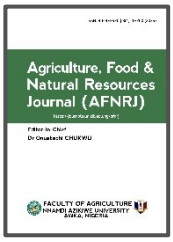
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Original Article

Effects of biochar and fertilizer on yield and actual seasonal crop evapotranspiration of rainfed watermelon in Ishiagu, Ebonyi State, Nigeria

OPEN ACCESS

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ABSTRACT

Soil infertility, declining yield, and decreasing water resources are constraints to agricultural productivity. This study investigated the effect of biochar and fertilizer on the actual seasonal crop evapotranspiration of rainfed watermelon in Ishiagu, Ebonyi State, Nigeria. Four treatments were used: control (T0), fertilizer only (T1), biochar only (T2), and biochar + fertilizer (T3). The treatments were each replicated three times in a randomized complete block design. Data was subjected to analysis of variance. Significant means were separated using Tukey Honestly Significant Difference at $p<0.05$. The amount of total seasonal rainfall during the experiment was 686.79 mm. The result showed that the actual seasonal crop evapotranspiration (ET) was estimated using the soil–water balance method and ranged from 602.95 to 615.83 mm across treatments. The ET was highest in T1 (615.83 mm). T0 had the lowest ET (602.95 mm), while T3 had a value of 603.92 mm, and T2 had 604.62 mm, respectively. Watermelon fruit yield differed significantly among treatments ($p < 0.001$); T3 produced significantly higher yield than all other treatments ($p < 0.05$). T3, despite having a lower ET value (603.92 mm) than that of T1 (615.83 mm), produced the highest yield, while its calculated actual seasonal crop evapotranspiration was numerically, slightly, lower than that of T1. The study concluded that the integration of biochar with fertilizer is a viable approach for improving both watermelon productivity and crop water productivity under rainfed conditions.

KEYWORDS: *Citrullus lanatus, Crop water productivity, Soil fertility, Watermelon yield,*

INTRODUCTION

Efficient agricultural water management requires estimation of actual seasonal crop evapotranspiration. Actual seasonal crop evapotranspiration (CWR) is the amount of water needed to supply its evapotranspiration needs from planting to harvest. Adequate soil water maintained by rainfall or irrigation does not limit plant growth and crop yield; irrigation scheduling has been based on CWR. Biochar is a co-product of pyrolysis (thermal degradation of organic material in low or zero oxygen environments). Its properties and stability depend on feedstock and pyrolysis conditions, such as temperature and residence time (Karam *et al.,* 2022). Hence, variations in crop productivity with biochar amendment have been reported — a Timor-Leste field trial found rice-husk biochar raised vegetable yields by 230% over the control on acidic tropical soils (Williams *et al.,* 2023), while a global meta-analysis found yield response depends on environment and management practice rather than being a fixed effect (Zhang *et al.,* 2023). Biochar effects on crop yield have been mainly attributed to increased plant available water (Razzaghi *et al.,* 2020), enhanced CEC and nutrient retention, and effects on soil microbial community (Bekchanova *et al.,* 2024).

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Watermelon (*Citrullus lanatus*) is an important vegetable, widely cultivated, accounting for 22% of harvested area of all vegetables. China, India, and Turkey are the leading producers, with China alone producing about 61% of world production (FAOSTAT, 2024). Despite its global economic importance, watermelon production faces persistent agronomic constraints such as soil-borne disease and declining soil fertility under continuous cropping (Tong *et al.,* 2025), underscoring the need for soil amendment strategies such as biochar and fertilizer application. Watermelon has a high actual seasonal crop evapotranspiration, varying with climate and irrigation — from 281–334 mm under drip irrigation in China (Zhang *et al.,* 2023) to 400–650 mm under full irrigation in the US (Gebeyhu & Markos, 2023). Biochar combined with fertilizer has been shown to increase yield more than either amendment alone (Isimikalu *et al.,* 2023).

The problems facing agricultural productivity range from soil infertility and declining yield to decreasing water resources. The addition of biochar to soils could be part of a sustainable strategy for efficient water use. Combining biochar with fertilizers could be better: a Nigerian field trial found that rice-husk biochar combined with inorganic fertilizer improved upland rice growth and yield across three soil types in the Southern Guinea Savannah (Isimikalu *et al.,* 2023), and a similar combination has been reported for horticultural crops on nutrient-poor tropical soils (Williams *et al.,* 2023). Field research combining biochar and fertilizer is still limited. A similar field trial at Ebonyi State (Ishiagu), combining rice-husk biochar and fertilizer under drip irrigation improved tomato yield and crop water use efficiency (CWUE), with combined treatments reaching a CWUE of up to 0.007113 t/ha.mm against 0.001184 t/ha.mm in the control (Adumbu *et al.,* 2024). Although biochar and fertilizer amendments have been shown to improve crop productivity in different environments, limited field-based information is available on their effects on the growth, yield and actual seasonal crop evapotranspiration of rainfed watermelon in the humid tropical environment of southeastern Nigeria. This is important because rainfall variability, soil fertility limitations and the absence of supplemental irrigation may influence both crop productivity and soil-water use. Therefore, evaluating these amendments under rainfed conditions in Ishiagu could provide locally relevant information for improving watermelon production.

Therefore, the study investigated the effects of rice-husk biochar and inorganic fertilizer on the growth and fruit yield of watermelon, determined the actual seasonal crop evapotranspiration under rainfed conditions in Ishiagu, Ebonyi State, Nigeria. Crop water productivity was also evaluated.

MATERIALS AND METHOD

Description of the Study Area

The research was carried out on the experimental farm of the Department of Agricultural and Bioenvironmental Engineering Technology, Federal College of Agriculture, Ishiagu, Ebonyi State, during the 2025 cropping season. Ishiagu is located in the southern part of the derived Savannah of Nigeria. It lies on latitude 5°58"N and longitude 7°38"E. The annual mean temperature is about 27.1°C, average relative humidity is 79%, and the mean annual rainfall is 1961 mm. Watermelon is one of the most important fruits in Nigeria, as it is consumed by almost every household. With the growing consumption of watermelon, there is a need to ensure high-quality fruits, since fruit quality can be affected by the timing and amount of inorganic fertilizer applied during production.

Experimental Setup

Preliminary investigations (bulk density, topographical survey, infiltration rate) were conducted. A total area of 48 m² was cleared, ploughed, and harrowed for planting watermelon. The experimental setup comprised four treatments, replicated three times in a 2 x 2 factorial experiment laid out in a Randomized Complete Block Design. Each plot was 2 m × 2 m, with 0.5 m alleys. There were four plants per plot, with 1.0 m spacing. Improved watermelon seeds (Heracles F1) were purchased from Agritropic, Enugu; NPK 15:15:15 fertilizer was purchased from Department of Agriculture, Ivo Local Government Area, Ebonyi State. Weeding and other agronomic practices followed standard cultural practices. Treatments are presented in Table 1.

Table 1: Details of the treatments

Treatment Code	Explanation
T0	Control
T1	Fertilizer (1t/ha)
T2	Biochar (5t/ha)
T3	Biochar + Fertilizer (5t/ha Biochar & 1t/ha Fertilizer)

T0= control, T1= fertilizer only, T2= biochar only, and T3= biochar + fertilizer.

Biochar Production

A fairly large quantity of rice husk was obtained from notable rice mills in Ishiagu for biochar production. The collected rice husk was sundried and then packed very well and transported to the SETRACO Nig. Ltd. Laboratory, Ihube where a muffle furnace was used under limited oxygen condition and at regulated temperature (450° C) for about twenty minutes to produce rice husk biochar. After pyrolysis, the biochar was ground to enable it to pass through a 2 mm sieve, ensuring that all the biochar used are of similar particle sizes.

Physical and Chemical Characterization of Soil and Biochar

The characterization of biochar and soil samples was carried out at the Soil Science Laboratory, Federal College of Agriculture, Ishiagu. Soil samples were taken from each treatment plot before planting and during harvest. Samples were analyzed for magnesium, calcium, sodium, potassium, phosphorous, exchangeable nitrogen, CEC, total organic

carbon, total organic matter, exchangeable acidity, bulk density, soil particle analysis, and soil moisture (weekly).

Determination of Crop Water Use and Crop Water Productivity

Soil-water content was measured weekly using a Rapid Soil Moisture meter (FieldScout TDR 150). The FieldScout TDR 150 was used with the manufacturer's default calibration for mineral soils; no site-specific gravimetric calibration was performed at the experimental site. Measurements were taken at three locations per plot at depths of 0–10, 10–20 and 20–30 cm; and the readings converted to water depth using the layer thickness. The change in soil-water storage was calculated from the difference between successive measurements. Actual evapotranspiration (ET) of watermelon was estimated using the soil–water balance equation (Rashid & Jia, 2019). The soil water balance equation can be expressed as:

$$ET = P - R - D - \Delta W \quad (1)$$

Where; ET is total crop evapotranspiration (mm); P is precipitation (mm); R is runoff (mm); and ΔW is change in soil water storage (mm) in the root zone, based on the average difference in soil water content between two successive measurements in the 0–30 cm depth; D is drainage (mm).

Runoff was collected using a 1.2 m × 1.2 m single runoff collector installed at the field's natural drainage outlet. Drainage was collected using a single lysimeter with watermelon planted in it, installed at a representative location within the experimental field. Because these components represent field-scale water movement rather than plot-specific processes, one lysimeter and one runoff collector were used for the entire experimental area rather than one per treatment plot. Each device was read in triplicate on each measurement occasion, and the mean of the three readings taken were used as the representative value. Precipitation was measured using two manual rain gauges installed randomly across the field. Change in soil water storage was determined separately for each treatment plot and replicate from soil water content differences between successive measurements at 0–10, 10–20, and 20–30 cm depths.

Crop water productivity: This was calculated as the ratio of fruit yield to actual seasonal crop evapotranspiration.

Agronomic Parameters

Vine length was measured from the base to the tip using a measuring tape, following standard practice (Zhang *et al.,* 2023). The lengths of all plants were measured, and the mean calculated and recorded for each treatment. Total number of leaves per treatment was counted weekly, and the mean calculated and recorded. Matured fruits were harvested twice weekly for three weeks and weighed; mean yield (t/ha) per treatment was calculated.

Statistical Analysis

The collated data were subjected to analysis of variance (ANOVA), regression, and descriptive analysis. Treatment effects on yield were tested using two-way ANOVA, with means separated by Tukey's Honestly Significant Difference (HSD) test at $\alpha = 0.05$. Growth parameters (vine length and leaf number), were analyzed by fitting treatment-specific regression curves to describe growth trends over time. Actual seasonal evapotranspiration was reported descriptively, as the water-balance components (drainage and runoff) were measured at the field scale without treatment-level replication. All analyses were carried out using Microsoft Excel and Minitab Statistical Software.

RESULTS AND DISCUSSION

Soil Physical and Chemical Properties of the Experimental Site

The pre-planting soil properties are presented in Table 2. The topsoil is classified as sandy clay loam (USDA method), suited to shallow-rooted crops like watermelon. Its fine texture reduces the need for frequent irrigation.

Average organic carbon in the topsoil before planting was 1.04%, within the range typical of cultivated soils in the region (Akpa *et al.,* 2016). Organic matter content was 1.79%, likely from leaf litter and root residue decay. Organic carbon was low (<2.0%), typical of humid tropical soils (Kome *et al.,* 2021). Available phosphorus and CEC were also very low, and mean pH was strongly acidic.

Meteorological Data of the Study Area

Rainfall: Heavy rainfall occurred early in the experiment (August–December 2025), rising gradually with peaks in September and October, then declining sharply from November. Total rainfall was 686.79 mm, with the highest daily total (25 mm) on Day 15 after planting (Figure 1).

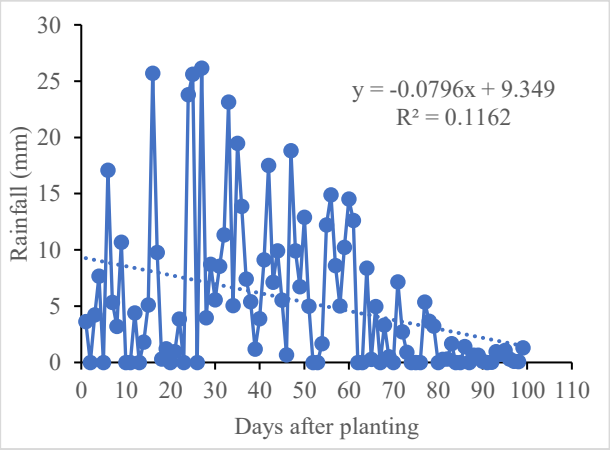


Figure 1. Rainfall trend during the experiment

Table 2: Biochar and initial physico-chemical characterization of soil at the experimental site before planting

Property	Soil	Property	Biochar
Sand (%)	70.97 ± 12.58	Ash content	40%
Silt (%)	5.83 ± 1.53	C:N Ratio	44.2
Clay (%)	23.20 ± 12.11	Moisture content	6%
pH	4.77 ± 0.06		8.78 ± 0.08
Phosphorus (ppm)	63.63 ± 13.18		69.63±12.20
Nitrogen (%)	0.09 ± 0.05		1.09 ± 0.04
Organic Carbon (%)	1.04 ± 0.55		1.91 ± 0.55
Organic Matter Content (%)	1.79 ± 0.95		2.43 ± 0.95
Calcium (cmol/kg)	5.87 ± 1.85		6.76 ± 1.04
Magnesium (cmol/kg)	1.47 ± 0.23		2.20 ± 0.22
Potassium (cmol/kg)	0.15 ± 0.10		0.27 ± 0.09
Sodium (cmol/kg)	0.20 ± 0.01		0.56 ± 0.04
Exchangeable Acidity (cmol/kg)	1.31 ± 0.28		0.84 ± 0.22
Cation Exchange Capacity (cmol/kg)	8.99 ± 1.72		10.28 ± 1.21

Relative humidity (RH) and air temperature. Mean monthly RH declined gradually from September to December, reaching its minimum in December, with daily values ranging from 60.12% (September) to 95.06% (November) (Figure 3). Mean air temperature ranged from 22.53°C to 26.29°C, rising gradually from September to November before declining again in December (Figure 2). Temperature was lower early on due to higher rainfall, and declined again later as rainfall increased.

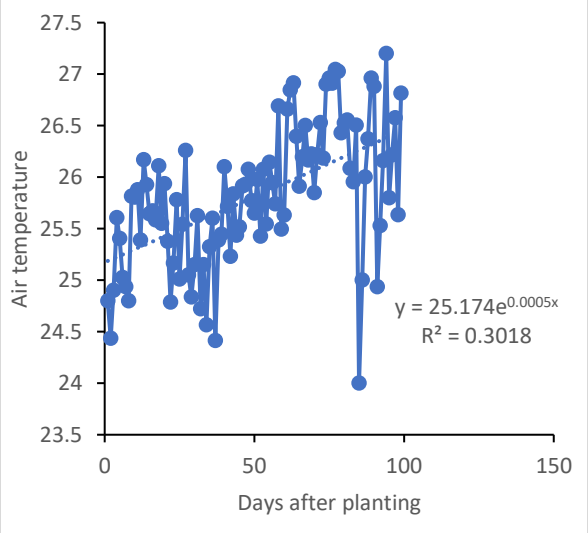


Figure 2. Mean air temperature trend during the experiment (range: 22.53–26.29°C).

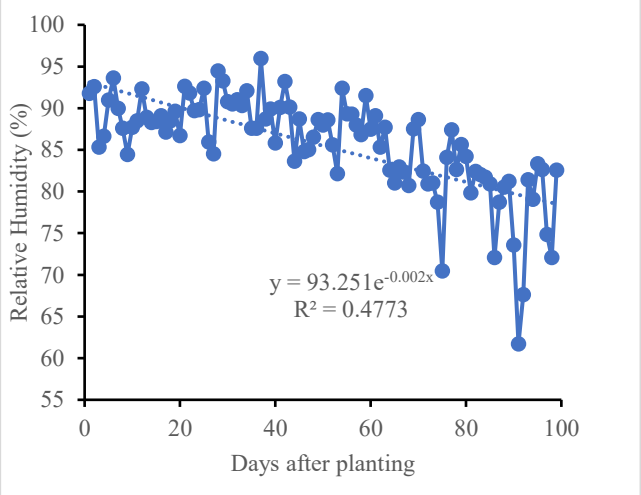


Figure 3. Mean relative humidity trend during the experiment (range: 60.12–95.06%).

Agronomic Responses of Watermelon under Fertilizer and Biochar Treatments

Vine length: Mean plant height across treatments and replicates, up to 84 days after planting (DAP), showed rapid vine growth during the vegetative and development stages, slowing at flowering, after which treatment differences became negligible (Figure 4). This agrees with Hajirad *et al.* (2025), who found crops generally peak mid-season and decline thereafter.

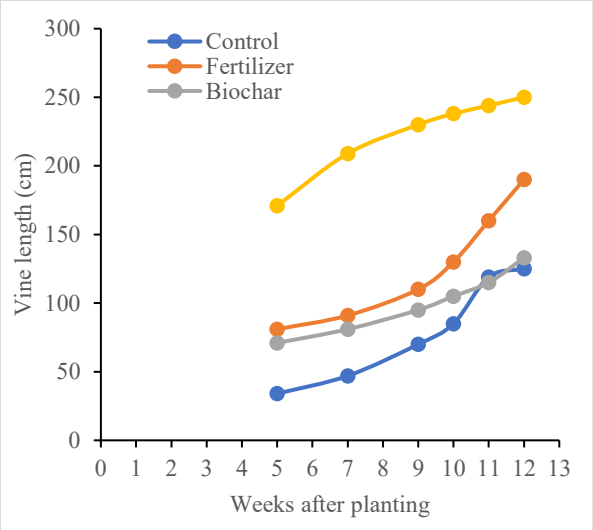


Figure 4. Dynamic change in vine length as a function of weeks after planting under the four treatments.

Total number of leaves. Leaf counts across treatments, up to 84 DAP, are shown in Figure 5. The biochar + fertilizer treatment produced more leaves than the other three, owing to better nutrient supply and water retention. Leaf number rose rapidly during the vegetative stage, with no notable treatment differences thereafter.

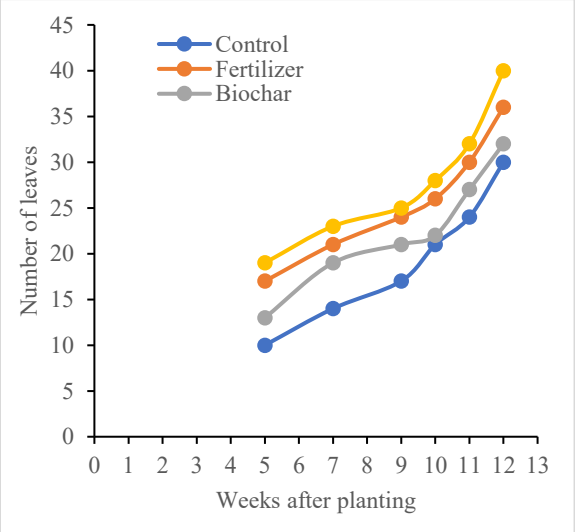


Figure 5. Dynamic change in number of leaves as a function of weeks after planting under the four treatments.

Effect of Fertilizer and Biochar on Watermelon Yield

Watermelon yield results are given in Table 3. Mean yield was significantly highest under biochar + fertilizer (T3) - about 3.0 times the control and 1.8 times fertilizer-only — followed by fertilizer alone, biochar alone, and the control.

This agrees with Isimikalu *et al.* (2023), who found combined biochar and fertilizer outperformed either amendment alone. It also matches a tomato trial in Ishiagu, where combined biochar + organic and biochar + inorganic fertilizer (3.38 and 3.29 t/ha) far exceeded biochar alone (1.31 t/ha) or the control (0.55 t/ha) (Adumbu *et al*., 2024) — consistent with the yield ranking here (T3 > T1 > T2 > T0). Watermelon's water-use response may depend on environment: a U.S. multi-variety trial found yield rose linearly with seasonal crop evapotranspiration, though water productivity varied (6.5–8.0 kg/m³) by variety even within one environment (Gebeyhu & Markos, 2023). Varietal differences in fertilizer and biochar response may partly explain the yield pattern observed here.

Table 3: Watermelon yield based on treatments (mean ± SD)

Treatment	Yield (t/ha)
Control (T0)	8.88 ± 1.94^{c}
Fertilizer (T1)	14.75 ± 1.76^{b}
Biochar (T2)	10.78 ± 1.72^{bc}
Biochar + Fertilizer (T3)	26.625 ± 2.29^{a}

Note: Means that do not share a letter are significantly different

Effect of Fertilizer and Biochar on Crop Evapotranspiration

Crop evapotranspiration is the actual amount of water lost to the atmosphere by the crop, which depends not only on the existing meteorological conditions but also on the availability of water to meet the atmospheric demand. Table 4 shows the crop actual seasonal crop evapotranspiration estimated by the soil water balance method for the various treatments, as the crop water productivity. Mean seasonal ET was highest under T1 and lowest under the control, with T2 and T3 intermediate (Table 4), against a common precipitation, runoff, and drainage depth applied uniformly across treatments. Also, Crop water productivity, was highest under T3. However, because the ET estimates were not statistically compared, the crop water productivity values are only presented descriptively.

This range of values (602.95–615.83 mm) is higher than the 281–334 mm two-season range reported for oasis watermelon under sub-membrane drip irrigation in an arid Chinese environment (Zhang *et al.,* 2023), but falls within the broader 400–650 mm seasonal water-requirement range reported for full-irrigation watermelon production in the United States (Morales *et al.,* 2023); these differences are consistent with the strong influence of climate, irrigation method, and variety of watermelon ET documented across these studies.

Table 4: Precipitation depth, runoff, drainage depth, change in water storage, actual seasonal crop evapotranspiration, and crop water productivity of watermelon

Treatment	Precipitation Depth (mm)	Runoff Depth (mm)	Drainage Depth (mm)	Change in water Storage	Seasonal ET (mm)	Crop water productivity ((kg ha^{-1} mm^{-1})
Control	686.79	6.19	41.32	-36.33	602.95	14.73
Fertilizer	686.79	6.19	41.32	-23.45	615.83	23.95
Biochar	686.79	6.19	41.32	-34.66	604.62	17.83
Fertilizer + Biochar	686.79	6.19	41.32	-35.36	603.92	44.09

In Table 4, T3 recorded the lowest calculated actual seasonal crop evapotranspiration among the two fertilized treatments, at 603.92 mm, compared with 615.83 mm for T1. T3 also produced the highest watermelon yield, 26.625 t ha^{-1}, as well as the greatest leaf number and tallest vines. This combination is notable because the development of a larger canopy would normally be expected to increase transpiration demand. However, the available water-balance data do not permit the difference in calculated actual seasonal crop evapotranspiration to be attributed solely to a superior drawdown of stored soil water. In particular, a limitation of the water balance approach used is that drainage and runoff were measured with a single lysimeter and a single runoff collector, respectively, at the field scale, rather than with instrumentation replicated across each treatment plot. Consequently, apparent treatment differences in seasonal ET are driven entirely by treatment-level differences in soil moisture storage (ΔW), not by measured differences in drainage or runoff, which were held constant across treatments by design. This means the ET estimates reflect within-plot soil water dynamics accurately, but do not capture any treatment-specific effects on deep percolation or surface runoff that biochar or fertilizer application might independently cause. Furthermore, the numerical difference observed in ET between T1 and T3 could not be statistically tested owing to evapotranspiration values derived from single field-scale drainage and runoff measurements without treatment-level replication or an associated variance estimate. Future studies should consider installation of replicated lysimeters and runoff collectors per treatment, alongside multiple lysimeter/runoff readings within each plot, to test this possibility directly and to permit statistical comparison of treatment ET values.

While the observed difference in calculated actual seasonal crop evapotranspiration should be interpreted with caution, owing to common precipitation, and same runoff and drainage values in the water-balance equation, several physically plausible mechanisms, consistent with reported biochar studies, may help explain the observed pattern. Biochar's porous structure may increase plant-available water-holding capacity (Razzaghi *et al.,* 2020), while its incorporation into the soil surface may reduce direct soil evaporation. In addition, improvements in cation exchange capacity and nutrient retention may have enhanced nutrient availability and supported greater canopy development (Williams *et al*., 2023; Bekchanova *et al.,* 2024). These mechanisms, however, were not directly measured in the present study and should therefore be regarded as possible explanations rather than demonstrated processes.

CONCLUSION AND RECOMMENDATION

During the 2025 cropping season, a field experiment was conducted, investigating the effects of biochar and fertilizer amendments on the growth, yield, and actual seasonal crop evapotranspiration of rainfed watermelon at the Research Farm of Agricultural and Bioenvironmental Engineering Technology, Federal College of Agriculture, Ishiagu. Earth pit-produced rice husk biochar was applied, as well as inorganic fertilizer, two weeks after germination. The treatments were: biochar + fertilizer, biochar only, fertilizer only, and control. Measurements included soil moisture, fruit yield, vine length, and leaf number. Biochar and fertilizer amendments enhanced watermelon growth, yield, and crop water productivity, with the combined treatment (T3) performing best overall, a pattern of potential practical value in water-scarce production areas. However, as this study was conducted over a single cropping season and one location, these findings should be considered preliminary. Multi-season and multi-site trials are recommended to establish consistency.

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Authors' Contributions

TA managed data collection, interpretation of data, writing of manuscript, material support, and wrote the first draft of the manuscript. BMS managed experimental design, reviewed literatures and first draft. All authors read and approved the final manuscript.

Ethical Statement

Not applicable.

AI Declaration Statement

The authors declare that no Artificial Intelligence (AI) tools were used in the generation, analysis, interpretation, or writing of this manuscript.

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