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Research Article

Simulation of Onion Response to Soil Moisture Stress at Different Growth Stages on Yield and Water Productivity Using Aquacrop

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Abstract

The objective of this study is to select the most effective water-saving techniques and improve the water productivity of irrigated onion. The phenological growth of onion, the crop was subjected to moisture stress during one, two, or three of the growth stages. The highest yield attained was 21.157 tons/ha and the lowest was 7.177 tons/ha. Treatments T3 & T4 were water stressed during second and last growth stages produce yields that weren't significantly different from the yield achieved under completely irrigated (T1). Compared to the maximum yield, 22.3% to 48.4% lower yields were recorded under treatments subjected to water deficiency during two growth stages. Treatments that were stressed during one growth stage had a 2.6 to 42.7% yield reduction relative to the maximum yield. The highest yield reduction was observed under treatment irrigated during the first growth stage (T8), followed by irrigated during first and second growth stages (T7), first and late stages (T5) and then treatment not irrigated during midseason (T2). This shows that a prolonged deficiency over three growing stages has more yield reduction (T8). Plots stressed during both third and fourth growth stages were producing lower yields indicating the severe effects of water stress during flowering and early bulb filling stages on yield. Water savings achieved under different treatments with no significant differences in yield from full irrigated plots range 11.8% to 21.7% (T4 & T3) respectively.

Keywords

Deficit Irrigation, Water Use Efficiency, Canopy Cover, Yield, Water Productivity

1. Introduction

Water is a strategic resource for social, economic, and environmental sustainability of different countries, particularly for water scarce countries where more than 40% of the present global population lives. It's used for food production to meet the needs of the expanding population [1]. Water is getting scarce, both in quantity and quality, not only in traditionally prone arid and semi-arid zones but also in regions where rainfall is abundant. Agriculture represents the major water user worldwide, and a general perception that agricultural water use is often wasteful using about 75% of freshwater being used for irrigation and has less value than other uses is widespread [2]. Due to uneven distribution of water resources with time and space, water demand exceeded supply in nearly 80 countries in the world [1].

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Agricultural production takes place in an environment characterized by risk and uncertainty. Even in areas under irrigation, water scarcity is common, and yields are often affected. Recently, the development of AquaCrop by FAO provides an improved and powerful approach for the assessment of the attainable yield of the major herbaceous crops as a function of water supply [3].

Irrigation has multiple roles in contributing to food production, self-sufficiency, food security and export. At the same time, the need to meet the growing demand for food requires increased crop production from less water. Deficit irrigation is an optimization strategy whereby net returns are maximized by reducing the quantity of irrigation water; crops are deliberately allowed to sustain some degree of water deficiency and yield reduction [4]. The concept of deficit irrigation dates from the 1970s, this technique is not generally espoused as a practical alternative to full irrigation by either academics or practitioners. It involves the use of precision irrigation; the knowledge needed spans a wide range of disciplines; the strategy involves pitfalls associated with the query of the knowledge required [5].

2. Material and Methods

2.1. Description of the Study Area

Ethiopia is situated between latitude 3 ° to 15 ° North and longitude 30 ° to 48 ° east. The study was conducted at Debre Zeit Agricultural Research Center main station. Its geographical extent ranges from 08°43’48” to 08° 46’45” Northern latitude and from 38°59’ 45” to 39°01’48” Eastern longitude. The area is positioned in the Central high land area of the country having tepid to cool sub-moist highland type climate. According to long-term record of meteorological data, the total annual rainfall of the study area is 810.3 mm 70% of which occurs from mid of June to mid of September, with its peak in July and August. The maximum and minimum temperature are 28.3 ℃ and 8.9 ℃ respectively with the average 19 ℃. The source of irrigation water in the study area is unconfined groundwater resource.

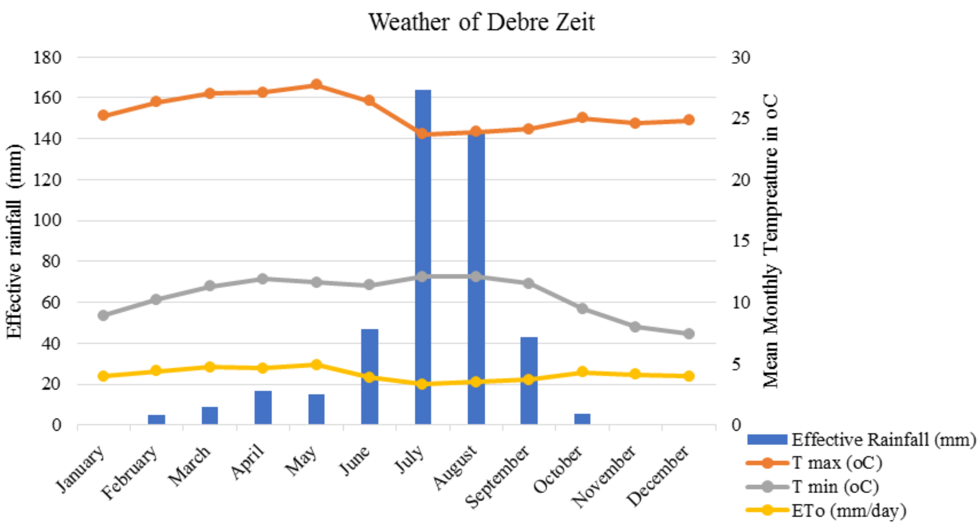

Figure 1. *The weather data analysis of the study area (Debre Zeit Agricultural Research Center).*

According to study Kidanewolde *et al.* and Tessema *et al.*, the kiremt (June- August) is the main rainy seasons and Tseday (September-November) is the spring season sometimes known as the harvest season [6, 7]. Bega (December- February) is attributed to the dry season. Belg (March–May) is the autumn season with occasional showers but it is short lasting rainfall. Belg in the study area receives quite small rainfall to support crop production whereas kiremt is known by long rainy season. About 76 % of the total rainfall of the area falls in kiremt or wet season, about 15% in belg and the rest is in bega or dry season which needs full irrigation in the area. The mean maximum temperature varies from 23.7 to 27.7 ℃ while the mean minimum temperature varies from 7.4 to 12.1 ℃ (Table 1 & Figure 1). However, maximum, and minimum reference Evapotranspiration (ETo) was recorded as 4.7 and 3.3 mm/day in May and July respectively (Table 1 & Figure 1).

2.2. Application of AquaCrop Model

AquaCrop is a crop simulation model that simulates attainable yields of herbaceous crops in response to water which address conditions where water is a limiting factor in crop production. It allows simulations of yield response to water under various management and environmental conditions, including climate change scenarios.

2.3. Experimental Design and Treatment Layout

The test crop was planted on 11 November 2017 and the recommended agronomic practices for onion was undertaken for the experimental field. This experiment was conducted in areas where the spatial and temporal moisture shortage is the main problem. The experiment was laid out in randomized complete block design (RCBD) with three replications. The experimental field contain plots of size 3 meters by 3 meters to accommodate five planting ridges with the ridge spacing of 60 cm. There was 1.5 meter spacing between adjacent plots and blocks have a buffer zone of 2 m from the main water supplying canal and 2.5 m between blocks to eliminate the influence of lateral water movement. Daily reference evapotranspiration (ET_O) and the irrigation schedule (quantity and time of irrigation water application) of fully irrigated control treatment was computed with the aid of CROPWAT 8.0 model based on daily meteorological data (maximum & minimum temperature, relative humidity, sunshine duration, and wind speed) and soil bulk density of the experimental site. The amount of irrigation water applied at each irrigation application were measured using 3" (inch) Parshall flumes. Until the plants were well established or recovered after transplanting of seedlings irrigation water must be provided for all treatments evenly and these take about 7 days after transplanting [8]. Therefore, irrigation treatment has been started after the fourth common irrigation application, once the readily available water was fully depleted.

Table 1. *Experimental treatment setup.*

Treatments	Growth stages				Plot numbers		
	Initial	Development	Midseason	Maturity	Rep_I	Rep_II	Rep_III
T1	1	1	1	1	2	9	21
T2	1	1	0	1	4	11	19
T3	1	0	1	1	1	12	23
T4	1	1	1	0	8	15	22
T5	1	0	0	1	5	14	24
T6	1	0	1	0	7	16	20
T7	1	1	0	0	3	10	18
T8	1	0	0	0	6	13	17

Remark: 1 means irrigated, and 0 means not irrigated during the respective crop growth stage

2.4. Method of Data Analysis

The collected experimental data of plant height, bulb diameter, above ground dry biomass, yield and water use efficiency of onion were subjected to the analysis of variance (ANOVA) using the general linear model of statistical analysis system (SAS) package. The actual data measured for canopy cover, above ground biomass, soil moisture content and yield were compared with the results obtained from the results of AquaCrop simulation. Finally, the model efficiency of AquaCrop was evaluated through statistical measures.

3. Results and Discussion

3.1. Soil Data Analysis

The laboratory analysis result of soil physical property indicates that the particle size distribution of the study site has an average value of 53.60% clay, 22.53% sand and 23.87% silt. Therefore, based on soil textural class determination triangle of international soil society system (ISSS) the soil of experimental site was clay in texture. The bulk density of the area has shown a slight variation with depth from 1.04 to 1.15g/cm^3 with average 1.1gcm^{-3}. This could be due to slight decrease of organic matter with depth and compaction due to the weight of the overlying soil layer which is ideal for plant root growth [9]. The average value of TAW was 175.05mm/m that is within the range of 175 – 250 mm/m which is the characteristic for clay soil [10]. The basic soil chemical analysis carried out showed that the average pH value of the experimental site through the analyzed soil profile was 6.35. However, onion can grow best in soils with pH range of 6.0 to 7.0 or 8.0 [11, 12] respectively and the pH of the experimental field showed was slightly acidic. The soil had an average cation exchange capacity of 51.39meq/100g in the depth of 60 cm profile and average electrical conductivity of (0.123 mS/cm) which is below the threshold value for onion yield reduction. Yield reduction occur in soils with an electrical conductivity greater than 1.2 dS/m [13].

3.2. Onion Bulb Yield

As shown in the Table 2, the variations in onion bulb yields between treatments were significantly different at the significance level of 5% ($P \leq 0.05$). The bulb yield of onion was significantly affected ($P \leq 0.05$) by the soil moisture stress at different growth stages and the maximum onion bulb yield (21.157 t/ha) was observed at non-stressed treatment (T1). However, it is not significantly different from the yields of T3 & T4, while relatively the lowest yield was registered under the treatment which was irrigated during first growth stage and stressed during other stages (T8) [14]. This result closely related to that of [15] who reported that the highest bulb yield of onion was obtained in non-deficit treatment, in which full crop water requirements were met during total growing period. Among the stress irrigation the control irrigation treatment practices have shown no significant difference on marketable bulb yield with treatments (T3 & T4) Table 2.

Generally, among the stressed irrigations applied, T3 and T4 produced the best marketable bulb yield which has no significant ($P \leq 0.05$) difference to non-stressed treatment (control treatment, T1) and while the lowest significant mean marketable bulb yield was obtained from T6. Similar to the present observation [16] also reported that water application with no deficit irrigation (full crop water requirements) at any stage of plant growth gave highest marketable yield. Results of [17, 18] also showed that marketable bulb yield of onion increased with increase in irrigation water amount is a linear relationship. Similar results were also reported by [19] who showed that dealing with improvement of water productivity is closely related to the irrigation practice of regulated deficit irrigation and has a direct effect on yield. As the amount of water applied decreases similarly, the crop yield also drops.

Table 2. *The amount of water saved, dry biomass, bulb yield and yield reduction.*

Treatment	Irrigation (m^3/ ha)	Biomass (t/ha)	Yield (t/ha)	IWUE (kg/m)	Water saved (%)	Yield reduction (%)
1	3207.72	25.000^{a}	21.157^{a}	36.793	0	0
2	2583.42	13.427^{c}	12.130^{cd}	20.747	19.5	42.7
3	2512.184	22.223^{ab}	18.473^{ab}	21.093	21.7	12.7
4	2828.178	23.147^{ab}	20.603^{ab}	24.563	11.8	2.6
5	1499.3	13.197^{c}	11.803^{d}	24.607	53.3	44.2
6	1708.2	19.447^{b}	16.437^{bc}	30.597	46.7	22.3
7	1375.6	12.407^{cd}	10.923^{de}	13.733	57.1	48.4
8	622	8.330^{d}	7.177^{e}	9.840	80.6	66.1
R-Square			0.86			
CV (%)			17.20184			
$LSD_{0.05}$			4.4698			

LSD = Least significance difference, CV = coefficient of variation

As presented in Table 3, the highest amount of water (80.6%) was saved while highest yield reduced (66.1%) in T8 and the lowest (11.8%) water was saved in T4 considering T1 as a control (crop water requirement base). The amount of water saved in T4 was 11.8% which is the lowest among other treatments but highest yield without significance yield difference ($p \leq 0.05$) compared to the control treatment (T1) as shown in Table 2. When the treatments are compared in terms of yield reduction T4 had lowest yield reduction (2.6%).

3.3. Simulation Using AquaCrop Model

The model has been calibrated based on the measured crop data of all the treatments. The main calibration parameters for canopy cover include the canopy growth coefficient (CGC), the canopy decline coefficient (CDC), water stress (P_{upper}, P_{lower} thresholds) affecting leaf expansion and early senescence. Canopy cover per seedling and initial canopy cover (CC_o) was estimated based on the general knowledge of the crop characteristics and the data from agronomic practice of row and plant spacing (0.30 m & 0.20) respectively. Hence, the estimated initial canopy cover (CC_o) for the given onion crop has been found 1.25% with 7.5 cm^2 $plant^{-1}$ of transplanted seedling canopy size (16.7 plants/m^2 or 166, 667 plants ha^{-1}). To estimate the canopy expansion rate, phonological data such as dates to emergence (transplanted recovery), maximum canopy cover, senescence and maturity were used. The model resulted in fast canopy expansion and very slow canopy decline. The canopy growth coefficient (CGC) and canopy decline coefficient (CDC) were 16.9% day^{-1} and 8% day^{-1} (0.544% GDD^{-1}) respectively.

Table 3. Phenological observations of onion crop from the study area (maximum rooting depth in 0.60 m).

Growth parameter	Calendar	GDD (degree days)
Recovered transplant	7 days	77
Maximum canopy cover	47 days	470
Maximum root depth	47 days	470
Start of canopy senescence	92 days	960
Start of yield formation	47 days	470
Length of building up HI	45 days	490
Maturity	122days	1393

3.4. Canopy Cover, Biomass, SMS and Yield

Visually, the simulated data for canopy cover correlate well to the observed values for both the calibration and validation periods (Figure 1). The simulated green canopy covers strongly correlated with the observed canopy cover of onion with a correlation coefficient of R^2 = 0.74. Both marketable bulb yield and above ground dry biomass were adequately simulated by the model. The simulated above ground dry biomass correlated well with the observed above ground dry biomass. The simulated above ground dry biomass strongly correlated with the observed biomass of onion. There was strong relationship between the observed and simulated biomass with correlation coefficient of R^2 = 0.988.

4. Conclusion

The study was aimed at developing a strategy to utilize the limited amount of available water as efficiently as possible and to help identify new water management technologies and practices for improved agricultural production and water productivity. This was achieved by varying irrigation strategies for the growth stages of onion on experimental field and simulating with AquaCrop using the data obtained from the experimental field and comparing the results of field experiment and simulation run on yield output, yield component, and water productivity to validate the model and to use recommendations for the same agroclimatic region. The efficient use of water resources is essential for the sustainable use and improvement of water production in the agricultural sector of Ethiopia. Based on the four phases of phenological growth (establishment, vegetative, flowering and bulb filling) of onions, the crop was subjected to water stress at one, two or three stages of growth. The highest yield achieved was 21.157 ton / ha and the lowest was 7.77 tons / ha. The treatment that was water stressed during the single growth phase, the second and final stage of growth, produced a yield that was not significantly different from the yield achieved under the full-scale treatment. The study has shown that there are no noticeable differences between the treatments that were irrigated during the whole growth phase (full irrigation) and those that were stressed during the development (T3) and maturity stages (T4). This indicates that water shortages in vegetative (development) and late stages did not have a significant effect on yields. That means at these stages of growth, water can be saved and by doing so more land can be irrigated by the stored water for additional production.

Abbreviations

ET_c Crop Evapotranspiration

Conflicts of Interest

The author declares no conflicts of interest.

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