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Integrated Effect of Partial Root Drying and Mulch on Onion Yield and Water Productivity in Ethiopia's Central Rift Valley

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Abstract

Irrigation is a vital practice in the Central Rift Valley of Ethiopia. However, water scarcity is the major limiting factor of agricultural production and productivity in the area. The field experiment was conducted on clay loam soil at the experimental field of Melkassa Agricultural Research Centre to evaluate the effect of furrow irrigation techniques and mulch types on onion yield and water productivity. The experiment was arranged in a split-plot design with three replications. The treatments include three furrow irrigation techniques (conventional, fixed, and alternate furrow irrigation) as main plot and mulch types (plastic and straw) and a control treatment of no mulch as sub-plot. The highest significant average bulb yield of 35.9 t/ha was obtained at the conventional furrow technique and the lowest average bulb yield of 24.6 t/ha was recorded at the fixed furrow irrigation technique. The bulb yield reductions with partial root drying that resulted in 50% water saving at both alternate and fixed furrow irrigation from conventional furrow irrigation were about 25, and 32%, respectively. The highest significant average bulb yield of 32.4 t/ha was obtained at the plastic mulch type and the lowest average bulb yield of 25.4 t/ha was recorded at no mulch treatment. The bulb yield increased with the use of mulch type from bare to straw and plastic mulch was 15 and 28%, respectively. Irrigating using conventional furrow technique using plastic mulch was found to be the most effective. It produced a significantly high bulb yield of 38.6 t/ha as against the fixed furrow method at no mulch type, which resulted in a bulb yield of 21.5 t/ha. Water productivity was higher for alternative furrow and lower water productivity was obtained from conventional furrow methods. Mulch types had a significant ($p<0.05$) influence on water productivity. Therefore, under a limited water supply area it can be concluded that more water-saving and associated increase in water productivity with alternate furrow irrigation and plastic mulch can solve the problem of water shortage. The study suggested that producing onion with plastic mulch resulted in higher product and water productivity.

Keywords: Deficit irrigation • Evapotranspiration • Partial root drying • Mulch • Onion • Water productivity • Furrow irrigation onion

Introduction

Background and justification

To sustain the rapidly growing world population, will need to increase agricultural production [1]. The world's cultivated area has grown by 12% and irrigated area has doubled over the last 50 years [2], and world fertilizer use has increased more and more. Driven by the fast expansion of irrigation and fertilizer consumption and others, agricultural production has grown between 2.5 and 3 times since the beginning of the 1960's [3]. FAO estimates that irrigated land in developing countries will increase by 34% by 2030, but the amount of water used by agriculture will increase by only 14%, thanks to improved irrigation management and practices. Access to water for productive agricultural use remains a challenge for millions of poor smallholder farmers, especially in sub-Saharan Africa, where the total area equipped for irrigation is only 3.2% of the total cultivated area [4]. Farmer-driven, informal irrigation is in many regions more prominent than formal irrigation.

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Irrigated agriculture is the main user of the available water resources. About 70% of the total water withdrawals and 60-80% of total consumptive water use are used in irrigation [5]. The irrigated area should be increased by more than 20% and the irrigated crop yield should be increased by 40% in 2025 to secure food for 8 billion people [6]. Therefore, water resources should be used with a higher efficiency or productivity. To achieve this goal, improvement in agricultural water productivity is highly imperative. Many investigations have been conducted to gain experience in the irrigation of crops to maximize performance, efficiency, and profitability, and investigations in water-saving irrigation still are continued [7]. Therefore, this project component has been developed to improve crop water productivity through different water-saving mechanisms.

The main issue for both irrigated as well as rain-fed areas is to improve water use efficiency [8]. Water use efficiency and agriculture production can be improved by improving soil and water management practices, and growing drought-tolerant and high-yielding cultivars.

Mulching is one of the good management practices among others to improve water use efficiency. Mulching material is divided into two types, *i.e.*, organic and inorganic materials. The most frequently used inorganic mulch is plastic mulch which is effective in controlling weeds and warming the soil [9]. The application of plastic mulch increases crop yield by improving solar energy, water and fertility status of soil, reducing soil water loss and removing weeds. It has been widely reported that both the grain yield and WUE are increased under mulches. Covering of soil with plastic mulch conserves soil moisture and regulates soil temperature. Improvement in soil physical properties such as soil texture, porosity, infiltration rate, organic matter and soil structure have frequently been reported for soil mulched with organic materials and plastic mulch. Mulching with plastic film enhanced water use efficiency by 14% as compared to control treatment, grain yield by 17% and biological yield by 19%. The yield increases are generally due to an increase in water content in the soil due to lesser evaporation.

An important adaptation of furrow irrigation is Alternate Furrow Irrigation (AFI) in which furrows are irrigated alternately rather than consecutively during irrigation water application. This is a form of Partial Root-Zone Drying (PRD) system that has been found to increase the production of various vegetables in Arid and Semi-Arid Land (ASAL) areas as well as save irrigation water. Partial root drying is a water-saving technology presently being investigated in many countries. There is now considerable evidence in the literature that growth in many plants is limited by water deficit. Plants develop adaptive growth and development changes as a result of chemical signals from roots in a drying soil e.g., limited shoot growth.

Objectives

- To evaluate the effect of Mulch types on yield and water productivity.
- To determine the effect of Furrow methods on yield and water productivity.
- To analyze and evaluate different techniques that enhance the water productivity and crop yield.

Materials and Methods

Experimental design

Field experiment was conducted at Melkassa Agricultural Research Center, Ethiopia. The experiment was designed as a split-plot design in RCBD and replicated three times. The treatments include three furrow techniques: Fixed, alternate, and conventional, and two mulch types (straw and plastic) and control as no mulch. The furrow techniques were in the main plot while mulch types were assigned to subplots. The mulching rate of 6 tons'/hectare wheat/barely straw and white plastic mulch with 30 microns' thickness and conventional furrow without mulch was considered as a control treatment for this experiment. Onion seedlings were prepared at the nursery. Onion is known by the two-row plant so transplanting was done on 40 cm, 20 cm and 10 cm spacing of row plant (*i.e.*, plant row spacing across furrow was 40 cm, across the ridge was 20 cm and along the ridge 10 cm between plants) (Table 1).

Treatments		**Treatment combinations**
Main plots	**Subplots**	
Conventional furrow irrigation	No mulch	CFI w̄ NM
	Straw mulch	CFI w̄ SM
	Plastic mulch	CFI w̄ PM
Fixed furrow irrigation	No mulch	FFI w̄ NM
	Straw mulch	FFI w̄ SM
	Plastic mulch	FFI w̄ PM
Alternative furrow irrigation	No mulch	AFI w̄ NM
	Straw mulch	AFI w̄ SM
	Plastic mulch	AFI w̄ PM

Table 1. Treatments and treatment combinations.

The experimental field was divided into 27 plots and each plot size was 3.6 m × 5.5 m dimension (19.8 m^2 plot area) to accommodate six furrows with a spacing of 60 cm and 5.5 m length. Each plot consisted of five ridges and six furrows. The blocks have a buffer zone of 1.2 m from water water-supplying canal and plots were separated by 2 m from each other to eliminate the influence of the lateral flow of water. A field channel was constructed for each block to irrigate the field. For each plot box shaped structures were constructed to dissipate the energy of water diverted to the plots. The amount of irrigation water applied was calculated using CROPWAT 8.0 software by using necessary input data (crop, soil and long-term climatic data). Irrigation water is applied up to field capacity by monitoring soil moisture content using gravimetric method and/or using soil moisture measuring devices at different soil depth intervals from the surface to the depth of maximum root zone depth depending on the crop type. Applied water to the field was measured by Parshall flume.

Data to be collected

Physical and chemical properties of soil: (Texture, bulk density, infiltration rate, FC, PWP, EC, CEC, OM, and PH).

- Chemical properties of irrigation water (Boron, EC, and PH).
- Date of irrigation (Irrigation amount applied at every event, rainfall record).
- Soil moisture content before every irrigation event.
- Daily weather variables (Rainfall, air temperature (maximum and minimum), wind speed, RH, U2 and sunshine hours).
- Irrigation efficiency for the system.
- Allowable depletion levels (P) will be collected from (EIAR or FAO recommendations).

Water productivity (WP)

Water productivity was estimated as a ratio of grain yield to the total Etc through the growing season and calculated using the following equation:

$$WP=(Y/ET)$$

Where WP is water productivity (kg/m^3), Y crop yield (kg/ha), and ET is the seasonal crop water consumption by evapotranspiration (m^3/ha).

Data analysis

Yield and yield components data and water productivity data were subjected to statistical analysis using SAS version 9.1.

Results and Discussion

To evaluate the yield response to mulch type in combination with the AFI, FFI and CFI methods, some direct and indirect measurements were made. These included computations of crop water requirement using climate data, determination of water use efficiency, and yield performance assessment.

Yield response of onion to furrow methods and mulch types

The highest average bulb yield of 35.9 t/ha was obtained at the conventional furrow technique and the lowest average bulb yield of 24.6 t/ha was recorded at the fixed furrow irrigation technique as presented in Table 2. The bulb yield differences were significant at a 5% level of probability. The bulb yield reductions with partial root drying that resulted in 50% water saving at both alternate and fixed furrow irrigation from conventional furrow irrigation were about 25, and 32%, respectively. Generally, the result shows that AFI is more efficient than FFI for an equal amount of water application Table 2. A similar study conducted on maize by Kang et al., confirmed that yield reduction in AFI was not significant, unlike FFI.

Mulching treatments had also shown a marked effect on onion bulb yield. Onion bulb yield increased significantly with no mulch to the use of mulch. The highest average bulb yield of 32.4 t/ha was obtained at the plastic mulch type and the lowest average bulb yield of 25.4 t/ha was recorded at no mulch treatment as presented in Table 2. The bulb yield differences were significant at a 5% level of probability. The bulb yield increased with the use of mulch type from bare to straw and plastic mulch was 15 and 28%, respectively. Generally, the result revealed that mulching is more efficient than no mulch for an equal amount of water application Table 2. This implies that mulching manages soil moisture by reducing evaporation and making a favorable environment for the potential crop yield production by improving soil physical properties and fertility; controlling weed and temperature fluctuations. The result is in line with Khaledian et al. who indicated that crop yield could be increased because of the improvements in soil physical properties and fertility under mulching. This result is also in agreement with the findings of Fereres and Soriano and Igbadun et al. that showed the reduction in soil evaporation when mulches cover the soil surface, more water remains potentially available in the root zone and, consequently, irrigation requirements could be decreased (Table 2).

Furrow types	Bulb yield t/ha	WP (kg/m^3)
CFI	35.9^a	6.5^c
AFI	26.4^b	9.2^a
FFI	24.6^b	8.6^b
CV	15.52	4.96
LSD	3.4	0.477
Mulch types	**Bulb yield, t/ha**	**WP (kg/m^3)**
PM	32.4^a	8.9^a
SM	29.2^b	8.3^a
NM	25.4^c	7.1^b
CV	10.39	11.47
LSD	1.64	0.755

Table 2. Integrated effect of mulching and furrow methods on onion yield and WP.

Significant interaction was observed with furrow irrigation techniques and mulch types at the 5% level of probability. Irrigating using conventional furrow technique and plastic mulch was found to be the most effective. It produced a significantly high bulb yield of 38.6 t/ha when compared to the fixed furrow method with no mulch type, which resulted in a bulb yield of 21.5 t/ha. The result also indicated that the use of alternate furrow irrigation combined with plastic mulch had no significant effect on onion bulb yield as compared to the control treatment resulting in yield reduction of onion by 5%.

Generally, the result shows that using mulch types significantly increases onion production when combined with furrow irrigation techniques. AFI is more efficient than FFI for equal amounts of water application Table 3. A similar study conducted on maize by Kang et al., confirmed that yield reduction in AFI was not significant, unlike FFI.

Water productivity

Furrow methods had a significant ($p<0.05$) influence on water productivity. Water productivity was higher for alternative furrow and lower water productivity was obtained from conventional furrow methods. Mulch types had a significant ($p<0.05$) influence on water productivity. Water productivity was higher for plastic mulch type treatment and lower water productivity was obtained from no mulch treatment due to low product. The study revealed that producing onion with plastic mulch resulted in higher yield production and water productivity as shown in Table 2. The interactive effect of furrow irrigation techniques and mulch types had a significant ($p<0.05$) influence on water productivity Table 3. The highest water productivity was recorded from the alternate furrow technique combined with plastic mulch type. The lowest water productivity was recorded from the conventional furrow technique that was bare or not mulched (control treatment). The result also indicated that the use of alternate furrow irrigation combined with plastic mulch resulted in yield reduction of onion by 5% and increased water productivity by 75% against control treatment. Generally, the result shows that AFI is more efficient than FFI for an equal amount of water application Table 3. A similar study conducted on maize by Kang et al., confirmed that yield reduction in AFI was not significant, unlike FFI.

Mulch types	Bulb yield (t/ha)			Water productivity (kg/ha)		
	Furrow types					
	CFI	AFI	FFI	CFI	AFI	FFI
NM	32.6^b	22.1^{ef}	21.5^f	6.0^d	7.7^c	7.7^c
SM	36.6^a	26.3^d	24.8^{de}	6.7^d	9.4^b	8.8^b
PM	38.6^a	30.9^{bc}	27.6^{cd}	6.9^{cd}	10.6^a	9.2^b
LSD (0.05)	2.83			1.08		

Table 3. Interaction effect of irrigation levels and nitrogen rate on onion bulb yield and WP.

Conclusion

The experimental results showed that marketable bulb yields and water productivity of onion can be increased significantly by mulching. Un-mulched plots resulted in higher crop water use, by way of increased evapotranspiration losses, compared to the mulched plots. The conventional furrow irrigation method, where water is applied to every furrow was superior to both the conventional with alternate and fixed furrow methods. If the alternate furrow method is to be used for onion production, water use productivity by the crop can be enhanced if the furrows are mulched. Economics of mulching was not evaluated as part of this study but it appeared that the practice of mulching as a strategy for enhancing moisture conservation in soils might not be cost-effective on a large scale.

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