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Effects of dry season irrigation and fertilizer micro-dosing on water application efficiency, agronomic performance and water use efficiency of *Amaranthus viridis*

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ABSTRACT

In most arable regions of Africa, fertilizer application and irrigation are cultural practices to improve soil fertility and reduce plant water stress especially during the dry cultivation seasons. Their application is beneficial if value of increase in crop yield due to climatic changes is sustained and improved. This study investigated the effects of urea and irrigation on water application efficiency, agronomic performance and water use efficiency of *Amaranthus viridis* in a humid rainforest zone of southwestern Nigeria during the dry season. It was conducted during the late and early dry seasons of year 2022 and 2023 respectively at the Teaching and Research Farm, Ekiti State Polytechnic, Isan Ekiti, Nigeria. There were two methods of irrigation (sprinkler and capillary) combined with urea fertilizer micro-dosing application rates of 0 and 40 kg N/ ha by fertigation, broadcast, drilling and spot placement replicated in a randomised complete block design. The data obtained were subjected to analysis of variance using Duncan's Multiple Range Test to separate the significant means at $p<0.05$. The capillary irrigation system when combined with fertigation significantly ($P < 0.05$) improved soil water application efficiency and water use efficiency of the amaranth over the sprinkler system. The micro-dosing application rate on the dry season capillary irrigation method was enough to support growth and obtain optimum yield of the leafy vegetable.

Keywords: Fertilizer micro-dosing; rainforest; water use efficiency

INTRODUCTION

Productive agriculture can be effective and efficient with adequate irrigation water to check the deficits of irregular rainfall. In order to promote sustainable agriculture, there is a need for very precise estimates of water addition and its movement in soil, land use and their environmental impacts as surface irrigation results to water runoff, soil and nutrient losses. This requires timely and precise management as climate changes and variations are now emerging concerns and threats to agricultural development (Poonia *et al.*, 2021). The total irrigation input and its contribution to vegetable production in Nigeria is low. These are

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challenges to vegetable production globally. Its application rate must however be higher, since it is synonymous to improving vegetable production generally (FAO, 2005). Ferreira *et al.* (2014) also observed a linear increase in amaranth crop yield with nitrogen fertilizer content when cultivated under moderate sowing density. Several agronomic management strategies have been developed and directed towards soil moisture conservation and increase crop water use (Luo *et al.,* 2018). Ranjan *et al.* (2020) reported that these strategies have aided yield increase when combined with appropriate irrigation methods. Maseko *et al.* (2019) observed that moderate N fertilizer application promotes agronomic traits and yield of amaranths. A high N supply with temporal variability increases plant growth dramatically (Wang *et al.*, 2022). A simulated yield increase in maize and wheat was observed by Mahmoud *et al.* (2021) with evenly irrigation and controlled drainage. The basic knowledge of water requirement of different crops is also an important practical consideration to improve water use and application efficiency in irrigation agriculture. Nutrient and water management on variety of crops requires effective approaches to achieve adequate water use efficiency during the dry season and in water scarce regions. The practice of different irrigation types is also dependent on location and water availability as water uptake by plants occurs when plant roots pressure exceeds soil water potential (Ferdinandez and Clothier, 2009). Jain *et al.* (2000) compared conventional surface water application with sub surface drip application frequently and observed increasing yields and water use efficiencies from sub surface drip applied crops. Water supply below maximum volume required for crop growth increases water use efficiency of crops through mulching and plant residue (Zhou *et al.*, 2011). The absence of water measuring equipment and farmers ignorance on deciding the time of irrigation and volume of water required for irrigation is a challenge (Panda, 2003). Proper leveling of land will enhance water application efficiency, prevent deep percolation, mitigate deficit irrigation and water accumulation on soil surface. An artificial water table has been adopted with the use of PVC pipes to supply water through subsurface soil. The PVC pipes act as water reservoir and water table which creates a pressure potential. The potential, surface tension and critical angle of water drives water in response to lower energy of evapotranspirative demand of crops. The objective of this study was to investigate the yield, water use and application efficiency of A*maranthus viridis* during the dry season in response to irrigation methods and fertilizer micro-dosing.

MATERIALS AND METHODS

Study Area

The study was conducted at the Teaching and Research Farm of Ekiti State Polytechnic, Isan-Ekiti, Nigeria (latitudes 7° 55′ 22″ N and longitudes 5° 18′ 43″ E with an altitude of 544 m above sea level) of the rainforest agroecological zone with annual rainfall of about 1350 mm. The daily average temperature range is between 27 and 30 ^{0}C. The soil is underlain by Precambrian basement complex developed from medium grained granite and gneiss parent rock (Soil Survey Staff, 1992). This makes it widely cultivated and densely populated. Its root zone depth is about 100 cm from the surface.

Experimental Design

The study was conducted during the late 2022 and early 2023 planting seasons. These periods fall within the dry cultivation seasons. The 0.02 ha land area was divided into 6 m x 1 m plots with inter-row spacing of 0.5 m within and between. The treatments on each plot consisted of: (1) 40 kg N/ ha (broadcasting) + sprinkler irrigation, (2) 40 kg N/ha (fertigation) + capillary irrigation (3) 40 kg N/ha (spot placement) + sprinkler irrigation (4) 40 kg N/ha (drilling) + sprinkler irrigation (5) 40 kg N/ha (fertigation) + sprinkler irrigation (6) 0 kg N/ha + sprinkler irrigation (control). The treatments were replicated four times in a randomized complete block design experiment. *Amaranthus viridis* seedlings were transplanted from the established nursery beds at 0.1 m within and 0.2 m between rows spacing on each plot. Two transplanting were done during each dry season within the two years study. Urea fertilizer was applied at 0 and 40 kg N/ ha by fertigation, drilling, broadcast and spot placement a week after transplanting. (Forty) 40 kg urea N/ha is the micro-dosing recommended rate. The capillary irrigation method is a novel PVC subsurface plastic pipe adopted for fertigation of leafy vegetables on the field. Cohesive forces within water molecules and adhesive forces between soil particles and water raised water in the capillary pipe to the rhizosphere. The surface irrigation method was an improvised sprinkler system (watering can) used by farmers to irrigate crops. The water was supplied evenly from one end to another over and across the soil surface at the shortest distance to reduce soil water and nutrient runoff. The two methods have been adopted by vegetable farmers for cultivation during the dry season and by farmers within the water scarce regions in order to sustain and improve food security. Forty (40) litres of irrigation water was applied at two days interval throughout cultivation period by both methods of irrigation.

Data Collection

Prior to cropping, composite surface soil of each plot (0 -15 cm) was sampled before cropping and transported to the laboratory where they were air dried, crushed and sieved through a 2 mm sieve for analyses. Soil pH was determined in 0.01 N $CaCl_2$ 1:2 soil /solution ratio (Peech *et al*., 1953). The organic carbon content of the soil was determined by modified Walkley-Black procedure (Nelson and Sommers, 1996). The exchangeable cations of the soil were extracted with 100 ml neutral 1 N NH_4OAC solution (Thomas, 1982). Sodium and Potassium concentrations of the extract were determined with flame photometer 2655-00 model, while Magnesium and calcium were determined with Atomic Absorption Spectrophotometer PG 990 model. Soil bulk density (Lowery *et al*., 1996; Blake and Hartge 1965) porosity and field moisture capacity (Flint and Flint, 2002) was determined from undisturbed core samples through cylindrical cores of 119 cm^3 volume from each plot. The moisture content of the soil was monitored within the topsoil till harvest on the plots by Time Domain Reflectometer (Topp *et al.,* 1980) to determine ability of the application methods in conserving water within the rhizosphere for effective vegetable growth (water application efficiency) of the irrigation methods.

$$Ea = \frac{WS}{Wp} x\ 100 \text{ -------------1}$$

Ea = water application efficiency (%),
Wp = amount of water delivered to the plot,
Ws = amount of water stored in the root zone during irrigation (Panda, 2003).

The mature vegetable stems (yield) were harvested, weighed and recorded three (3) weeks after transplanting. The vegetables were carefully uprooted and washed with water so as to remove adhering soils from the roots. They were drained off excess water and weighed to obtain the total fresh weight on a sensitive weighing balance with 0.01g precision and recorded. Thereafter, placed in the oven until constant weight was achieved at 65 ^{0}C and recorded to obtain the dry weight for water use efficiency (WUE) of *A. viridis*.

$$WUE = \frac{Y}{ET_C} \quad \text{---------}2$$

Where:
WUE (kg ha^{-1} mm^{-1}) represents water use efficiency for biomass yield
Y (kg ha^{-1}) represents dry biomass yield and
ETc (mm) is the total crop evapotranspiration (Wang *et al*., 2013)

$$Kc = \frac{ETc}{ETo} \quad \text{----------------}3$$

Where ETo is the reference evapotranspiration. Daily reference evapotranspiration was obtained by the FAO 56 Penman-Monteith method (Allen *et al.,* 1998).

$$ETo = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{T+273}u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \quad \text{-----------------}4$$

K_C = Crop coefficient value, K_C (0.7, 1.05, 0.95) for small vegetables was obtained from crop coefficient table, FAO paper 56 (Allen *et al.,* 1998).

Data Analysis

Analysis of variance was performed on data collected from soil properties, water application efficiency, the amaranth yield and its water use efficiency within two years of the study with the SAS software package (SAS, 2003). Significant different means were separated using Duncan's Multiple Range Test at 5 % level of significance.

RESULTS AND DISCUSSION

Prevailing weather conditions and Soil Physical Properties

The climatic data at the experimental site during the two years study is presented in Table 1. The total annual rainfall in the year 2022 was about 1427 mm. It was well distributed between April and August although, the vegetable was cultivated towards the end of the year as it was a dry season study. Rainfall amount was low between November and December when the cultivation was done. The mean daily temperature and humidity was 30.2 ^{0}C and 74 %, respectively. Rainfall amount was also well distributed in the year 2023 between March and August with mean daily temperature of 29.7 ^{0}C and mean humidity of 72.6 %. Climatic conditions of the experimental station were as expected during the period of the experiment (dry season of the years). This trend was similar with the climatic report of Ayinla and Odetoye (2015) and Akintola (1986). Soil physical properties of the experimental site are shown in Table 2. The bulk density values within the plots were below the critical value for root growth in sandy loam soils and will not affect root growth of leafy vegetables and *A. viridis* performance. The bulk density (weight per unit volume) ranged between 1.27 mg/m^3 and 1.30 mg/m^3 across the plot. However, the differences were not statistically significant ($P < 0.05$) within most plots. Ghuman *et al.* (1991) observed that slight increase in soil bulk density values of tropical soils may be as a result of manual clearing of topsoil vegetation and slight impact of tropical rainfall. Their porosities and field moisture contents were not statistically significant ($P < 0.05$) across the plots.

Table 1: Climatic data at the Teaching and Research Farm, Ekiti State Polytechnic, Nigeria in 2022 and 2023

Month	2022			2023		
	Rainfall (mm)	Mean temperature (^{0}C)	Relative humidity (%)	Rainfall (mm)	Mean temperature (^{0}C)	Relative humidity (%)
January	0	31.7	40.5	0	32.1	41.2
February	0	33.4	68.4	3.0	31.4	70.5
March	85.0	31.3	70.2	33.5	30.7	67.8
April	74.0	32.1	78.1	78.5	31.4	77.2
May	190.0	29.7	79.3	195.0	28.5	78.4
June	174.0	29.5	80.3	188.0	30.0	79.2
July	238.0	27.4	84.5	245.0	26.5	83.7
August	202.0	26.5	83.7	214.0	27.2	82.5
September	217.0	27.4	81.2	NR	NR	NR
October	245.0	29.7	83.4	NR	NR	NR
November	2.4	32.6	72.8	NR	NR	NR
December	0	31.4	74.2	NR	NR	NR
Annual	1427.4	30.2	74.72	957	29.7	72.6

Source: Meteorological Unit, Teaching and Research Farm, Ekiti State Polytechnic, Nigeria
NR= Not Recorded

Soil Chemical Properties

The soil chemical properties of the plots used for the study in response to laboratory analyses are shown in Table 2. The low pH of the soil is a characteristic of soils in the humid rainforest as it is attributed to deep percolation and leaching of soil basic cations within the topsoil. The cations are then replaced with acidic cations (H^+ and Al^{3+}) on soil exchange site. This value is also as a result of the acidic nature of the parent material of the experimental unit soils (Adepetu *et al.*, 2014). The pH values for the soils were not statistically significant ($P < 0.05$) and falls within optimum range for major leafy vegetable production as reported by Liu and Hanlon (2015).

Table 2: Soil physical and chemical properties

Plot	Soil physical properties			Soil chemical properties					
	BD (mg/m^3)	Porosity (%)	FMC (%)	pH	SOC (g/Kg^{-1})	Ca^{2+}	Mg^{2+}	K^+	Na^+
						---------- cmol kg^{-1} soil-----------			
1	1.29ab	47	23	5.6	1.44	0.50a	0.11	0.34a	0.02a
2	1.27ab	47	22	5.5	1.42	0.55a	0.12	0.31b	0.02a
3	1.28ab	48	23	5.5	1.43	0.48a	0.11	0.34a	0.03a
4	1.30a	48	22	5.6	1.44	0.47a	0.11	0.36a	0.01a
5	1.29ab	47	23	5.5	1.42	0.43b	0.12	0.33a	0.02a
6	1.28ab	49	23	5.5	1.44	0.46a	0.11	0.35a	0.01a

Means within the same column with the same alphabet are not significantly different at α= 5% according to Duncan's Multiple Range Test; BD = Bulk density, FMC = Field moisture capacity, SOC = Soil Organic Carbon

The soil within the experimental unit is poor in organic carbon. This is peculiar to soils of the humid tropics according to Idowu *et al.* (2017). This result may also be due to historical records of continuous cultivation within the plots as there were no significant difference ($P < 0.05$) on the soils within the unit. The exchangeable cations also showed no significant difference ($P < 0.05$) as expected across the plots due to low soil organic carbon content of the soils. These values are low and below the critical values of basic cations for soils of the humid tropics (Adepetu *et al.,* 2014).

Fresh Weight and Water use Efficiency of *Amaranthus viridis*

The green amaranth fresh yield weight and water use efficiency is presented in Table 3. The green amaranth fresh yield weight performed better through the capillary irrigation method which also significantly ($P < 0.05$) increased its water use efficiency as it was more water efficient through the subsurface water application method. It had the highest yield (5701.7 kg/ha) and WUE (7.85 kg/ha/mm). The control plot recorded the lowest yield (2994.4 kg/ha) and WUE (3.78 kg/ha/mm). This implies that WUE and its utilization was highly affected by volume of water applied through the capillary pipe to the plots and absorbed by the vegetable seedlings during growth, unlike seedlings of surface irrigated plots. The maximum WUE also corresponded with the maximum yield with equal volume of water applied across the treatments. This is an indication that reducing water volume applied through capillary irrigation can be achieved without significant reductions in the amaranths fresh yield and WUE during its dry cultivation period within the humid rainforest zone. This observation connoted Dukes and Scholberg (2005) findings as they reported 11 % irrigation water savings and yield increase with subsurface drip irrigation compared to sprinkler irrigation. Ogunlela and Sadiku (2017) also reported similar findings through the use of soil moisture sensors as it not only reduced the volume of water applied, but also increased the yield of *A. cruentus.*

Table 3: Effects of fertilizer micro-dosing and irrigation on yield and water use efficiency of *A. viridis*

Treatment	Yield (Kg/ha)	Water use efficiency (Kg/ha/mm)
Trt 1	4369.4b	5.74b
Trt 2	5701.7a	7.85a
Trt 3	4140.0b	5.64b
Trt 4	4306.7b	5.72b
Trt 5	3734.2b	4.71b
Trt 6	2994.4c	3.78c

Means within the same column with the same alphabet are not significantly different at $\alpha = 5\%$ according to Duncan's Multiple Range Test

Trt 1 = 40 kg urea N/ ha (broadcasting) + sprinkler irrigation, Trt 2 = 40 kg urea N/ha (fertigation) + capillary irrigation, Trt 3 = 40 kg urea N/ha (spot placement) + sprinkler irrigation, Trt 4 = 40 kg urea N/ha (drilling) + sprinkler irrigation, Trt 5 = 40 kg urea N/ha (fertigation) + sprinkler irrigation, Trt 6 = 0 kg urea N/ha + sprinkler irrigation (control).

The subsurface capillary irrigation device only supplies water to the seedlings when it is required. The significantly higher water use efficiency in treatment 2 (40 kg N applied through capillary irrigation) may be as a result of increased evapotranspiration due to the water application method on the soil. Evapotranspiration rate was higher in the subsurface irrigated soils and influenced the green amaranth water use. This agrees with the findings of Ufoegbune *et al.* (2016). The result shows that the high evapotranspiration rate led to rapid growth and developmental of the green amaranth and more water was efficiently used up for the sudden physiological changes of the vegetable seedlings. Sprinkler irrigation without urea application treatment (control) had the lowest yields when compared with other treatments. This implies that reducing the amount of water applied to green amaranth growth during the dry cultivation period is possible without significant reductions in performance and yield.

The yield advantage of the capillary irrigated seedlings of the amaranth and the micro-dosing urea application method was due to the fact that the water and nutrient applications were frequent and in close proximity to the shallow rooting system of the vegetable seedlings unlike other micro-dosing and fertilizer application methods in the study. The lower yield from other treatments might be due to the fact that excess water was applied through the manual sprinkler irrigation method. This might have washed away, and leached nutrient applied and present within the soil and affected the yield output of the treatments negatively. The use of controlled irrigation through the capillary irrigation method allowed the plants use water and nutrients efficiently and reduced nitrogen leaching. This finding has suggested WUE as a good criterion for evaluating irrigation effectiveness. The micro-dosing effect of fertigation and the subsurface irrigation method in this study could be seen in the rapid and timely early growth of the vegetable seedlings as observed in the fresh yield. This influenced early development of the plant during the dry season, which aided the vegetable to intercept solar radiation and soil moisture evaporation. The fertilizer application method influenced the plant development and apportioned more of the water extracted by the roots to transpiration, thereby increased WUE. These effects persisted and stabilized until harvest. Other micro-dosing treatments might have suffered moderately from drought stress due to the sprinkler irrigation method adopted on the soil and affected the amaranth yield and water use efficiency.

Soil Water Application Efficiency

The effectiveness of both irrigation systems in storing water in the crop root zone (WAE) is represented in Table 4. Soil water storage is an important component of soil during dry season cultivation. There was low rainfall during the study period which could have contributed to low moisture storage within the soil (November 2022 to February 2023) as indicated in Table 1. The little precipitation (2.4 mm for November 2022 and 3.0 mm for February 2023) was not sufficient to improve soil moisture content during the dry season in the humid rainforest as the rainfall amount for the cultivation period was below normal for soil moisture recharge. The application efficiency was low with sprinkler method and slightly higher in the capillary method. This could be due to the high soil moisture consumption rate by the crop at a faster water and fertilizer application methods. Hatfield and Dold (2019) attributed this to high rate of soil moisture consumption in their previous study. This also agrees with the report of Steduto *et al.* (2009) who observed that increased crop transpiration accelerates soil moisture reduction rate. The faster soil moisture depletion under the fertilizer treatment was attributed to improved crop growth that accelerated soil moisture utilization and eventually reduced water within the rhizosphere. The atmospheric temperature above a certain threshold (high temperature) during the study period could have reduced WAE of the sprinkler irrigated plots (Gourdji *et al.*, 2013). The significantly lower WAE was related to infiltration of the coarse textured soil, which allowed rapid infiltration capacity and conductivity of sprinkler irrigation water at the soil surface. Silting, tillage modification and cracking, which occurred at the soil surface affected the soil aggregates and infiltration rate. The control plots recorded significantly lower water application efficiency in comparison with other treatments. This could be attributed to exposure to evaporation losses especially with no fertilizer applied which could have utilized and retained water within the soil. The submerged capillary pipes contributed to higher water application efficiency in treatment two (2) by conserving soil water that would have been lost to erosion and direct evaporation. This was as a result of timely application interval of water by the capillary irrigation device and successive root absorption. The high significant difference was also due to improved irrigation uniformity and control of the irrigation depth with a flexible irrigation scheduling under the capillary irrigation method. Fertilizer applied at micro-dose rates have been reported to increase soil moisture conservation especially in ridge technique (Saidia *et al.*, 2019) and thus minimizing the losses due to volatilization, surface evaporation and erosion.

Table 4: Effects of fertilizer micro-dosing and irrigation on soil water application efficiency

Treatment	Volume applied (cm)	Water application efficiency (%)
Trt 1	240	3.56b
Trt 2	240	4.98a
Trt 3	240	2.68bc
Trt 4	240	3.30bc
Trt 5	240	2.88bc
Trt 6	240	2.37c

Means within the same column with the same alphabet are not significantly different at α= 5% according to Duncan's Multiple Range Test

Trt 1 = 40 kg urea N/ ha (broadcasting) + sprinkler irrigation, Trt 2 = 40 kg urea N/ha (fertigation) + capillary irrigation, Trt 3 = 40 kg urea N/ha (spot placement) + sprinkler irrigation, Trt 4 = 40 kg urea N/ha (drilling) + sprinkler irrigation, Trt 5 = 40 kg urea N/ha (fertigation) + sprinkler irrigation, Trt 6 = 0 kg urea N/ha + sprinkler irrigation (control).

CONCLUSION

This study supported dry season water application management through a novel capillary irrigation system especially in water scarce regions as it sustained yield and water use efficiency of the amaranth.

It showed that not only methods and amount of fertilizer applied influences vegetable yield, water use and application efficiency, irrigation type and method is also as important. Reducing the full irrigation water supply to *Amaranthus viridis* till maturity influences positively its yield.

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