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Effect of Moisture Stress at Different Growth Stage on Potato (*Solanum tuberosum L.*) Yield and Water Productivity at Kulumsa, Ethiopia

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Abstract

Water shortage is one of the major challenges faced by the current agricultural systems worldwide, especially in arid and semi-arid regions. The response of potato crops to moisture stress was evaluated in Ziway Dugda district for two consecutive years during the dry season. The objective of the study was to determine the effect of soil moisture stress at different growth stages on the yield and water productivity of potatoes. Fifteen treatments were combined and imposed at four growth stages. The experiment was arranged in a Randomized Complete Block Design (RCBD) with three replications. The combined result of two years indicated that, moisture stress imposed at different growth stages significantly ($P<0.05$) affected potato tuber yield, and water productivity. The highest tuber yield (19,521 kg/ha) was obtained at control treatments where all the growth stage is irrigated, this result is followed by a treatment receiving moisture stress only during the late season (19,516 kg/ha). On the other hand, the lowest tuber yield (5,663 kg/ha) was obtained when the potato crop was irrigated only during the initial season. The highest water productivity (8.70 kg/m^3) and the lowest WP (3.56 kg/m^3) were obtained when potato was irrigated only at the initial stage (T_{15}) and irrigated in all states except the mid-season stage (T_4). Treatments that received irrigation only at the initial stage showed better water productivity. Therefore, in areas where irrigation water is not limited potatoes should be irrigated in all growth stages (T_1), otherwise, irrigate potatoes only during the development stages or development and midseason to maximize water productivity.

Keywords: Potato • Crop growth stages • Moisture stress • Potato • Water productivity

Introduction

Irrigated agriculture is undoubtedly the largest consumer of fresh water, accounting for approximately more than two-thirds of the total freshwater use [1]. It has been estimated that nearly 40% of the global food supply is produced by irrigation agriculture, which makes irrigation water becoming the largest single consumer of water on the earth. The shortage of irrigation water due to the competition of the industry and urban consumption threatens food security worldwide [2]. It is crucially important to efficiently manage irrigation and water consumption while maintaining or preferably yield through the development of technologies [3].

Drought already poses one of the most important constraints to plant growth and terrestrial ecosystem productivity in many regions all over the world and water availability is becoming even scarcer for agricultural communities. The influencing factors include inadequate rainfall, excessive levels of salts in the soil solution or the increasing diversion of limited fresh-water resources to competing urban and industrial uses [4,5].

Potato (*Solanum tuberosum*) is the fifth most produced main crop in the world after sugar cane (*Saccharum officinarum*) wheat (*Triticum aestivum*), rice (*Oryza sativa*), and maize (*Zea mays*). Its production has increased from 314,208 thousand tonnes in 2007 to 388,191 thousand tonnes in 2017 [6]. Modern cultivars are successful in improving tuber yield, yet they are sensitive to drought. Drought is multidimensional stress as it affects physiology, morphology, ecology, biochemical and molecular traits of plants [7]. Potato has shallow roots that make it prone to drought resulting from limited water availability [8]. Several *in vitro* and field studies have been conducted to understand the effect of drought stress on potatoes [9]. Reduction in the number of shoots, plant height, leaves numbers and area, stolons, root length, and expansion have been reported in previous studies. Plants have adopted various strategies to withstand drought stress through avoidance or tolerance [10]. However, it is very complicated to characterize drought tolerance in potato cultivars as

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the different yields of different cultivars are not related to specific physiological or morphological traits [11].

Under conditions of scarce water supply and drought, these practiced in irrigated agriculture could lead to greater economic gains by maximizing yield per unit of water. Therefore, in areas with water shortages, it is important to see in which particular condition to apply stress in a crop. For example, this could be applied through selecting the tolerant growth stage of a particular crop which leads to higher water productivity. This enables irrigators to understand specific crop growth stages and the level of stress to be imposed to enhance water productivity as the yield response can vary depending on crop sensitivity at that growth stage [12].

A period of interrupted growth, through drought, during this phase may result in the production of undersized and malformed tubers. Thus a regular supply of moisture from the beginning of stolon formation to maturity should be ensured [13]. Many experimental results stated that water stress at the early two stages *i.e.* colonization and tuberization showed sharp negative response to the yield of potato compared with bulking and tuber enlargement stages Hassan, et al. Therefore, the knowledge of critical stages of water stress is essential for judicious use of irrigation water specially when supply of irrigation water is limited, irrigation strategy may be based on avoiding soil moisture stress during the period of colonization, tuber initiation, yield formation by restricting the water supply during early vegetative and later part of growth period [14]. Pre-planting moisture is also important for optimum growth and yield of potato [15]. They considered pre-emergence, colonization, stage, tuberization and bulking stage as critical stages for potato.

Furthermore, studies have shown that water deficit occurs during certain stages of the growing season improves fruit quality, although water limitations may determine fruit yield losses [16]. Therefore, the objective to determine the effect of moisture stress at different growth stages on tuber yield and water productivity of potato.

Materials and Methods

Experimental site description

The study was carried out in Ziway Dugda district, Shelled PA of Arsi Zone, Oromia Regional State, Ethiopia. The study area located around 180 km from Addis Abeba capital city of Ethiopia. The experimental area is between 08°02'19"N to 39°00'59"E, and situated in an average elevation of 1700 m a.s.l. the study area has a semi-arid climatic condition with a mean monthly maximum and minimum temperature of 26.3°C and 12.3°C, respectively. It is characterized by a unit-modal low and erratic rainfall pattern with an average annual rainfall of 689 mm. Soil texture of the study area is Silt clay. An experimental site has 31, 15 and 16% soil field capacity, permanent wilting point and total available water respectively, while, the bulk density is 1.25 g/cm.

Experimental design and crop management

The experiment was laid out in Randomized Complete Block Design (RCBD) with three replications. Potato (Gudene variety) was planted on plot size of 4 m x 5 m. The plot has furrow spacing of 0.75 m and planted on both side of the ridge at row and plant spacing of 0.375 and 0.3 m, respectively. The treatment setup was combined as follows in Table 1.

Treatments	Description
T_1	Irrigate all growth stages (check)
T_2	Irrigate all stages except initial stage
T_3	Irrigate all stages except development stage
T_4	Irrigate all stages except mid-season stage
T_5	Irrigate all stages except maturity stage
T_6	Irrigate all stages except initial and development stages
T_7	Irrigate all stages except initial and mid-season stage
T_8	Irrigate all stages except initial and maturity stages
T_9	Irrigate all stages except development and mid-season stages
T_{10}	Irrigate all stages except development and maturity stages
T_{11}	Irrigate all stages except mid-season and maturity stages
T_{12}	Irrigate only at maturity stage
T_{13}	Irrigate only mid-season stage
T_{14}	Irrigate only development stage
T_{15}	Irrigate only initial stage

Table 1. Treatments combination.

All experimental plots were irrigated with uniform amount of water few days before planting to make the soil workable. To ensure the plant establishment two common irrigations was provided to all plots before commencement of the differential irrigation. Irrigation water was applied at allowable soil moisture depletion (p=0.25) of the total available soil moisture throughout crops growth stage. All experimental plots were fertilized with recommended rate of Urea (206 kg/ha) and NPS (295 kg/ha) fertilizer, respectively. NPS fertilizer was applied to all plots as basal dose at planting, while the recommended rate of Urea fertilizer was uniformly applied in splits, half at planting and the remaining half prior to hilling.

Measured depths of irrigation water were delivered to each plot according to the treatment arrangements and irrigation schedule through a water measuring device, namely two inch parshall flume, which was installed few meters before the start of experimental plots. Crop Water Requirement (CWR) was calculated using CropWat version 8.0 software and soil water was monitored by gravimetric method. Based on the calculated CWR, Irrigation water was applied according to the treatment arrangement and furrow irrigation method was used to apply treatment. Soil samples before and after irrigation was taken from control treatment plots to check the moisture content before and after irrigation not to go above field capacity and below allowable moisture depletion level. The crop was harvested at full maturity after 110 days of planting.

Data collection and statical analysis

Tuber yield and yield component data's including: plant height and the Number of Tuber Per Plant (NTPP) were collected. Water productivity and the effect of water stress on crop performance were quantified from WP and yield response factors (K_y), respectively. Water productivity was calculated as a ratio of total tuber yield to the total water applied through cropping season (Central Statistics, 2011).

Water Productivity (kg/m^3)=Total Tuber Yield (kg)/Crop Water Use (m^3)

The yield response factor (K_y) was estimated from the relationship.

$$\left[1-\left(\frac{Y_a}{Y_m}\right)\right] = K_y\left[1-\left(\frac{ET_a}{ET_m}\right)\right]$$

Where, Y_a=Actual harvested yield,

Y_m=Maximum harvested yield,

K_y= Yield response factor,

ET_a=Actual evapo-transpiration and

ET_m=Maximum evapo-transpiration

Data's were statistically analyzed using Statistical Analysis System (SAS) software version 9.0 with the General Linear Model (GLM) procedure. Mean separation using Least Significant Difference (LSD) at 5% probability level was employed to compare the differences among the treatments mean.

Results and Discussion

Effect of moisture stress on potato tuber yield and yield components

Number of tuber per plant: The analysis of variance revealed that moisture stress at different growth stages had a highly significant (P<0.01) effect on number of tuber per plant (Table 2). Maximum number of tuber (14) was obtained due to T_5 (Irrigate all stages except initial and maturity stages) [17]. However, the maximum number of tuber obtained at T_8 was statistically similar with tuber number observed at treatment T_1, T_2, T_{11} and T_{13}. On the other hand, minimum number of tuber was observed at treatment T-9 (Irrigate all stages except development and mid-season stages). However, the minimum number of tuber observed is statistically similar with treatment T_3, T_6, T_{12}, and T_{15} (Table 2) [18]. The result shows that application of moisture stress during development (T_3) and initial and development (T_6 and T_{12}) growth stages leads to a reduction of number of tuber per plant. Claypool and Morris, also working in the United States, found over a 6 years period that a larger number of tubers were formed when the plants were irrigated before flowering [19]. On the other hand, Edmundson reported that irrigation started at an early stage of growth had little effect on the total number of tubers produced by the plant [20].

Potato tuber yield: The analysis of variance shows that moisture stress at different growth stages of potato had a highly significant (P<0.01) effect on tuber yield of potato (Table 2). Maximum tuber yield of 19,521 kg/ha was obtained due to control (irrigation all stage) treatment. However, the highest tuber yield obtained at control treatment was statistically similar with potato yield obtained when moisture stress imposed only during initial, development, maturity (late season) and when moisture stress imposed during initial and maturity seasons [21]. On the other hand, minimum tuber yield of 5,663 kg/ha was obtained when potato irrigated only during initial season, stressing the rest growth stages. However, the minimum tuber yield obtained when irrigation applied only during initial were statistically similar with potato yield obtained during irrigate only maturity seasons [22]. Application of irrigation water only during the initial and late seasons leads to a reduction of 70.99% and 51.24% than the control treatment, respectively. On the other hand, comparable yield of potato obtained when moisture stress applied during only the initial and late season [23].

If the plant undergoes water deficit during later part of crop life cycle it reduces the yield but larger potatoes were obtained and plant usually produces small size potatoes if the plant experiences water deficit during early growth period indicating early growth period more susceptible to water stress and water plays an important role on tuber size distribution [24]. Cappaert, et al. stated that potato is tolerant to water stress before tuber formation period [25].

Generally, the study showed that moisture stress during development and mid stages affected tuber yield highly especially when combined with other stages. This is in line with the former D. R. Lynch N, et al. reported that early and midseason moisture stress had the greatest negative impact on tuber yield of the eight varieties, Atlantic and Conestoga appear to be particularly sensitive to stress at these two growth stages [26]. Midseason stress also appeared to reduce specific gravity. The results are in consistent with former findings of D. R. Lynch N, et al. the results of the study demonstrate the importance of maintaining adequate soil moisture at all stages during crop development [27]. Clark and Knorr also advised that irrigation should not be given before tuber set, while Sandsten and Fairfield reported that once the tubers had set then irrigation was required sufficiently often to keep the soil moist until the crop matured [28]. Some of the earliest experimental work on this crop was carried out in the United States. Welch compared the effect of 5 irrigation treatments over two seasons, irrigation being started and terminated at different stages of growth. The highest yield of marketable potatoes was obtained when water was first applied as the tubers began to form and thereafter as often as necessary until maturity; irrigating before tuber formation resulted in a lower yield. Harris obtained similar results and emphasized the importance of an even supply of water after tuber formation [29]. These results indicated that early irrigation increased the number of tubers while late irrigation increased their size.

Treatments	Tuber yield(kg/ha)**	NTPP**	WUE (kg/m^3)**
T_1	19,521^{a}	11.50^{ab}	4.16^{cd}
T_2	19,516^{a}	11.17^{ab}	4.86^{bcd}
T_3	16,481^{ab}	9.77^{bcd}	4.79^{bcd}
T_4	11,397^{cde}	9.87^{bc}	3.56^{d}
T_5	19,015^{a}	10.45^{b}	5.60^{bcd}
T_6	14,924^{bc}	9.37^{bcd}	5.35^{bcd}
T_7	13,949^{bcd}	10.53^{b}	5.96^{bc}
T_8	16,891^{ab}	14.00^{a}	6.04^{b}
T_9	10,464^{de}	6.50^{d}	5.82^{bc}
T_{10}	12,076^{cde}	10.03^{b}	5.56^{bc}
T_{11}	9,889^{e}	10.00^{ab}	5.19^{bcd}
T_{12}	9,519^{ef}	9.20^{bcd}	8.19^{a}
T_{13}	11,952^{e}	11.73^{ab}	7.93^{a}
T_{14}	10,062^{de}	10.43^{b}	8.11^{a}
T_{15}	5,663^{f}	6.57^{cd}	8.71^{a}
LSD 0.05	3,963	3.33	1.85
CV (%)	25.65	28.53	26.9

Table 2. Effect of moisture stress at different growth stage on yield and yield component of potato at Kulumsa during 2015/16 and 2016/17.

Means followed by the same letters in a column are not significantly different from each other at a 5% probability level.

Water productivity: Soil moisture stress at different growth stages of potato shows a highly ($p<0.01$) influence water productivity (Table 2). The highest water productivity of 8.71 kg/m^3 was observed at T_{15} treatment (irrigate only initial stage). The maximum water productivity observed at T_{15} was statistically similar with T_{12}, T_{13} and T_{14} treatments. On the other hand, the minimum water productive of 3.50 kg/m^3 was observed at T_4 treatment which was followed by T_{12}. However, this was not statistically different from water productivity obtained at treatments of 1, 2, 3, 5, 6, and 11. Water use efficiency of potato crop varied between 5.4 to 12 kg/m^3 with respect to irrigation, programme regime, amount of fertilizer and production technique. The water use efficiency for irrigated potato crops in humid and subtropics areas lies between 4-7 kg/m^3 as compared to furrow irrigated crop where water use efficiency was 4.54- 4.66 kg/m^3 [30,31]. The water use efficiency for drip irrigated potato varies from 5.19-5.74 kg/m^3 as compared to furrow irrigated crop which ranged from 4.7-6.63 kg/m^3 under 30 percent irrigation regime in both the irrigation system [32].

The reduction of water from full irrigation all stages (T_1) to irrigating only the initial stage (T_{15}) leads to an improvement of saving by 86%. However, this improvement in water productivity is compromised by a reduction of grain yield by 70.99% as compared from the control treatment [33]. Generally, treatments that received lower irrigation water showed better water productivity as compared to treatments that received higher irrigation water. Hence, treatment (T_8) received irrigation water at all stages except initial and maturity was statistically different from irrigate all stages (T_1) treatment by water productivity and in contrary to this no statistically different was observed to tuber yield production between these treatments (T_1 and T_8) [34].

Therefore from this study we observed that potato is sensitive to moisture stress during both stage at development and mid growth stage. The study of Kumar and Minhas 1994 on moisture stress prevails that, at tuber initiation stage, the yield loss is greater (31%) than at tuber development stage (21%), and this is due to greater reduction in photosynthesis (40%) and leaf area (35%) at tuber initiation stage than at tuber development stage [36]. It has been also reported that water shortage during tuber bulking stage decreased yield to a greater extent than during other growth stage *i.e.* tuber initiation as during bulking a gradual increase in water stress decreased yield and increased small size tubers [37].

Yield response factor (K_y): The observed yield response factors (K_y) result of potato tuber production ranged between 0.00 and 1.24. The magnitude of K_y value indicates the sensitivity of the irrigation protocol for water stress and subsequent yield decrease. According to Kirda, et al. the K_y value for field crops goes from 0.2 to 1.15 which agrees with the reported result [38]. Form the study result of Table 3 the highest K_y was 1.24 attained at the treatment (T_4) of irrigating all stages except mid-season. The higher K_y values could be an indication of severity water stresses at that stage on potato tuber yield. The lowest 0.00 was observed followed by 0.10 at irrigating all stage except initial stage (T_2) and Irrigate all stages except maturity stage (T_5), respectively. This indicated that the water stress at this stage did not affect potato tuber yield significantly [39]. This implies that the rate of relative yield decrease resulting from water stress is proportionally lower to the relative evapotranspiration deficit. From Table 3 result, moisture stress happened at development and mid-season stages, the yield reduction rate is extremely higher than stressed the crop at initial and late stage (Table 3).

TRT	Water applied (mm)	Tuber yield (kg/ha)	Water saved (%)	Yield reduction (%)	Crop response factor (K_y)
T_1	466.65	19521	-	-	-
T_2	401.6	19516	3.94	0.03	0
T_3	344.25	16481	26.23	15.57	0.59
T_4	309.7	11397	33.63	41.62	1.24
T_5	344.4	19015	26.2	2.59	0.1
T_6	279.2	14924	40.17	23.55	0.59
T_7	244.65	13949	47.57	28.54	0.6
T_8	279.35	16891	40.14	13.47	0.34
T_9	187.3	10464	59.86	46.4	0.78
T_{10}	222	12076	52.43	38.14	0.73
T_{11}	187.45	9889	59.83	49.34	0.82
T_{12}	122.25	9519	73.8	51.24	0.69
T_{13}	156.95	11952	66.37	38.77	0.58
T_{14}	122.4	10062	73.77	48.46	0.66
T_{15}	65.05	5663	86.06	70.99	0.82

Table 3. Effect of moisture stress at different growth stage on water productivity, water saving, yield reduction and crop response factor at Kulumsa during 2015/16 and 2016/17.

Conclusion

From the experiment, the maximum tuber yield was obtained from full irrigation followed by irrigating all stage except late-season stage. For crop water productivity the maximum water productivity obtained from irrigating only initial stage. The study showed that, stressing potato at development and mid-season, and when combined with other stages the yield reduce highly and the water productivity is also reduced. Therefore, it can be concluded that under good water resource condition for irrigation, potato could be irrigated all stage to obtain higher tuber yield. Moreover, stressing potato in the late season also gave similar yield and therefore it could be practice when irrigation water is limited. However, for further improving water productivity under water scarce condition, potato could be irrigated only at development and mid-season. Therefore, in area where irrigation water is scarce one can use with holding irrigation water at all stage except only initial or late stages to save considerable water only during maturity stage is recommended for the study area and similar agro-ecology and soil type.

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