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Effect of Drip and Furrow Irrigation on Yield, Water Productivity and Economics of Potato (*Solanum tuberosum* L.) Grown under Semiarid Conditions

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Abstract

Irrigation management is key to obtain profitable growth in areas of water scarcity. Thus, the interest in highly efficient irrigation systems to irrigate row crops is growing. In this study, the water-use efficiency and economic feasibility of potato crop grown under drip and furrow irrigation systems were compared on the farmer's field under semi-arid conditions. Data showed better plant growth, more tubers per plant and improvement in the crop yield under drip irrigation system compared to furrow irrigation system. The final yield of 51.8 tons/ha with the net profit of 2912 \$/ha and benefit-cost ratio of 2.66 was achieved with drip irrigation compared to the final yield of 32.6 tons/ha, net profit of 1432 \$/ha and benefit-cost ratio of 1.29 with furrow irrigation. In addition, drip irrigation exhibited significantly higher irrigation water use efficiency (16.3 kg/m³) and water use efficiency (14.1kg/m³) and lower evapotranspiration (374 mm) compared to furrow irrigation. Conclusively, the drip irrigation system proved to be more beneficial with respect to water saving, tuber yield and net farmer's income. The effective use of water through high-efficiency irrigation systems will go a long way in reducing wastage of scarce irrigation water resources thus addressing the national water crisis in the future.



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Introduction

The district Toba Tek Singh, Pakistan falls under semi-arid regions and is known for cotton production due to a well-developed canal irrigation network. Agriculture of this region is completely dependent on the canal water supply because groundwater is saline. In the last few years, a decline in water availability and irregular canal water supply associated with various pest problems caused a reduction in cotton yield and subsequently farm income. Farmers are bound to shift to some other remunerative crops. Vegetables may be a good option but it requires frequent and ensured water supply because they are considered very sensitive to soil moisture stress [1]. Potato cultivation would be a possible alternative to increase the farm income if efficient and reliable irrigation management strategies are adopted to maintain optimum moisture in the effective root zone. It can be achieved best with the use of a high-efficiency irrigation system coupled with suitable irrigation scheduling under limited water resources, particularly in the semi-arid region.

Due to brackish underground water and expected limited water supplies, interest in highly efficient irrigation systems to irrigate row crops is growing. Saving water in such areas is a constant concern and new methods and irrigation strategies are urgent. On-farm water storage is needed to ensure regular supply for the high-efficiency irrigation system because, due to one and other reasons, canal water supply is not regular and groundwater quality is not fit for irrigation. Though furrow bed irrigation has proven its potential to increase yield and water productivity of potato crop, the climatic conditions and scarcity of water in this region seem more suitable to drip irrigation because drip irrigation ensures the judicious supply of moisture and nutrients to plants which helps in better growth and yield [2]. Drip irrigation is instrumental in saving a considerable amount of water, fertilizers, and pesticides and increasing the quality of potato tubers. Thus, the income of farmers and in fact socioeconomic uplift of such areas is expected by adopting a high-efficiency irrigation system [3]. Drip irrigation offers advantages like fewer nutrient leaching, higher yield compared to surface irrigation, a dry soil surface for improved weed control and crop health and the ability to apply water and nutrients to the most active part of the root zone [4]. Potato (*Solanum tuberosum* L.) is the 4th important crop by

production after wheat, rice and maize in Punjab, Pakistan. It is high yielding, having a high nutritive value and gives high returns to farmers. Potato is grown on an area of 161.9 million hectares with 3507.1 thousand tons of production averaging 21.90 tons/ha during the year 2017 in Pakistan [5], which was very low as compared to the yields of leading potato growing countries of the world. Potato is a water stress-sensitive crop [6]. In semiarid environments, the limited water supply may result in crop water stress that can affect potato growth and development adversely. Many researchers have shown how potato yield can be affected by water stress and irrigation timing [7].

The superiority of drip irrigation over traditional irrigation methods in terms of yield and economics is now a well-established fact [10]. But the economic viability of the drip irrigation system for potato cultivation in areas where canal water is scarce and stored for using drip irrigation systems is yet to be answered. It creates doubt whether agriculture with drip irrigation would be economically viable or not because an additional investment is required for a water storage tank apart from the drip irrigation system cost. It is, therefore, imperative to evolve efficient, economical and reliable irrigation management strategies for successful potato cultivation to increase productivity and profitability of the existing production system for canal irrigated areas of the semi-arid environment. Although studies of drip irrigation for potato crop have been conducted in many parts of the world [11], local information on the response of the potato crop to the drip irrigation system is required to assess the economics and feasibility of using drip irrigation system under local conditions so that scientifically based practical guidelines may be developed for potato growing farming community [12]. In this study, we compared the effect of surface irrigation and drip irrigation systems on yield, water productivity, evapotranspiration and economics of the potato crop to enhance the use of advanced irrigation strategies to uplift the socio-economic condition of farmers in the future.

Materials and Methods

A field study was conducted in a farmer's field in District Toba Tek Singh, Punjab, Pakistan during 2018-19. The latitude of the area is 30° 58' 07.94" N 72° 41' 52.29" E and altitude of 163.9 meters above sea level. The climate of the experimental site was semi-arid with extremely hot summers and cold

winters (Table 1). The soil profile of the experimental site is presented in Table 2. The experiment was laid out under a randomized complete block design (RCBD) with two blocks for each of the two treatments tested: (1) drip irrigation and (2) furrow irrigation. The experimental area was 4682.3 m² and each block consisted of four plots of 4.5 m × 40 m each. Potato *cv.* Cardinal was planted manually at a depth of 10–12 cm on September 20, 2018, with a distance of 0.8 m between rows and 0.25 m between plants (5 plants/m²) and harvested on January 4, 2019, under drip irrigation and January 20 under furrow irrigation. The recommended dose of nutrients, *i.e.*, 250, 150, 350 kg/ha of N, P, K was applied as urea, triple superphosphate (TSP) and sulfate of potash (SOP), respectively. In a drip irrigation system, nutrients were applied as fertigation, while in furrow irrigation, broadcasting was done. Fertigation was started two weeks after sowing and was stopped 30 days prior to the end of the crop period in drip irrigation system.

Table 1 Monthly means of minimum and maximum temperature (T) and reference evapotranspiration (ET₀) during the growth period of potato.

Month	T Min	T Max	Rainfall (mm)	ET ₀ /d (mm)
Sep. 2018	17	32	11.2	5.10
Oct. 2018	9	26	8	3.63
Nov. 2018	4	20	4	2.32
Dec. 2018	2	16	0	1.50
Jan. 2019	5	12.7	0	1.36
Feb. 2019	7	15.4	13.4	1.93

Daily crop evapotranspiration (Etc) was estimated by integrating climatic data and soil data, crop resistance by using a computer model CROPWAT. The input data includes climate data (maximum and minimum temperature (°C), air humidity (%), daily sunshine (hours) and wind speed (m/s), rainfall data (daily/monthly rainfall data), crop date (crop planting and harvesting dates and its Kc values at different growth stages) and soil data (soil is light, medium or heavy, moisture in the soil profile). Daily weather data, including daily maximum and minimum air temperature, relative humidity, wind speed, rainfall, and solar radiation were collected from Ayub Agriculture Research Faisalabad, Punjab Pakistan. CROPWAT calculated daily ETC and the irrigation depth required using the procedure described in FAO-56 [13]. CROPWAT gives reference

evapotranspiration, which is multiplied with crop coefficient to get the crop evapotranspiration.

$$ETc = Kc \times ET_0$$

Where Etc = crop evapotranspiration (mm/day); Kc = crop coefficient and ET₀ = reference evapotranspiration (mm/day).

Irrigation was applied after sowing by cut-throat flume in surface furrow irrigation, while in the drip irrigation system, water was applied through a drip irrigation system that consisted of a pump, fertilizer venture, disc filters, control valves, pressure gauges and a flow meter [3]. The amount of irrigation water was controlled by the flow meter. Each treatment had one valve to control the water application. Irrigation scheduling was on a daily basis using estimated crop water requirements. All other management and agronomic practices were the same for all treatments. The yield from each plot was recorded and converted to tons per hectare (t/ha⁻¹). The water use efficiency (WUE, kg/m³) and irrigation water use efficiency (IWUE, kg/m³) were calculated as follows:

$$WUE = Y \text{ (kg/ha)} / ETc \text{ (m}^3\text{)}$$

Where Y=yield of irrigated plant (kg/ha) / ETc = actual evapotranspiration

$$IWUE = Y \text{ (kg/ha)} / I \text{ (m}^3\text{)}$$

Where Y = yield (kg/ha)/ I (seasonal irrigation)

To assess the economic viability of different irrigation systems for potato production, both fixed and operating costs were taken into consideration. Net returns were estimated as the difference between gross income and total production cost. Gross returns were the product of yield and the wholesale market price of potato. The benefit-cost ratio and net profit were carried out to determine the economic feasibility of the crop using surface and drip irrigation. The seasonal system cost of the drip irrigation system included depreciation, and repair and maintenance cost of the system. The data were analyzed using analysis of variance (ANOVA) and to find differences among treatments least significant difference method (LSD) was used at *P* = 0.05 level as described earlier [14].

Results and Discussion

Tuber yield and yield components

The drip irrigation method had a significant effect on potato yield and yield components, except the number of tubers/plant, which may be associated

with the cultivar and other environmental conditions (Table 3). The study indicated better plant growth, more tubers/plant and enhancement in the crop yield under drip irrigation compared to furrow irrigation. However, the tuber numbers/plant were not affected significantly by irrigation methods. Similar results have been reported by Onder et al. [15] that the number of tubers/plant were not significantly influenced by the irrigation methods. The overall average yield resulted from the drip irrigation system was significantly higher (51.8 t/ha) over furrow irrigation (32.6 t/ha), which accounted for a 37% yield increase. This yield increase can be attributed to significantly higher mean tuber weight and tuber yield per plant in drip irrigation compared to furrow irrigation. The better performance under drip irrigation may be attributed to the maintenance of favorable soil moisture, which in turn helped the plants to utilize moisture as well as nutrients more efficiently, resulting in the more efficient functioning of the stem and leaves which helped increase photosynthesis and translocation because of minimum lodging and delayed senescence of the leaves [16]. Our results are in conformity with the finding of Yuan et al. [17] who reported that although water stress reduced photosynthetic efficiency but the stress during the critical periods of tuber initiation and bulking had the most drastic effect on the tuber

yield. It can be suggested from the data that drip irrigation is a better management option affecting crop yield and yield components under water deficit conditions of the semi-arid climate.

Phenological stages

The data of phenological stages of potato monitored for each treatment clearly indicate that those were delayed with furrow irrigation compared to the drip irrigation method during the whole crop cycle (Table 4).

Crop water requirement

By using CROPWAT for windows 10.0, actual evapotranspiration was estimated 562 mm for conventional furrow irrigation method while irrigation water requirement (IWR) under the drip irrigation system was recorded as 374 mm using the same procedure and model. This may be attributed to differences in soil depletion, plant height, total growing season and irrigation depth. Data regarding the volume of water applied presented in Table 5 shows that more water was applied in furrow irrigation (499 mm) compared to drip irrigation (324 mm) with 35% water saving. Similarly, other researchers working on the drip irrigation system concluded that by using drip irrigation system, 80% of water can be saved [18], [19]. The data suggested that drip-irrigated treatment consumed about 45%

Table 2 Chemical characteristics of the soil at the experimental site.

Depth (cm)	pH	EC (dS/m)	Bulk density (g/cm ³)	Avail-P (mg/kg)	Avail-K (mg/kg)	OM %	SAR	Sand %	Silt %	Clay %	Soil texture
0–30	7.58	0.22	1.36	9.5	400	1.46	6.3	16	70	14	loam
30–60	7.8	0.21	1.40	5.3	160	1.04	4.9	16	69	15	

EC = electrical conductivity; OM = organic matter; SAR = Sodium Absorption ratio

Table 3 Potato yield and yield components as affected by drip and furrow irrigation method.

Irrigation method	Tubers yield (t/ha)	Emergence (%)	Leaves /plant	Plant height (cm)	Tubers/plant	Tubers weight g/plant	Tubers yield g/plant
Furrow irrigation	32.6b	91.2	41.2	40.9	8.9	228.3a	1271b
Drip irrigation	51.8a	97.1	44.0	45.7	9.6	341.1b	2871a
LSD	2.1	NS	NS	NS	NS	1.2	3.1

Table 4 Phenological stages of potato and dates (days) of their appearance as affected by drip and furrow irrigation systems.

Phenological stage	Drip irrigation (date)	Furrow irrigation (date)
Planting	20 Sep	20 Sep
Emergence	10 Oct (20)	14 Oct (24)
Stem elongation	27 Oct (37)	02 Nov (43)
Tuber initiation	09 Nov (50)	12 Nov (53)
Flowering	28 Nov (69)	30 Nov (70)
Maturity	25 Dec (96)	28 Dec (97)
Harvest	04 Jan (107)	20 Jan (120)

less water than conventional furrow irrigation. These results are in conformity with Onder et al. [15] who reported that seasonal potato had evapotranspiration of 375 mm for drip irrigation compared to 485 mm for furrow irrigation. Faberio et al. [20] achieved highest tuber yield of 45.2 t/ha with 597 mm irrigation water while Doorenbos and Kassam [21] and Ünlü et al. [22] reported that highest potato yield could be obtained with seasonal potato evapotranspiration from 350 mm to 800 mm for different agroclimatic conditions.

Water-use efficiency

In this study, different irrigation methods influenced irrigation water-use efficiency (IWUE) of potato. Table 6 shows significantly higher IWUE (16.3 kg/m³) with the drip irrigation method compar-

Table 5 Amounts of irrigation water, rainfall and actual evapotranspiration under drip and furrow irrigation methods.

Treatment	No. of irrigations	Rainfall (mm)	IWA (mm)	ET (mm)
Furrow	17	15.6	499	562
Drip	95	15.6	324	374

IWA= irrigation water applied; ET = evapotranspiration

Table 6 Irrigation water use efficiency (IWUE), water use efficiency (WUE) and crop coefficient (Kc) for potato under different irrigation methods.

Irrigation method	IWUE (kg/m ³)	WUE (kg/m ³)	Kc
Furrow irrigation	6.68b	5.95b	0.78
Drip irrigation	16.3a	14.1a	0.54
LSD	2.875	2.112	0.21

Table 7 Economic analysis of drip and furrow irrigation methods for the potato crop.

Sr. No.	Cost	Drip	Furrow
1	Fixed cost/ha*	1043	0
2	Seasonal system cost/ha		
	a. Depreciation	94	0
	b. Repair and maintenance	21	0
	c. Total	115	0
3	Seasonal cost of cultivation/ha	987	1103
4	Seasonal total cost (2c+3)**	1102	1103
5	Water used (m ³)	3823	5868
6	Yield (tons/ha)	51.8	32.6
7	Income from produce/ha	4034	2536
8	Net profit (7-4)	2912	1432
9	Benefit-cost ratio (8/4)	2.66	1.29
10	Net profit/ha/m ³ of water use	0.77	0.24

* Fixed cost includes the cost of drip irrigation system

** Total seasonal cost includes expenses incurred on land preparation, seed, fertilizer, pesticide, fuel, operation and maintenance cost of drip irrigation system.

-ed to the furrow irrigation method (6.68 kg/m³). The higher IWUE reveals that potato yield was utmost with less water expense under the drip irrigation system. Since the IWUE is the function of crop yield and total water applied, conventional furrow irrigation used a higher amount of water than the drip irrigation method (Table 6). Water use efficiency (WUE) of drip-irrigated treatment was also significantly higher and differed from furrow-irrigated treatments in the growth season ($P<0.05$). The WUE for drip irrigation was 14.1 kg/m³ while for furrow irrigation, it was 5.95 kg/m³. Similar results have been reported by Li et al. [23].

Economic feasibility

Drip irrigation method resulted in a higher net profit of 2912 \$/ha with benefit-cost ratio of 2.66 while a comparatively lower net profit of 1432 \$/ha with benefit-cost ratio of 1.29 was recorded in furrow irrigation method (Table 7). We reported similar results previously for sweet pepper [24]. The lower benefit-cost ratio recorded in furrow irrigation treatment was due to higher production and less fertilizer expenditure under drip irrigation as reported by Narayamoorthi [25]. Drip irrigation also exhibited higher net profit per m³ of water used (0.77 \$/ha) due to the less water used (3823 m³) compared to furrow irrigation. The highest net return of 2912 \$/ha obtained in drip irrigation that was 51% higher than furrow irrigation, proving the beneficial effect of the drip irrigation system. Our results are in conformity with Al-Omran et al. [26] and Andoh et al. [27].

Conclusion

Irrigation management is a key to obtain profitable growth in areas of water scarcity having the brackish nature of underground water. Fortunately, there is ample scope to improve crop water productivity, particularly in areas where water is scarce and yields are currently low. Many areas of Punjab like District Toba Tek Singh are facing a dramatic shortage of water resources for agriculture due to both scarcity of rainfall and considerable competition for water. Drip irrigation induces favorable soil moisture conditions in the active crop root zone, which was conducive for good growth of crop to achieve the optimum quantity and quality of crop yield and water use efficiency. The results of this study are particularly important as it may allow to increase farmer incomes, through a better tuber quality and lower production costs. Furthermore, the water saved may be used more profitably to

irrigate supplemental lands, thus achieving a more efficient and rational use of land and water resources. Last but not the least, drip irrigation significantly increased tuber yield of potato and improved WUE due to consumption of less water. However, use of drip irrigation with appropriate irrigation scheduling is very important for improving WUE and increasing crop yield of potato in semiarid climate.

Conflict of Interest

The author declares no conflict of interest in this study.

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