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Effects of water and fertilizer stress on the yield, fresh and dry matter production of grain Amaranth (*Amaranthus cruentus*)

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Abstract

The effects of crop yield, fresh and dry matter partitioning of grain amaranth (*Amaranthus cruentus*) in relation to different water stress and different levels of fertilizer application were studied. Grain amaranth was planted in the predominantly sandy loam soil. The treatments applied include replenishing soil moisture back to field capacity and imposing moisture stress 75% and 50% of the amount of water applied to bring soil moisture to field capacity. Within each treatment were varying levels of fertilizer application based on plant density and influence area at 100%, 75% and 50%. The actual crop evapotranspiration (ET_a) was determined by using a weighing lysimeter and the reference evapotranspiration (ET_p) was determined by using the pan evapotranspiration method. The results showed that water had significant effect on the total plant weight, stem weight, leaf weight, and root weight with p-values of 0.000, 0.001 and 0.000 respectively. However fertilizer and its interaction with water had no significant effect on total plant weight, stem weight, and root weight with p-values of 0.15 and 0.75, 0.22 and 0.68, and 0.37 and 0.79 respectively. For total plant weight, root, leaf wet and dry weights however, fertilizer had significant effect with p-values of 0.04, 0.042, 0.011 and 0.039 for dry matter. None of water, fertilizer and their interactions had any significant effect on dry matter concentration and the harvest index of the plant and dry matter concentration of the partitioned components of the plant. Fresh matter accumulation increased with time for all the combinations until after the seventh week of planting beyond which fresh accumulation started reducing. Plots with moisture content kept at field capacity and 100% fertilizer application recorded the highest fresh and dry matter production, while those with 50% of the moisture content at field capacity and 50% of the fertilizer requirement recorded the least fresh and dry matter production. Yield was highest for plots with the water content kept at field capacity and 100% fertilizer application recording an average value of 22.87 ton/ha and least with plots with 50% of the moisture content at field capacity and 50% of the fertilizer treatment recorded 12.55 ton/ha. The study shows that moisture stress seriously affects grain amaranth than fertilizer stress. Also it shows that the fresh and dry matter accumulation and yield of grain amaranth depends on the on the soil moisture status.

***Keywords*:** Grain amaranth; crop yield; fresh; dry matter; partitioning; moisture stress; fertilizer application.

Introduction

The relationship between water and crop yield is not a simple one, in addition to soil moisture, several variables which include climatic factors such as temperature, solar radiation, wind velocity, relative humidity, generic and physiological factors, diseases and pests, and hydro-meteorological hazards also affect crop production (Doorenbos and Kassam, 1979). Some of these variables are difficult or in some cases impossible to control. Igbadun and Oyebode (2000) defined moisture stress as the state a plant enters when the water potential is sufficiently, Generally, when the full crop water requirement is not met, water deficit in the plant can develop to a point where the crop growth and yield are adversely affected (Edmundo et al., 1998, Adeniran, 2004). Romagoza and Fox (1993) reported that for a certain degree of physical stresses (water, fertilizer, temp-erature and heat stresses) some high yielding crop

Table 1. Soil Physical and Chemical Properties of the Soil

Soil Property	
Soil Depth	0 – 15 cm
Soil Textural Class	Loamy Sand
Soil Gravel Content	9.80%
pH	6.7
Electrical Conductivity	0
Organic Carbon	0.20%
Organic Matter	2.10%
E.S.P	3.80%
Base Saturation Percent	95.30%
Sodium Absorption Ratio	0.055
Exchangeable Cations (Cmol/Kg. of Soil)	
Ca	0.2
Mg	1
K	0.38
Na	0.06
Exchangeable Acidity	0.08
C.E.C	1.59

varieties may yield more than stress resistant genotypes. If the stress beyond a certain level the opposite occurs and the high yield potential genotype may yield less than those having lower yield potential. Ceccarelli (1991) defined this phenomenon as "cross over". Most stressful environments are characterized by the occurrence of more than one physical stress at the same time or through the growing cycle. The effects of stress in different periods of the growing season interact in a complex manner. Simplifications are introduced by assuming that the stress effects in each period are independent. To express the combined effect of stress in several periods, multiplicative or additive procedures are used. Determination of the parameters of these functions requires extensive local experimental data. This is not always available in irrigation project area in developing countries. According to Taskiris (1982), crop water production functions derived from experiments are usually valid only near the location where they are provided. This is because the absolute quantity of water to produce a given yield differs greatly between locations. More so, no crop water function is universally applicable to all crops, growing season and climate (Rhenals and Bras, 1981). It is therefore necessary to formulate, or evaluate crop yield models for different locations and crops. There has been little organized research locally to generate such information on crop response to different amount of water-use and fertilizer application throughout their growth stages. The objectives of this study were to study the effect of water stress and varying levels of fertilization on fresh and dry matter production and partitioning (in relation to time) and yield of grain amaranth (*Amaranthus Cruentus*).

Materials and methods

Description of the Project Site

The study was conducted on the experimental plot close to the Department of Agricultural Engineering, University of Ilorin, Kwara State, Nigeria located approximately on the latitude $08^0 30'$ N and longitude $04^0 35'$ E at an elevation of about 340 m above mean sea level. Ilorin is in the Southern Guinea Savannah Ecological Zone of Nigeria with annual precipitation of about 1300 mm. The wet season begins towards the end of March and ends in October, with a dry spell in August. The dry season starts in November and ends in March.

Layout and Instrumentation

The site having a total land area of about 256 m^2 was cleared and destumped manually by use of hand tools such as axe, cutlass and hoe. It was then ploughed twice with a tractor. An area of 144 m^2 was selected because it was relatively level and rakes were used to level the soil upturned by the plough. A rain shelter was constructed over a 36m^2 area for shielding the crops from additional precipitation. Eleven litre pots which were drilled for the purpose of drainage where filled with 12.334 kg of air-dried, loamy sand soil at 1.1% moisture content. The soil, which was collected from the topsoil of a different plot behind the Agricultural Engineering Department, was mixed thoroughly and samples were taken to determine the soils chemical properties. The filled pots were then arranged on the field and spaced 30 cm x 30 cm apart between pots of the same treatment and 50 cm when separating the various treatments and their replicates of varying fertilization levels. The treatments applied include the following; 100% water application (control), 75% water application (moderate stress), and 50% water application (severe stress).

Replications for the treatments was such that each treatment had three replicates but with varying levels of fertilization (i.e. 100%, 75%, and 50%). Fertilizer was applied at the rate of 90 Kg/ha as recommended by Ojo (1998) for the optimum growth of amaranth. A meteorological station was set up to observe the weather conditions as the plant grew. The various instruments in the station include: cup counter anemometer, rain gauges, evaporation pans, and Stevenson screen housing the wet and dry bulb thermometer and maximum and minimum thermometer. Data for relative humidity and wind run was read off the wet and dry bulb thermometers and anemometer respectively at three-hourly intervals from 6.00h GMT to 18.00h GMT.

Table 2. Statistical Analysis of Variance (ANOVA) for fresh matter production

Variable	Factor interaction	df	F	p-value	Remark
Total fresh plant weight	Water	2	8.844	0.007	Significant
	Fertilizer	2	2.660	0.040	Significant
	Water-fertilizer	4	0.452	0.771	Not significant
Fresh leaf weight	Water	2	14.856	0.000	Significant
	Fertilizer	2	4.954	0.011	Significant
	Water-fertilizer	4	1.571	0.199	Not significant
Fresh stem weight	Water	2	15.787	0.000	Significant
	Fertilizer	2	2.645	0.082	Not significant
	Water-fertilizer	4	0.788	0.539	Not significant
Fresh root production	Water	2	9.720	0.000	Significant
	Fertilizer	2	3.421	0.042	Significant
	Water-fertilizer	4	1.436	0.238	Not significant

The rain gauges, maximum and inimum thermometer and the evaporation pans were checked and reset by 9.00h GMT daily.

Crop Management

24 g of the amaranth seed (accession NH84/453Y) was mixed with 200 g of 2 mm sieved air-dried soil and planted by broadcasting on the 8th October 2004. The seed germinated 4 – 6 days later. Thinning was done 2 weeks after planting to four plants per pot when the plant height was about 3cm and in the third week to two plants per pot. Fertilizer NPK 20:10:10 was applied at the rate of 90kg/ha with an influence area of 25cm x 25cm per plant 4WAP. A second application at the rate of 144kg/has was done 6WAP. Weeding was also done on the days of fertilizer application. Soil sampling for the determination of moisture content available for plant growth was done before each irrigation and a day after irrigation. The moisture content was the calculated by gravimetric method. Random sampling was also done on a weekly basis to determine the number of leaves, plant height and yield (fresh) per pot for all the treatments. Crop height were measures using a meter rule, number of leaves per plant was counted and the fresh and dry weight of harvest for all the treatments (both stressed and unstressed) and their replicates were determined immediately after harvest by weighing the plants. Drainage was also measured from the drain pots of each treatment. Evapotranspiration for both stressed and unstressed treatments were calculated using the water budget method (James, 1998 and Michael, 1999) shown in equation (1).

$$ET = P + I - (D + R + \Delta S) \quad (1)$$

where ET is the actual crop evapotranspiration (ET_a) determined with a weighing lysimeter, P is precipitation, I is irrigation, D is the drainage, R is the surface runoff and ΔS is the change in soil moisture content. The reference evapotranspiration (ET_o) in eqn (1) was determined using the pan evapotranspiration reported by Allen et al., (1998) stated below:

$$ET_o = K_p E_p \quad (2)$$

where ETo is reference crop evapotranspiration (mm/day), Kp is pan coefficient and Ep is pan evaporation (mm/day).

Crop Sampling

Crop sampling was started three weeks after planting. Buckets containing crop to be sampled were well watered to make sampling easy and prevent the root from being cut from the main plant. Two plants in the sampled buckets were removed, washed very well and then put in labeled envelopes. In order to obtain accurate results, the plants were then weighed quickly to avoid loss of soil moisture to the environment. The plant was then partitioned into leaves, stem and root. The weight of each of the components were taken and recorded against the particular plant. After taken the fresh weights, the plant was put in an oven at 105^{0}C for 24 hours of constant power supply. The plant was then taken and put in a desiccator for 1 hour before weighing and noting the weight. The dry matter concentration was calculated as ratio of the dry matter accumulated to the total fresh matter accumulations. The same method was used to determine the components parts. The crop harvest was determined by expressing the economic yield as a fraction of the total plant, where the economic yield included the stem and the leaves. Therefore, the harvest index was determined as the ratio of the shoot weight to the total plant weight. The harvest index was determined for the fresh and dry matter separately in order to compare them to see if there is any significant

Table 3. Statistical Analysis of Variance (ANOVA) for plant dry weight

Variable	Factor interaction	df	F	p-value	Remark
Total plant dry weight	Water	2	14.866	0.000	Significant
	Fertilizer	2	4.3999	0.018	Not significant
	Water-fertilizer	4	1.907	0.771	Not significant
Dry leaf production	Water	2	9.893	0.004	Significant
	Fertilizer	2	4.433	0.039	Significant
	Water-fertilizer	4	1.170	0.823	Not significant
Dry stem production	Water	2	13.719	0.000	Not significant
	Fertilizer	2	1.528	0.038	Significant
	Water-fertilizer	4	2.096	0.097	Not significant
Dry root production	Water	2	16.893	0.000	Significant
	Fertilizer	2	2.269	0.115	Not significant
	Water-fertilizer	4	1.422	0.242	Not significant

Table 4. Statistical Analysis of Variance (ANOVA) for harvest indices

Variable	Factor interaction	df	F	p-value	Remark
Wet matter harvest index	Water	2	0.850	0.434	Not significant
	Fertilizer	2	1.288	0.286	Not significant
	Water-fertilizer	4	2.399	0.064	Not significant
Dry matter harvest index	Water	2	0.310	0.735	Not significant
	Fertilizer	2	2.640	0.082	Not significant
	Water-fertilizer	4	3.313	0.018	Significant

difference in the two values. The crop water use efficiency (E_u) was determined as follows:

$$E_u = \text{Yield (kg/ha)/Seasonal evapotranspiration (mm)} \quad (3)$$

where E_u is the water use efficiency (kg/ha.mm).

Results

Soil Properties

Some physical and chemical properties of the soil are presented in Table 1. The soil is sandy loam in texture. It has it has low organic content and pH shows that it is slightly acidic.

Crop growth and development

The result from the weekly sampling of the plant height is as shown in Fig 1 which indicates that there was a sharp change in gradient as from Week 5. This shows that only two growth stages, the early season growth stage and the rapid growth and development stages had occurred. Although four stages are to be expected in a growth cycle, the plants were harvested at growth stage two because after that stage, the economic value of the crop reduced with time and the onset of inflorescence. Also, the crop is usually marketed between growth stages one and two, when the plant is still young, fresh and succulent. The definition of these growth stages was necessary for the determination of the relative yield and ET at these stages.

The effects water and fertilizer application on fresh matter production

Fig 2 shows the fresh matter accumulation for the different water and fertilizer treatments. It was observed that the fresh matter accumulation increased with period of growth up to the seventh week after which it started to reduce for most of the treatments, except in the treatment combinations having 100% water application (W_3) at the three fertilization levels F_1 to F_3, that is W_3F_1, W_3F_2 and W_3F_3. This period corresponds to initiation of flowering in the crop. Since the desire of the farmer is to maximize fresh vegetable obtainable, it is best harvest the crop during the seventh week which is the time when this can be achieved. The analysis of variance (ANOVA) for the effect of the treatments on total plant fresh matter is presented in Table 2. Water and fertilizer signify-cantly affected fresh matter production while the interaction of fertilizer with water had no significant effect. Water and fertilizer also had significant effects on fresh leaf production of the crop, but the effect of their interaction was not significant. Water alone significantly affected the fresh stem weight while fertilizer and the interaction with water had no significant effect on the stem weight. Table 2 also shows that only water significantly affected fresh root

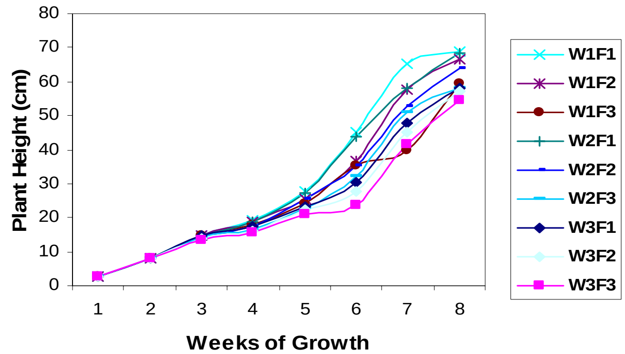

Fig 1. Plant height during the period of study

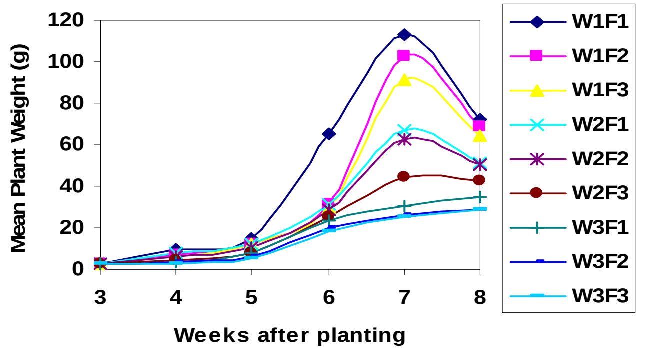

Fig 2: Effects of water and fertilizer application on fresh matter production

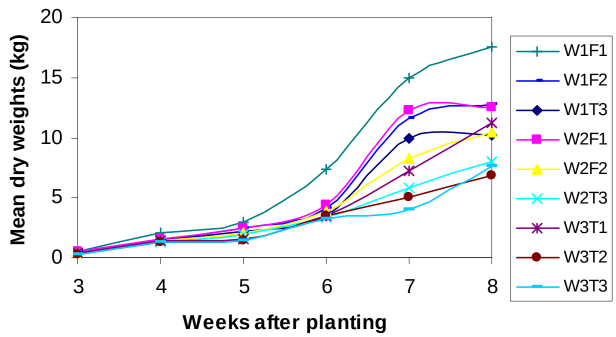

Fig 3. Effects of water and fertilizer on dry weight

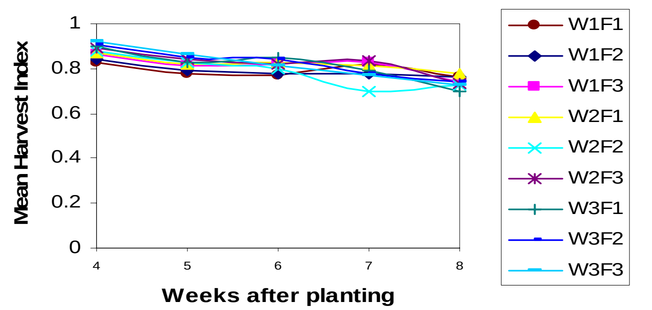

Fig. 4 Effects of water and fertlizer on Harvest index for fresh weight

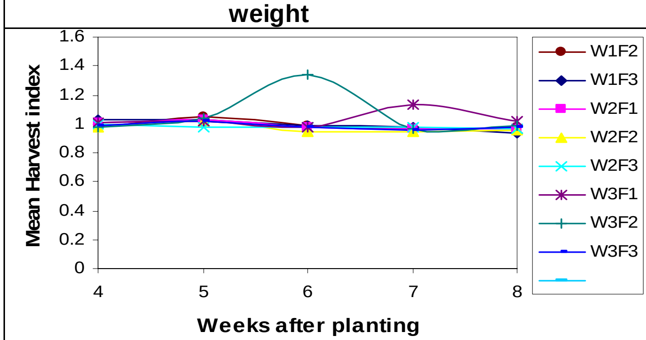

Fig 5. Effects of water and fertilizer on Harvest index for dry matter

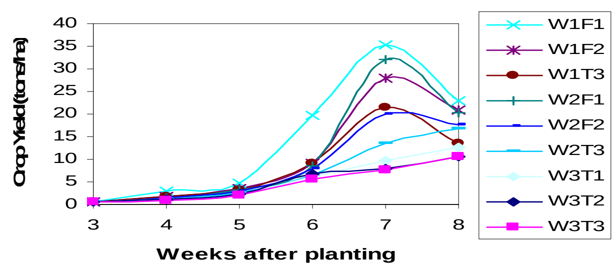

Fig 6. Yields for the different treatment combinations

production, while fertilizer and its interaction with water had no significant effect.

The effects water and application on dry matter production

Fig 4. shows the effects of water and fertilizer application on dry matter production of grain *Amaranthus*. Dry matter production increased with time, treatment W_1F_1 had the highest dry matter production throughout the season. The dry matter production for the crop did not fall after the seventh week, which means that the farmer who prefers dry matter instead of fresh matter, he could delay harvest till the eight week. Table 3 shows that water had significant effects on the total plant dry weight. However, fertilizer and the interactions with water produced no significant effects on total plant dry weight. Water and fertilizer had significant effects on dry leaf production, but the interaction between water and fertilizer had no significant effect.

Table 5. Relative Yield for the Growth Stages

Treatment	Relative Yield (Y_o/Y_m) for growth stages	
	I	II
W_1F_1	1	1
W_1F_2	0.7167	0.9130
W_1F_3	0.7104	0.5960
W_2F_1	0.6575	0.8937
W_2F_2	0.6406	0.7735
W_2F_3	0.5835	0.739
W_3F_1	0.5116	0.5875
W_3F_2	0.4968	0.4677
W_3F_3	0.4292	0.4639

Where (i) W_1, W_2 and W_3 represent water applied at 100%, 75% and 50% of the water required to bring soil to field capacity and R_1, R_2 and R_3 represent amount of fertilizer 100%, 75% and 50% applied.

Only water significantly affected stem dry matter production, while fertilizer and the interactions between water and fertilizer had no significant effect. Dry root matter production was also significantly affected, while fertilizer its interaction with water had no significant (Table 3).

Crop harvest indices

Fig 5 showed the crop harvest index for grain amaranth as it changed with time for fresh and dry matter respectively. Harvest index decreased with time for both fresh and dry matter respectively. None of the treatments or their interactions significantly affected fresh and dry matter harvest indices. Table 4 showed that none of the factors; water, fertilizer and the interaction between water and fertilizer had any significant difference on the dry matter harvest index with p-values of 0.410, 0.346 and 0.472 respectively.

Yields and relative evapotranspiration

The variation of yield with time of planting is as shown in Fig 6. The relative yields was then determined is as presented in Table 5. The treatment combination with 100% moisture and fertilizer application (W_1F_1) recorded the highest yield while those with 50% moisture and fertilizer treatments (W_3F_3) recorded the least yield. The relative ET for the growth stages is as shown in Table 6.

Table 6. Relative Evapotranspiration for the growth stages

Treatment	Relative Yield (Y_o/Y_m)	
Growth Stages	I	II
W_1F_1	1	1
W_1F_2	0.7167	0.9130
W_1F_3	0.7104	0.5960
W_2F_1	0.6575	0.8937
W_2F_2	0.6406	0.7735
W_2F_3	0.5835	0.739
W_3F_1	0.5116	0.5875
W_3F_2	0.4968	0.4677
W_3F_3	0.4292	0.4639

Where W_1, W_2 and W_3 and R_1, R_2,R_3, I and II are as defined in Table 3.

(ii) I and II represent the early season growth stage and the rapid gr

The peak consumptive use was recorded with the seventh week for all the treatments. The final yield and seasonal ET were highest for treatment combination W_1F_1 and least for treatment W_3F_3.

Discussion

The results showed the effect of water stress significantly affected total plant weight, stem weight, leaf weight and root weight. Fertilizer significantly affected total plant weight, root, leaf wet and dry weights. Olaniyi and Ajibola (2008) reported similar results that the application of each of N and P significantly increased the plant height, number of leaves, fresh shoots, dry matter and seed yields of corchorus olitorius above the control (no fertilizer was used). However fertilizer and its interaction with water had no significant effect on total plant weight, stem weight, root weight, dry matter accumulation and dry matter concentration of the partitioned plant components. This is because fresh matter accumulation and yield of grain amaranth depends on the on the soil moisture status. The study shows that moisture stress seriously affected grain amaranth than fertilizer stress. Similar observation was made by Meyers (1996) that amaranth growth was significantly affected by moisture stress while Meyers (1996) and Elberhri et al., (1993) reported that amaranth does not need much nitrogen fertilizer.

Conclusion

The study shows that the yield and growth of amaranth was greatly affected by moisture and the amount fertilizer stress. The timing of water application affected the amount of evapotranspiration, because the more moisture in the soil, the more the moisture available for evaporation by the atmosphere. Both water and fertilizer application had significant effects on both fresh and dry matter productions, but the effect of water was more pronounced on the crop than that of fertilizer. Also water, fertilizer and their interaction significantly affected the dry matter partitioning. The crop harvest index for leafy amaranth decreased with time and both water and fertilizer had no significant effect on it. The overall results show that grain amaranth responds well to adequate water supply and sufficient fertilizer for its development and yield. It is therefore economically feasible to irrigate the crop based on the irrigation treatment that supplies adequate soil moisture for crop growth and yield.

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