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Verification of the Efficiency of Alternate Furrow Irrigation on Amount of Water Productivity and Yield of Onion at Sekota Woreda

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Abstract

Efficient water use becomes an important issue in recent years because of the lack of available water resources in some areas is increasing and a serious problem. Globally and more particularly in developing Countries, changing water availability and quality is a complex problem, and management options are not easy. Therefore Partial root-zone drying is a practice of using irrigation to alternately wet and dry (at least) two spatially prescribed parts of the plant root system to simultaneously maintain plant water status at maximum water potential and control vegetative growth for seasonal plant development. The experiment was conducted on the 2017/2018 irrigation season at the irrigation scheme of Sekota woreda. Three irrigation methods alternating furrow irrigation (AFI), conventional furrow irrigation (CFI), and fixed furrow irrigation were verified on separate plots. The design of the experiment was RCBD with four farmers as replications. Each irrigation method was used a 75% amount of irrigation water for five days irrigation interval for verified irrigated onion. The results show that total irrigation water applied in the AFI and FFI treatment was roughly half (3038 m^3) that applied to the CFI treatment (6078 m^3). There was a significant reduction in irrigation water used with the AFI but a non-significant reduction on the onion yield production. The AFI water productivity was astatically significantly different from FFI and CFI. The water productivity obtained 4.05 kg m^{-3} with AFI and 3.16 kg m^{-3} with FFI which was nearly double the 2.15 kg m^{-3} with CFI. Alternate furrow irrigation (AFI) is gaining interest as a means of saving water while minimizing loss in crop production. In the AFI system, the total water used was half of the CFI system. Rather than using 6076 m^3/ha of water for 1 hectare in the CFI system, it is possible to double the irrigated area to 2 hectares in the AFI system. The onion needs a high amount of irrigation water during the development stage, but in the FFI system, as half of the root stays dry throughout the growth period, continuous stress significantly reduces fresh bulb yield.

Keywords: Alternate furrow irrigation • Irrigation amount • Sekota • Water productivity • Yield of onion

Abbreviations

AFI: Alternative Furrow Irrigation; CFI: Conventional Furrow Irrigation; FFI: Fixed Furrow Irrigation; WP: Water Productivity

Introduction

Onion (Allium cepa L.) belongs to the genus Allium of the family Alliaceous which was believed to be originated in southwestern Asia, being the center of domestication and variability, from where it was spread first across the world and has been cultivated for over 4700 years as annuals for bulb production purposes (Brewster, 2008). The onion is recognized as one of the most important vegetable crops cultivated throughout the world since its introduction to the world. It has grown mainly as a food source and used as cousins and value addition for different dishes. In Ethiopia, the consumption of the crop is very important in the food seasoning and in daily stews as well as in different vegetable food preparation uses and also the chemical flavonoids, anthocyanins, fructooligosaccharides and organosulphur compounds found in the onion is considered as medicinal and health benefits to fight different diseases including cancer, heart and diabetic diseases [1].

Onion is one of the most popular vegetables in Ethiopia with a volume of 2,648,493.54 Quintal onion bulbs from 29,517.01 ha of lands. Onion is among the largest production and highly commercialized vegetable crops in the Amhara region grown under irrigation. Currently, farmers in most irrigable areas of the Amhara region produce a large number of onion bulbs every year. For instance, in the 2015/16 production year, the region has 12,262.79 hectares of land covered by onion crops (CSA, 2016). Efficient water use has become an important issue in recent years because the lack of available water resources in some areas is increasingly becoming a serious problem. During the last two decades, water-saving irrigation techniques such as deficit irrigation (DI) and partial root-zone drying (PRD) or alternative furrow irrigation (AFI) have been developed and tested for field crops and fruit trees. Most recently, these irrigation techniques are being tested also in vegetable crops such as tomatoes [2]. Water use efficiency should be improved by reduced leaf Transpiration. Stomata control the door of plant gas exchange and transpiration water loss. Recent Investigations have shown that stomata may directly respond to the availability of water in the soil such that they may reduce their opening according to the amount of water available in the soil. Alternate furrow irrigation was practice for a number of crops such as potato, tomato, soybean, and corn to conserve water [3-5]. In the study on tomato at Orissa (India), alternate furrow irrigation gave the highest water use efficiency (5,140 kg ha^{-1} mm^{-1}) among several furrow treatments. Alternate furrow irrigation can prevent severe leaf water deficit, which develops in the shoots when irrigation is drastically reduced. It is well known that leaf growth and shoot elongation are inhibited when shoot water deficit develops and turgor is reduced as a result.

Globally and more particularly in developing Countries, changing water availability and quality pose complex problem and management options are not easy. The changing situation comes partly from increasing demands such as population, industry, and domestic requirements and partly from the consequences of climatic change [6]. Therefore, great emphasis is placed in the area of crop physiology and crop management with the aim to make plants more efficient in water use under dry conditions [7]. Partial root-zone drying is a practice of using irrigation to alternately wet and dry (at least) two Spatially prescribed parts of the plant root system to simultaneously maintain plant water status at maximum water potential and control vegetative growth for prescribed parts of seasonal parts of plant development [8].

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The concept of alternate furrow irrigation is that:

- In alternate furrow irrigation less surface water is wetted and less evaporation from the surface occurs.
- More lateral roots are stimulated and a chemical signal is produced in drying roots to reduce the shoot water loss.
- The amount of water needed (irrigation water use), time, and labor requirement for Irrigation is decreased.
- Water use efficiency was nearly double by using this method.

Methods

Study area

The study was conducted for one irrigation season 2017/18 in woleh on five farmer trial site about15km from Sekota town. Sekota woreda is one of the woreda in the wag-himra zone administrative of the Amhara region. The experimental sites are found within 1384757N and 505143 E of longitude and an altitude of 2119 m. The Agro-climatically of the woreda is situated in dry areas. The meteorological data were used extrapolated from nearby station abiady; maychew and Lalibela were used for the designing of irrigation infrastructures. The long term average ETO in the study area was 4.47 mm/ day. The mean annual maximum temperature ranges from 23.1°C to 28.6°C. The woreda receives an annual average rainfall of the area ranges from 329 mm to 833 mm. most of the rain is received from the fourth week of June to the end of August. The coincidence of late-onset, early cessation, and uneven distribution of rainfall with the short effective season has resulted in terminal dry spells, recurrent drought, and unreliable rain-fed cropping in the area (Figure 1).

Crop selection and crop agronomy in the study areas

The most important irrigable crops in the irrigation schemes were identified in terms of crop type, market opportunity, crop variety, and length of the growing season. Considering all these factors, onion with Bombay red variety was selected as an experimental crop. The experiment of onion variety has a total growing period of 115 days including transplanting up to harvesting with the initial crop growth stage about 20 days, crop development stage of 30 days, midseason Stage of 40 days, and late-season stage of 25 days, which was derived from CROPWAT software. The experimental plot size of 10 m×10 m double row planting with the spacing of 40 cm×20 cm×10 cm (between rows including the furrow × between rows on the bed × between plants in a row) was used respectively. The spacing between the plots was 1m. Blanket recommended fertilizer rate of NPS 100 kg at transplanting and urea fertilizer of 200 kg at half transplanting and half 45 days was applied in experimental sites. Both diseases and weed infestation were regularly monitored, and proper management action has been undertaken timely. Thribes were observed during the early seedling establishments on the actual field, vegetative, and plant development stages. Profit was used to control the disease infestation which was practiced by protection researcher recommendation

Crop Water Requirement of onion

Calculation of crop water requirement, net irrigation requirement, and schedule of the water application was carried out with inputs of soil, climatic, and crop data, and the CROPWAT Computer model was implemented for undertaking the operation. The model requires crop data such as crop type, planting date, growth stage days, maximum rooting depth, Kc values, depletion fraction and yield reduction coefficient, and climatic data including maximum and minimum temperature, rainfall, wind, sunshine hours and relative humidity and soil type. Climatic data of the experimental sites were collected from neighboring stations and extrapolated using LocClim Software. For calculating the crop water requirement, given the input of the required data, the reference evapotranspiration was calculated first using the Penman-Monteith equation in the CROPWAT program [9]. Composite soil samples were collected from field plots and the soil textural analysis was done soil analysis method and soil textural class was determined from soil textural triangle. Field capacity, permanent wilting point, and moisture at saturation were determined from laboratory analysis of soil samples.

Total Available Moisture (TAM) in the soil for the crop during the growing season was calculated as Field capacity (FC) minus wilting point (PWP) times the current rooting depth (D) of the crop as indicated in the following relation. TAM=(FC-PWP)*D. Readily Available Moisture (RAM) was calculated as TAM*P, Where P is the depletion fractions defined by the crop coefficient (Kc) files. The estimated crop water requirements were converted into the field irrigation water requirement. The net irrigation requirement (NIR (mm/period)) was determined based on the equation. NIR=CWR-Peff, where, CWR=crop water Requirement (mm/period), Peff=Effective precipitation. The exact volume of water needed to fulfill the irrigation water requirement throughout

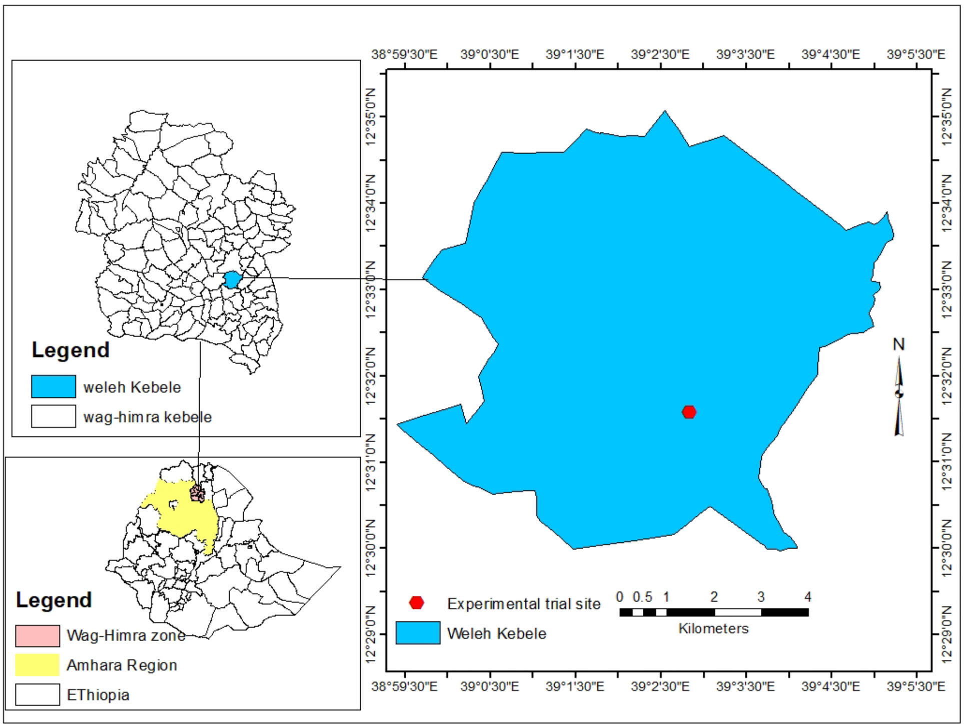

Figure 1. Map of the study area.

the growing season was calculated using the equation below.

Gross irrigation requirement (mm) = Net irrigation requirement (mm)

Application efficiency

Water productivity, also known as water use efficiency, was determined as the ratio of crop yield per unit area, in terms of grain, to crop evapotranspiration (mm), and was expressed as kg of grain or biomass per m^3 of consumed water.

Water use efficiency (kg/m^3) = total yield of onion (bulb)

Water delivered up to harvesting

Furrow irrigation was the method used for applying water for this experiment. Since water is applied directly to the plot; conveyance and distribution losses were ignored and 90% irrigation application efficiency was taken.

Experimental set up

The design of the experiment was RCBD with four as farmer replications. Infield experiment three furrow irrigation water application methods were verified. Alternate furrow irrigation (AFI), Conventional furrow irrigation (CFI) and fixed furrow irrigation (FFI), and the recommended irrigation amounts; 75%. Alternate furrow irrigation that one of the two neighboring furrows was alternately irrigated during consecutive watering. Fixed furrow irrigation was fixed one of the two adjacent furrows while the Conventional furrow irrigation was also the conventional way where every furrow irrigated during each watering. The frequency of irrigation water was applied at 5 days irrigation interval; hence all plots were irrigated 20 times throughout the growing season. There was 1.2 mm of rainfall throughout the growing season. Prior to planting all plots were irrigated with an equal amount of water up to the field capacity. Weeding and other agronomic practices were conducted on time equally for each treatment. Handheld watering Cane was used to control the amount of water entering each furrow. Agronomic parameters like bulb diameter, plant height, marketable yield, unmarketable yield, total yield, and water productivity were collected as per the schedule.

Data analysis

All the agronomic, yield, and water productivity data recorded and being subjected to analysis. Analysis of variance was performed using Statistics 10.0 statistical Software. The effects considered significant in all statistical calculations if the P-values were ≤ 0.05. Means were separated using Fisher's Least Significant Difference (LSD) test.

Treatment set up

1. 75% CROPWAT fixed depth and Alternate furrow irrigation (AFI) at 5 days interval.

2. 75% CROPWAT fixed depth and Conventional furrow irrigation (CFI) at 5 days interval.

3. 75% CROPWAT fixed depth and Fixed furrow irrigation (FFI) at 5 days interval.

Result and Discussion

The results of the experiment there no statistically significant difference in the plant height, marketable and unmarketable yield of onion the application of 75% amount of irrigation water at five days of irrigation intervals on alternate and conventional furrow irrigation methods (Table 1). But there was a significant difference in bulb diameter and water productivity (Tables 1 and 2). AFI enables more efficient use of irrigation water associated with some water stress compared to CFI this is why the significant difference in bulb diameter as well as water productivity. However, the analysis result on irrigation type showed that the application of alternative furrow irrigation type has a statistically significant difference in all parameters as compared to fixed furrow except bulb diameter. It is obvious that conventional furrow irrigation is labor-intensive and time-consuming, each furrow is irrigated at each frequency of irrigation, and however, alternate irrigation consumes half of the labor, time and amount of required irrigating. In addition to this advantage in the experimental result, alternate furrow irrigation with 75% of irrigation water saves the highest total yield of 122.9 qt/ha while the conventional and fixed ones with double amount of water application gave 132 qt/ha and 96 qt/ha total yield respectively. This result in line with the finding of [10] alternate furrow irrigation was achieved better total and marketable yield of potato as compared to conventional and fixed ways of furrow irrigation methods. On the other hand the finding of alternative furrow irrigation system in areas where there is water scarcity as well as labor expensiveness is the best options to increase the production of onion and other vegetables.

As shown in Table 1 the marketable onion bulb yield was obtained from CFI (129.47 qt/ha) and AFI (120.03 qt/ha) systems were significantly different from FFI (92.82 qt/ha) system. The statistical analysis of the onion crop yield obtained in our experiment is presented in Table 1. It shows that the difference in onion crop yield obtained with CFI and AFI was non-significant. However, A slight yield reduction obtained by AFI compares with CFI. A slight reduction in crop yield with AFI compared to CFI was also reported by [4,11]. The results also in agreement with the finding of (Slatni et al., 2011, Crabtree et al., 1985) using alternative furrow irrigation methods insignificant a yield reduction on sorghum and soybean production as compared to conventional furrow irrigation methods. This is also supported by [12] who found that AFI may result in insignificant cotton yield production because too little water is applied, particularly when evaporative rates are very high. Under the AFI method, the onion plant root system was partially wetted which could result in reduced stomatal conductance and a reduction in plant transpiration. Photosynthesis and dry matter accumulation can, however, be less affected by this partial stomata closure [13] and also the roots on the irrigated side of the furrow (wet soil) will continue to take up water to try and meet the required water demand of the plant [13,14] reported that plants with two halves of their root system under alternate drying and wetting cycles resulted in reduced stomatal opening but without a significant increase in leaf water deficit. This is part of the reason there was a non-significant reduction in crop yield in AFI compared with CFI. Kang [13] also observed a high grain yield for maize subjected to a half reduction in the amount of irrigation applied. Sepaskhah and Ahmadi [8] also recommended partial root-zone drying (similar to AFI) for better fruit quality and increased crop water productivity in areas with limited water resources. Table 2 shows that the crop water productivity of AFI, CFI, and fixed methods for growing onion. The highest water productivity of 4.05 kgm^{-3} was obtained with AFI followed by FFI with 3.16 kgm^{-3} and conventional furrow irrigation, which had the lowest water productivity of 2.15 kgm^{-3}. It shows that the variation in WP for all treatments were highly significant, which highlights the effect the method of irrigation has on water productivity. Ibrahim and Emara (2010) reported the AFI method had a higher WP compared with the CFI method. Slatni [15] reported that AFI resulted in a slight decrease in crop yield but increased water productivity [4] also reported that AFI enables more efficient use of irrigation water but with a lower crop yield associated with some water stress compared to CFI. There was a significant reduction of 75% in the volume of water applied to the AFI treatments. This means 6076 m^3 volume of water is needed to irrigate the 1-hectare area in the CFI system which is enough to irrigate the 2-hectare area of land in the AFI system. So, when the area to be irrigated becomes double in the AFI system using the saved volume of water, the yield obtained also becomes double. The reason why the yield result is

Table 1. The mean bulb diameter, plant height, marketable, total and unmarketable yield of onion Experimental season of 2017/2018.

Treatment	Ph (cm)	Bd (cm)	My (qt/ha)	Unmy (qt/ha)	Ty (qt/ha)
AFI	50.4[a]	4.31[b]	120.03[a]	2.89	122.92[a]
CFI	50.3[a]	4.68[a]	129.47[a]	3.13	132.6[a]
FFI	47.01[b]	4.32[b]	92.82[b]	3.34	96.16[b]
CV (%)	1.11	1.9	5.08	15.82	5.15
LSD (0.05)	0.95	0.14	10.03	NS	10.45

Means with the same letter are not significant different. Bd= bulb diameter; ph= plant height; my= marketable yield; Ty=total yield; Unmy= unmarketable yield well-performing as compared to the CFI system is probably because of better application efficiency and physiological response associated with AFI [13,16] and less evapotranspiration associated with AFI. This result conformity with [17,18] applied the same amount of water alternate furrow irrigation obtained highest maize and wheat grain yield production and water productivity as a contrast to conventional and fixed furrow irrigation techniques. In addition to that [19] accomplished that the alternate furrow irrigation system generally increases sugar cane production, water productivity, and field water use efficiency (Table 2).

Infield experiment observed that conventional furrow irrigation is labor-intensive and time-consuming each furrow is irrigated at each frequency of irrigation and however, alternate irrigation consumes half of the labor, time, and amount of required irrigating. In addition to this advantage in the experimental result, alternate furrow irrigation saves the highest total yield of 12.29 ton/ha while the conventional (double amount of water) and fixed furrow irrigation system gave 13.2 ton/ha and 9.39 ton/ha total yield respectively. Therefore, in areas with scarce water resources for irrigation in Sekota woreda or agro climatically similar areas can use 75% (3038 m^3/ha) of water at five days interval in alternate furrow irrigation methods irrigation water application throughout the whole growing season was obtained optimum total yield production of irrigated onion Table 3 shows that economic water productivity (WP (e)) of onion crops in the AFI, FFI and CFI irrigation methods the highest (WP(e)) 36.41 birr/m^3 was obtained in AFI followed by FFI with 27.81 birr/m^3 and CFI irrigation 19.68 birr/m^3 which had the lowest Economic water productivity(WP(e)). Table 4 indicated that for every 1.00 birr invested for Conventional furrow Irrigation the farmers including 1.00 birr and the other 27.71 birr loosed and obtained an additional 7.85 birr after recovering on Alternative furrow Irrigation. Since MRR>100% AFI is economically feasible. The total cost included operating and variable operating costs (land preparation, seeds, Fertilizer, and chemicals) based on the planted area. Therefore, the operating costs of AFI were the same as the conventional CFI and FFI. The Variable costs depended on the irrigation events and water unit price. The water unit price was estimated 3.5 birr/1000m^3

Table 2. Effect of applied water and furrow irrigation method on water productivity of onion.

Treatment	Number of irrigation	Irrigation water(m^3/ha)	Total yield (t/ha)	Water productivity (kg/m^3)
75%AFI	20	3038	12.29[a]	4.05[a]
75%CFI	20	6076	13.26[a]	2.15[c]
75%FFI	20	3038	9.62[b]	3.16[b]
CV (%)	_	_	5.15	10.07
LSD	_	_	10.45	0.45

Table 3. Economic water productivity of onion in alternate furrow irrigation (AFI) conventional furrow irrigation (CFI) and fixed furrow irrigation (FFI**).**

Treatment	Total Gross benefits (TGB) birr/ha	Irrigation water (m^3/ha)	Economic water productivity (WP(e)) birr/m^3
AFI	110610	3038	36.41
FFI	84510	3038	27.81
CFI	119610	6076	19.68

Table 4. Partial budget analysis for the experimental irrigation treatments.

Treatment	Unadjusted yield (t/ha)	Adjusted bulb yield by 10% (t/ha)	Total gross benefits (birr/ha)	Total cost that vary (birr/ha)	Net benefits (birr/ha)	MRR
AFI	12.29	11.061	110610	12490.63	98119.37	785.543
FFI	9.39	8.451	84510	12490.63	72019.37	D
CFI	13.29	11.961	119610	24981.27	94628.73	-27.946

NB. “D” stands for domination

according to irrigation water prices of the Awash River basin Authority [20]. The total water cost for each Season was calculated by multiplying the water unit price by the total amount of irrigation water required for the onion crop.

Therefore 10.633 birr/3038 m^3 for AFI and FFI where as 21.266 birr/6076 m^3 for CFI and the labor cost due to irrigation events are 12480 birr for AFI and FFI but 24960 birr for CFI which shown that higher cost in labor as well as water price than the two.

Conclusion

Results obtained from the study show that in the AFI system the total water used half of the CFI system, but yield obtained was slightly reduced due to high evaporation with a little amount of water applied. AFI provides this Significant amount of water (3038 m^3/ha) saved. AFI is a water-saving irrigation method that was suited for onion production without a significant bulb yield loss with maximum water productivity. AFI systems saved labor and time used for irrigation water which is half of the CFI system. Because of the CFI system, four furrows irrigated at the same time while for AFI only two furrows out of four furrows. This may improve the working conditions of the technology allow irrigators to move on the dry furrows.

This reduction in applied water is also important to minimize the risks of soil sod city development in irrigated areas, especially when the quality of irrigation water deteriorated. Rather than using 6076 m^3/ha of water for 1 hectare in the CFI system, it is possible to double the irrigated area to 2 hectares in the AFI system. The onion needs a high amount of irrigation water during the development stage, but in the FFI system, as half of the root stays dry throughout the growth period, continuous stress significantly reduces fresh bulb yield. The alternative furrow irrigation system is the best technology among the tested technologies to be recommended for the communities of the study area, because of its high water application efficiency, yield performance, in addition to time, labor, and irrigation cost saving. So alternative furrow irrigation system in areas where there is water scarcity as well as labor expensiveness is the best options to increase the production of onion. Therefore, it is advised that areas with insufficient water resource for irrigation in Sekota or agro-climatically similar areas can use of 75% (3038 m^3) of irrigation water at five days interval in alternative furrow irrigation methods throughout the growing season, for optimum production of irrigated onion.

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