 62%, the range for the experiment plot is 25% only (Table 2).

Table 2: Summary statistics of soil moisture level at different conditions

Statistics	(Experiment 2 Plot: with-biochar & with-pump)	(Experiment 1 Plot: no-biochar & with-pump)	(Control Plot: no-biochar & no-pump)
Maximum (%)	**65.0**	**65.0**	**87.5**
Minimum (%)	40.0	40.0	25.5
Average (%)	***54.0***	***53.0***	***61.4***
Standard Dev. (%)	7.0	7.5	15.8
Range (%)	25.0	25.0	62.0

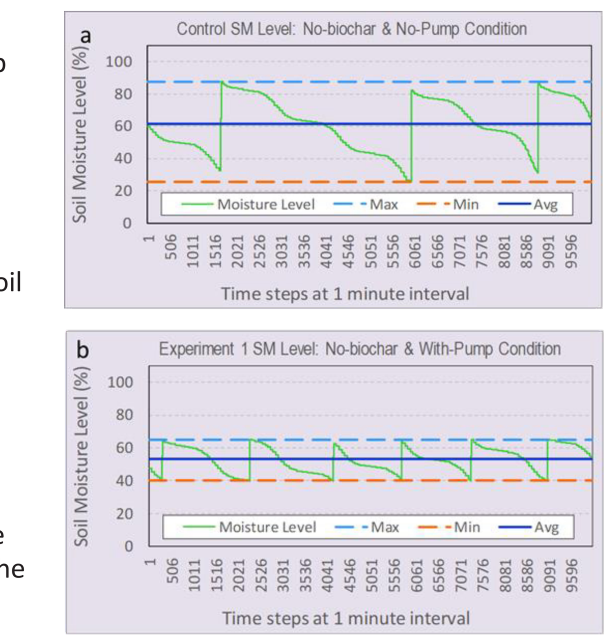

Figure 10. Effect of irrigation pump controller at moisture level: (a) Control plot: no-biochar & no-pump and (b) Experiment plot 1: no-biochar & with-pump conditions

Discussion:

- Effect of Biochar on water consumption was analyzed by comparing the amount of water pumped into Experiment plot 1 (no-biochar) and Experiment plot 2 (with-biochar).
- At the Experiment plot 1, the number of times the pump turned on is higher than that at the Experiment plot 2 showing less water consumption at the Experiment plot 2 where biochar was applied to (Figure 11(Below)).

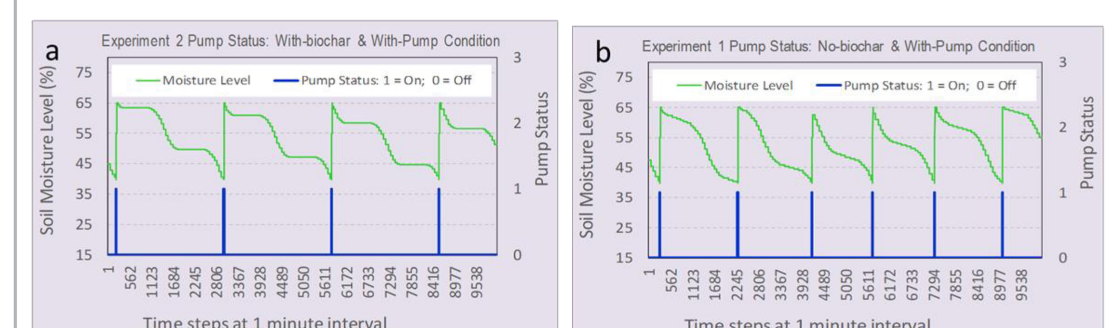

Figure 11: Time series plot of pump status with soil moisture level for (a) Experiment plot 2: with-biochar & with-pump (b) Experiment plot 1: no-biochar & with-pump conditions.

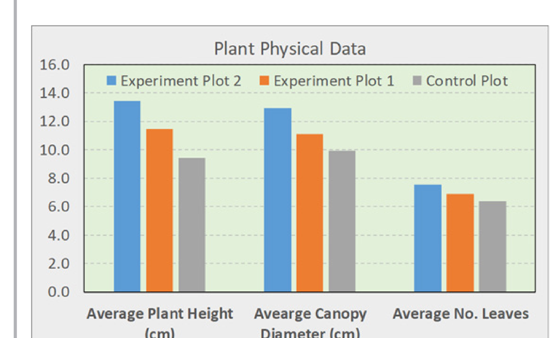

Figure 12: Plant height, canopy diameter, and the number of leaves per plant for all the plants in 7th week

- Figure 12 (Left) shows plants in the experiment plots are in general healthier than the control plot specially in the Experiment plot 2 where biochar has been applied

- While the weekly water savings with irrigation pump controller itself is about 13.4%) the water savings combined with biochar and pump controller is about 27.1% (Figure 13 (Right)).

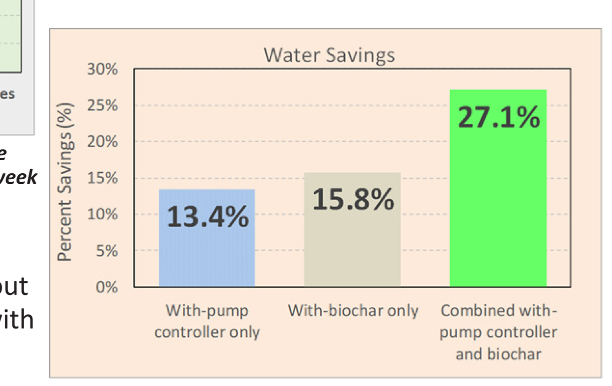

Figure 13: Percent Water Saving

Conclusion

- Biochar amends soil properties and increase water holding capacity, as a result less water was required in the experiment plot 2 when biochar was applied.
- About 15.8% water savings was possible just by using biochar soil amendment.
- With biochar and pump controller together, the total savings was 27.1%.
- Using the control system and biochar approximately 67,635 and 136,328 gallons/acre/season water savings are possible respectively for pump controller only and pump controller with biochar to commercially irrigate an acre of spinach.
- Physical data shows that spinach in the experiment plot are in general healthier than the control plot.
- In future, this experiment can be improved utilizing temperature, humidity, evapotranspiration sensor etc. Other soil tests can be used as well.

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