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Full Length Research Paper

Deficit Irrigation Application Using Center Pivot Sprinkler Irrigation for Onion Production

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ABSTRACT

When properly applied, deficit irrigation is believed to improve water use efficiency and water productivity without significantly reducing yield. The main objective of this study was to evaluate water use efficiency and water productivity of deficit irrigation application using sprinkler irrigation. The experiment was conducted at Lay Bir farm, in Jabitehnan woreda, West Gojam Zone of Amhara Region with three (full, three-quarter, and half of) irrigation application levels. The experiment was designed in Randomized Complete Block Design (RCBD) and the field layout was radially set at 2^o angle interval per treatment. The center pivot sprinkler installed in the experimental area was irrigating a total of 37.7 ha of which 1.8 ha was taken for this research. The performance of different irrigation levels were evaluated using the following performance indicators: onion bulb yield, number of onion plant at harvest, dry matter percentage and WUE. The major findings indicated that the yield of full application level was 40 tons/ha, the three quarter of irrigation application level was 33.7 tons/ha while that of half of the irrigation application levels gave 21.6 ton/ha. The number of onion plant at harvest were also found to be 246038, 281007 and 409305 plants per ha for the half, three-quarter and full application levels, respectively. The corresponding dry matter percentages were 3140.9 kg/ha, 4852.3 kg/ha and 5853.4 kg/ha, consequently. However, the difference between three- quarter and full irrigation application rates exhibited no significant difference .There was significant difference between the number of onion plant at harvest obtained under the three treatments indicating the fact that effect of the stress is higher on yield and on plant count. The dry matter obtained with half of irrigation application was significantly lower than that obtained under the three-quarter and the full irrigation amount . Nevertheless, there was no significant difference between three-quarter and full of the irrigation applications. IWUE values obtained were 57.1, 59.4 and 52.8 kg/ha.mm for the half, three-quarter, and full of the irrigation applications. Moreover the CWUE values were 65.1, 67.6 and 60.2 kg/ha.mm. The variability among the three treatments however was not statistically significant. Based on this study, it can be concluded that onion yield is highly dependent on the amount of water applied.

Key words: *Deficit irrigation, Water productivity, Water use efficiency*

INTRODUCTION

Irrigation plays a crucial role in addressing the main challenges caused by food insecurity and rainfall uncertainty. FAO (2002) estimated that 80% of the additional production required to meet the demands of the future will have to come from intensification and yield increase. Intensification of agricultural production by using selected seed and fertilizer in the rainfed system is expected to face daunting challenge due to the vagaries of weather and rainfall uncertainty.

Most Ethiopian farmers depend on rain-fed agriculture. However, rainfall is very erratic, and drought occurs very frequently. The Amhara region is not an exception with most parts of the region suffering from insufficient and unreliable rainfall. Due to severe soil erosion on the highlands, soils of the region are shallow in depth, have very low moisture retention capacity and low organic matter. These adversities of climate and soil resulted in the prevalence of soil moisture deficit for most of the year, which led to the loss of crop production. In most places of the region, rain occurs only in few months of the growing season and is usually short and intense resulting in high runoff, which goes un-utilized. It is thus important to use the limited amount of available rainfall as efficiently as possible for better crop growth.

Consequently, the country is finding it difficult to cope with drought shocks because of its frequency and increasing population pressure. Under such circumstances, the only reliable way to stabilize agricultural productivity is through irrigation. It has been loudly and clearly said that if the country is to feed its ever increasing population and to lessen the risk of catastrophes caused by drought and increase in population density in the arid and sparsely populated areas, irrigation development is an important issue.

The nation wide investment towards harnessing the water resources of the country in general and on irrigation development in particular is impressive by all measures. The total area under irrigation is estimated to be about 250 000 ha compared to the 3.5 Mha potential irrigable land with surface water (Awulachew *et al.*, 2005)

The government is investing heavily on huge irrigation projects like Tendaho, Kessem, etc. This is over and above the irrigation development effort by the Regional States. At the same time, however, quite a number of schemes are either fully or partially being abandoned. This is mainly due to lack of proper management. There are plenty of evidences pointing that management of irrigation water has not received adequate attention as the development of new schemes while the cost incurred for constructing irrigation schemes is increasing by the year.

The big challenges for the coming decades will be the task of increasing food production with less water, particularly in countries like Ethiopia where water is the most critical and limiting factor for agricultural production. Hence efficient use of irrigation water, wherever it is available, has been an important consideration in the drought prone areas of the country.

In order to increase food production and stabilize agricultural productivity, a two-pronged strategy is needed. These are increasing water productivity in existing irrigation schemes through modernization of such schemes, and/or increasing the area under irrigation by developing rainfed schemes into irrigated schemes. With increasing scarcity and growing competition for water, there will be a limit to bring rainfed systems under irrigation. However, there are plenty of opportunities in improving the performance of the developed systems. Effort should be made to grow more crops with a limited amount of water by reducing avoidable irrigation water wastages.

On such strategy currently pursued in many parts of the world is the adoption of deficit irrigation, especially in arid and semi-arid regions. This is an optimization strategy in which irrigation is applied during drought-sensitive growth stages of a crop. Outside these periods, irrigation is limited or even unnecessary if rainfall provides a minimum supply of water. Water restriction is limited to drought-tolerant phonological stages, often the vegetative stages and the late ripening period. Total irrigation application is therefore not proportional to irrigation requirements throughout the crop cycle. While this inevitably results in plant drought stress (Steduto *et al.,* 2009) and consequently in production loss, deficit irrigation maximizes irrigation water productivity (English *et al.*, 1990). In other words, deficit irrigation aims at stabilizing yields and at obtaining maximum crop water productivity rather than maximum yields (Zhang *et al.,* 1999). Deficit irrigation is also known to decrease the risk of certain fungal diseases linked to higher humidity on onion in comparison with full irrigation (Kirda, 2002; Kirda *et al.,* 1999)

From an economic standpoint, maximum profit for farmers may be obtained with the fulfillment of the entire crop water requirements. However, practicing deficit irrigation could increase the irrigated area or the frequency of cultivation. For many crops, high yields as well as high water use efficiency values could have been obtained provided the right choice of the period of water application is made. Under the conditions of the growing season, appropriate irrigation management practices would have allowed for the area covered by many crops to be doubled and in some crops increased with some percentage with no decrease in yield. With a limited yield reduction, the area cropped by some crops could have been also doubled, with a substantial increase in economic returns (Bazza, 1994).

The technique has already been applied to a wide variety of crops and findings have been encouraging. Raes *et al.*, (2008) discussed that deficit irrigation can increase water use efficiency without severe yield reductions. For example, for winter wheat in Turkey, planned deficit irrigation increased yields by 65% as compared to winter wheat under rainfed cultivation, and had doubled the water use efficiency as compared to rainfed and fully irrigated winter wheat. Similar positive results have been reported for cotton. Experiments conducted in Turkey and India indicated that the irrigation water use for cotton could be reduced up to 60 percent of the total crop water requirement with limited yield losses. In this way, high water productivity and a better nutrient-water balance was obtained (Zwart and Bastiaanssen, 2004).

Certain underutilized and horticultural crops such as quinoa also respond favorably to deficit irrigation when tested at experimental and farmer level for the crop (Geerts *et al.*, 2008). It was found that yields could be stabilized at around 1.6 tons per hectare by supplementing irrigation water if rainwater was lacking during the plant establishment and reproductive stages. Applying irrigation water throughout the whole season (full irrigation) reduced the water productivity. For other crops, the application of deficit irrigation resulted in a lower water use efficiency and yield. This is the case when crops are sensitive to drought stress throughout the complete season such as maize (Pandey *et al.,* 2000).

There are different ways where deficit irrigation could be applied. But the degree of control varies depending on the irrigation methods. Surface irrigation methods are often difficult to apply deficit irrigation because of poor irrigation water control. On the other hand, drip and sprinkler irrigation methods are preferable to less efficient traditional surface methods as it is much easier to apply measured amount of water at the right time and place. The use of sprinkler irrigation in Ethiopia is expanding. Fincha Sugar Factory farm was among the earliest to introduce sprinkler irrigation on a large scale. Recently, more and more farms have started to install sprinkler irrigation. One such farm is Bir Farm in Gojam where this research was made. Here, sprinkler system is used to grow onion, a crop which is known to fetch high return on investment, and its production is expected to increase in the future because of increasing demand. Hence, studying deficit irrigation application for onion as a test crop under sprinkler irrigation is expected to generate useful new information which would help agricultural water management endeavors in the country.

This study was, therefore, proposed and executed with the specific objective of studying the water use efficiency of onion using sprinkler irrigation in order to address the potential of deficit irrigation application using sprinkler irrigation.

MATERIALS AND METHODS

Description of the Study Area

The experiment was conducted at Lay Bir farm, in Jabitehnan Woreda, West Gojam Zone of Amhara Region, which is located 400 km North West of Addis Ababa and 170 km South East of Bahir Dar. The area has an annual rainfall of 1031mm, and average minimum and maximum temperatures of 11.9 and 29.0 ^{o}C, respectively. The altitude is about 1692 m.a.s.l, and at a latitude and longitude of 10°N and 37°E, respectively (Bir Farm Metrological Station).

The soil in the experimental site is red (nitosol) with moderate organic matter content and acidity. The major crops grown include maize, wheat, sorghum, soybean, haricot beans, onion and pepper. Among these crops, onion is the largest irrigated crop. Cereal crops like maize, wheat and sorghum are rainfed. In the study farm, both surface and sprinkler irrigation methods are practiced but the area under sprinkler irrigation is fast expanding.

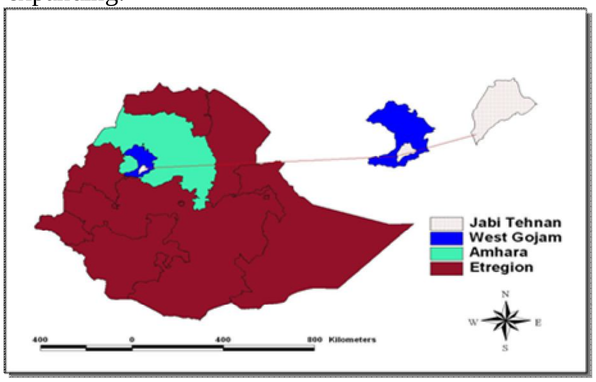

Figure 1. Location map of the study area

Experimental Design, Treatment Setting and Field Layout

The experimental design was Randomized Complete Block Design (RCBD) with three treatments and three replications. The three treatments were 50% water stress (Half of the irrigation application), 25% water stress (Three-quarter of the irrigation application) and no stress (full of the irrigation application). Each treatment was replicated three times. The field layout was radial set at 2^0 angle and 346.5 m radius. The center pivot sprinkler installed in the experimental area was irrigating a total of 37.7 ha. From this total area, about 1.8 ha was devoted to this experiment. The area is obtained from the 18^0 segments of the circle with a radius of 346.5 m. The plot area per treatment was 2094 m^2(2^0) taken. In order to overcome the effect of overlapping between two adjacent treatments, the actual area considered for sampling was the central 13.25 m^2 area of the plot.

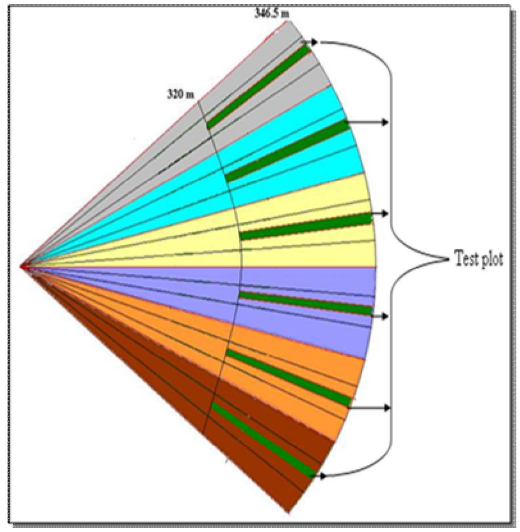

Figure 2. Schematic diagram of the experimental plot

Soil sampling and measurements

Soil samples were taken from the experimental plots after the seasonal rain stoped and before the first irrigation started. Samples were taken randomly from nine places, two at each experimental plot in a depth range of (0-30 cm and 30-50 cm) by using auger. After taking samples from the selected sites and depths, physical and chemical parameters such as soil moisture content, pH, OM, bulk density, field capacity and permanent wilting point values were measured at Bahir Dar Soil Laboratory. The soil infiltration rates were measured with the help of double ring infiltromter in the experimental site.

Gravimetric method was used to measure soil water content. The soil samples were placed in an oven for 24 hours at $105^0{}_C$ in order to determine the soil moisture content. The moisture content of the soil samples on volume bases were determined by multiplying the gravimetric water content on weight basis by the bulk density. Soil pH was measured in 1:1 soil: water mixture by using a pH meter. Distilled water was used as a liquid in the mixture. Ten gram air dried (< 2 mm diameter) soil was weighed into 100 ml beakers and 10 ml distilled water was added to 1:1 soil/water suspension and transferred to an automatic stirrer and stirred for 30 minutes and pH on the upper part of the suspension was measured as per recommendation of Sahlemedhin and Taye (2000).

The soil bulk density is defined as the oven dry weight of soil in a given volume as it occurs in the field, and this was determined using undisturbed soil samples taken with core sampler. Soil bulk-density data was measured on 18 cores of 98.17 cm^3 volume in the field at two depths 0-30 cm and 30-50 cm, oven dried for 24 hrs at 105 ^{0}C.

Water content on mass basis (θ_m) was measured using equation 1 (Michael, 1997).

$$\theta_m = \left[\frac{M_w \times 100}{M_s}\right] \quad (1)$$

Where θ_m is water content on mass basis (%), M_w is mass of water (gm), and M_s is mass of soil after oven dry (gm)

Soil bulk density (ρ_b) was calculated using equation 2 (Michael, 1997).

$$\rho_b = \frac{M_s}{V_b} \quad (2)$$

Where ρ_b is Soil bulk density (g/cm^3),
M_s is the mass of soil after oven dry (gm), and
V_b is bulk volume of soil (cm^3).

The volumetric water content was estimated from gravimetric water content
using equation 3 (Michael, 1997).

$$\theta_v = \theta_m \times \rho_b \quad (3)$$

Where θ_v is volumetric water content (%),
θ_m is water content on mass basis (%),
ρ_b is soil bulk density (g/cm^3) and

Both the water content at field capacity and permanent wilting point were measured using pressure plate apparatus, and the available water, which is the water between field capacity and permanent wilting point, was computed using equation 4 (Michael, 1997).

$$TAW = 10\left[\theta_{FC} - \theta_{PWP}\right] \quad (4)$$

Where TAW is available water, mm/m
θ_{Fc} is field capacity in volume basis (%) and
θ_{pwp} is permanent wilting point percent by volume.

Weather data

The ten year temperature, humidity, sunshine hours, wind speed, rainfall and other necessary data were collected from Bir Farm Metrological Station. The data were used to estimate the crop water requirement using the CROPWAT model (Smith *et al.*, 2002).

Crop and Irrigation Water Requirement of Onion

The values of ET_o estimated by using CROPWAT model based on climatological parameters need to be adjusted for actual crop ET_o. The crop water requirement of the test crop was calculated by multiplying the reference ET_o with crop coefficient (K_c). The water requirement (ET_c) of onion was calculated using crop coefficient approach on the basis of meeting the evapotranspiration rate of a disease free crop, growing in large field under optimal soil conditions including sufficient water and fertility and achieving full production potential under the given growing environment .

Statistical analysis of monthly reference evapotranspiration (ET_o) calculated for individual years for historical records (1998-2007) at Bir Meteorological Station. The mean annual reference evapotranspiration was 4.27 mm/day. The mean maximum value was 5.67 mm/day and occurs in April while the mean minimum 3.1 mm/day occurred in July. The crop coefficient of onion, as given in CROPWAT software.

Isaya (2001) reported that the K_c values for onion lies between 0.4 and 0.6 for initial stage, 0.7- 0.8 for crop development stages, 1.0-1.1 for mid - season stage and 0.9-1.0 for late season stage. Other crops data such as stage lengths (in days), rooting depths (m), depletion level (P), and yield response factors (K_y) were adopted from CROPWAT software (FAO, 2002).
The seasonal irrigation water requirement was found to be 664.5 mm. This amount was needed for full irrigation level treatments. Accordingly, the three-fourth and half irrigation levels were calculated to be about 498 mm and 332 mm, respectively.

Water application depth and irrigation interval

The design depth of application and irrigation interval, which are a function of intake characteristics and water storage capacities of the soil were determined by CROPWAT model (Smith *et al.*, 2002). All treatments were conducted according to the initial plan and received 21 applications. Whenever rain occurs during the irrigation interval that depth was subtracted from the up coming irrigation. The amount of rainfall which occurred during irrigation interval was on December which was 3.25 mm and on March 1 mm and this amount was subtracted from succeeding irrigations.

Capacity of the sprinkler

The required capacity of a sprinkler system depends on the size of the area to be irrigated (design area), the gross depth of water applied at each irrigation, and the net operating time allowed to apply water to this depth .The discharge capacity of the system was calculated by using equation 5 (Michael, 1997).

$$Q = 2780 \times \frac{A \times D}{F \times H \times E} \quad (5)$$

Where Q is discharge capacity of the system, l/s,
A is area to be irrigated, hectares,
D is net depth of water application, cm,
F is number of days allowed for the completion of one irrigation,
H is number of actual operating hours per day,
E is water application efficiency and Parameters indicate for total sprinkler area.

Discharge of sprinkler nozzle

The discharge of sprinkler nozzle was computed by using equation 6 (Michael, 1997) and information provided in the sprinkler set.

$$q = ca\sqrt{2gh} \tag{6}$$

Where q is nozzle discharge, m^3/s

a is cross sectional area of nozzle,(m^2)

h is pressure head at the nozzle, m

g is acceleration due to gravity, m/s^2

c is coefficient of discharge which is a function of friction & contraction losses

(The coefficient c of good nozzle should be 0.95 to 0.96).

Application rate of the sprinkler

The application rate was measured by using equation 7 (Michael, 1997).

$$A = k\left[\frac{\theta}{a}\right] \tag{7}$$

Where A is Application rate (mm/hr),

a is wetted area of sprinkler (377000 m^2),

θ is Sprinkler discharge (l/min) and

k is unit constant (k= 60/for A in mm/hr).

The time of application at any radial distance "r" from the pivot point was calculated by dividing the wetted diameter of the sprinkler nozzle at distance r by the speed of the lateral using equation 8 (Cuenca, 1989).

$$T_a = \left[\frac{D_w T_r}{2\pi r}\right] \tag{8}$$

Where T_a is time of application, h, D_w is wetted diameter of sprinkler at distance r from pivot point, m, T_r is time per revolution, h and r is radial distance from pivot point, m

Uniformity

Data for computation of uniformity of water distribution was measured by placing 9 cm opening diameter and 11.5 cm deep cans located along a line extending radially from the point 70 m away from the center of the pivot at 2 m spacing between each cans. The Christiansen uniformity coefficient was then calculated using equation 9 (Allen, 1993).

$$CU = 100 \times \left[1 - \frac{\sum X}{n.m}\right] \tag{9}$$

Where, CU is distribution coefficient Christiansen (%),

$\sum X$ is summation of deviations from the mean depth collected,

m is the mean depth collected and

n is the number of observations

Method of planting

Red Cruel variety of onion was sown on November 21, 2008.The spacing between plants and rows was 10 and 30 cm respectively. The fertilizer was applied at a rate of 300 kg/ha DAP and 400 kg/ha Urea. Weed control was made using hand weeding and cultivation. Disease was controlled by using moncozeb pesticides which was sprayed at a rate of 3 kg/ha in ten days interval for a month.

Yield measurement

With the intention of comparing the yield and yield related parameters performance of the three water applications on onion bulb yield, onion dry matter percentage and number of onion plant at harvest were collected from all plots, weighed and converted to hectare basis and analyzed statistically.

Water use efficiency

The water use efficiency was calculated by dividing harvested yield in kg by unit volume of water (kg/m^3). Two kinds of water use efficiencies, namely total water use efficiency (CWUE) and irrigation water use efficiency (IWUE) defined below were used (Zhang *et al.*, 1998).

Irrigation water use efficiency

Irrigation water use efficiency was calculated by equation 10 (Zhang *et al.*, 1998).

$$IWUE = \frac{Y}{V_{tawp}} \times 100 \tag{10}$$

Where IWUE is irrigation water use efficiency (kg/ha.mm),

Y is yield produced (kg/ha) and

V_{tawp} is irrigation application (mm)

3.2.11.2. Crop water use efficiency

Crop water use efficiency was calculated by equation 11 (Zhang *et al.*, 1998).

$$CWUE = \frac{Y}{ET} \tag{11}$$

Where $CWUE$ is crop water use efficiency (kg/ha.mm)

Y is yield produced (kg/ha) and

ET is Evapotranspiration, mm

Data Analysis

Data were analyzed using ANOVA technique using GenStat software. Mean separation was made using the LSD.

(12)

RESULT AND DISSCUSSION

Soil Characterization

The results of particle size distribution analysis of soil in the experimental site are presented in Table 1.

Table 1. Average particle size distribution

Depth (cm)	% Particle size distribution Sand	Silt	Clay	Textural class (USDA)
0-30	11	34	55	Clay
30-50	9	23	68	Clay

Table 2 provides results of organic matter content (OM), pH, field capacity, permanent wilting point, total available water and bulk density of soil of the experimental site. According to Brady (2002), the soil is slightly acidic. The basic infiltration rate of the soil was 6mm/h.

Table 2. Average bulk densities, organic matter, field capacity, PWP, and TAW.

Sampling depth(cm)	Bulk Density (g/cm^3)	Organic Matter (OM)%	pH	FC* (%) V/V	PWP** (%) V/V	TAW*** mm/m
0-30	1.250	2.10	5.9	32.30	12.96	193.4
30-50	1.40	1.95	6.5	29.96	12.90	170.6
Average	1.33	2.03	6.2	31.13	12.93	182.0

**** FC-Field Capacity, ** PWP-Permanent Wilting Point, ***TAW-Total Allowable Water***

Table 2 also shows the values of TAW, FC and PWP. Mean values of TAW were 193.4 mm per meter at the top and 170.6 mm per meter in the subsurface soil. Representative value of TAW was computed by considering 30 cm depth form the surface and 20 cm depth for the subsurface soil and was found to be 182.0 mm per meter depth of soil (Table 2).

Sprinkler Capacity, Water Application and the Time of Application

The required capacity of a sprinkler system calculated using equation 8 was 59 l/s. The discharge of the specific nozzle varied from 0.38 l/s at nozzle diameter of 6 mm to 0.47 l/s at nozzle diameter of 21 mm.

The average application rate of a center pivot sprinkler according to equation 10 Section 3.2.7 was 5.6 mm/h. The time of application at any radial distance “r” from the pivot point using equation 11varied from 0.79 to 0.15 h.

Distribution Uniformity

Uniformity, calculated using Christiansen Coefficient of Uniformity (CU), was 91.3% According to Allen (1993), the distribution uniformity ranked very good. This very god distribution uniformity might have been observed due to the fact that the system was new (one year old while the study was made) and fully automatic and electronically controlled. According to Hanson (2005), a uniformity of 100 percent means the same amount of water infiltrates everywhere in a field. No irrigation system, however, can apply water at 100 percent uniformity. Regardless of the irrigation method, some parts of a field infiltrate more water than other areas. More drainage below the root zone implies higher non uniformity and differences in infiltrated water throughout the field.

Yield Performance

The mean effects of water applications on yield are presented in Table 3. The treatments that received only one-half of the irrigation application (T_1) throughout the growing season produced 21.6 tones per hectare; the treatment receiving only three-forth of the irrigation water requirement throughout the growing season produced 33.7 tones per hectare, and the treatment receiving full application rate throughout the growing season produced 40 tones per hectare.

Table 3. The effect of water application level on onion yield

Water application level	**Yield (kg/ha)***
Half irrigation	21635 [b]
Three-quarter irrigation	33711 [a]
Full irrigation	40000 [a]
LSD (0.05)	7314.3
CV	10.2
SE $\bar{x}$	2634.5

****mean of three observations, and means followed by the same letter are not significantly different.***

Comparing the means of yields obtained, the treatment provided with half of irrigation application level was significantly lower than the other two application rates ($p<0.05$). However, the difference (25% of irrigation water) between three quarter and full irrigation water application rates exhibited no significant difference ($p>0.05$), though there was an actual difference of 6289 kg/ha. The highest yield was obtained when the full irrigation was applied. This showed that onion would give maximum yield when full amount of the irrigation water estimated by the CROPWAT model was applied.

The effect of water application level on the number of onion plant per hectare was presented in Table 4. The difference among all treatment means were significantly different ($p<0.05$). The highest number was obtained under full irrigation water application and lowest yield was obtained under the half irrigation water application.

Table 4. The effect of water application level on onion plant at harvest.

Water application level	Number/ha*
Half irrigation	246038 [c]
Three-quarter irrigation	281007 [b]
Full irrigation	409305 [a]
LSD (0.05)	17752.4
CV	2.8
SE $\bar{x}$	6394.2

*mean of three observations, and means followed by different letter are significantly different.

The effect of water application level on onion dry matter converted on hectare basis is presented in Table 5. There was significant difference (P<0.05) between the onion dry matter obtained under half and three-quarter irrigation and between the half and the full irrigation application levels. Nevertheless, there was no significantdifference between the three-quarter and full irrigation application levels (p>0.05). The variability observed here agrees with onion yield obtained in Table 3.

Table 5. The effect of water application level on onion dry matter

Water application level	Onion dry matter/ha*
Half irrigation	3140.9 [b]
Three-quarter irrigation	4852.3 [a]
Full irrigation	5853.4 [a]
LSD (0.05)	1674.2
CV	16
SE $\bar{x}$	1907

*mean of three observations, and means followed by different letter are significantly different.

The relative yield reductions compared to full irrigation application are presented in Table 6.

Table 6. Relative yield reduction of onion

Water application levels	Actual yield (ton/ha)	Yield reduction (ton/ha)	Yield reduction (%)	Rank
Half irrigation	21.635	18.365	45.9	1
Three-quarter irrigation	33.711	6.289	15.7	2
Full irrigation	40.000	-	-	

The Relative yield reduction for 50% reduction in irrigation water application was 18,365 kg ha^{-1} or 45.9 % and a 25% reduction in irrigation water gave a relative yield reduction of 15.7%. Many studies have been reported on the irrigation of onions (Olalla *et al*., 1994). They proved that the bulb yield, dry matter production and number of onion plant at harvest are highly dependent on the application of sufficient amount of water.

Yield – water- relationship

Yield difference between treatments can be attributed to their respective irrigation practice. The relationship between yield (tons/ha) and the depth of irrigation water (mm) for each treatment is presented in Figure 3.As the depth of irrigation application increases, the yield also increased for the application ranges considered in this study.

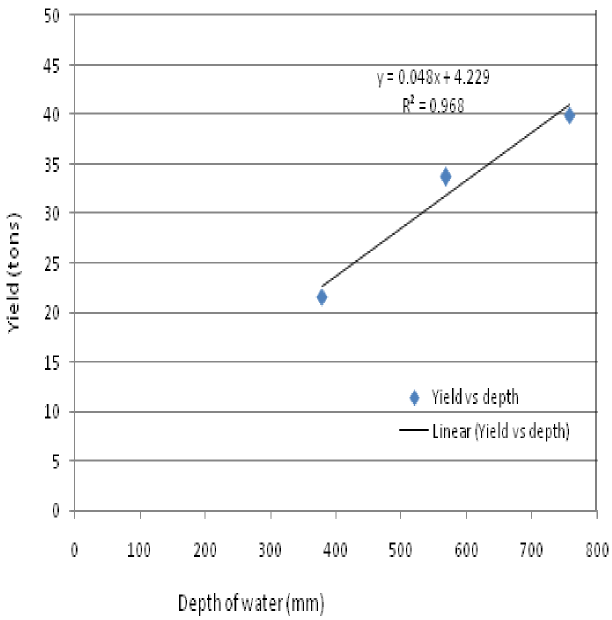

Figure 3. Yield water relationships

From Figure 3, it can be generalized that about 97% of the yield variability between treatments can be attributed to the difference in the amount of water applied through irrigation. Bazza (1999) from experiments on sugar beet and wheat concluded that more than 90% of the yield variation was coming from the variability in depth of irrigation application regardless of the time of application. Hence, what was observed in this experiment is in agreement with what have been reported earlier by (Olalla *et al*., 1994).

Evaluation of Water Use Efficiency

To evaluate the water use performance of the three application levels in terms of their water use efficiency, two water use efficiency indices were estimated: crop water use efficiency (CWUE) and irrigation water use efficiency (IWUE).

Crop water use efficiency (CWUE)

With the intention of comparing CWUE of the three application levels, CWUE was calculated with equation 14 and the result obtained is presented in Table 7.

Table 7. The effect of water application level on crop water use efficiency

Water application level	CWUE (kg/ha.mm)*
Half of CWR	65.1 [a]
Three-quarter of CWR	67.6 [a]
Full of CWR	60.2 [a]
LSD (0.05)	14.46
CV (%)	9.9
SE $\bar{x}$	5.2

mean of three observations, and means followed by same letter are not significantly different.

Results revealed that there was no statistically significant difference (P>0.05) among the CWUE values of the three water application levels though the highest application efficiency was obtained when three-quarter of the crop water requirement was applied. The highest yield was obtained when full amount of the irrigation water was applied, but the water productivity was highest when three-quarter of the irrigation amount was applied. The amount of water saved compared to full application of 756.9 mm was 189.2 mm (25%). When water is a limiting factor, this would be used to irrigate 25% more land. Based on this result, it will be difficult to deduce that higher water productivity would be obtained applying deficit irrigation of any level. Perhaps narrowing the range of the deficit and/or applying the stress at different growth stages of the crop would help to find the exact point where the deficit should be applied.

Irrigation water use efficiency (IWUE)

To characterize half, three-quarter and full water application levels in terms of irrigation water use efficiency, the IWUE was computed using equation 13 and the result obtained is presented in Table 8.

Table 8. Effect of water application level on IWUE

Water application level	IWUE (kg/ha.mm)*
Half irrigation	57.13 [a]
Three-quarter irrigation	59.37[a]
Full irrigation	52.83 [a]
LSD (0.05)	12.75
CV	10.0
SE $\bar{x}$	4.6

mean of three observations, and means followed by same letter are not significantly different.

The variability among treatments in terms of irrigation water use efficiency was also not significant (P>0.05). However, the highest IWUE was obtained when the three-quarter of the irrigation water was applied. The value obtained is with the range of values discussed in the previous Section II, but the variability among treatments is not statistically significant. Again this may be due to the fact that ranges of values considered are too wide. Hence the lower the amount of water applied the lower the proportion of yield obtained. Consequently, it has not been possible to get a small decrease in the yield compared to the reduction in the amount of water applied.

SUMMARY AND CONCLUSION

Summary

Most Ethiopian farmers depend on rain-fed agriculture. However, rainfall is very erratic, and drought occurs very frequently; therefore, efficient use of irrigation water using appropriate irrigation systems and management is an important consideration in the drought prone areas for improved crop production.

One of the irrigation management practices which could result in water saving is deficit irrigation, which is maintaining the moisture content of the soil below the optimum level throughout the growing season and it is possible to identify which water deficit would have a limited effect on crop production.

In this study, attempt was made to evaluate the water use efficiency and water productivity by applying full, three-quarter, and half of the crop water requirement using onion as a test crop.

The yield obtained for half of irrigation application rate was significantly lower than the other two application rates ($p<0.05$). However, the difference between the yields under three quarter and full irrigation application rate exhibited no significant difference ($p>0.05$). This showed that onion gives maximum yield when the amount of water applied is maximum.

There was significant difference ($P<0.05$) between the number of onion plant at harvest obtained under full, three-quarter, and half of irrigation application levels. This indicated that the large number of onion plant would be obtained when water application is full. The onion dry matter obtained under half Vs three-quarter and half Vs full of irrigation application levels were significantly different ($P<0.05$). Nevertheless, there was no significant difference between three-quarter, and full of irrigation application levels ($p>0.05$), though there was a significant reduction (25%) in the volume of water applied. The reason probably is due to better application efficiency obtained with three quarter of the irrigation applications. This is consistent with the significant loss of water that has been associated with full irrigation applications. That means the above specified amount of water application has an effect on onion dry matter.

The variability in WUE; however, was not found to be significant. This implies that the smaller the amount of water applied the lower will be the yield. This was some how observed in the straight line water productivity function. Perhaps reducing the range and stressing the plant at different physiological stages might have helped to find the best time where water could be saved without a substantial lowering of the yield.

CONCLUSION

From the results obtained in this deficit irrigation application experiment the following conclusions are drawn.

1. The maximum yield was obtained when the full amount of irrigation water was applied, but the water productivity was highest when three-quarter of irrigation water was applied. Hence if water is not a limiting factor, full amount of water should be applied in order to get maximum yield. But when water is limiting, three-quarter of the full application gives a comparable yield. The 25%water saved could help to irrigate additional land. Admittedly, the variables such as continuous soil moisture monitoring and evaluation of deep percolation have not been included for logistical reason. Hence, more comprehensive information needs to be captured by using appropriate devices.
2. The prospects of using sprinkler irrigation to evaluate the performance of deficit irrigation is high. It was possible to apply the right amount of water on the right time and space.

Recommendation

The recommendations drawn from this research are:

1. This experiment made using sprinkler irrigation was the first of its kind in the universities graduate research system. Lessons have been learned, in the process and incorporated in the thesis compared what was proposed initially. Hence I recommend for future research to review the experience presented in this thesis.
2. The experiment was undertaken by taking a limited number of water application levels (treatments) for logistical reasons. As one of the predicament of graduate research, the experiment is a one season one place experiment; hence repeating the experiment in space and time, and using other test crops shall improve the validity of the finding
3. The test crop considered here is onion. But other major crops like pepper, tomato, soybean, haricot bean, wheat, sorghum, maize and sunflower also are growing under irrigation in the farm; hence water use efficiency and water productivity should be tested for all these crops.

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