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A Sustainable Irrigation System for Small Landholdings of Rainfed Punjab, Pakistan

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Citation: Aziz, M.; Rizvi, S.A.; Iqbal, M.A.; Syed, S.; Ashraf, M.; Anwer, S.; Usman, M.; Tahir, N.; Khan, A.; Asghar, S.; et al. A Sustainable Irrigation System for Small Landholdings of Rainfed Punjab, Pakistan. *Sustainability* **2021**, *13*, 11178. https://doi.org/10.3390/su132011178

Academic Editor: Michael S. Carolan

Received: 3 September 2021
Accepted: 30 September 2021
Published: 11 October 2021

Abstract: Drip irrigation has long been proven beneficial for fruit and vegetable crops in Pakistan, but the only barrier in its adoption is the high cost of installation for small landholders, which is due to overdesigning of the system. In the present study, the cost of a conventional drip irrigation system was reduced by redesigning and eliminating the heavy filtration system (i.e., hydrocyclon, sand media, disc filters (groundwater source), pressure gauges, water meters, and double laterals).Purchasing the drip system from local vendors also reduced the cost. Field trials were conducted during 2015 and 2016 to observe the productive and economic effects of low-cost drip irrigation on vegetables (potato, onion, and chilies) and fruits (olive, peach, and citrus). The low-cost drip irrigation system saved 50% cost of irrigation and increased 27–54% net revenue in comparison with the furrow irrigation system. Further, water use efficiency (WUE) was found from 3.91–13.30 kg/m^3 and 1.28–4.89 kg/m^3 for drip irrigation and furrow irrigation systems, respectively. The physical and chemical attributes of vegetables and fruits were also improved to a reasonably good extent. The present study concluded that low-cost drip irrigation increased the yield by more than 20%, as compared with traditional furrow irrigation, and thus, it is beneficial for the small landholders (i.e., less than 2 hectares).

Keywords: agricultural economy; drip irrigation system; net revenue; small landholders; sustainable irrigation

1. Introduction

Irrigation, along with other quality inputs, is crucial for the livelihood and food security of Pakistan [1]. Land and water management practices are two very important components to outstrip the water use efficiency and livelihood of rainfed areas [2,3]. In the present system of irrigation, low water use efficiency, and low agricultural productivity are the topmost concerns of the Government of Pakistan [4]. Two possible ways to enhance agricultural productivity include either bringing more area under farming (horizontal expansion) or increasing the production per hectare (vertical expansion) [5]. Historically farmers of Pakistan have been using conventional irrigation methods comprising basin, border, and furrow to irrigate the crops, in which the entire fieldis watered without considering the actual crop water requirement. These traditional methods of irrigation have created immense issues such as waterlogging and salinity, and on the other hand, their application efficiency is very low [6]. There are numerous substitute strategies to improve the water application efficiency such as using drip-and-sprinkler irrigation, considering climatic and land parameters, as well as altering the cropping pattern or varieties [4].

Punjab is Pakistan's agro-economic hub that contributes to about 80 percent of the country's food needs [7]. During the last some decades, climate change has had a crucial effect on the country's water resources. In response, progressive farmers started using high-efficiency irrigation systems. Due to their high initial and operational costs, small landholders are constrained to employ these modern technologies due to their poor economic conditions and low potential returns. Modern technologies are necessary to address water scarcity and enhance crop performance and water productivity. The use of high efficiency and low-cost irrigation system is one of many options to overcome the water losses caused by conventional methods [8]. Drip irrigation system, when compared with the furrow irrigation system, gives the optimum potential to enhance yields and irrigation water use efficiency [9]. Evidently, the furrow irrigation system involves a little initial cost, and it appears to be beneficial, but in reality, furrow irrigation systems require vigorous labor for their establishment and need regular maintenance due to having low application efficiency (45%), as indicated in a study by [10].

Efficient systems such as drip irrigation have been tested in various crops and found to be beneficial in water resources conservation and water productivity enhancement. Many farmers have limited financial resources to install this system. Pakistan is an agricultural country that is currently facing the problem of water scarcity to fulfill different crop requirements. Drip/trickle irrigation technology was introduced in Pakistan during the early 21st century. After years of research and promotion of high-efficiency irrigation systems through subsidized schemes, drip irrigation technology has become available for easy adoption by farmers. Due to high installation costs, less awareness, and training of farmers for its use, this technology still needs to be tested and evaluated at farmer's fields to achieve large-scale farmer adoption [11,12]. Although the subsidized schemes of the government have promoted drip-and-sprinkler technologies, training and knowledge support to farmers for shifting toward high-value cash crops are limiting factors [13]. Farmers worldwide have been using drip irrigation systems since the 1990s, but the trend of adoption is quite moderate in Pakistan for small landholders because of (1) excessive designing, which makes this system very costly for small landholdings and (2) poor management of drip irrigation system.

Keeping in mind the adoption constraints by the small landholders, the current study planned to redesign the system by setting up the simpler parts without the involvement of companies. Hence, the main objectives of this research study were to (1) redesign the system and examine the economics of a low-cost drip irrigation system for small landholders (farmers with lands less than 2 hectares) and (2) compare the drip irrigation system with furrow irrigation in terms of water saving and yield improvement.

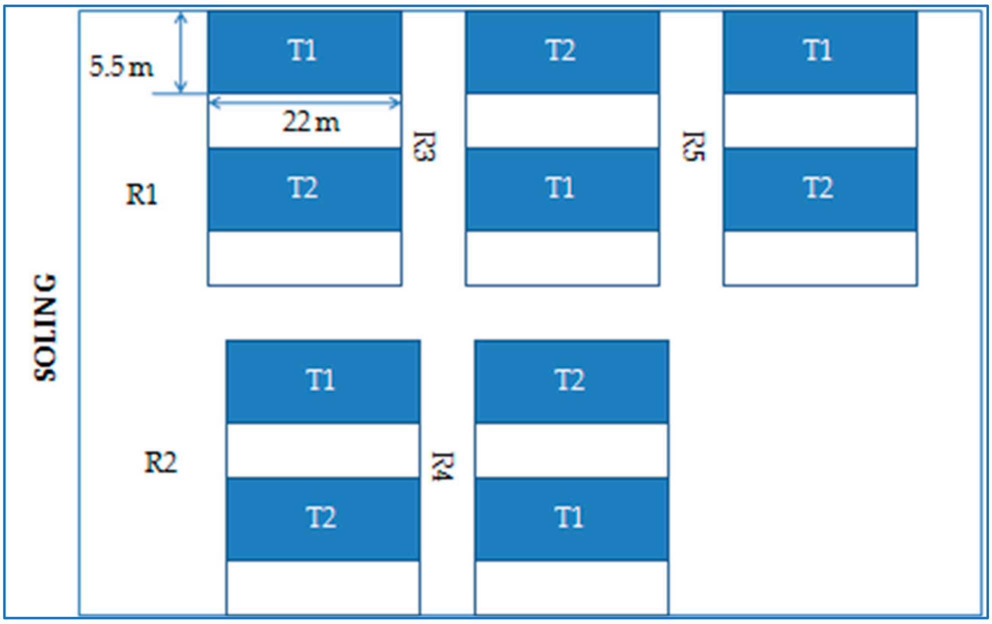
2. Materials and Methods

The experiment was conducted at Barani Agricultural Research Institute (BARI), which is located at 72°43.4′ longitude, 32°55.5′ latitude, having an altitude of 522 m. The weather conditions of Chakwal are arid to semiarid with annual rainfall varying from 500 to 1000 mm (1979–2016) [14]. The soil of the experimental site is piedmontalluvial (plains order: ALFISOL belongs to Therpal/Satwal/Kotli series). The physical and chemical properties of the soil as reported [15] are presented in Table 1.

Table 1. Soil physical and chemical properties of the experimental site.

Physical and Chemical Properties of Soil	Depth below Ground Surface	
	0–15 cm	16–30 cm
Clay (%)	10	10
Silt (%)	30	30
Sand (%)	60	60
Nitrogen (%)	0.8	2.0
Phosphorus (ppm)	5.0	3.4
Potassium (ppm)	138.0	132
Organic matter (%)	0.6	0.33
Electric conductivity (dS/m)	0.3	0.25
pH	7.68	7.79

The trials were set up in a completely randomized block design (RBCD) with two treatments T1 (low-cost drip irrigation) and T2 (conventional furrow irrigation), each having five replications, as shown in Figure 1a–d. Furrows and ridges were prepared by means of a ridger, keeping the maximum length of furrow as 30 m to avoid deep percolation losses.



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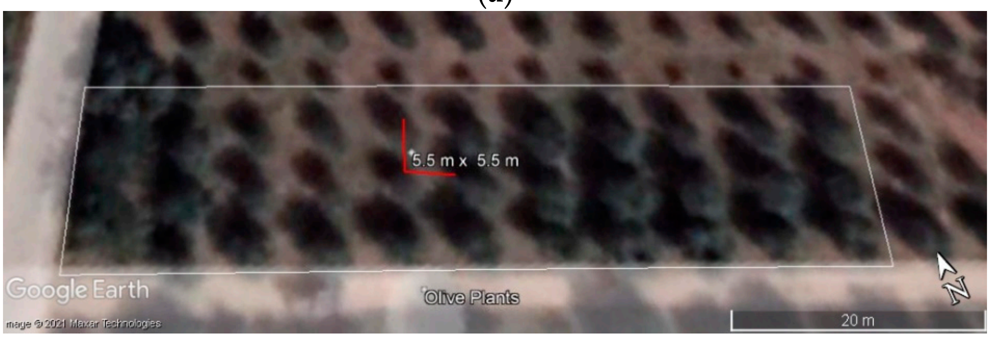

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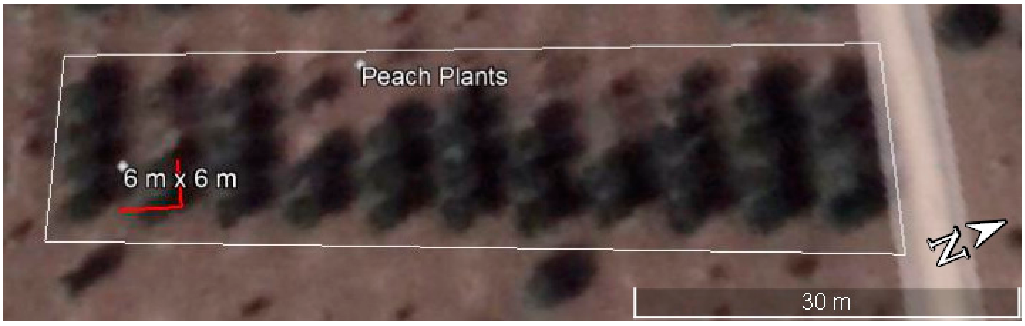
Figure 1. *Cont.*



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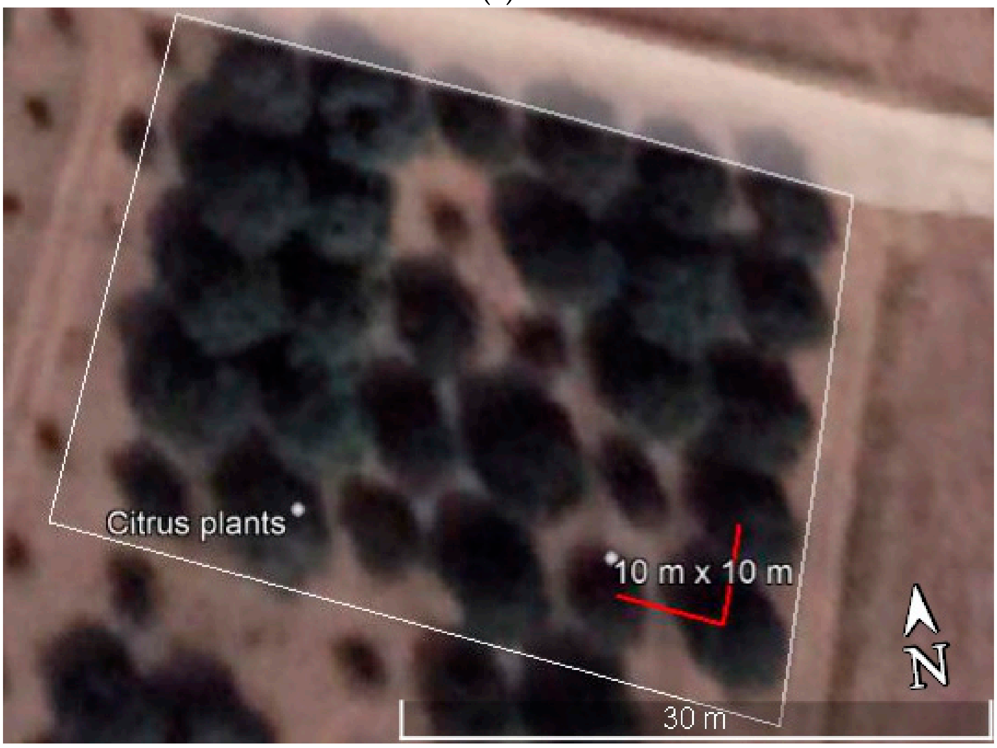

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Figure 1. (**a**) Block diagram of vegetables (potato, onion, and chilies) plots; (**b**) the layout of olive plant; (**c**) the layout of peach plant; (**d**) the layout of citrus plant.

In Figure 1a, R1, R2, R3, R4, and R5 refer to replications, and T1 and T2 refer to treatments.

Vegetables were sown as per conventional farmers' practice, and plants having age of six years were selected from the existing orchards of BARI, as depicted in Figure 1b–d. The planting geometry of vegetables (potato, onion, and chilies) and plants (olive, citrus, and peach) is presented in Table 2.

A low-cost drip irrigation system was designed and installed in the fields manually. This system comprised a main and sub main lines for each set having 38 mm dia pipe made of polyvinyl chloride (PVC), further attached to lateral lines having 16 mm dia made of low-density polyethylene (LDPE) fitted with 0.006 m^3/h drippers (Figure 2). In all crops, lateral lines were placed parallel to the plant lines. Lateral lines with built-in drippers were used for row crops (onion, potato, and chilies), while two (2) drippers/plants were placed on the lateral line for fruit plants (olive, peach, and citrus). The parts of the drip irrigation system were purchased from local vendors (local market) and installed manually (without the involvement of a company). Testing of drippers was performed to check the pressure and flow variations by using the standard method described in [16]. Pressure and flow rates were maintained and recorded as given in Table 3.

Table 2. Planting geometry of the crops (vegetables and plants).

Crops (Variety Name)	Age of Plant	Row-Row Distance (m)	Plant-Plant Distance (m)	Area/Plant (m^2)	Total Area under Crop (m^2)
Potato (Desirie)	1 season	0.61	0.204	0.124	1220
Onion (Phulkara)	1 season	0.69	0.101	0.070	1220
Chilies (Ghotki)	1 season	0.735	0.46	0.338	1220
Olive (BARI Zaitoon1)	6 years	5.5	5.5	30	990
Peach (Early Grand)	6 years	6	6	36	1584
Citrus (Musambi)	6 years	10	10	100	3000

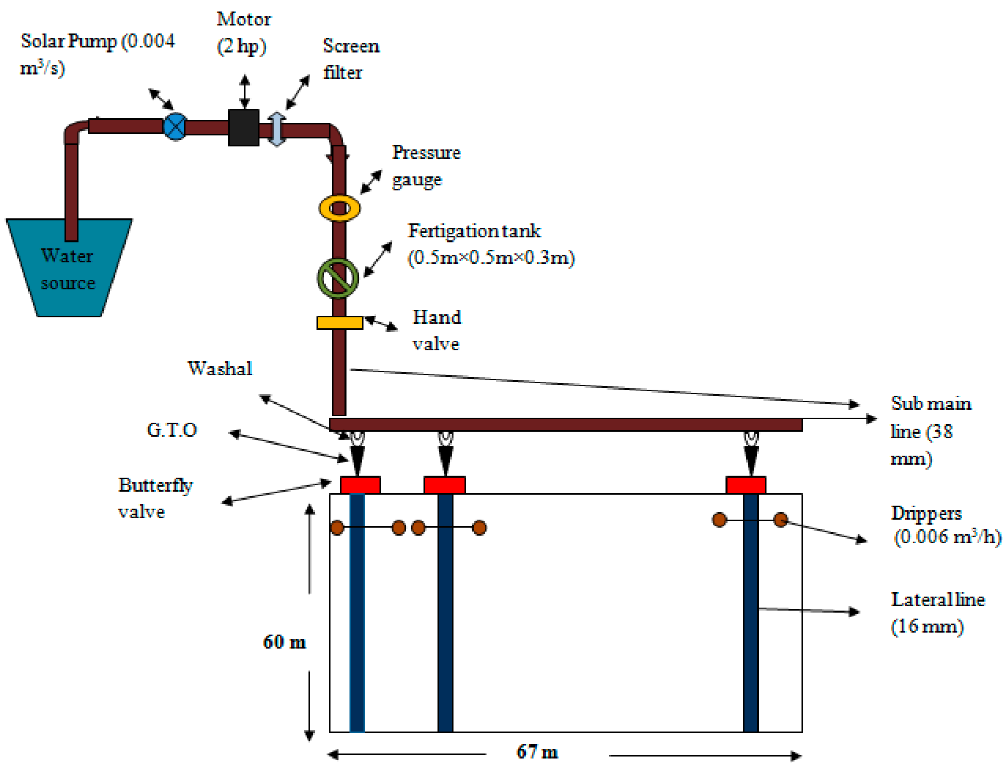


Figure 2. Schematic diagram of the low-cost drip irrigation system.

Table 3. Pressure and flow variation in the low-cost drip irrigation system.

Emitter	Pressure (kPa)	Flow Rate (m^3/h)
1	215	0.0062
2	210	0.0063
3	210	0.0012
4	195	0.0095
5	120	0.0064
6	190	0.0064
7	200	0.007
8	230	0.0063
9	210	0.0064
Average	197.778	0.006
Midpoint	175	0.0101
Variation calculation (%)	−9	−11
Acceptable range	<±10%	<±5%

A typical drip system is normally equipped with a venturi injector; including a heavy filtration unit (hydrocyclon filter, sand media filter, and disc filter). However, in the present study, only a screen filter was used at the inlet point of the water source. A simple drum (0.5 m × 0.5 m × 0.3 m) was placed for fertigation instead of a venturi injector to reduce the cost of the system (Figure 2). The life span of the low-cost drip irrigation system was considered to be 10 years, as adopted by [17]. The solar pump with a flow rate of

0.004 m^3/s was installed for pumping water. The effective life span of the solar pump was assumed to be 30 years, as adopted in [18].

For irrigation scheduling, vacuum-gauge-type tensiometers were installed down to effective root depths. Irrigation applications were scheduled on 60% soil moisture depletion (SMD) after accounting for effective rainfall. The irrigation requirements of crops were calculated using the moisture retention curve (Figure 3). The effective rainfall was calculated using CROPWAT 8.0 model, as shown in [19].

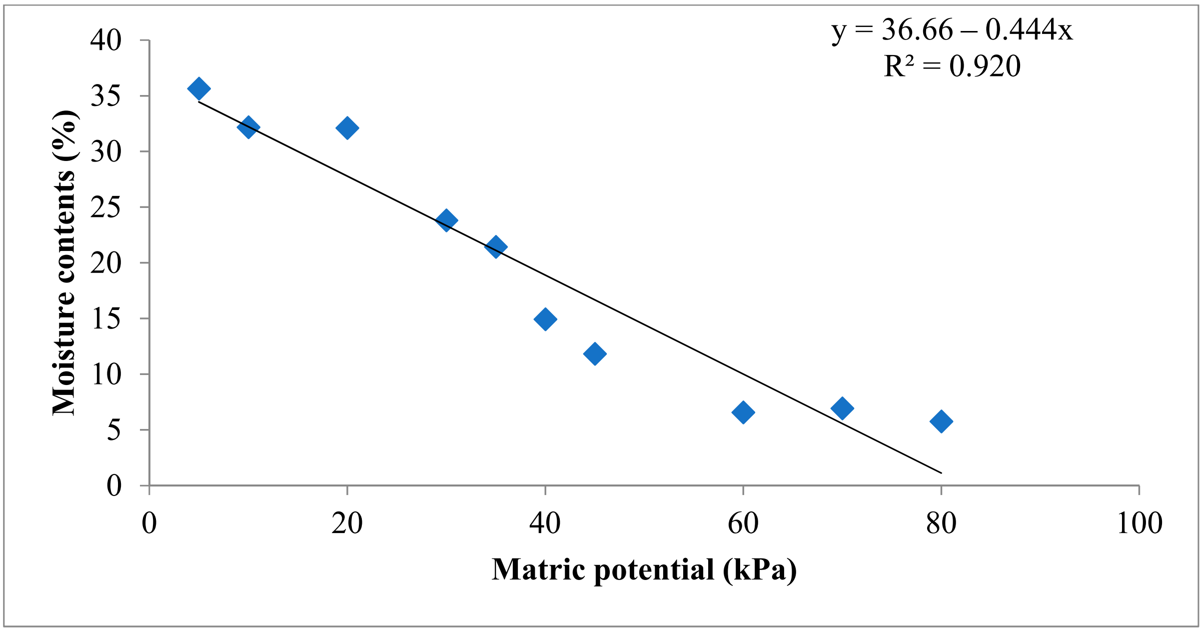


Figure 3. Moisture retention curve.

2.1. Experimental Data Collection and Analysis

Pre sowing moisture contents were determined gravimetrically from a depth of 15 cm to 90 cm, with an interval of 15 cm. To schedule irrigation, soil moisture contents were taken using tensiometers (Figure 3), after 7-day intervals from each of the experimental sets. The seasonal crop water requirements were assessed with the CROPWAT 8.0 model for which input data comprising climate data (maximum and minimum temperatures (°C), relative humidity (%), sunshine hours (hours), wind speed (km/day), and rainfall (mm)) were acquired from the nearest weather station installed at the campus, while crop data (planting and harvesting dates, Kc values at each growth stage, root depth (m), plant height (m)) and soil data (soil type, total available water (mm/meter), maximum rain infiltration rate (m/day), and initial soil moisture depletion (%)) were recorded on-site.

2.1.1. Vegetative Growth

Crops (onion, potato, and chilies) attributes, i.e., plant height (m), root depth (m), and leaf area (m^2) were measured at the time of harvest. Plant height and root depth were measured from randomly selected 20 plants/replication with the help of a measuring tape. Leaf area (m^2) was calculated by selecting 5 plants/treatment by separating the leaves from the plant, washed with plain water, and drying them in the open air, using a portable leaf area meter. For fruit trees (olive, peach, and citrus), the plant height (m) and canopy volume (m^3) were calculated according to the formula: 0.536 × tree height × crown diameter, as proposed in [20].

2.1.2. Yield

Yield data of row crops (onion, potato, and chilies) were recorded on each picking from each trial. Similarly, for fruit trees (olive, peach, and citrus), yield data of each fruit tree were measured in (kg)/tree at the time of each picking.

2.1.3. Fruit Quality

Fruit quality was assessed by selecting 20 fruits per treatment at random and determining physical and chemical characteristics of fruit, including fruit length and diameter (mm), fruit weight (kg)/plant, and its health, with visual observation. Fruit length and diameter were calculated by digital Vernier caliper in the laboratory. A total of 10fruits per replication were selected to record juice quality of citrus and peach such as total soluble solids (TSS) by hand refractometer, titrable acidity (%), as citric acid according to [21], and juice contents (%), as proposed in [22]. For all selected crops, the cross-sectional data of fixed costs, variable costs, depreciation costs, and the net return attained during the experimental period 2015–2016 for both drip and furrow irrigation systems were determined.

3. Results

3.1. Water Application

Water application to a rainfed crop depends on the water availability at the time of sowing and the amount of precipitation received throughout the growing season. For this purpose, long-term rainfall analysis was very important. The weather data for the last 37 years (1979–2016) were collected at the weather station of Soil and Water Conservation Research Institute (SAWCRI), Chakwal, located adjacent to the experimental field, and were analyzed to use in CROPWAT for estimation of crop water requirements. Rainfall data of 2015 and 2016 are shown in Figure 4.

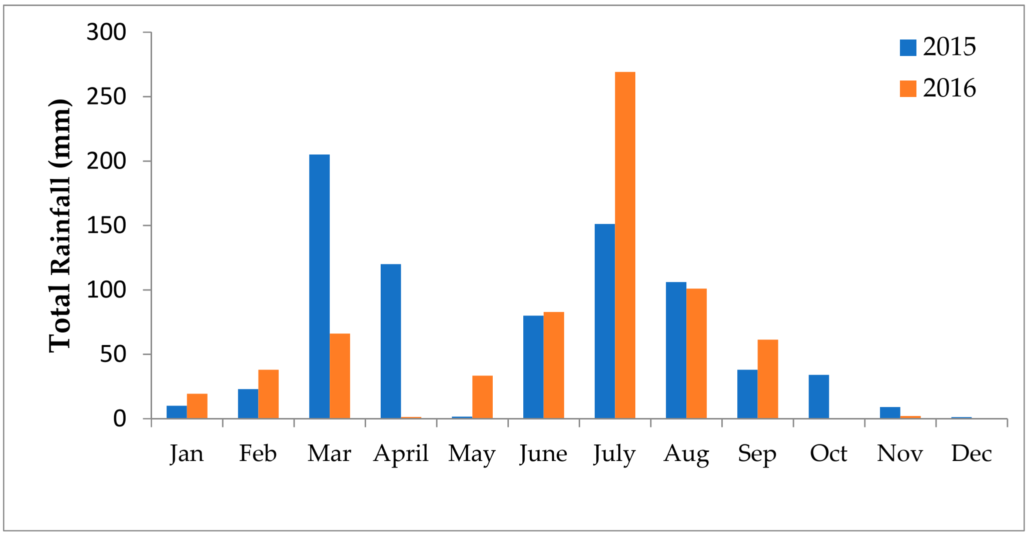


Figure 4. Monthly rainfall (mm) for the experimental period.

Total rainfall during the years 2015 and 2016 was 779 and 675 mm, and effective rainfall was 580 and 502 mm, respectively. The comparison of monthly climatic data with long-term means climatic data showed that total rainfall received during 2015 was higher than in 2016, and 62 % of yearly rainfall was received during the months of July to September in both years. Table 4 shows the amount of effective rainfall and irrigation (m^3) applied to each crop through drip and furrow irrigation techniques, along with the consequent yield (kg/ha) and water use efficiency (WUE) values during cropping seasons of 2015 and 2016.

Table 4. Water and yield data of different crops averaged over two years (2015–2016) at BARI.

Crop	Water Requirement (m^3/ha)	Effective Rain Fall (m^3)	Water Applied (m^3)		Water Saving (%)	Yield (kg/ha)		Yield Increase (%)	Water Use Efficiency (WUE) (kg/m^3)	
			Drip	Furrow		Drip	Furrow		Drip	Furrow
Potato	1500	280	1350	2440	45	10,930	7287	33	8.10	2.99
Onion	2000	1060	1040	1880	45	13,832	9201	33	13.30	4.89
Chilies	5040	3550	1660	2980	44	13,049	9077	30	7.86	3.05
Olive	5940	4790	1280	2870	55	5000	3667	27	3.91	1.28
Peach	7370	4790	2780	6450	57	25,676	19,270	25	9.24	2.99
Citrus	8480	4790	4100	9220	56	35,135	26,027	26	8.57	2.82

The amount of water applied to each crop was calculated by subtracting the effective rainfall from the total water requirement. Effective rainfall was calculated by using the CROPWAT model, which has the built-in function that uses various parameters, along with total rainfall. Table 4 shows that drip irrigation required 50% less water, as compared with furrow irrigation, to achieve the required SMD. Moisture levels were kept at an optimal range (60% SMD), which improved the plant production and quality. Drip irrigation allowed the rows between plants to remain dry, reduce weed growth, and reduce leaching of water and nutrients below the root zone. The water use efficiency (WUE) values under the drip irrigation system and furrow irrigation system ranged from 3.91 to 13.30 kg/m^3 and 1.28–4.89 kg/m^3, respectively. It was observed that water use efficiency was maximum in onion under drip irrigation (13.30 kg/m^3). The results showed that drip irrigation gave three times more yield per unit of water applied in all vegetables and fruit crops when compared with furrow irrigation. Water use efficiency was exceptionally low in the furrow irrigation system due to conveyance, deep percolation, and evaporation losses. The results of this study are in line with [12], who reported that a low-cost drip system used 30–40% less water, as compared with the furrow irrigation method. Water savings were also higher (55%, 57% and 56%) in water-intensive crops such as olive, peach, and citrus, respectively (Figure 5).

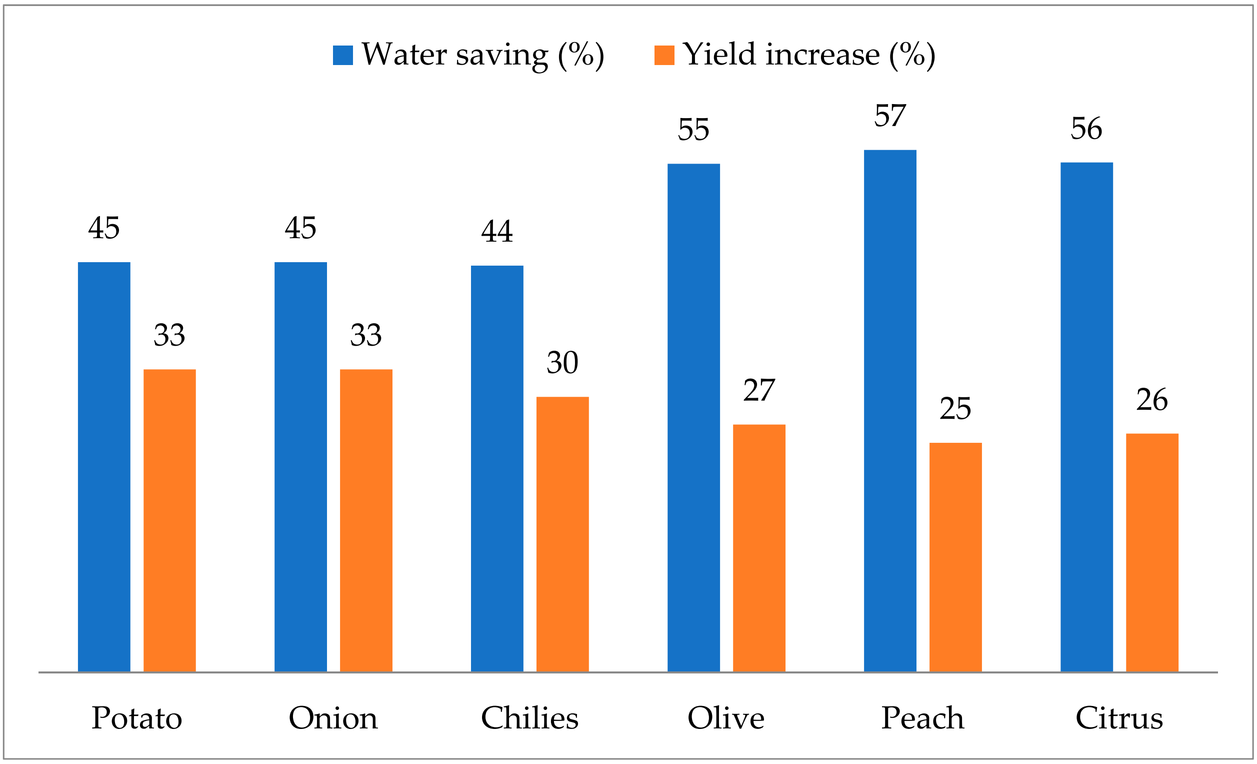


Figure 5. Increase in yield (%) and water saving (%) under drip irrigation system, averaged over 2 years (2015 and 2016).

3.2. Effect of Irrigation on Physical and Chemical Properties of Fruit

Values obtained from the treatments related to plant height (m), root depth (m), fruit weight/plant (kg), leaf area (m^2) for row crops (onion, potato, and chilies) and fruit plants (olive, peach, and citrus) are shown in Table 5, and values of plant height (m), fruit weight/plant (g), canopy volume (m^3), fruit length (mm), fruit diameter (mm), fruit weight/plant (kg) for fruit plants (olive, peach, and citrus) are given in Table 6.

Table 5. Effect of irrigation treatments on plant attributes of vegetables and fruit plants (averaged over 2 years).

Parameters/Crops		Plant Height (m)	Root Depth (m)	Fruit wt./Plant (kg)	Leaf Area (m^2)	Fruit Length (mm)	Fruit Diameter (mm)
Potato	Drip	0.6	0.33	0.391	0.2241	88	55
	Furrow	0.52	0.36	0.348	0.2012	75	48
Onion	Drip	0.51	0.27	0.136	0.0425	65.5	70.9
	Furrow	0.44	0.31	0.11	0.0385	59.2	62.4
Chilies	Drip	0.92	0.39	0.438	0.0475	55.5	
	Furrow	0.85	0.42	0.347	0.0398	50.4	44.4
Olive	Drip	2.1	15	4.3	19.3	14.9	2.03
	Furrow	1.9	12	3.2	17.4	12.8	1.75
Peach	Drip	3.5	130	26.48	87	6.31	116
	Furrow	3.0	100	25.2	74	5.94	105.5
Citrus	Drip	2.0	95	9.7	66	77	120
	Furrow	1.85	75	8.4	62	7	115

Table 6. Effect of irrigation treatments on chemical parameters of fruit juice (averaged over 2 years).

Parameters	TSS (°Brix)		Titratable Juice Acidity (%)		Juice Contents (%)	
Treatments / Fruits	Drip	Furrow	Drip	Furrow	Drip	Furrow
Peach	5.3	3.5	0.5	0.36	48.5	46.3
Citrus	10.3	9.56	0.45	0.3	57.5	55.2

From the data in Table 5, it is obvious that vegetative growth parameters of all crops (plant height, leaf area, and canopy volume, and fruit wt. (kg) per plant) increased in the treatment of drip irrigation system. The drip irrigation system maintained soil moisture around the plant roots by maintaining the soil physical properties, which could be a possible reason for the enhanced plant growth and yield under drip irrigation. Similar results were reported in [23–25] for potato, onion, and chilies, respectively, and in [26–28] for olive, peach, and citrus, respectively.

The chemical properties of peach and citrus juice were also recorded, as shown in Table 6, which included total soluble salts (TSSs), Brix, titratable juice acidity (%), and juice contents (%). Some studies [20,27] reported an increase in TSS and titratable acidity under drip irrigation treatment as the amount of water applied decreased, and in the furrow irrigation system, plants received ample water; thus, the values of fruit juice quality parameters were reduced. The comparative wet conditions that enhanced the fruit size may be conducive for the production of higher total soluble salts (TSSs). High soil moisture levels helped in increasing titratable acidity and juice contents.

3.3. Economic Evaluation

The drip irrigation method requires an initial fixed cost for installation, and the cost depends on the crop nature, plant spacing, water requirement, discharge of the dripper, and distance from the water source. The crops with more plant to plant and row to row distance require a relatively low capital cost. Moreover, the fixed cost also depends on the quality of the materials used for the system. In Pakistan, the adoption of drip irrigation systems is quite slow mainly because of overdesigning of the system. In Government-sponsored subsidized schemes, high-efficiency irrigation systems are generally equipped with solar-powered groundwater pumps, heavy filters, fertigation chambers, etc. Further, many companies are involved in designing (who overdesign in their interest) without good experience, installing the drip system by adding large and unnecessary parts such as filters, gauges, fertigation tanks, water meters, etc., which make the system costly. The management of such systems is difficult for common farmers; therefore, they are reluctant to install the system. In this study, the authors proposed a low-cost/economical drip irrigation system by eliminating unwanted parts, purchasing the parts from local vendors, and installing them manually. All costs involved in making furrows and designing/installing the low-cost drip irrigation system are listed in Tables 7 and 8.

Table 7. Fixed costs and depreciation costs of furrow irrigation system.

Crops	Fixed Cost			Depreciation Cost (Labor Involved in Irrigation and Furrow Repairing)
	Pumping Cost	Laser Leveling Cost + 8 Daily Paid Labor @ 365 Rs/Day	Ridge Making through Tractor + 8 Daily Paid Labor @ 365 Rs/Day	
	Rs/ha	Rs/ha	Rs/ha	Rs/ha
Potato	10,033	8788	7518	14,834
Onion	10,033	8788	7518	14,834
Chilies	10,033	8788	7518	22,250
Olive	10,033	8788	0	44,501
Peach	10,033	8788	0	44,501
Citrus	10,033	8788	0	44,501

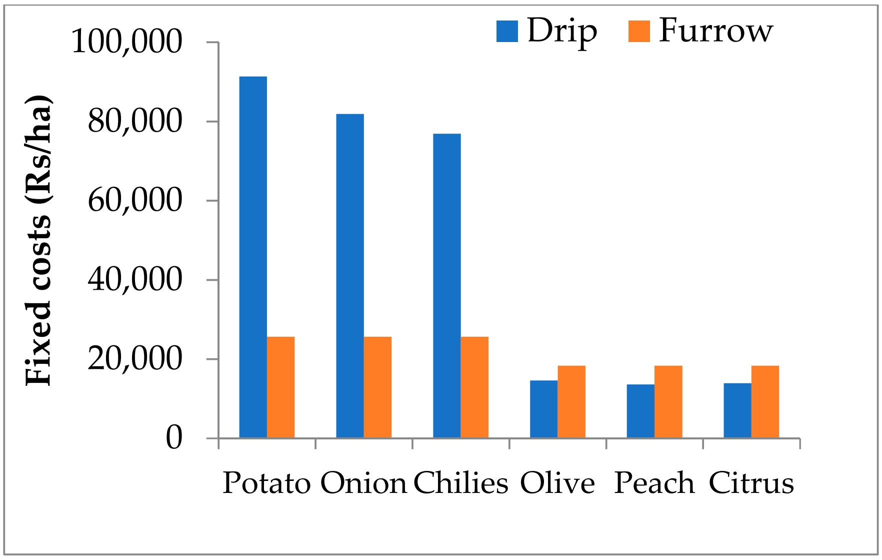
Table 8. Fixed costs for the drip irrigation system.

Crops	Total Cost of the System (Rs/ha)	Life of the Drip System (Years)	Pumping Cost of the System (Rs/ha)	Life of the Solar Pump (Years)	Fixed Cost [(A/B) + (C/D)]
	A	B	C	D	Rs/ha
Potato	874,090	10	118,500	30	91,359
Onion	779,468	10	118,500	30	81,897
Chilies	729,211	10	118,500	30	76,871
Olive	106,175	10	118,500	30	14,567
Peach	96,576	10	118,500	30	13,608
Citrus	99,342	10	118,500	30	13,884

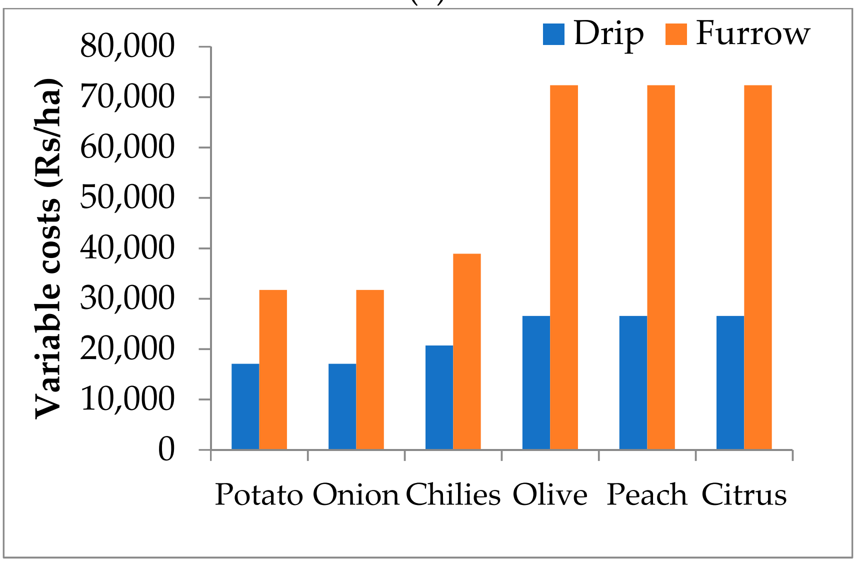
4. Discussion

Irrigation was scheduled with respect to effective rainfall events during crop growing seasons. Irrigation scheduling devices (tensiometers) were installed to monitor the soil moisture to schedule the irrigation events. Water saving in drip irrigation (Figure 5) was high because the furrow system is less efficient (50%), excess amount of water leached down to the groundwater, and consequently, a large amount of irrigation had to be applied to meet the crop water requirement. The findings of this study are in close agreement with [29], for vegetables, and [30] for fruit crops. The data presented in Figure 5 show the percent increase in yield and water saving in the drip irrigation system. Drip irrigation increased production and, at the same time, increased the quality of fruit, reducing shoot growth, as was reported in [28]. Numerous research studies suggested that wetting only 20% to 50% of the effective rooting depth of full-grown deciduous fruit trees is adequate to maximize yield, provided enough water is available to meet water requirements during critical periods of fruit development, as proposed in [31]. Plant growth is badly affected when using the furrow irrigation method because after irrigation, soil moisture contents change from saturation to field capacity to dryness, and therefore, plants bear moisture stress before the next irrigation. A minimum interval of irrigation throughout the crop growing season creates water and nutrient balance and ensures optimum growth of the crop.

Figure 6a–e presents the complete comparison of all costs, i.e., fixed costs, variable costs, and depreciation costs, involved in the establishment and operation of furrow and drip irrigation systems. The total cost of installation of drip irrigation per hectare was calculated as Rs 50,000–150,000, assuming 10 years of its useful life, with a payback period of 1–2 years for fruit plants and 3–6 years for vegetables. The fixed capital costs varied for all crops due to variation in plant spacing of the respective crops (Table 2); it included the cost of installation of drip system, along with pumping cost using a solar pump. Fixed costs in furrow irrigation comprised the cost of land leveling through laser leveler and the tractor expenses to make ridges (Table 7). Laser leveling required 4–4.15 h/acre to level 10 cm to 15 cm deep layers of soil. Short-level furrows required accurate field grading, which was performed by machines. The plowing and furrowing were also performed by machines. These operations required skilled labor, fuel, and machinery tools, and all these cots added to the fixed costs of the furrow irrigation method (Table 7). The variation in variable costs was mainly due to incurred expenses with the purchase of seeds, fertilizers, pesticides, weedicides, and labor involved in field operations. In the drip irrigation system, the labor cost was half, as compared to the furrow irrigation system, because in furrow irrigation, more labor was required for hoeing, weeding, and watering operations. The drip irrigation system required lower field operations, which also reduced the cost of the system. Depreciation costs in drip irrigation systems include the repair and maintenance of drip parts such as damage or leakage in lateral lines, drip emitter clogging, etc., which was fixed for all crops (Figure 6a). In the furrow irrigation system, the depreciation cost comprised the cost of labor for the repair and maintenance of furrows after every irrigation or a high-rainfall event. Every month during the crop season eight (8) persons were deployed for these operations for a hectare.

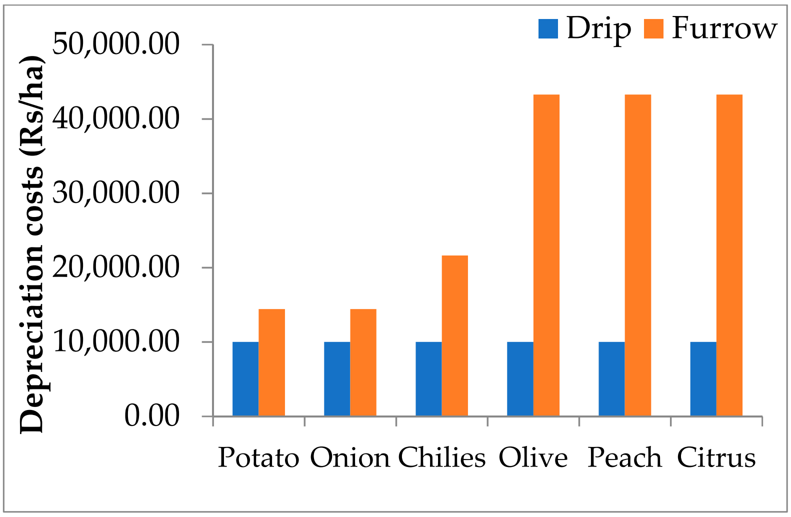


(**a**)

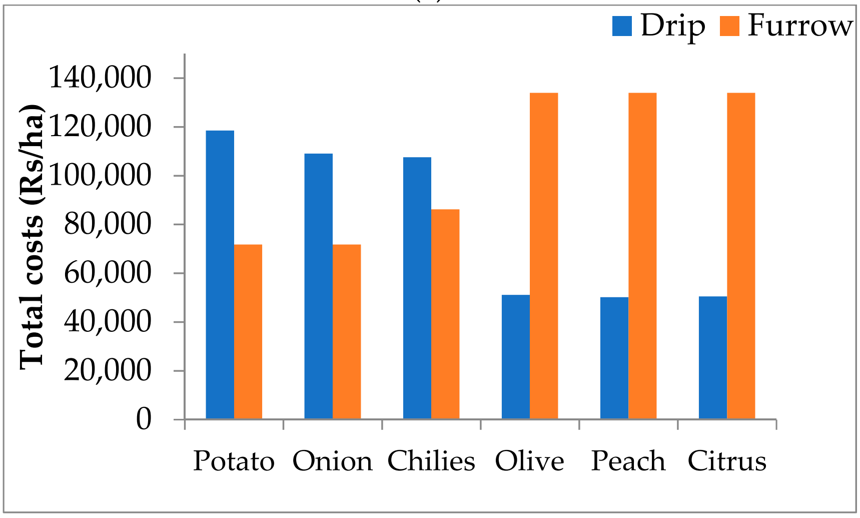


(**b**)

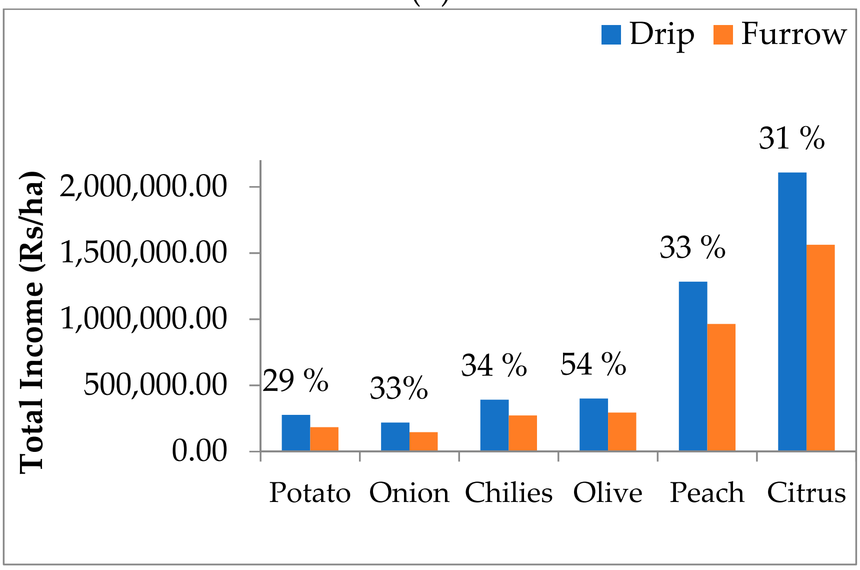
Figure 6. *Cont.*



(**c**)



(**d**)



(**e**)

Figure 6. (**a**) Comparison of fixed costs incurred in T1 and T2; (**b**) comparison of variable costs incurred in T1 and T2; (**c**) comparison of depreciation costs incurred in T1 and T2; (**d**) comparison of total costs incurred in T1 and T2; (**e**) comparison of total income received from T1 and T2.

The gross returns were computed by multiplying the average market rate with the yield of respective vegetables and fruits during the crop harvesting period. The seasonal gross expenditure, gross return, net return, and percentage increase in net return for drip irrigation and furrow irrigation systems for all the selected crops are also depicted in Figure 6d,e. The results revealed that the highest percentage net return per hectare under drip irrigation system was recorded for olive (54%) and the lowest percentage net returns recorded for potato (29%), as shown in Figure 6e.

Financial viability analysis was performed by computing the net present value of crops and fruit plants by discounting both the costs and the returns at the prevailing rate of interest (10%), which is shown in Table 9. From the table, it is clear that net present values of crops and fruit plants were computed for the entire life of the drip system (10 years). Net present values in Table 9 showed that the low-cost drip system discounted cash flows over the entire life of the drip set (10 years). The tear-wise net present worth was estimated to calculate the number of years required to recover the capital cost of the drip system. The payback period for olive, peach, and citrus was 2 years, 1 year, and 1 year, respectively, and for potato, onion, and chilies, the payback period was 5 years, 6 years, and 3 years, respectively. The cost incurred on the drip irrigation system was Rs 118,451 for potato and Rs 108,989 for onion; thus, the payback period for both crops is maximum. Due to narrow plant spacing in potato and onion, the initial costs of drip sets were high.

Table 9. Net present worth and payback periods of drip irrigated crops.

Crops	Net Present Value (Rs/ha) @ 10% Discount Rate	Pay Back Period (Years)
Potato	65,247	5
Onion	38,185	6
Chilies	139,032	3
Olive	202,235	2
Peach	746,163	1
Citrus	1,252,415	1

Gross expenditures in the drip irrigation system were higher because of the high initial investment. However, the gross income in the drip irrigation system was high because of the good quality of produce and high yield. Furrow irrigation system consistently underperformed in the case of all the vegetables and fruit crops.

5. Conclusions

From the results of this study, it was concluded that the low-cost drip irrigation system applies water near the roots of the plant, as per requirement, and therefore produces more vegetables and fruits with less water. The low-cost drip irrigation under rainfed conditions saved up to 86% of irrigation water and increased yield by 26–33%, as compared with the furrow irrigation method. Reduced cost of labor in irrigation, fertilizer application, and weeding, combined with increased economic returns, leads to higher economics of vegetable production under the drip system. Fruits and vegetables performed well in the drip irrigation system; however, as observed in this study, the performance of vegetables (potato, onion and chilies) was far low, as compared with fruit plants (olive, peach, and citrus). Based on the present research findings, the average cost of drip sets was calculated to be Rs 50,000–150,000 per hectare for all given crops. It was also concluded that the gross expenditures of the low-cost drip irrigation set can be fully recovered in the second year of crops and orchards. The low-cost drip irrigation was found efficient and economically viable, gave long-term benefits for small landholders, and is feasible/suitable for those areas where the capital costs of existing drip systems are the main barrier to their adoption. There is considerable potential for farmers to grow their orchards and vegetables by installing a low-cost drip irrigation system in their farms/fields.

Author Contributions: Conceptualization, methodology, execution, data curation, writing—original draft preparation, M.A. (Marjan Aziz); formal data analysis, interpretation of results, review and final revision, S.A.R.; investigation, M.A.I.; resources, S.S.; software, S.A. (Saira Anwer) and S.A. (Sana Asghar); validation, N.T., M.U. and A.K.; acquisition of parts and repair maintenance, J.A.; writing—review and editing, M.A. (Muhammad Ashraf). All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not Applicable.

Informed Consent Statement: Not Applicable.

Data Availability Statement: Not applicable.

Acknowledgments: The authors are indebted to Abdul Majid, ICARDA office in Pakistanfor providing technical guidance and moral help, and Bareerah Fatima from Pakistan Council of Research in Water Resources (PCRWR), Islamabad, is highly acknowledged for her help in completing this study.

Conflicts of Interest: The authors declare no conflict of interest.

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