JEE Journal of Ecological Engineering

Journal of Ecological Engineering, 2025, 26(1), 66–82
https://doi.org/10.12911/22998993/195268
ISSN 2299–8993, License CC-BY 4.0

Received: 2024.10.23
Accepted: 2024.11.15
Published: 2024.12.01

Optimizing the application of biochar to improve irrigation efficiency and enhance the growth of chili plants in loam soil

Widowati[1*], Agnes Quartina Pudjiastuti[2], Linda Praseyorini[3], Retno Wilujeng[1], Utik Tri Wulan Cahya[1]

[1] Agrotechnology Study Program, Faculty of Agriculture, Tribhuwana Tunggadewi University, Jl. Telaga Warna, Tlogomas, Lowokwaru District, Malang City, East Java, 65114, Indonesia
[2] Department of Agricultural Economics, School of Graduate, Tribhuwana Tunggadewi University, Jl. Telaga Warna, Tlogomas, Lowokwaru District, Malang City, East Java, 65114, Indonesia
[3] Department of Water Resources Engineering, Faculty of Engineering, Brawijaya University, Jl Veteran, Malang, Indonesia
* Corresponding author's e-mail: widwidowati@gmail.com

ABSTRACT

Drought significantly threatens crop production by causing groundwater deficits, which hinder plant growth and development. Biochar has demonstrated its potential to improve soil water and nutrient retention. The study aimed to determine the optimal biochar dosage to promote the best growth of chili pepper plants under drip and conventional irrigation systems, calculating plant water needs and watering scenarios. Conducted in Dusun Bawang, Tunggulwulung Village, Malang, the study collected soil samples from Sumbergondo Village, Bumiaji District, Batu City. The experimental design employed a nested structure with eight irrigation treatments (drip and conventional) and four biochar doses (0%, 2%, 4%, and 6% of soil weight, each polybag containing 6 kg of soil). Each treatment was repeated four times, consisting of five units for each treatment, resulting in 160 experimental units. The chili pepper variety Ori 212 was planted in polybags pre-treated with chicken manure as a base fertilizer. NPK pearl fertilizer was applied at half the recommended dose. This study concluded that applying biochar at an optimal dosage of 4% can significantly promote the growth of chili plants. Integrating biochar with drip irrigation systems has proven effective in enhancing growth, especially in loam soils. The average potential evapotranspiration rate was measured at 3.91 mm/day. A water surplus was recorded from the third week of October to April, while a water deficit was noted from May until the third week of October, highlighting the necessity for efficient irrigation management. The water needs of chili plants varied across their growth stages. In the early phase, the requirement was 173 ml/day, which increased to 341 ml/day during the growth phase, peaked at 606 ml/day during fruit formation, and decreased to 598 ml/day during maturation. This rise in water demand reflects the plants' development.

Keywords: biochar, drip irrigation, plant growth, soil chemical properties, water requirement.

INTRODUCTION

Chili pepper (*Capsicum frutescens*) is Indonesia's vital horticultural commodity and spice plant. Despite high demand, productivity remains a challenge, largely due to the adverse effects of climate change, particularly global warming. The increase in Earth's temperature, caused by the accumulation of greenhouse gases, negatively impacts crop production. Buthia et al. (2018) stated that global warming has led to significant crop losses worldwide, including for chili peppers. Temperature indirectly regulates plant growth by influencing the balance between photosynthesis and respiration rates (Yanez-Lopez et al., 2012). High temperatures affect various aspects of plant physiology, directly or indirectly affecting crop yields (Erickson et al., 2001). Several studies have demonstrated the direct impact of temperature fluctuations on chili pepper production (Garruna-Hernandez et al., 2014). Climate change and increasingly extreme weather conditions also pose significant risks to agricultural yields globally (Reyes et al., 2021).

Moreover, rising global temperatures, irregular rainfall patterns, and extreme weather events further exacerbate the drought risk for the agricultural sector (Alotaibi, 2023).

Drought threatens crop production, primarily by causing groundwater deficits that hinder plant growth and development. Reports from the FAO (2020) and IPCC (2022), along with the research by Dalezios et al. (2017), indicate that agricultural production instability due to drought could lead to a global food crisis. Limited access to adequate water and inefficient irrigation methods make agriculture increasingly vulnerable to drought (Yadaf et al., 2022). To address this issue, efficient water management and advanced irrigation technologies, such as drip irrigation, are critical. Irrigation demand is expected to rise by 8–9% by the mid-21st century, while rainfall is projected to decrease by 11–18% (Woznicki et al., 2015). The research by Ayars et al. (1999), Pascale et al. (2011), and Venot et al. (2017) emphasized the importance of drip irrigation for improving water use efficiency and crop productivity.

Beyond effective irrigation, the agricultural practices that enhance plant growth are also essential. Organic materials like biochar have proven beneficial in improving soil fertility, water retention, and overall plant productivity, making them a viable solution to combat drought. The application of biochar addresses the challenge of balancing plant productivity with reduced greenhouse gas emissions (Wiesmeier et al., 2013). Biochar, a carbon-rich substance derived from biomass pyrolysis without oxygen (Smith, 2016), has been shown to enhance soil properties, such as structure, nutrient availability, and water retention (Zheng et al., 2019). This can increase irrigation water infiltration and boost soil water-holding capacity, thus enhancing plant growth and nutrient absorption (Liu et al., 2021). Studies confirm that biochar increases soil organic carbon, pH, total nitrogen, phosphorus, and cation exchange capacity, improving soil fertility and water retention, ultimately promoting plant growth (Bao, 2024). Furthermore, biochar has been shown to enhance soil porosity and aggregation, positively impacting crop yields by improving soil quality (An et al., 2023).

Biochar can also reduce plant water requirements by increasing water use efficiency and minimizing soil water evaporation, aligning with drip irrigation principles, which aim to conserve water. Sokol et al. (2019) demonstrated that drip irrigation reduces water usage while increasing crop yields compared to conventional methods, offering significant advantages by directing water precisely to plant roots, thus minimizing the losses through evaporation and runoff. Drip irrigation can reduce water use by 9-70% and increase yields by 8–50% compared to flood irrigation.

Combining drip irrigation technology with biochar application has improved plant growth and yield under drought conditions. Research by Umair et al. (2019) demonstrated that subsurface drip irrigation enhances both water productivity and irrigation efficiency, with increases of 24.95% and 19.59%, respectively, compared to conventional flood irrigation. Similarly, Pei et al. (2023) highlighted the potential of drip irrigation to optimize resource efficiency by tailoring water and nutrient delivery based on plant needs. This supports the notion that combining biochar and drip irrigation improves water efficiency and crop yields, especially under drought conditions, by optimizing resource management to boost plant productivity (Pei et al., 2023).

Numerous studies also affirm that biochar enhances the positive effects of drip irrigation by improving growth, yield, and water use efficiency. This underscores that combining biochar and drip irrigation represents a more sustainable agricultural practice, promoting higher productivity while conserving water. Cartika et al. (2023) found that drip irrigation increased chili pepper yields by 8.39%, improved water use efficiency, reduced production costs by 13.04%, and boosted farmers' income by 9.25% compared to manual irrigation. When used with biochar, this method further improves water efficiency and yields. Wang et al. (2021) showed that drip irrigation under plastic mulch optimized water management in the cultivation of indigowood root (*Isatis tinctoria* L.).

The impact of drought on crop production and strategies to enhance plant resilience under suboptimal environmental conditions have been extensively studied. For instance, El–Mageed et al. (2022) explored various drip irrigation schemes in rice cultivation, demonstrating that environmental changes directly affect plant growth and yield, with chili pepper yield attributes varying across different environments (Cabral et al., 2017). Additionally, research indicates that rhizobacteria can improve plant resistance to environmental stresses like drought, thereby enhancing growth and productivity under various water availability conditions (El–Mageed et al., 2022).

Sandy loam soils, common in some agricultural areas, present specific challenges for plant growth, such as rapid drainage and drying, particularly under high-temperature and dry conditions. Bekchanova et al. (2024) suggested that biochar is particularly beneficial for sandy soils, contributing to improved yields. Chili peppers require consistent moisture levels, and excessively dry conditions can inhibit their growth. Sandy soils typically have low nutrient levels, and nutrients can easily leach away, preventing plants from obtaining sufficient nutrition. Due to their low nutrient retention, these soils require frequent and proper fertilization.

To address these challenges, adding organic materials like manure, compost, or biochar can enhance soil fertility and water retention while maintaining moisture through careful irrigation management. Due to their complementary roles, the combined use of biochar and drip irrigation in chili pepper cultivation, particularly in Entisol soils, offers promising benefits. Determining the appropriate biochar dosage within a drip irrigation system remains crucial for optimizing chili yields according to soil conditions and plant needs.

Drip irrigation technology is a widely recognized solution for addressing water scarcity in agriculture. Its adoption can significantly reduce water usage compared to conventional irrigation techniques. While the combined use of biochar and drip irrigation has been less explored in chili farming, this study presents a novel approach by integrating proven technologies with varying biochar doses to develop a comprehensive solution to the challenges of water shortages in sustainable agriculture. For sandy loam Entisol soils, incorporating biochar alongside drip irrigation can significantly boost plant growth and productivity. This study aimed to determine the most effective biochar dosage to optimize chili pepper growth in drip and conventional irrigation systems, assessing plant water requirements and irrigation strategies. This finding can provide valuable information for farmers in soil management and selecting the most suitable irrigation methods.

RESEARCH METHODS

The research consisted of several stages, namely (1). Determination of water requirements for chili plants, (2). Operation of the Drip Irrigation System. (3). Application of drip irrigation to plants and conventional water supply. (4). Experiment fields in polybags for drip and conventional irrigation on chili pepper plants using 4 doses of biochar.

Determinationwater requirements for chili plants

Determining the value of plant water requirements can be determined by calculating the plant Evapotranspiration (ETc) value using the following formula: (Safei and Alex, 2008)

$$ETc = Kc \times ETo \tag{1}$$

where: ETc – plant evapotranspiration (mm/day), ETo – constant evaporation/reference crop (mm/day), Kc – crop coefficient.

The ETo value is calculated based on the Penman-Monteith method, with the following formula: (Usman, 2004).

$$ET_o = \left[0.408\,\Delta\,(Rn - G) + \left\{\frac{\gamma 900}{T + 273}\right\} U_2 (ea - ed)\right] / [\Delta + \gamma(1 + 0.34\,U_2)] \tag{2}$$

where: Rn – net radiation equivalent to evaporation (mm/day), G – soil heat flux (MJ/m^{2}day), γ – psychometric constant (kPa/0C), T – average temperature, U2 – wind speed at a height of 2 m (m/s) (ea-ed) – difference between saturated vapor pressure and actual vapor pressure (kPa).

To calculate the ETo value, climatological data such as maximum-minimum temperature data, wind speed, air humidity, and duration of sunlight for the last 10 years (2012–2023) are needed. Furthermore, the ETo value is multiplied by the plant coefficient (Kc) value at each growth phase. The Kc values of chili plants are 0.4, 0.75, 1.1, 1. Each for the early plant phase (0-30 HST), vegetative (31–70 HST), flowering and fruiting (71–120 HST), and ripening (121–150 HST) (Doorenbos and Kassam, 1979). Meanwhile, to calculate the water requirements of plants in polybags, the following formula is required:

$$ETc_{ploybag} = ET_o \times Kc \times 0{,}1 \times A \tag{3}$$

where: $ETcpolybag$ – water requirements for plants in polybags (ml/day), ETo – potential evapotranspiration (mm/day), Kc – plant coefficient, A – cross-sectional area of polybag (cm^2).

Operation of drip irrigation system

a) Preparation stage: Prepared tools and materials to create a drip irrigation network. Water reservoir as a reservoir with a height of 50 cm from top to bottom. The height distance was 45 cm from the top surface of the reservoir to the water distribution hole. The height distance was 35 cm from the bottom of the reservoir to the ground surface. Water was distributed through a main pipe from the reservoir as a primary channel of 0.5” PVC (dim). The height distance was 40 cm from the reservoir to the bottom of the ground surface, and the height distance was 35 cm from the bottom of the ground surface until the water was distributed to the planting medium so that there was a height difference of 5 cm as a slope.

b) The drip irrigation system provided water through a hose along the plant row, where each polybag had its own emitter (Figure 3). Each row of plants was given a 6.7 m long bamboo pole with a distance between water channels in each polybag of 66 cm. There were 4 long bamboo poles for drip irrigation on the left and right, where 80 polybags were placed with a distance between polybags of 54x40 cm (Figure 3). Bamboo poles were used to place secondary hoses tied with wire. Every 66 cm was given a T-shaped tool to channel water from the secondary to the tertiary hose to the polybags on the left and right. Tertiary hose with a length of 20 cm, size 3/16 dim. Each polybag was attached with a 50 cm long bamboo to support the tertiary hose. The support poles were attached to the planting medium to a depth of 15 cm. The clear plastic hose measuring 5/16 dim (tertiary) was given an emitter to drip water into each polybag (Figure 1). The tertiary hose was tied to the support pole with a plastic rope.

c) Data retrieval
  - The emitter test circuit was operated 6 times by setting the height to 33–35 cm so that each emitter discharge was uniform.
  - The dripping water was collected and measured with a measuring cup. Within 3 seconds, there were 2 drops, and each emitter measured the volume of water collected. The volume of application water for each emitter was measured using a measuring cup within 2 minutes, which contains 13.35 ml.
  - The operation of the irrigation network was stopped after the measurement was complete.

The main pipe tap could be opened and closed during drip irrigation. The water tap was opened at the part leading to the secondary and tertiary hoses connected to the emitter. The reservoir was filled with water with a volume of 400 liters (length 119 cm, width 63 cm, height 53 cm) in 20.4 minutes with a water speed of 7 seconds/liter. The drip irrigation pipe tap was stopped after the measurement was complete. It took 1 hour 15 minutes (1.25 hours) to add 500 ml of water. During the growth of the plants, water was provided according to a watering schedule measured in mm/day, or every 2 to 3 days (500 to 1,500 ml over 1.25 to 3.75 hours). Watering was done in the afternoon.

Conventional water supply

Conventional watering uses a dipper with as much water as given in the drip irrigation system, and based on the habits of farmers providing irrigation using water can as much as 27.428 mm/ha or around 200–400 ml/day/plant (Sumarna and Stallen, 1991). The amount of water given was adjusted to the results of the calculation of the water needs of chili plants.

Field pot experiments using soil samples treated with various doses of biochar to evaluate the effects of drip and conventional irrigation methods on the growth of chili pepper plants. The research was conducted in Bawang Hamlet, Tunggulwulung Village, Lowokwaru District, Malang City. The research soil samples were taken from Sumbergondo Village, Bumiaji District,

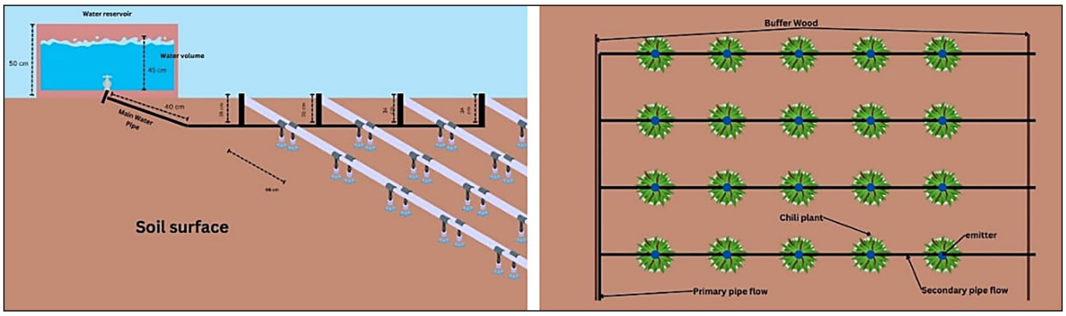

Figure 1. Drip irrigation design

Batu City, at 0–30 cm depth. The Entisol type of soil with a loam texture has a composition of 47% sand, 38% dust, and 15% clay. The analysis of organic carbon (C) was conducted using the Walkley and Black method, while nitrogen (N) was determined through the Kjeldahl method. Phosphorus (P) levels were assessed using the Olsen method. Soil pH was measured in a 1:1 ratio with water. Additionally, cation exchange capacity (CEC) and the levels of exchangeable cations – potassium (K), sodium (Na), calcium (Ca), and magnesium (Mg) – were determined by saturation with 1 N ammonium acetate (NH_4OAc) at a pH of 7.0. Potassium and sodium concentrations were quantified using flame photometry, while calcium and magnesium levels were analyzed through atomic absorption spectrophotometry, and water content was measured using gravimetry. The chemical characteristics of the soil are presented in Table 1.

Eight treatments (Table 2) were tested using a Nested Design with four replications. The low, medium, and high dose biochar treatments were 0%, 2%, 4%, and 6% of the soil sample weight. Soil samples weighing 6 kg were placed in a 35 × 35 cm polybag. Each treatment had 5 plants as experimental units, with 160 pots.

This research used rice husk from rice milling for biochar raw material. Biochar production used pyrolysis equipment at a temperature of 600 °C; every 20–30 kg of rice husk produces 10–12 kg of biochar (average shrinkage 2/3) with a processing time of 3–4 hours in the renewable energy laboratory of Tribhuwana Tunggadewi University, Malang.

This study applied chicken manure as the base fertilizer in all treatments as much as 200 g/polybag, 2.5 g humus mixed with 0.25 ml humic acid dissolved in 2 liters of water for 160 plants. Humus and humic acid are given every 2 weeks from 4–10 MST. Plants were fertilized with NPK pearl 16:16:16 at half the recommended dose. The chemical composition of chicken manure fertilizer and rice husk biochar is presented in Table 3.

Biochar was applied early, along with the preparation of the planting medium with a dose according to the treatment. Biochar was mixed

Table 1. Chemical properties of research soil samples

pH (H_2O)	pH (KCl)	C–Org (%)		N-Total (%)		P-Total (mg P_2O_5/100g)	K-Total (mg K_2O/100 g)
5.95	4.50	7.44		0.76		60	87
Water content (%)	P_2O_5 (ppm)	Cation dd (cmol)(+)/kg				CEC (cmol)(+)/kg	Amount of base cations (cmol)(+)/kg)
		K	Ca	Mg	Na		
9.30	70	1.26	8.48	1.00	0.60	3.87	11.34

Table 2. Research treatment

No.	Treatment code	Treatment
1	TB0%	drip irrigation without biochar (0%)
2	TB2%	drip irrigation + biochar 120 g (2%)
3	TB4%	drip irrigation + biochar 240 g (4%)
4	TB6%	drip irrigation + biochar 360 g (6%)
5	KB0%	conventional irrigation without biochar (0%)
6	KB2%	conventional irrigation + biochar 120 g (2%)
7	KB4%	conventional irrigation + biochar 240 g (4%)
8	KB6%	conventional irrigation + biochar 360 g (6%)

Table 3. Chemical composition of chicken manure and rice husk biochar

Sample	pH H_2O	pH KCl	C–Org (%)	N-Total (%)	P-Total	K-Total
					(% P_2O_5) (HCl 25%)	(% K_2O) (HCl 25%)
Chicken manure fertilizer	6.72	6.30	32.51	3.57	0.95	2.45
Biochar	9.65	9.10	3.57	0.41	0.14	1.81

evenly with chicken manure and soil, then sprayed with Nordox (fungicide/bactericide 56 WP). After that, it was placed into a polybag, 1 liter of water was added to it, and left for 7 days. After 7 days, the superior chili variety Ori 212 was planted. The chili seeds had been sown previously for 25 days.

Table 4 describes the variables observed in the study, which consisted of soil and Plant analysis. Data analysis in research was carried out using statistical software like SPSS, followed by the BNT test at a 5% significance level.

RESULTS AND DISCUSSION

Determining water requirements for chili plants

The value of chili plant water requirements is known by calculating the ETc (Actual Evapotranspiration) value based on the formula from Safei and Alex (2008), which is obtained from the multiplication of the Eto and Kc (Plant Coefficient) values. The Potential Evapotranspiration (Eto) value is obtained from the analysis results using the Cropwat Version 8.0 application with climate data sourced from BMKG Karangploso, Malang Regency. Climate data for the last 20 years (2003–2023) include maximum and minimum temperatures, air humidity, wind speed, and duration of exposure. The calculation of the Eto value can be seen in Table 5. The analysis results show that the average value of the potential evapotranspiration rate in the research location area is 3.91 mm/day. Several researchers have shown the same results: the potential evapotranspiration value in the Malang Raya area ranges from 3–6 mm/day (Singal, 2017; Idfi, 2021). The potential evapotranspiration value of each region will be different. Regions with high average temperature, air humidity, and duration of exposure will also have high potential evapotranspiration values (Zhang and Wang, 2021).

A water balance calculation analysis is necessary to understand the hydrological cycle and ensure adequate water availability for plants in the research area (Hartanto, 2017). Effective rainfall and evapotranspiration data are sufficient to provide information on the estimated amount of water needed (irrigation) to determine the period of surplus and deficit water on the land. The analysis of the water balance of this area is expected to be a guide in determining the start of planting and irrigation water needs. The water balance of the research location area can be seen in Figure 2.

On the basis of the calculation results, the water surplus occurred in the 3rd week of October to April, while the water deficit occurred in May to the 3rd week of October. Water surplus and deficit refer to the difference between effective rainfall and evapotranspiration. If rainfall exceeds evapotranspiration, there will be a water surplus, and vice versa. This water balance is very necessary to determine the existence of a water surplus and deficit for plants because it is useful in determining the water needs of plants (Pereira et al., 2020).

The ETc value is divided based on the growth phase when calculating it. According to FAO, the

Table 4. Observation variables study

Observation variables	Types of observation	Observation time
Soil chemical analysis	C-Organic, pH, N, P, K-total and K, Na, Ca, Mg available, CEC	1 Week after application
Plant growth and development	Plant height, number of leaves, number of branches, number of flowers	2–10 Weeks after planting

Table 5. Potential evapotranspiration calculation

Month	Eto mm/day	Month	Eto mm/day
January	3.58	July	3.57
February	3.55	August	4.13
March	3.71	September	4.76
April	3.79	October	4.88
May	3.75	November	4.16
June	3.53	December	3.5
Average 3.91			

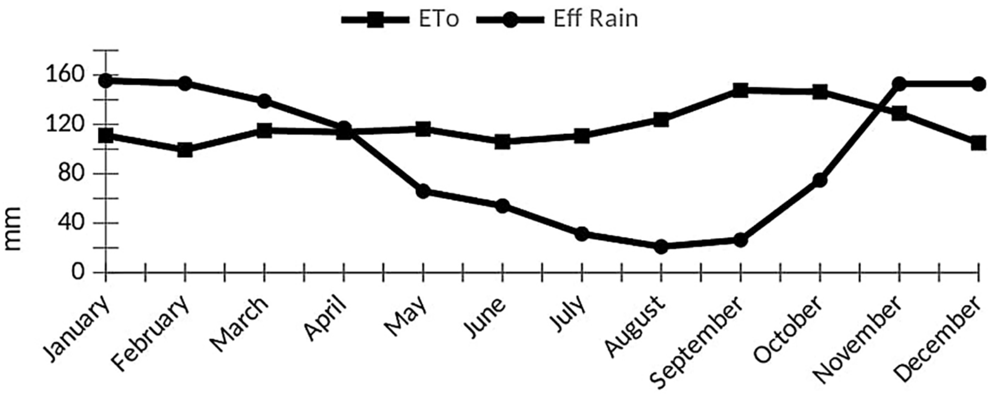

Figure 2. Regional water balance

plant growth stage is divided into four, namely *Initial Stage* (early growth, soil covers the plant about 10%), Crop Development Stage (continued growth, plants covered by soil 70–80%, plants grow to their maximum), Mid-Season Stage (flowering and seeding), and Late Season Stage (ripening and harvesting). From the results of the ETo analysis and the Kc value reference, the ETc value can be seen in Table 6.

On the basis of Table 7, it is known that the water requirement of chili plants in the early phase is 173 ml/day, the growth phase is 341 ml/day, the fruit formation phase is 606 ml/day, and the ripening phase is 598 ml/day. The maximum water requirement occurs during the fruit formation phase and then decreases during the fruit ripening phase. This follows Hanafi et al. (2010), who stated that the water requirement of plants is influenced by the type and age of the plant (growth phase). When the plant grows, the water requirement will increase according to its growth and reach a maximum during the maximum growth phase (fruit formation). After reaching a maximum, the plant's water requirement will decrease in line with seed ripening.

To simplify the technical aspects of water supply in the treatment (polybags), the scenarios for water supply, both conventional and irrigation, can be seen in Table 7.

On the basis of Table 7, it can be seen that in the early phase, the water given is greater than the plants' water needs, so there is a water surplus. Meanwhile, from the growth phase to the ripening and harvest phase, the water given is not sufficient for the water needs of the chili plants. This will inhibit plant growth. Plants will only grow optimally and produce high yields if their water needs are met in the right amount of time (Safei

Table 6. Plant water requirements (ETc)

Variables	Growth phase			
	Beginning	Growth	Fruit formation	Maturation
Age (days)	0–30	31–70	71–120	121–150
Eto (mm/day)	3.53	3.71	4.50	4.88
Kc	0.40	0.75	1.10	1.00
A (cm)	1225	1225	1225	1225
ETc (ml/day/plant)	173	341	606	598

Table 7. Water supply scenarios

Variables	Growth Phase			
	Beginning	Growth	Fruit formation	Maturation
Age (days)	0–30	31–70	71–120	121–150
ETc (ml/day/plant)	173	341	606	598
Scenario (ml/day/plant)	200	350	650	650

and Alex, 2008). Water is needed by plants for forming carbohydrates in photosynthesis and is the main component of plants (Islami and Utomo, 1995; Hans and Fiona, 2005). The results of the analysis of soil samples after 1 week of incubation are presented in Tables 8 and 9.

The effect of biochar doses on the chemical properties of soil after 1 week of incubation

The initial soil pH of 5.95 is categorized as slightly acidic. The pH is very important for the growth of chili plants, because it affects the availability of nutrients. After being given chicken manure (0% biochar), the pH increased to 6.17 because it contains the organic matter that can increase soil pH. Despite the increase, the soil is still in the slightly acidic category. Adding biochar has a significant positive effect, increasing the pH to neutral. Soil pH increases along with biochar doses. Likewise, as reported by Premalatha et al. (2023), the application of biochar from water hyacinth increases soil pH, and the increase is directly proportional to the biochar dose. Biochar has alkaline properties that help neutralize acid in the soil. The increase in soil pH can be attributed to the high pH of biochar, which is 9.65 (Table 3). Biochar is a soil additive that increases soil pH. This effect (on soil pH in H_2O and KCl) is strongest after biochar application at a rate of 10 t ha^{-1} (Šimanský1 and Alan, 2017).

Optimal availability of organic C is important in increasing soil fertility and supporting plant growth. Because soil organic matter has 7.44% organic C, which is very high, applying biochar at various doses can increase organic C to 7.80 to 7.89%. Mašek et al. (2019), biochar is used as a carbon storage strategy because of its lower decomposition rate in the soil. The C content increases with biochar levels. After biochar application alone or in combination with lower N levels, the higher the biochar dose, the better the soil structure (Juriga et al., 2018).

Total N levels increased after being treated with a dose of biochar, from high (initial) to very high (treatment), as did total P levels. and total K increased from high to very high categories, the increase in N, P, K is shown in Table 4. Rice husk biochar produced from pyrolysis with limited oxygen or without oxygen (Vu et al., 2022) to evaporate organic matter so that it remains on the porous surface with positively charged elements K^+, Na^+, Ca^{2+}, Mg^{2+} (Konneh et al., 2021). The results of soil sample analysis after 1 week of incubation are presented in Table 9.

Basic fertilizer and biochar were applied to store and provide nutrients, including phosphorus (P). The levels of available P in the initial soil and treated soil showed very high criteria (Table 8). The availability of P in the soil is crucial for plant growth. Initially, the soil had a P availability of 70 ppm, but the availability of P increased by 295 ppm after being given manure as a basic fertilizer. Chicken manure is rich in nutrients, including P, which can significantly increase the availability of this element in the soil. The dose of biochar affects the availability of P in the soil, but this figure is still lower than that achieved by manure alone. Pyrolysis temperature affects the availability of P in biochar; high concentrations of labile

Table 8. Results of soil sample analysis after 1 week of incubation

Treatment	pH (H_2O)	pH (KCl)	C–Org (%)	N-Total (%)	P-Total (mg P_2O_5/100g)	K-Total (mg K_2O/100g)
Biochar 0%	6.17	6.20	7.75	1.25	136	171
Biochar 2%	6.88	5.10	7.80	1.18	112	222
Biochar 4%	6.80	5.50	7.86	1.13	111	282
Biochar 6%	7.02	6.10	7.89	1.14	116	335

Table 9. Results of soil sample analysis after 1 week of incubation

Treatment	Water content (%)	P_2O_5 (ppm)	Cation dd (cmol)(+)/kg				CEC (cmol)(+)/kg	Amount of base cations (cmol)(+)/kg)
			K	Ca	Mg	Na		
Biochar 0%	9.62	295	1.23	9.68	3.75	1.32	29.36	15.98
Biochar 2%	9.45	199	4.01	12.26	5.01	0.58	20.53	21.86
Biochar 4%	9.17	220	4.08	9.89	3.14	0.96	24.85	18.07
Biochar 6%	8.33	287	5.15	9.37	3.09	1.06	26.26	18.67

calcium phosphate are found in low-temperature biochar, while the stable form of P is dominant at temperatures above 600 °C (Bruun et al., 2017). Biochar produced at pyrolysis temperatures between 300 °C and 500 °C has a high P content, while biochar produced at > 500 °C has significantly less labile P due to the formation of insoluble and stable P forms (Adhikari et al., 2019). This study used the biochar made at temperatures > 500 °C, indicating that manure is more effective in increasing P availability. However, nutrient use efficiency is higher when biochar-based fertilizers are used (Cao et al., 2019). Although the biochar dose is higher, this value is still below the 295 ppm obtained from manure alone. This shows that despite a slight increase, the contribution of manure remains greater.

Soil improvement with biochar positively affects soil density, and the magnitude of the changes varies depending on the dose of biochar and soil type (Pandian et al., 2024). The soil used in this study had a low CEC (3.87 cm)(+)/kg) (Table 1), making it difficult to store nutrients; thus, the number of base cations was also low (11.34 cm)(+)/kg). Therefore, basic fertilizer, such as chicken manure fertilizer, is needed in all treatments. In particular, the application of manure has made the soil CEC very high (29.36 cmol)(+)/kg), but if given biochar, CEC becomes moderate to high, 20.53–26.26 cmol)(+)/kg (Table 8). Table 3 shows that chicken manure contains many nutrients and organic materials, which can increase CEC. Khan et al. (2023), adding organic fertilizers, such as compost and manure, enriches the soil with organic matter and plant nutrients. Basic fertilizers and biochar at a dose of 120–360 g (2–6%) do not seem to be enough to produce a significant effect compared to just basic fertilizers. However, biochar can increase the ability of soil to retain water, although it is not as effective as manure in increasing CEC in this soil type. This can be seen from the poor growth of chili plants compared to the treatment given by biochar (Figure 3–6). Ghorbani et al. (2019) assessed the impact of rice husk biochar at three different concentrations (0, 1%, and 3% w/w) on two different soil types (sandy loam and clay). They found that biochar application at 1% and 3% increased the CEC of sandy loam soil by 20% and 30%, while the comparable increases for clay soil were 9% and 19%, respectively. Similarly, Luo et al. (2013) used three levels of biochar to improve the properties and productivity of degraded soil and found an increase in CEC at all doses (up to 17.3%) compared to the control (2.72 cmol kg^{-1}) with CEC values of 3.03, 3.19, and 3.15 cmol kg^{-1} for biochar applications of 1.5, 5, and 10%, respectively. Increasing the dose of biochar also increases the total porosity of the soil proportionally (Liu et al., 2020), resulting in a decrease in soil density and an increase in the infiltration rate (Herath et al., 2013). This will have a positive effect on the water holding capacity. The study implies that chicken manure fertilizer provides a clear increase in CEC from low to very high, making it the main choice for increasing fertility in sandy loam soils with low CEC. Although biochar can improve soil quality, its effectiveness is more visible at higher doses.

The effect of biochar dosage on the growth of chili plants with drip and conventional irrigation on sandy clay soil

Chili plants had an increase in height, number of leaves, number of branches, and number of flowers compared to those without biochar. Low, medium, and high doses (2–6%) with drip irrigation produced the same growth in plant height (4 WAP), number of leaves (4 and 6 WAP), and number of branches (4 WAP). Biochar application changes soil properties and provides more nutrients for plant growth. Li et al. (2024) reported that initial soil properties, environmental conditions, biochar sources, characteristics, and application rates are the main factors influencing the impact of biochar on crop yields and soil properties. Joseph et al. (2021) stated that plants respond differently to biochar according to their type. Adding various doses of biochar positively affected plant growth compared to no biochar. The growth of chili plants at 10 weeks after planting (WAP) entered a strong vegetative growth phase. Chen et al. (2018) reported that applying 5% biochar benefited plant performance in dense soil. It has also been reported by Gao et al. (2021) that the recommended biochar application rate is 10.1–20 t. Similarly, Ścisłowska et al. (2015) reported that biochar has positive effects on soil quality and crop yields. Oladele et al. (2019) found that applying rice husk biochar of 12 t ha^{-1} at a soil depth of 0 to 10 cm increased soil water content (12%). Higher levels of biochar were associated with increased soil water content at the measured soil depths. Lateef et al. (2019) observed that the water retention capacity in soil with biochar was 67.17%, while that of soil without biochar was

55.5% after 20 days of study. Similarly, Liu et al. (2018), also observed that the water retention capacity of biochar in soil was greater than that of untreated soil. This may be due to the increase in soil organic matter and total porosity.

Chili plants grow better with drip irrigation than conventional one (Figure 5–8). This is in line with Lepaja et al. (2024), drip irrigation offers unmatched advantages, including uniform water distribution to each plant, which cannot be achieved with alternative irrigation methods. The drip irrigation delivers water directly to the plant's roots, reducing water loss through evaporation. Ren et al. (2023) found that applying biochar-based fertilizer with drip irrigation can significantly enhance root growth and increase the leaf area index during the growing period. Utilizing drip irrigation can result in substantial water savings compared to surface irrigation, with reductions ranging from 40% to 60% while simultaneously potentially doubling the yield. Overall irrigation efficiency varies across surface irrigation methods, typically reaching 30 to 40%, sprinkler irrigation 60–70%, and drip irrigation shows the highest efficiency at 85 to 90% (Goyal, 2013; Potkonjak, 1995), while according to Wilson and Bauer (2014), the efficiency of the drip irrigation system is more than 90%.

Chili plants showed a significant increase in height and had increasingly sturdy stems. The number of leaves on chili plants increased, contributing to the increase in photosynthesis. Chili plants began to produce lateral branches, which helped increase the number of flowers. This branch growth is very important for increasing yields. In the flower formation phase, chili plants begin to produce flowers, an important indicator of plant health and yield potential. Therefore, the number of flowers observed are still in bud and bloom. Chili plants at 10 MST showed more signs of preparation for flowering, with an increase in the number of branches and flowers.

PLANT HEIGHT

Rice husk biochar produced from the pyrolysis process can improve the chemical properties of the soil (Tables 4 and 5) to support plant growth. Biochar helps retain nutrients and prevents leaching (Mustaffa et al., 2023), so nutrients can be available longer for plants. Low biochar doses (2%) began to show positive effects on the growth of vegetative parts of plants, especially plant height.

On the basis of the analysis of plant height variance in irrigation type, the F count value is 2.39 < 4.26, so there is no significant difference (irrigation type treatment does not affect the height of 2 MST). The addition of biochar nested in the type of irrigation shows the F calculation value 2.64 >

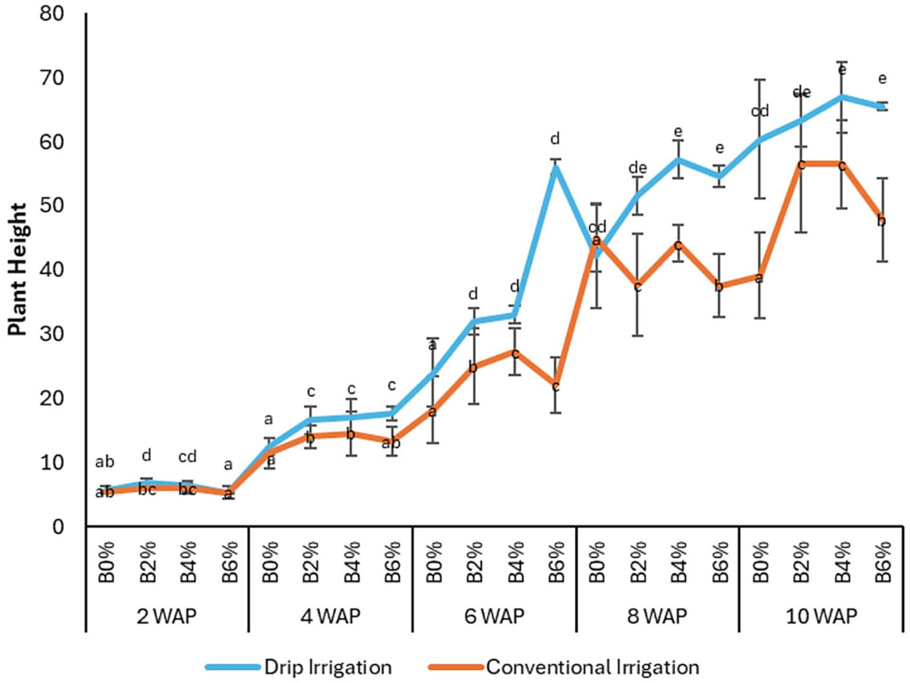

Figure 3. Effect of biochar dose on the height of chili pepper plants on drip and conventional irrigation

2.51, which is significantly different (treatment of adding biochar nested in the type of irrigation) and affects the height of 2 MST). At 4, 6, 8, and 10 MST, the type of irrigation was very different (F count 10.72 > 7.82) at 4 MST, significantly different (F Count 4.76 > 4.26) at 6 MST, significantly different (F count 5.09 > 4.26) at 8 MST, and was very significantly different from F count 32.73 > 7.82 (10 MST). At 4 MST, the irrigation type treatment affects plant height, where conventional irrigation (15.96 cm) shows higher plant growth than drip irrigation (13.35 cm). However, at 6, 8, and 10 MST, plant height growth was better with drip irrigation than conventional, 36.25 cm and 23.16 cm (6 MST); 51.42 cm and 41.13 (8 MST); and 64.00 cm and 50.03 cm (10 MST), respectively. The plant height growth during 2–10 MST from both types of irrigation is presented in Figure 5. The addition of biochar nested in the irrigation type influenced plant height growth 4 MST (F count value) 2.95 > 2.51) and 10 MST (value F count 3.29 > 2.51). At 4 MST, the use of 2–6% biochar produced the same plant height as drip irrigation (average 17.13 cm), which was still better than conventional irrigation (14.09 cm), while at 10 MST, the application of 4–6% biochar showed the same plant height, with an average of 66.21 cm. This was not the case at 6 and 8 MST, which were not significantly different (biochar dose treatments nested in irrigation types did not affect plant height).

Drip irrigation slowly and evenly delivers water directly to the root zone, keeping the soil moisture stable and optimal. This helps reduce stress due to the lack of water on plants. Unlike in conventional irrigation, it can reduce soil aeration, especially if too much water is absorbed, particularly in soils with low porosity. This can interfere with root respiration and slow down nutrient absorption.

NUMBER OF LEAVES

The analysis of the variance of the number of leaves in the irrigation type shows that the F value count is 0.24 < 4.26, so there is no significant difference (irrigation type treatment does not affect the number of leaves 2 MST). On the basis of the addition of the dose of biochar nested in the type of irrigation, the F count value is shown as 1.71 < 2.51, and there is no significant difference. This means that the biochar dose does not affect the number of leaves at 2 MST. At 4, 6, 8, and 10 MST, types of irrigation affect the number of leaves (F count)31.67 > 7.82 at 4 MST; F count 63.99 > 7.82 at 6 MST; F count 63.50 > 7.82 at 8 MST, and 41.61 > 7.82 at 10 MST, and all are very significantly different. At 4 MST, plants produced more leaves (34.79) under drip irrigation than conventional (23.44). The biochar treatment with a 2–6% dose produced the same number of leaves with an average of 42.03 (drip irrigation), better than conventional treatment (13.98). At 6 MST, leaves were 75.10 (drip irrigation), more than 43.29 (conventional). The biochar with a dose of 2–6% produced the same number of leaves with an average of 89.78 (drip) and more than the biochar with a dose of 4–6% with an average of 53.92 (conventional). It should also be noted that the biochar with a dose of 2% produced 39.33 leaves (conventional). At 8 MST, the number of leaves was higher with drip irrigation (138.19) than with conventional (79.65). The biochar dose of 4–6% produced more leaves with drip irrigation with an average of 172.46 than the dose of 2% (143.17). Meanwhile, conventionally, the number of leaves with an average of 99.42 (dose of 4–6%). Until the age of 10 MST, the number of leaves of plants with drip irrigation was more than conventional, namely 215.06 and 101.33, but the number of leaves was the same in the 2% and 4% biochar treatments with an average of 256.21. The development of the number of leaves in various observations is shown in Figure 4.

Research shows that applying various doses of biochar can increase cilli pepper plants' growth. Watering plants with drip irrigation showed better growth compared to conventional irrigation. This is due to better water use efficiency, a more consistent nutrient supply around the roots, and more effective water penetration. Unlike conventional irrigation, drip irrigation can potentially increase nutrient leaching, especially nitrogen, which is soluble and can be carried to deeper soil layers, far from the reach of plant roots.

NUMBER OF BRANCHES

At the age of 4 MST, the plants began to branch. The results of the analysis of the number of branches on the type of irrigation showed F value count 19.25 > 7.82 (4 MST); F count 12.03 > 7.82 (6 MST); F count 34.61 > 7.82 (8 MST); F count 49.35 > 7.82 (10 MST) which all indicate significantly different (irrigation type treatment) affect the number of branches 4, 6, 8, 10 MST). At 4 MST, drip irrigation produced more branches (3.37) than conventional irrigation

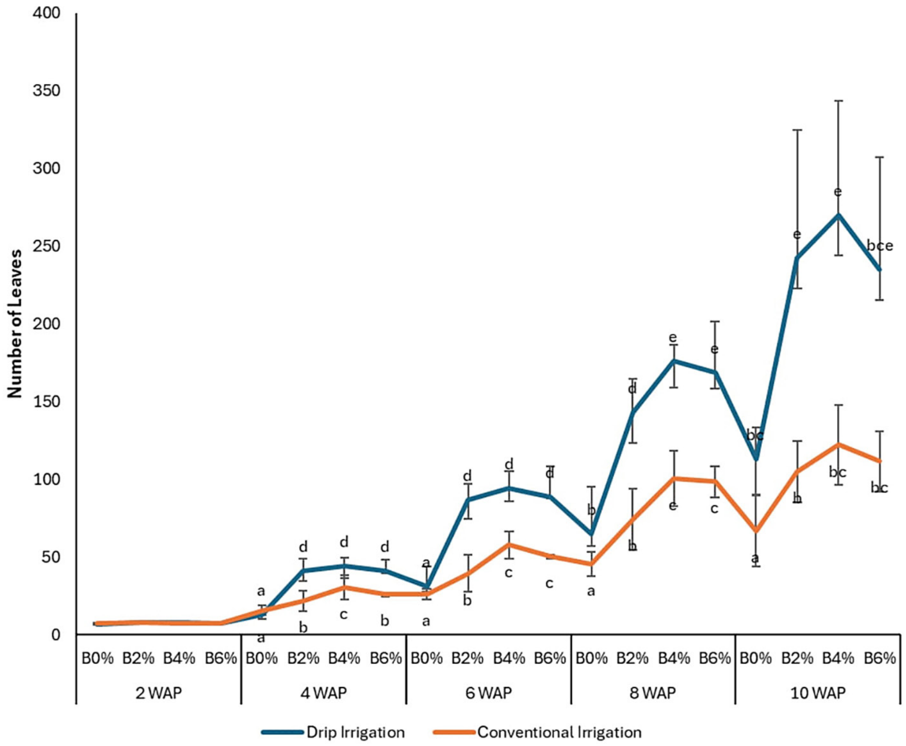

Figure 4. Effect of biochar dose on the number of leaves of chili pepper plants on drip and conventional irrigation

(2.27). At 8 MST, the number of branches from drip irrigation was greater than conventional one, 11.75 and 7.19, respectively. On the basis on the biochar nested in the type of irrigation with the F Count value8.47 > 3.67 (4 MST); F count 10.50 > 3.67 (8 MST); and F count 6.17 > 3.67 (10 MST) which indicates significantly different (biochar dose nested in irrigation type) affects the number of branches 4, 8, 10 MST). This indicates proper watering that directly provides water to the root zone so that the roots receive the moisture needed to support the development of plant branches.

At a dose of 4 MST, 2–6% produced the same number of branches, namely 4.64 (drops). Likewise, the number of branches was the same at a dose of 4-6% conventionally (3), and a dose of 2% (conventional) produced 2 branches, which were still better than the control. This was not the case at 6 MST; the addition of biochar nested in the type of irrigation with an F count value 1.74 < 2.51 then there is no significant difference (the treatment of biochar doses nested in the irrigation type does not affect the number of branches). Unlike 8 MST, 4% biochar dose produced the highest number of branches with drip irrigation (15.75). The number of chili plant branches from drip irrigation was greater than conventional, namely 26.71 and 12.58, respectively, and the highest number of branches in 4% biochar dose (34.75). The number of chili pepper plant branches with a drip irrigation system was greater than conventional (Figure 5).

Biochar dosage can improve chili pepper plants' growth, especially in drip irrigation. Drip irrigation supplies water directly to the roots of plants with better efficiency, because it reduces evaporation and increases water use so that plants can utilize water and nutrients better. The biochar from agricultural by-products with high porosity and good water-holding capacity increases soil moisture and nutrients (Diep et al., 2020). Conventional irrigation causes more water to fill the planting medium in polybags, causing variations in moisture between the root zone and the soil surface. The soil may experience saturated conditions after irrigation, followed by rapid drying, especially in the upper layer, causing moisture fluctuations that can harm plants.

NUMBER OF FLOWERS

At 10 weeks, the chili plants have reached a fairly mature vegetative stage. Biochar can increase water retention in the soil, which supports root growth that can absorb and release nutrients slowly, thereby increasing the availability of nutrients for plants.On the basis of the analysis of the types of irrigation, it shows very difference from

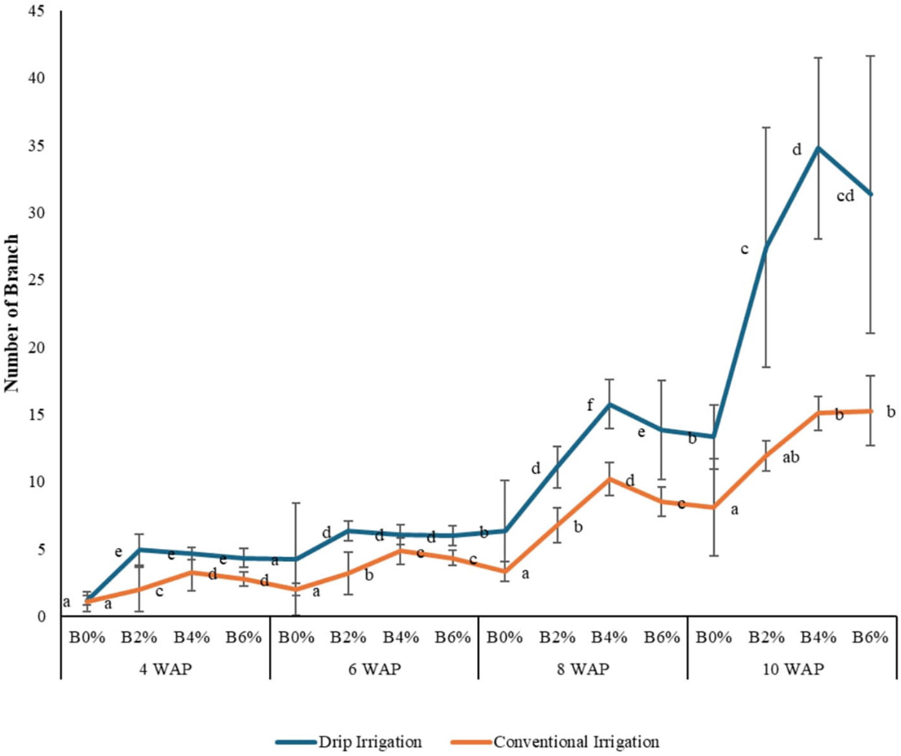

Figure 5. Effect of biochar dose on the number of branches of chili pepper plants on drip and conventional irrigation

F value count 48.28 > 7.82 (8 MST) and 40.20 > 7.82 (10 MST) (irrigation type treatment) affect the number of flowers 8 MST). The number of flowers with drip irrigation was higher than conventional, respectively, 33.35 and 11.31 (8 MST) and 126.71 and 31.81 (10 MST). Drip irrigation causes plants to experience less risk of stress due to lack of water. Consistent soil moisture helps plants focus their energy on vegetative growth, including flower formation (flower buds and blooms), rather than struggling to find water. Depending on the addition of biochar nested in the type of irrigation, the value of F calculation 8.86 > 3.67 is very significantly different. At 8 MST, drip irrigation, the number of flowers from biochar dose of 4–6% showed the same number of flowers (46.71), but the dose of 2% produced a lower number of flowers (30.42). Up to 10 MST, the dose of 4–6% showed the same number of flowers in drip irrigation with an average of 173.17 (Figure 6). Using biochar in the

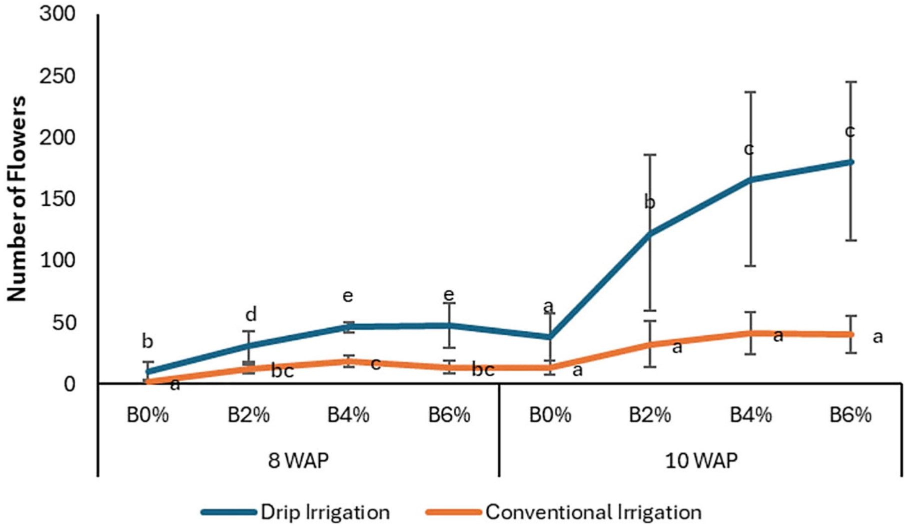

Figure 6. Effect of biochar dose on the number of flowers in chili pepper plants on drip and conventional irrigation

right dosage can increase the number of flowers in chili plants. Biochar plays a role in balancing nutrients, which is crucial to support the flowering stage. With the right dosage of biochar, chili plants can produce more flowers.

CONCLUSIONS

This study revealed that the soil is in the slightly acidic category (pH 5.95), which affects the availability of nutrients and the growth of chili plants. Adding biochar significantly changes the pH to neutral due to its alkaline properties. The availability of organic C is an important factor for soil fertility, with an initial value of 7.44%, which is very high, and the application of biochar successfully increased the organic C content to between 7.80 and 7.89%, which also contributes to the ability to retain water. The total levels of N, P, and K also increase after biochar treatment, with all of these elements reaching a higher category. The availability of P is very important for plant growth, where chicken manure significantly increases the P content from 70 ppm to 295 ppm, showing greater effectiveness compared to biochar. Soil with low CEC (3.87 cmol(+)/kg) makes it difficult to store nutrients, so the amount of base cations is low. Chicken manure is shown to be able to increase the CEC to a very high level, while biochar shows a moderate to high increase in CEC at doses of 2–6%. The effectiveness of biochar in improving soil quality is more visible at higher doses.

This study indicated that biochar, especially at doses between 2–6%, has a positive impact on the development of chili pepper plants in drip and conventional irrigation systems. After 10 WAP, the plants showed good vegetative growth, as reflected by an increase in height, number of leaves, branches, and flowers. The chili plants watered with drip irrigation and added with biochar showed better height growth than those using conventional irrigation. Biochar helps increase nutrient retention and soil moisture, thus supporting optimal root growth. Applying biochar contributed to the increased growth of chili plants, where drip irrigation produced more leaves, branches, and flowers at the end of the observation. This positively impacts the photosynthesis process and plant energy production to form flowers. Combining biochar and drip irrigation systems increases the number of flowers, which is very important for crop yields. Stable soil moisture from drip irrigation allows plants to direct their energy to flowering.

This study recommended using biochar in the right dose (4%) to produce optimal chili pepper growth. Further research is needed under field conditions with irrigation methods under various soil conditions and extrapolating field research with modern methods.

Acknowledgment

The authors would like to express their gratitude to the Ministry of Education, Culture, Research, and Technology of Higher Education in Indonesia for providing research funding through the Fundamental-Regular Grant for the year 2024.

REFERENCES

1. Abd El-Mageed T.A., Abd El-Mageed S.A., El-Saadony M.T., Abdelaziz S., Abdou N.M. (2022). Plant growth-promoting rhizobacteria improve growth, morph-physiological responses, water productivity, and yield of rice plants under full and deficit drip irrigation. *Rice, 15*(16), 1–16. https://doi.org/10.1186/s12284-022-00564-6
2. Alotaibi M. (2023). Climate change, its impact on crop production, challenges, and possible solutions. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca, 51*(1), 13020. https://doi.org/10.15835/nbha51113020.
3. An X., Liu Q., Pan F., Yao Y., Luo X., Chen C., Liu T., Zou L., Wang W., Wang J., and Liu X. (2023). Research advances in the impacts of biochar on the physicochemical properties and microbial communities of saline soils. *Sustainability, 15*(19), 14439.
4. Ayars J.E., Phene C.J., Hutmacher R.B., Davis K.R., Schoneman R.A., Vail S.S., Mead R.M. (1999). Subsurface drip irrigation of row crops: a review of 15 years of research at the water management research laboratory. *Agric Water Manag, 42*(1), 1–27.
5. Bao Z., Dai W., Su X., Liu Z., An Z., Sun Q., Jing H., Lin L., Chen Y. and Meng J. (2024). Long-term biochar application promoted soil aggregate-associated potassium availability and maize potassium uptake. *GCB Bioenergy, 16*(4), 13134.
6. Bekchanova M., Campion L., Bruns S., Kuppens T., Lehmann J., Jozefczak M., Cuypers A., Malina R. (2024). Biochar improves the nutrient cycle in sandy-textured soils and increases crop yield: a systematic review. *Environmental Evidence, 13*(3), 1–34. https://doi.org/10.1186/s13750-024-00326-5
7. Bhutia K.L., Khanna V..K., Meetei T.N.G, Bhutia N.D. (2018). Effects of climate change on growth

and development of chilli. *Agrotechnology, 7*(180), 1–4. https://doi.org/10.4172/2168-9881.1000180

8. Bruun, S., Harmer, S. L., Bekiaris, G., Christel, W., Zuin, L., Hu, Y., Jensen, L.S., Lombi, E. (2017). The effect of different pyrolysis temperatures on the speciation and availability in soil of P in biochar produced from the solid fraction of manure. *Chemosphere, 169*, 377–386. https://doi.org/10.1016/j.chemosphere.2016.11.058
9. Cabral N.S.S., Medeiros A.M., Neves L.G., Sudre C.P., Pimenta S., Coelho V.J. (2017). Genotype x environment interaction on experimental hybrids of chili pepper. *Genet Mol Res, 16*(2), 1–9. https://doi.org/10.4238/gmr16029551
10. Cao H., Ning L., Xun M., Feng F., Li P., Yue S., Song J., Zhang W., Yang H. (2019). Biochar can increase nitrogen use efficiency of Malus hupehensis by modulating nitrate reduction of soil and root. *Appl. Soil Ecol. 135*, 25–32. https://doi.org/10.1016/j.apsoil.2018.11.002
11. Cartika I., Murtiningsih R., Sembiring A., Sulastiningsih N.W.H., Moekasan T.K., Prabaningrum L., Setiawatii W. and Hasyim, A. (2023). Drip irrigation system: useful technique to improve chili production. *In IOP Conference Series: Earth and Environmental Science, 1183*(1), 012010. https://doi.org/10.1088/1755-1315/1183/1/012010
12. Chen X.W., Wong J.T.F., Chen Z.T., Tang T.W.L., Guo H.W., Leung A.O.W., Charles W.W.N., Wong M.H. (2018). Effects of biochar on the ecological performance of a subtropical landfill. *Sci Total Environ, 644*, 963–975. https://doi.org/10.1016/j.scitotenv.2018.06.379
13. Dalezios N.R, Gobin A., Tarquis Alfonso A., Eslamian S. (2017). Agricultural drought indices: combining crop, climate, and soil factors. *Handb Drought Water Scarcity Princ Drought Water Scarcity.*
14. Doorenbos, J., Kassam, A.H. (1979). *Yield response to water irrigation, FAO irrigation and drainage Paper 33*. Rome (IT): Food and Agriculture Organization of the United Nations.
15. Pham D.T., Nguyen H.N., Nguyen L.V., Tran O.V., Nguyen A.V., Dinh L.P.T., Vu N.V. (2021). Sandy soil reclamtation using biochar and clay-rich soil. *Journal of Ecological Engineering, 22*(6), 26–35. https://doi.org/10.12911/22998993/137445
16. Erickson A.N., Markhart A.H. (2001). Flower production, fruit set, and physiology of bell pepper during elevated temperature and vapor pressure deficit. *J Amer Soc Hort Sci, 126*(6), 697–702. https://doi.org/ 10.21273/JASHS.126.6.697
17. FAO. (2020). World Food and Agriculture - Statistical Yearbook 2020 [Internet]. Rome, Italy: FAO; 2020 [cited 2024 Mar 30]. 366. (FAO Statistical Yearbook – World Food and Agriculture). Available from: https://www.fao.org/documents/card/en/c/cb1329en.
18. Gao Y., Shao G., Yang Z., Zhang K., Lu J., Wang Z., Wu S., Xu D. (2021). Influences of soil and biochar properties and amount of biochar and fertilizer on the performance of biochar in improving plant photosynthetic rate: a meta-analysis. *Eur J Agron, 130*, 26345. https://doi.org/10.1016/j.eja.2021. 126345
19. Garruna-Hernandez R., Orellana R., Larque-Saavedra A., Canto A. (2014). Understanding the physiological responses of a tropical crop (*capsicum chinense* jacq.) at high temperature. *PLoS ONE 9*(11), e111402. https://doi.org/10.1371/journal.pone.0111402
20. Ghorbani M., Asadi H., Abrishamkesh S. (2019). Effects of rice husk biochar on selected soil properties and nitrate leaching in loamy sand and clay soil. *Int Soil Water Conserv Res, 7*, 258–65. https://doi.org/10.1016/j.iswcr.2019.05.005
21. Goyal M.R. (2013). Management of drip/trickle or micro irrigation. Apple Academic Press. Canada, 1–10.
22. Herath H.M.S.K., Arbestain M.C., and Hedley M. (2013). Effect of biochar on soil physical properties in two contrasting soils: An alfisol and an andisol. *Geoderma, 209*(210), 188–197. https://doi.org/doi:10.1016/j.geoderma.2013.06.016
23. Intergovernmental Panel on Climate Change (IPCC). 2022. Climate change and land: ipcc special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems [internet]. Cambridge: Cambridge University Press. [cited 2024 Mar 30]. Available from: https://www.cambridge.org/core/books/climate-change-and-land/AAB03E2F17650B1FDEA514E3F605A685
24. Joseph S., Cowie A.L., Van Zwieten L., Bolan N., Budai A., Buss W., Lehmann J. (2021). How biochar works, and when it doesn't: A review of mechanisms controlling soil and plant responses to biochar. *GCB Bioenergy, 13*(11), 1731– 1764. https://doi.org/10.1111/gcbb.12885
25. Khan M.A., Basir A., Adnan M., Fahad S., Ali J., Mussart M., Mian I.A., Ahmad M., Saleem H.M., Naseem W., El Sabagh A., Al-Tawaha A.M., Arif M., Amanullah, Saud S., Nawaz T., Badshah S., Hassan S., Munir I. (2023). Biochar to improve crops yield and quality under a changing climate. in sustainable agriculture reviews 61: biochar to improve crop production and decrease plant stress under a changing climate, 57–73. Cham: Springer International Publishing. https://doi.org/10.1007/978-3-031-26983-7_2.
26. Konneh M., Wandera S.M., Murunga S.I., Raude J.M. (2021). Adsorption and desorption of nutrients from abattoir wastewater: modelling and comparison of rice, coconut, and coffee husk biochar. *Heliyon, 7*(11). https://doi.org/10.1016/J.heliyon.2021.E08458
27. Lateef A., Nazir R., Jamil N., Alam S., Shah R., Khan

M.N., Saleem M., Rehman S. (2019). Synthesis and characterization of environmental friendly corncob biochar based nano-composite–A potential slow release nano-fertilizer for sustainable agriculture. *Environ Nanotechnol Monit Manage, 11*, 100212. https://doi.org/10.1016/j.enmm.2019.100212

28. Lepaja L., Lepaja K., Kullaj E., Balaj N. 2024. The influence of drip irrigation on water efficiency in pear cultivation. 2024. *Journal of Ecological Engineering, 25*(7), 241–245. https://doi.org/10.12911/22998993/188579.
29. Liu Q., Yanhui Z., Liu B., Amonette J.E., Lin Z., Liu G., Ambus P., Xie Z. (2018). How does biochar influence soil N cycle? A meta-analysis. *Plant and Soil, 426*, 211–25. https://doi.org/10.1007/s11104-018-3619-4
30. Liu D., Feng Z., Zhu H., Yu L., Yang K., Yu S., Zhang Y., Guo W. (2020). Effects of corn straw biochar application on soybean growth and alkaline soil properties. *BioResources 15*, 1463–1481.. https://doi.org/doi:10.15376/biores.15.1.1463-1481
31. Liu L., Li J., Wu G., Shen H., Fu G., Wang Y. (2021). Combined effects of biochar and chicken manure on maize (*Zea mays* L.) growth, lead uptake and soil enzyme activities under lead stress. *PeerJ, 9*, 11754.
32. Luo, Y., Durenkamp, M., Nobili, M.D., Lin, Q., Devonshire, B.J., and Brookes, P.C. (2013). Microbial biomass growth following incorporation of biochars produced at 350oC or 700oC, in a silty-clay loam soil of high and low pH. *Soil Biol. biochem. 57*, 513–523. https://doi.org/10.1016/j.soilbio.2012.10.033
33. Juriga, M., Šimanský, V., Horák, J., Kondrlová, E., Igaz, D., Polláková, N., Buchkina, N., Balashov, E. (2018). The effect of different rates of biochar and biochar in combination with n fertilizer on the parameters of soil organic matter and soil structure. *Journal of Ecological Engineering. 19*(6), 153–161. https://doi.org/10.12911/22998993/92894
34. Wiesmeier, M., Hübner, R., Spörlein, P., Geuß, U., Hangen, E., Reischl, A., Schilling, B., von Lützow, M., Kögel-Knabner, I. (2013). Carbon sequestration potential of soils in southeast Germany derived from stable soil organic carbon saturation. Global. *Change Biology. 20*, 653–665. https://doi.org/10.1111/gcb.12384
35. Mašek O., Buss W., Brownsort P., Rovere M., Tagliaferro A., Zhao L., Xu G. (2019). Potassium doping increases biochar carbon sequestration potential by 45%, facilitating decoupling of carbon sequestration from soil improvement. *Sci Rep, 9*(1), 1–8. https://doi.org/10.1038/ s41598-019-41953-0
36. Mustaffa M.R.A.F., Pandian K., Chitraputhirapillai S., Kuppusamy S., Dhanushkodi K. (2023). Synthesis of biochar-embedded slow-release nitrogen fertilizers: Mesocosm and field scale evaluation for nitrogen use efficiency, growth and rice yield. *Soil Use Manage, 40*(1), 1–17. https://doi.org/10.1111/sum.12959
37. Oladele S., Adeyemo A., Adegaiye A., Awodun M. (2019). Effects of biochar amendment and nitrogen fertilization on soil microbial biomass pools in an Alfisol under rain-fed rice cultivation. *Biochar, 1*, 163–76. https://doi.org/10.1007/s42773-019-00017-2
38. Pandian K., Vijayakumar S., Mustaffa M.R.A.F., Subramanian P., Chitraputhirapillai S. (2024). Biochar – a sustainable soil conditioner for improving soil health, crop production and environment under changing climate: a review. *Front. Soil Sci. 4*, 1376159. https://doi.org/10.3389/fsoil.2024.1376159
39. Pascale S.D., Costa L.D., Vallone S., Barbieri G., Maggio A. (2011). Increasing water use efficiency in vegetable crop production: from plant to irrigation systems efficiency. HortTechnology, 21(3), 301–8.
40. Potkonjak Svetlana. 1995. The economy of drip irrigation. 20 Years of drip irrigation in Yugoslavia. Beograd, 207–212.
41. Ren T., Fan P., Zuo W., Liao Z., Wang F., Wei Y., Cai X., Liu G. (2023). Biochar-based fertilizer under drip irrigation: More conducive to improving soil carbon pool and promoting nitrogen utilization. *Ecological Indicators 154*, 110583. https://doi.org/10.1016/j.ecolind.2023.110583
42. Reyes F., Gosme M., Wolz K.J., Lecomte I., Dupraz C. (2021). Alley cropping mitigates the impacts of climate change on a wheat crop in a Mediterranean environment: a biophysical model-based assessment. *Agriculture, 11*(4), 356. https://doi.org/10.3390/agriculture11040356
43. Ścisłowska M., Włodarczyk R., Kobyłecki R., Bis Z. (2015). Biochar to improve the quality and productivity of soils. *Journal of Ecological Engineering, 16*(3), 31–35. https://doi.org/10.12911/22998993/2802
44. Smith, P. (2016). Soil carbon sequestration and biochar as negative emission technologies. Glob. *Change Biol. 22*, 1315–1324.
45. Sokol J., Amrose S., Nangia V., Talozi S., Brownell E., Montanaro G., Khaled A.N., Mustafa K.B., Bahri A., Bouazzama B., Bouizgaren A., Mazahrih N., Moussadek R., Sikaoui L., Winter A.G. (2019). Energy reduction and uniformity of low-pressure online drip irrigation emitters in field tests. *Water, 11*(6), 1195.
46. Umair M., Hussain T., Jiang H., Ahmad A., Yao J., Qi Y., Zhang Y., Min L., Shen, Y. (2019). Water-saving potential of subsurface drip irrigation for winter wheat. *Sustainability, 11*(10), 2978. https://doi.org/10.3390/su11102978
47. Venot J.P, Kuper M, Zwarteveen M. (2017). drip irrigation for agriculture: untold stories of efficiency, innovation and development. *Taylor & Francis, 386*. https://doi.org/10.4324/9781315537146

48. Šimanský V., and Klimaj A. (2017). How does biochar and biochar with nitrogen fertilization influence soil reaction? *Journal of Ecological Engineering, 18*(5), 50–54. https://doi.org/10.12911/22998993/74948
49. Vu, K.T., Dinh Thi Lan, P., Nguyen, N.T.H., Thanh, H.N. (2022). Cadmium immobilization in the rice - paddy soil with biochar additive. *Journal of Ecological Engineering, 23*(4), 85–95. https://doi.org/10.12911/22998993/146331
50. Wang Z., Zhang H., Wang Y., Zhou, C. (2021). Integrated evaluation of the water deficit irrigation scheme of indigowoad root under mulched drip irrigation in arid regions of Northwest China based on the improved TOPSIS method. *Water, 13*(11), 1532.
51. Wilson C. and Bauer M. (2014). Drip irrigation for home gardens. Colorado State University. *Fact sheet, 4*, 702.
52. Woznicki S.A., Nejadhashemi A.P., Parsinejad M. (2015). Climate change and irrigation demand: uncertainty and adaptation. *Journal of Hydrology: Regional Studies 3*, 247–264. http://dx.doi.org/10.1016/j.ejrh.2014.12.003
53. Li X., Wu D., Liu X., Huang Y., Cai A., Xu H., Ran J., Xiao J., Zhang W. (2024). A global dataset of biochar application effects on crop yield, soil properties, and greenhouse gas emissions. *Scientific Data, 11*(57). https://doi.org/10.1038/s41597-023-02867-9
54. Yadav M., Vashisht B.B., Jalota S.K., Kumar A., Kumar D. (2022). Sustainable water management practices for intensified agriculture. In: Dubey SK, Jha PK, Gupta PK, Nanda A, Gupta V, editors. Soil-water, agriculture, and climate change: exploring linkages [Internet]. Cham: Springer International Publishing. [cited 2024 Mar 30]. 131–61. https://doi.org/10.1007/978-3-031-12059-6_8
55. Yanez-Lopez R., Torres-Pacheco I., Guevara-Gonzalez R.G., Hernandez-Zul MI., Quijano-Carranza J.A., Rico-Gracia E. (2012). The effect of climate change on plant diseases. *African Journal of Biotechnology 11*(10), 2417–2428. https://doi.org/10.5897/AJB10.2442
56. Zheng, Y., Han X., Li Y,. Yang J., Li N., An N. (2019). Effects of biochar and straw application on the physicochemical and biological properties of paddy soils in northeast china. *Scientific Reports 9*, 16531. https://doi.org/10.1038/s41598-019-52978-w