International Journal on Food, Agriculture, and Natural Resources
Volume 04, Issue 04, Page 96-102
ISSN: 2722-4066
http://www.fanres.org

Original Paper

Determination of Irrigation water requirement and scheduling of onion at Low land area of Wag-himra, Northern Ethiopia

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Received: 30 November 2023; Revised: 28 December 2023; Accepted: 30 December 2023
DOI: *https://doi.org/10.46676/ij-fanres.v4i4.250*

***Abstract*— In order to ensure sustainable agriculture and improve living standards, it is crucial to implement water-efficient irrigation practices. Accurate irrigation scheduling plays a vital role in enhancing irrigation efficiency. This two-year field experiment conducted at the Abergelle irrigation scheme aimed to determine crop water requirements and develop irrigation schedules specifically for market-oriented crops, with a focus on onions. A factorial arrangement randomized complete block design was employed, consisting of three irrigation intervals (3, 4, and 5 days), three levels of CROPWAT, and fixed application depths (125%, 100%, and 75% ETc). Additionally, one farmer practice was used as a control. The findings revealed that applying 75% CROPWAT at 3-day intervals resulted in higher water productivity and saved 2873 m3 ha-1 compared to the farmers' usual irrigation practice. The implementation of this irrigation strategy proved to be beneficial for the irrigated crops.**

***Keywords*— CROPWAT fixed depth, Onion, Schedule, water productivity, yield**

I. INTRODUCTION

Water scarcity is a major problem for agriculture in most parts of the world, especially in lowland areas. The growing scarcity of water in many parts of the world has increased the need to improve the productivity of irrigation water. Since agriculture is the sector that uses the most water and its use is considered inefficient, any increase in water productivity is considered to have a significant impact on the regional and global water balance [1]. Irrigation maps provide all or most of the water needed by crops in arid and semi-arid regions [2]. Each stage of crop development, primarily the initial stage, crop development stage, mid-season stage, and late-season stage, requires a specific amount of water. Crops transpire water at their maximum rate when the soil moisture is full or has reached field capacity. However, with the amount, intensity, duration, frequency, and distribution of rainfall required by nature, crops rarely receive the amount of water they actually need to meet optimal productivity [3]. Identifying and implementing agricultural and water management practices that eliminate water shortages and improve water productivity is the key to building new water storage facilities [4]. Deficit irrigation was shown to be the most effective method in arid areas with low water availability but high yields [5]. In the time of shortage, a key strategy for reducing irrigation water consumption is termed as deficit irrigation, which refer as the delivery of water below the full crop water requirement [6]. In semiarid, arid, and other similar areas, the best water-saving technology for obtaining the best crop yields in irrigated agricultural systems is deficit irrigation with conventional crop furrow application methods [7]. Knowing the water requirements of the crop is critical to ensure the best crop yield with the least amount of water use. Productive scheduling of irrigation water is important to develop proper management of irrigated land. Crop selection and application of an efficient management system all depend on determining the response of crop production to irrigation. This allows the timing of irrigation to determine to maximize yield, water use efficiency, and overall profit [8].

The agricultural sector is closely associated with large-scale food crop production based on irrigation and is the largest user of water resources in the world [9]. Irrigated agriculture has difficulty in optimizing the use of water resources due to a lack of crop water demand studies for important crops resulting inadequate irrigation schedules and low water use efficiency. Using the same amount of water and standard irrigation schedules to maximize the use of agricultural land is a good practice that can be effectively applied to increase crop yields. This method has been identified as a water-saving method for growing of field crops in various arid and semi-arid countries [10]. By determination the water requirements of crops, irrigation schedules can be developed that improve production, income, and water savings [11]. Effective water management is necessary to optimize crop yield per unit of water and to sustain irrigated agriculture in perpetuity [12]. Irrigation fields in Wag-lasta districts are not monitored for water content before and after irrigation. Despite the long history of irrigation, farmers' experience in the area is very limited [13]. Onion is an important vegetable crop and requires a significant amount of water to obtain optimal yields in the district. As water scarcity becomes more severe, producers must adopt water-saving techniques to maintain water productivity. However, the potential trade-offs between water use efficiency and crop yield in deficit irrigation and scheduling for onion production in the area has not been fully explored. Due to the complexity of scheduling techniques, the cost and availability of soil-water monitoring tools, the lack of various local climatic data, and lack of soil-water parameters, poor irrigation scheduling has been identified as the main obstacle to the sustainability of small-scale irrigation schemes in Ethiopia [14]. Water scarcity is a major constraint to agricultural production in the northern Ethiopia, especially in the Abergelle district. Because water is the limiting factor, producers must balance the need to maintain crop productivity with the need to conserve water. Water scarcity is the most common constraint to agricultural development in the arid lands of the district. The district's irrigation scheme has greatly expanded irrigated agriculture. However, because farmers irrigate their crops based on traditional know-how, water efficiency in agricultural production is very low, resulting in nutrient leaching and severe water shortage problems in the study area. One of the challenges to the efficient use of limited water resources in irrigated agriculture is the lack of water-saving techniques in main crop cultivation, such as deficit irrigation and irrigation scheduling. Due to inadequate water management, farmers in the district apply approximately the same amount of water to crops at different stages of growth. Despite the fact that irrigation has long been used by farmers of different sizes, there is no efficiently and effectively managed irrigation water technology. There is little or no information on crop water management practices such as crop water requirements and irrigation schedules on farms that are constantly irrigated with the irrigation scheme. Onions, on the other hand, are the main vegetable crop grown under irrigation in the command area. However, water requirements and schedules for onions have not been studied in the Abergelle irrigation scheme. These factors serve to focus these studies providing information for effective water management practices for this particular crop. Therefore, the objective of this study is to determine crop water requirements and irrigation schedules for onion in order to optimize resource allocation and improve yield and water productivity.

II. MATERIAL AND METHODS

A. *Description of the study site*

The field study was conducted during the two consecutive irrigation seasons of (2018/19 and 2019/20) in the Abergelle district, Wag-himra zone, Amhara region, northern of Ethiopia. The study site is located at 12.54o N, 38.56o E, and 1312 m elevation. The main source of income for the residents is agriculture, which is a mixed cropping system of crops and livestock. The most important animals raised in the area are cattle, sheep, and goats (Abergelle breed). The main crops grown in the area are sorghum (Sorghum bicolor), pearl millet (Pennisetum glaucum), sesame (Sesamum indicum L.), teff (Eragrostis tef), wheat (Triticumaestivum L.), and cowpeagrains. Horticultural crop such as mango (Manifera Indica), banana (Mussa Spp.), citrus fruits, pepper (Capsicum species), tomato (Solanum lycopersicum), and onion (Allium cepa L.) are also present. Topographically, there are plateaus, mesa, canyons, and ravins that have been covered by rivers and streams for thousands of years. In addition, the Abergelle of the Bare irrigation scheme is characterized by moderate and high slopes and relatively flat terrain, and includes a number of valleys and plains that are often used for agriculture and grazing.

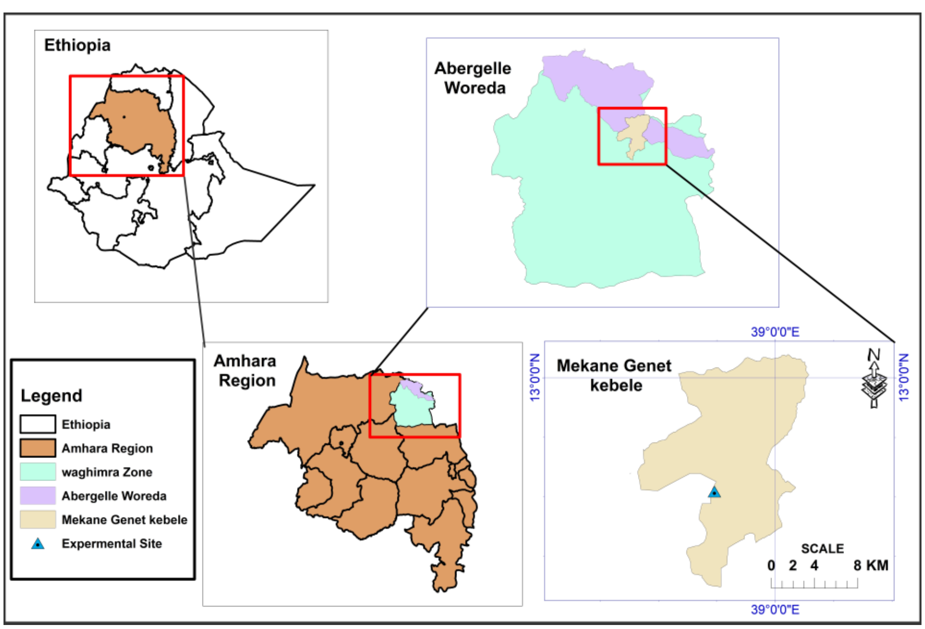

Fig.1. location map of the study area

B. Climate Characteristics

The climate of the area is characterized by unimodal rainfall characteristics, with the rainfall pattern being dominated by the main rainy season in July and August .The average rainfall in the area is 622.37 mm, with an irregular and uneven distribution among seasons and years .The average monthly minimum and maximum air temperatures during the irrigation season are 15.4°C and 25.08°C, respectively, while the average annual minimum and maximum air temperatures are 24.5°C 36°C, respectively. The area is defined by an unconformable Precambrian basement covered by Paleozoic–Mesozoic sedimentary sequences overlaid by tertiary volcanic [15].

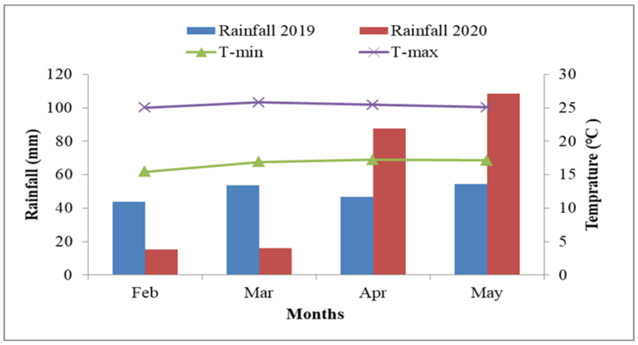

Fig. 2. Rainfall, maximum (T-max) and minimum (T-min) temperatures during the irrigation season

C. Soil characteristics

The soils at these sites are sandy clay loams belonging to the Cambisol soil class. Using an auger, soil samples were taken from the study sites at depths of 0 – 20, 20 – 40, and 40 – 60 cm before irrigation. These were sun-dried in the shade, crushed, sieved, and analyzed for texture, PH, Organic matter, total nitrogen, and available P using the hydrometer procedure. The field capacity of the samples was (20.46, 23.3, and 24.29%) and permanent wilting point (12.61, 15.65, and 15.05%) respectively, in the two irrigation seasons. The hydrometer method was used to determine the particle size distribution. The wet digestion method was used to determine organic carbon [16]. Total nitrogen content was analyzed by the Micro-Kjeldahl method [17]. Soil PH was measured using digital PH at a soil sample to water ration of 1:2.5 [18]. Available phosphorus was measured by the Olsen method [19].

TABLE I. SOIL PROPERTIES OF THE EXPERIMENTAL FIELD

Soil properties	*Value*	*Rating*
PH (by 1:2.5 soil water ratio)	7.05	Neutral
Total nitrogen (%)	0.01	Very low
Available phosphors (ppm)	0.84	Low
Organic carbon (%)	1.05	Low
Electronic conductivity(ms/cm)	0.42	Low

D. Parameter requirements CROPWAT 8.0 Model

The interference of CROPWAT widow version 8.0 was used for irrigation planning. Crop data (crop type, planting date, crop coefficient (Kc) value, and stage date) and climate input parameters, soil type, root depth, and depletion fraction were input using CROWAT 8.0 version. The ETc was determined by multiplying the reference evapotranspiration (ETo) by the crop coefficient [20]. Climate data as inputs for ETo determination:

$$ETc = Kc * ETo \qquad (1)$$

E. Crop type and growth stage

Information from FAO irrigation and drainage document No. 56 was used because there was no actual onion Kc at the study site [20]. The growing period of onion is 120 days, divided into 25 days in the early stages 40 days in the development stage, 30 days in the mid- stage, and 25 days in the late stage.

F. Determination of effective rainfall

Usable rainfall is equivalent to effective rainfall [21]. Unexpected rainfall was measured using with rain gauges and converted to effective rainfall with the CROPWAT8.0 model using USDA procedures [22].

$$P_{effective} = \frac{P_{total}\,(125-0.2*Ptotal)}{125} \quad \text{for } P_{total} < 250\text{mm} \qquad (2)$$

$$P_{effective} = 125+0.1*P_{total} \quad \text{for } P_{total} > 250\text{mm} \qquad (3)$$

G. Experimental design and procedures

Three different irrigation depths (125%, 100%, and 75%) and three irrigation intervals (3, 4, and 5 days) were used in the experiment. Each treatment and its arrangement are listed in Table 1. The treatments were replicated in three times. All agronomic practices were uniformly applied in each treatment. Plots were 2.4 m x 3 m double rows of the onion variety Bombay red, planted at spacing of 40 cm x 20 cm x10 cm. Half of the urea fertilizer was applied at planting and half was applied 45 days after planting at a rate of 92 kg ha-1. In this experiment, a canning system was used as a method of applying water. The CROPWAT 8.0 model was used to calculate the ETc of the onion crop' and the model was used as reference for treatment selection. Based on the treatment code arrangement, common irrigation water was applied to the onion vegetative in each plot. Rainfall and irrigation must be sufficient to meet the crop's evapotranspiration needs to prevent agricultural water stress. In other words, the amount of water required without being supplied by rainfall, referred to as net irrigation requirement (NIR) at any given moment throughout the crop growing season, is transported from the water source to the crop root zone. Some water is lost pipe, such as seepages, leakage, and evaporation from irrigation canals. Because of this loss, additional water must be supplied to compensate for the amount that needs to be stored in the crop root zone. The amount that must be supplied is known as the gross irrigation requirement (GIR) [23].

$$NIR = ETc - Pe \qquad (4)$$

$$GIR = \frac{NIR}{Ea} \qquad (5)$$

Where ETc is the crop's evapotranspiration (mm/season), Pe is effective rainfall (mm/season), NIR is net irrigation requirement (mm/season), GIR is gross irrigation requirement (mm/season), and Ea is application efficiency (assumed 70%).

H. Data collection

Data collected included plant height, bulb weight and diameter, marketable and unmarketable yields, and water productivity. Water use efficiency (kg m-3) was calculated from the ratio of total yield (kg) to total water (m3) delivered up to the harvesting [24].

$$\text{Water productivity(WP)} = \frac{\text{Total yield of onion(kg)}}{\text{water delivered } (m^3)} \quad (6)$$

TABLE II. TREATMENT COMBINATIONS AND AMOUNT OF WATER APPLIED

Treatments	Amount of applied water (mm)
125% CROPWAT fixed depth and at 3 days interval	507.3
100% CROWAT fixed depth and at 3 days interval	368.2
75% CROPWAT fixed depth and at 3 days interval	342.95
125% CROPWAT fixed depth and at 4 days interval	457.35
100%CROPWAT fixed depth and at 4 days interval	354.3
75% CROPWAT fixed depth and at 4 days interval	336.65
125% CROPWAT fixed depth and at 5 days interval	440.1
100% CROPWAT fixed depth and at 5 days interval	358.1
75% CROPWAT fixed depth and at 5 days interval	331.7
Farmer practice irrigation depth and irrigation interval in days	630.25

Note: Farmers do not irrigate at fixed interval of daysrather than for the benefits of the users; sometimes two days, sometimes –three days, and vice versa.

I. Data analysis

SAS statistical software version 9.1 was used for analysis of variance (ANOVA) and correlation analysis. At a probability level of 5%, the least significant difference test was used to compare means.

III. RESULTS AND DISCUSSION

A. Physiological and Growth parameters of the crop

Plant height and unmarketable yield were non-significant (P<0.05) according to analysis of variance but significant in the bulb weight and bulb diameter of onion (Tables 3 and 4). The highest plant height, bulb diameter, bulb weight, and unmarketable yield were measured among the treatments at 125% fixed application depth at 5 and 3 days. Plant height and bulb diameter were 43.7 cm and 46.5 cm at 5 and 3 days of 125% fixed depth application respectively. The lowest plant height and bulb weight brained from 75% CROPWAT fixed application depth with 5 days was 40.9 cm, and 51.97 gm respectively. However, the lowest unmarketable yield of onion was 0.78 t ha-1 at 125% CROPWAT fixed depth application at 5-day interval. This indicates that the timing and amount of water applied had a significant effect on bulb's weight [25]. There were numerical differences in plant height among treatments, but no statically significance differences.

TABLE III. INTERACTION EFFECTS OF DEPTH AND FREQUENCY ON PLANT HEIGHT AND BULB DIAMETER OF ONION CROP.

Frequency	**Plant height (cm)**				**Bulb diameter (mm)**			
	Depth				**Depth**			
	125%	**100%**	**75%**	**F_d**	**125%**	**100%**	**75%**	**F_d**
3days	42.8	41.0	40.0		46.5	45.9	42.5	
4days	43.0	41.7	41.3		46.2	43.0	40.9	
5days	43.7	42.0	40.9		44.2	44.8	40.7	
Ff				41.5				61.15
LSD	Ns				3.5			
CV	6.19				6.65			

Where Fd = farmers irrigation depth practice; Ff = farmer irrigation frequency or interval practice; LSD = list significance difference and CV = coefficient variation

TABLE IV. INTERACTION EFFECTS OF DEPTH AND FREQUENCY ON BULB WEIGHT AND UNMARKETABLE YIELD

Frequency	**Bulb weight (gm)**				**Unmarketable yield (t ha^{-1})**			
	Depth				**Depth**			
	125%	**100%**	**75%**	**F_d**	**125%**	**100%**	**75%**	**F_d**
3days	59.19	57.15	54.5		1.16	1.04	1.06	
4days	56.66	54.88	53.97		0.98	1.03	1.04	
5days	56.26	55.14	51.97		0.78	0.96	1.05	
Ff				61.15				1.12
LSD	6.79				Ns			
CV	10.04				53.15			

B. Marketable yield

The marketable yield of onions exhibited significant differences (P<0.05) based on both irrigation depth and frequency. As indicated in Table 5, the highest recorded onion yield was 11.88t ha^{-1}, achieved with a CROPWAT depth of 125% and irrigation every 3 days. Conversely, the lowest onion yield obtained was 8.66t ha^{-1}, associated with a CROPWAT depth of 75% and irrigation every 5 days. These findings highlight the impact of irrigation practices on onion productivity. On the other hand, the results of 75% CROPWAT fixed application depth using a 3-day irrigation interval were the best marketable optimum yield onion crop production. However there was minimum yield reduction without significant this is in line with the finding of. Irrigation schedule affects yield components and morphological traits of onion [26]. Irrigation frequency had a significant impact on the growth and production of the onion crop. This result was consistent with the findings of [27].

C. Total yield

Overall, total onion yields showed highly significant differences (P<0.05) with irrigation depth and irrigation frequency. The maximum total onion yield was obtained at a CROPWAT fixed depth of 125% and an irrigation interval of 3 days, with a value of 13.04 t ha-1. The lowest total onion yield was obtained 9.71t ha-1at 75% CROPWAT depth and 5 days irrigation interval (Table 5). This is consistent with the findings of [28] . Interaction effects of depth and frequency on the total yield of onion crop (Table 5). The results showed that the 3-day irrigation interval at 75% CROPWAT fixed irrigation depth had the best yield (12.06 t ha-1) and yield-related components in onion production. Farmers use too much amounts of water for irrigation and irrigation intervals are too short, resulting in low yields with this practice. As yields increase, irrigation applications often decrease. However, statistics show that the maximum overall results were equivalent to yields with 75% ETc. A previous study in [29] found similar results. This result was consistent with the finding that under deficit irrigation, achieving full irrigation requirements along the crop allows it to establish a sufficient biomass and root system to increase marketable yields [30], the depth and frequency of application lids to rise total tuber yield in potato production stated to be the appropriate amount. This study, unlike others, accounted for the interaction between irrigation schedule and d irrigation depth. The results showed that longer irrigation intervals resulted in insufficient irrigation and significantly reduced yields (Table 5).

TABLE V. INTERACTION EFFECTS OF IRRIGATION FREQUENCY AND DEPTH ON MARKETABLE YIELD (MY), TOTAL YIELD (TY) AND WATER PRODUCTIVITY (WP)

Frequency	MY (t ha^{-1})				TY (t ha^{-1})				WP (Kg m^{-3})			
	Depth				Depth				Depth			
	125%	100%	75%	F_d	125%	100%	75%	F_d	125%	100%	75%	F_d
3days	11.88	11.67	11.0		13.49	12.71	12.06		3.03	4.11	4.29	
4days	9.46	10.62	11.1		10.44	11.5	12.14		2.59	4.08	4.22	
5days	8.96	10.35	8.66		9.74	11.31	9.71		2.44	3.97	3.6	
Ff				9.6				10.7				2.7
LSD	0.98				1.27				0.48			
CV	7.97				9.42				11.56			

TABLE VI. CORRELATION COEFFICIENTS FOR PLANT HEIGHT, BULB DIAMETER AND WEIGHT, MARKETABLE YIELD, UNMARKETABLE YIELD, TOTAL YIELD AND WATER PRODUCTIVITY

	PH	BD	BW	MY	UMY	TY	WP
PH	1						
BD	0.236895386ns	1					
BW	0.108385009ns	0.098121835ns	1				
MY	0.36135229ns	0.41670998ns	0.073847643ns	1			
UMY	0.473049228**	0.521414195**	0.146233718ns	0.197240809ns	1		
TY	0.424763217*	0.485519357**	0.045249925ns	0.985890561***	0.358544502*	1	
WP	0.208950034ns	0.18009817ns	0.118680048ns	0.668471291***	0.136289697ns	0.659530619***	1

(P<0.05)*** Very high significance; ** highly significance difference; * significance difference; ns = non-significance difference

D. Water productivity

The interaction between depth and frequency showed a significant difference (P<0.05) in water productivity of the onion crop. Table 5 shows that maximum water productivity (4.29 kg m-3) was obtained at 75% CROPWAT fixed application depth with 3-day intervals and minimum water productivity (2.44 kg m-3) was at 125% CROPWAT fixed application depth with 5 days interval. These findings confirm that declared crop production depends on water consumption rate and that all parameters affecting water use for yield and evaporation/transpiration have a positive impact on water use efficiency [30]. The most limited water is often involved in the most efficient water [31]. Water use efficiency decreased from 4.29 kg m-3 to 2.44 kg m-3 when total irrigation application increased from minimum irrigation (75% ETc, 3 days) to maximum irrigation (125% ETc, 3 days). Similarly [32] reported that water use efficiency of onion increased with deficit irrigation (75% ETc). These results indicate that 75% CROPWAT fixed irrigation depth in 3 day interval achieved higher WP values compared to others and saved 2873 m3 ha-1 of irrigation water compered to farmer irrigation. It provides additional irrigated land 0.84 ha which gained 10.44 t ha-1 yield of onion as compared to farmer irrigation practice. The saved water can be used for additional cultivation in water scarce areas, especially to increase cultivated land in areas where natural resources are scarce, and these findings are consistent with [33]. These results are also agree with the findings of [34]. Deficit irrigation increases water productivity compared to full irrigation, as experimentally shown in various crops. [27] Reported that water productivity decreases with increasing irrigation depth. Water productivity increases when irrigation water is conserved. The result of this investigation in comparison to the prior study shows that an increased irrigation deficit with longer irrigation intervals causes the water productivity to diminish as a result of decreases brought on by stressed crops and hot climates that produce more evaporation that increases crop water demand. Longer irrigation intervals (frequency) and less water are applied to the crop results in stress and reduce onion yield, which affects water productivity. Yield per unit of water decreased as the water levels increased and the difference in irrigation frequency increased (Table 5). Farmers' practices have lower yields and water productivity. This is the same as reported by [35]

IV.CONCLUSIONS

The irrigation depth and frequency have a significant impact on onion crop production and water productivity, as indicated by this study. The interaction effect between the depth and frequency of irrigation plays a crucial role in determining the yield and water productivity of onions in small-scale irrigation schemes. The study found that by applying irrigation at 75% of the CROPWAT fixed depth every 3 days, a yield of 12.5 tons per hectare and a water productivity of 4.3 kilograms per cubic meter were achieved. This irrigation approach resulted in significant water savings of 2873 cubic meters per hectare compared to the traditional farmer irrigation method, allowing for an additional 0.84 hectares of irrigated land and a yield increase of 10.44 tons per hectare. Therefore, it is recommended to use the 75% CROPWAT fixed depth with a 3-day irrigation interval in areas such as Abergelle, irrigation schemes, and similar agro-ecological regions.

ACKNOWLEDGEMENTS

The researchers of this experiment are deeply grateful to the Amhara Agricultural Research Institute for funding the research work and the Sekota Dry land Agricultural Research Center for supporting logistics during the research and providing additional information for this paper.

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