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# Multi-locational trials to compare the relative water use and vegetable crops productivity by drip irrigation and conventional furrow irrigation systems in district Toba Tek Singh, Pakistan

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**Abstract**
Multi-location trials to compare the relative water use and vegetable crops productivity by drip irrigation and conventional furrow irrigation systems were carried out for two years (2012-13 and 2013-14) on off season vegetables grown under plastic tunnels at 16 sites in district Toba Tek Singh, Pakistan. Data pooled from these trials showed that compared to furrow irrigation, drip irrigation increased off season vegetables yield on an average by 24% with reduced application of fertilizer, pesticides and water by 55%, 19% and 65%, respectively. All the crops consumed less water under drip irrigation as compared to furrow irrigation system. Average water use efficiency increased by 62% for capsicum, 64% for cucumber, 58% for green papers, 53% for tomato and 52% for bitter gourd under drip irrigation system as compared to furrow system. Drip system increased net profit on an average by 52% as compared to conventional surface irrigation with a higher benefit cost ratio (BCR) of 2.33. The vegetable growers were also asked to answer the in-depth farm level survey regarding benefits of use of drip irrigation to verify the results of the above studies. The survey results showed that drip irrigation has been widely adopted for vegetable crop in the district. Although capital cost and managerial expertise for using the drip irrigation system are high, a farmer participatory appraisal showed that adoption of this irrigation system is rapidly increasing in the district. Most serious issue for growers in the district is non availability of spare parts and clogging of emitters. These findings indicate an urgent need for Research and Development (R&D) for better operation and maintenance of drip irrigation system and proper irrigation scheduling using this technology.
**Keywords** Off season vegetables, drip irrigation, water use efficiency.

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## Introduction

Presently in Pakistan 0.69 million ha area is cultivated with vegetable with an annual production of 8.5 million tones. It is estimated that by 2030, the vegetable demand of the country would be around 25 million tones. To achieve this target, attention must be focused on the vertical expansion, strengthened with the boom of the technology instead of horizontal expansion just by increasing the crop area [1].

Government of Punjab has launched Punjab Irrigated Agriculture Productivity Improvement Project (PIPIP), which recommended the deployment of hi-tech drip irrigation system for precision farming to achieve vertical growth in crop production. High-tech interventions include drip and sprinkler irrigation for row crops, i.e., maize, cotton off season vegetables and orchards. Drip irrigation with its ability to small and frequent applications of water has created interest among off season vegetable growers because of less water requirement, less fertilizer use, increased production and better quality product. Economic evaluation of drip irrigation in off season vegetables, i.e., tomato, hot pepper, capsicum, cucumber, bitter gourd, pumpkin, melon and watermelon in district Toba Tek Singh reveals that, this system conserves considerable amount of water and results better returns despite higher initial investment [2].

Environment of Punjab province is conducive for the production of many off-season vegetables under plastic tunnel. By using tunnel technology, farmers can have their vegetable crop earlier and can earn much more as compared to normal crop season. Despite high returns, non-availability of irrigation water is hindering the expansion of area under off season vegetables [3]. Vegetable production through drip irrigation system is, therefore, gaining popularity among educated farmers as it provides them with an opportunity to save the input resources by using less than 60% water, fertilizer and other resources. Drip irrigation, thus, helps to overcome the three main impediments that impact off season vegetable production under a tunnel, chronic water shortages, high insect, pest and diseases attack due to increased relative humidity under flood conditions, lower yield and low value of crop production. This way, drip irrigation in tunnel farming protects the soil environment and decrease nutrient leaching with considerable reduction in pesticide use [4].

Review of literature regarding the use of drip irrigation system showed high irrigation efficiency with drip systems ranges from 75-95% compared to 25-50% for surface irrigation [5]. Similarly, increased irrigation water use efficiency by using drip irrigation system in tomato has also been reported by Fan et al. [6]. Iqbal et al. [2] recorded higher yield of off season vegetables under drip irrigation than the surface irrigation system, while Yasemin et al. [7] observed no significant difference in vegetable's yield between the these two irrigation systems. Yields and net income of capsicum increased by 57% and 54%, respectively, by using drip and plastic mulch culture together [8] and Ismail et al. [9] reported high water use efficiency of drip system in combination with plastic mulch in case of capsicum; however, drip irrigation improved marketable yield and fruit quality in case of tomato. A lot more similar research work has been done to increase vegetable productivity [10, 11] but little attention is given to evaluate the impact of drip irrigation in improving vegetable productivity in Pakistan.

Therefore, this research was undertaken to determine the response of off season vegetables to drip and furrow irrigation at farmers field level. Comparative water use efficiency and economic analysis of both irrigation systems for the off-season crops were also carried out in district Toba Tek Singh to help boost its production within the study area and other similar environments.

## Materials and methods

The studies pertaining to the comparative performance of drip irrigation systems and conventional surface irrigation in terms of crop and water productivity were carried out on off season vegetables grown under plastic tunnel at 16 sites in district Toba Tek Singh, Punjab, Pakistan for two consecutive years (2012-13 and 2013-14). District Toba Tek Singh is situated at latitude 30°57'N and longitude 30°40' 'at altitude of 826 m above the sea level. The soils of study sites range from sandy loam to clay loam with Ece 0.20-0.18 $dSm^{-1}$, pH 7.6-7.7, organic matter 0.60-0.45% and Olsen-P 2.5-4 mg $kg^{-1}$ soil. Cultural practices for off season vegetables, i.e., Capsicum, cucumber, green peppers, tomato and bitter gourd were followed as per the recommendations by the Agriculture Department Government of Punjab. Nurseries of capsicum, green peppers, tomato and bitter gourd were sown in plastic trays having a mixture of soil composite and transplanted 25 days old seedlings in double row planting geometry (Fig 1) with a plant to plant spacing of 35 cm. An experimental area at each site was 4682.313 $m^2$ with 48 numbers of beds. The 16 plastic tunnels were erected, having three beds in each tunnel covered. The distance between laterals was 1.37 m, row to row distance was 30 cm on one bed and plant to plant distance was 35 cm. The height of the tunnel was 2.134 m, width was 3.5 m and length was 60.96 m (Fig. 2).

Recommended levels of N (180 kg $acre^{-1}$), P (50 kg $acre^{-1}$) and K (50 kg $acre^{-1}$) were used as urea, triple super phosphate (TSP) and sulfate of potash (SOP), respectively under drip irrigation and fertilizer was applied as per farmers' practice under furrow irrigation. A total of 1.7 kg of urea, 0.5 kg TSP and 0.5 kg SOP $acre^{-1}$ were applied on a daily basis through fertilizer venture to each treatment, while fertilizer was broadcasted in furrow irrigation at land preparation, vegetative growth and flowering according to local farmers practice.

The plants were irrigated with the help of drip and furrow (as flood) systems as per requirement. In furrow system, irrigation was scheduled at weekly interval. Drip irrigation system at each location has a typical control unit consisted of a pump, fertilizer venture, gravel filter, disc filters, control valves, pressure gauges and a flow meter. The data of water applied through drip were recorded through water flow meters. Each treatment (zone) had one valve to control water application. The lateral lines of 16-17 mm diameter LLDPE pipes were laid along the crop rows and each lateral served two rows of the crop with emitters of flow rate 2.3-2.60 LPH spaced at 0.3-0.4 m along the drip line. The UPVC pipes of 90-160 mm diameter were used for main and 40-90 mm diameter was used for sub-main. The main line was directly connected to a 16-36 HP diesel engine installed to lift water from the source. The amount of water to be applied to each treatment was based on cumulative evaporation from class A pan. The crop water requirement of different vegetable crops was computed on a daily basis using the following formula:

$$Etc = ETO \times Kc$$

Where
ETc = crop evapotranspiration (mm $d^{-1}$)
Kc = crop coefficient
ETO = reference crop evapotranspiration (mm $d^{-1}$)

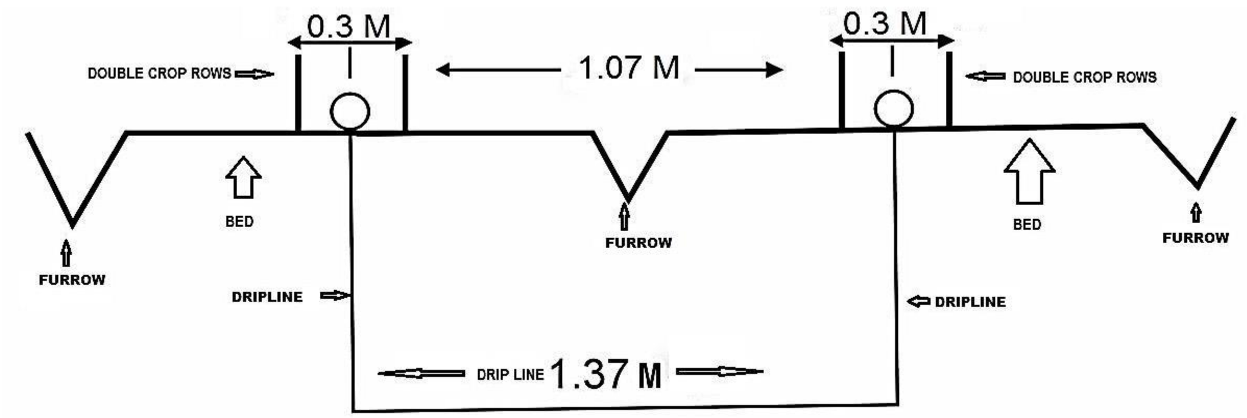


**Fig. 1** The scheme of drip irrigation system including plant to plant distance, placement of driplines and distance between driplines.

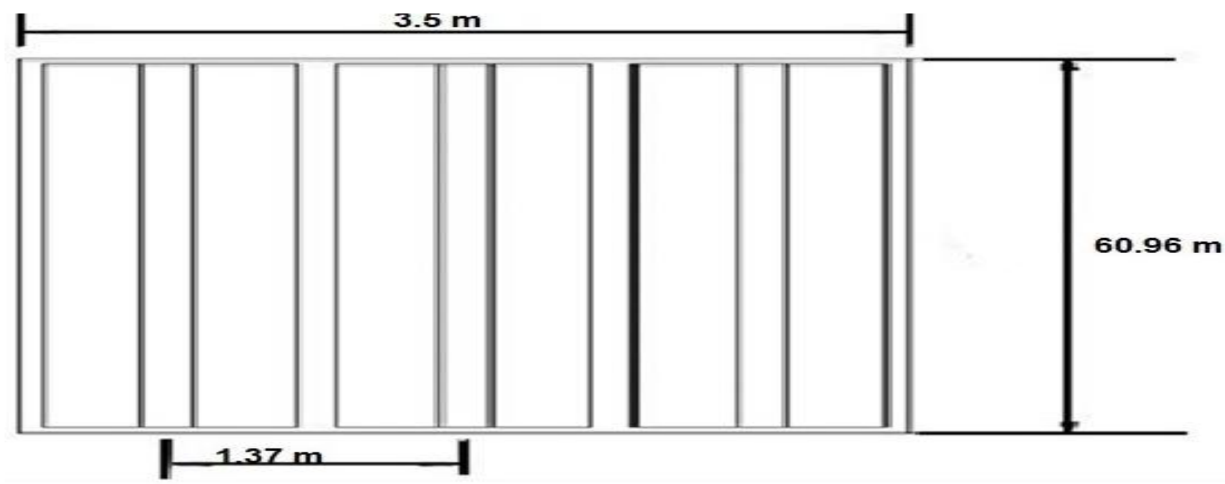


**Fig. 2** The height, width and length of tunnels used for drip irrigation system.

Daily time to operate drip irrigation system was worked out taking the peak daily consumptive use divided by application rate. Calculation assumed the soil to be at field capacity. The data of water applied in furrow were measured with cut throat flume. Data on water use, number of irrigations, water used per irrigation, and total yield were recorded for all off season vegetable crops for drip and furrow irrigation and then converted into acre basis. Benefit cost ratio (BCR) and net profit were carried out to determine the economic feasibility of the crop for drip irrigation and surface irrigation systems by the following formulas:

Net income = Crop income / seasonal total cost

BCR = Net profit / seasonal total cost

Total seasonal cost was calculated as: depreciation + cost of cultivation + cost of mulch. The cost of cultivation includes expenses incurred in the land preparation, seed, fertilizer, crop protection measures, irrigation water, transportation and other input cost.

The income from produce was calculated using prevailing average market price. Where comparison with conventional irrigation system was not available, data from adjacent farmers was collected and analyzed. After harvesting crops, water use efficiency (WUE) of each irrigation system was calculated to compare the performance of the two irrigation systems.

WUE = Total water used ($m^3$) / total yield (kg)

All the data were subjected to sample's T-Test using the Microsoft Excel program.

## Results and discussion

Production of vegetables in district Toba Tek Singh is affected adversely by water deficiency due to lack of canal water and brackish underground nature of water. *In-situ*, use of high-tech irrigation, especially drip irrigation with appropriate irrigation scheduling may boost off season vegetable production under plastic tunnels in the district. The results of this study showed that most of vegetables exhibited an indeterminate growth habit with simultaneous vegetative and reproductive growth. The lifespan of off season vegetables crops ranges between 6 and 7 months inside the plastic tunnel which is much higher than the crop grown under normal summer season (4 to 5 months). Farmers usually apply large quantities of water and heavy fertilizer doses in conventional flood irrigation system to achieve higher yield, but high humidity under plastic tunnel increased the incidence of insect, pest and diseases which often result in poor crop productivity. Drip irrigation ensured the controlled moisture and judicious supply of nutrients to plants that led to the expansion of production period which in turn, resulted in more productivity and net income.

Our results further revealed a statistically significant increase in marketable crop yield with considerable reduction in cost of production, pesticide and fertilizer use. The total amounts of irrigation water applied to each irrigation treatment during both the study years indicated that the amount of irrigation water applied per acre in furrow for capsicum (3332m$^3$), cucumber(4376 m$^3$ ), green peppers(1784 m$^3$), tomato (3168m$^3$), bitter gourd (2107 m$^3$) was much higher than that of drip. On an average, 70% more water (ranging from 30-119%) was applied to crops in furrow system compared with that through drip system (Table I).

The effectiveness of off season vegetables to use water at all growth period was described in terms of WUE and calculated as a ratio of total yield (kg) to total water consumed by the crop (m$^3$). Average water use efficiency increased by 62% for capsicum, 64% for cucumber, 58% for green papers, 53% for tomato and 52% for bitter gourd under drip irrigation system compared to furrow system (Table I). On an average, drip irrigation used about 57% of the water used by the surface irrigation systems, thus giving much higher water use efficiencies. All vegetable crops consumed less water under drip irrigation as compared to furrow irrigation system. In drip irrigation system, water is applied drop by drop only to the root zone of the plants. Thus, a large amount of water away from the root zone could be saved. Similar higher water use efficiency of drip system in combination with plastic mulch has been reported by other researchers [13, 14].

The average fruit yield was increased by 30% for capsicum, 32% for cucumber, 27% for green pepper, 26% for tomato and 6% for bitter gourd in drip irrigated plots compared to furrow irrigated plots. The results of the present investigation also revealed improved marketable yield and fruit quality in case of off season vegetables through drip irrigation. The increased fruit yield under drip irrigation might be due to better plant growth and more numbers of fruits per plant achieved by the more judicious supply of water and nutrients to the plants throughout the growing season, which also resulted in improved water and fertility management, reduced disease and weed pressure. With the drip irrigation system, irrigation takes place frequently, allowing the root zone soil moisture content to be kept at an optimal level, which enables the crop to easily capture required water and nutrients and grow healthier. In addition, the water and aeration stress cycles found with furrow irrigation are avoided, resulting in higher water and crop productivity as reported by Tagar et al. [15].

Economic analysis provides information about the economic viability of the technology based on the decision making behavior of individual farmers. Benefit cost ratios of both irrigation systems were computed by dividing benefit to the costs for each individual farmer. Benefit cost ratio(BCR) for surface irrigation was lower than for drip irrigation but the total variable cost ratio was higher in surface irrigation systems, which meant that drip irrigation systems gave higher returns per variable costs incurred. Drip system increased the yield and net seasonal income by 6-32 %, 46-59 % as compared to conventional surface irrigation with a benefit cost ratio of 1.63-2.33 for different off season vegetables. The study revealed that per acre cost of production of drip irrigation was 3-13% lower than that of furrow irrigation while the gross income received from one acre of drip irrigation was 27-35 percent higher as compared to flood irrigation. Due to lower cost of production and higher sale price, the Benefit cost ratio (BCR) was higher for drip irrigation over furrow irrigation. (Table II).The highest Benefit cost ratio (BCR) value observed for drip irrigation indicted the most profitable irrigation system in terms of net production. Having compared total costs, total production and total net production of one acre of off season vegetables, drip irrigation was observed the most profitable and useful irrigation system for the district. Similar trends have been reported in net profit, benefit cost ratio and net profit per m$^3$ of water used for capsicum [16] and for tomato crop [17].

Drip irrigation resulted in significantly higher net profit per m$^3$ of water used under drip irrigation compared to furrow irrigation system. The net profit per m$^3$ of water used was higher for all vegetables under drip irrigation with less water use while net

**Table 1** Water requirement, water use efficiency and energy cost for off season vegetables grown under drip irrigated in plastic tunnels. The data is 2 years average of 16 sites.

| Crop | Irrigation system | Number of Irrigation | Water used $m^3$/ acre | Irrigation cost ($/acre) | WUE (Kg/ $m^3$) | Net profit ($) / $m^3$ of water | Number of Pesticide used |
|---|---|---|---|---|---|---|---|
| Capsicum | Drip | 124 | 1709 | 116.69 | 30.9 | 2.89 | 14 |
| | Furrow | 20 | 3332 | 173.85 | 11.6 | 0.70 | 17 |
| Cucumber | Drip | 117 | 1994 | 135.02 | 31.3 | 3.02 | 15 |
| | Furrow | 23 | 4376 | 193.64 | 11.1 | 0.52 | 18 |
| Green pepper | Drip | 116 | 1363 | 93.90 | 31.1 | 4.28 | 8 |
| | Furrow | 14 | 1784 | 120.37 | 12.8 | 1.36 | 10 |
| Tomato | Drip | 126 | 1980 | 75.00 | 5.8 | 2.58 | 16 |
| | Furrow | 11 | 3168 | 88.00 | 2.68 | 0.79 | 18 |
| Bitter Gourd | Drip | 82 | 1471 | 66.50 | 29.6 | 2.67 | 10 |
| | Furrow | 15 | 2107 | 126.66 | 14.2 | 0.91 | 13 |

WUE = water use efficiency

**Table 2** Economic analysis of off season vegetables grown under drip and conventional furrow irrigation system. The data is 2 years average of 16 sites.

| Crop | Irrigation system | Production kg/ acre | Gross income ($/ acre) | Fertilizer cost ($/acre) | Cost of production ($/acre) | Net income ($/acre) | BCR |
|---|---|---|---|---|---|---|---|
| Capsicum | Drip | 48853 | 7319.46 | 252.38 | 2491.19 | 4629.13 | 1.95 |
| | Furrow | 33937 | 4737.14 | 583.95 | 2568.36 | 2015.51 | 0.7 |
| Cucumber | Drip | 63857 | 8015.17 | 322.81 | 3242.50 | 5042.18 | 1.63 |
| | Furrow | 43342 | 5721.07 | 678.98 | 3583.28 | 2165.93 | 0.63 |
| Green pepper | Drip | 32871 | 7600.71 | 263.92 | 2020.31 | 5481.94 | 2.33 |
| | Furrow | 23750 | 4937.50 | 520.89 | 2184.39 | 2716.23 | 0.92 |
| Tomato | Drip | 11500 | 6700.00 | 169.00 | 2041.00 | 4659.00 | 2.28 |
| | Furrow | 8500 | 4875.00 | 498.10 | 2366.10 | 2508.90 | 1.06 |
| Bitter gourd | Drip | 32000 | 5850.00 | 275.66 | 2181.50 | 3658.50 | 1.7 |
| | Furrow | 29850 | 4358.33 | 556.03 | 2530.53 | 1827.80 | 0.73 |

BCR = Benefit cost ratio

profit per $m^3$ of water was lower for all vegetables under furrow irrigation with higher water use, thus proving the beneficial effect of drip irrigation system. An average of 16 sites for two years revealed that drip irrigation system exhibited considerable saving in fertilizer use (ranging from 49-66%) over conventional flood irrigation, which might be due to fact that fertilizers were applied in drip system only to the plant root zone often to more closely match crop nutritional needs which may have minimized the fertilizer loss due to run-off and deep percolation.

A considerable reduction in pesticide use ranging from 11-19% was observed under drip irrigation system over flood irrigation (Table I). As the crop root zone is maintained at optimal soil moisture levels, root diseases are often reduced and incidence of insect, pest and disease minimized due to the controlled humidity under plastic tunnel. Drip irrigation for delivery of insecticides represents a dramatic reduction in risks to farm workers, the environment, and non-target organisms. The insecticides applied through drip systems are delivered directly to the root zone and are taken up by the crop; pesticide drift and run-off are virtually eliminated (Table 2). Similar benefits of drip irrigation over the furrow irrigation system have been reported by other researchers [18, 19].

In addition to data collection, as described above, the vegetable growers were also asked to answer the in-depth farm level survey regarding benefits of use of drip irrigation to verify the results of the above studies. Most of the benefits realized by the vegetable growers by adopting drip irrigation technology are increased crop productivity, increased cropping intensity and increased farm income. This also includes reduced cost of scarce resources, lower cost or less need for hiring labor, or less need for chemicals or irrigation water. The community or social based benefits include increased employment availability per acre of land, increased availability of employment at critical periods of the year when work is not available locally and reduced product prices. Vegetable growers (95%) told that the most important benefits of drip irrigation were improved water and fertilizer delivery efficiencies compared to surface irrigation which confirm the findings of above studies. Improved nutrient delivery with drip irrigation probably results from nutrient application timed more closely to crop demand. A total 90% of drip irrigation vegetables were fertilized by NPK which increased crop yield under plastic tunnel. Vegetable growers (85%) reported higher yield and better disease control with drip irrigation compared to the conventional furrow irrigation system. The incidence of Insect, pest and diseases were reduced with drip irrigation compared to flood under plastic tunnel.

Challenges with drip irrigation included high installation cost, emitter clogging problem, operation and maintenance issues, lack of readily available parts and expertise. Clogging problem was reported as a major challenge to successful drip irrigation by 25% vegetable growers. Drip irrigation emitters are prone to clogging with salinity or biological material [20]. Another challenge with drip irrigation system mentioned by 30% vegetable growers was over irrigation. Growers without sufficient information or training have a tendency to over irrigate in an effort to completely wet the soil in the bed. This effort usually results in water saving below the root zone. Use of tensiometer, moisture meter, site specific evapotranpiration estimate through proper research can help maximize irrigation efficiency and minimize over irrigation.

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