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Improving Onion Farming with Smart Irrigation: Using Wetting Front Detector to Boost Water Efficiency and Crop Yields in Northern Ethiopia

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Author's contribution

The sole author designed, analysed, interpreted and prepared the manuscript.

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ABSTRACT

Water scarcity and the decline in soil fertility remain the most limiting factors in intensifying agricultural production in the dry land agricultural system. A two-year field experiment was conducted at Hamedo and Hatsebo irrigation sites, Northern Ethiopia, aiming to introduce, evaluate, and promote of a relatively simple, accurate and practical irrigation scheduling technologies. In doing so, a field experiment was design and laid out in randomized complete block design (RCBD). Four factorial treatments (methods of irrigation scheduling Wetting Front Detector (WFD), Simple Calculation Method (SCM), FAO CropWat-8 Method (FAO), and compared with the standard check, farmer's irrigation scheduling practice (FIP)) were evaluated with three replications. A combined analysis of the two-year (2020 and 2021) experiment was made for marketable Onion bulb yield (MYld), Water Productivity (WP) and other agronomic parameters such as bulb diameter (BD), bulb length (BL) and bulb weight (BW) using statistical software (R-software). The experiment result

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shows, in each experimental site (HAMEDO & HATSEBO), no statistical significant differences on BD, BL, BW at (P < 0.05), while, MYld, TYld shows significant differences in both locations. Compared with the standard check (FIP) scheduling practice the production and productivity of onion bulb (MYld) with (FAO, WFD, SCM) throughout the growing season application has shown significant differences at HAMEDO irrigation scheme. The higher IWP was observed with a scheduling method of WFD. On the other hand, a significant yield reduction of onion bulb (MYld) was observed at HAMEDO with the scheduling method of FIP and SCM. Based on this experiment, the wetting front detector (WFD) saved more than 15% of irrigation water compared to FAO CropWat-8 method at Hamedo irrigation scheme. Similarly, compared with the standard check (FIP) scheduling method the production and productivity of onion bulb (MYld) the WFD scheduling method has shown significant differences at HATSEBO irrigation scheme rather a relatively higher IWP was observed at SCM and FAO scheduling methods. In conclusion, the production and productivity of onion bulb (MYld) and irrigation water productivity is significantly affected with the proper scheduling practice in both locations. However, the effects on other yield parameters were not statistically significant throughout the treatments. The WFD scheduling method is a better option for sand clay loam soil textured at Hamedo irrigation scheme for optimum onion bulb (MYld) production and IWP. Therefore the technology is better to demonstrate at farmer's level to increase farmer's water management habit.

Keywords: Onion bulb yield; irrigation scheduling; wetted front detector; water productivity.

1. INTRODUCTION

It is widely recognized that population growth and economic development will lead to an increasing competition for scarce water resources [1,2]. Irrigated agriculture as the largest water consuming sector faces challenge to produce more food with less water [3]. Increasing crop water productivity (CWP) is therefore necessary to meet the challenge [4]. A sound knowledge of CWP and water resources availability at fine spatial and temporal resolution is therefore very importance for understanding the water and food relationship and for assessing the feasibility of the virtual water strategy in improving water use efficiency in a country [5]. The achievements of irrigation in ensuring food security and improving rural welfare have been impressive; however, past experience also indicates problems and failures of irrigated agriculture. In addition to large water use and low efficiency, environmental concerns are usually considered the most significant problem of the irrigation sector. Environmental problems include excessive water depletion, water quality reduction, water logging, and salinization [6,7]. Moreover, inappropriate irrigation practices, accompanied by inadequate drainage, have often damaged soils through over-saturation and salt build-up. Meanwhile, sustainable irrigation water management should simultaneously achieve two objectives: sustaining irrigated agriculture for food security and preserving the associated natural environment [8,7]. A stable relationship should be maintained between these two objectives now and in the future, while potential conflicts between these objectives should be mitigated through appropriate irrigation practices.

As a result, improved moisture control and irrigation are essential to achieve these goals. As reported by [9], the major agricultural use of water is used for irrigation, which, thus, is affected by decreased supply. Hence, innovations are needed to increase the efficiency of use of the water that is available. Better management of agricultural water for increased productivity and efficiency and "more crops per drop" are of vital importance [10,11]. Likewise, a two-pronged strategy, increasing water productivity in existing irrigation schemes and increasing the area under irrigation is needed to increase food production through irrigation. In this regard, innovation in irrigation scheduling technologies and practices need to be evaluated, introduced and promoted at a scheme level in the dry land area irrigated agricultural system.

The greatest challenge of the agricultural sector is to produce more food from less water, which can be achieved by increasing Crop Water Productivity (CWP). On the other hand, CWP can be increased significantly if irrigation is reduced and crop water deficit is interdentally induced. With proper design, and installation of water control structures (irrigation scheduling), efficiency of surface irrigation can be significantly improved. Nowadays, there are different surface irrigation application systems developed to improve irrigation water use efficiency, distribution uniformity and storage efficiency. One basic principle towards efficient utilization of surface irrigation is to design the method with optimum and practical irrigation scheduling practice. Similarly, introduction, evaluation and promotion of the best irrigation scheduling technologies and practice give an opportunity for a better control over the amount, frequency and duration of irrigation application time. It is presumed that optimum and practical irrigation scheduling technologies and practices in surface irrigation method can help to save irrigation water both by minimizing evaporative and deep percolation losses at the same time [12]. However, the main challenge with optimum irrigation scheduling practice is the matter of its practical application. Most farmers are not capable of measuring the exact stream flow (Q), application duration (td), application frequency (T) or the amount irrigation water required at the field. Besides, most irrigation schemes are traditional. Such irrigation schemes do not have irrigation facilities for proper irrigation scheduling instead, they are fully operated with the individual farmer's knowledge and experience. On the other hand, the dryland irrigated agricultural system is mostly challenged with shortage of irrigation water. Therefore, the introduction, evaluation and promotion of a relatively simple, accurate and practical irrigation scheduling technologies and/ or practice such as the FAO CropWat, Wetted front detector, and the simple calculation method plays a significant role in addressing some the prominent constants explained above. Hence this study aimed (i) to introduce, evaluate and promote the best (relatively simple, accurate and practical irrigation scheduling technology), (ii) to improve the efficiency of surface irrigation systems performance, and (iii) to enhance the capacity of farmer’s irrigation water management at scheme level.

2. MATERIALS AND METHODS

2.1 Description of the Study Area

The experimental site is located between latitude of 14° 10' - 14° 35' N and longitude of 38° 40' - 38° 40' E, 14° 01' - 14° 10' N and longitude of 38° 40' - 38° 50' E, mean altitude of 1872m and below 2080 meters above sea level (MASL) at Hatsebo and Hamedo irrigation schemes respectively (Fig. 1). The average annual rainfall of the area varies from below 450 to 750mm and seasonal rainfall pattern at the experimental area shows Uni-modal distribution, which extends from June to early September. The mean annual temperature ranges from a minimum of 11 ℃ to a maximum of 27℃. The composition of sand, silt and clay percentages, for the experimental site, was 11%, 35% and 54%, at Hatsebo and 11%, 35% and 54%, at Hamedo on the surface soil (0-30 cm) respectively. Thus, the soil was characterized as dark clay and sandy clay loam textured and the field capacity (FC) and permanent wilting point (PWP) of the soil were found to be 37.3% and 11.4% respectively at Hatsebo and Hamedo with total available water of 122.5 mm and 51 mm per meter length respectively.

2.2 Experimental Design and Treatment Setup

Materials such as Parshal Flumes, Wetted Front Detector (WFD) and/or Tensiometers (TDR) Auger and core sampler vegetable seeds (Onion), inorganic fertilizers, Meteorological data are required. Four irrigation scheduling practices (including, Farmers experience, FAO CropWat, Simple calculation, and Wetted front detector (WFD) methods will be used for optimum irrigation scheduling practice at Hamedo and Hatsebo irrigation schemes. Moreover, the experiment will be laid down with randomized complete block design (RCBD) of three replications having a plot size of (4 m * 5 m). Agronomic and irrigation data related to days to 50% flowering and maturity, bulb diameter and length marketable and non-marketable yield, depth of irrigation and its scheduling were collected, computed and documented.

2.3 Data Collection

Soil Sampling: Soil Texture, organic carbon, bulk density, water retention at field capacity (FC) and permanent wilting point (PWP) and soil pH were collected diagonally from two soil depths (0-20 cm and 20-40 cm) from each irrigation scheme and experimental unit. Soil moisture content before and after irrigation was collected once at initial stage and late growth stage of the crop. Besides, Soil moisture before planting (initial) and at harvesting (residual) was measured and monitored throughout the growing stage of the onion crop. Both primary and secondary data were collected to fulfill this experimental study. Primary data collected from the experimental station includes soil infiltration rate, soil samples, irrigation depth, irrigation interval, agronomic data, and crop yield and yield components. Moreover, all secondary data such

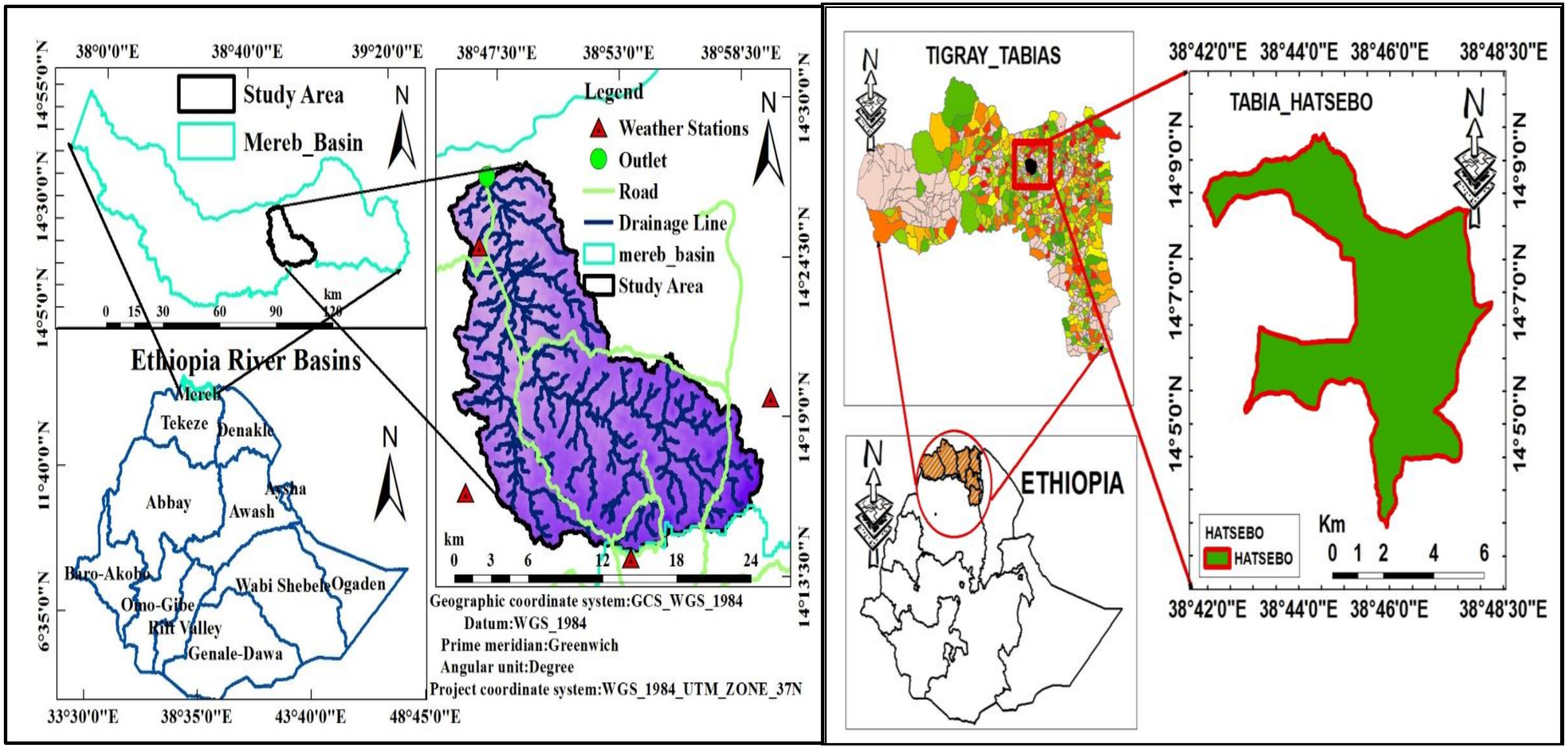

Fig. 1. Study area description: Hamedo & Hatsebo in Central Zone of Tigray (ArcGIS)

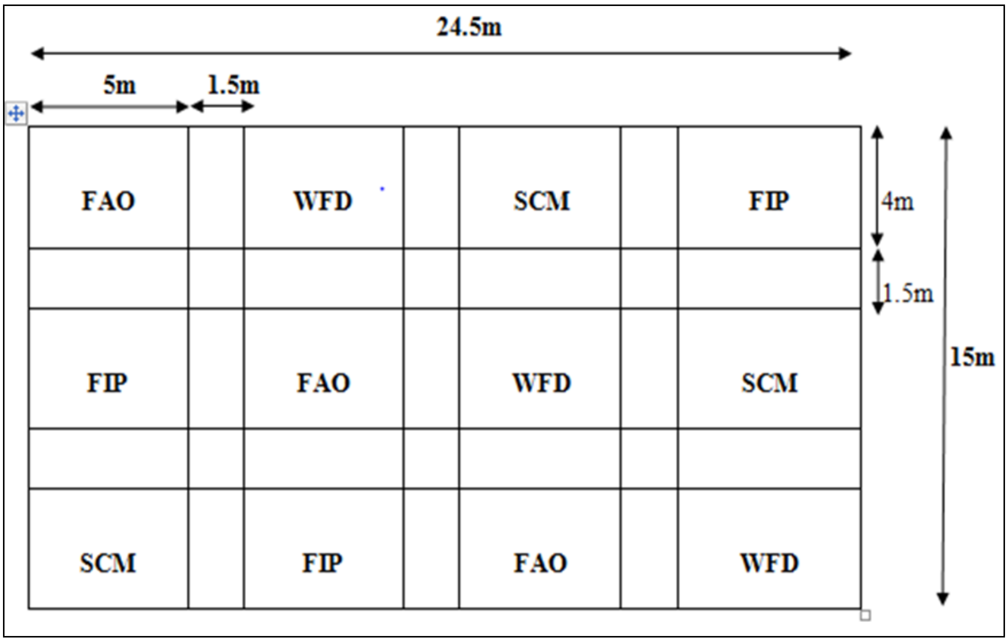

Fig. 2. Field layout and treatment arrangements

as climate data, crop data and soil data were collected from different sources. Climate data were collected from the Ethiopian National Meteorological Agency (ENMA), 1km away from Aksum airport metrological station for Hatsebo and 2 km away Rama Metrological station for Hamedo.

Agronomic Data Collection: The agronomic data, which was very sensitive through different methods of irrigation scheduling bulb weight (cm), bulb diameter (cm), and bulb length (cm), as well as marketable, unmarketable, and total fresh yield (kg/ha), were collected. These parameters were taken from the middle of the experimental plots (1 m x 1 m) to minimize the boarder effect.

2.4 Seedling Preparation and Transplanting

Onion seeds (Bombay Red varieties) were obtained from horticultural research team in Axum agricultural research center and Six seedbeds were prepared at both research stations with an area of 1 m X 5 m = 5 m^2. During the seedling stage, all management Practices required for the seedling weed management, fertilizer application, irrigating with water-can and spraying chemicals were frequently done. The onion seedlings ware transplanted to each plot after 54 days with spacing of 20 cm between ridge, 40cm between furrow and 5 cm between plants [13].

2.5 Crop water Requirement and Irrigation Scheduling

Metrological data (minimum& maximum, temperature, Relative humidity, wind speed, and daily sunshine hours) were used to determine ETo using modified FAO Penman Monteith method. Crop water requirement was determined from the input data, ETo and Kc. Net irrigation requirement was calculated by subtracting effective rain fall from the estimated crop water requirement. The gross irrigation to be applied to each of the respective treatment was computed using 60% application efficiency (Gross irrigation requirement (mm) = net irrigation requirement (mm) / irrigation efficiency (%)) [14]. Similarly, irrigation scheduling was computed using FAO CROPWAT program.

$$CWR = ETo * Kc \quad ------------1$$

Where: - CWR = crop water requirement ETo = reference evapotranspiration Kc = crop coefficient

Effective rainfall was determined using The FAO dependable method. Hence, net irrigation requirement was computed as.

$$IRn = CWR - Peff \quad ------------2$$

Where: - IRn = net irrigation requirement and Peff is effective rain fall (mm)

2.6 Irrigation Application and Water Productivity

Irrigation requirement computed in a daily basis for surface irrigation was measured and applied to the field based on the deficit level specified earlier.

Water application duration (time) was computed as:

$$Td = \frac{IRg*FL*FW}{60Q} \qquad ---------- 3$$

Where, Td: water application duration (min), IRg= Gross water application Depth (mm); FL = furrow length (mm), FW = furrow width (m) and Q = discharge (l/s) measured from Parshall flume. The water use efficiency was calculated by dividing harvested yield in kg per unit volume of water (kg/m3). Two kinds of water use efficiencies namely total water use efficiency (CWUE) and net irrigation water use efficiency (IWUE) was calculated as below.

$$\text{CWUE (CWP)} = \frac{\text{Yld}}{\text{IRn}} \qquad -------- 4$$

$$\text{IWUE} = \frac{\text{Yld}}{\text{IRg}} \qquad -------- 5$$

Where; CWUE: crop water use efficiency (kg ha-mm); IWUE: Field water use efficiency (kg ha-mm); Yld: yield (kg/ha); IRn: net irrigation requirement (mm); IRg: gross irrigation water requirement (mm).

The simple calculation method to determine the irrigation schedule is based on the estimated depth (in mm) of the irrigation applications, and the calculated irrigation water need of the crop over the growing season [15].

2.7 Installation of Wetting Front Detector (WFD)

The Wetting Front Detector (WFD) was developed at the Commonwealth Scientific and Industrial Research Organization (CSIRO) in Australia in response to the low adoption of these existing irrigation tools [16,17]. This instrument is a very simple tool that helps to measure how deeply water has penetrated into the soil after an irrigation event and monitor nutrient losses in soils [17]. Additionally, with this tool, there are no wires, no electronics, and no batteries for the WFD to work. Studies show that WFD saved water [18], reduced labor, and increased crop yield [19]. In addition, the mechanical version has a float visible at the surface to provide the signal that a wetting front has reached the prescribed depth. Therefore, WFD was developed in an attempt to attain maximum simplicity for an irrigator, especially for illiterate farmers.

As illustrated in Fig. 3, two wetting front detectors were used for every treatment that was irrigated through the instrument, so one WFD was installed at the shallow depth and the second WFD was installed at the deep root zone of the plant. The installation depth for WFD is estimated based on [20] the guidelines for wetting front

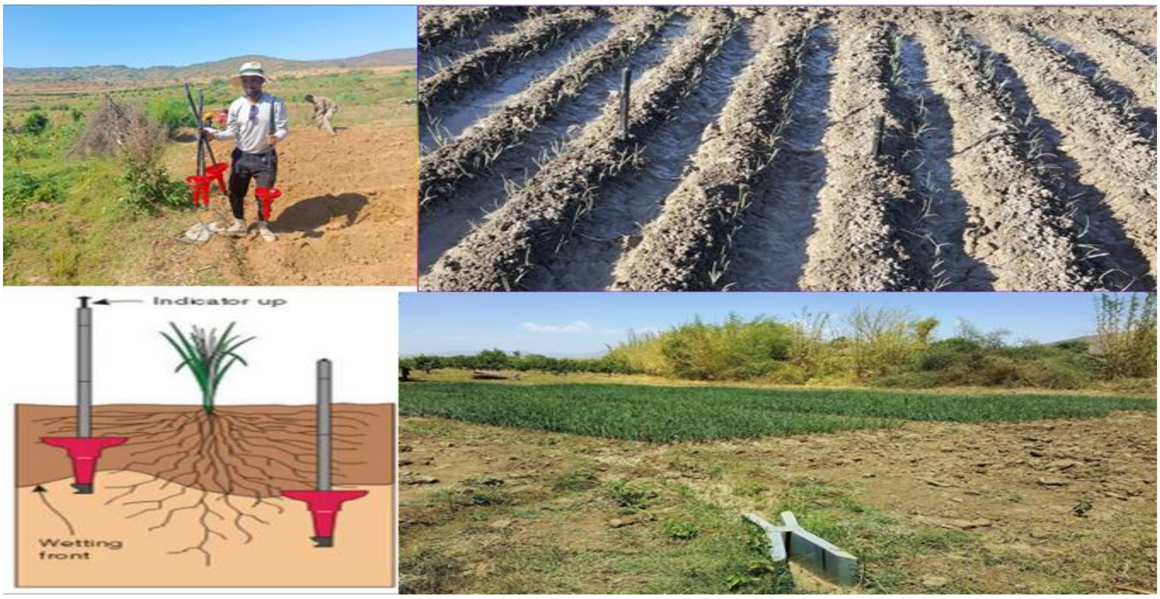

Fig. 3. Installation of the wetted front detector (WFD) at the field level

detector, i.e., with a yellow flag installed at 1/3rd of the effective root and wetting the front detector with a red flag installed at 2/3rd of the root depth. So for this experiment, the funnel was buried in the soil within the root zone at 20 cm for the yellow flag and 40 cm for the red flag, which is an effective root zone in the soil.

3. RESULTS AND DISCUSSION

3.1 Soil Data Analysis

Soil samples collected from both experimental sites has been analyzed in a soil laboratory for (FC, PWP, BD, Texture, pH, EC, CEC, OMC, TN, and AvP,) and up on analysis the following results was obtained (Table 1).

The collected data such as irrigation amount, crop water use, and crop yield and water use efficiency was checked on normality and transformed where necessary. Afterwards a one way analysis of variance (ANOVA) test at the 5% probability level ($P<0.05$) was conducted using R software. Mean and standard deviation (SD) results for pH, EC, OM, TN, Av P, BD, FC and PWP are shown in Table 2. The comparison was carried out to test whether fields between the treatments differed significantly, which might partially influence the crop and water productivity results obtained within the experiment. No significant differences between both irrigation treatments for all measured soil properties were found. The average pH of 8.6 is suitable for onion production. The soil texture of most of the experimental plots is clay and sand clay loam, a medium textured soil, suitable for onion is growing [21]. In both locations at all treatments similar field capacity (FC) and permanent wilting point (PWP) were obtained.

3.2 Crop Growth and Yield Parameter Analysis

Onion yield was measured at plot level (kg/m^2) for all treatments and converted to (kg/ha) using the harvested area multiplying by 10^4. Water productivity is the total yield per quantity of water applied. Several factors affect water productivity such as: crop management, soil preparation, soil type, irrigation scheduling, crop variety and climate [22].

Many studies on the effect of irrigation application have shown significant variations on the performances of different plant growth parameters [23,24]. The Tables (3 & 4) below presents the effect of different technologies of irrigation scheduling and irrigation application on onion bulb yield and yield parameters such as marketable and total onion yield (MYld & TYld), bulb length (BL), bulb diameter (BD), and bulb weight (BW).

Combined statistical analysis of the two-year field experiment of onion bulb production and its corresponding crop water productivity over the two irrigation sites shows a statistically significant ($P=0.05$) differences all along treatments (Tables 3, 4, 5 and 6). From the table below (Table 3, and Table 4), ANOVA table for the combined analysis of agronomic data (onion bulb components) at Hamedo irrigation scheme, statistically significant difference was not observed in all the agronomic parameters except in Onion bulb yield and the corresponding water productivity (IWP) due to treatments at ($P < 0.05$). At Hamedo, statistically significant difference was not observed in agronomic parameters like BD and BL ($P >0.05$). Maximum and minimum Marketable onion bulb yield, MYld (54.ton/ha & 42.8 ton/ha) was obtained from scheduling with the help of wetted front detector (WFD) and FAO scheduling method respectively. The scheduling methods (FAO, WFD, and SCM) treatments has shown significant difference in onion bulb MYld as compared to the standard check, (FIP) application at ($P < 0.05$). At Hamedo the higher and lower IWP (8.9 & 5.7) Kg/m^3 was observed with scheduling method of WFD and FIP respectively. In the irrigation scheduling, WFD had the highest bulb diameter, bulb weight, marketable yield and total yield. The overall analysis result revealed that wetting – front detector (WFD) saves 15% of irrigation water and helps to learn water saving with increasing crop productivity of onion at Hamedo irrigation scheme compared with FAO. Similarly, results of [25] show, farmers saved 16% of irrigation water

Table 1. Treatment setting

Method of Irrigation Scheduling	Treatments
FAO CropWat-8 Method (FAO	T_1
Wetting Front Detectors (WFD)	T_2
Simple Calculation Method (SCM)	T_3
Farmers Irrigation Practice (FP)	T_4

Table 2. Soil sample analysis result; A) Hamedo; B) Hatsebo

Soil Data Analysis	A) Hamedo	B) Hatsebo
Soil Texture	Sandy clay loam	Clay
Field Capacity (FC)	0.198	0.396
Permanent Welting Point (PWP)	0.137	0.274
Bulk Density (BD)	1.72	1.26
PH Level (PH)	8.6	9.4
Electrical Conductivity (EC)	0.89	1.5
Organic Mater Content (OMC)	0.96	0.8
Cation Exchange Capacity (CEC)	16.7	59.8
Total Nitrogen (TN)	0.01	0.013
Available Phosphorus (AvP)	8.6	14.5

Table 3. ANOVA table for the combined analysis of agronomic data @Hamedo scheme

Treatments	Bulb diameter(cm)	Bulb length(cm)	Bulb weight(gm.)	Marketable Yield(ton/ha)	Total Yield(ton/ha)
FAO	$3..7^{a}$	4.7^{a}	41.0^{a}	42.8^{ab}	43.7^{ab}
WFD	4.1^{a}	4.8^{a}	45.3^{ab}	54.0^{a}	54.9^{a}
SCM	3.6^{a}	4.9^{a}	35.8^{ab}	38.7^{ab}	39.1^{ab}
FIP	3.5^{a}	4.8^{a}	31.0^{b}	29.6^{b}	31.5^{b}
CV (%)	3.5	4.7	5.1	8.0	6.8
LSD (0.05)	ns	ns	ns	8.9	8.5

Table 4. ANOVA table for the combined analysis of water productivity @ Hamedo scheme

Treatment	MYld (ton/ha)	IRn (m^3/ha)	IRg (m^3/ha)	CWP (kg/m^3)	IWP (kg/m^3)	IWS (%)	Rank
FAO	42.8	4224	7040	10.1	6.0^{b}	0	4
WFD	54.0	3690	6150	14.6	8.9^{a}	15	1
SCM	37.0	3048	5080	12.1	7.3^{ab}	7.8	2
FIP	29.6	3126	5210	9.5	5.7^{b}	7.2	3
CV (%)				9.8	10.2		
LSD (0.05)	ns	ns	ns	ns	ns	ns	

Where MYld = Marketable Yield IRn = Net irrigation requirement IRg = Gross irrigation requirement CWP = Crop water productivity IWP = Irrigation water productivity IWS = Irrigation water save ns = no significant differences

using WFD compared with FAO and, [26] saved 16% of irrigation water using WFD compared to farmer's practices (FP).

The highest water productivity was obtained from the WFD method of irrigation scheduling (Table 4). On the contrary, FAO CropWat-8 Method revealed the least water productivity. The WFD method of irrigation scheduling demonstrates that 14.6 kg of onion could be gained from 1 m3 of water. This indicates the WP is an important element in improving water management for sustainable agriculture, food security, and healthy ecosystem functioning.

At Hatsebo, statistically significant difference was not observed among treatments in all agronomic parameters except in the onion bulb yield MYld at ($P < 0.05$). Maximum and minimum Marketable onion bulb yield, MYld (49.4ton/ha & 31.7 ton/ha) was obtained from scheduling with the help of WFD and FAO scheduling method respectively. At Hatsebo, the higher and lower IWP (8.5 & 7.6) Kg/m3 was observed with a scheduling method of SCM and WFD respectively. Based on this experiment, the wetting front detector saved more than 15% of irrigation water compared to FAO CropWat-8 method (Table 4) at Hamedo whereas more than 21% irrigation water was wasted at Hatsebo (Table 6). Thus location specific statistical analysis, conclusion and recommendation have been made for this research work.

Table 5. ANOVA table for the combined analysis of agronomic data @ Hatsebo scheme

Treatments	Bulb diameter(cm)	Bulb length(cm)	Bulb weight(gm.)	Marketable Yield(ton/ha)	Total Yield(ton/ha)
FAO	5.7[a]	4.1[a]	74.1[a]	31.7[b]	32.4[b]
WFD	5.3[a]	4.7[a]	70.1[a]	49.4[a]	49.8[a]
SCM	5.7[a]	4.3[a]	66.7[a]	36.1[b]	36.4[b]
FIP	5.3[a]	4.3[a]	57.7[a]	34.2[b]	34.9[b]
CV (%)	10.5	11.5	16.9	6.9	7.1
LSD (0.05)	ns	ns	ns	4.9	5.1

Table 6. ANOVA table for the combined analysis of water productivity @ Hatsebo scheme

Treatment	MYld (ton/ha)	IRn (m^3/ha)	IRg (m^3/ha)	CWP (kg/m^3)	IWP (kg/m^3)	IWS (%)	Rank
FAO	31.7	2352	3920	13.5	8.1	0	1
WFD	49.4	3792	6320	13.1	7.8	-21.2	4
SCM	36.1	2554	4256	14.1	8.5	-8.6	2
FIP	34.2	2621	4368	13.1	7.8	-11.4	3
CV (%)				6.9	6.9		
LSD (0.05)	ns	ns	ns	ns	ns	ns	

4. CONCLUSION

The magnitude of each treatment (FAO, WFD, SCM, FIP) varies over location due to experimental treatments, Agro climate & Soil texture hence, location specific statistical analysis, conclusion and recommendation has been made for this research work. In each experimental sites (Hamedo & Hatsebo), results shows no statistical significant differences on BD, BL, BW at (P < 0.05), while, MYld, TYld shows significant differences in both locations.

Compared with the standard check (FIP) scheduling practice the production and productivity of onion bulb (MYld) with (FAO, WFD, SCM) throughout the growing season application has shown significant differences at Hamedo irrigation scheme. The higher IWP was observed with a scheduling method of WFD. On the other hand, a significant yield reduction of onion bulb (MYld) was observed at Hamedo with the scheduling method of FIP and SCM.

Similarly, compared with the standard check (FIP) scheduling method the production and productivity of onion bulb (MYld) with (FAO, SCM,) has shown no significant differences at Hatsebo irrigation scheme rather a relatively higher MYld and IWP was observed at SCM and FAO scheduling method respectively. In conclusion, the production and productivity of onion bulb (MYld) and irrigation water productivity is significantly affected with the proper scheduling practice in both locations. The wetting front detector (WFD) saved more than 15% of irrigation water compared to FAO CropWat-8 method and WFD was better effective at sand clay loam than pure clay soil. Thus, the saved water can irrigate additional irrigable land at Hamedo When WFD use as irrigation scheduling method.

The production and productivity of onion MYld and the corresponding IWP in small scale irrigation holders can be optimized with proper and location specific irrigation scheduling practicing technology. The WFD scheduling method is a better option for both irrigation schemes for optimum onion bulb (MYld) production and IWP. Therefore the technology is better to demonstrate at farmer's level to increase farmer's water management habit.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

I declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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COMPETING INTERESTS

Author has declared that no competing interests exist.

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