Ameliorative roles of compost on okra (*Abelmoschus esculentus* L.) exposed to drought stress at vegetative and reproductive growth stages

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Abstract

Okra growth and yield are adversely affected by drought at different growth stages. This is aggravated by poor soil fertility. In this study, the roles of compost applied at 0, 5 and 10 t/ha on the tolerance and morpho-physiological response of okra (NHAe 47-4) exposed to varying levels of water stress (25%, 50%, 75% and 100% field capacity, FC), at different growth stages (vegetative, reproductive and vegetative-reproductive stages) for ten days duration were assessed. Data were collected on okra growth and yield, leaf relative water content (LRWC), leaf photosynthetic pigments (LPG) and proline accumulation. Results showed that drought stress reduced LRWC, LPG, growth and yield of Okra. This reduction was more evident in okra plants exposed to severe stress for 10 days and at the reproductive stage. Soil amendment with compost however, had cushioning effect on drought stressed okra. Compared to control, it increased the LRWC, LPG, growth and yield of okra. The ameliorative roles of compost were however, dependent on stress intensity, compost dosage, okra growth stage and stress duration. Though, okra plants stressed at 25% FC were more affected by drought stress, but compared to the un-amended soil, those grown on amended soil were more tolerant. Higher compost rate was superior to lower rates. Whereas, higher proline accumulation was recorded in plant exposed to 25% field capacity without amendment, proline accumulation was reduced in the plants grown on compost amended soil and exposed to drought which was an indication of stress reduction. Generally, okra stressed at vegetative growth stage only was able to recover rapidly and had better yield compared to those stressed at reproductive growth stage. It is concluded that addition of compost to soil could reduce the drought stress effect on okra.

Keywords: drought; organic amendments; osmolytes; oxidative stress; photosynthetic pigments; vegetables

Introduction

Plants being sessile face a lot of challenges trying to escape from adverse environmental conditions on the field. These conditions impose stress on the plant which in turn affect their growth and development. Stress is an altered physiological condition which is caused by unfavourable environmental conditions that are capable of disrupting the plant metabolic activities and equilibrium (Jaleel *et al.*, 2009; Wahsha *et al.*, 2012). These unfavourable environmental conditions could be biotic or abiotic in nature. Among the abiotic, drought is one of the major factors that determine the success of crop production (Gamze *et al.*, 2005). Changes in the water

balance and the amount of water available in soil are crucial for crop growth and development (Fuhrer, 2003; Krouma, 2010). Substantial reduction in the plant growth and yield due to water stress has been reported (Burke, 2007; Manivannan *et al.*, 2008; Jalal *et al.*, 2012; Hayatu *et al.*, 2014; Adejumo *et al.*, 2018). Severe drought stress induces production of reactive oxygen species which might in turn degrade the cell biomolecules (Lawlor and Cornic, 2002).

To survive the period of adverse environmental conditions, crop plant responds by redirecting the metabolic processes to the production of osmo-protectants such as proline, glycine betaine and glutathione (Hasanuzzaman *et al.*, 2018). These help in maintaining the cell homeostasis and chemical balance (Hossain *et al.*, 2012). Among these chemical substances called osmo-protectants, proline production by plant in the face of different environmental challenges has been widely reported (Heuer, 1999; Hossain *et al.*, 2012). It plays different roles in plant stress adaptation by enhancing oxidative stress tolerance (Tsegay and Andargie, 2018). Drought most especially has been found to induce the production of proline in different crops (Adejumo *et al.*, 2018; Hasanuzzaman *et al.*, 2018). Increase in proline content was also reported in plants growing on heavy metal contaminated soil (Adejumo *et al.*, 2015).

The damage caused by drought and crop response however, depend on stress intensity, duration, crop species, soil health conditions and crop growth stage. Among these, soil health conditions in term of nutrient status and organic matter content determine the level of tolerance and adaptability to different environmental stresses including drought. Soil health which is a factor of soil nutrient status directly affects plant health most especially under unfavourable weather conditions. This is because a well-fed crop is likely to tolerate and withstand adverse conditions than the crop grown on low nutrient soils. Similarly, soil organic matter plays a pivotal role in enhancing soil texture and structure which will in-turn increase water retention ability of the soil.

Organic fertilizers like poultry manure, cow dung and compost have been used by farmers to supplement the soil organic matter deficiencies in order to improve soil health and increase crop yield. Decomposing plant residues are reported to release substantial levels of nutrients and organic matter into the soil (Yih-Chi *et al.*, 2009). Compost made from materials of plant and animal origin has been found to increase the yield of crops grown on nutrient depleted or deficient soil (Rennevan *et al.*, 2008; Adejumo *et al.*, 2010; Fleming *et al.*, 2010). Apart from improving the soil fertility, it has also been reported to enhance crop growth on heavy metal contaminated soils by ameliorating the effect of heavy metals on crop (Rennevan *et al.*, 2007; Fleming *et al.*, 2010; Adejumo *et al.*, 2013). However, the physiological mechanisms for drought stress tolerance in crop at different growth stages and the roles of organic manure in alleviating drought induced damage in crop need to be well elucidated for the purpose of enhancing crop yield under environmental stresses and to adapt the crop to climate change. Previously, we reported the adverse effect of longer duration of severe water stress on crop most especially at reproductive stage (Adejumo *et al.*, 2018), the objective of the study therefore was to determine the roles of organic amendment in drought tolerance response of okra exposed to water deficit at various growth stages. Application of organic amendment for optimum crop yield in the face of changing climatic conditions will be a promising approach for adapting to climate change and increasing crop tolerance to environmental stresses.

Materials and Methods

The experiment was conducted at the screen house of the Department of Crop Protection and Environmental Biology, University of Ibadan, Nigeria. The soil used for the experiment was sandy-loam with high proportion of sand (79.2%). The bulk density was 1.6 g/cm³ and the field capacity was 11.6% on gravimetric basis. Chemical analysis of the soil showed that the soil was slightly acidic with pH of 5.24 in water and 5.01 in KCl. The organic matter, total nitrogen and available phosphorus were 23.2 g/kg, 2.4 g/kg and 43.69 mg/g respectively while, the micro nutrients were 94.23 mg/g of Mn, 80.11 mg/g of Fe, 2.92 mg/g of Cu

and 63.11 mg/g of Zn (Adejumo *et al.*, 2018). Compost was made from Mexican sunflower (*Tithonia diversifolia*) and poultry manure. The materials were laid out in ratio 3:1 of plant materials to poultry manure (on dry weight basis) after sorting and chopping using Partially Aerated Composting Technique (PACT-2) as described by Adediran *et al.* (2006).

Experimental procedures

Local cultivar of okra seed (NHAe 47-4) sourced from National Horticultural Research Institute (NIHORT), Ibadan was used. The experiment was laid out in a completely randomised design (CRD) with thirty (30) treatments as shown below and replicated three (3) times. Okra plants were stressed at the vegetative stage, reproductive stage and combination of vegetative and reproductive stages across four different field capacities, FC, (i.e. 25%, 50%, 75% and 100% FC) and three levels of organic amendment (0 t/ha, 5 t/ha and 10 t/ha). The treatments acronyms are as shown below in Table 1.

Table 1. The acronyms used for the experimental treatments

Stress stages	25% FC without compost	25% FC with 5 t/ha compost	25% FC with 10 t/ha compost	50% FC without compost	50% FC with 5 t/ha compost	50% FC with 10 t/ha compost	75% FC without compost	75% FC with 5 t/ha compost	25% FC with 10 t/ha compost
Vegetative stage	$SV_{25}C^\circ$	$SV_{25}C^5$	$SV_{25}C^{10}$	$SV_{50}C^\circ$	$SV_{50}C^5$	$SV_{50}C^{10}$	$SV_{75}C^\circ$	$SV_{75}C^5$	$SV_{75}C^{10}$
Reproductive stage	$SR_{25}C^\circ$	$SR_{25}C^5$	$SR_{25}C^{10}$	$SR_{50}C^\circ$	$SR_{50}C^5$	$SR_{50}C^{10}$	$SR_{75}C^\circ$	$SR_{75}C^5$	$SR_{75}C^{10}$
Vegetative and reproductive stages	$SVR_{25}C^\circ$	$SVR_{25}C^5$	$SVR_{25}C^{10}$	$SVR_{50}C^\circ$	$SVR_{50}C^5$	$SVR_{50}C^{10}$	$SVR_{75}C^\circ$	$SVR_{75}C^5$	$SVR_{75}C^{10}$
No stress	$100FC^\circ$	$100FC^5$	$100FC^{10}$						

SV - stress at vegetative stage; SR - stress at reproductive stage; SVR - stress at vegetative and reproductive stages; C°, C^5 and C^{10} – dosage of compost.

Planting of okra and treatment imposition

Prior to planting of okra seeds, compost dosage relative to corresponding treatment was incorporated into the soil two weeks before planting. Three seeds were sown into each pot and were irrigated regularly to 100% field capacity (FC) for two (2) weeks. At two weeks after sowing, the seedlings were thinned to one seedling per pot. Drought stress was achieved by decreasing irrigation water gradually during 4 days. Soil moisture probe (tensiometer) was used to determine the percentage moisture content of the pots and this was used to determine the quantity of water needed to keep the pots at the corresponding field capacities. Drought stress was imposed at 18 DAS and 46 DAS (days after sowing) for vegetative and reproductive stresses, respectively. For the vegetative stress, drought was imposed on plants to be stressed at vegetative stage only by starving it for 10 days while unstressed plants were watered regularly. Similarly, drought was imposed on plants to be stressed at reproductive stage only by starving it for 10 days while other unstressed plants were given full irrigation. The unstressed plants were irrigated at 48 hours intervals to 100% field capacity.

Data collection

Growth and yield parameters

Data were collected fortnightly on vegetative parameters such as plant height, number of leaves and leaf area. Leaf area was estimated using graphical method as described by Adejumo *et al.* (2018).

Leaf area = $\dfrac{\textit{number of holes X 4mm}^2}{\textit{100}}$

Enlargement quotient was calculated by the formula $A = eL^2$, where A = leaf area, e = enlargement quotient and L = length of midrib (Abdullahi and Jasdanwala, 1991). The enlargement quotient for NIHORT

NHAe 47-4 was 0.936542. Leaf area dimension was recorded fortnightly and mean value estimated. Leaf area measurement was in centimetre square (cm²).

Leaf relative water content

This was determined at vegetative and reproductive stages of water stress, by cutting top-most fully expanded leaves. Leaf relative water content (LRWC) was evaluated using the formula proposed by Slavick (1979).

LRWC (%) = $\frac{(FW - DW)}{(TW - DW)} \times \mathbf{100}$

Where, LRWC = leaf relative water content, FW = fresh weight, DW = oven-dried weight, TW = turgid weight.

Chlorophyll, carotenoid and porphyrins estimation

These were determined during vegetative and reproductive stress stages following the procedure described by Sarroupulou *et al.* (2012). Briefly, 0.1 g of fresh leaves was taken from each plant and boiled in 15 mL of 96% (v/v) ethanol in a water bath at a temperature of 79.8 ºC for three hours. The absorbance of chlorophyll a and b was measured at 665 nm and 649 nm respectively, carotenoid at 440 nm. Total porphyrins, absorbances were determined at 575, 590 and 628 nm, which are the absorption peaks for protoporphyrin, magnesium-protoporphyrin and proto-chlorophyllide, respectively using UV/VIS Spectrophotometer (Spectrumlab 752s, Ningbo, China).

Proline estimation

Proline was estimated in okra leaves according to Bates *et al.* (1973) using UV/VIS Spectrophotometer (Spectrumlab 752s, Ningbo, China) and was measured at 520 nm. Proline concentration on fresh-weight basis was calculated as follows:

μ Moles per g tissue = $\frac{\mu g \text{ proline per ml x ml of toluene}}{115.5} \times \frac{5}{g \text{ sample}}$

Yield and dry matter determination

At maturity fresh okra fruits were harvested at three (3) days interval, weighed and recorded for fruit yield determination. For estimation of dry matter yield, the whole plant in each pot was harvested at 12 WAS (weeks after sowing). The okra plant was partitioned into root and shoot while the fresh weight was taken and recorded before oven-drying at a temperature of 80 ºC for 96 hours and the dry weight taken after cooling the samples to room temperature.

Data analysis

Data were analysed using analysis of variance of the SPSS (ver. 23, SPSS Inc, Chicago, IL). Interactions with significance were used to explain the results. For interactions not significant, means were separated using least significant difference.

Results

Effect of interaction of water regime, treatment stage and compost dosage on leaf relative water content (LRWC)

Generally, water deficit significantly reduced the growth and yield of plants stressed at both stages of growth compared to control. Compost however, increased growth and yield of okra plants compared to control (okra grown on un-amended soil) except in severe stress condition (i.e. 25% FC) where the cushioning effect of compost was minimal. The leaf relative water content (LRWC) at week 4 was affected by water deficit,

especially in okra exposed to severe water stress of 25%. At 4 WAS, there was a reduction in this treatment irrespective of the compost treatment compared to other treatments and control. Those stressed at vegetative stage had reduced LRWC but compost addition increased the LRWC compared to the control especially in those that were to be stressed at reproductive stage (Figure 1). The effect of compost on LRWC at 4 weeks after planting was generally not significant compared to LRWC at 8 weeks after sowing under severe stress. At this sampling period (8WAS), those that received water deficit treatment at vegetative stage had recovered and had greater value of LRWC compared to those stressed at reproductive stage and at both stages. The lowest values were still recorded in the okra that received 25% FC (Figure 2).
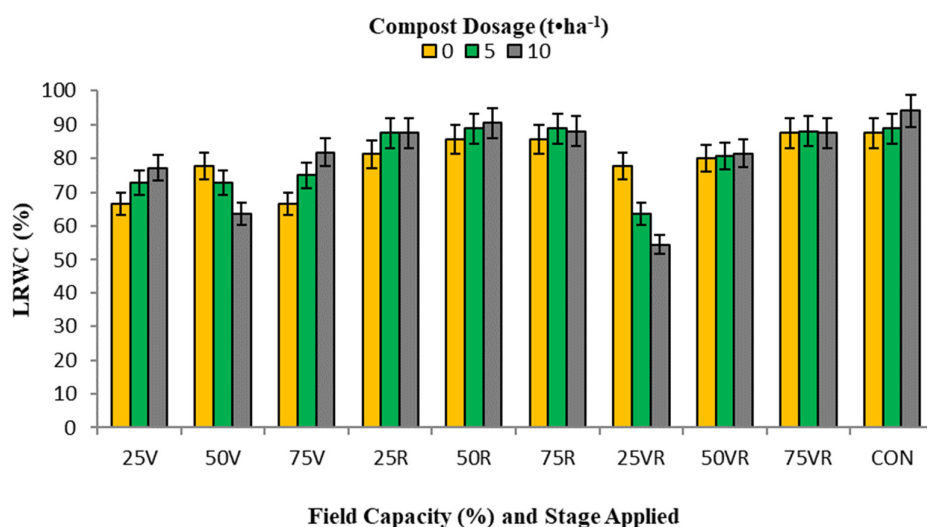
Figure 1. Effect of interaction of water regime, treatment stage and compost dosage on leaf relative water content (LRWC) at 4 weeks
The 25, 50 and 75% represent field capacity; V (vegetative), R (reproductive), and VR (vegetative and reproductive) represent the stage at which the deficit was applied. Data in the interaction analyzed with Least Squares Means, and means separated with LSD
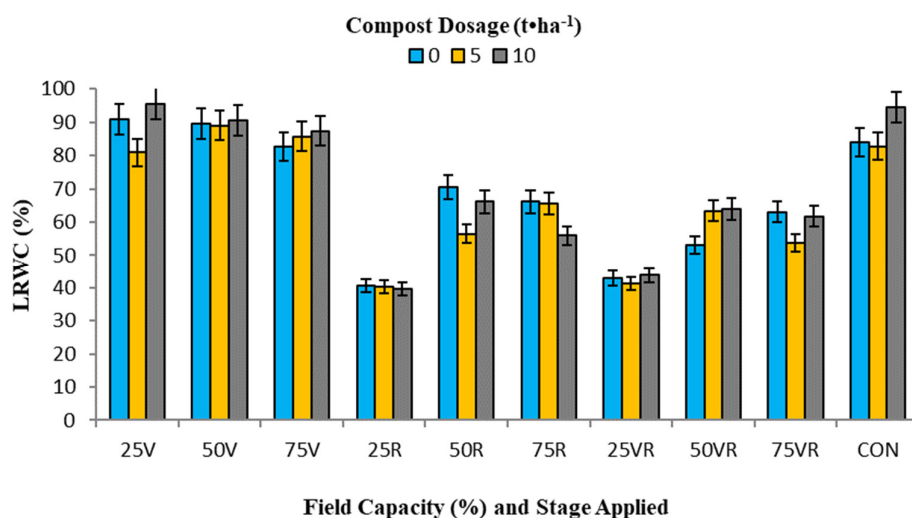

Figure 2. Effect of interaction of water regime, treatment stage and compost dosage on leaf relative water content (LRWC) at 8 weeks.
The 25, 50 and 75% represent field capacity; V (vegetative), R (reproductive), and VR (vegetative and reproductive) represent the stage at which the deficit was applied. Data in the interaction analyzed with Least Squares Means, and means separated with LSD.

Effect of water deficit and stage of exposure and compost treatments on okra vegetative growth

The plant height was reduced under 25% FC especially in okra plants exposed to water stress at vegetative stage only and at both vegetative and reproductive stages compared to those stressed at reproductive stage only and control (Figure 3). Plant height however, increased in okra under compost treatments with higher compost rate performing better than lower rates. Compost application of 10 t/ha had better performance relative to 5 t/ha of compost in all the watering regimes, but no significant difference was recorded at both vegetative and reproductive stages of stress (Figure 4). As observed for LRWC, the effect of compost on plant height at 4 weeks was not significant compared to that of 8 weeks. Treatments without compost amendment recorded lower plant height. The effect was more pronounced in the 100 and 75% FC and 10 t/ha gave the highest value compared to lower rates (Figure 5). The leaf area at 4 weeks sampling period was the highest in okra plants that were to be stressed at reproductive stage while the lowest was recorded under 25% FC and stressed at vegetative stage (Figure 6). On the cumulative effect of compost application on leaf area at 8 weeks, higher compost rate enhanced leaf area production in the stressed plant compared to control (Figure 7). The lowest leaf area value was however recorded for the plant exposed to 25% FC (Figure 8). The okra plant stressed at vegetative stage only had the highest leaf area compared to other growth stages while the lowest was recorded in those stressed at both stages (Figure 9).
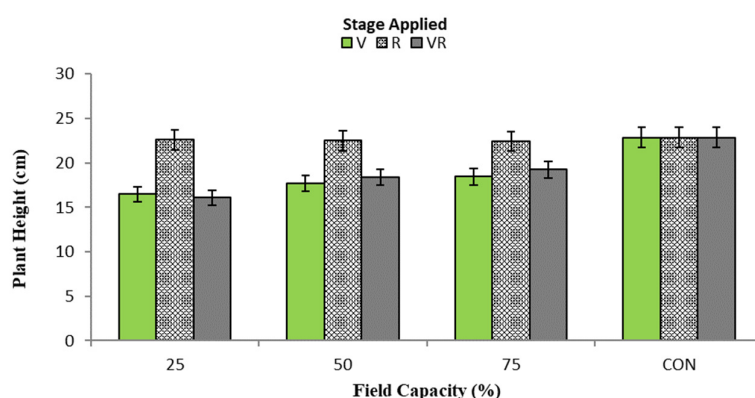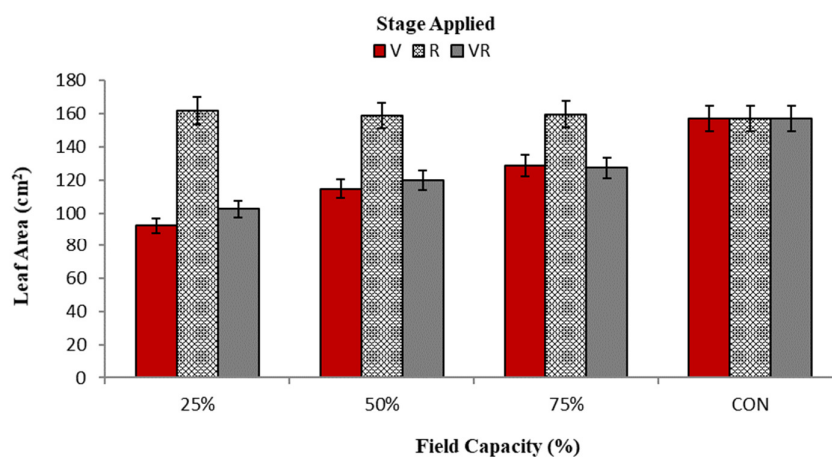

Figure 3. Effect of water deficit and treatment stage on plant height of okra at 4 weeks
V (vegetative), R (reproductive), and VR (vegetative and reproductive) represent the stage at which the deficit was applied. Data in the interaction analysed with Least Squares Means, and means separated with LSD.
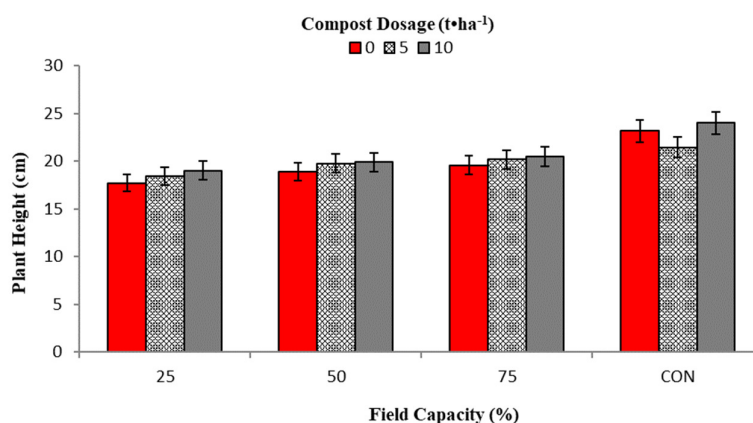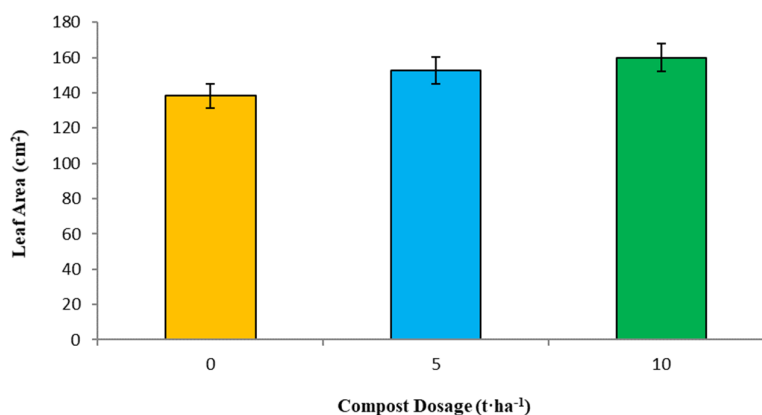

Figure 4. Effect of water deficit and compost dosage on plant height of okra at 4 weeks
0, 5 and 10 represent compost dosage. Data in the interaction analysed with Least Squares Means, and means separated with LSD.
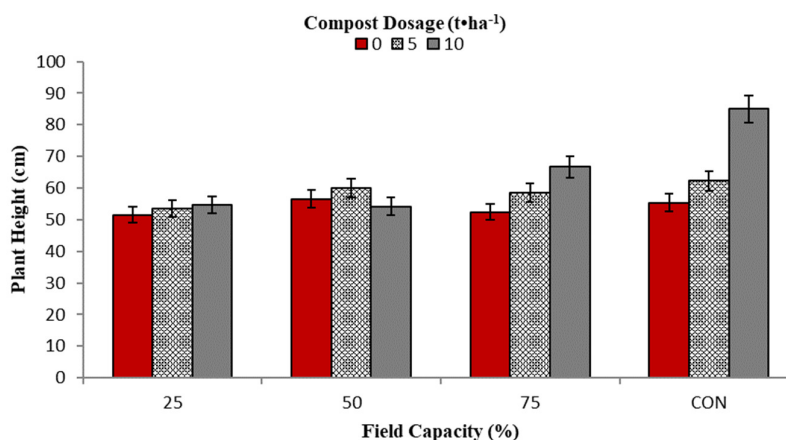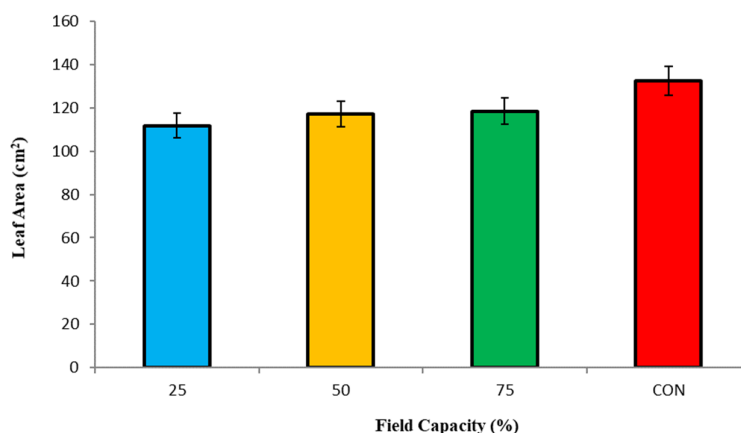
Figure 5. Effect of water deficit and compost dosage on plant height of okra at 8 weeks
0, 5 and 10 represent compost dosage. Data in the interaction analysed with Least Squares Means, and means separated with LSD.
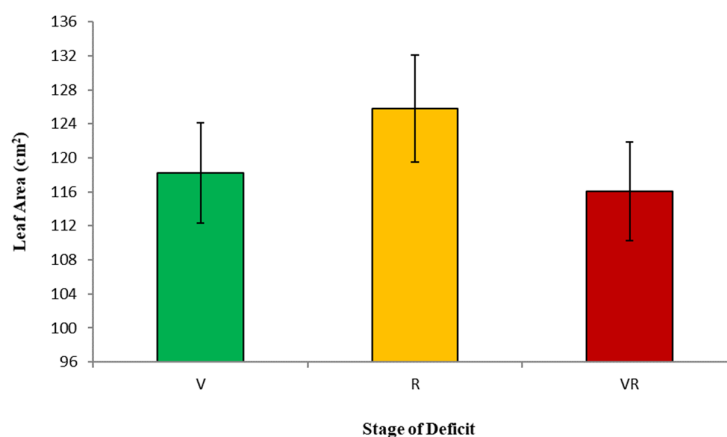

Figure 6. Effect of water deficit and treatment stage on leaf area of okra at 4 weeks
V (vegetative), R (reproductive), and VR (vegetative and reproductive) represent the stage at which the deficit was applied. Data in the interaction analysed with Least Squares Means, and means separated with LSD.

Figure 7. Effect of compost dosage on leaf area of okra at 8 weeks. 0, 5 and 10 represent compost dosage
Data in the interaction analysed with Least Squares Means, and means separated with LSD.

Figure 8. Effect of water deficit on cumulative mean leaf area of okra
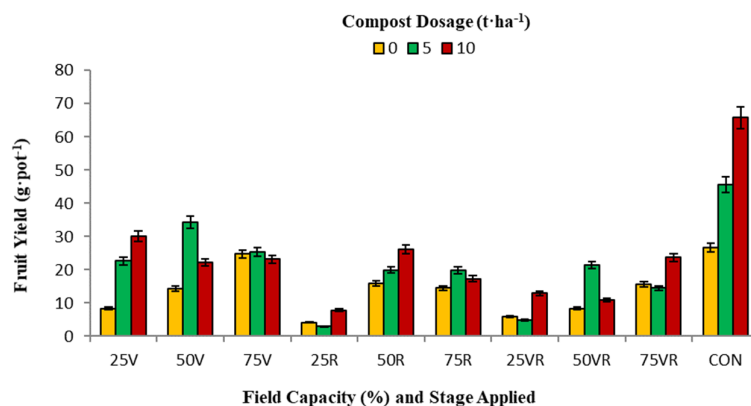Data in the interaction analysed with Least Squares Means, and means separated with LSD

Figure 9. Effect of treatment stage on cumulative mean leaf area of okra
V (vegetative), R (reproductive), and VR (vegetative and reproductive) represent the stage at which the deficit was applied. Data in the interaction analysed with Least Squares Means, and means separated with LSD.

Effect of interaction of water regime, treatment stage and compost dosage on fruit yield and biomass accumulation of okra

Water stress significantly decreased the fruit yield of all stressed plants and the level of yield reduction was dependent on stress severity and stage of stress imposition. Stress at reproductive growth stage considerably caused fruit yield reduction, but compost addition increased fruit yield especially with higher rate (10t/ha) relative to plants grown without compost. The effect of compost on fruit yield was more pronounced compared to the growth parameters and higher compost rate enhanced fruit production in all the treatments. Though, control (100% FC) had the highest fruit yield, but addition of compost enhanced fruit production in all stressed okra compared to the un-amended treatment (0t/ha). The severe water stress of 25% FC at reproductive stage reduced the fruit production in okra while the lowest was recorded under 0t/ha while there was about 276% increase in fruit production under this water regime in those stressed at vegetative stage only and 116% increase in those stressed at both stages with the addition of 10t/ha compost. Compost treatment also enhanced fruit production in okra plant that received drought treatment at vegetative stage only. For instance, severe drought stress of 25% FC at vegetative stage only ($SV_{25}C°$, $SV_{25}C^5$ and $SV_{25}C^{10}$) increased fruit yield and recorded higher yield relative to other plants that were stressed at reproductive growth stage under same stress condition (i.e. 25% FC) (Figure 10). Similar to fruit yield, though, there was a general reduction in

biomass accumulation compared to control treatment (100% FC). Biomass accumulation was also enhanced with compost application under drought stress with 10 t/ha being superior.
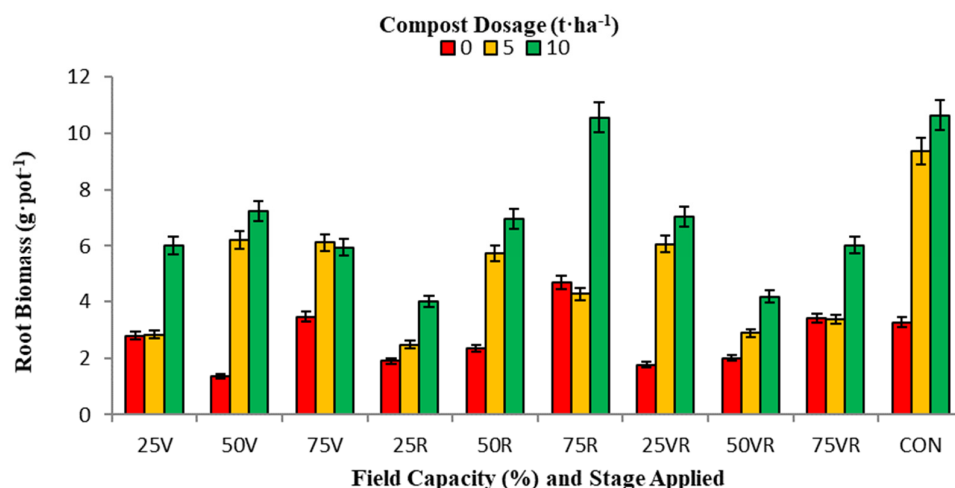

Figure 10. Effect of interaction of water regime, treatment stage and compost dosage on fruit yield of okra
The 25, 50 and 75% represent field capacity; V (vegetative), R (reproductive), and VR (vegetative and reproductive) represent the stage at which the deficit was applied. Data in the interaction analysed with Least Squares Means, and means separated with LSD.

Biomass accumulation in the shoot was enhanced by compost amendment and higher rate was better than lower rates. The stage of exposure had greater impact on the biomass accumulation and the okra plant exposed only at reproductive stage had higher biomass accumulation in the shoot. The effect of severe water deficit at reproductive stage only and those exposed at both stages was reduced with the addition of 10t/ha compost to the soil. The response was better in those stressed at this stage compared to that of vegetative stage. Moderate water stress at 50 and 75% FC however, responded positively to compost addition more than 25% FC (Figure 11). The root biomass also increased with increasing compost treatment especially at the lowest field capacity of 25% FC and for all stages. Addition of compost enhanced root biomass production compared to control in all the water regimes with higher rate performing better than lower rate. Variations were observed in other treatments and there was significant reduction in control plants compared to the stress treatment. At moderate water stress as observed under shoot biomass, the addition of compost significantly reduced the effect of water deficit stress (Figure 12).
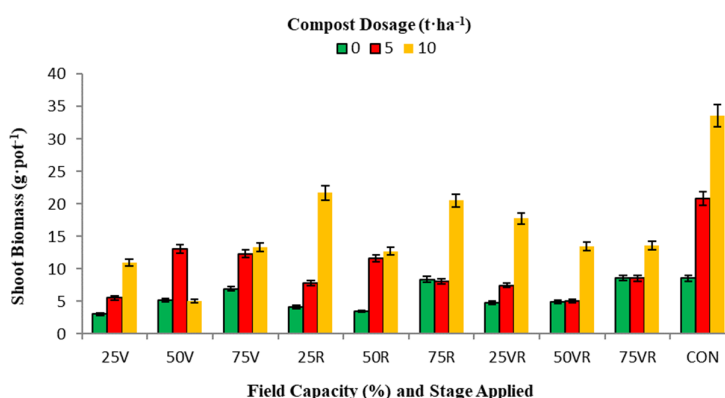
Figure 11. Effect of interaction of water regime, treatment stage and compost dosage on shoot biomass of okra
The 25, 50 and 75% represent field capacity; V (vegetative), R (reproductive), and VR (vegetative and reproductive) represent the stage at which the deficit was applied. Data in the interaction analysed with Least Squares Means, and means separated with LSD.
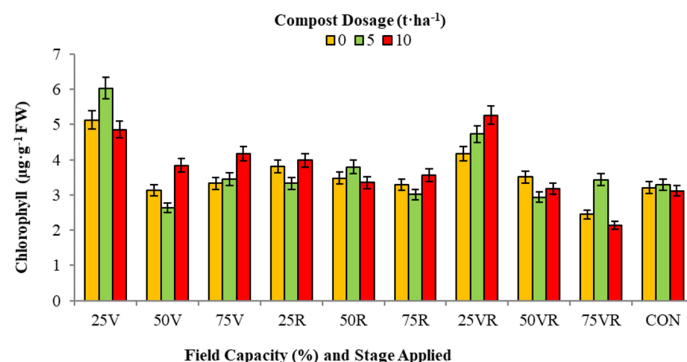
Figure 12. Effect of interaction of water regime, treatment stage and compost dosage on root biomass of okra
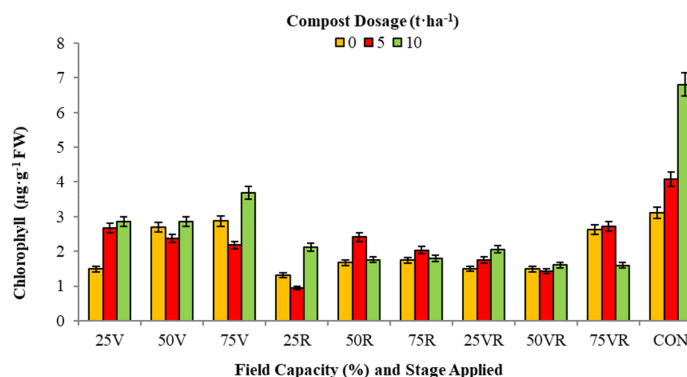
The 25, 50 and 75% represent field capacity; V (vegetative), R (reproductive), and VR (vegetative and reproductive) represent the stage at which the deficit was applied. Data in the interaction analysed with Least Squares Means, and means separated with LSD.

Effect of interaction of water regime, treatment stage and compost dosage on chlorophyll content of okra leaf

Surprisingly, at 5 weeks after planting, unlike what was observed for other parameters, exposure to water deficit stress at vegetative stage only and at both vegetative and reproductive stages under 25% FC enhanced chlorophyll production in okra leaf compared to other treatments including control whereas, drought stress at reproductive stage, decreased the total chlorophyll content. Stress at vegetative stage increased the chlorophyll level in these severely stressed plants relative to control and plants that were to receive drought treatment at reproductive stage. Compost amendment however increased the chlorophyll content than untreated plant (0t/ha). Meanwhile, at 8 weeks after planting, there was a general reduction in the chlorophyll contents compared to the control and those treated with 10 t/ha compost had the highest chlorophyll content at this sampling period. The reduction in chlorophyll content was more pronounced in those exposed to water deficit at reproductive stage only and at both stages. (Figures 13 and 14). At the vegetative stage, the concentration of carotenoid in the leaf tissues was more in okra plants exposed to 75% FC at V stage only followed by that of 50% FC at VR stage. At this stage the carotenoid content was low irrespective of organic amendment but this was reversed at reproductive growth stage. At 8 weeks after planting, the carotenoid content was more in 75% FC but there was an increase as compost rate increased (Figures 15 and 16). Relative to 50% and 75% FC irrigation regimes, okra plant stressed at 25% FC for ten days at vegetative stage had the highest porphyrin content as observed for chlorophyll. The mechanism for this is not well understood since the total porphyrin and chlorophyll levels are expected to decrease under stress condition. Addition of compost was found to increase the total porphyrin level especially in vegetatively stressed plants that had compost incorporated into their soil under severe drought stress (25% FC) (Figures 17 and 18).
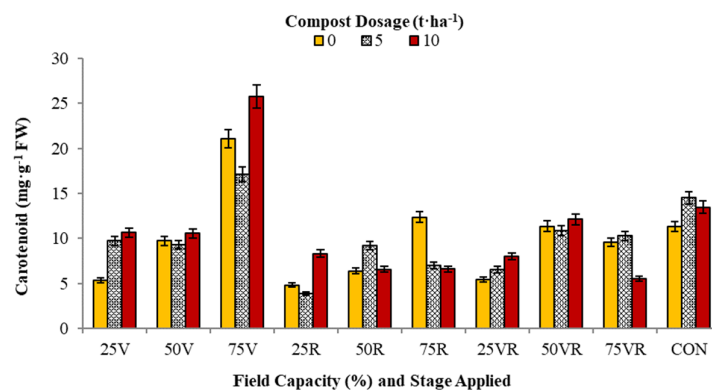
Figure 13. Effect of interaction of water regime, treatment stage and compost dosage on chlorophyll content of okra leaf at 5 weeks

The 25, 50 and 75% represent field capacity; V (vegetative), R (reproductive), and VR (vegetative and reproductive) represent the stage at which the deficit was applied. Data in the interaction analysed with Least Squares Means, and means separated with LSD.

Figure 14. Effect of interaction of water regime, treatment stage and compost dosage on chlorophyll content of okra leaf at 8 weeks

The 25, 50 and 75% represent field capacity; V (vegetative), R (reproductive), and VR (vegetative and reproductive) represent the stage at which the deficit was applied. Data in the interaction analyzed with Least Squares Means, and means separated with LSD.
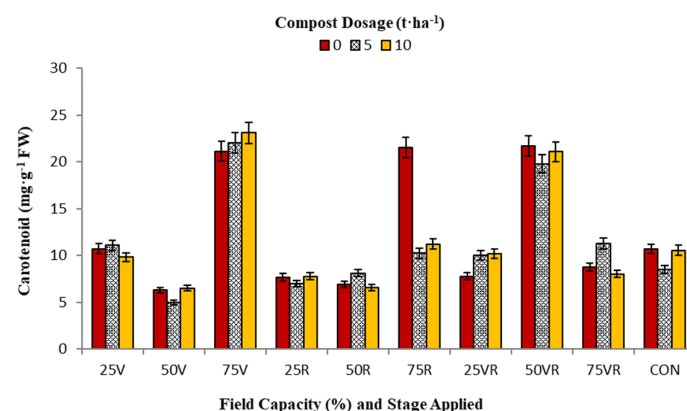
Figure 15. Effect of interaction of water regime, treatment stage and compost dosage on carotenoid content of okra leaf at 5 weeks

The 25, 50 and 75% represent field capacity; V (vegetative), R (reproductive), and VR (vegetative and reproductive) represent the stage at which the deficit was applied. Data in the interaction analysed with Least Squares Means, and means separated with LSD.
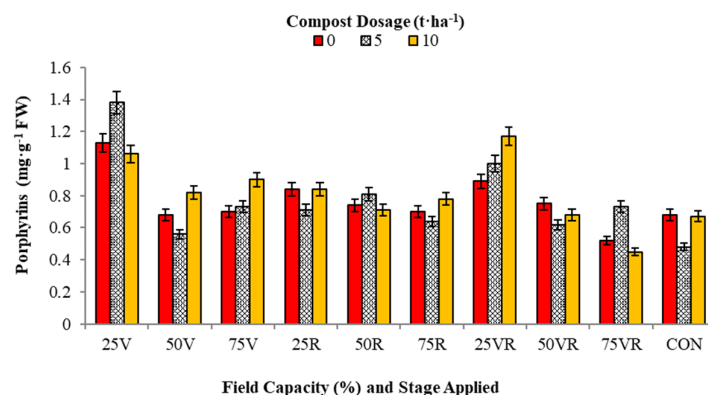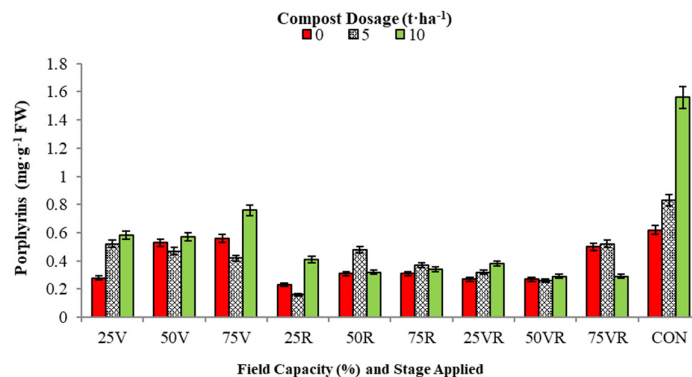
Figure 16. Effect of interaction of water regime, treatment stage and compost dosage on carotenoid content of okra leaf at 8 weeks

The 25, 50 and 75% represent field capacity; V (vegetative), R (reproductive), and VR (vegetative and reproductive) represent the stage at which the deficit was applied. Data in the interaction analysed with Least Squares Means, and means separated with LSD.

Figure 17. Effect of interaction of water regime, treatment stage and compost dosage on porphyrin content of okra leaf at 5 weeks

The 25, 50 and 75% represent field capacity; V (vegetative), R (reproductive), and VR (vegetative and reproductive) represent the stage at which the deficit was applied. Data in the interaction analysed with Least Squares Means, and means separated with LSD.

Figure 18. Effect of interaction of water regime, treatment stage and compost dosage on porphyrin content of okra leaf at 8 weeks

The 25, 50 and 75% represent field capacity; V (vegetative), R (reproductive), and VR (vegetative and reproductive) represent the stage at which the deficit was applied. Data in the interaction analyzed with Least Squares Means, and means separated with LSD.
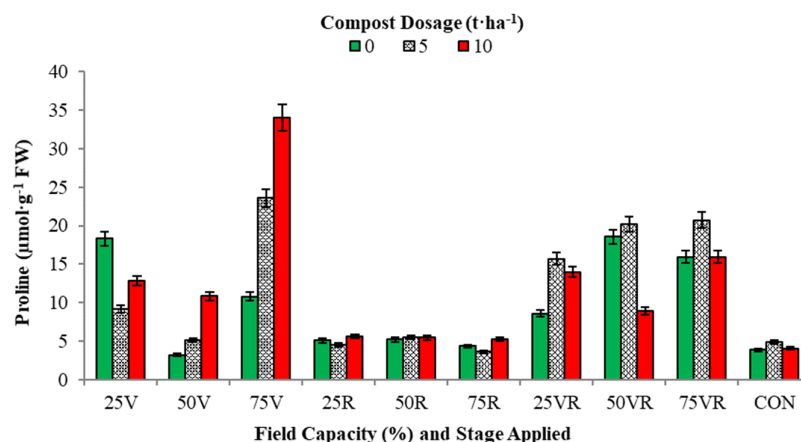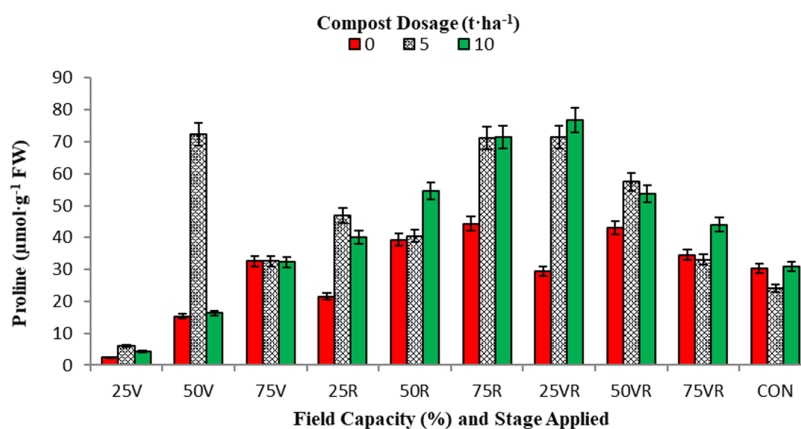
Effect of interaction of water regime, treatment stage and compost dosage on proline content of okra leaf

Proline, an osmolyte widely reported in environmental stress was accumulated in all stressed plants at the vegetative stress stage irrespective of organic amendment dosage. At 5 weeks after planting, proline content was more in plants exposed to drought stress at vegetative stage alone and those that were receiving treatments at both V and R stages, while, the lowest was recorded in those that were to be stressed at R stage alone and control. At 8 weeks after planting, compared to the control and the unstressed plants at this stage, proline concentration was more in plants exposed to stress at R stage alone and those treated at both V and R stages. The influence of compost addition on proline production was more pronounced at this stage. The higher the amount of compost the more the amount of proline produced under drought stress (Figures 19 and 20).

Figure 19. Effect of interaction of water regime, treatment stage and compost dosage on proline content of okra leaf at 5 weeks
The 25, 50 and 75% represent field capacity; V (vegetative), R (reproductive), and VR (vegetative and reproductive) represent the stage at which the deficit was applied. Data in the interaction analysed with Least Squares Means, and means separated with LSD.

Figure 20. Effect of interaction of water regime, treatment stage and compost dosage on proline content of okra leaf at 8 weeks
The 25, 50 and 75% represent field capacity; V (vegetative), R (reproductive), and VR (vegetative and reproductive) represent the stage at which the deficit was applied. Data in the interaction analysed with Least Squares Means, and means separated with LSD.

Discussion

Drought stress is an inevitable occurrence in the face of climate change. The symptomatic effects of drought stress on crop plant were growth inhibition and general yield reduction. Drought stress caused significant increase in flower abortion and delayed fruiting. The strategies must therefore be developed to enhance crop adaptation and resilience to climate change and promote food security. In this study, the use of organic amendments helped in improving the soil physic-chemical properties which in turn enhanced drought tolerance in okra when compared to un-amended control treatment. Cook *et al.* (2006) stated that application of organic amendment to the soil improved top-soil physical conditions especially with respect to temperature, evaporation and water content. The nutrient compositions and water retention capacity were probably improved through compost application in this study as was evident in all the growth and yield data. Compost amendments must have also enriched the soil with essential nutrients (such as N, P and K) (Hanay *et al.*, 2004; Lakhdar *et al.*, 2008) which in turn enhanced okra yield more than unamended control. Zero-compost application in 100FC° treatment resulted in lower vegetative growth and reduction in reproductive development. More importantly, apart from increasing plant growth, retaining water in the soil more than control, and increasing the nutrients in compost amended soil, the ability of compost to accelerate recovery after drought stress was also observed. The effect however, varied depending on application rate. Though all rates stimulated quicker recovery from stress compared to control, but this was more pronounced at higher application rate.

Furthermore, compost, though, played ameliorative roles in increasing growth parameters of okra plants but had little effect under severe drought stress conditions. For example, in this study, compost applications of 5 and 10 t/ha seemed to be insufficient in maintaining vegetative growth and leaf water content of okra stressed at 25% FC for a duration of 10 days. This could be attributed to the fact that, under water shortage conditions, nutrient absorption and water uptake are limited, and this could have led to reduction in growth, decreased leaf expansion, reduction in light absorption and photosynthetic potential of plant under severe water stress (Ahmadian *et al.*, 2011a). Drought stress was also found to cause reduction in leaf production in a proportionate manner depending on stress severity. It induced premature abscission, senescence of adult leaves, thus resulting in decreased available photosynthetic area and total leaf area per okra plant. Hessini *et al.* (2009) indicated that, the decrease in total biomass production was mainly associated to a reduction in leaf area and photosynthesis. Efficient nutrient release for cell division and enlargement in compost treated plants, could have enhanced leaf expansion which is manifested in increase in dry matter accumulation.

Drought stress at reproductive stage, decreased the total chlorophyll content compared to that of vegetative stress. This could be due to physiological changes that normally accompany reproductive development. The instability of protein complexes and destruction of chlorophyll due to increase in the activity of chlorophyll degrading enzyme, chlorophyllase under stress condition might have also contributed to this (Idrees *et al.*, 2010). Surprisingly, on the proline accumulation in okra plant, it was observed that, the higher the amount of compost, the more the amount of proline produced under drought stress. Proline accumulation due to drought stress has been reported to occur due to increased synthesis coupled with decrease in degradation (Heuer, 1999). Compost application therefore, favoured proline biosynthesis in this study and decreased its degradation. This could probably be one of the mechanisms employed by compost to enhance tolerance and ameliorate stress. In part, higher proline synthesis could be attributed to compost ability in supplying the necessary materials and providing favourable conditions for proline synthesis. Addition of compost could have also enhanced the proline production in drought stressed okra crop so as to increase the osmoprotection strategy in okra during drought. The applied compost could have also improved soil physical condition and enhanced water retention, all of which contributed to stress tolerance in okra under water deficit conditions compared to unamended soil (Misra *et al.*, 2002).

Compost addition also increased fruit yield especially with higher rate (10t/ha) relative to plants grown without compost. This is an indication of the compensatory role of the organic amendment applied at 10 t/ha

in stimulating and increasing okra yield production. The variation observed in okra response to drought stress with respect to fruit yield that was more in those stressed at vegetative stage than those stressed at reproductive stage could be as a result of premature abortion of flower buds and fruits as a result of water deficit. Early senescence of leaves and leaf abscission at reproductive stage could have also contributed to limiting photosynthesis and CO_2 assimilation. Generally, the high yield obtained from the use of compost compared to control confirms the findings of previous researchers (Ganuga *et al.*, 1998; Adejumo *et al.*, 2011; Nguyen *et al.*, 2012) who reported the effectiveness of Mexican sunflower in soil fertility management.

Conclusions

It could be concluded that, though, drought stress generally caused yield reduction, but compost addition increased okra growth and fruit yield especially with higher rate (10t/ha) relative to plants grown without compost. Fruit yield was more in those stressed at vegetative stage than those stressed at reproductive stage. Early senescence of leaves was observed in okra stressed at reproductive stage. The rate of recovery was enhanced in the stressed plants with compost addition compared to the control. Stress at vegetative stage increased okra fruit yield compared to the unstressed plants.

Authors' Contributions

The authors contributed equally to this study and the writing of the manuscript. Both authors read and approved the final manuscript.

Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

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