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Growing media, water stress and re-watering effects on the growth and dry matter production of cocoa seedlings

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Abstract: Cocoa (*Theobroma cacao*) seedlings are very sensitive to water stress during the nursery stage and early field establishment. Sawdust, carbonated rice husk, and compost in the following ratios (i) 60: 40: 0 – M1, (ii) 60: 30: 10 – M2, (iii) 60: 20: 20 – M3, (iv) 60: 10: 30 – M4, (v) 60: 0: 40 – M5, and (vi) topsoil – M6 as control were used to investigate the effect of growing media, water stress, and re-watering on the growth, dry matter production, and partitioning of cocoa seedlings. Each combination was subjected to water stress 6 weeks after sowing for a period of 4 weeks, after which they were rewatered. Plant height, stem girth, leaf number and area, and seedling biomass were significantly higher in soilless potting media as compared to topsoil. M4 and M5 significantly recorded the highest total dry weight, plant height, stem girth, leaf number, leaf area, and root volume before imposition of water stress. Following imposition of water stress, cocoa seedlings grown in M4 and M5 showed a recovery that was superior to the other growing media, indicating that higher proportions of compost together with sawdust and carbonated rice husk provide an alternative for growing cocoa seedlings.

Keywords: cocoa, water stress, re-watering, growing media, carbonated rice husk

1. Introduction

Cacao is an important cash crop in Ghana; it accounts for a significant part of Ghana's GDP and foreign earnings [1]. Cocoa industry in Ghana provides livelihood for about 4 million farmers and their households [2].

Cocoa production per unit area in Ghana has been on decline since 2010 [3]. Efforts to improve cocoa production in Ghana and to achieve the 1 million metric tonnes produced in 2010 have been targeted, increasing yield through rehabilitation, soil fertility management, and the use of improved varieties, with little attention to the production of quality seedlings and subsequent survival and establishment in the field. Sustainable cocoa production is limited by seedling mortalities at the nursery stage and on the field due to high temperature, uneven distribution of rainfall, and drought [4; 5; 6; 7].

Climate change is likely to intensify the current stress factors, such as increasing temperature, uncertain rainfall patterns, and moisture deficits, on cocoa seedling growth and development in the nursery and field in the coming years. One strategy to overcome the climate change effect could be the development of growing media that increases the resilience of cocoa seedlings against unfavourable weather conditions.

Nursery growing media affects the quality of cocoa seedlings [8], their establishment in the field and eventual development [9]. The traditional nursery growing medium is topsoil obtained from farmlands. The continuous use of topsoil as growing medium causes land degradation and is therefore not environmentally sound [10]. The compactness of topsoil also restricts seedling root growth and therefore affects overall seedling growth and establishment in the field. In recent times, there have been renewed efforts to search for environmentally sound options for raising cocoa seedlings at the nursery. [11] reported that a good growing medium enhances the growth of a healthy fibrous root system, and it can be used to support and supply nutrients in order to achieve a healthy plant growth.

Recent studies have paid attention to the use of soilless growing media that are organic-based, less expensive, and suitable for plant growth [12]. The ability of an organic substrate in retaining moisture for plants will help overcome the issue of crops being stressed during uncertain weather conditions. [13] noted that the application of organic amendments increased water stress resistance in corn varieties. Compost and biochar (carbonated rice husk) are among the best organic substrates that could enhance the water- and nutrient-holding capacity and availability of growing media with a view to improving plant resilience against water stress.

Compost has been demonstrated to be efficient in improving the resilience, yield, and tolerance of plants to harsh conditions [14]. Applying compost could improve water-holding capacity, soil organic matter content, and mineral nutrition [15; 16]. Compost also has other beneficial effects on soil structure and decreases the soil pH [17]. Previous research has demonstrated that adding compost to soil can increase its ability to withstand environmental pressures by increasing, among other things, microbial activity [18]. Microorganisms are crucial for a stable, secure, and sustainable agricultural and biomass production because they considerably contribute to the compost's absorption of nutrients through biochemical transformations [19].

It has been proven that biochar can be added to soil in order to improve soil fertility and reduce water stress [20]. Biochar supports crop production under water stress conditions by improving moisture retention [21; 22].

Applying biochar and compost together resulted in a synergistic effect on water-holding capacity and soil nutrients [23]. Furthermore, the combined application of biochar reduces the application of chemical fertilizers and improves soil structure [24; 25].

The objective of the present study, therefore, was to evaluate the combined effect of carbonated rice husk (biochar) and compost on growth performance, dry matter production and partitioning, susceptibility to water stress, and response to the re-watering of cocoa seedlings in the nursery.

2. Materials and methods

Experimental site

The study was conducted in pots (polybags) at a nursery of the University of Ghana's Forest and Horticultural Crops Research Centre (FOHCREC), Kade. Kade, the capital of Kwaebibirem District, is in the eastern part of Ghana and falls within the semi-deciduous forest zone. It is 114 m above sea level on latitude 6˚09' and 6˚06'N and longitude 0˚55' and 0˚49'W. The average temperature and relative humidity in the area is 28^{0}C and 78% respectively.

Experimental materials

The treatments consisted of five different combinations of growing media (M) obtained by mixing sawdust (S), carbonated rice husk (CRH), biochar and compost (C) at different percentage ratios: M1: S + CRH + C (60:40:0), M2: S + CRH + C (60:30:10), M3: S + CRH + C (60:20:20), M4: S + CRH + C (60:10:30), M5: S + CRH + C (60:0:40), and M6: Topsoil. Topsoil (M6) was included as control. The topsoil from the Kokofu series (Lixisols) was sampled from a field at FOHCREC at a depth of 0–20 cm. The carbonated rice husk (biochar) and the compost were locally prepared. The size of the polybag used was 20 x 15 cm and was perforated at the base for aeration and drainage. The various combinations of the soilless growing media were thoroughly mixed and filled into the polybags as per the required ratio v/v. The quantity of M1, M2, M3, M4, M5, and M6 used to fill each polybag weighed 297.1, 280.6, 355.5, 381.7, 401.4, and 1,210.0 g respectively. Each treatment consisted of 60 plants and was arranged in a completely randomized block design with three replications. The polybags were placed on a wooden platform to prevent direct contact with the soil. The setup was watered and stabilized for 24 hours before sowing the cocoa seeds. Seeds were sown at one seed per pot (polybag). Thirty days after planting, each plant was given 150 ml solution of 10 g NPK fertilizer per litre of water twice a week. Watering was maintained at 80% field capacity for the first six weeks. The hybrid cocoa seeds were obtained from the Research Centre's cocoa plantation established with the help of Ghana Cocoa Board.

Six weeks after planting, 20 plants of each treatment were sent to a protected place, where water stress was imposed on them for 4 weeks. To minimize evaporation, the surfaces of the growing media were covered with aluminium foil sheets. Twenty plants of each treatment continued to receive normal watering. Drought plants were re-watered to 80% field capacity for a period for 8 weeks after the imposition of water stress. Twelve plants of each treatment were used for the determination of biomass production and partitioning.

Growing media analysis

Physical characteristics

Bulk density was estimated using the core method based on the below formula:

$$\text{Bulk density} = \frac{\text{Weight of oven dry core soil}}{\text{volume of the sample } \left(\text{g cm}^{-3}\right)} \quad (1)$$

Total soil porosity was estimated from bulk density and particle density using the below formula:

$$\text{Total porosity} = \frac{\text{Bulk density}}{\text{Particle density}} \quad (2)$$

Water-holding capacity was determined as the volume of water retained by a medium after drainage.

Chemical characteristics

Total nitrogen was determined with a macro-Kjeldahl apparatus. The phosphorus content was determined using molybdenum blue colorimetric method, while potassium content was determined by a flame photometer. Calcium and Mg were determined as described by [26]. The NO_3 and NH_4 were determined based on the procedure described by [27]. The pH of the media was determined in a 1:5 suspension with a pH meter. Electrical conductivity (EC) of the 1:5 extract was determined with an EC meter. Total organic matter (OM) content was determined by the ignition method at 550^{0}C. Organic carbon analyser was used to measure the organic carbon (OC) content.

Plant growth analysis

The measurement of parameters started with seedling emergence one week after planting. Germination was periodically recorded every week from the date of sowing and continued until the germination ceased. Germination indices were measured as follows:

$$\text{Rate of Germination} = \frac{1}{\text{Germination Time}} \tag{3}$$

$$\%\ \text{emergence} = \frac{\text{Total Number of Seeds Geminated}}{\text{Total Number of Seeds Sown}} \times 100\ \% \tag{4}$$

$$\text{Germination Index} = \frac{\text{Number of Geminating Seeds}}{\text{Days of First Count}} + \frac{\text{Number of Germinating Seeds}}{\text{Days of Final or Last Count}} \tag{5}$$

Data on seedling growth parameters and dry mater production were measured before and after imposition of the drought stress and at the end of the re-watering period. Data were collected on seedling growth parameters such as plant height, stem diameter (girth), leaf number, total leaf area, leaf chlorophyll content, leaf weight, stem weight, root weight, root length, and root volume. Dry matter yield and distribution (leaves, stem, roots, and shoot-to-root ratio) were measured. The cocoa seedlings' response to water stress and re-watering were evaluated.

Statistical analysis

Data were statistically treated using analysis of variance (ANOVA) in GenStat software version 12. Duncan Multiple Range Test (DMRT) was used to separate significant means at 5% probability ($P < 0.05$).

3. Results

Growing media – Physical and chemical properties

The water-holding capacity (WHC) of the soilless growing media (M1 to M5) was significantly higher ($p < 0.05$) than that of the topsoil (*Table 1*). No significant differences were recorded among the various soilless growing media in terms of air porosity. However, the topsoil had a higher porosity than the soilless media. The bulk density of the topsoil (1.14 g/cm^3) was significantly ($p < 0.05$) higher than that of the soilless media (M1 to M5). The lowest bulk density value among the growing media was recorded in M1 (0.33 g/cm3) (*Table 1*).

Table 1. Physical properties of the growing media

Codes	Growing media	Water-holding capacity (%)	Bulk density (g/cm³)	Porosity (%)
M1	S + CRH + C (60:40:0)	73.5^{ab}	0.33^{d}	54^{b}
M2	S + CRH + C (60:30:10)	75.3^{a}	0.53^{c}	55^{b}
M3	S + CRH + C (60:20:20)	75.8^{a}	0.62^{b}	56^{b}
M4	S + CRH + C (60:10:30)	70.3^{b}	0.67^{b}	57^{b}
M5	S + CRH + C (60:0:40)	70.8^{b}	0.73^{a}	57^{b}
M6	Topsoil	40.0^{c}	1.14^{e}	61^{a}

Note: Values with the same letters in the same column are not significantly different ($p < 0.05$) by DMRT.

The pH of the topsoil was more acidic (5.7) than that of the soilless growing media (M1–M5), while M1 was the most basic (7.8) growing medium (*Table 2*). Soilless growing media containing compost had a lower pH than those without compost (M1). Increasing the compost content enhanced the EC of the growing media from 591 dS/cm (M1) to 772 dS/cm (M5). M6 showed a significantly lower EC (300 dS/cm) value than the rest of the growing media. The C/N ratio of the soilless growing media (M1–M5) increased with increasing the amount of CRH (*Table 2*). The topsoil had significantly lower C/N ratio (3.7) (*Table 2*).

Table 2. Chemical properties of the growing media

Chemical properties	Growing media					
	M1	M2	M3	M4	M5	M6
pH	7.8^{a}	6.8^{b}	6.6^{b}	6.6^{b}	6.1^{b}	5.5^{c}
EC (dS/cm)	460^{c}	591^{ab}	676^{b}	688^{b}	772^{a}	300^{d}
C/N	81.1^{a}	28.9^{b}	26.4^{b}	24.0^{b}	16.9^{b}	3.7^{c}
N (%)	0.21^{c}	0.57^{b}	0.61^{b}	0.66^{b}	0.82^{a}	0.26^{c}
OC (%)	17.03^{a}	16.48^{ab}	16.11^{ab}	15.0^{ab}	13.82^{b}	0.96^{c}
S (%)	0.03^{b}	0.02^{bc}	0.09^{a}	0.08^{a}	0.07^{a}	0.01^{c}
OM (%)	2.8^{d}	6.3^{b}	10.5^{ab}	11.5^{ab}	13.8^{a}	5.2^{c}
NH_4 (mg/kg)	309.6^{c}	360.2^{b}	367.2^{b}	367.0^{b}	403.2^{a}	144.3^{d}
NO3 (mg/kg)	209.2^{d}	243.2^{c}	367.2^{b}	381.6^{b}	408.8^{a}	108.0^{e}
P (%)	0.11^{c}	$0.14b^{c}$	0.14^{bc}	0.17^{b}	0.25^{ab}	0.42^{a}
K (%)	2.2^{b}	2.6^{ab}	2.7^{a}	2.7^{a}	2.7^{a}	0.8^{c}
Ca ($cmol_{(+)}$/kg)	3.4^{b}	4.5^{ab}	4.8^{ab}	5.4^{a}	5.6^{a}	2.3^{c}
Mg($cmol_{(+)}$/kg)	3.7^{a}	3.0^{ab}	2.7^{b}	2.6^{b}	2.9^{ab}	1.3^{c}

Note: Values with the same letters in the same row are not significantly different ($p < 0.05$) by DMRT.

Germination indices

In terms of percentage emergence, the soilless growing media did not differ significantly ($p < 0.05$) (M1–M5). However, the topsoil (M6) recorded a significantly ($p < 0.05$) lower percentage emergence (78%) compared to the soilless growing media (*Table 3*) and a significantly ($p < 0.05$) lower (0.08) germination index (GI) than the other growing media. Among the soilless growing media, the lowest GI was recorded in M1 (0.11). The number of days from sowing to 50% seedling emergence was significantly higher (20) for M6 than for the other growing media (*Table 3*).

Table 3. Effect of growing media on the germination indices of cocoa seeds

Growing media	Rate of germination (day^{-1})	Germination index	Days to 50% emergence	Emergence (%)
M1	0.049^{ab}	0.11^{ab}	9.0^{b}	100^{a}
M2	0.052^{a}	0.13^{a}	8.0^{b}	100^{a}
M3	0.053^{a}	0.13^{a}	8.0^{b}	100^{a}
M4	0.053^{a}	0.13^{a}	8.0^{b}	100^{a}
M5	0.050^{a}	0.12^{a}	8.0^{b}	100^{a}
M6	0.030^{c}	0.08^{c}	20.0^{a}	80^{b}

Note: Values with the same letters in the same column are not significantly different ($p < 0.05$) by DMRT.

Growth, biomass production, and partitioning

M5 produced a significantly ($p < 0.05$) greater plant height (23.4 cm), higher number of leaves (9.9) and leaf area (245.9 cm^2) among the growing media six weeks after planting (*Table 4a*). M6 produced the lowest plant height (17.0 cm), stem girth (0.1 cm), and root volume (0.6 cm^3), but it recorded the highest chlorophyll content (14.6) among the growing media. There was no difference in the stem girth among the soilless growing media.

Table 4a. Effects of growing media on the growth of cocoa seedlings before water stress, six (6) weeks after sowing

Growing media	Plant height (cm)	Stem girth (cm)	Number of leaves	Leaf area (cm^2)	Root length (cm)	Root volume (cm^3)	Chlorophyll content
M1	20.0^{c}	0.2^{a}	5.7^{d}	147.2^{d}	13.4^{c}	1.2^{b}	7.1^{d}
M2	20.9^{c}	0.2^{a}	7.0^{c}	174.0^{c}	15.0^{b}	1.7^{ab}	8.1^{cd}
M3	21.7^{b}	0.2^{a}	7.0^{c}	181.2^{c}	15.2^{b}	1.9^{a}	8.2^{cd}

Growing media	Plant height (cm)	Stem girth (cm)	Number of leaves	Leaf area (cm²)	Root length (cm)	Root volume (cm³)	Chlorophyll content
M4	22.1[b]	0.2[a]	8.5[b]	194.1[b]	16.6[a]	2.2[a]	9.9[c]
M5	23.4[a]	0.2[a]	9.9[a]	245.9[a]	16.9[a]	2.4[a]	10.5[b]
M6	17.0[d]	0.1[b]	7.3[c]	153.7[dc]	13.6[c]	0.6[c]	14.6[a]

Note: Values with the same letters in the same column are not significantly different ($p < 0.05$) by DMRT.

M5 produced the highest leaf and stem and root dry weight, resulting in the highest total dry weight (1.99 g) (*Table 4b*). M6, on the other hand, produced the least leaves, stem and root dry weight and hence the lowest total dry weight (1.37 g). M6, however, recorded a significantly higher shoot-to-root ratio (8.6).

Table 4b. Effects of growing media on total biomass production and partitioning of cocoa seedlings before water stress treatment, six (6) weeks after sowing

Growing media	Leaf dry weight (g)	Stem dry weight (g)	Root dry weight (g)	Total dry weight (g)	Shoot/root ratio
M1	0.77[c]	0.55[b]	0.34[a]	1.66[b]	3.9[c]
M2	0.82[b]	0.53[b]	0.34[a]	1.69[b]	4.3[bc]
M3	0.84[b]	0.54[b]	0.33[a]	1.71[b]	4.0[bc]
M4	0.85[b]	0.56[b]	0.35[a]	1.76[b]	5.0[b]
M5	0.99[a]	0.64[a]	0.36[a]	1.99[a]	4.5[bc]
M6	0.73[c]	0.48[c]	0.14[b]	1.37[c]	8.6[a]

Note: Values with the same letters in the same column are not significantly different ($p < 0.05$) by DMRT

At the end of the water stress period, M5 produced a significantly higher plant height (24.2 cm), number of leaves (10.9), root volume (3.0), and chlorophyll content (26.8) (*Table 5*). M6, on the other hand, produced a significantly lower plant height, stem girth, number of leaves, root volume, and chlorophyll content. Among the soilless media, chlorophyll content increased with increasing the amount of compost. None of the soilless growing media produced a significant difference ($p < 0.05$) in stem girth. In well-watered plants, M4 produced the greatest plant height (30.2 cm), the highest number of leaves (16.9), root length (31.9), and root volume (5.9 cm^3) (*Table 5*). However, M5 recorded the highest chlorophyll content (33.4). M6 recorded the lowest plant height (20.8 cm), stem girth (0.2 cm), number of leaves (7.7), root length (18.5 cm), and root volume (1.8 cm^3). There was no difference in stem girth among the soilless growing media.

Table 5. Effects of growing media on the growth of water-stressed and continuously watered cocoa seedlings ten (10) weeks after sowing

Growing media	Plant height (cm)	Stem girth (cm)	Number of leaves	Root length (cm)	Root volume (cm³)	Chlorophyll content
Water-stressed						
M1	20.1^{c}	0.2^{a}	7.0^{c}	15.4^{c}	1.6^{b}	17.8^{d}
M2	22.3^{bc}	0.2^{a}	9.5^{b}	18.0^{b}	$2.2a^{b}$	18.8^{d}
M3	22.7^{bc}	0.2^{a}	9.5^{b}	18.7^{b}	2.3^{ab}	21.0^{c}
M4	23.9^{a}	0.2^{a}	9.8^{b}	19.9^{a}	2.8^{a}	24.5^{b}
M5	24.2^{a}	0.2^{a}	10.9^{a}	18.9^{b}	2.7^{a}	26.8^{a}
M6	17.9^{d}	0.1^{b}	7.3^{d}	16.0^{d}	0.8^{c}	4.2^{e}
Continuously watered						
M1	22.7^{c}	0.3^{a}	9.0^{d}	21.4^{d}	3.6^{c}	27.5^{c}
M2	26.0^{bc}	0.3^{a}	12.0^{c}	26.5^{c}	4.5^{b}	30.4^{bc}
M3	26.5^{bc}	0.3^{a}	13.5^{c}	26.9^{c}	4.7^{b}	30.6^{bc}
M4	30.2^{a}	0.3^{a}	16.9^{a}	31.9^{a}	5.9^{a}	32.6^{b}
M5	28.1^{b}	0.3^{a}	15.7^{b}	29.4^{b}	5.4^{a}	33.4^{a}
M6	20.8^{d}	0.2^{b}	8.7^{d}	18.5^{e}	1.8^{d}	30.1^{bc}

Note: Values with the same letters in the same column are not significantly different ($p < 0.05$) by DMRT.

At the end of the water stress period, total biomass production was reduced by 43, 52, 51, 49, 29, and 42% in M1, M2, M3, M4, M5, and M6 respectively (*Table 6*). Biomass production was less affected in M5 than the other growing media. Plant total dry weight differed significantly between the soilless growing media (M1–M5) and the topsoil (M1) under drought stress. M5 produced the highest leaf, stem, and root dry weight and hence the highest total dry weight (3.4 g) (*Table 6*). M6, on the other hand, produced the least leaves, stem and root dry weight and hence the lowest total dry weight (1.8 g). M6, however recorded a significantly higher shoot-to-root ratio (6.5).

Table 6. Effects of growing media on biomass production and partitioning of water-stressed and continuously watered cocoa seedlings ten (10) weeks after sowing

Growing media	Leaf dry weight (g)	Stem dry weight (g)	Root dry weight (g)	Total dry weight (g)	Shoot/root ratio
Water-stressed					
M1	$1.0b^{c}$	0.7^{b}	0.3^{bc}	2.0^{bc}	5.7^{b}
M2	$1.0b^{c}$	0.8^{b}	0.4^{b}	2.2^{bc}	4.5^{c}

M3	1.2^{b}	0.8^{b}	0.4^{b}	2.4^{b}	5.0^{bc}
M4	1.7^{ab}	0.8^{b}	0.5^{b}	3.0^{b}	5.0^{b}
M5	2.0^{a}	0.9^{a}	0.5^{a}	3.4^{a}	5.8^{b}
M6	0.8^{c}	0.5^{c}	0.2^{c}	1.5^{c}	6.5^{a}
Continuously watered					
M1	1.9^{c}	1.0^{b}	0.6^{b}	3.5^{c}	4.8^{b}
M2	2.8^{b}	1.1^{ab}	0.7^{b}	4.6^{b}	5.6^{ab}
M3	2.9^{b}	1.3^{ab}	0.7^{b}	4.9^{b}	6.0^{a}
M4	3.6^{a}	1.4^{a}	0.9^{a}	5.9^{a}	5.4^{ab}
M5	2.8^{b}	1.3^{ab}	0.7^{b}	4.8^{b}	5.9^{a}
M6	1.4^{c}	0.8^{c}	0.4^{c}	2.6^{d}	5.5^{ab}

Note: Values with the same letters in the same column are not significantly different ($p < 0.05$) by DMRT.

Under well-watered conditions, M4 produced the highest leaf (3.6 g), stem (1.4 g), root (0.9 g,) and hence total (5.9 g) dry weights (*Table 6*), whilst M6 recorded the lowest leaf (1.4 g), root (0.4 g), and total (2.6 g) dry weights ten weeks after planting. The highest and the lowest shoot-to-root ratio were obtained in M3 (6.0) and M1 (4.8) respectively. Among the soilless growing media, M1 produced the lowest dry biomass for all parameters measured.

At the end of the re-watering period, none of the cocoa plants in M6 recovered. The imposition of water stress resulted in the death of all cocoa plants in M6 (*Table 7*). M5 produced the greatest plant height (59.1 cm), the highest number of leaves (20.1), root length (29.9), and chlorophyll content (39.3) at the end of the re-watering period. Among the soilless growing media, M1 recorded the lowest values for all the growth parameters measured. The highest root volume (19.2 cm^3) was obtained in M4.

Table 7. Effects of growing media and re-watering on the growth of water-stressed and continuously watered cocoa seedlings, eighteen (18) weeks after planting

Growing media	**Height (cm)**	**Girth (cm)**	**Number of leaves**	**Root length (cm)**	**Root volume (cm^3)**	**Chlorophyll content**
Water-stressed						
M1	25.6^{d}	0.6^{b}	7.3^{d}	24.2^{c}	14.3^{d}	25.7^{d}
M2	51.2^{c}	1.0^{a}	10.2^{c}	28.0^{b}	16.1^{c}	35.1^{c}
M3	52.7^{bc}	1.0^{a}	18.3^{b}	29.3^{a}	18.3^{b}	36.7^{b}
M4	56.3^{b}	1.0^{a}	19.4^{a}	29.5^{a}	19.5^{a}	38.9^{ab}
M5	59.1^{a}	1.0^{a}	20.1^{a}	29.7^{a}	18.8^{ab}	39.3^{a}
M6	0.0^{e}	0.0^{c}	0.0^{e}	0.0^{d}	0.0^{e}	0.0^{e}

Growing media	Height (cm)	Girth (cm)	Number of leaves	Root length (cm)	Root volume (cm^3)	Chlorophyll content
Continuously watered						
M1	34.2^{d}	0.8^{b}	24.2^{c}	24.3^{c}	15.7^{d}	24.3^{d}
M2	47.2^{c}	1.1^{a}	30.3^{b}	28.0^{b}	19.0^{c}	34.3^{c}
M3	49.2^{b}	1.2^{a}	31.8^{ab}	29.3^{a}	22.7^{b}	36.5^{b}
M4	49.7^{b}	1.2^{a}	32.4^{a}	29.0^{a}	25.7^{a}	37.2^{a}
M5	56.7^{a}	1.2^{a}	33.0^{a}	29.8^{a}	25.9^{a}	37.9^{a}
M6	39.1^{e}	0.8^{b}	20.7^{d}	19.5^{d}	10.4^{e}	25.7^{e}

Note: Values with the same letters in the same column are not significantly different ($p < 0.05$) by DMRT.

In the continuously watered plants, M5 produced the greatest plant height (56.7 cm), the highest number of leaves (33.0), root length (31.9 cm), root volume (25.9 cm^3), and chlorophyll content (37.9) (*Table 8*). However, M1 recorded the lowest plant height (34.2 cm) and chlorophyll content (24.3). M6 recorded the lowest number of leaves (20.4), root length (19.5 cm), and root volume (10.4 cm^3). The lowest stem girth (0.8 cm) was obtained by M1 and M6.

At the end of the re-watering period, M5 recorded the highest leaf dry weight (11.6 g), stem dry weight (10.6 g), total dry weight (28.0 g), and shoot-to-root ratio. Among the soilless growing media, M1 obtained the lowest biomass production for all parameters measured (*Table 8*).

M5 obtained the highest leaf dry weight (13.0 g), stem dry weight (9.0 g), root dry weight (5.7 g), and hence the highest total dry biomass (27.9 g). The highest shoot-to-root ratio was observed in M3. Total biomass production increased with increasing the amount of compost. M6 recorded the lowest biomass production (*Table 8*).

Table 8. Effects of growing media and re-watering on biomass production and partitioning of water-stressed and continuously watered cocoa seedlings, eighteen (18) weeks after planting

Growing media	Leaf dry weight (g)	Stem dry weight (g)	Root dry weight (g)	Total dry weight (g)	Shoot/root ratio
Water-stressed					
M1	2.5^{e}	2.1^{d}	1.8^{c}	6.4^{e}	2.5^{c}
M2	5.0^{d}	4.3^{c}	3.6^{b}	12.9^{d}	2.6^{c}
M3	9.5^{c}	9.2^{b}	4.3^{ab}	23.3^{c}	3.4^{b}
M4	10.5^{b}	9.8^{b}	4.9^{a}	24.0^{b}	4.1^{ab}
M5	11.6^{a}	10.6^{a}	4.8^{a}	28.0^{a}	4.8a

Growing media	Leaf dry weight (g)	Stem dry weight (g)	Root dry weight (g)	Total dry weight (g)	Shoot/root ratio
M6	0.0[f]	0.0[e]	0.0[d]	0.00[f]	0.0[d]
Continuously watered					
M1	6.5[e]	4.6[d]	2.7[c]	13.8[e]	4.1[a]
M2	8.2[d]	6.1[c]	4.1[b]	18.4[d]	3.5[b]
M3	9.9[c]	7.9[b]	4.1[b]	21.9[c]	4.3[a]
M4	11.2[b]	7.9[b]	4.7[b]	23.3[b]	4.0[a]
M5	13.0[a]	9.0[a]	5.9[a]	27.9[a]	3.7[ab]
M6	3.0[f]	3.0[e]	2.7[c]	8.7[f]	2.2[c]

Note: Values with the same letters in the same column are not significantly different ($p < 0.05$) by DMRT.

4. Discussion

Effective and affordable measures that enhance crop productivity are required for the sustainable management of water stress. The integrated use of biochar and compost in plant growth media is considered an efficient and affordable measure as it is environmentally sound. Several studies have demonstrated their effectiveness in enhancing crop growth and output under water-stressed conditions.

Physico-chemical properties of the growing media used for the study

The growing media were analysed for certain physico-chemical characteristics. Data reported showed a considerable variability in most of the physico-chemical properties, especially between the soilless growing media and the topsoil. The soilless growing media with compost included had an improved physico-chemical status for better plant growth and development due to increased aeration, water-holding capacity, and nutrient content. Increasing the amount of compost resulted in increased nutrient content. The increased C/N ratio with increasing the amount of CRH is likely due to greater organic C content. Among the soilless growing media, pH increased with increasing the amount of CRH. Organic matter content and the macronutrients N, P, K, Ca, and S increased with increasing the amount of compost.

The influence of growing media on germination indices of cocoa seeds

The soilless growing media used in this study had a higher rate of seedling emergence (number of seedlings appearing every 5 days), and it took fewer days to reach 50% emergence. This might be due to their higher WHC and low BD as compared to the topsoil medium. The high WHC of the soilless growing media is likely to have reduced the imbibition period and allowed seedlings to emerge at a faster rate, reducing the number of days to reaching 50% emergence compared to the low WHC of the topsoil. High bulk density affects seedling emergence, as indicated by [28]. It was noticed at the nursery that the shoot had emerged, which suggests that the high BD of the topsoil may have inhibited the emergence of the cotyledons. However, it took longer for the cotyledons to emerge, while some never did, and they eventually died. The high BD may have also prevented seedling emergence and caused some seeds to suffocate and perish by producing soil compaction after watering. This finding is consistent with [29], who claimed that soil compaction occurs when plants are cultivated in soil-filled containers due to the frequent watering requirements of the plants. Similar findings of low seedling emergence of African breadfruit in 100% soil media as compared to medium comprised of 1:2:3 Rice hull: PM: River sand were also reported by [30].

Effects of growing media and water stress on the growth and biomass of cocoa seedlings

Drought stress severely affects plant biomass allocation, photosynthetic rate, and growth [31]. Crop growth and development are limited under water stress conditions. The results showed that growing media and water stress significantly affected cocoa seedling growth, biomass production, and partitioning.

During drought imposition, water availability for the cocoa plants decreased in all the growing media. The soilless growing media with an improved physico-chemical status were less affected. The results of the study showed that the plant growth medium containing compost significantly performed better for plant growth parameters compared to the topsoil. The study indicated that shoot growth and root production increased with increasing the amount of compost for the soilless growing media. The positive effect of compost on plant growth may be a result of increased nutrient availability [32; 33], which in the present study was reiterated by increased N, P, K, Ca, S, and also organic matter content, which could increase water availability. The higher potassium concentration in the media may have contributed to the conservation of water during drought, as it is widely known that potassium enhances plant water status, the turgor pressure of cells, and stomatal regulation [34]. Again, the application of compost in soil is reported to increase the crop's tolerance to abiotic stresses by improving microbial activity [18]. Generally, seedling growth responses to water stress indicated that media M4 and M5 were the best. Seedlings grown in these media had delayed the appearance of water stress symptoms, indicating a better water economy. After imposition of water stress, seedlings grown in these media remained turgid for a longer period than those grown in other growing media, especially in the topsoil. Biomass production was less affected in the medium (M5) containing the highest amount of compost.

The effect of water stress in M6 was more prominent. In general, the topsoil produced seedlings with poorer growth. The imposition of water stress resulted in the death of all the plants in M6. This might be due to the poor root development observed for M6, which might be the result of high bulk density, which, in turn, discourages root development and hence plant growth and development.

Effects of growing media and re-watering on water-stressed cocoa plants

Cocoa plants in soilless growing media with compost recovered rapidly after re-watering as a result of a larger root system, which improves the crop's ability to utilize more water [33]. This study showed that compost-formulated soilless media increased seedling growth and accelerated recovery after drought stress compared to the topsoil. This is a result of the larger root system, which could improve the crop's ability to take up water during re-watering. CRH had less effect on cocoa plants' water stress recovery than compost, but it may help to maintain a more stable growing-media water content than topsoil due to its higher water-holding capacity in the short term.

This study has proved that increasing the amount of compost incorporation increased cocoa seedling growth and accelerated the recovery of plants after drought stress. Overall, all the soilless growing media with compost (M2–M5) were able to recover after one week of re-watering, whilst it took two weeks for M1 without compost. All the plants in the topsoil (M6) were unable to recover and subsequently died. The quicker recovery of the plants with increasing the amount of compost (M2–M5) could be attributed to the larger root system, as indicated by higher root biomass production, which could lead to increased water and nutrient absorption by the plants. The enhanced recovery could also be attributed to increased microbial activities [35].

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