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Evaluation of Deficit Irrigation on Potato Yield and Water use Efficiency in Gedeo Zone, South Region

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Abstract: Increased water scarcity necessitates the implementation of water-conserving irrigation management practices tosustain crop production, especially in water-limited areas. A two-year field study was conducted during 2020 and 2021 to evaluate the effect of deficit irrigation on potato yield and water use efficiency. The experiment was conducted in randomized complete block design with four irrigation levels (100% ETc (crop evapotranspiration), 85% ETc, 70% ETc, and 55%ETc). The results showed that, deficit irrigation level have a significant difference in number of tuber per plant, marketable, total yield and water use efficiency. Potato yield significantly reduced with deficit irrigation level. Next to full irrigation the maximum yield was obtained under 85% ETc and 70%ETc with better crop and irrigation water use efficiency. Maximum crop and irrigation water use efficiency was obtained under 55% ETc. The partial budget analysis showed that the maximum acceptable MRR was obtained from 70%ETc and the highest net benefit was obtained under full irrigation. Therefore, in area where sufficient amount of water is available full irrigation is recommended to obtain maximum yield, but in water scarce area applying 85%ETcand 70%ETc is recommended with 17.5% and 23.2% yield reduction respectively with acceptable economical benefit.

Keywords: Deficit, Potato, ETc, Water use efficiency.

Research Paper

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INTRODUCTION

Ethiopian farming is mainly dependent on rain-fed smallholder agricultural system. In the absence of sufficient rainfall, there is always low agricultural production, thereby creating food shortage and food insecurity (Tilahun *et al.*, 2008).

Potato (Solanumtuberosum L.) has potential for adaptation to diverse growing conditions of the tropics. The shorter growing period makes it possible for a small scale farmer to fit this crop into intensive cropping systems and have more than one crop on the same land in a year (Gebremedhin *et al*., 2008).

Water is becoming scarce, not only in arid and drought-prone areas, but also in regions where rainfall is abundant (Pereira *et al*., 2002). In some locations, the available water supply is inadequate to produce the maximum yield on irrigable land. In other regions, the water available for irrigation is already regulated and requires deficit irrigation. For many surface water projects, the annual supply of irrigation water is limited by reservoir capacity and annual reservoir inflow. These examples highlight the need for deficit irrigation management on a seasonal basis (Martin *et al*., 1989).

The application of water below the ET requirements is termed deficit irrigation (DI). Irrigation supply under DI is reduced relative to that needed to meet maximum ET (English, 1990).

Irrigated agriculture is the primary user of diverted water globally, reaching a proportion that exceeds 70–80% of the total in the arid and semi-arid zones. It is therefore not surprising that irrigated agriculture is perceived in those areas as the primary source of water, especially in emergency drought situations. Currently, irrigated agriculture is caught between two perceptions that are contradictory; some perceive that agriculture is highly inefficient by growing ‘water-guzzling crops’ (Postel *et al*., 1996), while others emphasize that irrigation is essential for the production of sufficient food in the future, given the anticipated increases in food demand due to world population growth and changes in diets (Dyson, 1999). Globally, food production from irrigation represents >40% of the total and uses only about 17% of the land area devoted to food production (Fereres and Connor, 2004).

Under conditions of scarce water supply, application of deficit irrigation (DI) could provide greater economic returns than maximizing yields per unit of water. The deficit irrigation has been considered worldwide as a way of maximizing water use efficiency (WUE) by eliminating irrigation that has little impact on yield (Kirda *et al.*, 1999). With deficit irrigation, the crop is exposed to a certain level of water stress either during a particular period or throughout the whole growing season (Kirda, 2000). Therefore, the objective of this research is to evaluate the effects of deficit irrigation on potato yield and to improve water productivity in the area through deficit irrigation practice.

MATERIALS AND METHODS

Description of the Study Area

The study was conducted at BuleWoreda, Gedeo Zone of southern nation nationality and peoples of Ethiopia, and it situated 390 km far south of the capital city of the country, Addis Ababa; 120 km to south of the capital city of SNNPRS, Hawassa; and 27 km from the Zonal capital city, Dilla town. It geographically lies between 60 04' 16" -60 23' 50" North latitude and 380 16' 20" -380 26' 11' East longitudes.

Xperimental Design and Treatment

The experiment was laid out in randomized complete bock design with four treatments and three replications. The treatments were, 100%ETc at all growing season, 85%ETc at all growing season, 70%ETc at all growing season, 55%ETc at all growing season were applied at the same irrigation interval. The size of each plot was 4m by 5m, space between the plot 1m and space between the replication 1.5m. The recommended space between the plant and the row 30cm and 75cm respectively was applied.

Soil Data

The soil was analyzed in laboratory, gravimetric method; pH meter method, soil and water ratio method were used to determine soil moisture content, pH value and electrical conductivity respectively.

Climate Data

The average climatic data (Maximum and minimum temperature, relative humidity, wind speed, and sun shine hours) on monthly basis of the study area were obtained from the new claim software. The potential evapotranspiration (ETo) was estimated using CROPWAT software version 8.

Average Climatic Data of the Experimental Site

Month	Min Temp (°C)	Max Temp (°C)	Humidity (%)	Wind (km/day)	Sun (hrs)	Rad MJ/m?/day	ETo mm/day
January	12	29.5	15	104	8.2	20.2	4.51
February	11.8	30.7	15	104	7.6	20.4	4.76
March	12.6	30.8	17	130	7.2	20.6	5.32
April	13.5	28.6	19	104	7.3	20.7	4.85
May	12.6	27.2	19	104	7.1	19.7	4.59
June	12.3	26.7	18	138	6.4	18.2	4.8
July	13.5	25.7	18	104	4.4	15.5	4.08
August	12.8	25.7	17	104	4.5	16.1	4.16
September	12.6	26.2	18	69	6	18.6	3.93
October	12.6	26.1	16	69	7	19.6	3.95
November	11.3	27.2	17	86	11.5	25.1	4.54
December	10.8	28.3	13	95	11.4	24.3	4.51
Average	12.4	27.7	17	101	7.4	19.9	4.5

Crop Data

Potato crop data required for CWR determination

	Growth stage				
Crop data	**Initial**	**Development**	**Mid**	**Late**	**Total**
Growing period	25	30	45	30	130
Crop coefficient(k_c)	0.5	0.8	1.2	0.95	
Rooting depth(m)	0.3	0.55	0.6	0.6	
Depletion level(p)	0.25	0.25	0.25	0.25	
Yield response(k_y)	0.45	0.8	0.8	0.3	
Source: FAO 56 (Allen *et al.*, 1998)					

Crop Water Determination

Crop water requirement refers to the amount of water that needs to be supplied, while crop evapotranspiration refers to the amount of water that is lost through evapotranspiration (Allen *et al.*, 1998). For the determination of crop water requirement, the effect of climate on crop water requirement, which is the reference crop evapotranspiration (ETo) and the effect of crop characteristics (Kc) are important (Doorenbos and pruitt, 1977). The long term and daily climate data such as maximum and minimum air temperature, relative humidity, wind speed, sunshine hours, and rainfall data of the study area were collected to determine reference evapotranspiration, crop data like crop coefficient, growing season and development stage, effective root depth, critical depletion factor of Onion and maximum infiltration rate and total available water of the soil was determined to calculate crop water requirement using cropwat model.

$$ETc = ETo \times Kc$$

Where, ETc = crop evapotranspiration, Kc = crop coefficient, ETo = reference evapotranspiration.

Irrigation Water Management

The total available water (TAW), stored in a unit volume of soil was determined by the expression:

$$TAW = \frac{(Fc - PWP) * BD * Dz}{100}$$

The depth of irrigation supplied at any time can be obtained from the equation

$$Inet(mm) = ETc(mm) - Peff(mm)$$

The gross irrigation requirement will be obtained from the expression:

$$Ig = \frac{In}{Ea}$$

Ea=application efficiency of the furrows (60%)

The time required to deliver the desired depth of water into each furrow will be calculated using the equation:

$$t = \frac{d * l * w}{6 * Q}$$

Where: d= gross depth of water applied (cm), t= application time (min), l= furrow length in (m), w= furrow spacing in (m), and Q= flow rate (discharge) (l/s)

Data Collection

Daily climate like maximum and minimum air temperature, relative humidity, wind speed, sunshine hours and rainfall data was collected to calculate crop water requirement. Soil moisture was determined gravimetrically. Amount of applied water per each irrigation event was measured using calibrated pareshall flume. During harvesting number of tuber per plant, marketable yield, unmarketable yield and total yield was collected.

Statistical Analysis

The collected data were analyzed using Statistical Agricultural Software (SAS 9.0) and least significance difference (LSD) was employed to see a mean difference between treatments and the data collected was statistically analyzed following the standard procedures applicable for RCBD with single factor.

RESULT AND DISCUSSION

Physical and Chemical Properties of Soil

The critical value of bulk density for restricting root growth varies with soil type (Hunt and Gilkes, 1992) but the general bulk density greater than 1.6 g/cm3 tend to restrict root growth (McKenzie *et al.*, 2002). Generally, according to USDA soil classification, a soil with electrical conductivity of less than 2.0 dS/m at 25°C and pH less than 8.5 are classified as normal soil. The laboratory result shows that the experimental site soil textural class was clay loam according to USDA textural classification. The average soil bulk density (1.18g/cm^3) is below the critical threshold level (1.4 g/cm3) and was suitable for crop root growth. The PH of soil was slightly acidic with average PH value of 5.37. Average infiltration rate of the experimental site were 6mm/hr.

Soil property	**Soil depth in (cm)**			
	0-20	**20-40**	**40-60**	**Average**
Textural class	**Clay loam**	**Clay loam**	**Clay loam**	**Clay loam**
Bulk density (g/cm3)	1.2	1.18	1.15	1.18
FC (Vol %)	26.7	27	28	27.23
PWP (Vol %)	12.8	13	14	13.27
TAW (mm/m)	175.14	176.4	176.4	175.98
pH	5.2	5.4	5.5	5.37
Infiltration rate				6mm/hr

Potato Response to Deficit Irrigation

The result showed that there is a significant difference between the treatments. The yield of Potato is significantly reduced with a deficit irrigation level. The maximum yield (35980.6kg/ha) was obtained under full irrigation. The yield of applying 85% ETc and 70% ETc has statistical significant difference. The minimum yield (22900kg/ha) was obtained from 55%ETc which is significantly reduced from 85% ETc and 100% ETc. Maximum and minimum crop water use efficiency and irrigation water use efficiency were obtained from 55%ETc (6.9kg/ m^3 and 9.8k/m^3) and 85% ETc (5.9 kg/ m^3 and 8.3 kg/ m^3), respectively. The result obtained in this experiment was in agreement with Niguse (2013) who observed that irrigation water stress throughout the season significantly decreased Potato yield. Ghazouani *et al.*, (2019) also discussed that different irrigation water depth affects potato yield.

TRT	NTPP	CWUE (kg/m3)	IWUE (kg/m3)	MY (kg/ha)	UMY (kg/ha)	TY (kg/ha)
100%ETc	22.9a	6.0ab	8.5ab	35338.9a	641.7	35980.6a
85%ETc	18.2b	5.9b	8.3b	29200.0b	494.4	29694.4b
70%ETc	12.1c	6.6ab	9.3ab	27105.6bc	558.3	27663.9bc
55%ETc	6.9d	6.9a	9.8a	22333.3c	566.7	22900.0c
CV	21.9	13	13	13.9	69.8	13.7
LSD	4	1	1.4	4799.4	NS	4832.6

TRT= treatment, NFPP= number of tuber per plant, CWUE= crop water use efficiency, IWUE= irrigation water use efficiency, MY= marketable yield, UMY= unmarketable yield, TY= total yield.

Partial Budget Analysis

Economic evaluation is analyzing the cost that invested during growing season and benefitgained from yield produced by application of water. Marginal Rate of Return (MRR) was used for analysis following the CYMMYT method (CIMMYT, 1988). Economic water productivitywere calculated based on the information obtained at the study site:size of irrigable area, agricultural input, price of water applied, and income gained from the sale of Potato yield by considering thelocal market price.However, the amount of irrigation water applied was varied between each treatment. The net income (NI) treatments were calculated by subtracting total cost (TC) from gross income (GI) and were computed as:

$$NI = GI - TC$$

The difference between net income of a treatment and its next higher variable cost treatment termed as change in net income (ΔNI). Higher net benefits may not be attractive if they require very much higher costs (CIMMYT, 1988). Hence, it is required to calculate marginal costs with the extra marginal net income. The marginal rate of return (MRR) indicates the increase of the net income, which is produced by each additional unit of expenditures and it is computed as follows:

$$MRR = \frac{\Delta NI}{\Delta VC}$$

Where, MRR= marginal rate of return, ΔNI= change in net income, ΔVC= change in variable cost

At the time of harvest the market price of Potato was 15 birr per kg and the cost of irrigation water was 5 birr/m3 (by considering cost of drinking water as the cost irrigation water). To analyze by the producer of dominance analysis, the treatments were set in their sort of increasing variable cost and their equivalent benefits were put aside. 50%ETc and 100%ETc showed the minimum andmaximum variable costs respectively. Based on the current prices of tomato yield produced andinput costs required for production, the economic analysis was carried out.

The highest netincome (480594 birr/ha) was obtained under 100%ETc and the least net income (298690 birr/ha) wasobtained under 55%ETc. However, as it is indicated in table, the largest MRR (1639.1 %) wasacquired under 100%ETc and the smallest MRR (800.2 %) was obtained under CFI. Therefore, thehighest economic return was observed at 100%ETc with net income of 480594 birr/ha and MRR of1639.1 %. The MRR tell us that the amount of additional income obtained for every 1 birr spent.Hence, 100%ETc acquired additional 16.39 birr for every 1birr spent.

TRT	AW (m3/ha)	OY (kg/ha)	GI (birr/ha)	FC (birr/ha)	VC (birr/ha)	TC (birr/ha)	N I (birr/ha)	MRR (%)
55% Etc	3222	22333.3	335000	20200	16110	36310	298690	0
70% Etc	4101	27105.6	406584	20200	20505	40705	365879	1528.8
85% Etc	4799	29200.0	438000	20200	23995	44195	393805	800.2
100%Etc	5858	35338.9	530084	20200	29290	49490	480594	1639.1

AW= Applied water, Oy = Observed yield, GI=Gross income, FC= Fixed cost, TRT= treatment, VC=Variable cost, TC=Total cost, NI=Net income, MRR=Marginal rate of return

Conclusion and Recommendation

Under situations of water scarcity exercising deficit irrigation could help in saving the scarce water that can be used to irrigate additional piece of land. The experiment result shows potato yield significantly reduced with increased deficit irrigation level. The maximum yield and economic benefit was obtained under 100%ETc and 55% ETc can save a substantial amount of water and gives high crop water use and irrigation water use efficiency, but significantly reduced the tuber yield. The tuber yield of applying 85% ETc is better than 70%ETc and 55%ETc. Therefore, to obtain maximum tuber yield and economic benefit applying full irrigation is recommended, but in water scarce area applying 85%ETc is recommended with 17.5% yield reduction.

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