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Effect of compost-biochar mixes and irrigation on the growth and yield of Amaranthus (*Amaranthus hybridus*) under two growing temperatures

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An experiment was carried out to study the sensitivity of *amaranthus* to different sources of soil nutrients and different amounts of irrigation water at different temperatures. Nitrogen (N) rich materials (compost/poultry manure) and carbon (C) rich material (biochar) used included poultry manure + rice husk biochar (PM+RB), poultry manure + sawdust biochar (PM+SB), rice husk compost + rice husk biochar (RC+RB), sawdust compost + sawdust biochar (SC+SB) mixed at 10 ton ha^{-1} N rich material to 5 ton ha^{-1} C rich material. Rice husk compost only, Sawdust compost only (at 10 ton ha^{-1} for each of RC and SC), NPK (400 kg ha^{-1}) and no amendments as Control were also used. Two irrigation amounts (0.1124 mm and 0.225 mm per pot), were imposed resulting in 12 treatment combinations, in a completely randomized design with 4 replicates. The experiment was repeated under two different temperatures of 37 and 30°C in the glass house and pot house, respectively. Data on growth, yield, water use and nutrient leaching were collected. PM+RB produced the tallest plants (31.67 cm) with 0.1124 mm irrigation at 30°C. PM+SB treated plants had more leaves (17) with 0.1124 mm amount of irrigation water at 37°C. NPK treated plants gave the highest stem girth (5.87 cm) and highest SPAD value (42.5%) with 0.1124 mm amount of irrigation water at 37°C. Leaf area index was highest (43) at 30°C for plants receiving NPK and 0.225 mm amount of irrigation water. NPK treated plants gave the highest fresh biomass of 36.93 g at 30°C but lowest biomass (13.01 g) at 37°C. PM+SB gave the highest fresh biomass weight of 16.7 g at 37°C and highest volume of leachate (123 ml) with 0.225 mm irrigation water at 30°C. At 37°C, SC gave the highest leachate volume (166 ml). The study indicates a good potential for sustaining crop yield with organic materials under increasing temperature and declining water resources that may be associated with changing climate.

Key words: *Amaranthus*, compost, biochar, climate change, irrigation frequency.

INTRODUCTION

Many countries in Africa have experienced rapid growth and diversification of agricultural production due to demands from both domestic and global markets. As a consequence, interventions in Africa have focused on exotic fruits and vegetables, for export markets. A serious downside to replacement of native crops by globally

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marketable crops is a reduction in diversity of seed stocks and vulnerability of cropping systems to climate variability. African Indigenous Vegetables (AIVs) or nutriceutical plants including *amaranthus* play a significant role in the health and food security of the underprivileged in both urban and rural settings. Surveys in East Africa show that AIVs display a higher profitability than exotic vegetables, and production of AIVs is highly relevant for small-scale farmers especially women as they require little financial input compared to exotic vegetables (Shackleton et al., 2009). The market potential for AIVs is very good. Several studies have highlighted great potential of AIVs especially due to their natural adaptation to the local conditions (Smith and Eyzaguirre, 2007; Nyarko and Quainoo, 2012).

Although environmental conditions are known to influence crop growth and global climatic changes are assumed to worsen cropping conditions in sub-Saharan African with dry spells becoming more frequent, only one paper published recently deals with the impact of soil moisture stress on AIVs (Olufolaji and Ojo, 2010). A few others focused on nutrient management (Ojo et al., 2007). It can be concluded that most aspects of the cultivation or cropping systems of AIVs are heavily under emphasized. The rain-fed production systems found throughout Sub-Saharan Africa are considered the most vulnerable to climate changes; choice of cropping system will become a key sustainability parameter and AIVs are obvious choices. The success of AIVs is strongly dependent on its sensitivity to key environmental variables especially water and nutrients (Olufolaji and Ojo, 2010).

However, the response of AIVs to climate sensitive variables are mostly not comprehensively determined or documented. Under depleting water and nutrient resources, recovery of nutrients and water from organic residues could enhance agro-sustainability. Organic soil amendments are critical in the development of sustainable urban production systems because they are important sources of carbon and nitrogen (De Lucia et al., 2013; Yadav et al., 2011). They are known to be important in regulating pH and contaminants transport in the soil. Sustained application of organic soil amendments are reported to boost yields, enhance N use efficiency, build up organic matter and reduce the accumulations of NO_3-N, salts and environmental contaminants such as heavy metals (Liang et al., 2012). Sawdust and rice husk are organic materials that when composted with poultry manure becomes enriched with nitrogen needed by plants. When these materials are charred to form biochar, they become important sources of carbon that could be mixed with composted N rich materials for improved productivity and carbon sequestration. Furthermore, addition of biochar to N rich materials has been shown to reduce leaching of N in soils (Agegnehu et al., 2015; Dempster et al., 2012; Yuan and Xu, 2012). It would therefore be important to also study growth and yield of *amaranthus* under different temperatures, water, nitrogen and carbon sources. The main objective of this study was to determine the response of *amaranthus* to different compost and biochar mixes at different growing temperatures. A second objective was to determine the influence of the amount of irrigation water and its interaction with compost-biochar mixes on the leaching potential and water use efficiency during the growing period of *amaranthus*

MATERIALS AND METHODS

Description of study sites

The study was set up as a pot experiment at the University for Development Studies (UDS), Nyankpala campus, Tamale, Ghana, glass house (at an average day time temperature of 37°C) and pot house (at an average day time temperature of 30°C). The experiment was carried out from October, 2014 to December, 2014.

Soil was collected from Kamina urban garden site in Tamale. The soil physical and chemical properties are presented in Table 1. As shown in the table, the soil is sandy loam and slightly acidic. The level of N is very low (0.06%). The data suggest that organic matter content is low (as indicated by organic carbon level of 0.58%) and P is very limited.

Poultry manure (PM) produced from a layer farm at University for Development Studies (UDS), Tamale, Ghana, Nyankpala campus, and commercial sawdust compost (SC) and rice husk compost (RC) compost produced at UDS, Nyankpala campus were used as nitrogen based soil mixes. Rice husk biochar and sawdust biochar (used as carbon based mixes) were produced following the method of the Japan International Research Center for Agricultural Sciences (JIRCAS, 2010).

Experimental design and treatments

The treatment combinations was 8 × 2 (mixes × irrigation), resulting in a 16 treatment combinations with 4 replications in a completely randomized design (Table 2). The experiment was then set up in the glass house (at 37ºC), and the same set up was repeated in the pot house (at 30ºC). The 0.225 mm irrigation represents full irrigation and 0.1125 represents halve of the crop water requirement. The two temperature values are fairly representative of the average temperatures for the dry and wet seasons (respectively) in northern Ghana. Plastic pots of a top diameter of 25 cm, a bottom diameter of 15 m and a height of 20 cm were filled with good top soil after mixing with respective treatments.

Field management

The soil and compost were sieved through a 4 mm sieve prior to mixing. At the plant house, pots were given either 0.1125 or 0.225 mm depending on treatment at two days interval. At the glass house, pots were given either 0.1125 or 0.225 mm daily depending on the treatment). As a result of the higher temperature in the glass house, the media dried out faster and therefore the irrigation frequency was higher for the glasshouse environment. As shown in Table 1, soil texture and characteristics were also obtained using the hydrometer method (Milford, 1997). Each pot had three holes at the bottom to allow free drainage, however the pots were placed in plastic basins to aid leachate collection. Three weeks old *amaranthus* seedlings were transplanted into each pot containing the respective organic mixes and irrigation treatments.

Table 1. Properties of the soil used for the experiment.

pH (CaCl2)	C (%)	N (%)	P (mg/kg)	C/N	Sand (63-2000 µm)	Silt (2-63 µm)	Clay (<2 µm)
5.22±0.15	0.58±0.08	0.06±0.01	3.79±0.04	10.15±0.71	34.17±4.40	58.88±4.55	6.58±0.19

Table 2. Experimental layout at the glass house* (37°C).

Nutrient mix	Replication 1		Replication 2		Replication 3		Replication 4	
	Irrigation mm		Irrigation mm		Irrigation mm		Irrigation mm	
	0.1125	0.225	0.1125	0.225	0.1125	0.225	0.1125	0.225
Poultry manure (10 ton ha^{-1}) + Rice husk biochar (5 ton ha^{-1})	T1R1**	T9R1	T1R2	T9R2	T1R3	T9R3	T1R4	T9R4
Poultry manure (10 ton ha^{-1}) + sawdust biochar (5 ton ha^{-1})	T2R1	T10R1	T2R2	T10R2	T2R3	T10R3	T2R4	T10R4
Sawdust compost (10 ton ha^{-1}) + sawdust biochar (5 ton ha^{-1})	T3R1	T11R1	T3R2	T11R2	T3R3	T11R3	T3R4	T11R4
Rice husk compost (10 ton ha^{-1}) + rice husk biochar (5 ton ha^{-1})	T4R1	T12R1	T4R2	T12R2	T4R3	T12R3	T4R4	T12R4
Sawdust compost only (at 10 ton ha^{-1})	T5R1	T13R1	T5R2	T13R2	T5R3	T13R3	T5R4	T13R4
Rice husk compost only (at 10 ton ha^{-1})	T6R1	T14R1	T6R2	T14R2	T6R3	T14R3	T6R4	T14R4
NPK (400 kg ha^{-1})	T7R1	T15R1	T7R2	T15R2	T7R3	T15R3	T7R4	T15R4
Control (no nutrient added)	T8R1	T16R1	T8R2	T16R2	T8R3	T16R3	T8R4	T16R4

*Same set up was repeated at the pot house (30°C). **Treatments were completely randomised. The treatment code T1R1 means Treatment 1 in replication 1. Same description is applicable to the other codes.

Data collection

Plant heights and number of leaves were measured following the methods of Abubakari et al., 2012. Stem girth was also measured using electronic calipers. Relative chlorophyll content {Soil Plant Analysis Development (SPAD)} was measured every weeks using a Minolta chlorophyll meter (model SPAD 502). Volume of leachate was measured using a measuring cylinder. All the parameters were measured at four weeks after transplanting (WAT). Fresh leaf and fresh root weight were measured as an above ground and below ground biomass respectively using an electronic balance at the end of the growing season (6 weeks after transplanting. Dry leaf weight and dry root weight were determined after oven drying leaves and roots biomass for 24 h at 60ºC.

Water use efficiency was calculated using the following formula:

Water Use Efficiency = Mb/Cw (kg/m^3)

Where: WUE=water use efficiency, Mb=Sum of weight (dry weight) leaves, stems, roots in kg and Cw=cumulative amount of water applied (m^3).

Laboratory and data analysis

Total N was determined using the Kjeldahl digestion method (Okelabo et al., 1993). Organic C was determined by the modified Walkley-Black Wet oxidation method as outlined by Nelson and Sommers (1982). Phosphate was determined by the colorimetery method (Watanabe and Olsen (1965). EC was determined by inserting the Electrode of the EC meter into the compost sample suspension (Rowell, 1994). Crison Basic EC meter CM39P was used for the determination of EC. Crison Basic pH meter, PH29P was used for the determination of pH. The concentrations of nutrients in compost and in soil samples (nitrate nitrogen, ammonia nitrogen) were done using UV/VIS Spectrophotometer. Nitrate as nitrogen was determined by the Hydrazine Reduction Method (Cataldo et al., 1975). Ammonia as ammonia nitrogen was determined by the indophenol blue method (Koroleff, 1976). Chemical analysis of the compost and biochar was carried out before transplanting (Table 3). Genstat version 9.2 was used to carry out the ANOVA for the data generated.

RESULTS

Although there were no significant differences among treatments (p=0.064) lower plant height (13.55 cm) was obtained in the Control treatment supplied with 0.225 mm irrigation at 30°C (Table

Table 3. Quality of the compost, biochar and manure used for the experiment.

Quality	Compost		Biochar		Manure
	Sawdust	Rice husk	Sawdust	Rice husk	Poultry
Total Nitrogen (%)	2.46±0.09	1.68±0.27	0.17±0.02	0.38±0.02	4.37±0.28
Organic Carbon (%)	38.40±1.40	35.66±4.04	35.54±0.05	40.8±1.15	25.40±1.00
Phosphorus mg/L	64±0.08	45±0.01	42.77±0.01	43±1.0	105±0.03
NO_3-N (mg/kg)	1117.81±26.87	827.89±5.90	-	-	-
NH_4-N (mg/kg)	38.28±2.73	76.45±2.77	-	-	-
Carbon nitrogen ratio	15.76±4.33	19.31±2.11	209.05±15.55	107.36±1.2	5.58±1
pH	7.28±0.09	6.85±0.06	-	-	-
Electrical conductivity	3.80±0.27	3.19±0.11	-	-	-

Table 4. Effect of mixes and irrigation water on plant height (cm) at 4 weeks after transplanting.

Treatment	37°C		30°C	
	(0.1125 mm)	(0.225 mm)	(0.1125 mm)	(0.225 mm)
CONTROL	9.83	10.43	23.9	13.55
NPK	17.28	3.58	27.02	25.4
PM+RB	13.88	20.43	31.67	27.23
PM+SB	20.08	19.58	26.65	26.08
RC	20.05	19.55	26.97	21.3
RC+RB	21.55	18.7	31.10	25.65
SC	20.83	21.23	27.50	23.82
SC+SB	17.53	18.98	26.40	23.20
FPr	0.04		0.064	
LSD (5%)	7.6		4.157	

4). When the same treatment was supplied with 0.1125 mm of water, growth was 23.9 cm at same temperature of 30°C. At 37°C, the Control treatment gave significantly ($p=0.04$) the lowest plant height of 9.83 cm (with 0.1125 mm) and 10.43 cm (with 0.225 mm). At 30°C, Poultry manure amended with Rice husk biochar gave the highest plant height of 31.67 cm (with 0.1125 mm irrigation) and 27 cm (with 0.225 mm irrigation). Plant height under PM+RH was 13.88 cm and 20.43 cm (with 0.1125 mm and 0.225 mm, respectively) at 37°C. Rice compost mixed with Rice husk biochar gave similar plant height as the PM+RB at 30°C. There were no significant differences ($p=0.438$) in number of leaves among all treatments under 30°C. However, under 37°C, NPK treatment supplied with 0.225 mm irrigation was significantly lower ($p=0.02$) in plant height (3.25) than all other treatments (Table 5).

There were no significant differences ($p=0.058$) in stem girth for all treatments under 30°C. However, stem girth (0.82 cm) was significantly lowest ($p<0.001$) for NPK supplied with 0.225 mm irrigation under 37°C. Furthermore there were reduction in stem girth under 37°C for the Control and PM+RB supplied with 0.1125 mm irrigation (Table 6).

There were no significant differences ($p=0.726$) in SPAD meter values of treatments at 30°C. The application of NPK together with 0.1125 mm amount of irrigation water gave Significantly ($p=0.003$) the highest SPAD meter value (42.5%) and the same treatment with 0.225 mm amount of irrigation water gave significantly ($p=0.003$) the lowest SPAD value of 9.7% (Table 7).

The Control treatment supplied with 0.225 mm amount of irrigation water at 30°C gave significantly the lowest ($p=0.003$) Leaf area index (LAI) of 6.76 and NPK supplied with 0.225 mm irrigation gave significantly the highest LAI of 43 ($p=0.003$). The Control treatment supplied with 0.1125 mm and 0.225 mm amount of irrigation water and the NPK treatment supplied with 0.225 mm amount of irrigation water gave significantly the lowest ($p<0.001$) LAI of 2.84, 4.88 and 1.07 respectively under the 37°C. The NPK treatment (with 0.1125 mm) and the PM+RB (with 0.225 mm) gave significantly highest LAI at 37°C ($p=0.003$). All treatments except NPK gave a lower LAI with 0.1125 mm amount of irrigation at 37°C (Table 8).

Table 5. Effect of mixes and amount of irrigation on leaf number at 4 weeks after transplanting.

Treatment	37°C		30°C	
	(0.1125 mm)	(0.225 mm)	(0.1125 mm)	(0.225 mm)
Control	12.75	13.25	15.50	13.25
NPK	12.75	3.25	16.75	15.75
PM+RB	11.00	13.25	13.50	15.75
PM+SB	17.00	11.50	15.50	15.25
RC	12.50	13.50	15.75	14.75
RC+RB	14.00	14.00	14.75	14.75
SC	14.50	13.75	12.75	14.25
SC+SB	12.25	13.75	14.25	14.25
FPr	0.02		0.438	
LSD (5%)	4.984		2.874	

Table 6. Effect of mixes and amount of irrigation water on stem girth (cm) at 4 weeks after transplanting.

Treatment	37°C		30°C	
	(0.1125 mm)	(0.225 mm)	(0.1125 mm)	(0.225 mm)
Control	2.26	3.74	3.97	3.14
NPK	5.87	0.82	4.54	5.63
PM+RB	3.75	4.23	5.37	4.66
PM+SB	4.66	3.89	4.52	4.28
RC	4.71	5.2	4.44	4.72
RC+RB	4.36	4.52	4.49	3.86
SC	4.18	4.44	4.31	4.36
SC+SB	4.35	4.89	4.21	4.05
FPr	<.001		0.058	
LSD (5%)	1.697		0.8666	

Table 7. Effect of amendment and irrigation on leaf SPAD at 4 weeks after transplanting.

Treatment	37°C		30°C	
	(0.1125 mm)	(0.225 mm)	(0.1125 mm)	(0.225 mm)
Control	20.2	25.8	30.57	27.32
NPK	42.5	9.7	35.02	34.8
PM+RB	27.1	34.1	36.17	31.35
PM+SB	36.0	27.4	30.45	32.76
RC	31.9	28.3	27.22	26.35
RC+RB	28.5	30.5	30.02	29.25
SC	31.5	31.3	31.45	30.0
SC+SB	30.4	29.9	28.65	26.7
FPr	0.003		0.726	
LSD (5%)	13.24		5.346	

The NPK treatment gave significantly the highest fresh and dry leaf weight of 36 g (p=0.013 and 4.17 g (p=0.007) respectively at 30°C, but this value was lowered by almost two-thirds at 37°C. Poultry manure

Table 8. Effect of amendment and irrigation on LAI at 4 weeks after transplanting.

Amendment	37°C		30°C	
	(0.1125 mm)	**(0.225 mm)**	**(0.1125 mm)**	**(0.225 mm)**
Control	2.84	4.88	17.78	6.76
NPK	22.25	1.07	24.58	43.00
PM + RB	8.90	22.57	21.52	23.23
PM+SB	13.92	15.47	14.09	18.48
RC	13.64	17.98	25.34	17.94
RC+RB	12.52	14.26	17.07	13.56
SC	10.23	9.94	15.67	15.91
SC+SB	10.35	14.55	21.31	12.47
FPr	<.001		0.003	
LSD (5%)	8.073		9.875	

Table 9. Effect of amendment on fresh and dry leaf weight per plant (g) at harvest.

Amendment	37°C		30°C	
	Fresh weight	**Dry weight**	**Fresh weight**	**Dry weight**
Control	3.94	0.91	6.78	1.25
NPK	13.01	1.63	36.93	4.17
PM+RB	15.73	2.85	24.22	3.74
PM+SB	16.71	2.96	22.77	3.17
RC	13.65	2.7	18.26	2.50
RC+RB	10.76	2.2	11.85	1.86
SC	10.79	2.22	12.01	2.22
SC+SB	11.51	2.13	15.6	2.15
FPr	0.013	0.007	<.001	<.001
LSD (5%)	9.278	1.073	5.659	0.8001

mixed with sawdust biochar gave significantly the highest fresh leaf weight of 16.71 g (p=0.013) and dry leaf weight of 2.96 g (p=0.007) under 37°C. The fresh leaf, dry leaf, fresh root and dry root weight were not significant under the two irrigation regimes and hence the data is not presented (Table 9). Root weight was significantly highest (1.97 g), p<0.001 under PM+RB treatment and lowest (0.5 g) in the Control treatment at 30°C. At 37°C, fresh root weight was significantly highest (2.92 g) in the RC treatment and lowest (0.88 g) in the Control treatment (p<0.001). However, SC+SB treatment gave significantly (p<0.001) highest dry root weight (0.76 g) with NPK treatment recording the lowest dry root weight of 0.18 g (Table 10).

At 30°C Poultry manure mixed with sawdust biochar with 0.225 irrigation, gave a volume of leachate (123.2 ml) significantly higher (p<0.001) than the Control (65.9 ml), NPK (48.2 ml) and Rice husk compost (54.7 ml. At 37°C, Sawdust compost with 0.225 mm of irrigation, gave a volume of leachate (166.1 ml) significantly higher than NPK, PM+RB, PM+SB, RC and SC+SB treatments. At 37°C, NPK treatment with 0.1125 mm amount of irrigation water, significantly (p<0.001) gave the lowest volume of leachate of 5.9 ml (Table 11). At 30°C, NPK and PM+RB treatments gave significantly (p<0.001) the highest water use efficiency of 600 kg m^{-3} each. At 37°C, the Control treatment and NPK treatment gave significantly the lowest water use efficiency of 90 kg m^{-3} and 100 kg m^{-3} respectively (Table 12).

DISCUSSION

The compost used for the study had good qualities compared to compost produced elsewhere (Leconte et al., 2009). The soil used for the study is generally low in N, organic carbon and is slightly acidic and hence needed aditional inputs of N and C (Abubakari et al., 2011; Abubakari et al., 2012). Other studies reported that compost and biochar have ameliorating effect on poor soils and that plant growth and nutrient uptake were enhanced by addition of organic materials to soils (Brito et al., 2014; Agegnehu et al., 2015). According to Schulz et al. (2014) addition of compost to soils increases the pH

Table 10. Effect of amendment on fresh and dry root weight per plant (g) at harvest.

Amendment	37°C		30°C	
	Fresh weight	Dry weight	Fresh weight	Dry weight
Control	0.88	0.26	0.50	0.26
NPK	1.48	0.18	1.91	0.49
PM+RB	2.64	0.59	1.97	0.54
PM+SB	2.36	0.54	1.56	0.51
RC	2.92	0.74	1.27	0.61
RC+RB	2.31	0.58	1.22	0.41
SC	1.84	0.45	1.10	0.47
SC+SB	2.37	0.76	1.29	0.47
FPr	<.001	<.001	<.001	0.143
LSD (5%)	0.849	0.24	0.6171	0.2311

Table 11. Effect of amendment on volume of leachate per pot (ml) 2-4 weeks after transplanting.

Amendment	37°C		30°C	
	(0.1125 mm)	(0.225 mm)	(0.1125 mm)	(0.225 mm)
Control	16.3	135.0	10.9	65.9
NPK	5.9	115.8	11.8	48.2
PM+RB	45.1	57.0	13.2	95.3
PM+SB	42.3	102.5	14.1	123.2
RC	13.2	64.1	19.7	54.7
RC+RB	32.8	135.3	15.7	119.9
SC	19.4	166.1	25.1	99.4
SC+SB	17.7	113.6	11.9	109.9
FPr	<.001		<.001	
LSD (5%)	34.10		20.41	

Table 12. Effect of amendment on water use efficiency of *amaranthus*.

Amendment	37°C	30°C
	Water use efficiency (kg m^{-3})	Water use efficiency (kg m^{-3})
Control	90	200
NPK	100	600
PM+RB	250	600
PM+SB	220	450
RC	170	340
RC+RB	200	310
SC	240	440
SC+SB	210	360
FPr	0.006	<.001
LSD (5%)	0.0923	0.1398

and makes nutrient.

Although the Control treatment gave the lowest plant height, leaf number, stem girth and SPAD meter value, treatment effects was not significant for these parameters at 30°C. At 30°C and with 0.1125 mm of irrrigation, poultry manure + rice husk biochar, rice husk compost + rice husk biochar and sawdust compost increased plant height by 32.4, 30, and 15%, respectively compared to

13% for NPK. However, at 37°C plant height decreased by compared to the control, the increament in plant height were 41.1%, 119.1%, 111.8% and 75.7 for poultry manure + plus rice husk biochar, rice husk compost plus rice husk biochar, sawdust compost and NPK respectively. NPK treamtments receiving 0.225 mm amount of irrigation water had significantly lowest plant height and number of leaves at 37°C. As NPK treatment receiving the 0.225 mm irrigation also had significantly higher volume of leachate as shown in Table 11, leaching of nutrients at higher temperature could have contributed to the poor performance of the NPK treatment. Combine use of compost and biochar is been reported to be more beneficial (Fischer and Glaser, 2012; Schulz and Glaser, 2012). Optimum use of compost and biochar improves nutrient and water retention (Liu et al., 2012). Use of organic amendents has also been shown to decreased volume of leachate and cumulative leaching volume was found to be inversely related to the above and below ground biomasss. Treatment effects on LAI index was significant at both 30 and 37°C. NPK gave significantly, the lowest LAI at 0.225 mm irrigation at 37°C, although it gave significantly highest LAI at 30°C. PM+RB which gave the lowest volume of leachate at 0.225 mm irrigation at 37°C, gave significantly the highest LAI under the same conditions.

The effect of the treatments on yield follows the same pattern as observed for growth parameters, with NPK showing significantly highest fresh and dry weight of leaves at 30°C. However, at 37°C, plant height increased 298.2%, 323%, 172.5% and 173.3 for PM+SB, PM+RB, RC+RB and SC respectively. This suggests addition of biochar to manure plays a significant role in reducing leaching and promoting yield of *amaranthus* (Agegnehu et al., 2015). It also suggests that addition of biochar will help when there is a rise in temperature due to climate change. Similar results were obtained for fresh and dry root weight at 30 and 37°C, but with PM+RB recording the highest fresh root weight. Root development appear to be generally higher at higher temperature (37°C) than at lower temperature (30°C), and addition of biochar appears to promote growth and yield high temperature. Water use is more efficient at 30°C, and NPK treatment is best in water utilization for higher productivity than organic treatments at this temperature. However, at 37°C, NPK treatment had poor water use efficiency and organic amendments especially poultry manure and rice husk biochar and sawdust compost are better in WUE.

Conclusion

The results suggest combination of nitrogen and carbon rich organic materials at appropriate irrigation levels have profound effect on plant growth and development especially under different temperature conditions. At lower temperatures inorganic fertilizers are very important in promoting growth yield. However, at higher temperatures organic materials rich in N (especially poultry manure) and C (sawdust biochar) are critical in retaining water and nutrients, promoting root develpment and enhancing fresh leaf weight of *amaranthus*. Although the organic materials rich in N and C gave higher volume of leachate under higher temperatures, the slow nutrient release potential could have reduced nutrient leaching. Therefore,at higher temperature as is the case in most Savanna areas of Northern Ghana where this experiment was conducted or as may occur in other areas due to climate change and rising temperatures, N rich materials such as poultry manure, rice husk compost, sawdust compost and the addition of C rich matrials (such as sawdust biochar) could be used to sustain growth and yield of *amaranthus*. The results also suggest that at higher temperatures and with full irrigation as typified by the application of 0.225 mm irrigation root development could be sustained by the use of rice husk compost amended with rice husk biochar.

Conflict of Interest

The authors have not declared any conflict of interests.

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