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YIELD AND WATER USE EFFICIENCY OF *AMARANTHUS CRUENTUS* GROWN UNDER SMS-BASED IRRIGATION SYSTEM

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ABSTRACT

The study was carried out to evaluate water use efficiency and yield of Amaranthus cruentus grown under soil moisture sensor-based (SMS-based) irrigation system. SMS-based irrigation controller was designed to automate irrigation events based on 100 %, 75 % and 50 % field capacity (FC) for the growth of Amaranthus cruentus. The findings of the study revealed that the SMS-based irrigation based on 50 % FC saved 57.17 % irrigation water, 75 % FC saved 43 % while 100 % FC saved 25.33 % irrigation water. Water use efficiency (WUE) ranged from 1.39 – 2.43 for WUE based on fresh weight while WUE based on dry weight ranged from 0.22- 0.4. SMS-based on 50 % FC had the highest WUE of 2.43 while manual irrigation had the lowest WUE of 1.39 based on vegetable fresh weight. The total fresh weight and shoot fresh weight ranged from 62.47g – 84.16 g and 52.22 - 66.92 g respectively. Total dry weight and shoot dry weight ranged from 9.13 - 13.30 g and 7.58 - 11.28 g respectively. SMS-based irrigation based on 100% FC had the highest total and shoot fresh yield while SMS-based irrigation based on 75 % FC had the highest total dry and shoot dry weight. Generally, the yield of Amaranthus cruentus were statistically similar for all the treatments. The relationship of total fresh weight and shoot fresh weight and number of leaves with WUE and volume of irrigation water were statistically significant $p \leq 0.05$ while that of total dry weight, shoot dry weight and plant height with WUE and volume of irrigation water were not statistically significant at $p \geq 0.05$. SMS-based irrigation had higher irrigation water use efficiency more than manual irrigation which resulted to irrigation water saving compared to the manual irrigation without reducing the yield of Amaranthus cruentus.

Keywords: Soil Moisture, Water Use Efficiency, Amaranthus, Fresh weight, Plant height

INTRODUCTION

Climate change is one of the most serious environmental threats to human beings as it adversely affects agricultural productivity. It has been projected that crop yield in Africa may fall by 10-50 % by 2050 due to climate change altering water availability, growing season, planting and harvesting calender (Rosegrant, *et al.,* 2008). Climate change affect the available volume of water for agriculture and this in turn affect the quality and quantity of crops produced (Sadiku and Sadiku, 2012) . In the developing countries such as Nigeria, most farmers practice rain-fed agriculture which results in low productivity and hence low income. Part of adaptation measures to combat the effects of climate change in some areas such as the Guinea, Sudan and Sahel Savannah region of Nigeria has been irrigated agriculture. Traditionally, hand pumps, canal water and rainfall were major sources of water supply for irrigation. This method has led to severe drawbacks like under irrigation and over irrigation which in turn causes leaching and loss of nutrient content of the soil (Suresh *et al.,* 2014) . Most of the time, farmers tend to use more water than required by manual techniques hence wasting water. Changing environmental conditions and shortage of water has led to the need for a system which efficiently manages irrigation of fields (Suresh *et al.,* 2014). As an alternative to traditional irrigation system, soil moisture sensor (SMS) based scheduling which apply low volume of water frequently to maintain a desired moisture range in the root zone that is optimal for plant growth can be substituted with traditional irrigation systems (Irmak and Haman, 2001). Although, soil moisture sensors are rarely used among vegetable growers in Nigeria to schedule irrigation. The method can save considerable volumes of irrigation water and can increase yield (Adeogun *et al.,* 2012), reduce production costs, leaching of nutrients and pollution of ground water. The aim of this research was to determine if soil moisture sensor-based irrigation system could reduce the irrigation water application while at the same time maintaining acceptable quality and yield of Amaranthus cruentus (Green amaranth).

MATERIALS AND METHODS

Materials

The experiment uses SMS-based irrigation controller (as automatic irrigation) and a manually operating irrigation controller. SMS-based irrigation controller consists of water storage tank, 16 plastic buckets (containing 21 kg of soil), PVC pipes, air valve, hose with one dripper serving each bucket.

Methods

The soil moisture sensor sensed the moisture level of the soil near the root zone of the plant based on the instructed upper/lower limit of the soil moisture sensor and give signal to the microcontroller to trigger the state of the pump. Whenever the soil moisture was at or below the lower limit of soil moisture, water was discharged to the root zone of the plant thus, maintaining the desired moisture level of the soil. The control for the experiment was irrigated based on the calculated irrigation interval. Amaranthus cruentus seeds (of accession NI from National Institute of Horticulture, Ibadan, Nigeria were mixed with 2 mm sieved air-dried soil and planted by broadcast. The experiments were conditioned in a screen house to eliminate the influence of precipitation. 16 buckets were filled with loam sand soil and water to field capacity to take the initial moisture content of the soil before the Amaranthus seeds were broadcast in the buckets of 245 mm depth, 255 mm top diameter and 210 mm bottom diameter. After the broadcasting, the experimental buckets were then lightly covered with soil, watered and covered with polythene sheet to aid early germination of the seeds. The seedlings were raised in the buckets for three weeks with routine watering and weeding when necessary, after which they were thinned to 3 plants per bucket. Harvest was carried out 8 weeks after planting.

Irrigation Treatments

Table 1 shows the different irrigation schedule for the growth of Amaranthus cruentus and Figure 1 shows the Layout of experiment

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Table 1: Irrigation Treatments

Treatments	Irrigation
I	100% field capacity (automated)
II	75% field capacity (automated)
III	50 % field capacity (automated)
IV	100% field capacity (Manual)

Water requirement of Amaranthus cruentus based on crop evapotranspiration

Water required daily per Amaranthus cruentus crop based on the evapotranspiration requirement of the crop was determined using equation (1) (Michael, 2008) .

$$V_{dp} = K_c \times ET_o \times C_c \times A_p \qquad (1)$$

where V_{dp} is the water required daily per plant (l/day), Kc is the crop coefficient of Amaranthus cruentus (Kc = 1.04 was used for Kc (Okechukwu, M. E,,Mbajiorgu and Kamai, 2015; Ufoegbune *et al.,* 2016), ETo is the reference evapotranspiration (mm/day) (ETo = 4.83 mm/day for peak value during the month of May (Chineke *et al.,* 2011; Ufoegbune *et al.,* 2012)), Ap is Area of the bucket ($A_p = 0.051077\ m^2$). one is used for Cc (crop cover).

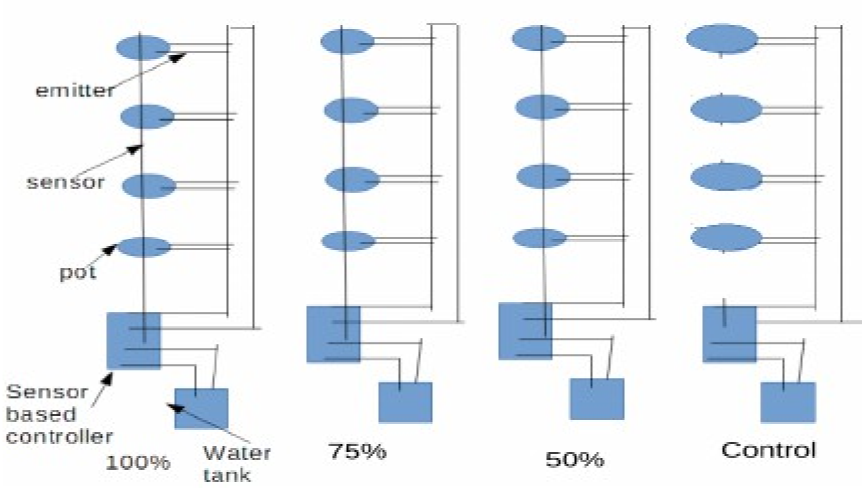

Figure 1: Layout of Experiment

$ETc = Kc \times ETo = 1.04 \times 4.83 = 5.02$mm/day . This is the daily water requirement. The volume of water required daily per Amaranthus cruentus based on the crop evapotranspiration requirement was given as

$V_{dp} = 1.04 \times 4.83 \times 51.077 = 256.57 mm^3/day$ which was equal 0.25657 litre/day. But for 2 days irrigation interval, it was 2 x 0.25657 which gave 0.51314 litres of water. For two stands of *Amaranthus cruentus*, volume of water required at 2 days irrigation interval (0.51314 litres multiplied by 2) gave 1.03 litres. At peak rapid growth stage, the volume of water required was calculated in the following expressions using 1.16 for Kc $V_{dp} = 1.16 \times 4.83 \times 51.077 = 286.17 mm^3/day = 0.28612$ litre/day Volume of water required for two (2) stands of Amaranthus cruentus at 2 days irrigation interval was 0.28612 x 2 x 2 = 1.144 litres.

Water requirement of *Amaranthus cruentus* for 100 % FC, 75 % FC and 50 % FC

The volume of water required in each bucket of the treatments was determined by multiplying the daily water requirement of each treatment by the area (0.051077 m2) of the bucket that contain the soil for growing the Amaranthus cruentus. The calculations for daily water requirement (ETc) for Amaranthus cruentus for the treatments (T) were done by multiplying ETc with percentage FC for each treatment. The calculated volume of water required (WR) for treatments were shown in the following expressions:

$WR = FC \times ETc \times Ap \times Iv$ ....(2)

i. Ti = 100 % of 5.02x 51.077= 0.2564 litre/day x 6 days = 1.54 litres (Automated)
ii. Tii = 75 % of 5.02 x 51.077 = 0.1926 litre/day x 6 days= 1.16 litres (Automated)
iii. Tiii = 50 % of 5.02 x 51.077 = 0.1282 litre/day x 6 days= 0.77 litre (Automated)
iv. Tiv = 100 % of 5.02 x 51.077 = 0.2564 litre/day x 6 days= 1.54 litres (Control)

Evaluation of Soil moisture sensor-based Irrigation System

Water used in each treatment was recorded for the computation of weekly water use. Water productivity (WP) or water use efficiency in kg ha-1 m-3 was determined using Equation (2) (Boutraa *et al.,* 2011).

$$WP_{total} = \frac{Total\ yield}{Water\ applied} \quad \text{..............(3)}$$

Growth and Yield of *Amaranthus cruentus*

The growth and development of the vegetables were visually rated for 5 weeks. The number of leaves per plant were counted and the plant height were measured during the growing period and at harvest. The plants were carefully uprooted, the roots were washed thoroughly with water to remove any adhering soil. Thereafter, the roots were drained off excess water and were weighed to obtain the total fresh weight. Following this, the roots were severed neatly and the weight of the shoot were immediately determined on a sensitive weighing balance with 0.01g precision and recorded as the fresh shoot weight. Thereafter,the shoot and the roots were placed in the oven maintained at 8 0 0 C until constant weight was achieved and the dry weight were recorded to determine the total dry and shoot dry weight.

Statistical Analysis

All statistical analysis were performed using Statistical Package for Social Science Student (SPSS) with general linear model procedure. Analysis of Variance (ANOVA) was used to determine treatment effects and Duncan Multiple Range Test was used for separation of means. Difference in means were considered significant at an alpha levels of 95 % or higher ($p \leq 0.05$) .

RESULT AND DISCUSSION

Volume of Irrigation water for Amaranthus cruentus

The calculated amount of water required for Amaranthus cruentus and the actual water discharged per replicate for the irrigation interval under soil moisture sensor-based irrigation system based on 100 %, 75 % and 50 % field capacity is presented on Table 2.

Table 2: Calculated amount of water for each irrigation treatment of Amaranthus cruentus

Irrigation treatments	Calculated volume (litre)	Actual volume discharge (litre)
100% FC	1.54	1.17
75% FC	1.16	0.93
50% FC	0.77	0.67
100% FC (manual)	1.54	1.54

Calculated volume of water for soil moisture sensor based on 100 %, 75 % and 50 % were 1.54 litres, 1.16 litres and 0.77 litre respectively while the actual water discharged for irrigation were 1.17 litres, 0.93 litre, 0.67 litre based on 100 %, 75 % and 50 % respectively. There were differences between the calculated volume of water and actual water discharge for irrigation within the interval. All the sensor based irrigation treatments except the control (manual irrigation based on 100% field capacity) used less water compared to the calculated volume of water based on the ETc.

The volume of water applied to the crops during the growing period is presented on Table 3. In all the automated irrigation treatments, treatment I (automated based on 100 % FC) discharged the most water where that of 50 % discharged the least water (Table 3). Treatment IV which is manual irrigation based on 100 % FC applied the same quantity of water per week throughout the growing period. The greatest amount (60 litres) of irrigation water was applied to the manually irrigated treatment followed by 100 % field capacity while 50 % field capacity received the least irrigation water.

Table 3: Total volume of water (litres) discharged during the growing period

Treatment	Weeks					Volume applied (Litres)
	III	IV	V	VI	VII	
100%	8.1	9.4	10.2	8.8	8.3	44.8
75%	5.6	8.2	8.4	6.3	5.7	34.2
50%	4.2	5.4	5.9	5.2	5.0	25.7
Control	12.0	12.0	12.0	12.0	12.0	60.0

There was sharp increase in the volume of water discharged from week four up to week 5 for all the automated treatments. As from week 6 there was reduction in water use. However, all the treatments used the largest volume of irrigation water at week 5 except the control experiment. The increase in water use of Amaranthus cruentus at week 4 and 5 after planting may be as a result of increased ET during these weeks. According to Ufoegbune *et al.* (2016); Ejieji and Adeniran (2010), there is usually a sharp change in ETc as from week 5. The result shows that week 4 and 5 correspond to the period of rapid growth and developmental stages of Amaranthus cruentus. So it is expected that more water is used up for the rapid physiological changes of the plants.

Irrigation Water use Efficiency/Water Productivity

Table 4 shows the irrigation water use efficiency (WUE) or water productivity of Amaranthus cruentus. The largest amount of irrigation water (60 litres) was applied to the control (100 % field capacity based on manual operation) while the lowest water was applied to 50 % treatment. Water use efficiency was highest on 50% treatment (2.43) based on vegetable fresh weight with the lowest applied water (25.7 litres) (Table). WUE based on vegetable dry weight was highest (0.4) for irrigation Treatment II.

The result showed that the treatments with the highest irrigation water application (treatment IV) resulted in the lowest water use efficiency of 1.39 and 0.22 for WUE based on vegetable fresh and dry weight, while the treatment with the lowest irrigation water (50 % FC) had the highest WUE (2.43) based on fresh weight (Table 4). Therefore, increasing irrigation volume did not necessarily result in higher yields. The soil moisture sensor-based treatments applied less water than the manual schedules (Control). The soil moisture sensor irrigation resulted into water saving compared to the control (manual irrigation based on 100 % FC). Irrigation based on 100 % FC automatic was able to save 25.33 % water compared to the control while those based on 75 % FC and 50 % FC saved 43 % and 57.2 % water respectively compared to the manual irrigation (Table 4).

Table 4: Irrigation water use efficiency (WUE)/Water Productivity of Amaranthus cruentus

Treatment	Total Volume of water (litre)	WUE (Fresh) (g/l)	WUE (%)	WUE (Dry) (g/l)	WUE (%)	Water saving (%)
I (100%)	44.8	1.88	135.25	0.26	118.18	25.33
II (75%)	34.2	2.26	162.59	0.40	181.82	43.00
III (50%)	25.7	2.43	174.82	0.36	163.64	57.17
IV (Control)	60.0	1.39	100.00	0.22	100.00	00.00

Results of previous works support the findings of this research. Dukes *et al.*(2003) got similar findings, they found 50 % reduction in water use in pepper plants using soil water based automatically irrigation system in comparison to daily manually irrigated treatments. Also, Dukes and Scholberg (2005) reported 11 % irrigation water savings with drip irrigation compared to sprinkler irrigation. The use of SMS not only reduced the volume of water applied, but also increased the yield compared to the manual irrigation. The use of SMS with a lower irrigation threshold increased the irrigation WUE of Amaranthus cruentus without statistically reducing yield. The SMS treatment based on 50 % FC resulted in 174 % WUE based on the vegetable fresh weight while SMS treatment based on 75 % FC resulted in 181.82 % WUE based on the vegetable dry weight while maintaining statistically similar yields with other treatments. No statistical differences were observed among the irrigation treatments (Table 4). The present results are in agreement with those obtained by Mishra and Shivakumar (2000); Alderfasi (2000); Ouda *et al.* (2011) for barley crop production.

Influence of Irrigation treatments on Agronomic Parameters of Amaranthus cruentus

Number of leaves and plant height

The effect of manual and soil moisture sensor based irrigation treatments on the number of leaves and height of Amaranthus cruentus were summarized Table 5. Amaranthus cruentus irrigated manually had the greatest number of leaves (19) and closely followed by those irrigated automatically based on 100 % FC (18) while those of 75 % and 50 % FC had the smallest number of leaves (17). However, automatic irrigation based on 50 % FC had the highest plant height (30.24 cm) and closely followed by automatic irrigation based on 100% FC (28.89 cm) while 75 % FC were the shortest (27.26 cm). The result of ANOVA (Table 6) showed no significant variation in both the number of leaves and plant height at $p \geq 0.05$. DMRT (Table 7) further showed that the numbers of leaves and plant height were not statistically different at $p \geq 0.05$ among the irrigation treatments. The result of this work contradict the result of Yu *et al.*(2010) where plant heights of roses controlled by a computer program for automatic watering were slightly higher than those manually irrigated.

Table 5: Average values for the Agronomic parameters of Amaranthus cruentus based on the irrigation treatments

	Agronomic Parameters					
			Fresh yield		Dry yield	
Treatments	No of leaves	Plant height (cm)	Total fresh weight (g)	Shoot fresh weight (g)	Total dry weight (g)	Shoot dry weight (g)
100% FC (Automated)	18.00 ± 5.80	28.89 ± 6.14	84.19 ± 17.22	66.92 ± 13.59	11.75 ± 5.85	8.70 ± 5.11
75% FC	17.00 ±5.49	27.26 ± 6.02	77.28 ± 19.75	62.66 ± 15.61	13.68 ± 6.50	11.28 ± 5.46
50% FC	17.00 ± 5.06	30.24 ± 8.74	62.47 ± 16.04	52.22 ± 13.58	9.13 ± 2.10	7.58 ± 1.60
100% FC (Control)	19.00 ± 4.92	28.50 ± 7.64	83.16 ± 36.94	66.86 ± 28.23	13.30 ± 6.00	10.70 ± 4.72

Table 6: Summary of Analysis of Variance on influence of Irrigation treatments on Agronomic parameters

Agronomic parameters	F	Sig.
Number of leaves	0.769	ns
Plant height (cm)	0.346	ns
Total fresh weight (g)	0.694	ns
Shoot fresh weight (g)	0.544	ns
Total dry weight (g)	0.586	ns
Shoot dry weight (g)	0.590	ns

Fresh and Dry Weight of Amaranthus cruentus

The influence of irrigation treatments on Amaranthus cruentus total fresh weight, shoot fresh weight, total dry weight and shoot dry weight is presented in Table 5. Automated irrigation based on 100 % FC had the highest total (84.19 g) and shoot fresh weight (66.92 g) while 50 % FC produce the lowest total (62.47 g) and shoot fresh weight (52.22 g). However, the total and shoot dry weight was highest for treatment II (75 % FC). Treatment III recorded the lowest total fresh, shoot fresh, total dry and shoot dry weight of Amaranthus cruentus . Although, both the fresh and dry yield of Amaranthus cruentus of were slightly higher than that of manual irrigation except irrigation based on 50 % FC. ANOVA result showed there were no significant variation at $p \geq 0.05$ in total fresh weight, shoot fresh weight, total dry weight and shoot dry weight among the four irrigation treatments. Separation of means done by DMRT further show no significant variation at $p \geq 0.05$ in total fresh weight, shoot fresh weight, total dry weight and shoot dry weight among the four irrigation treatments. The result of this work go contrary to the findings of Gowing *et al.*(1990); Dry and Loveys (1998); Guang-Cheng *et al.*(2010). Guang-Cheng *et al.*(2010) found lower total dry weight for pepper grown under time space deficit irrigation (TSDI) compared to non-stressed plants. Gowing *et al.*(1990); Dry and Loveys (1998) too reported a reduction in shoot, root and total fresh weight growth under deficit irrigation conditions of automatically irrigated plants compared to the manual irrigation. However, work of Phene and Howell (1984); Smajstrla and Locascio (1996).

Table 7: Summary of Duncan multiple range t-test on influence of Irrigation treatments on Agronomic parameters

Agronomic parameters	Automated			Control
	100%	75%	50%	100%
Number of leaves	18.33a	16.69a	16.58a	19.37a
Plant height (cm)	28.89a	27.26a	30.24a	28.50a
Total fresh weight (g)	84.19a	77.28a	62.47a	83.16a
Shoot fresh weight (g)	66.92a	62.66a	52.22a	66.86a
Total dry weight (g)	11.75a	13.68a	9.13a	13.30a
Shoot dry weight (g)	8.70a	11.28a	7.50a	10.70a

Means with the same letter horizontally are not significantly different at ($p \geq 0.05$)

Dukes *et al.*(2003) supported the findings of this work. Phene and Howell (1984) reported similar tomato yield for both automated soil matrix sensor irrigation system and irrigated based on pan evaporation with less water used for irrigation. Smajstrla and Locascio (1996), reported 40 - 50 % reduction in water use compared to the manual irrigation with the use of switching tensiometer without reducing yield. Amayreh and Al-Abed (2005) confirmed in their research the potential of soil moisture based scheduling to reduce water applications as opposed to traditional time based schedules. In this research, soil moisture based treatments applied between 25 % and 57 % less water than comparative time based schedules which are typically used for irrigation scheduling. The results show that the reduction in the amount of water applied can be achieved without significant reductions in yield.

Relationship between volume of irrigation water applied, Irrigation parameters and Agronomic parameters of Amaranthus cruentus

Volume of irrigation water applied and water saving

The relationships of volume of water applied per irrigation treatment with WUE and water saving based on dry and fresh weight were linear relationships with significantly high determination coefficients (Figure 2 and 3). The result shows that WUE based on fresh weight, dry weight and water saving increased linearly with volume of water applied to the crops. The result indicates that WUE and water saving are highly affected by volume of water applied to the growing plants. Coefficient of determination of irrigation water and total fresh weight and shoot fresh weight were statistically different while coefficients of determination R 2 for total dry weight, shoot dry weight and plant number of leaves were statistically not significant at $p \geq 0.05$ (Figure 4 and 5). The result indicates that the total fresh yield, shoot fresh weight and number of leaves were highly influenced by volume of water applied to the growing plants while the volume of irrigation water applied did not have effect on the total dry and shoot dry matter content as well as plant height (Figure 6 and 7). The total fresh weight, shoot fresh weight, plant height and number of leaves increased linearly with WUE with statistically significant coefficients of determination R 2 values of 0.59, 0.61, 0.96 and 0.05 respectively (Figure 8, 9,10 and 11) while that of plant height, total dry weight and shoot dry weight were statistically not significant at $p \geq 0.05$. The result indicates that the maximum WUE did not correspond to the maximum yield.

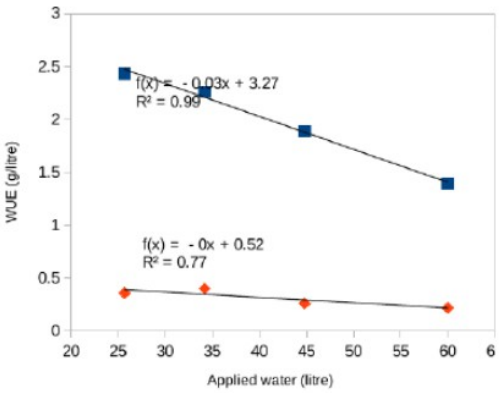

Figure 2: Relationship between WUE and irrigation water

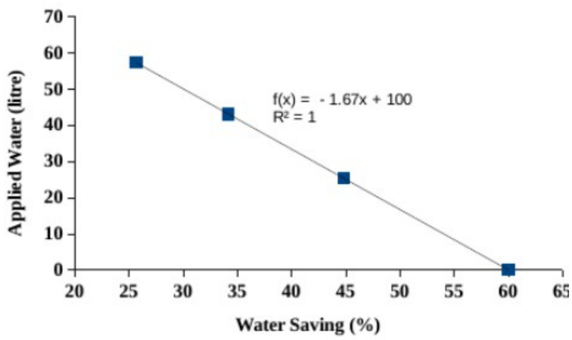

Figure 3: Relationship between Water saving and irrigation water

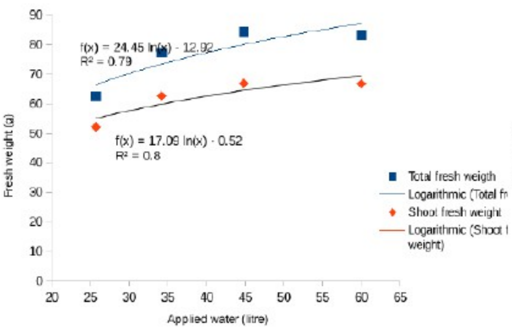

Figure 4: Relationship of irrigation water with vegetable fresh weight

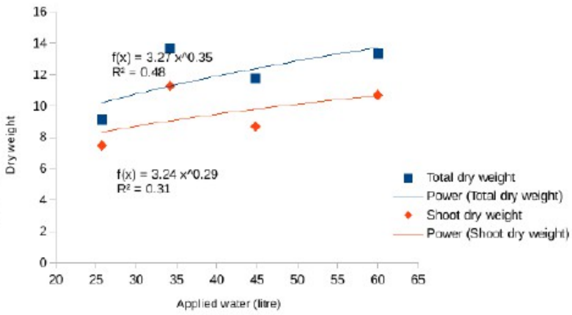

Figure 5: Relationship between irrigation water and Vegetable dry weight

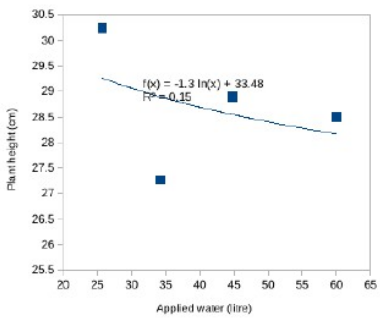

Figure 6: Relationship of Plant height and irri-

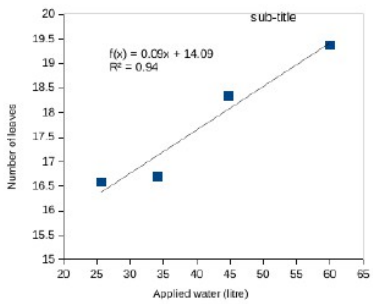

Figure 7: Relationship of Number of leaves and

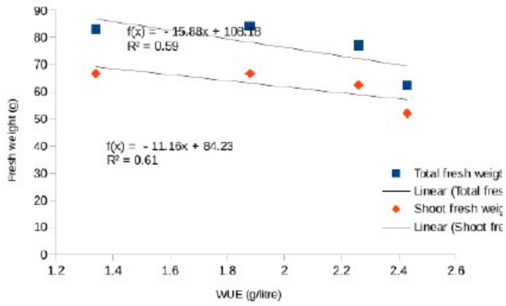

Figure 8: Relationship of WUE and Vegetable Fresh weight

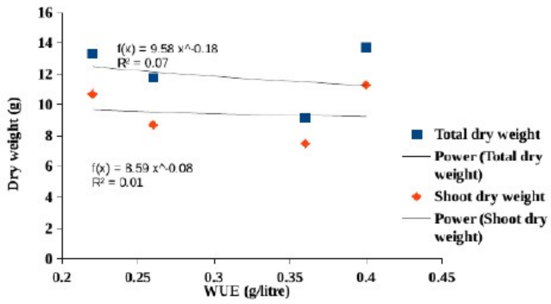

Figure 9: Relationship of WUE and Vegetable dry weight

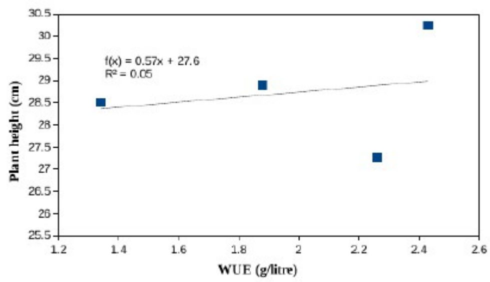

Figure 10: Relationship of plant height and WUE

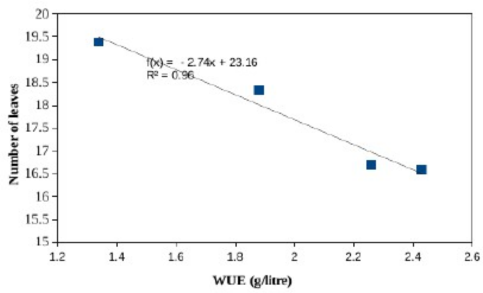

Figure 11: Relationship of Number of leaves and WUE

Conclusion

Soil moisture sensor-based (SMS-based) irrigation resulted to irrigation water saving compared to the manual watering. SMS-based on 50 % FC saved the largest volume of water (57.17 %) followed by 43 % by SMS-based on 75 % FC. SMS based on 50 % FC had the highest WUE of 2.43 based on plant fresh weight while SMS based on 100 % FC had the lowest WUE of 1.39. Thus, increasing irrigation volume did not necessarily result in higher yields. Estimated water consumption for Amaranthus cruentus was lower than the actual water used. Although, the highest total fresh weight of 84.19 g and shoot fresh weight of 66.92 g were recorded for SMS irrigation based on 100% FC which was closely followed by that of manual irrigation. The total dry weight, shoot dry weight, number of leaves and plant height were statistically similar for all the irrigation treatments. Regression analysis showed WUE, water saving, total fresh weight, shoot fresh weight and number of leaves were highly influenced by volume of water applied to the growing plants while the volume of irrigation water applied did not have effect on the total dry and shoot dry matter content as well as plant height. Future research should be carried out to test the efficiency of the SMS system in open field with various crops.

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