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Water Productivity of Mustard Green (*Brassica juncea* L.) Under Drip Irrigation Systems and Organic Matter Addition

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ABSTRACT

Drip irrigation technique, in combination with the utilization of organic matter like as biochar and cocopeat, can increase water productivity by tailoring irrigation water to plant demands. This study was to investigate how organic matter can improve water productivity in mustard green production utilizing a drip irrigation technique. The greenhouse pot experiment analyzes the effect of adding varying quantities of biochar and cocopeat to mustard greens' growth medium using a drip irrigation technique. The findings indicate that adding organic matter reduced the quantity of water needed for irrigation. The soil and biochar combination treatment at a 1:1 ratio resulted in the highest water productivity for mustard green, whereas the control treatment produced the least. Mustard green grows optimally in a soil + biochar (1:1) growing medium, yielding the most water productivity at 16.8 g/L. Biochar can boost biomass yield by twice as much as the control treatment. Furthermore, biochar can increase mustard green water productivity by more than 300% when compared to mustard green, which relies solely on soil for planting medium. Further study is needed to investigate the effects of biochar features on water holding capacity, field capacity, and wilting point in different soil types to improve irrigation efficiency.

1. INTRODUCTION

Mustard green, a popular vegetable, has received attention for its potential health advantages. Agronomically, mustard is an annual plant with a relatively short lifespan of 30-35 days after planting that may be grown in both lowland and highland situations. These plants are also easy to care for when their water requirements are satisfied, and damp soil conditions can help them develop more completely. Mustard green output in Indonesia was 60,871 tons in 2019, with a projected increase to 69,626 tons by 2021 (BPS-Statistics Indonesia, 2023). This growth highlights the need to raise customer demand in terms of quality and quantity (Saputra & Amien, 2022).

The agriculture sector uses the greatest amount of water, accounting about 70% of total withdrawals (Ingrao *et al*., 2023). The increasing demand for water as the population grows has resulted in more scarce water supplies. Water efficiency is an important aspect of water management during plant cultivation. Previous studies have shown that water efficiency in agriculture is influenced by factors such as resource endowment, water resource structure, planting structure, agricultural economic level, degree of agricultural mechanization, and farmland water conservation construction (Wang *et al*., 2023). Balancing the adequate water supply with a high yield of agricultural products is highly desirable. Therefore, the development of water management strategies is required to optimize crop growth.

Considering the challenge of enhancing water efficiency, drip irrigation technologies could be an option for increasing agricultural yields while lowering water usage. Drip irrigation supplies water to plants by releasing water through a dropper positioned around their roots. It has been shown to reduce water use by up to 95% compared to sprinkler irrigation and surface irrigation, which have efficiency levels of just 80% (Silalahi & Daulay, 2012). Continuously applying modest quantities of water through drip irrigation systems can help maintain stable soil moisture levels and avoid water loss from percolation and runoff. However, high evaporation rates, particularly in hot and dry climates, are inevitable. Since the capacity to absorb and retain water is influenced by the growth medium, combining drip irrigation with additional materials in the growth medium can make this strategy even more effective.

The use of a proper growing medium has a significant impact on plant development. The ideal planting medium must fulfill numerous criteria, including good water-binding ability, water conservation, air circulation, and moisture retention in the root zone. The continued use of topsoil as a deep-growing medium can affect soil quality (Irawan & Kafiar, 2015). One alternative to topsoil is to use organic material from agricultural waste in a growth medium combination (Amaliah *et al*., 2020). Organic matter is considered capable of storing water while also providing appropriate aeration, making it ideal for use as a soil component (Augustien & Suhardjono, 2017).

Cocopeat and biochar are organic materials that can be used as growing medium mixtures (Bariyyah *et al*., 2015). Cocopeat is a fine powder made from crushing and extracting coconut fibers. Cocopeat has a high water-binding ability, an advantage over other organic matter-growing medium (Nontji *et al*., 2022). Furthermore, the addition of biochar to soil culture medium can improve soil aggregate stability, C-organic content, cation exchange capacity, water retention, and nutrient resistance by increasing soil carbon. Because of its particular structure (Akmal & Simanjuntak, 2019) and activity, it helps to preserve water content in soil (Villagra-Mendoza & Horn, 2018; Głąb *et al*., 2018). Experimental investigations show that biochar improves soil water retention due to its high porosity, hydrophilic domains, and large specific surface area (Razzaghi *et al*., 2020). Organic matter was used in this study to improve green mustard water productivity under drip irrigation. To assess the impact of organic matter on water use efficiency and plant growth, this study employed organic materials such as biochar and cocopeat. The purpose of this study is to determine the best combination of soil and organic matter for cultivating mustard greens to increase water availability in planting medium.

2. MATERIALS AND METHODS

2.1. Planting and Maintenance Conditions

Mustard plants were seeded in 3×1 m^2 seedbeds with manure-rich soil. The beds were fertilized two weeks before sowing and uniformly scattered across the seedbeds, carefully watered, and covered with fine soil to a depth of 1-2 cm. After ten days, the seedlings were transplanted to polybags and selected for consistent growth and height. Cocopeat, which was added as a planting medium, was 100% coconut husk, whereas the biochar employed in this study was made from rice husk. According to IBI (International Biochar Initiative) guidelines, rice husk biochar produced in this study is classed as grade two, with a fixed carbon value range of 30% to 60%. Fertilization was applied at the seedling stage and three weeks after planting, using the appropriate doses (Table 1) with the environmental condition is shown in Table 2.

Table 1. Fertilizer composition

Fertilizing period	Fertilizer	Dosage (kg/ha)	Dosage (g/m²)	Dosage (g/pot)
Preplanting	Urea (40%)	187	18.7	0.48
	Potassium Sulphate (36%)	311	31.1	0.79
	KCL (60%)	112	11.2	0.28
3 weeks after planting	Urea (40%)	187	18.7	0.48
	KCL (60%)	112	11.2	0.28

Table 2. Environmental conditions

Month	Temperature (°C)	Solar Radiation (W/m²)	Wind Speed (m/s)	Relative Humidity (%)
July	26.44 ± 0.22	78.78 ± 13.86	2.88 ± 0.53	81.57 ± 3.70
August	26.64 ± 0.34	79.34 ± 12.41	3.19 ± 0.44	79.18 ± 2.19

2.2. Design of Experiment

The experiment employed a randomized block design, with five treatments, six replications, and thirty samples. This study used five planting mediums: P0: soil, P1: (soil: biochar 1:1), P2: (soil: biochar 2:1), P3: (soil: cocopeat 1:1), and P4: (soil: cocopeat 2:1). Polybags (30 cm x 30 cm) packed with soil and organic matter were used as mustard green planting medium. Each polybag contained a plant that has been seeded in loam-textured soil.

2.3. Irrigation Water Calculation

The amount of irrigation water was determined by calculating the plant water requirements (Equation 1). The water requirement for mustard greens was determined by standard evapotranspiration (ET_o), and plant coefficient (Table 3). The Penman-Monteith equation was used to calculate ET_o (Equation 2).

$$ET_c = ET_o \times Kc \tag{1}$$

$$ET_o = \frac{0.408\,(\Delta P)\,(Rn - G) + \gamma \frac{900}{T+273} U_2\,(e_s - e_a)}{\Delta + \gamma\,(1 + 0.34\,U_2)} \tag{2}$$

where ET_o is potential evapotranspiration (mm/day), ET_c is crop evapotranspiration, Rn is solar radiation on the plant surface (MJ/m²/day), G is a change in soil heat (MJ/m²/day), T is average air temperature (°C), U_2 is wind speed (m/s), e_s is saturated vapor pressure (kPa), e_a is actual vapor pressure (kPa), ΔP is vapor pressure slope curve (kPa/°C), γ is psychometric constant (kPa/°C), and Kc is plant coefficient. The crop coefficient (Kc) of mustard green is 0.3 during vegetative phase, 1.2 during generative, and 0.6 during final stage (Hasmalinar *et al*., 2020).

2.4. Drip Irrigation Uniformity

Drip irrigation uniformity testing was performed to determine the amount of water distribution at each emitter in a drip irrigation system. The homogeneity of the droplets was assessed by measuring the volume and discharge generated by each emitter, which is estimated using equation 3 (Kusmali *et al*., 2015; Mustawa *et al*., 2017).

$$CU = 100\left(1 - \frac{\sum_{i=1}^{n} |x_i - \bar{x}|}{\sum_{i=1}^{n} x_i}\right) \tag{3}$$

where CU is uniformity coefficient, $\bar{x}$ is average volume in the container (L/min), n is number of observations, and x_i is a value of each volume in the container (L/min).

2.5. Observation and Measurement

Observations of mustard green growth included plant height and the number of leaves. The number of leaves and plant height are used to estimate mustard green growth. The plant height is measured from bottom to top. The number of leaves was determined by counting the leaves that have fully opened. The mustard greens were harvested at 35 days after planting (DAP). Every 10 days, the number of leaves and height of the plant were measured. Mustard green growth was measured at three stages: vegetative (1-10 DAP), generative (11-20 DAP), and final (21-30 DAP).

2.6. Water Productivity of Green Mustard

Plant water productivity is defined as the ratio of total production to total water used throughout the plant growth cycle (Nurfaijah *et al*., 2015). Water productivity (WP) was only assessed once since the needed value is acquired during crop harvesting (Farida *et al*., 2018).

$$WP\ (\mathrm{kg/m^3}) = \frac{Yield\ (\mathrm{kg})}{Total\ Water\ Use\ (\mathrm{m^3})} \tag{4}$$

2.7. Data Analysis

The data from this study were analyzed using analysis of variance (ANOVA). If there were significant differences, post-hoc testing was performed using Duncan's Multiple Range Test (DMRT) with a significance level of α = 5%.

3. RESULTS AND DISCUSSION

3.1. Mustard Green Irrigation Water Requirement

The ET_o value in the vegetative stage is 23.1 mm, 23.5 mm in the generative period, and 28.1 mm in the final period (Figure 1). Changes in ET_o value cause fluctuations in relative humidity, wind speed, temperature, and solar radiation (Wang *et al*., 2020). Meanwhile, the highest ET_c value during the generating stage was 28.2 mm, while the lowest ET_c value during the vegetative period was 6.93 mm. The surface area of plants reaches its highest during the generative stage, resulting in increased water evaporation, and when the leaves fall, evaporation and leaf area decrease (Kusmali *et al*., 2015). As a result, the irrigation water consumption is increased during the generative period. The Meteorology, Climatology, and Geophysical Agency of Indonesia defines the dry season as total rainfall < 50 mm, and the rainy season as total rainfall > 50 mm. The mustard greens planting period in this study is included in the dry season since the average total rainfall is 19 mm. The rainy season will last from October 2022 to January 2023, followed by the first dry season from February to May 2023 and the second dry season from June to September 2023.

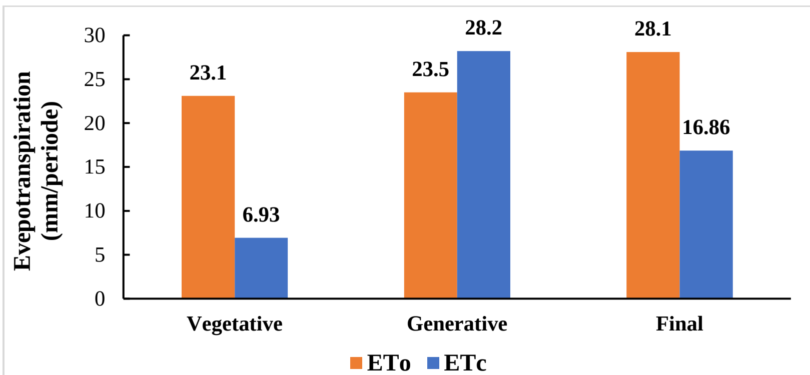

Figure 1. ET_o and ET_c of mustard green during the growing period

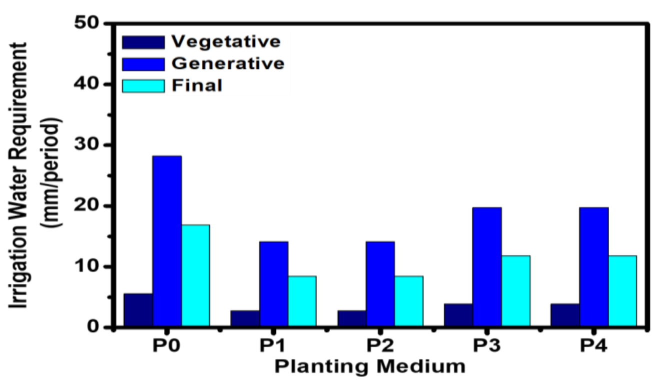

Figure 2. Irrigation water for green mustard in various planting medium.

Figure 2 shows that the impact of organic matter application on water productivity, where the irrigation water requirement reduce around 50% for biochar planting medium and 30 % for cocopeat planting medium (P1 and P2). The addition of biochar and cocopeat can increase soil water content which can reduce the amount of irrigation water. Biochar on average decreased bulk density by 9%, and it significantly increased available water in the coarse-textured soils (by 45%) compared to the medium and fine-textured soils (by 21% and 14%, respectively) (Razzaghi *et al*., 2020). Biochar intrapores can increase field capacity, permanent wilting point, and plant-available water (Liu *et al*., 2017). Biochar particle size, intraporosity, and hydrophobicity can alter during field application and impact soil water retention. For example, natural phenomena like bioturbation can reduce the size of biochar particles (Ponge *et al*., 2006), freeze-thaw cycles (Carcaillet, 2001), and plant root penetration (Lehmann *et al.*, 2003). Biochar hydrophobicity can prevent water from penetrating into biochar intrapores, thus inhibiting an improvement in soil water retention. While, Cocopeat is hydrophilic in nature where moisture will be evenly distributed on the surface of the powder. Cocopeat has a fairly high water absorption capacity, which is around 8-9 times its weight, and increase available water of 16.24 % (Setiawan *et al.*, 2017).

The homogeneity coefficient of the drip irrigation system was measured before the planting experiment began. The droplet uniformity value in this investigation meets the ASAE standard for *CU* value requirements. Figure 3 shows the highest average *CU* value of 97.7% was produced from P2 treatment (Soil + Cocopeat, 2:1) and the lowest at 93.9% from P0 (only soil), indicating that the water irrigation in the drip irrigation installation was evenly distributed.

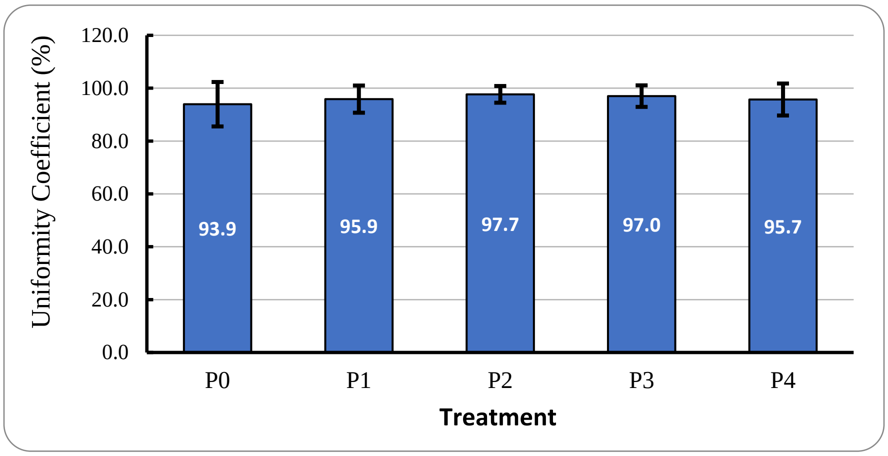

Figure 3. The uniformity coefficient of drip irrigation installation

3.2. Effect of Organic Matter on Mustard Green Growth

The addition of organic matter to the planting medium has a significant effect on mustard green height and number of leaves with significance values less than 0.05. Specifically the ANOVA results in *p*-value of 0.000 for plant height and *p*-value = 0.009 for number of leaves. Mustard green has optimal growth in soil + biochar (1:1) growing medium with a height of 19.5 cm and nine leaves (Table 3). Biochar can affect microbial activity, plant growth, and nutrient utilization (Yu *et al.*, 2013). Furthermore, when used as a planting medium, biochar tends to stabilize water storage more than cocopeat because it has more porous, balanced micro and macropores that promote efficient air circulation and have a high-water absorption capacity. The right dose of biochar in the soil can increase the moisture content in the soil that maintains the value of field capacity and wilting point (Li *et al.*, 2021). However, the excessive use of biochar can cause excessive soil aeration, resulting in insufficient soil moisture levels (Yu *et al.*, 2013). On average, the soil and cocopeat mixture produced fewer leaves than the other treatments. This is suggested because the presence of tannins in cocopeat is causing the poor response to plant development (Gunadi & Sumiartha, 2019). Tannin is a chemical that inhibits gibberellin hormone action and impairs P and K transport, causing roots, stems, and leaves to develop slower (Irma *et al.*, 2022).

Table 3. Significant effect of treatment on the plant height and number of leaves of mustard green

Planting Medium	Height	Number of Leaves
P0 (Soil)	11.8^{a}	6^{a}
P1 (Soil + Cocopeat, 1:1)	12.6^{ab}	7^{a}
P2 (Soil + Cocopeat, 2:1)	13.2^{ab}	7^{a}
P3 (Soil + Biochar, 2:1)	14.3^{b}	7^{ab}
P4 (Soil + Biochar, 1:1)	17.5^{c}	9^{b}

Note: different lowercases following mean values are significantly different based on DMRT at α = 0.05.

3.3. Mustard Green Water Productivity

Results from ANOVA show that biomass yield (weight) and the water productivity of mustard were significantly affected by organic matter additions to the planting medium. The significance value is 0.000 both for biomass yield and water productivity. Water plays a crucial function and is necessary in huge quantities for plant growth; about 85-90% of plant cells and tissues are composed of water (Dewi, 2023). Lack of water can hinder the photosynthetic process, causing a reduction of leaf growth in plants, whereas an increased number of leaves would automatically raise the weight of the plant biomass. Hence, the value of water productivity will be directly proportional to the weight of the plant and inversely proportional to the water provided (Pacetti *et al*., 2025).

The soil and biochar combination treatment at a 1:1 ratio resulted in the highest water productivity for mustard green, whereas the control treatment had the lowest (Table 4). Adding charcoal to soil can significantly increase seed germination, plant growth, and crop yields (Semida *et al*., 2019). The level of the increase in accessible water content is proportional to the amount of biochar added to the soil; the more organic material in the soil, the higher the maximum water content (Toková *et al*., 2023). Biochar reduced bulk density by 9% on average across all soil textural groups, whereas field capacity and wilting point improved significantly for coarse-textured soils (by 51% and 47%, respectively) and moderately for medium-textured soils (by 13% and 9%) (Razzaghi *et al*., 2020). This study found that using biochar in planting media has the potential to boost water productivity by more than 300 percent. The soil plus biochar treatment yielded the maximum water productivity (16.8 g/L). The qualities of biochar determine its ability to preserve water. Biochar, which is high in nitrogen and oxygen, could be an excellent water retention agent for maintaining soil moisture (Zhang *et al*., 2024). As a result, future research must examine the impact of biochar features on accessible water content, field capacity, and wilting point discover the best biochar characteristic for increasing water availability and irrigation efficiency.

Table 4. Significant effect of treatment on the biomass yield and water productivity of mustard green based on DMRT

Planting Medium	Biomass Yield (g)	Water Productivity (g/L)
P0 (Soil)	5.9^{a}	4.6^{a}
P1 (Soil + Cocopeat, 1:1)	6.0^{a}	6.7^{b}
P2 (Soil + Cocopeat, 2:1)	6.6^{a}	7.4^{b}
P3 (Soil + Biochar, 2:1)	8.2b	12.7^{c}
P4 (Soil + Biochar, 1:1)	10.9^{c}	16.8^{d}

Note: different lowercases following mean values are significantly different based on DMRT at $\alpha = 0.05$.

4. CONCLUSION

The findings indicate that adding organic matter boosts mustard greens' water productivity. Biochar outperformed both cocopeat and the control treatment in terms of water retention. The findings indicate that biochar could minimize the amount of water required to irrigate mustard plants using a drip irrigation method. Mustard green grown in soil+biochar (1:1) had the maximum plant height, number of leaves, and water productivity. Furthermore, the findings indicate that adding organic matter increases biomass yield. Water productivity in mustard plant cultivation could increase by 300% over the control treatment. These findings support the use of biochar as an organic material to boost water productivity. Future study is required to evaluate the effect of biochar characteristics on water retention to determine the ideal influence of biochar on improved irrigation efficiency.

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