Tanzania Journal of Science 50(2): 323-333, 2024
ISSN 0856-1761, e-ISSN 2507-7961

Effects of Urea Fertilizer on Yield and Water Productivity of *Amaranthus viridis* in the Tropical Rainforest and the Derived Savanna of Nigeria

Kabiru A Shittu[1]*, Omotayo B Adeboye[2], Durodoluwa J Oyedele[3], Abdul-Salam M Murtadha[1] and Wasiu A Lamidi[4]
[1]*Department of Agronomy, Faculty of Agricultural Production and Management, College of Agriculture, Osun State University, Osogbo, Nigeria. PMB 4494, Osogbo. Nigeria.*
Email: kabiru.shittu@uniosun.edu.ng
[2]*Department of Agricultural and Environmental Engineering, Obafemi Awolowo University, P.M.B. 13, Ile-Ife, Nigeria; Email: adeboyeob@oauife.edu.ng*
[3]*Department of Soil Science and Land Resources Management, Faculty of Agriculture, Obafemi Awolowo University, P.M.B. 13, Ile-Ife, Nigeria. Email: doyedele@oauife.edu.ng.*
[4]*Teaching and Research Farm, College of Agriculture, Osun State University, PMB 4494, Osogbo, Nigeria. Email: elijah.akinrianade@uniosun.edu.ng*
[4] *Department of Agricultural Engineering, Faculty of Engineering, Osun State University, PMB 4494, Osogbo, Nigeria. Email: wasiu.agunbiade@uniosun.edu.ng*
**Corresponding Author:* *kabiru.shittu@uniosun.edu.ng*
Received 25 Jan 2024, Revised 21 Jun 2024, Accepted 27 Jun 2024, Published 30 Jun 2024
https://dx.doi.org/10.4314/tjs.v50i2.12

Abstract

The experiment was conducted using a lysimeter in June, 2014 in Saki (Derived Savanna) and Ile-Ife (Tropical Rainforest) to determine the crop coefficients and the effects of Urea fertilizer on the yield and water productivity of *Amaranthus viridis* in Nigeria. The loamy sandy soil in the top 15 cm was sampled, air-dried and analysed. Eighteen (18) kg of the air-dried and sieved soils were weighed into the thirty-two (32) lysimeters. Drill method was used for the sowing and the seeds were spread within 2 cm in the lysimeter. Urea fertilizer was applied at 0, 40, 80 and 160 kg N/ha twice during the growing season. The crop coefficients at the initial, mid, and late stages ranged from 0.15 to 0.41 in Ile-Ife, while in Saki, they ranged from 0.29 to 1.15 under Urea fertilizer. In Saki, the peak crop evapotranspiration was 1.21 mm/day for 0 kg N/ha of Urea while in the Ile-Ife, the crop evapotranspiration was 1.83 mm/day for 160 Kg N/ha of Urea. Water productivity in Saki and Ile-Ife were 45.47 kg/ha mm and 18.58 kg/ha mm respectively for 160 kg N/ha. This implies that A*maranthus viridis* required more water during canopy expansion and flowering in Ile-Ife than in Saki.

Keywords: Derived Savanna; *Amaranthus viridis;* lysimeter; Urea; Agroecology; Crop coefficient

Introduction

The management of nutrient and water resources is a key challenge in agriculture. Global climate change results in an increment in temperature, and such rise can increase potential evapotranspiration and further aggravate the drought in semi-arid regions (Muluneh et al. 2015). Araya et al. (2012) reported that the decline in crop yields was mainly due to drought. Soil water content is the key limiting factor for crop growth in arid regions. Higher water consumption by crops increases soil drought and leads to a decline in crop productivity (Brookshire and Weaver 2015). Moisture is constantly being taken up by plants together with nutrients and is lost by transpiration. Water serves four general roles in plants: it is the major constituent of the physiologically active tissue; as a reagent in photosynthetic and hydrolytic processes; as a solvent for solutes and it is essential for the maintenance of turgidity for crop growth (Shittu et al. 2017)

As the human population increases, crop demands also increase (Sharma et al. 2017). Successive planting of crops with growing water demands may cause a decline in shallow groundwater (Zhang et al. 2013). Soil desiccation and the decline in groundwater have negative effects on soil water balance, leading to reductions in the drought-resistance ability and growing rates of crops and causing adverse effects on the growth of subsequent crops (Wu et al. 2015, Zheng et al. 2012, Chen et al. 2008).

Food security has long been associated with a vision of an abundance of grains, roots, and tubers – the staple crops that provide affordable sources of dietary energy. But this picture is changing as the concept of nutrition security has become embedded in that of food security and the importance of dietary diversity for good health has moved to the fore. Healthy, high-quality diets require the consumption of a wide range of food categories in the right quantities. Globally, the prevalence of hunger has declined to 795 million in 2015 (FAO et al. 2015), indicating progress in ensuring adequate access to staple foods as measured in terms of caloric intake. However, an estimated 2 billion people are affected by insufficient intakes of micronutrients (WHO 2016)

Amaranthus viridis are essential sources of the micronutrients needed for healthier diets. Potassium in vegetables helps to maintain healthy blood pressure, their dietary fibre content reduces blood cholesterol levels and may lower the risk of heart disease, folate (folic acid) reduces the risks of birth defects, and vitamin A keeps eyes and skin healthy, while vitamin C not only keeps teeth and gums healthy but also aids in iron absorption. Recognizing the important nutritional benefits of fruits and vegetables, the World Health Organization (WHO) recommends a minimum intake of 400 g per day to prevent chronic diseases (especially heart diseases, cancers and diabetes) and supply needed micronutrients (especially calcium, iron, iodine, vitamin A and zinc) (WHO 2015, WHO/FAO 2003). However, consumers today, even those with higher incomes, are believed to be missing this target. More attention to filling this dietary gap and enabling consumers to tap the nutritional power of vegetables is required

Water productivity (WP) is the ratio of yield to evapotranspiration during the growing season. It helps to save water by controlling water supply through the better determination of crop water requirements and development of biological and physical criteria (Katerji et al. 1997) leading to precise determinations of irrigation schedules for the efficient performance of irrigation systems supplying water to the field (Pereira et al. 2002, Ramirez and Harmsen 2011)

Water requirements of crops vary substantially during the growing period due to variations in crop canopy and climate conditions. Knowledge of the water requirements of different crops is an important practical consideration to improve water productivity in irrigated agriculture. Water stress may arise through an excess or deficiency of water. Excess water or flooding on the fields of indigenous vegetable farms is a problem because it causes stress by limiting the amount of oxygen available to the roots of plants. This in turn limits respiration in the roots, nutrient uptake, and critical root function, thereby resulting in poor plant growth, yield, and crop quality (Qassim et al. 2002). In addition, it makes the plants more prone to disease. The adverse effects of waterlogging on Indigenous vegetable crops are often due to decreased availability of O_2 and accumulation of phytotoxins (Armstrong and Armstrong 2001). Oxygen deficiency inhibits aerobic respiration, resulting in severe energy deficiency and the eventual death of vegetable crops. Waterlogging can also reduce the availability of some essential nutrients such as N and increase the availability of other nutrients such as iron (Fe) and manganese (Mn) in vegetable fields.

The knowledge of the precise values of the crop coefficient (K_c) is particularly important for the determination of the water requirements of the *Amaranthus viridis* crops, in terms of water management. Therefore, it is essential to determine the water consumption of *Amaranthus viridis* crops with the aid of Lysimeter under the conditions of their cultivation areas, with sustainable use of the water resources

Lysimeters are the most accurate and direct standard method for evapotranspiration (ET) measurements (Jensen et al. 1990). Lysimeters, weighing and drainage types have been used for measuring crop water use, determining crop coefficients, and other works on plant-soil, water and atmosphere relations and are considered a basic method to calibrate evapotranspiration models (Zeggaf et al. 2008, Centinari et al. 2009). *Amaranthus viridis* is an economic crop in Southwest Nigeria. However, the responses of the crop to different rates of urea in a lysimeter in the region has not been studied. Therefore, this study investigated the effect of urea fertilizer on yield and water productivity of *Amaranthus viridis*. The objectives of this study are to (i) determine the crop evapotranspiration and crop coefficients (K_c) of lysimeter-grown *Amaranthus viridis* and (ii) determine the response of *Amaranthus viridis* to different application rates of urea fertilizer.

Materials and Methods

Study area

The trial was conducted in June, 2014 on a Lysimeter at two agroecologies in southwest Nigeria. The two sites are. (i) Teaching and Research Farm, Obafemi Awolowo University, (O.A.U.) Ile–Ife (Tropical Rainforest) and (ii) Teaching and Research Farm, Oke-Ogun Polytechnic, Saki (Derived Savanna). Teaching and Research Farm, O.A.U., Ile–Ife lies approximately between latitudes 7^{o}31'N and 7^o 33'N; and longitudes 4 ^{o} 33'E and 4 ^{o} 34'E. This site is within the Tropical Rainforest. The climate is hot and humid having a distinct dry season and bimodal rainy season with peaks in June and September. The average annual rainfall is about 83.89 mm. The average humidity is 81.84%; the maximum temperature is 32.90^{o}C; the minimum temperature is 21.95^{o}C; the sunshine hour is 6.60; potential evapotranspiration (PET) is 3.79 mm/d and the wind is 1.96 km/d (Table 1). Teaching and Research Farm, Oke-Ogun Polytechnic, Saki is within the Derived Savanna agro-ecological zone of southwest Nigeria with latitudes 8° 22′N and 8° 25′N; and longitudes 3° 38′E and 3° 40′E; and elevation is approximately 300 m above sea level. The weather was hot and humid characterised by distinct dry and rainy seasons, with an average annual rainfall of about 12.43 mm. The average humidity is 70.30 %; the maximum temperature is 32.80^{o}C with 20.83^{o}C as the minimum temperature. The PET is 3.61 mm/d and the wind speed is 1.45 km/d (Table 2).

Table 1: Climatic data for Ile-Ife, Nigeria in the year 2014.

Month	Humidity (%)	Air temperature (^{o}C)		Rainfall	Wind speed	ET$_o$
		Minimum	Maximum	(mm)	(km/day)	(mm/day)
January	72.15	21.15	35.06	0.66	0.46	4.10
February	61.05	19.96	32.98	0.26	0.59	3.70
March	75.14	22.98	35.33	0.22	1.11	4.10
April	78.32	21.93	32.61	0.31	0.75	3.70
May	82.17	22.34	33.41	26.10	0.35	3.90
June	88.13	23.14	32.34	2.70	0.57	3.60
July	88.81	22.22	31.23	148.00	0.67	3.50
August	86.23	22.53	31.45	132.80	0.45	3.50
September	91.00	22.06	30.65	224.70	11.88	3.40
October	90.73	21.56	31.60	213.11	4.47	3.70
November	86.84	22.64	34.14	254.23	0.93	4.10
December	81.45	20.84	34.02	29.12	1.20	4.20
Mean	81.84	21.95	32.90	85.89*	1.96	3.79

*Average rainfall, ET_o = Reference evapotranspiration

Table 2: Climatic data for Saki, Nigeria in the year 2014.

Month	Humidity (%)	Air temperature (°C)		Rainfall (mm)	Wind speed (km/day)	ET (mm/ day)
		Minimum	Maximum			
January	36.83	19.55	35.22	0.50	1.12	3.50
February	44.79	21.52	36.66	1.00	1.67	3.80
March	62.06	22.52	36.31	11.40	2.55	4.00
April	69.95	21.94	34.82	4.70	2.43	3.90
May	79.24	21.24	32.35	17.60	1.22	3.60
June	81.20	21.04	31.54	5.30	1.33	3.50
July	86.66	20.45	29.42	35.90	1.14	3.20
August	87.45	19.68	27.97	5.00	1.51	3.10
September	85.97	20.55	30.07	15.50	1.32	3.40
October	82.24	20.45	31.15	43.60	0.99	3.60
November	76.03	21.22	33.45	8.70	1.04	3.90
December	51.12	19.85	34.69	0.00	1.04	3.80
Mean	70.30	20.83	32.80	12.43*	1.45	3.61

*Average rainfall, ET_o = Reference evapotranspiration

Experimental design and layout of the lysimeter experiment

A portable smart lysimeter (1000 mm x 1000 mm x 6000 mm) was developed at Obafemi Awolowo University to measure the crop coefficient and evapotranspiration requirements of the *Amaranthus viridis* and data storage. The lysimeter study was conducted simultaneously in the Rainforest zone, (Ile-Ife) site and the Derived Savanna zone (Saki site). Topsoil, 0 – 15 cm depth, of Iwo series was excavated at the adjacent demonstration field in the Teaching and Research Farm and air dried in the field laboratory. The excavated air-dried soils were allowed to pass through a 5 mm sieve for uniformity and to mimic the conditions on the field. Eighteen (18) kg of the air-dried and sieved soils were weighed into the thirty-two (32) lysimeters and placed on the locally made benches in O.A.U. and Saki. Sub-sampled from the air-dried and sieved soil was taken to a reputable laboratory for selected soil physicochemical analysis. Cotton wool and gravel bedding of 2 cm depth were placed at the bottom of each lysimeter to act as a filtering mechanism and facilitate drainage. A drainage assembly was provided for leachate collection. Fabricated moisture sensors that were calibrated with standard and data logger systems were installed in each lysimeter to monitor the moisture content of the soil. The soil layer was alternately saturated and drained until the bulk density inside the lysimeter was close to that of the field soil. After draining the excess water, the soil in the lysimeter was allowed to drain for two days. The lysimeters were arranged in a randomized complete block design.

Drill method of sowing was used and the seeds of the vegetables were spread within 2 cm to prevent over-crowding of the crops. Three tea spoonfuls of the seed of *Amarantus viridis* were planted per experimental plot. Urea fertilizer was applied at four different rates in two doses (0, 40, 80 and 160 kg N/ha) i.e. N_0, N_1, N_2 and N_3. The first fertilizer application was done two weeks after crop germination while the second application was carried out immediately after the first harvest which took place 8 weeks after planting. Extract from *Azadirachta indica* (Neem plant) was applied at 5 cl/Litre weekly immediately after emergence to control pests and diseases.

Daily climatic data were obtained from an automated weather station located about 100 m from the experimental fields in O.A.U. and the Saki Meteorological Station). Daily maximum temperature, (T_{max}) and minimum Temperature (T_{min}) (°C), solar radiation

(W/m^2), rainfall (mm), and ET_o (mm) were measured. The shoots were cut at 2 cm above the soil surface using a stainless-steel knife and oven-dried to a constant weight at 65°C to obtain dry biomass. The first biomass was harvested 8 weeks after planting while the second harvest was done 4 weeks after the first harvest.

Measurements of Crop evapotranspiration (ET_C) and Crop coefficient (K_c)

Climate parameters such as daily maximum and minimum air temperature and daily maximum and minimum relative humidity, wind speed, solar radiation, sunshine hours and rainfall were collected at the Meteorological station of the Obafemi Awolowo University, Ile-Ife, Osun State located some 120 m away from the site of the experiment. The data collected were used to estimate the reference evapotranspiration using the FAO-Penman Monteith model in Eqn. (1) (Allen et al. 1998):

$$\mathrm{ETo} = \frac{0.408\Delta\,(Rn - \mathrm{G}) + 900\gamma\,\mathrm{u}_2\frac{\mathrm{e_s} - \mathrm{e_a}}{\mathrm{T}} + 273}{\Delta + \gamma\,(1 + 0.34\,\mathrm{u}_2)} \qquad (1)$$

where: ET_o = Reference evapotranspiration [mm day^{-1}], Rn = Net radiation [MJ m^{-2} day^{-1}], G = Soil heat flux density [MJ m^{-2} day^{-1}] = 0 (In general G is negligible in the daily calculation of reference ET because g is small on daily basis (Allen et al. 1998), t = Mean daily air temperature at 2 m height [°C], u_2 = Wind speed at 2 m height [m s^{-1}], e_s = Saturation vapour pressure [kPa];, e_a = Actual vapour pressure [kPa], e_s-e_a = Saturation vapour pressure deficit [kPa], Δ = Slope of the vapour pressure curve [kPa $°C^{-1}$] and γ = Psychrometric constant [kPa $°C^{-1}$]. The daily evapotranspiration of the crop (ET_c) was measured by determining the daily drop in water level of the burette. The amount of water lost from the lysimeter through evapotranspiration causes a drop in the water level in the burette. The initial and final readings were recorded and the difference between the two gave the crop evapotranspiration daily. The crop coefficient (K_c) of the crop was determined using Eqn. 2 (Fasinmirin et al. 2009):

$$\mathrm{Kc} = \frac{Crop\ evapotranspiration\ (ETc)}{\mathrm{piration\ evapotransreference}\ ETo} \qquad (2)$$

Soil water content was determined weekly at a depth of 20 cm using a digital soil moisture meter. Potential evapotranspiration (PET) was obtained from the automated weather station using the FAO Penman–Monteith approach (Allen et al. 1986). The weather data used were minimum temperature, maximum temperature, humidity, rainfall, wind speed, and solar radiation. The soil water balance for the root zone is in Eqn. (3) (Zhang 2023):

$$(P + C) - (R + D + ET_C) = \Delta S \qquad (3)$$

where P is the rainfall (mm); C is capillarity which is assumed to be negligible; R is runoff assigned the value of zero since the runoff was negligible being plain level ground; D is the drainage, also considered negligible.

Statistical analysis

Amaranthus viridis yield was estimated based on the harvested biomass which was estimated per treatment combination type to identify which treatment had the best effect on yield. All the biomass yield parameters determined were analysed using Statistical Analysis Systems (SAS), and the Duncan Multiple Range Test at a 95% significant level (SAS 1999).

Results and Discussion

Physical and chemical properties of soil

Data on selected physical and chemical properties of the soils studied under the Lysimeter trial before planting is presented in Table 3. The pH in the water of the soil was 6.74, and the soil was very slightly acidic (Adepetu et al. 2014), and can support the optimal growth of *Amaranthus viridis* (Huang 2017). The soil was loamy sand in texture and low in organic matter (OM) and total N, according to the critical levels of 3.0% OM, and 0.2% total N, recommended for *Amaranthus viridis* production in the ecological zone of Nigeria (Akinrinde and Obigbesan 2000). Other nutrient elements are in the appropriate proportion that can sustain the good growth of vegetables.

Table 3: Physical and chemical properties of the soil before the *Amaranthus viridis* production

Soil properties	**Result**
Sand (%)	72.68
Silt (%)	12.06
Clay (%)	15.26
Textural class	Loamy Sand
Soil pH (H_2O)	6.74
N (%)	0.06
P (ppm)	27.91
Organic matter content (%)	0.93
K (cmol/kg)	7.16
Ca (cmol/kg)	1.84a
Mg (cmol/kg)	1.23
Na (cmol/kg)	3.08

Crop evapotranspiration

The calculated crop evapotranspiration for 2014 for the two agroecologies (Tropical Rainforest and Derived Savanna) is presented in Table 4. The variations in ET_c between the Rainforest and the Derived savanna were relatively small. In Rainforest agroecology, there was a significant difference among the treatments at the initial stage (emergence stage) of crop development. Treatment with 160 kg N/ha had the highest ET_c (1.83 mm/day) and was significantly different from 80 kg N/ha (1.26 mm/day). Treatments with 40 and 0 kg N/ha that had 0.89 mm and 0.66 mm/day respectively had the least ET_c value. This means that daily water use of 160 kg N/ha was the highest and different from other treatments. This may be due to higher nitrogen nutrients that might be released to produce higher biomass that would be exposed to higher solar radiation, which can be accompanied by higher temperature that often results in quick evaporation of water from soil and water surfaces. This observation was also reported by (Fasinmirin et al. 2009). Although there were advances in crop growth and root development (vegetative stage) that led to an increase in moisture loss through evaporation from the soil surface and transpiration from the plant surface, there was no significant difference in ET_c at the mid-stage of growth of *Amaranthus viridis*, at maturity stage, the mean ET_c of 40 kg N/ha (0.78 mm/day) was the highest and was statistically distinguishable from other treatments. The implication is that 0, 80, and 160 kg N/ha with lower ET_c had lower water consumption of water compared to, 40 kg N/ha had the highest ET_c. (0.78 mm/day)

Under the Derived Savanna agroecology, at the initial stage, 0 kg N/ha with an ET_c of 1.21 mm was the highest and significantly different from other treatments. The order of increase in ET_c was as follows: 0 > 40 > 160 and 80 kg N/ha for 1.21mm, 1.07 mm, 0.60 mm, and 0.47 mm respectively. At the mid-stage of crop production, Treatment with 80 kg N/ha had the highest ET_c value (2.70) and was significantly higher than other treatments. Table 4 shows that the ET_c increases rapidly during the (mid-stage) vegetative and flowering stages, at 0 and 40 kg N/ha in Tropical Rainforest, indicating that crop water requirement was highest during this crop growth stage. This finding is similar to those reported by Fasinmirin et al. (2015). However, with 80 and 160 kg N/ha, evapotranspiration decreased. Derived Savanna showed that the ET_c increases rapidly during the vegetative and flowering stages at 80 and 160 kg N/ha and decreases at lower fertilizer rates of 0 and 40 kg N/ha.

Table 4: Crop evapotranspiration of *Amarantus viridis* during the 2014 wet season in Tropical Rainforest and Derived Savanna on lysimeters studies

	ET_c - Crop evapotranspiration (mm/day)					
Treatments (kg N/ha)	Ini.	Mid.	Late.	Ini.	Mid.	Late.
	Tropical Rainforest			Derived Savanna		
0	0.66c	1.01a	0.45b	1.21a	0.06b	0.90a
40	0.89c	1.00a	0.78a	1.07b	0.06b	1.01a
80	1.26b	1.02a	0.20b	0.47c	2.70a	0.65a
160	1.83a	1.36a	0.28b	0.60c	0.27b	0.64a
Mean	1.16	1.09	0.43	1.06	0.77	1.05
Std dev.	0.49	0.49	0.28	0.70	1.16	0.74
Minimum	0.56	0.05	0.12	0.40	0.01	0.44
Maximum	1.87	1.98	0.97	2.17	2.85	3.22

Crop coefficient of *Amarantus viridis* over the two agro-ecologies

The crop coefficient of *Amarantus viridis* during the 2014 wet season in Tropical Rainforests and Derived Savanna on lysimeters studies is presented in Table 5. Treatment with 0 kg N/ha under the Tropical Rainforest had a crop coefficient (K_c) ranging from 0.20 at the initial crop growth and gradually increased to 0.38 and later dropped (0.15) at the late stage of crop development. Treatment with 40 kg N/ha follows the same pattern. During the initial stage of crop growth, the *Kc* value started from 0.27 and then peaked at 0.37 during the mid-stage of growth. The K_c *was* reduced to 0.27 during the harvest. Elevated K_c during the peak season has also been reported by other studies (Maestre-Valero et al. 2017, Snyder and O’Connell 2007). Unlike treatments 0 and 40 kg N/ha, which follow the sigmoid curve, 80 and 160 kg N/ha did not follow the same pattern.

The crop coefficient under Derived Savanna agroecology during the 2014 wet season on lysimeter study is presented in Table 5. For 0 kg N/ha treatment, K_c ranged from 0.63 in the initial crop growth gradually decreasing toward the mid-stage to 0.02, and later increased to 0.31 during the harvest time. The 80 kg N/ha of Urea had a high K_c of 3.32 at the initial stage and later dropped to 1.10 at the mid-stage which further decreased to 0.23, Table 5. The K_c for 160 kg N/ha of Urea was 0.18 at the initial stage and later decreased to 0.10 at the mid-stage of crop development and later peaked at 0.57 during the harvest period. Comparable to these results, Elevated K_c during the peak season has also been reported by other studies (Maestre-Valero et al. 2017, Snyder and O’Connell 2007).

Table 5 shows that (K_c) at mid-stage was higher compared with the initial and late stages of vegetable crop production in Tropical Rainforest agroecology, this simply implies that much more application of water during the vegetative and flowering stages than at emergence and senescence. However, the (K_c) at the initial (emergence) stage was higher in the Derived savanna, this suggests that a higher amount of water is needed at the initial stage of development

Table 5: Crop coefficient of *Amarantus viridis* during the 2014 wet season in Tropical Rainforest and Derived Savanna on lysimeters studies

	Crop coefficient (K_c)					
Treatments (kg N/ha)	K_c ini.	K_c mid.	K_c late.	K_c ini.	K_c mid.	K_c late.
	Tropical Rainforest			Derived Savanna		
0	0.20c	0.38a	0.15a	0.63b	0.02c	0.31a
40	0.27c	0.37a	0.27a	0.33b	0.02c	0.34a
80	0.38b	0.38 a	0.07a	3.32a	1.01a	0.23a
160	0.56a	0.51	0.10a	0.18b	0.10b	0.57a
Mean	0.35	0.41	0.15	1.15	0.29	0.36
Std dev.	0.15	0.18	0.10	7.52	0.43	0.26
Minimum	0.17	0.02	0.04	0.17	0.00	0.15
Maximum	0.57	0.74	0.33	19.71	1.06	1.12

Biomass yield and water productivity

Biomass yield of *Amarantus viridis* during the 2014 wet season on lysimeters studies for two different agroecologies. (Figure 1) showed that the yield of vegetables was affected by different levels of nitrogen fertilizer application. Derived Savanna had a higher biomass yield and was significantly different ($p < 0.05$) from that of the Tropical Rainforest during the 2014 growing season. The yields were boosted with increasing Nitrogen fertilizer rate (Figure 1). Also, with a higher degree of applied urea under the two agroecologies, the differences were not statistically significant except for 160 kg N/ha treatments. On average, application of urea fertilizer at 160 kg N/ha yielded 2.39 and 3.07 t/ha in Tropical rain forests and Derived Savanna, respectively with significant differences between the two agroecologies. This can be attributed to a heavy downpour that could cause leaching of essential nutrient elements and stress by limiting the amount of oxygen available to the roots of the plants. This in turn limits respiration in the roots, nutrient uptake, and critical root function resulting in poor plant growth, yield, and quality, this agrees with Qassim et al. (2002) and Shittu et al. (2023). Also, the control treatment produced biomass of 1.12, and 2.17 t/h in the Tropical rainforest, and the Derived Savanna respectively (Figure 1).

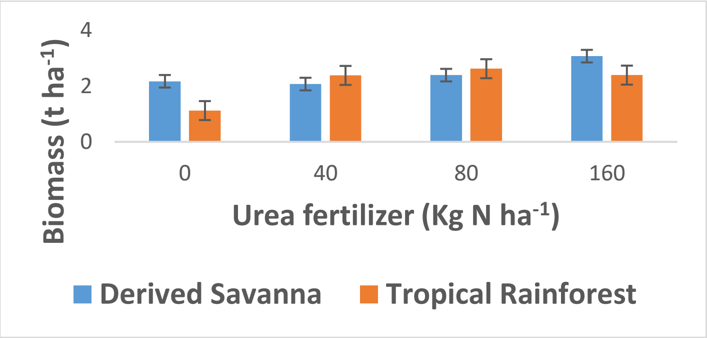

Figure 1: Biomass yield of *Amarantus viridis* during the 2014 wet season on lysimeters studies for two different agroecologies.

Water productivity of *Amarantus viridis*

Water productivity of *Amarantus viridis* during the 2014 wet season on lysimeters studies for two different agroecologies is presented in Figure 2. Only the treatment with 160 kg N/ha showed higher water productivity for the Derived Savanna and was significantly different from the Tropical

Rainforest. Results from the experiment carried out revealed that 160 kg N/ha of Urea can produce 45.47 kg/ha mm of *Amaranthus viridis* in the Derived Savanna while the same amount of fertilizer can produce 18.58 kg/ha mm of the vegetable in the Tropical Rainforest. The water productivity was 30.09 and 31.86 kg/ha for the Derived, and Tropical Rainforest respectively with urea of 80 kg/ha. However, at 40 kg/ha of Urea, the water productivity was 36.66 and 37.07 kg/ha mm for the Derived and the Tropical Rainforest respectively.

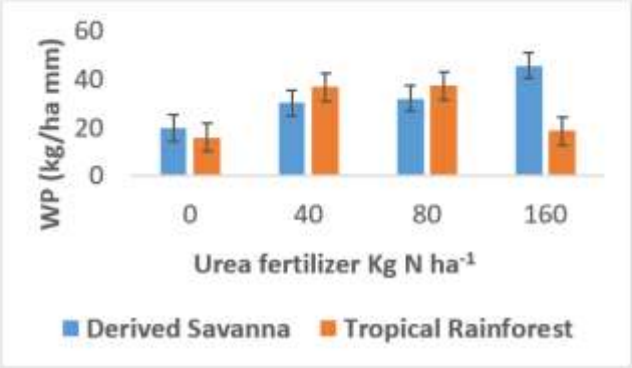

Figure 2: Water productivity of *Amarantus viridis* during the 2014 wet season on lysimeters studies for two different agro-ecologies

Conclusion

Effective management of water and urea fertilizer for sustainable production of A*maranthus viridis* in tropical and derived savannah is important. Under the tropical rainforest agroecology, the application of 160 kg N/ha of urea had the highest crop evapotranspiration of 1.83 mm/day. However, applications of 40, and 0 kg N/ha had 0.89, and 0.66 mm/day respectively, and were the minimum in the season. The crop coefficient at mid-stage was higher compared with the initial and late stages of the crop in Tropical Rainforest agroecology. This implies that A*maranthus viridis* required more water during canopy expansion and flowering than at emergence and senescence. However, the crop coefficient at the initial stage was higher in the Derived Savanna than in the Tropical Rainforest. This means that more water was required at the initial stage of the crop in the area. Urea fertilizer of 160 kg N/ha had water productivity of 45.47 kg/ha mm for *Amaranthus viridis* in the Derived Savanna, and 18.58 kg/ha mm in the Tropical Rainforest. Furthermore, 40 to 80 kg N/ha in the Derived Savana had lower water productivity compared to the Tropical rainforest. The Derived Savanna had the highest water productivity at 160 kg N/ha. Further studies are required on other cultivars in the study areas.

Conflicts of interest

The authors declare that they have no competing interests in this work

References

Adepetu JA, Adetunji MT and Ige DV 2014 Soil fertility and crop nutrition. Soil acidity and liming. Jumak Nigeria Ltd. 108pp

Allen RG, Pereira LS, Raes D and Smith M 1998 Crop Evapotranspiration, Guidelines for Computing Crop Water Requirements. FAO *Irrig. Drain*. 56: 356.

Akinrinde EA and Obigbesan GO 2000 Evaluation of the fertility status of selected soils for crop production in five ecological zones of Nigeria. In: O Babalola, ed, Proceedings of the 26th Annual Conference of Soil Science Society of Nigeria; 2000 Oct 30 – Nov 3; Ibadan, Nigeria. pp 279-288

Allen RG 1986 A Penman for all seasons. *J. Irrig. Drain. Eng*. 112(4): 348 - 368.

Araya A, Stroosnijder L, Habtu S, Keesstra SD, Berhe M and Hadgu KM 2012. Risk assessment by sowing date for barley (*Hordeum vulgare*) in northern Ethiopia. *Agric. For. Meteorol*. 6: 30–37, 154-155

Armstrong J and Armstrong W 2001 An overview of the effects of phytotoxin on phragmites australis in relation to dieback. *Aquatic Bot.* 69: 251-268.

Brookshire EN and Weaver T 2015 A long-term decline in grassland productivity is driven by increasing dryness. *Nat. Commun*. 6: 1-7.

Centinari M, Poni S, Filippetti I, Magnanini E, Intrieri C 2009 Evaluation of an open portable chamber system for measuring cover crop water use in a vineyard and comparison with a mini-lysimeter approach. *Agric. For. Meteorol*. 149: 1975-1982.

Chen HS, Shao MA and Li YY 2008. Soil desiccation in the loess plateau of China. *Geoderma* 143 (1): 91–100.

Fasinmirin JT, Olufayo AA, Oguntunde GP, Oguntuase MA 2009 Parametrizing Simple Model between Yield and Evapotranspiration for *Amaranthus cruentus* under Drip and Sprinkler Irrigations. *Int. J. Plant Prod*. 3(1): 1735-8043.

Fasinmirin JT, Reichert JM, Oguntunde PG and Ajayi AE 2015 Greenhouse evapotranspiration and crop factor of *Amaranthus cruentus* grown in weighing lysimeters. *African J. Agric Res.* 10(34): 3453-3461

Huang, L Liu X Wang Z, Liang Z, Wang M, Liu M and Suarez D. L 2017. Interactive effects of pH, EC and nitrogen on yields and nutrient absorption of rice (*Oryza sativa* L.). *Agric. Water Manage.* 194*:* 48-57.

Jensen ME, Burman RD, Allen RG 1990 Evapotranspiration and irrigation water requirements. Manual of Practice No. 70, ASCE, NY 331pp

Katerji N, van Hoorn JW, Hamdy A, Mastrorilli M and Mou Karzel E 1997 Osmotic adjustment of sugar beets in response to soil salinity and its influence on stomatal conductance, growth and yield. Agric. *Water Manage.* 34: 57– 69.

Maestre-Valero J, Testi L, Jiménez-Bello M, Castel JR and Intrigliolo DS 2017 Evapotranspiration and carbon exchange in a citrus orchard using eddy covariance. *Irrig. Sci.* 35: 397-408

Muluneh A, Biazin B, Stroosnijder L, Bewket W and Keesstra S 2015. Impact of predicted changes in rainfall and atmospheric carbon dioxide on maize and wheat yield in the Central Rift Valley of Ethiopia. Reg. *Environ. Change* 15: 1105–1119.

Pereira LS, Oweis T and Zairi A 2002 Irrigation management under water scarcity. *Agric. Water Manage*. 57: 175-206.

Qassim A, Ashcroft B, Hickey M, Hulme J and Hoogers R 2002 Irrigation scheduling for vegetable crops: Growers Guide. The state of Victoria, Department of Natural Resources and Environment. In: R. Niskanen, R. and Jain, M.S. (eds*.). Crop management and post-harvest handling of horticultural products: Crop fertilization, nutrition and growth*. Enfield, USA: Science Publishers, Inc pp 1-53.

Ramirez VH and Harmsen WE 2011 Water vapor flux in agroecosystems: methods and models review. In: Labedski, L. (ed.), *Evapotranspiration*. INTECH Open Access Publisher pp 3-48.

SAS Institute 1999 Statistic users's guide: Basics, 1990 ed. SAS Inst., Cary, NC, USA pp 891-996.

Sharma NK, Singh RJ, Mandal D, Kumar A, Alam NM, and Keesstra S 2017. Increasing farmer’s income and reducing soil erosion using intercropping in rainfed maize-wheat rotation of Himalaya, India. *Agric. Ecosyst. Environ*. 247: 43–53.

Shittu KA, Oyedele DJ and Babatunde KM 2017 The effects of moisture content at tillage on soil strength in maize production. *Egypt. J. Basic Appl. Sci.* 4(2):139-142.

Shittu KA, Adeboye OB, Oyedele DJ, Lamidi WA, Babatunde KM and Murtadha MA (2023) Impact of Tillage practices on properties of soil, evapotranspiration, and productivity of cowpea in Nigeria. *Trop. Subtrop. Agroecosyst.* 26: 1-12

Snyder R and O'Connell N 2007 Crop coefficients for micro-sprinkler-irrigated, clean cultivated, mature citrus in an arid climate. *J. Irrig. Drain. Eng*. 133: 43–52.

WHO/FAO 2003 Diet, Nutrition and the Prevention of Chronic Diseases. Report of a Joint FAO/WHO Expert Consultation. WHO Technical Report Series 916. World Health Organization, Geneva.

WHO 2015 Promoting Fruit and Vegetable Consumption around the World. World Health Organization, Geneva.

WHO, 2016. Database on Anaemia, Vitamin and Mineral Nutrition Information System (VMNIS). World Health Organization, Geneva

Wu Y, Liu TX, Paredes P, Duan LM and Pereira LS 2015 Water use by a groundwater dependent maize in a semi-arid region of Inner Mongolia: evapotranspiration partitioning and capillary rise. *Agric. Water Manage*. 152: 222–232.

Zeggaf AT, Takeuchi S, Dehghanisanij H, Anyoji H, Yano T (2008). A Bowen Ratio Technique for Partitioning Energy Fluxes between Maize Transpiration and Soil Surface Evaporation. *Agron. J.* 100(4): 988-996.

Zhang, J, Xiang L, Zhu C, Li W, Jing D, Zhang L, Liu Y, Li T and Li J 2023 Evaluating the irrigation schedules of greenhouse tomato by simulating soil water balance under drip irrigation. *Agric. Water Manage. 283*: 108323.

Zhang YJ, Meinzer FC, Qi JH, Goldstein G and Cao KF 2013 Midday stomatal conductance is more related to stem rather than leaf water status in subtropical deciduous and evergreen broad leaf trees. *Plant Cell Environ*. 36: 149–158.

Zheng X, Zhu JJ, Yan QL, Song LN 2012 Effects of land use changes on the groundwater table and the decline of Pinus sylvestris var. mongolica plantations in southern Horqin Sandy Land, Northeast China. *Agric. Water Manag*. 109: 94–106.