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The Effect of Soil Amendments and Shading on the Yield of Red Chili (*Capsicum annum* L.) in a Sandy Dryland

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Abstract: Low nutrient along with intense sunlight levels in sandy drylands, often lead to poor crops yield. This study examined the effects of soil amendments and shading on the yield of red chili plants cultivated in a sandy (70% sand, 15% clay and 15% silt) dryland environment. The experiment was conducted in Gumantar Village, North Lombok Regency from May to September 2024. The C-organic content of the soil was 1.11% with only 0.09% of total nitrogen. The soil amendment treatments included no soil amendment, chicken manure, and seaweed biochar. The shading treatments consisted of two levels: no shading and shading using a 200-micron UV plastic with 14% diffusive ultraviolet ray. All treatments were arranged factorially using a randomized block design with three replications. The results indicated that soil amendments and shading did not significantly affect plant growth, certain soil chemical properties, or microbial populations, possibly due to its short time effect. However, both types of soil amendments and UV plastic shading increased the yield of red chili plants by approximately 6.0% compared to the treatment without any amendments or without shading. This study shows that soil amendment and shading with UV plastic improve tomato yield in sandy dryland soils.

Keywords: Biochar; Manure; Microbes; Organic matter; UV plastic

Introduction

This research can serve as a strategy to achieve the second goal of the Sustainable Development Goals (SDGs), which aims to eliminate hunger, particularly in sandy dryland areas. Four primary topics have been identified to help achieve the goal of being free from hunger by 2030: (1) Elimination of the threat of hunger, (2) Eradication of malnutrition, (3) Ensuring high productivity and income (4) Establishing a sustainable agricultural production system that is resilient and adaptable to climate change (Lile et al., 2023). Therefore, the effective utilization of drylands to support food security—an essential aspect of the second SDG goal—must focus on achieving high, sustainable, and climate-resilient productivity. Agricultural practices that address these topics include agronomic management strategies that are resilient to the impacts of climate change (Alizadeh et al., 2023).

To enhance the productivity and income of farmers in drylands, it is essential to choose crops that have both high productivity and economic value. Alongside these factors, the production of these crops must be stable and sustainable (Ahmed et al., 2022). Thus, the selected crops and cultivation practices should benefit both human welfare and soil health. One vegetable that stands out for its high economic and nutritional value is chili. Often called red chili (*Capsicum annuum* L.), it is an important horticultural commodity in Indonesia. Chili production in Indonesia varies significantly with the seasons, while the demand for this commodity remains relatively stable throughout the year.

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Chili plants require a significant amount of nutrients (Jaya et al., 2021), which often leads to the intensive use of inorganic fertilizers. To address this issue in drylands, it is essential to develop crop cultivation practices that can enhance soil carbon content and reduce greenhouse gas emissions (Plaza-Bonilla et al., 2015). One major contributor to greenhouse gas emissions in the agricultural sector is the excessive and prolonged use of inorganic fertilizers (Walling & Vaneeckhaute, 2020).

The excessive use of large amounts of inorganic fertilizers has a negative impact on both soil health and the environment, particularly regarding the relationship between microbes and plants (Huang et al., 2019). Therefore, there is a pressing need for sustainable and efficient chili cultivation technologies that can thrive in dryland conditions. One effective way to enhance soil quality and increase crop yields is by incorporating organic matter (Berhe et al., 2022). Organic matter can be sourced from various materials such as plant waste, chicken manure, cow manure, or goat manure. Additionally, biochar, a high-carbon material, is commonly used as a soil amendment. Biochar is produced through the pyrolysis process, which involves the low-oxygen burning of biomass, resulting in carbon and ash (Lehmann & Joseph, 2015).

Organic matter in the soil enhances its physical, chemical, and biological properties, which in turn increases the efficiency of water and fertilizer usage (Voltr et al., 2021). As organic matter content rises, the diversity of soil microbes—responsible for nutrient cycling and plant protection—also improves (Gryta et al., 2020). Recently, biochar derived from seaweed has gained popularity due to its high macro nutrient and carbon content (Katakula et al., 2020), making it a valuable soil amendment (Roberts et al., 2015). The application of manure and biochar into the soil represents an effective agronomic management strategy to enhance the growing environment for plants, helping to properly express their genetic potential. Regularly adding organic matter to the soil also promotes sustainable crop cultivation practices (Akanmu et al., 2023).

Another factor that affects plant productivity in dry land is the high intensity of sunlight and temperature. Plants using the C3 photosynthesis cycle, such as chili peppers, are particularly sensitive to high temperatures and intense light. When temperatures exceed 30°C, the number of flowers that drop increases, which reduces the percentage of fruit formation (Garruña-Hernández et al., 2012; Husen et al., 2023). In tropical areas, light intensity can reach as high as 1800 μmol m^{-2} s^{-1} (Grace et al., 1998). This elevated light intensity can cause both air and soil temperatures—essentially the plant microclimate—to rise, negatively impacting plant yields (Masabni et al., 2016). To optimize chili pepper yields, it is essential to implement agronomic management strategies that reduce sunlight intensity.

One effective agronomic management technique for reducing sunlight intensity is shading. Research conducted in the Mediterranean region indicates that using plastic shading with a 22% shading level can significantly enhance vegetable crop yields. The percentage increase in yield varies depending on the species of vegetables being cultivated (Paskhin et al., 2022). This increase in crop yield is attributed to improvements in the microclimate around the plants, including reduced temperatures and lower sunlight intensity. High temperatures can negatively impact nutrient absorption from the soil, thereby affecting the nutritional content of vegetables (Mishra et al., 2023). Additionally, incorporating biochar into the soil not only improves its physical, chemical, and biological properties but also helps lower soil temperatures (Ahmad Bhat et al., 2022). This study aims to investigate the effects of agronomic management on the yield and yield components of red chili plants grown in sandy drylands.

Method

The research method employed in this study was experimental. It consisted of a field trial conducted in Dusun Amor-amor, Gumantar Village, Kayangan District, North Lombok Regency, from March to September 2024. The agronomic management treatments tested included the application of organic matter and the use of plastic shading. The organic matter factor had three levels: no organic matter, chicken manure organic matter, and seaweed biochar organic matter, each applied at a dosage of 10 tons per hectare. The shading factor comprised two conditions: no shading and shading. The plastic used for shading was polyethylene, with a thickness of 200 microns, capable of blocking 14% of ultraviolet (UV) radiation, which is referred to as UV plastic. All treatments were arranged factorially within a randomized block design, with three replications for each treatment.

The experimental activities began with the selection of land for the experimental site and the sowing of seeds. The chosen land had previously been used for planting tomatoes and was already prepared with beds. These beds were then divided into experimental plots, each measuring 600 cm in length. The width of the beds is 120 cm at the bottom and 100 cm at the top, with a height of 20 cm. There is a distance of 50 cm between each bed within the block and a distance of 75 cm between the blocks. Each plot contains existing planting holes measuring 60 x 60 cm, resulting in a total of 20 planting holes per plot.

After cleaning up the remnants of the previous plants, minimum tillage is conducted by loosening the old tomato planting holes. In the loosened soil, a base fertilizer in the form of NPK compound fertilizer (16-16-16) is applied at a rate of 760 kg/ha, which translates to 22.8 g per planting hole. Additionally, chicken manure and biochar are applied at a rate of 10 tons/ha, or 300 g per hole. Once the base fertilizer and organic matter are applied, the existing plastic mulch covering the beds is tightened. The experimental plots are then left undisturbed for two weeks while maintaining moisture to ensure that the fertilizer and organic matter decompose and mix evenly into the soil.

Chili seeds of the Landung variety are sown in seedling trays filled with a medium composed of equal parts chicken manure, husk, and soil (1:1:1). Seedlings that have developed four leaves, approximately 28 days after sowing, are transplanted in the afternoon when the experimental plots are sufficiently moist. Subsequent activities include staking, installing shading treatments, follow-up fertilization, pest and disease control, and pruning.

To create the shading, a dome-shaped bamboo frame is constructed, standing about 150 cm tall in the middle and approximately 100 cm at the edges of the plot. The plastic on the edges of the frame is rolled up to a height of 50 cm, allowing for maintenance activities while ensuring good air circulation within the shaded area.

Follow-up fertilization for chili plants was done three times: first, 15 days after planting (DAP) with a dose of 80 kg/ha; second, at 35 DAP with a dose of 120 kg/ha; and third, at 56 DAP with a dose of 240 kg/ha. To prevent pest disturbances, which can cause both direct and indirect damage (including serving as virus vectors), pesticide applications with the active ingredient spirotetramat were performed weekly. Additionally, to prevent anthracnose disease during fruit ripening, fungicides containing azoxystrobin and difenoconazole were sprayed.

Before starting the experiment, we collected initial data on soil texture and several chemical properties that influence soil fertility. We measured various indicators of successful agronomic management in the plants, which included plant height, stem diameter, number of leaves, total chlorophyll content, number of fruits per plant, fruit weight per plant, and total fruit weight per plot.

The treatments' effects on the plant microenvironment, including organic carbon content, cation exchange capacity (CEC), and microbial population, were observed 60 days after planting (DAP). Additionally, other environmental variables, such as air temperature and humidity around the planting area, were measured daily using a thermos-hygrometer. We analysed the collected data using Analysis of Variance (ANOVA) at a 5% significance level. The significant effects of the treatments on the measured variables were determined using the Honest Significant Difference (HSD) test, also at a 5% significance level.

Result and Discussion

General Overview of Experimental Conditions

The primary pest issue encountered was thrips, which act as vectors for viruses. Virus infections occurred unevenly among the plants as they entered their generative phase, potentially affecting crop yield. Another disease that impacted the plants, particularly the chili fruits, was anthracnose. This disease caused the fruits to drop prematurely when fully developed, and it also exhibited uneven distribution across the experimental plots, which could further influence crop yield. To prevent virus spread, regular spraying was conducted to control thrips, the agents responsible for transmitting the virus. Additionally, fungicide spraying was routinely performed to inhibit the spread of anthracnose disease on the fruit.

Environmental conditions, including air temperature and relative humidity (RH), were optimal for the local superior chili pepper variety, specifically the Landung variety. During the experiment, the average maximum air temperature was 34°C, while the average minimum temperature was 25.3°C. For the Landung chili variety, which is suited for planting in lowland tropical areas, these temperatures are still considered ideal. Some research indicates that the optimal temperature range for chili plants is between 25°C and 30°C; temperatures below 15°C or above 30°C can negatively impact plant growth and yield (Deng et al., 2024). Additionally, the average RH during the experiment was 68.3%, which is suitable for the growth of chili plants.

Soil with a sandy texture (70% sand, 15% clay, and 15% silt) tends to have a relatively low fertility level. This is evident in Table 1, which shows that the organic carbon content is very low to low. Organic carbon is a crucial factor that influences other soil chemical properties, such as nitrogen content, pH, and cation exchange capacity. Interestingly, the available phosphorus content is very high, and the potassium content is also elevated. The intensive agricultural practices of growing chili and tomato crops, along with the application of NPK compound fertilizer, likely lead to an accumulation of phosphorus and potassium residues in the soil. However, the low organic carbon, or organic matter content, reduces the soil's ability to retain water. Increasing the organic matter content in sandy soil can significantly enhance its water-holding capacity (Libohova et al., 2018).

Table 1. Soil chemical properties data at the site prior to the experiment

Component	Value	Catagory
pH H_2O (Electrometry)	6.81	Neutral
C-organic % (Wakey & Black)	1.11	Low
N total % (Kjeldahl)	0.09	Very low
P available ppm (Bray)	149,01	Very high
K total % (AAS)	0.67	High
Ca exchange meq/100g (Amonium Acetate)	4.75	Low
Mg exchange meq/100g (Amonium Acetate)	1.26	Moderate
Cation Echange Capacity meq/100g (Amonium Acetate)	12.47	Low

Effect of Soil Amendments on Observed Parameters

There was no interaction between soil amendments and shading in their effects on the observed parameters. Soil amendments significantly impact the number of fruits per plant, fruit weight per plant, and fruit weight per plot. In contrast, shading significantly influences the number of productive branches, the total number of fruits, the fruit weight per plant, and the fruit weight per plot. However, neither of these factors affected plant growth variables, total chlorophyll content in the leaves, total microbial activity in the soil, organic carbon content, or soil cation exchange capacity (CEC).

Soil amendments using chicken manure and seaweed biochar had a significant impact on plant height. However, these treatments did not show a significant effect on other growth parameters, such as stem diameter, the number of leaves, or the number of productive branches observed at the first harvest (see Table 2). Despite the high nutrient composition of the chicken manure (organic C 29.15%, total N 1.15%, total P 4.44%, total K 2.58%, total Mg 1169.4 ppm, Ca 3.87%, and B 182.38 ppm) and seaweed biochar (organic C 43.60%, total N 1.48%, total P 0.10%, total K 2.66%, total Fe 359 ppm, total Zn 14 ppm, and humic compounds 5.56%), it's likely that the nutrients critical for chili plant growth were adequately provided by the base and follow-up fertilizers applied. The sufficient nutrient conditions in the soil may have resulted in some plant growth parameters remaining unaffected by the treatments. Biochar and manure did not significantly influence tomato yield and biomass in their single experiment (Gao et al., 2022). The long-term effects of these soil amendments might be more beneficial, particularly for soil health and crop production (Omara et al., 2022).

Table 2. Effect of treatments on growth variable of red chili

Treatment				Parameter
	Plant height (cm)	Stem diameter (cm)	Leaves number	Productive branches
Shading				
Without sahading	70.5	0.99	87.7	7.3^{a}
UV plastic shading	74.4	1.01	86.0	8.7^{b}
HSD 5%	-	-	-	*0.74*
Soil amendment				
Without amendment	70.7^{ab*}	0.97	80.6	7.9
Checken manure	69.7^{a}	1.01	86.8	7.7
Seaweed biochar	76.9^{c}	1.02	93.1	84
HSD 5%	4.77	-	-	-

*Values in the same column and the same treatment followed by different letters are significantly different according to Honestly Significant Different at 5% level.

The plant height observed in this study was greater than that recorded for the same variety in previous research. However, the stem diameter remained relatively consistent. In the previous study, the Landung chili variety was intercropped with peanuts, which may have led to some competition between the red chili and peanut plants, potentially impacting the plant height. Additionally, the number of leaves on the red chili plants in the prior study was nearly three times higher than what was found in this study. This discrepancy likely occurred because, in previous research, the plants were affected by a virus, resulting in many small and numerous young leaves (Safta et al., 2024).

Soil amendment treatments did not significantly affect the number of productive branches of chili plants (see Table 2). The number of productive branches observed in this study was relatively low, as red chili plants typically have more than 10 productive branches. It's important to note that the count of productive branches was taken only at the first harvest. Red chili plants exhibit a semi-indeterminate growth type, meaning they continue to grow even after producing flowers and fruit. Additionally, the number of productive branches varies significantly depending on the specific variety of the red chili plants (Mahmud et al., 2023).

The results indicated that applying chicken manure and seaweed biochar as soil amendments did not significantly impact the organic carbon content in the soil, cation exchange capacity (CEC), total microbial counts, or total chlorophyll levels in the leaves of chili plants (see Table 3). In contrast, in the earlier study (Gao et al., 2022) was reported that manure and biochar could enhance CEC and nitrogen availability in the topsoil. However, this study utilized a different approach, with soil samples collected from a depth of 5 cm to 10 cm. Additionally, it is worth noting that the manure used in the mentioned study was cow manure, while the biochar was derived from softwood and almond shells.

Soil samples for microbial observation and leaf samples from chili plants were collected 60 days after planting (DAP). The application of soil amendments did not significantly affect the total chlorophyll in the leaves or the total microbial populations in the soil. This finding contradicts previous studies, which suggested that soil amendments could enhance microbial populations in the soil (Liu et al., 2023) and increase chlorophyll content in the leaves (Fallah et al., 2021). As noted earlier, tomato plants became infested by thrips during the fruit development stage prior to the first harvest. This thrips infestation caused the chili leaves to curl upwards and turn brown, resulting in a loss of chlorophyll. Earlier it was reported that pest attacks on leaves could reduce total chlorophyll levels (Lu et al., 2022).

The absence of a significant impact from soil amendments on the total number of microbes (including fungi and bacteria) in the soil is likely due to the relatively short treatment period of 60 days. In contrast, a study by Dong et al. (Dong et al., 2024), which examined soil amendments over three years, demonstrated an increase in microbial activity in the soil. Additionally, another research also revealed that the effects of biochar on soil microbial populations and activity can vary significantly depending on the soil type, especially in short-term experiments (Yue et al., 2023).

Soil amendment treatments had a significant impact on yield, measured in terms of fruit weight per plant and total fruit weight per plot, as well as the number of fruits per plant. However, fruit length and diameter were not significantly affected by these treatments (see Table 4). Both chicken manure and seaweed biochar increased the number of fruits per plant by approximately 6.2% compared to the treatments without soil amendments. Nevertheless, there was no notable difference in the effects of chicken manure and biochar on the number of fruits, fruit weight per plant, or total fruit weight per plot. Previous studies have shown that soil amendments, including manure, biochar, or a combination of both, can enhance crop yields (Jeffery et al., 2017; Lei et al., 2024; Zhang et al., 2022). This increase in yield is closely associated with how these amendments improve the soil's water-holding capacity, especially in sandy soils (Bekchanova et al., 2024).

Effect of UV Plastic Shading on Observed Parameters

UV plastic shading treatments had an impact on several factors, including the number of productive branches, the number of fruits per plant, fruit weight per plant, and total fruit weight per plot (see Tables 2 and 4). However, plant growth variables such as plant height, stem diameter, and leaf count were not significantly influenced by UV plastic shading (refer to Table 2). Additionally, supporting parameters like fruit length, fruit diameter, total chlorophyll levels, total microbial counts, cation exchange capacity (CEC), and soil organic carbon were also not significantly affected by UV plastic shading, as demonstrated in Table 3.

Table 3. Effect of treatments on total chlorophyl in leaves, total microbes in the plant rhizosphere, C-organic in the soil and cation exchange capacity (CEC)

Treatment	Parameter			
	Total Chlorophyl (mg/l)	Total mikrobes (CFU)×10^6	C-Organic (%)	CEC (meq/100 g)
Shading				
Without sahading	62.03	14.63	1.41	10.44
UV plastic shading	63.73	16.01	1.46	10.14
HSD 5%			-	
Soil amendment				
Without amandement	64.26	13.60	1.38	9.99
Checken manure	62.28	16.54	1.49	10.53
Seaweed biochar	62.09	15.82	1.44	10.36
HSD 5%	-			-

The use of UV plastic to mitigate UV light radiation has become common in the horticultural industry, particularly for field crops and as coverings for plastic greenhouses. Research indicates that employing UV plastic shading can enhance the yield of crops such as tomatoes (Papaioannou et al., 2012), lettuce (Lycoskoufis et al., 2022), and cucumbers (Hassan et al., 2014). However, there have been no studies on the effects of UV plastic shading on field-grown chili peppers. According to result of a previous research, UV light radiation has a negative impact on the growth of chili plants by (Legarrea et al., 2010). The UV plastic used in this study can block 14% of UV radiation, which helps reduce the negative effects of UV exposure on chili plants by the same percentage. An increase in chili plant yield and its components begins with a rise in the number of productive branches (Table 2). Productive branches are defined as those that produce fruit; thus, a higher number of productive branches correlates with increased fruit production and, accordingly, greater crop yield (Table 4). The increase in productive branches among chili plants due to UV plastic shading results from enhanced photosynthetic activity. In this study, high yields of approximately 35 tons per hectare were achieved through both UV plastic shading and soil amendment treatments.

UV plastic not only reduces UV radiation but also decreases the overall amount of sunlight entering the experimental plots. This reduction in sunlight intensity is particularly beneficial for lowering the evapotranspiration rate of plants, especially in sandy drylands with limited water availability. Lower evapotranspiration rates can enhance photosynthetic activity (Katsoulas et al., 2020), increasing the production of photosynthate. This photosynthate is utilized to form productive branches and fruits, which ultimately boosts crop yields under shading treatments. The variation in data regarding fruit weight per plant is likely due to uneven disturbances from viruses and anthracnose in the treated plants.

The length and diameter of chili fruits were not influenced by the UV plastic shading treatment (Table 4). It appears that these two characteristics are primarily determined by the plant's genetic factors rather than the treatment conditions. One study shows that there is a common genetic control affecting peduncle length, fruit length, and fruit diameter (Setiamihardja & Knavel, 1990). Additionally, another study indicates that the diameter of chili fruit is strongly inherited from parent plants, alongside other traits such as fruit weight per fruit, fruit weight per plant, and the timing of the first harvest (Sharma et al., 2010).

Table 4. Effect of treatments on yield and yield components of red chili

Treatment	Parameter				
	Fruits number per plant	Fruit weight per plant (g)	Fruit length (cm)	Fruit diameter (cm)	Fruit weight per plot (kg)
Shading					
Without sahading	83.5[a*]	1053.8[b]	12.4	1.46	19.92[a]
UV plastic shading	86.1[b]	1012.0[a]	12.0	1.45	20.96[b]
HSD 5%	*1.97*	*39.80*	-	-	*0.40*
Soil amendment					
Without amandement	81.5[a]	994.5[a]	12.2	1.46	19.51[a]
Checken manure	86.3[b]	1052.2[b]	12.3	1.46	20.98[b]
Seaweed biochar	86.6[b]	1052.1[b]	12.0	1.46	20.85[b]
HSD 5%	*1.97*	*39.80*	-	-	*0.40*

*Values in the same column and the same treatment followed by different letters are significantly different according to Honestly Significant Different at 5% level

The UV plastic shading treatment had no impact on plant height, stem diameter, or the number of leaves. There aren't many studies investigating the effects of UV plastic on the growth of red chili plants in the field. Most research focuses on the impact of different shading types on tomato plants. For instance, a study found that the height, stem diameter, and number of leaves of tomato plants were unaffected by the shading colour used (Tezcan et al., 2023). Additionally, another study on chili plants indicated that the number of leaves is more influenced by genetic factors than by environmental factors (Sashaan et al., 2023).

Supporting parameters such as total chlorophyll, total microbial content, organic carbon, and cation exchange capacity (CEC) were found to be unaffected by UV plastic shading. While UV plastic is expected to create more favourable conditions for photosynthesis, reviews by (Katsoulas et al., 2020) indicate that plant species respond differently to this treatment. Some plants increase their photosynthetic activity due to UV plastic shading, while others may decrease or remain neutral. It is believed that the Landung red chili variety responds neutrally to UV plastic shading, which explains why its total chlorophyll levels do not show significant differences. Furthermore, no existing literature supports the impact of UV plastic shading on total microbial content, organic carbon in the soil, or CEC.

Conclusion

The yield of red chili plants grown in dry land is significantly affected by the use of soil amendments and UV plastic shading; however, there is no interaction between these two treatments. Additionally, there is no difference in yield between red chili plants treated with chicken manure and those treated with seaweed biochar. All the treatments tested resulted in an approximate 6% increase in yield compared to untreated red chili plants. This research demonstrates that effective agronomic management in the cultivation of red chili plants in dryland areas can serve as a strategy to achieve the second goal of the Sustainable Development Goals (SDGs). By increasing the yield of red chili plants, which are both economically and nutritionally valuable, and by adding organic matter to the soil, we can promote sustainable and climate-adaptive agriculture.

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Author Contributions
Idea and methodology of the study, I Komang Damar Jaya (IKDJ) and Lalu Wahyu Ardis Pandya (LWAP); field establishment and coordinating for data collection, LWAP and Jayaputra; data analysis and interpretation Bambang Budi Santoso (BBS). Preparation of the draft, IKDJ and LWAP; writing-review, BBS and Jayaputra; editing, LWAP.

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Conflicts of Interest
The authors declare no conflict of interest.

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