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Effects of Irrigation Regime on Soil Properties and Yield of Onion at Bontanga Irrigation Scheme of Northern Ghana

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ABSTRACT
The study evaluated the effect of irrigation regime on soil properties and onion yield at the Bontanga irrigation scheme. Randomised Complete Block Design was used on Red Creole onion variety using four treatments: 117%, 100%, 80% and 60% of the crop water requirement of onion with five replicates. The results indicated that mean bulb weight ranged from 3.167 to 4.213 t/ha with no significant difference observed among the various treatments (P > 0.05). However, the irrigation regime of 117% recorded the highest yield, with the yield decreasing with decrease in water application rate. There were significant differences between the soil moisture content at different weeks after transplanting for the various treatments. There was no significant difference among treatments for soil pH and nitrogen, but there was a decline in soil pH and nitrogen with decrease in water application. There was a significant increase in soil Potassium and Phosphorus contents between initial and after irrigation regimes of 60 and 117%. There was no significant difference among treatments for organic carbon content. After application of the various irrigation treatments, there was a significant increase in soil magnesium and calcium contents with respect to the initial contents of the soil, but with no significant difference among treatments. There was also a significant difference between each treatment and the initial cation exchange capacity. Farmers should adopt the minimum 60% irrigation regime in order to save water, while increasing yield. The study results suggested vegetable farmers could apply only nitrogen fertilizers or organic manure since phosphorus and potassium are available through irrigation.

INTRODUCTION

Irrigation water is supplied to supplement the water available from rainfall and the contribution to soil moisture from ground water. In many areas of the world the amount and timing of rainfall are not adequate to meet the moisture requirement of crops, making irrigation essential to raise crops necessary to meet the needs of food and fibre (Micheal, 1978). One way to address the issue of water shortage is through development of irrigation scheduling techniques such as deficit irrigation, which are not necessarily based on full crop water requirement. Deficit irrigation serves as a means of reducing water consumption while minimizing adverse effects of limited water on yield (English and Nakamura, 1989; English and Raja, 1996, Kirda, 2002). In this method, the crop is exposed to a certain level of water stress, either during a particular period or throughout the whole growing season.

In many parts of the world, onion (*Allium cepa* L.) is considered as an important vegetable crop and is mostly grown on irrigated lands (Martin *et al*., 1989). According to Obeng *et al.* (2007), the cultivation of onion in West Africa is concentrated in Burkina Faso, Northern Nigeria, Niger, Senegal and Northern Ghana. In Ghana, however, the crop is grown commercially in the Northern and Upper Regions, especially in areas around Bawku and Bolgatanga. Other production areas are Ashiaman, Dawhenya, Akatsi, Nsawam, Prestea, Koforidua, Kwahu, Mankessim and Berekum. In Ghana, the most popular onion *(Allium cepa* L.) cultivar is Bawku Red whereas Early Texas Grano and Red Creole are exotic cultivars which are also grown. In 1995, shallots and onion production in the country was 29,000 tonnes, covering an area of 1,970 ha (Vordzorgbe, 1997).

Decline in soil fertility is an important challenge facing food security in developing countries (Amalu, 2002). Fawusi *et al*. (1981) reported that although farmers know that chemical fertilizers were important for maintaining soil fertility, healthy plant growth and raising good harvest, the high cost of chemical fertilizers for resource poor farmers and the indiscriminate application of fertilizers affect the pH of the soil and ion antagonism. Brady (1996) stated that the impacts of pH in soil concentration influences the availability of plant nutrient. Soil pH is also responsible for the solubility of numerous nutrient elements. Onions are also sensitive to highly acidic soils and grow best when the pH is between 6.2 and 6.8. According to Raemaekers (2001), Karim and Ibrahim (2013) and FAO (2013) onion has average tolerance to soil pH ranging from 6 to 7. IFA (2000) reported the application of both organic manure and inorganic fertilizers is sufficient to improve soil fertility for sustainable levels of vegetable production.

A survey undertaken by MoFA (2010) indicated that in the Northern region of Ghana, soil pH ranges from 4.5-6.7, organic matter 0.6 ─ 2.0%, total nitrogen 0.02 ─ 0.05%, available phosphorus 2.5 ─ 10.0 (mg/kg soil) and available calcium 45 ─ 90 (mg/kg soil). This resulted from a high level of environmental and land degradation, bush fires, fragmented land, and deforestation for farming, urbanization, continued cropping and over grazing. Phosphorus deficiency is widespread in most soils of northern Ghana, and ferruginous nodules contained in some soils in the region highlight the deficiency problems, because they act as P sinks. Ferruginous nodules are present in many soils in Ghana and constitute a major problem in P nutrition (Abekoe and Tiessin, 1998). According to Fosu *et al.* (2001), organic matter content in the Guinea and Sudan savanna zones of Ghana is generally low with a mean around 1% in cultivated fields.

Irrigation needs for onion, like any other crop is location specific. The crop water requirement of onion is not evenly spread over the growing season, but depends largely on a number of factors, including the species, growth stages, soil properties and climatic conditions. Little is known about the response of the onion crop to different irrigation regimes, including water saving options in northern Ghana where onion is predominantly cultivated under irrigation during the dry season. Also little is known about the impact of irrigation water application regimes on soil properties in northern Ghana. In view of these, this study sorts to investigate the above two limitations.

MATERIALS AND METHODS

Study Area

The Bontanga Irrigation Scheme is located in the Northern Region of Ghana, in the Kumbungu district, 34 kilometres northwest of Tamale, the regional capital. It lies between latitude 9º 30" to 9º 35" N and longitude 1º 20"and 1º 04"W. The scheme has a potential area of 800 ha with 495 ha as the present irrigable land, of which 240 ha is used for lowland rice cultivation and 255 ha for upland vegetable production such as okra, pepper, onion and maize. The vegetables are produced mainly in the dry season, from October to April and rice in both the dry and wet seasons. The upland is free draining soil and plots are designed for furrow irrigation while the lowland soil is heavily textured and irrigated by flooding. The system works under gravity from the dam through the canals, laterals and to the various farms. The maximum, life and dead storage of the reservoir is 25 million m^3, 20 million m^3 and 5 million m^3, respectively. Two (2) main canals and twenty eight (28) laterals aid the distribution of water to the farms. Figure 1 is a map of the Bontanga Irrigation Scheme.

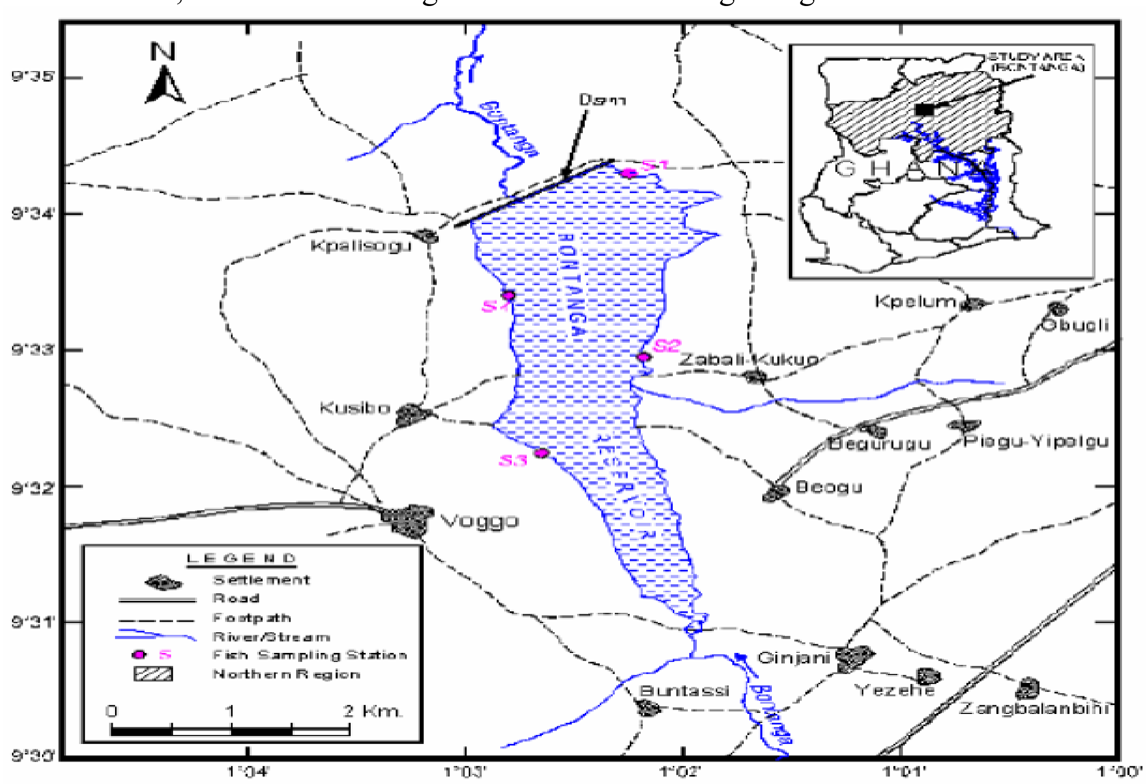

Figure 1: Map of Bontanga irrigation Scheme (Abdul-Ganiyu *et al.*, 2012).

A global positioning system (GPS) was used to take the coordinates of the study area and a map was extracted from the Google earth. Table 1 showed the GPS coordinates of various locations in the study area. Figure 2 and 3 shows google earth maps of the experimental units.

Table 1: GPS Coordinates of the Study Area

Location	Latitude (W)	Longitude (N)	Altitude (m)
Dam wall	1°01'42.92"	9°33'59.11"	122.2248
	1°01'23.52"	9°34'12.39"	121.0056
	1°01'08.47"	9°34'22.74"	123.1392
Lateral 5	1°01'21.75"	9°34'33.36"	117.348
	1°01'31.38"	9°35'23.45"	113.6904
Canal	1°01'31.90"	9°35'23.56"	113.9952
	1°01'32.90"	9°35'23.75"	113.9952
Experimental Plot	1°01'31.52"	9°35'19.77"	115.2144
Plot Demarcations			
Point A	1°01'31.90"	9°35'20.37"	115.2144
Point B	1°01'31.23"	9°35'20.43"	115.2144
Point C	1°01'31.12"	9°35'19.24"	115.5192

Point D	1°01'31.77'	9°35'19.18'	115.2144

Figure 2: A Google Earth Map of the Bontanga Irrigation Scheme (Google Earth, 2010).

Figure 3: A Google Earth Map of the Experimental Plot (Google Earth, 2010).

Cultural Practices

Ploughing and bed laying were undertaken to prepare the cropping field. The pre-emergence weedicide pendimethalin at 500 g a.i./litre was then sprayed on the field-beds. After land preparation, onion seedlings were transplanted 42 days after nursing on the field, at crop spacing of 20 cm × 15 cm, resulting in a crop density of 160 plants per plot of size 6 m^2. A total of 450 kg/ha NPK (15:15:15) fertilizer was applied by a split application at two weeks and twelve weeks after transplanting (WATP). Hand hoe was used to control weed growth during the crop growth. The insecticide emamectin benzoate (Rate: 15ml/15L) and fungicide mangozeb at 80 % w/w were also applied across the field at two and eight weeks (WATP). After transplanting, 117 %, 100 %, 80 % and 60 % of the crop water requirements of the crop (ETc) was applied as treatments for 95 days duration. Water application was done daily in the morning. The total water used during irrigation was 3647.242 m^3/ha, 3117.3 m^3/ha, 2493.84 m^3/ha, and 1870.38 m^3/ha respectively, for 117 %, 100 %, 80 %, and 60 % irrigation regimes.

Experimental Design

The experiment was arranged in a Randomised Complete Block Design (RCBD) with four treatments in five replicate blocks. The ET_c irrigation regimes included 117% (practiced by farmers), 100%, 80%, and 60% on a total land area of 226.2 m^2. The plot size was 1.2 m × 5 m and a block size of 7.8 m^2 was used. Both row and block alleys were 1 m. Figure 4 shows the field layout for the experiment.

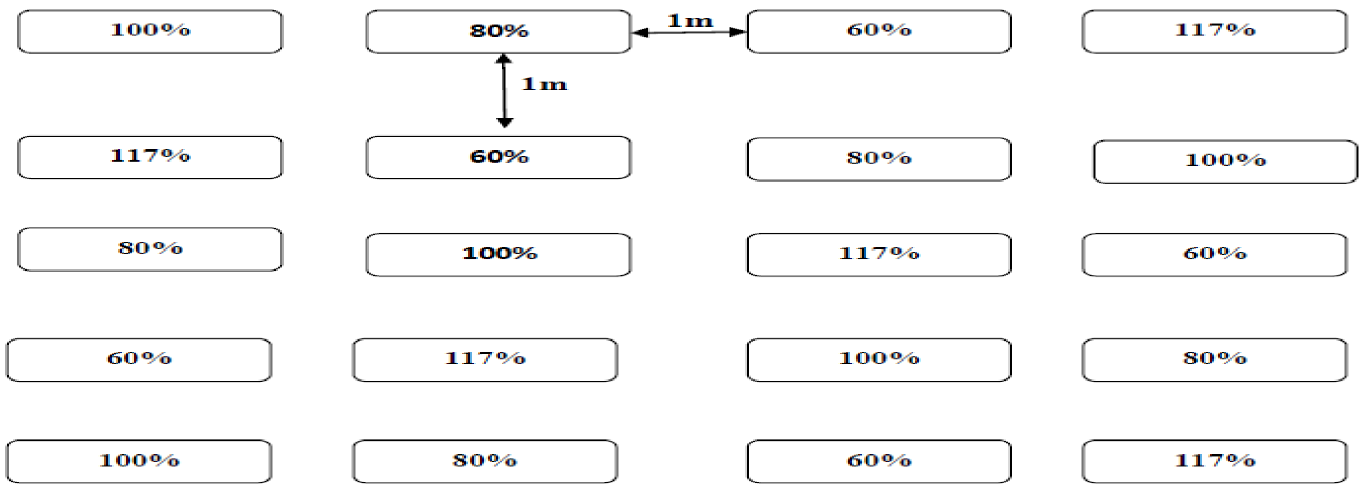

Figure 4: Experimental field layout

Soil Analysis

Soil samples were randomly taken from the upper, middle and lower portion of the experimental plots before planting and after harvest using a soil auger at a depth of 0 - 15 cm. A total of twenty five soil samples was collected and air dried. Soil aggregates were crushed in a mortar and sieved with a 2 mm sieve. The following soil parameters were then analysed in the Savannah Agricultural Research Institute laboratory: Soil texture using USDA method, Soil pH was analysed and recorded using the IITA (1982) method; the total Nitrogen N was analysed using micro Kjeldahl methods (Novozamsky *et al.,* 1983). Phosphorus (P) was determined using Bray and Kurtz (1945). Exchangeable Cations (Potassium (K), Calcium (Ca) and Magnesium (Mg) were determined. Determination of the concentration of potassium in the soil extract was done using the flame photometer (Toth and Prince, 1949). Calcium and Magnesium were also determined from the soil extract, using the Atomic Absorption Spectrophotometer (AAS). Organic Carbon (OC) was determined using Nelson and Sommers (1996). Cation Exchange Capacity (CEC) was determined using a flame photometer.

Soil Moisture Content

Using Time Domain Reflectrometer (30 cm depth), soil moisture content was determined and recorded for various treatments at 4, 6, 8 and 10 (WATP) after an initial soil moisture content was taken. Each plot was divided into three sections and data was taken within each section. The resultant average on each plot was then recorded as the moisture content for the plot.

Agronomic data

Bulb yield was estimated by harvesting crops on each plot distinctively and weighing them separately.

RESULTS AND DISCUSSIONS

Effects of Irrigation Regimes on Soil Moisture Content

Soil moisture content as influenced by different irrigation regimes showed significant differences in the various treatments (Figure 5). Soil moisture content reduced from the initial soil moisture content (28 %) with respect to all irrigation regimes. Irrigation regime of 117 % had the highest mean soil moisture content of 19.78 %, whereas 60 % irrigation regime recorded the least 15.83 %. According to FAO (2013), onion like most vegetable crops, is sensitive to water deficit and for high yield, soil water depletion should not exceed 25 % of available soil water. When the soil was kept relatively wet, root growth reduced and this favoured bulb enlargement. From the results, soil moisture content at all the irrigation regimes was in line with findings of FAO (2013).

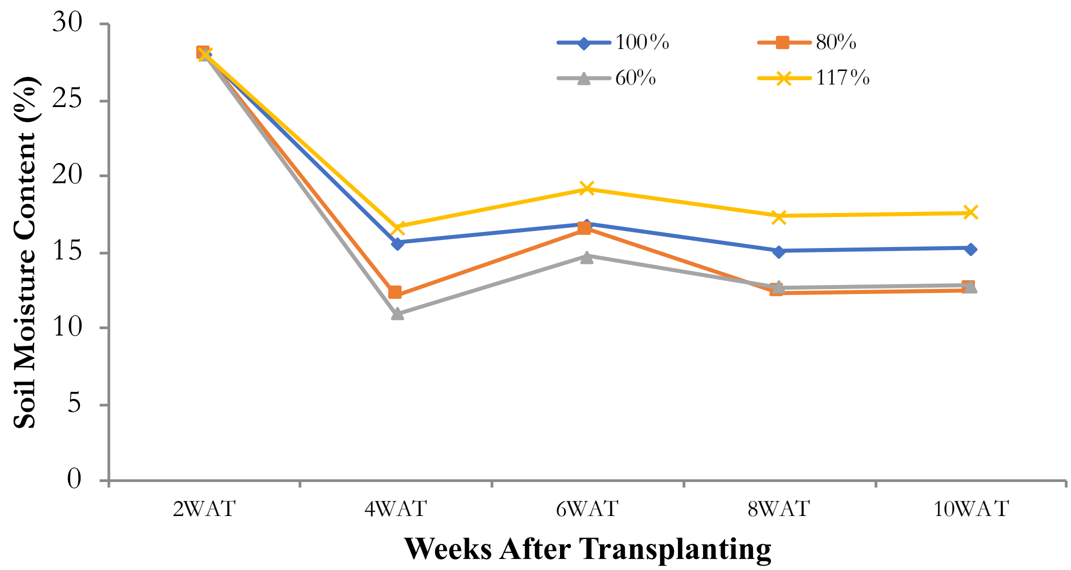

Figure 5: Soil Moisture Content as Affected by Different Irrigation Regimes

Effects of Irrigation Regimes on Soil pH

The average soil pH as recorded before treatment application was 4.91. There was no significant difference among treatments. There was a decline in soil pH level to a range of 4.3 – 4.4 lower than the range in northern Ghana (4.5-6.7) as reported by MoFA (2010) as a result of different irrigation regimes (Figure 6). FAO (1976) classified tropical soil pH ranging from 4.5-5.5 and 7.5-7.8 as medium and that ranging from 4.0 - 4.5 as low. FAO (2013) and Raemaekers (2001) established that onion has average tolerance to soil acidity ranging from pH 6 to 7. The increased soil acidity due to treatment might affect onion yield. It was then evident that soil pH is affected by irrigation.

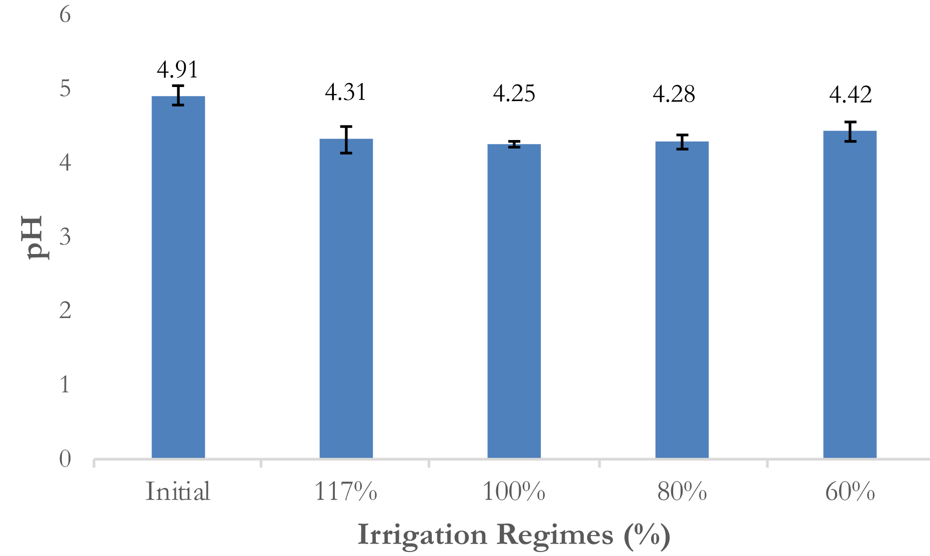

Figure 6: Soil pH as Affected by Different Irrigation Regimes. Bars Representing Standard Errors.

Effects of Irrigation Regimes on Soil Nitrogen, Phosphorus and Potassium Content

The average nitrogen content of the soil recorded before treatment application was 0.08 %. After application of irrigation treatments, there was a significant decrease comparing each treatment to the initial value (Figure 7). Irrigation treatments recorded soil nitrogen contents ranging from 0.030 – 0.044 %. Irrigation regime of 60 % recorded the least soil nitrogen content of 0.030 %, whereas 0.044 % was recorded by the irrigation regime of 80 % as the highest nitrogen content among treatments, although similar results were attained at 100 % and 117 %.

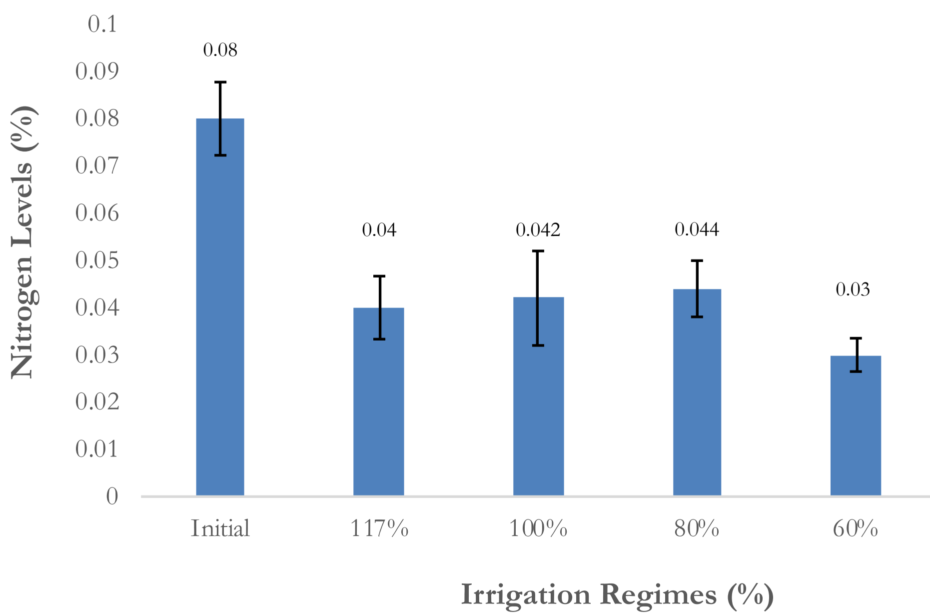

Figure 7: Soil Nitrogen Content as Affected by Different Irrigation Regimes. Bars Representing Standard Errors.

Effect of Different Irrigation Regimes on Soil Potassium and Phosphorus Content

The average initial potassium and phosphorus content of the soil were 81.6 ppm and 10.3 ppm respectively. There was an increase in both soil nutrient parameters after treatment application (Table 2). There was a significant increase in soil potassium content between initial and after irrigation regimes of 60 and 117 %. Soil phosphorus content also increased significantly between initial and after the irrigation regime of 117 %. Irrigation regimes of 60 % and 100 % recorded 20.5 ppm and 14.8 ppm, respectively, as the highest and least soil phosphorus content. Also, irrigation regimes of 60 % and 100 % recorded 160.0 ppm and 122.5 ppm, respectively, as the highest and least soil potassium content. FAO (1976) classified tropical soil phosphorus content greater than 10 mg/kg (10 ppm) as high and potassium content also greater than 0.4 as Cmol/kg as high. By these standards, the soil nitrogen content is very low whereas that of phosphorus and potassium are high.

Table 2: Effect of Different Irrigation Regimes on Soil Potassium and Phosphorus Content

Parameter			Treatments (%)			Grand Mean	LSD 5%	CV (%)	F.Pr Values
	Baseline	117	100	80	60				
K(ppm)	81.6	144.0	122.5	154.0	160.0	132.4	65.9	37.7	0.129
P(ppm)	10.3	16.0	14.8	17.2	20.5	15.8	9.2	44.0	0.263

Effects of Different Irrigation Regimes on Soil Organic Carbon

The results of soil organic carbon content as influenced by the different irrigation regimes are presented in Figure 8. The organic carbon content of the soil as recorded before treatment application was 0.694 %. However, after application of treatments, there was a significant decrease in soil organic carbon content with respect to the initial organic carbon content of soil. There was no significant difference among treatments. As such organic carbon content ranged from 0.484 % being the highest mean recorded by 100 % irrigation treatment to 0.424 % as the least mean recorded by 80 % irrigation treatment. By FAO (1976) standards, the soil organic carbon content recorded was very low (< 2 %) with respect to tropical soils for crop production. Abu and Malgwi (2014), also reported that the application of water depths of 85 % TAW and 8 days frequency significantly enhanced soil organic carbon (OC) content, and consequently, promoted macro-aggregate stability measured by mean weight diameter and micro-aggregate stability measured by aggregating silt and clay and clay flocculation index as well as infiltration rate.

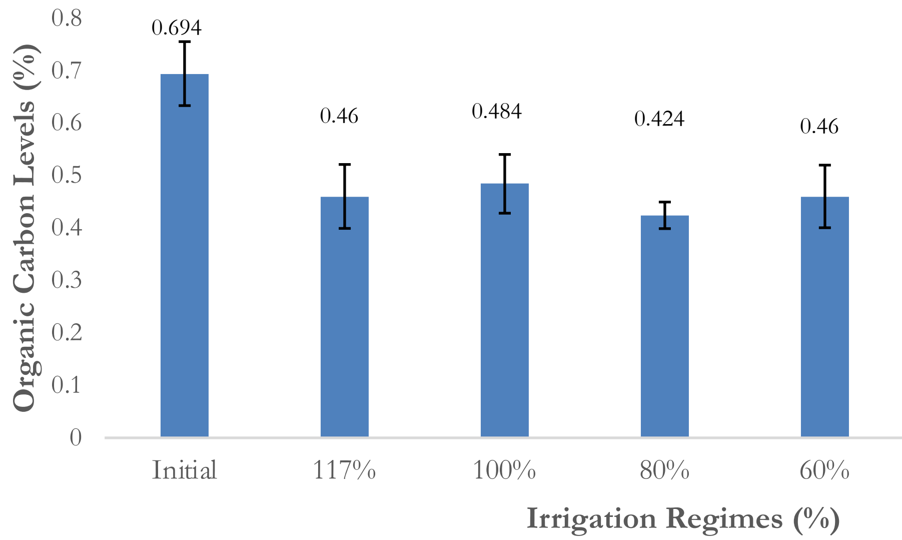

Figure 8: Soil Organic Carbon Content as Affected by Different Irrigation Regimes. Bars Representing Standard Errors.

Effects of Different Irrigation Regimes on Soil Magnesium, Calcium and CEC

The results of soil magnesium content as influenced by the different irrigation regimes showed initial soil magnesium content was 36 ppm (Figure 9). After application of the various irrigation treatments, there was a significant increase in soil magnesium content. As such magnesium content ranged from 222 ppm being the highest recorded by 100 % irrigation treatment to 167 ppm, also being the least recorded by 80 % irrigation treatment, although similar results were attained there were no difference among treatments.

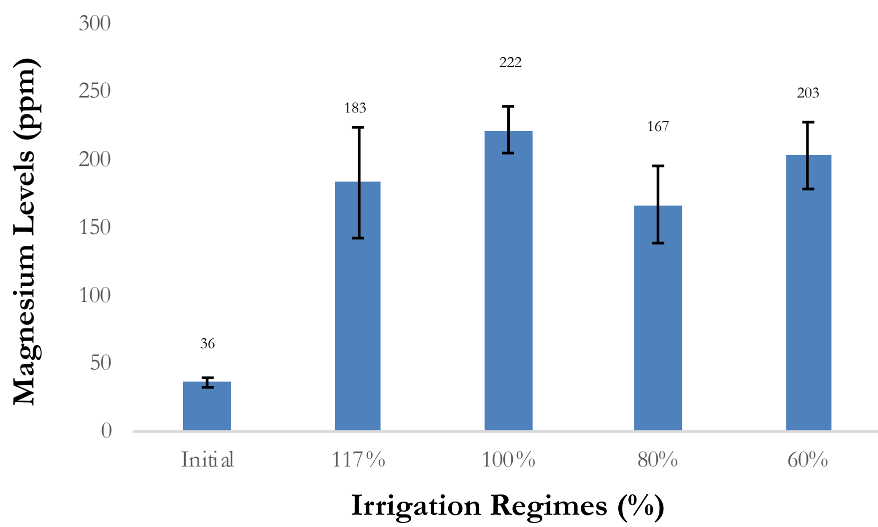

Figure 9: Effect of Different Irrigation Regimes on Soil Magnesium Content. Bars Representing Standard Errors.

The results of calcium content of the soil as influenced by the different irrigation regimes resulted in calcium content recorded before treatment was 175 ppm (Figure 10). However, after treatments, there was a significant increase in soil calcium content with respect to the initial calcium content of the soil. There was no significant difference among treatments, but with calcium content ranging from 906 ppm as the highest mean recorded by 117% irrigation treatment to 660 ppm as the least mean recorded by 80 % irrigation treatment. The calcium content, however, was within the range recorded by MoFA (2010) (45-90 mg/kg) after irrigation treatments were applied. Petterson *et al.* (1983) reported an increased content of Mg, Ca and S under fertigation and are mainly ascribed to the positive interactions of the nutrients and moisture and also their greater availability due to increased organic inputs.

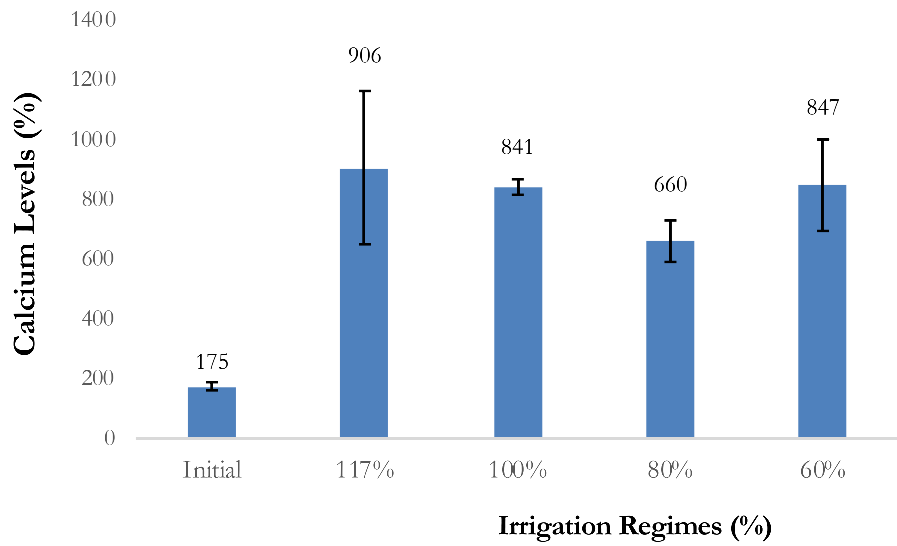

Figure 10: Effect of Different Irrigation Regimes on Soil Calcium Content. Bars Representing Standard Errors.

There was a general increase in the cation exchange capacity (CEC) of the soils after application of each treatment (Figure 11). There was a significant difference between each treatment and the initial cation exchange capacity of the soil except for irrigation regime of 80 %. Cation exchange capacity of soils per treatments ranged from 5.22 – 6.61 cmol at the end of the experiment, whereas the initial CEC of the soil was 2.71 cmol. According to FAO (1976) standards, the resultant cation exchange capacity is low, in that they are all less than 8 cmol/kg. Drip irrigation treatments sustain soil CEC and organic carbon of the soil as compared to the conventional methods of irrigation (Dubey *et al.*, 2003). Contrary to the results, Shakoor *et al.* (2012) reported that flood irrigation caused a reduction in soil CEC in both top and subsoil.

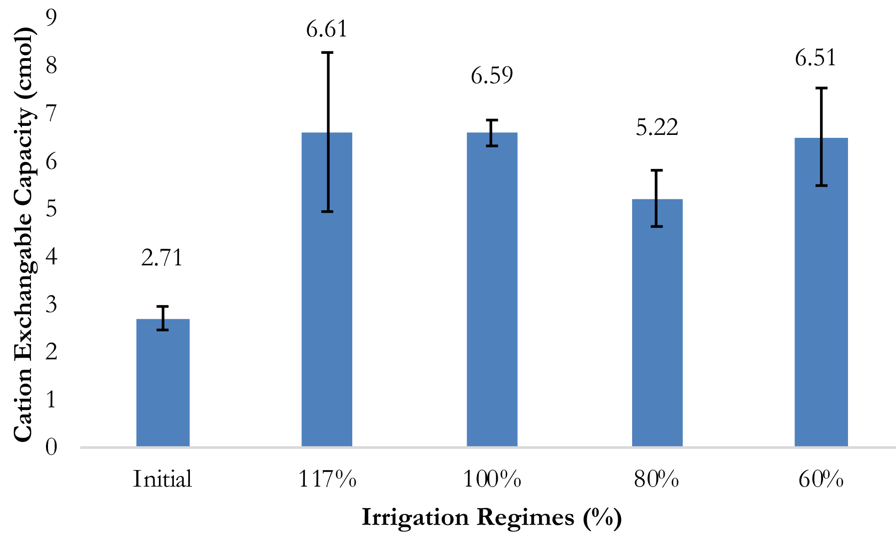

Figure 11: Influence of Different Irrigation Regimes on Soil CEC. Bars Representing Standard Errors.

Effects of Irrigation Regimes on Onion Yield

The effect of different irrigation regimes on the weight of the harvested bulb per hectare after cropping ranged from 3.167 to 4.213 t/ha (Figure 12). No significant difference was observed among the various treatments and the baseline. However, the irrigation regime of 117 % recorded the highest weight of yield, with the yield decreasing with water application rate. This is in line with findings of Addai *et al.* (2014), which indicated that there is no significant difference between yields based on irrigation rate. Reports from Borivoj *et al.* (2010); Nagaz *et al.* (2012) and Biswas *et al.* (2010) on the other hand illustrated that onion yield was significantly affected by irrigation. FAO (2013) indicated that when the soil is kept relatively wet, root growth is reduced and this favours bulb enlargement. Adding to this, Al-Kaisi (2005) also established that the most critical growth period of onions to water stress is the bulb formation and development stage.

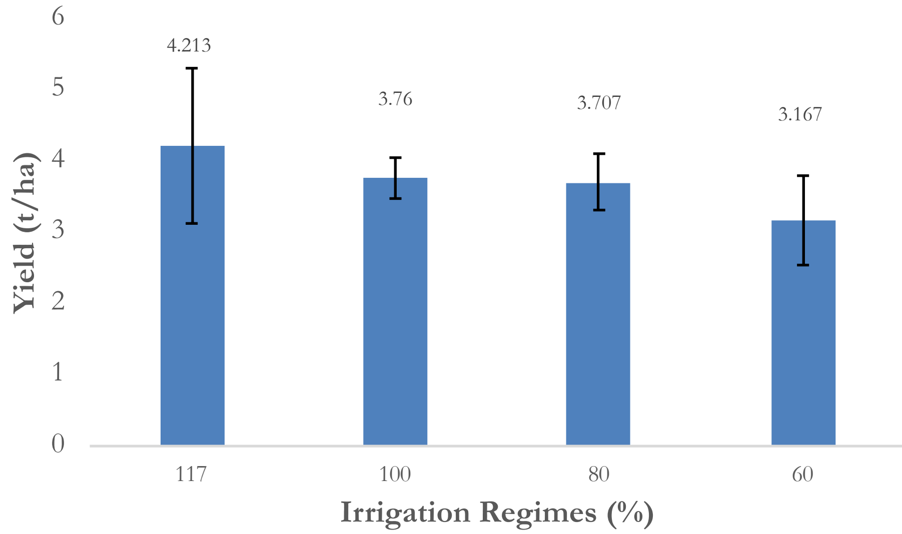

Figure 12: Effect of Different Irrigation Regimes on Onion Yield. Bars Representing Standard Errors.

Relationship between Soil Nutrient Properties

Correlation analysis was used to determine the relationship between various soil nutrients after irrigation treatments. At a significance level of $p<0.001$, soil nitrogen content positively correlated with soil pH and soil organic carbon content, but negatively correlated with soil phosphorus, cation exchange capacity, calcium, potassium and magnesium content (Table 3). Soil organic carbon negatively correlated with soil cation exchange capacity, calcium, potassium and magnesium content, but positively correlated with phosphorus and soil pH. The phosphorus content of soil correlated negatively with soil pH, but positively correlated with soil magnesium, potassium, calcium and cation exchange capacity. Soil pH then correlated negatively with soil calcium, cation exchange capacity, potassium and magnesium content. There was a positive significant correlation between soil cation exchange capacity and magnesium, potassium and calcium content. A positive significant correlation as well existed between soil calcium content and soil potassium and magnesium content. At a significant level of <0.001 there was a positive correlation between soil potassium content and soil magnesium content. These results are indicated in Table 3.

Table 3: Correlation Analysis of Soil Nutrients Showing a Two-sided Test of Correlations Different from Zero

Nutrients		Correlation			
%_N_kjeldahl	1	-			
		-			
%_O_C_Walkley_Black	2	0.8518	-		
		(<0.001)	-		
Bray1_P_ppm	3	-0.1503	0.0005	-	
		(0.4734)	(0.9980)	-	
CEC_cmol_kg	4	-0.3780	-0.1934	0.6247	-
		(0.0624)	(0.3542)	(<0.001)	-

Ca_ppm	5	-0.4689 (0.0180)	-0.2967 (0.1498)	0.6120 (0.0011)	0.9852 (<0.001)	- -			
K_ppm	6	-0.2952 (0.1520)	-0.1295 (0.5373)	0.6588 (<0.001)	0.9577 (<0.001)	0.9361 (<0.001)	- -		
Mg_ppm	7	-0.4744 (0.0166)	-0.2963 (0.1503)	0.5154 (0.0084)	0.8646 (<0.001)	0.8388 (<0.001)	0.8040 (<0.001)	- -	
pH_1_5_H2O	8	0.7247 (<0.001)	0.7803 (<0.001)	-0.1195 (0.5695)	-0.2991 (0.1464)	-0.4025 (0.0461)	-0.1784 (0.3936)	-0.3670 (0.0711)	- -
		1	2	3	4	5	6	7	8

Soil Nutrient Properties, Soil Moisture Content and Crop Yield

Correlation analysis was undertaken to know the relationship between various soil nutrients, soil moisture content and crop yield after different irrigation treatments. At a significance level of <0.001, soil moisture content negatively correlated with soil pH, organic carbon content, potassium, calcium, magnesium, cation exchangeable capacity and crop yield (Table 4). Crop yield as well positively correlated with soil pH, organic carbon content, nitrogen, potassium, calcium and the cation exchangeable capacity of the soil.

Table 4: Correlation Analysis of Soil Nutrients, Soil Moisture Content and Crop Yield Showing a Two-sided Test of Correlations Different from Zero

Variable		Correlation						
pH(1:2.5 H2O)	1	- -						
% O.C(Walkley-Black)	2	0.5890 (0.0063)	- -					
% N(kjeldahl)	3	0.3122 (0.1803)	0.7533 (<0.001)	- -				
Bray1 P(ppm)	4	0.0277 (0.9076)	0.2976 (0.2025)	0.0181 (0.9396)	- -			
K(ppm)	5	0.2271 (0.3356)	0.3582 (0.1210)	0.0808 (0.7347)	0.6137 (0.0040)	- -		
Ca(ppm)	6	0.1035 (0.6641)	0.2761 (0.2386)	0.0552 (0.8171)	0.5791 (0.0075)	0.9643 (<0.001)	- -	
Mg(ppm)	7	0.3432	0.4642 (0.0392)	0.2226 (0.3455)	0.4149	0.7795	0.6884 (<0.001)	- -

		(0.1385)			(0.0689)	(<0.001)					
CEC(cmol/kg)	8	0.1751 (0.4604)	0.3331 (0.1513)	0.0914 (0.7016)	0.5669 (0.0092)	0.9780 (<0.001)	0.9861 (<0.001)	0.7943 (<0.001)	- -		
Yield(kg/ha)	9	0.5074 (0.0224)	0.5642 (0.0096)	0.5281 (0.0167)	0.2494 (0.2890)	0.5168 (0.0197)	0.5143 (0.0203)	0.3278 (0.1583)	0.5080 (0.0222)	- -	
Soil moisture content	10	-0.1865 (0.4310)	-0.0724 (0.7618)	0.0273 (0.9090)	0.1540 (0.5169)	-0.1061 (0.6563)	-0.0719 (0.7631)	-0.1255 (0.5980)	-0.1132 (0.6346)	-0.0417 (0.8613)	- -
		1	2	3	4	5	6	7	8	9	10

CONCLUSION AND RECOMMENDATIONS

Cation Exchange Capacity of the soil increased significantly after application of various irrigation water regimes except for irrigation regime of 80 %. There was no significant difference in soil pH levels among treatments, but a significant decrease after application of treatments. After application of irrigation treatments, there was a significant decrease in the soil nitrogen content from the initial value. There was also a significant increase in soil potassium content after irrigation regimes of 60 and 117 %. Soil phosphorus content also increased significantly after water irrigation regime of 117 %. There was a significant increase in soil organic carbon, magnesium and calcium content from the initial compared to that after various irrigation regimes. The study showed that production of onion in dry season (February to May) under deficit irrigation of 20 % and 40 % and over irrigation of 117% did not significantly affect the yield.

The following are recommendations for further studies; in the event of water deficit, farmers should adopt 60 % irrigation regime in order to save water, while increasing yield, considering the low pH level of the soil, liming should be done to increase the soil pH and the study should be repeated over space and time taking into consideration various soil conservation measures, such as mulching and application of organic manure so as to improve upon soil nitrogen which reduces with irrigation.

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