Research Article

# Drip Irrigated Vegetable Productivity under Tunnel in Potohar

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**Abstract** | Food security of rain-fed area is highly dependent on resource efficient practices under the current anthropogenic and climate change induced challenges in Pakistan. There is urgent need to adopt improved technologies capable of producing more with less water and to ensure continuous food supply throughout the year. For this purpose, growing off-season vegetables under plastic tunnel have elevated importance, because of comparatively less capital cost and skills requirement. Keeping in view these challenges, this study was conducted to evaluate the water and land productivity of drip irrigated off-season tomato *(Lycopersicon esculentum Mill.)* and cucumber *(Cucumis sativus)* under tunnel farming compared with traditional open-air farming method in Potohar, a rainfed area in Pakistan. The results indicated increased production potential per unit of land (46%) and per unit of water (74%) and larger farm income (3.47 BCR) than the traditional open-air farming method. These production benefits can be instrumental in improving livelihood and nutrition of remotely located rain-fed farmers in the country in general and Potohar region in particular. However, these findings may be valid for the site-specific conditions, thus needs to be evaluated for recommendations under the wide environmental conditions of rain-fed areas of the country.

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## Introduction

According to Pakistan economic survey (GOP 2017-18), agriculture accounts for around 21% of the Gross Domestic Product (GDP) and a major source of livelihood of 43.5% of rural population. Although a significant percentage of population is directly or indirectly associated with agriculture, profit margin in majority of the agricultural products is relatively low. Specifically, for vegetables, lack of sufficient storage facilities and poor processing industry results in loss of valuable vegetable produce (Akhtar, 2015). Since most of the vegetables are seasonal and market is flooded with the produce during the season, farmers have a very low profit margin in Pakistan (Rani *et al*., 2013).

Vegetables plays an important role in the local food security of Pakistan (Ahmad and Farooq, 2010). They are generally short duration crops and are mostly grown in limited areas of farms. The increasing population puts further pressure on vegetable production and cost in the country. Vegetables are very sensitive to the timely availability of required amount of irrigation water, which is difficult to achieve under the conventional irrigation methods. Similarly, weather fluctuation also poses serious threats to vegetable survival under open air conditions. Furthermore, vegetables are sensitive to planting time, thus may only be grown in certain period of time during a year. Absence of


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storage infrastructure on farms and lack of vegetable processing industry in the country, further exacerbate the importance of off-season vegetables production and associated income in Pakistan. Therefore, off-season vegetables farming can be a profitable business in Pakistan as indicated by (Tahir and Altaf, 2013). Tunnel farming can be adopted for growing off-season vegetables (Muhammad *et al*., 2015). This technology, not only reduces growth time, minimizes the risks of unfavorable weather (Cheema *et al*., 2004) but also increase farm income by delivering produce during off-season, when demand is on peak. Additionally, farmers can obtain more yield and better-quality crop, which provides good return and improves the economic conditions and nutrition of farming communities.

Tunnel farming is normally adopted for growing off-season vegetables, generally in a partially controlled environment, but can be used whole year for seasonal crops, as well. The tunnels are generally covered with transparent plastic sheet on top and black plastic sheet as mulch, during winter season (Muhammad *et al*., 2014). The sunlight passes through transparent plastic sheet and is absorbed by the black sheet spread over the soil. This raises the temperature during winter. The black plastic sheet on the soil or plastic mulch serves three purposes i.e. trap heat, reduce evaporation water loss and eliminate growth of weeds (Nasir *et al*., 2011). Temperature variations are generally managed through selection of cover sheet type, while water input can be managed through selection of irrigation methods. In tunnels, high temperature under shining sun is a challenge, which can be controlled by opening the tunnel doors, installing vents or lifting and lowering the sheets of plastic. The plastic sheet is generally replaced with green net, which reduce sun heat into the tunnel and reduce high temperature damage to vegetable during hot summer. Tunnels can extend the growth period of vegetables by four months, two in spring and two in fall.

There are many types of tunnel (Boulard *et al*., 1997) but three types (High, low and walk-in) are common in Pakistan (Table 1). The high tunnels are easy to manage (soil preparation, picking, spraying) and used for tomatoes, cucumbers, sweet peppers etc. The low tunnels are used for cucumber, melon, watermelons, bitter guard and squashes. The walk-in tunnel is medium size and are generally used for tomato, cucumber, sweet pepper, hot pepper etc.

**Table 1:** *Specification of different kinds of tunnels commonly used in Pakistan (1US$=Pak Rs 103).*

| Kind of tunnel | Height (ft) | Width (ft) | Length (ft) | Approximate cost (US$/acre) |
|---|---|---|---|---|
| High tunnel | 10(center), 6.5 (ends) | 30 | 190 | 5825 |
| Low tunnel | 3 | 5 | 190 | 291 |
| Walk in tunnel | 6 | 12 | 190 | 1165 |

Traditional irrigation methods (Basin, border, furrow) have limited control during irrigation application (Akbar *et al*., 2001), thus result in greater humidity, which make vegetables vulnerable to diseases and pests (Frey *et al*., 2020), thus are generally not recommended under tunnel farming. Efficient irrigation methods, such as drip irrigation, because of its high application efficiency and uniformity, are generally recommended under tunnel farming (Mazher *et al*., 2014). Experiments have shown maximum water saving in drip irrigation system (up to 95%) compared to surface furrow (up to 50%), solid set sprinklers (up to 80%) and portable sprinkler (up to 75%) (Smajstrla *et al*., 1988; Sanders, 2001). Hence, drip irrigation is more appropriate method of irrigation application to vegetables under tunnel farming. However, the effectiveness of drip irrigation for improving the yield and water productivity of vegetables under tunnel farming in Potohar has not been yet fully established. Therefore, this study was planned to evaluate the water and land productivity of tomato and cucumber under drip irrigated tunnels and to assess their benefit cost analysis under the local conditions of Potohar.

## Materials and Methods

*Site description*

The Potohar region stretch over around 2.2 million hectares area and covers the wet watershed features in the Rawalpindi division of Punjab province in Pakistan. This study was conducted on two sites 1: Rawal sub- watershed at Satrameel in the foot hill of Murree and 2: Mini dam command area developed at Thatti Gujran village in Tehsil Fateh Jang area. Details of the two sites and the tunnels are given in the following sections.

*Satrameel*

The Rawal watershed is stretched in the twin districts of Islamabad and Rawalpindi. The Rawal watershed feeds the Rawal Dam, which is a strategic asset and meet primarily the drinking water requirements in the twin cities of Rawalpindi and Islamabad alongside some agricultural allocations. The major issues being faced by the Rawal watershed area are urbanization, sewage discharges without treatment, active erosion, non-existence of any cooperative communal structure and livelihood issues. The sub-watershed called Satrameel is situated in the watershed of Rawal lake near Islamabad in southern part of the Margalla hills, between latitude $33^0$ 45' 90" to $33^0$ 46' 16" N and longitude $73^0$ 12' 44" to $73^0$ 12' 81" E with 625 to 723 meters elevation above mean sea level. The drainage area of the Satrameel sub-watershed is 12.64 ha. The study area falls in one of the hilly areas having deforestation problems of natural vegetation, over grazing and cutting of trees. The degraded scrub forest of Satrameel sub-watershed drains into Rawal Lake as surface runoff.

*Fateh jang*

Fathejang is a tehsil of Attock district in the Punjab province of Pakistan. The experimental site is located in village Thatti Gujran, which is located at around 70 km from Islamabad. The geographical attributes of experimental area are 33 32' 45"to 33 32' 55"N and 72 42' 5" to 72 42' 15" E latitude and longitude respectively. The total area of Thatti Gujjran field site is about 20 acres with unlevelled land surface terrain, using terraces for crop production. The annual rainfall of around 1000 mm is supplemented with irrigation water through rain water harvesting/runoff fed mini dam covering around 7 acres of land on the farm with around 35-acre ft capacity. Irrigation application is powered through a solar driven pumping system of around 6 lps discharge and 5 hp DC motor using high efficiency irrigation systems.

*Experimental trials establishment*

The tomato (Sahil – indeterminate cultivar widely used under tunnel) and cucumber (Sahar) for this study was planted in two tunnels one each at Satrameel and second at Fateh jang field stations of CEWRI, NARC Islamabad. The land preparation under tunnels commenced with 6-inch-deep cultivation followed by application of farm yard manure and then rotary hoeing. A furrow spacing of around 4 ft with bed top width of around 3 ft was constructed manually at both sites. The tomato and cucumber nursery of around 3-inch height was transplanted into the tunnels at around 2.5 ft plant to plant spacing and 2ft 10-inch row to row spacing for tomato and 2 ft 3-inch plant to plant spacing and 2.5 ft row to row spacing for cucumber. The open-air trial was conducted for tomato only at Satrameel field station, in close vicinity of the tunnel, in the same plot to avoid variability of temperature, radiant energy, soil fertility etc. The experimental plot of given size was selected and the plant to plant spacing was kept the same as inside the tunnel. Only nitrogen/Urea chemical fertilizer was used and other nutrients requirement were fulfilled using farm yard manure. The details of agronomic practices are given in Table 2.

*Data collection*

**Soil moisture content:** The soil moisture was determined gravimetrically using king tube of 2 cm internal diameter and 90 cm long. The soil samples collections were generally conducted before and after irrigation application. Wet soil samples were collected at three depths 0 -15 cm, 15- 30 cm, 30-60 cm and weighed immediately. The samples were dried in an oven for around 24 hours at 105°C and the weight of the dry samples were recorded after oven drying. The dry bulk density was calculated by dividing the dry weight by the volume of soil collected. The percent moisture content was measured using the formula given below. The volumetric moisture content was determined by multiplying the gravimetric soil moisture content, respective profile depth and bulk density.

$$\text{Gravimetric Moisture Content (\%)} = \frac{\text{weight of water}}{\text{Weight of dry sample}} \times 100$$

**Irrigation application:** The irrigation was applied using drip irrigation with dripper capacity of 8 liters/hour per plant to both tunnel and open-air tomato plants. Irrigation scheduling was based on soil moisture deficit in the range of 50% depletion of available water (155mm of water per 60 cm root zone depth), which was measured before irrigation using gravimetric method in both tunnel and open-air systems. Irrigation application was recorded in cubic meter using water meter, while the depth of irrigation was calculated by dividing the total volume applied by the land area covered by the tunnel and the area of open-air plot.

**Yield and yield components:** The plant height was determined on weekly basis. The tomato production

**Table 2:** *Details of experimental trials on tomato and cucumber under tunnels and open air at Satrameel and Fateh Jang.*

| **Object** | **Satrameel** | **FatehJang** |
|---|---|---|
| **A: Tomato 2015-16** | | |
| Sowing date | Oct 4, 2015 | Oct 4, 2015 |
| Seed variety | Sahil (Hybrid) | Sahil (Hybrid) |
| Tunnel area | 960 sq.ft (40'x24') | 1571 sq. ft (81'x19.4') |
| Number of tomato plants | 180 | 247 |
| Fertilizer | 4 dozes of urea (@750 gm) | 4 dozes of Urea (@1500 gm) |
| **B: Cucumber** | | |
| Sowing date | Sept 26, 2015 | Sept 28, 2015 |
| Seed variety | Sahar | Sahar |
| Tunnel area | 800 sq. ft (40' x 20') | 1571 sq. ft |
| Number of tomato plants | 170 | 338 |
| Fertilizer | 2 dozes of Urea (@700gm) | 2 dozes of Urea (@1500 gm) |
| **C: Tomato 2016-17** | | |
| Sowing date | Oct 6, 2016 | |
| Seed variety | Sahil (Hybrid) | |
| Tunnel area | 800 sq.ft (40'x20') | |
| Number of tomato plants | 144 | |
| Fertilizer | 4 dozes of urea (@700 gm) | |
| **D: Tomato 2017-18** | | |
| | **Tunnel-satrameel** | **Open air in satrameel** |
| Sowing date | Oct 10, 2017 | February 20, 2018 |
| Seed variety | Sahil (Hybrid) | Sahil (Hybrid) |
| Tunnel area | 800 sq.ft (40x20) | 67 ft x 2.25ft |
| Number of tomato plants | 144 | 30 |
| Fertilizer | 4 dozes of urea (@700 gm) | dozes of urea (@500 gm) |

per each of nine selected plants and total production from tunnel was separately recorded during the season. Pictorial view of tomato under tunnel is shown in Figure 1.

**Figure 1:** *Tomato under tunnel at Fateh jang.*

**Water productivity:** The water productivity (*WP*) is a generic term used for determining the physical or economic output per unit of water application (Purcell and Associates, 1999), while land productivity (LP) is the ratio between physical or economic output per unit of land area. The water productivity of tomato under tunnel was determined as the ratio between the total green weight and/or price (US$=Pak Rs 103) of tomato production during the season to the total irrigation water applied during the season as given below:

$$\text{Water Productivity} = \frac{\text{Tomato green weight or Price (US\$)}}{\text{Irrigation water Applied}}$$

The land productivity was calculated as the ratio of green weight of tomato production during the season to the land area cultivated. The land productivity is determined as given in the following expression:

$$\text{Land Productivity under tunnel} = \frac{\text{Tomato green weight or Price (US\$)}}{\text{Area of tunnel or open air}}$$



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*Benefit cost analysis*

The data for the benefit cost ratio (BCR) analysis were recorded for the year 2015-16 only for tomato and cucumber under tunnel at both sites. The cost considered for analysis was input cost of labor, fertilizers, pesticides and cultural practices. One US$ was equivalent to Pak Rs. 103, exchange rate during the experimental period. The income was calculated by considering average price of Rs 50 (US$ 0.485) per kg of cucumber and Rs 40 (US$ 0.388) per kg of tomato in both sites. The capital cost of tunnel including polythene sheet, green net, and cost of irrigation water was not considered in the calculations.

## Results and Discussion

*Soil moisture and irrigation application*

Irrigation application and soil moisture variations in root zone of tomato under tunnels at both Satrameel and Fateh jang sites during 2015-16 are summarized in Figure 2. A total of eighteen (16 mm average depth) and seventeen (17.4 mm average depth) irrigations were applied to tomato under tunnels at Satrameel and Fateh jang sites respectively during 2015-16, while thirty (10 mm average depth) and thirty-five (8 mm average depth) irrigations were applied during 2016-17 and 2017-18, respectively at Satrameel to tomato under tunnel. In contrast, a total of twenty-eight irrigations with average of around 12 mm irrigation depth were applied to open-air field during the 2018 season. Total irrigation depths applied during tomato season were 287 mm at Satrameel and 296 mm in Fateh jang during 2015-16, while at Satrameel 299 mm and 280 mm were applied during 2016-17and 2017-18, respectively. The average seasonal root zone water content remained 167 mm at Satrameel and 177 mm at Fateh jang during 2015-16, while at Satrameel the average root zone water content remained at around 173 mm during both 2016-17 and 2017-18 seasons. However, the total irrigation application was 339 mm with average root zone water content of 166 mm for the open-air treatment during the 2018 tomato season.

Irrigation application and available water in root zone (60 cm) profile of cucumber at Satrameel and Fateh jang are summarized in Figure 3 during 2015-16. A total of 73 mm and 80 mm irrigation depth were applied to cucumber at Satrameel and Fathe Jang sites respectively during five irrigation events at both sites. The average available water in the root zone (60cm) was 174 mm at Satrameel and 173 mm at Fateh jang field sites.

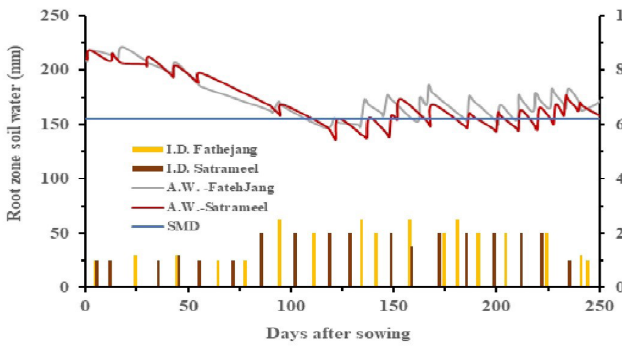


**Figure 2:** *Soil water balance with available water in 60cm root zone profile and irrigation applications to tomato under tunnels in Satrameel and Fateh jang 2015-16.*

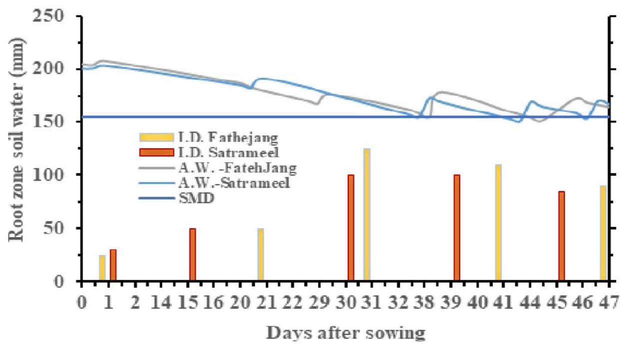


**Figure 3:** *Soil water balance with available water in 60cm root zone profile and irrigation applications to cucumber under tunnels in Satrameel and Fateh jang.*

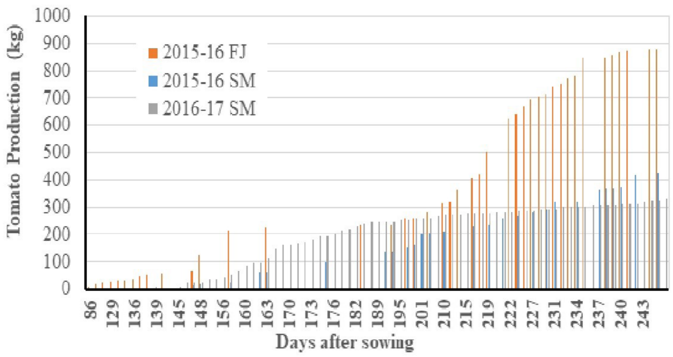


**Figure 4:** *Cumulative tomato production from two tunnels one at Satrameel (SM) during 2015-16 and 2016-17 and one at Fateh jang (FJ) during 2015-16.*

*Tomato and cucumber production*

The green weight of tomato produced from each tunnel at both sites are summarized in Figure 4. A total of 875 kg green tomato yield was harvested in 42 picking with average production of 21 kg per picking from Fateh jang. The production ranges from 4 kg to 118 kg per picking day in Fateh jang field station during 2015-16. For Satrameel site a total production of 425 kg was harvested in 29 picking days with average production of around 15 kg per picking during 2015-16 and 328 kg was harvested during 39 picking days with average production of 8 kg per picking day during 2016-17. At Satrameel the production per picking ranged from 2 kg to 42 kg during the 2015-16 season, 3 to 18 kg during 2016-17 and 4 to 17 kg during 2017-18. A total of 434 kg of tomato was produced during the 2017-18 season under the tunnel and 57 kg under the open-air field.

The green weight of cucumber produced under tunnels in Satrameel and Fateh jang during the season are summarized in Figure 5. The total cucumber produced were 175 kg and 313 kg under given tunnels sizes at Satrameel and Fateh jang sites respectively. The production was achieved during seven picking events on both sites.

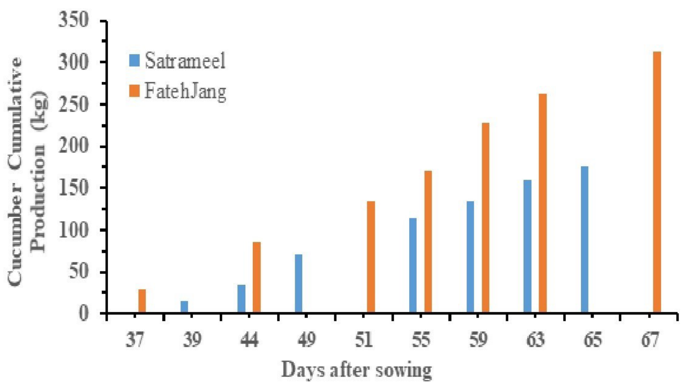


**Figure 5:** *Cucumber production from two tunnels at Satrameel and Fateh jang.*

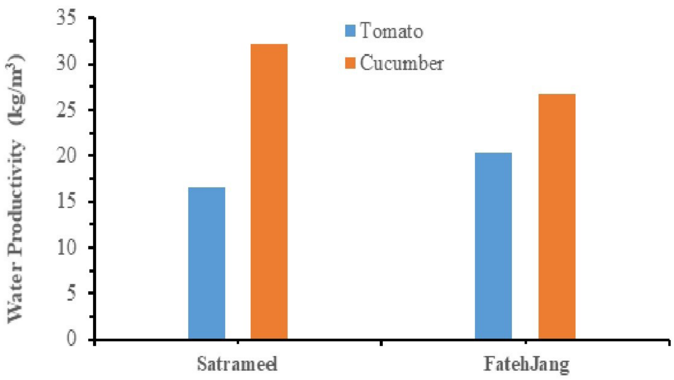


**Figure 6:** *Irrigation water productivity (kg/m³) of tomato and cucumber under two tunnels one at Satrameel and one at Fateh jang during 2015-16.*

*Water and land productivity*

The water productivity of tomato and cucumber for the year 2015-16 are summarized in Figure 6. The water productivity (WP) of tomato ranged 18 kg/m$^3$ to 21 kg/m$^3$ with average values of 17 kg/m$^3$ and 20 kg/m$^3$ for Satrameel and Fateh jang sites, respectively For cucumber the WP ranged 27 kg/m$^3$ to 32 kg/m$^3$ with average values of 32 kg/m$^3$ and 27kg/m$^3$ for Satrameel and Fateh jang sites, respectively during 2015-16. The results of water and land productivity of tomato during three seasons 2015-16, 2016-17 and 2017-18 under tunnel and during 2018 under open-air are summarized in Table 3. The results showed 74% larger water productivity and 46% larger land productivity of tomato under tunnel compared with traditional open air production system.

**Table 3:** *Water and land productivity of tomato under tunnel during three seasons 2015-16, 2016-17 and 2017-18 and under open air during 2017-18.*

| Tomato | Satrameel | | | | Fathejang |
|---|---|---|---|---|---|
| | 2015-16 | 2016-17 | 2017-18 | 2017-18 Open air | 2015-16 |
| Yield (kg) | 425 | 327.5 | 434.5 | 57 | 879 |
| Irrigation (mm) | 287 | 299 | 280 | 339 | 296 |
| WP (kg/m$^3$) | 16.6 | 14.7 | 20.9 | 12 | 20.3 |
| WP ($/m$^3$) | 6.44 | 5.70 | 8.11 | 4.66 | 7.88 |
| LP (kg/m$^2$) | 4.8 | 4.4 | 5.84 | 4 | 6.0 |
| LP ($/m$^2$) | 1.86 | 1.71 | 2.27 | 1.55 | 2.33 |

The land productivity of tomato and cucumber under tunnel is given in Figure 7 for both Satrameel and Fateh jang sites. Results showed land productivity in the range of 4.5 to 6 kg/m$^2$ for tomato and 2.1 to 2.4 kg/m$^2$ for Cucumber.

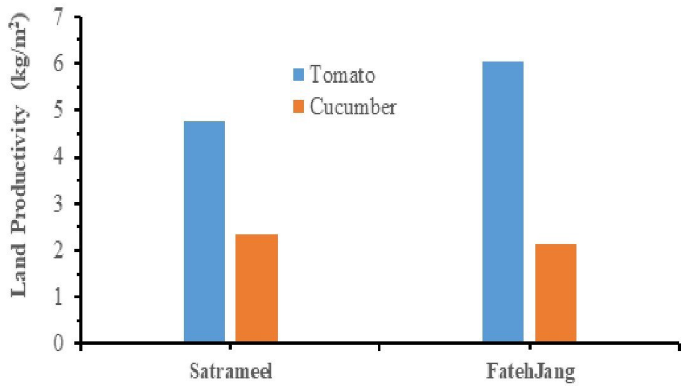


**Figure 7:** *Land productivity of tomato and cucumber under tunnel at Satrameel and Fateh jang during 2015-16 season.*

*Benefit cost analysis*

The benefit cost analysis of tomato and cucumber under tunnels at Satrameel and Fathejang are summarized in Figure 8 for the year 2015-16 only. The results showed benefit cost ratio (BCR) of 2.09 and 3.47 for tomato and cucumber respectively at Fateh jang site. The BCR of 1.83 and 4.83 was identified for tomato and cucumber respectively at Satrameel site.

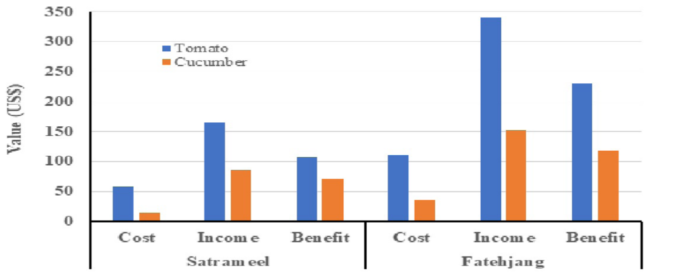


**Figure 8:** *Benefit cost analysis of cucumber and tomato under tunnels of given sizes at Satrameel and Fateh jang field stations during 2015-16.*

The irrigation applications to tomato under tunnel ranged 280 to 299 mm, which is below the average water need of tomato in this locality but the 339 mm irrigation applications under open air field conform to the finding of (Khokhar, 2013), who reported around 20 mm per week in cool and 70 mm per week during warm months. The reduced (21% less water than open-air system) water application may be attributed to the efficient use of limited water with drip irrigation and controlling the evaporation losses with surface mulching, which agrees with the findings of several relevant studies (Berihun, 2011; Panigrahi *et al*., 2019). The irrigation water applied using drip irrigation was mainly utilized in fulfilling the transpiration needs of tomato and cucumber, because the contribution by evaporation and deep drainage losses was negligible, as mentioned by Nasir *et al*. (2011) under drip irrigated plastic mulching.

The tomato production under tunnel ranged 44 to 60 ton/ha, which is up to six time larger than the country average reported by (Khokhar, 2013) and 46% larger, when compared with the open-air production under the current study. These results conform with the findings of Malik *et al*. (2018), Biswas *et al*. (2015) and Hussain *et al*. (2001), who reported land productivity of up to 41.45 ton/ha in research farm and up to 161 ton/ha for tomato under tunnel/hydroponic system. The reason for the larger productivity under tunnel farming may be attributed to better maintenance of the land fertility, controlled temperature up to certain extent during unfavorable weather and humidity control, protection from wild animals, diseases and insects and better water conservation, as mentioned by Muhammad *et al*. (2015). Similarly, the efficient irrigation application using drip irrigation helped in controlling the fertility losses due to excessive deep drainage and leaching of nutrients, generally experienced under the traditional surface irrigated open-air cultivation system (Vázquez *et al*., 2006; Zotarelli *et al*., 2009). All these factors helped in increasing the tomato and cucumber production and reducing the irrigation water input.

The water productivity of vegetables under tunnel is significantly larger than the traditional farmer managed vegetable production methods in surrounding areas, when compared with the data reported by Rabnawaz *et al*. (2015). The reason might be attributed to larger yield (44 to 58 ton/ha) than the farmer managed average yield (17.1 ton/ha) and the reduced irrigation application with drip irrigation, which has been shown with irrigation application efficiencies above 90% (Sanders, 2001; Wu and Gitlin, 1983; Denis *et al*., 2018). The larger (46%) yield and reduced (21%) irrigation applications resulted increased (74%) water productivity of tomato under tunnel farming than the open-air production.

The maximum benefit cost ratio (BCR) of tomato (2.09) and cucumber (4.83) under the current study indicates higher income on investment, which is larger than the farmer managed values of tomato (2.52) in Punjab (Ali *et al*., 2017) and cucumber (1.29) in Nowshera (Ishaq *et al*., 2003), closer areas. The reasons might be attributed to the lower input cost and greater production from the tunnel farming than the traditional open-air vegetable production system. Other reason of higher income may be the reasonably higher profit margins by selling the perishable produce (tomato and cucumber) at the time when market is not flooded with seasonal vegetables (Mazhar *et al*., 2019).

Vegetables are important for balanced daily diet, as they are good source of vitamins, proteins, nutrients and carbohydrates (Hussain *et al*., 2011). Traditional vegetable production is poor, while raising off-season vegetables in tunnel is a recent phenomenon in Pakistan, thus there is lack of expertise, materials and management skills in the country (Fatima *et al*., 2020) and awareness issue (Rizvi *et al*., 2020). The current study on tomato and cucumber has indicated better quantity and quality vegetable production with reduced land and water use, thus indicated greater prospects for future development in the Potohar region. The current study has indicated increased benefits of tunnel farming for producing off-season vegetables than to traditional open-air production. However, the study did not consider many environmental factors, thus may be valid for the site-specific environmental conditions, thus detailed studies needs to be conducted to identify further potential of tunnel farming under the wide environmental conditions of the country.

## Conclusions and Recommendations

- Tomato and cucumber can be successfully grown under drip irrigated tunnels in Potohar and have the potential to improve farm profitability under water limited conditions;
- Water productivity of 14 to 20 kg/m$^3$ and land productivity of 4 to 6 kg/m$^2$ can be instrumental in saving water and increasing farm production for self-consumption or marketing;
- Net benefit of up to RS 24000 (US$233) per tunnel during Tomato season and up to RS 12000 (US$117) per tunnel during Cucumber season can be helpful in improving livelihood and nutrition of farming community;
- Drip irrigated tomato under tunnel can increase 74% and 46% water productivity and land productivity, respectively than traditional tomato growing under open-air irrigation, thus can be instrumental in producing more from less water and limited land.

## Novelty Statement

As far as the authors are aware, there is no similar research work carried out related to identifying the land and water productivity and profitability of vegetables (tomato and cucumber) under tunnel in Potohar using drip irrigation in comparison to open air conventional vegetable farming.

## Author's Contribution

**Ghani Akbar**: Conceived the idea, conducted literature review, synthesized the data, wrote the paper and presented the results, discussions and conclusions.
**Muhammad Asif**: Supported in literature review, data collection and data compilation
**Zafar Islam**: Supported in field experimentation and data collection

*Conflict of interest*
The authors have declared no conflict of interest.

## References

Ahmad, M. and U. Farooq. 2010. The state of food security in Pakistan: Future challenges and coping strategies. Pak. Dev. Rev., pp. 903-923. https://doi.org/10.30541/v49i4IIpp.903-923

Akbar, G., M. Yasin, S. Ahmad, M. Ahmad and M. Ashraf. 2001. Comparative performance of sprinkle and surface irrigation methods. Sarhad J. Agric. (Pakistan), 17(4): 601-608.

Akhtar, S., 2015. Food safety challenges, a Pakistan's perspective. Critical reviews in food science and nutrition. 55(2): 219-226. https://doi.org/10.1080/10408398.2011.650801

Ali, Q., M. Ashfaq and M. Khan. 2017. An economic analysis of off-season tomato production in Punjab. J. Anim. Plant Sci., 27(1): 294-301.

Berihun, B., 2011. Effect of mulching and amount of water on the yield of tomato under drip irrigation. J. Hortic. For., 3(7): 200-206.

Biswas, S., A. Akanda, M. Rahman and M. Hossain. 2015. Effect of drip irrigation and mulching on yield, water-use efficiency and economics of tomato. Plant Soil Environ., 61(3): 97-102. https://doi.org/10.17221/804/2014-PSE

Boulard, T., P. Feuilloley and C. Kittas. 1997. Natural ventilation performance of six greenhouse and tunnel types. J. Agric. Eng. Res., 67(4): 249-266. https://doi.org/10.1006/jaer.1997.0167

Cheema, D., P. Kaur and S. Kaur. 2004. Off-season cultivation of tomato under net house conditions. ISHS. Acta Hortic., 659: 177-181. https://doi.org/10.17660/ActaHortic.2004.659.21

Denis, B., F. Watanbbe, S. Suzuki and S. Kuga. 2018. Optimal water use on low pressure drip irrigation system for tomato cultivation in Uganda. J. Arid Land Stud., 28(S): 77-80.

Fatima, H., L.K. Almas and S. Haroon. 2020. Comparative water efficiency analysis of sole and multiple cropping systems under tunnel farming in Punjab-Pakistan. J. Water Resour. Prot., 12(06): 455. https://doi.org/10.4236/jwarp.2020.126027

Frey, C.J., X. Zhao, J.K. Brecht, D.M. Huff and Z.E. Black. 2020. High tunnel and grafting effects on organic tomato plant disease severity and root-knot nematode infestation in a subtropical climate with sandy soils. Hortic. Sci., 55(1): 46-54. https://doi.org/10.21273/HORTSCI14166-19

GOP, 2017-18. Agricultural Statistics of Pakistan, Pakistan Bureau of Statistics, Agricultural Statistics Division.

Hussain, J., N. Rehman, A. Al-Harrasi, L. Ali, R. Ullah, F. Mabood, H. Hussain and M. Ismail. 2011. Nutritional prospects and mineral compositions of selected vegetables from Dhoda Sharif Kohat. J. Med. Plants Res., 5(29): 6509-6514. https://doi.org/10.5897/JMPR11.478

Hussain, S.I., K.M. Khokhar, T. Mahmood, M.H. Laghari, M.M. Mahmud, H.V. Crops, I. NARC and N. HRI. 2001. Yield potential of some exotic and local tomato cultivars grown for summer production. Pak. J. Biol. Sci., 4(10): 1215-1216. https://doi.org/10.3923/pjbs.2001.1215.1216

Ishaq, M., G. Sadiq and S.H. Saddozai. 2003. An estimation of cost and profit functions for offseason cucumber produce in district Nowshera. Sarhad J. Agric., 19(1): 155-162.

Khokhar, K.M., 2013. Present status and prospects of tomatoes in Pakistan.

Malik, A.M., K. Mughal, S. Mian and M. Khan. 2018. Hydroponic tomato production and productivity improvement in Pakistan. Pak. J. Agric. Res., 31(2): 133-144. https://doi.org/10.17582/journal.pjar/2018/31.2.133.144

Mazhar, M.S., B.E. Bajwa, G. McEvilly, G. Palaniappan and M.R. Kazmi. 2019. Improving vegetable value chains in Pakistan for sustainable livelihoods of farming communities. J. Environ. Agric. Sci., 18: 1-9.

Mazher, I., S. Fayyaz-ul-Hassan, H. Tamoor, N. Aadal, M. Azeem and T. Muhammad. 2014. Evaluation of comparative water use efficiency of furrow and drip irrigation systems for off-season vegetables under plastic tunnel. Int. J. Agric. Crop Sci., 7(4): 185-190.

Muhammad, S., A. Saghir, I. Ashraf, K. Asghar and R. Kousar. 2015. An impact assessment of tunnel technology transfer project in Punjab, Pakistan. World Appl. Sci. J., 33(1): 33.

Muhammad, S., A. Saghir, I. Ashraf, K.A. Awan and M. Alvi. 2014. Factors affecting the training of vegetable growers about tunnel farming under Fruit and Vegetable Development Project (F and VDP) Punjab, Pakistan. Indian J. Agric. Res., 48(1). https://doi.org/10.5958/j.0976-058X.48.1.007

Nasir, M., A. Moazzam and A. Shahbaz. 2011. Effect of mulching on vegetables production in tunnel farming. Mycopath, 9(1): 21-24.

Panigrahi, B., D. Paramjita and J. Paul. 2019. Impact of drip and furrow irrigation on tomato yield under mulch and non-mulch conditions. Int. J. Commun. Syst., 7(5): 3202-3207.

Purcell, B. and Associates. 1999. Determining a framework, terms and definitions for water use efficiency in irrigation, Land and Water Resources Research and Development Corporation, Narrabri, NSW. pp. 26

Rabnawaz, M., T.S. Khan and M. Khan. 2015. Comparative study of crop water productivity at farm level under public and civil canal irrigation systems in Peshawar, Pakistan. Sarhad J. Agric., 31(3): 175-182. https://doi.org/10.17582/journal.sja/2015/31.3.175.182

Rani, S., M.A. Khan, H. Shah and A.S. Anjum. 2013. Profitability analysis of organic cauliflower, radish and turnip produce at National Agriculture Research Centre, Islamabad, Pakistan. Asian J. Agric. Rural Dev., 3(12): 929.

Rizvi, S.A.A., M. Asim and S. Manzoor. 2020. Issues, Challenges, and Scope of Supply Chain Management in Fruits and Vegetables in Pakistan. IEEE-SEM, 8(1): 20-30.

Sanders, D.C., 2001. Using plastic mulches and drip irrigation for vegetable production. Using plastic mulches and drip irrigation for vegetable production.

Smajstrla, A., B. Boman, G. Clark, D. Haman, D. Harrison, F. Izuno and F. Zazueta. 1988. Efficiencies of Florida agricultural irrigation systems: Gainesville, University of Florida, Institute of Food and Agricultural Sciences. Bulletin, 247: 15.

Tahir, A. and Z. Altaf. 2013. Determinants of income from vegetables production: A comparative study of normal and off-season vegetables in Abbottabad. Pak. J. Agric. Res., 26(1).

Vázquez, N., A. Pardo, M. Suso and M. Quemada. 2006. Drainage and nitrate leaching under processing tomato growth with drip irrigation and plastic mulching. Agric. Ecosyst. Environ., 112(4): 313-323. https://doi.org/10.1016/j.agee.2005.07.009

Wu, I. and H.M. Gitlin. 1983. Drip irrigation application efficiency and schedules. Trans. ASAE, 26(1): 92-0099. https://doi.org/10.13031/2013.34180

Zotarelli, L., M.D. Dukes, J. Scholberg, R. Munoz-Carpena and J. Icerman. 2009. Tomato nitrogen accumulation and fertilizer use efficiency on a sandy soil, as affected by nitrogen rate and irrigation scheduling. Agric. Water Manage., 96(8): 1247-1258. https://doi.org/10.1016/j.agwat.2009.03.019