IRRIGATION AND DRAINAGE
Irrig. and Drain. **62**: 330–339 (2013)
Published online 5 May 2013 in Wiley Online Library (wileyonlinelibrary.com) **DOI**: 10.1002/ird.1734

IMPROVING WATER PRODUCTIVITY THROUGH MICRO-IRRIGATION IN ARID PUNJAB REGIONS[†]

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ABSTRACT

Inadequate water supply in a canal command area is a major limiting factor for sustainable crop production, as well as for adoption of crop diversification options. Shifting from conventional (surface) irrigation to micro-irrigation in conjunction with an auxiliary reservoir is a possible alternative for managing irrigation water shortages. The auxiliary reservoir provides a reliable water supply for the micro-irrigation system during the period when the canal system is not operational. To study the techno-economic feasibility of a proposed technological package, an auxiliary reservoir of 1500 m^3 capacity was constructed at the Research Farm of Central Institute of Post Harvest Engineering and Technology, Abohar, India, which received a canal supply from an outlet of the Panjawa minor of the Abohar distributory of the Sirhind canal system. Drip irrigation was used to irrigate *kinnow* (*Citrus reticulata* Blanco.), guava (*Psidium guajava* L.), pomegranate (*Punica granatum* L.), tomato (*Lycopersicum esculentum* L.) and capsicum (*Capsicum annuum* L.). Drip and micro-sprinkler both were used for potato (*Solanum tuberosum* L.) and onion (*Allium cepa* L.). These crops were also grown with surface irrigation methods (border or furrow depending upon the crop) as control. Results of the study indicated that the interventions were able to save a substantial amount of irrigation water (3–46%) compared to surface methods, along with higher yields, a doubling of water productivity and more profits per mm of irrigation water. The study clearly showed that micro-irrigation in conjunction with an auxiliary reservoir should be recommended in canal-irrigated commands in order to improve water productivity and farmers' income in arid regions of Punjab. Copyright © 2013 John Wiley & Sons, Ltd.

KEY WORDS: micro-irrigation; auxiliary reservoir; water productivity: economics

Received 16 January 2012; Revised 4 January 2013; Accepted 4 January 2013

RÉSUMÉ

L'insuffisance de l'approvisionnement en eau d'un canal est un facteur limitant majeur pour la durabilité de la production agricole, ainsi que pour l'adoption des options de diversification des cultures. Le passage de l'irrigation conventionnelle à la micro-irrigation associée à un réservoir auxiliaire est une alternative possible pour gérer les pénuries d'eau d'irrigation. Le réservoir auxiliaire fournit un approvisionnement fiable en eau pour le système de micro-irrigation pendant la période où le système du canal n'est pas opérationnel. Pour étudier la faisabilité technico-économique du paquet technologique, un réservoir auxiliaire d'une capacité de 1500 m^3 a été construit à la ferme de recherche de l'Institut central de l'ingénierie et de la technologie post-récolte, à Abohar, en Inde, qui reçoit l'eau de la prise de Panjawa mineure, sur le système de canaux de Sirhind. L'irrigation goutte à goutte a été utilisée pour irriguer du Kinnow (*Citrus reticulata* Blanco.), du goyavier (*Psidium guajava* L.), du grenadier (*Punica granatum* L.), de la tomate (*Lycopersicum esculentum* L.) et du poivron (*Capsicum annuum* L.). Le goutte à goutte et la micro aspersion ont été utilisés à la fois pour la pomme de terre (*Solanum tuberosum* L.) et l'oignon (*Allium cepa* L.). Ces cultures ont également été produites avec des méthodes d'irrigation de surface (en planches ou en billons en fonction des cultures) comme témoin. Les résultats de l'étude indiquent quelles interventions ont pu sauver des quantités appréciables d'eau d'irrigation

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[†] Améliorer la productivité de l'eau par la micro-irrigation dans les régions arides du Punjab.

(3–46%)par rapport aux méthodes de surface, ainsi que des rendements plus élevés, le doublement de la productivité de l'eau et plus de profits par mm d'eau d'irrigation. L'étude a clairement montré que la micro-irrigation associée à un réservoir auxiliaire peut être recommandée dans les systèmes d'irrigation pour améliorer la productivité de l'eau et le revenu des agriculteurs dans les régions arides du Punjab. Copyright © 2013 John Wiley & Sons, Ltd.

MOTS CLÉS: micro-irrigation; réservoir auxiliaire; productivité de l'eau; économie

INTRODUCTION

Food grains, pulses, fruits, and vegetables have to be produced from limited land and declining water resources to meet the food and nutritional security of the ever-increasing population of the world. The government of India has created irrigation potential to harness the yield potential of dry regions by providing canal networks. However, the water supply is irregular, inadequate, and inequitable in the area irrigated by the canal (canal command). The situation is worst at the downstream end of the canal command and yield potential is adversely affected. The yield variations of rice and wheat were found to be 10–40% between the upstream and downstream ends of watercourses (Tyagi *et al.*, 2005). The overall efficiency of canal irrigation systems worldwide is very low. This deficiency has resulted in poor utilization of irrigation potential, created at huge cost. The average overall project efficiency of several canal irrigation projects has been estimated at 23–40% (Walters and Bos, 1989). Navalwala (1991) reported that 71% of irrigation water is lost in the conveyance from source head to the actual field. The wastage of water during conveyance and application ultimately results in delivery of only 30–35% of stored water for plant uptake (Anbumozhi *et al.*, 2001). Kumar *et al.* (2009) found that integration of rainwater harvesting and gravity-fed micro-irrigation systems is an effective method of water management for growing vegetables. Srivastava *et al.* (2010) observed that irrigation efficiency can be increased up to 95% by replacing the irrigation method from conventional (border or furrow) to pressurized irrigation. Micro-irrigation has wide adaptability in semi-arid and arid regions where water supply remains limited (Cetin *et al.*, 2004; Singh *et al.*, 2001, 2007). However, a regular water supply is a prerequisite to get maximum benefit from a micro-irrigation system. Hence, an auxiliary reservoir becomes an important component in planning of micro-irrigation systems especially when canal water supply is intermittent. An auxiliary reservoir is a storage structure (pond/tank) constructed in the canal irrigated area allowing farmers to store precious canal water and use it more judiciously through micro-irrigation for crop production (Kumar *et al.*, 2008; Srivastava *et al.*, 2010). Sometimes, during a lean period (a period with low demand for canal water) or in the rainy season when canal water is not required for irrigation of crops, it can be easily stored in an auxiliary reservoir for use during critical periods through the micro-irrigation system (Kumar *et al.*, 2008; Kumar and Singh, 2010; Singh *et al.*, 2010).

The south-west region of Punjab falls in the arid zone of the country and groundwater is saline and not fit for irrigation. The region is traditionally known as a cotton-growing area. Farming in this region is completely dependent on the canal water supply. Canal water availability is considered the major limiting factor for crop production and diversification in the irrigation commands. To assess the feasibility of an auxiliary reservoir in conjunction with micro-irrigation in the canal command area and to explore the possibility of crop diversification options, particularly with vegetables and fruit crops in view of problems in cotton cultivation in the area, the Central Institute of Post Harvest Engineering and Technology (CIPHET), Abohar, constructed an auxiliary reservoir and conducted experimental studies with micro-irrigation for different crops. This paper discusses details of the design and construction of an auxiliary reservoir, design of a micro-irrigation system, water productivity and economic feasibility analysis for different vegetable and fruit crops. Results of the study would be useful to promote crop diversification in canal commands of semi-arid and arid regions.

MATERIALS AND METHODS

Experimental site

The experiment was conducted at the research farm of the Central Institute of Post Harvest Engineering and Technology (CIPHET), Abohar, Punjab, India (Figure 1).The soil at the experimental site was sandy loam. The pH of soil ranged from 7.8 to 8.5. The groundwater in the region was saline in nature with electrical conductivity ranging from 4.6 to 14.5 dS m^{-1}. The pH of groundwater was around 8.5. The Abohar region falls in an arid region having an average annual rainfall of 269 mm and reference crop evapotranspiration of 1140 mm (Figure 2). The annual reference crop evapotranspiration was estimated using pan evaporation and pan factor (K_p) values (Doorenbos and Pruitt, 1977).

Approximately 70% of the total annual rainfall is received during July, August, and September. There is a dry period from October to June. These rainfall patterns indicate that the region had no seasonal water surplus and there is a need to use available limited canal water more judiciously. Mean

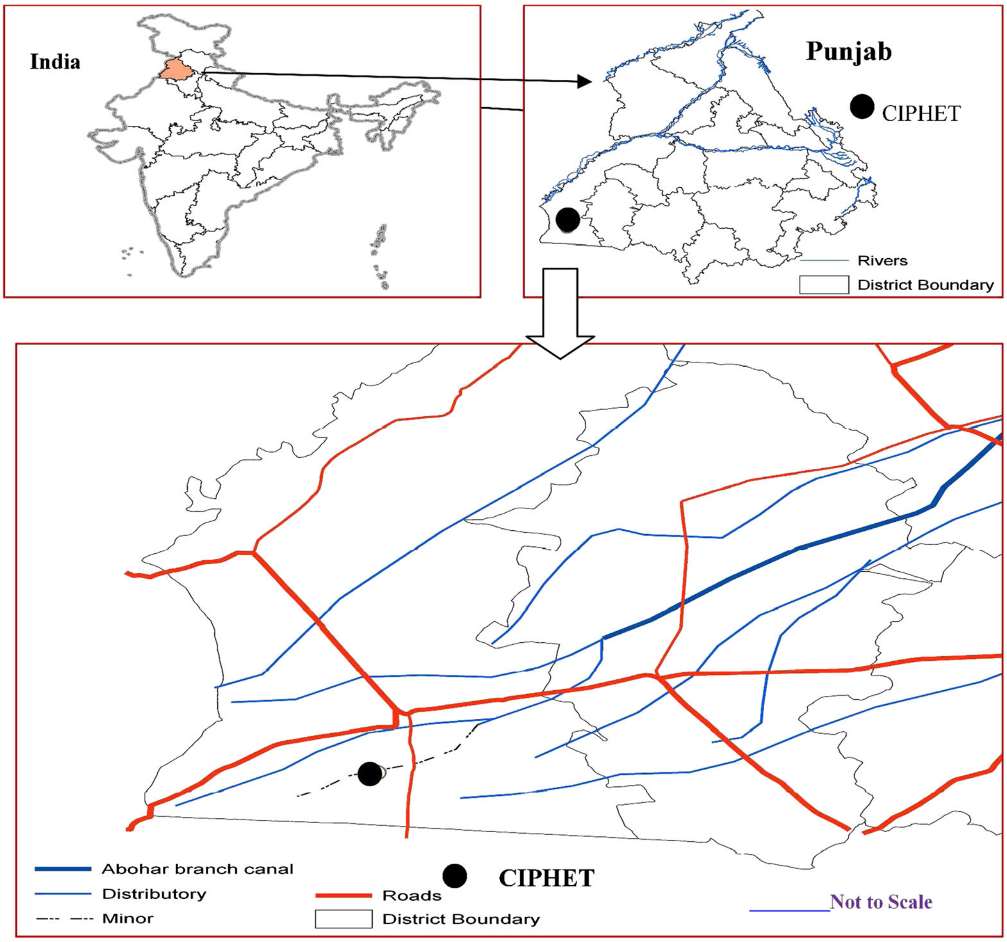

Figure 1. Location map of the study area. This figure is available in colour online at wileyonlinelibrary.com/journal/ird

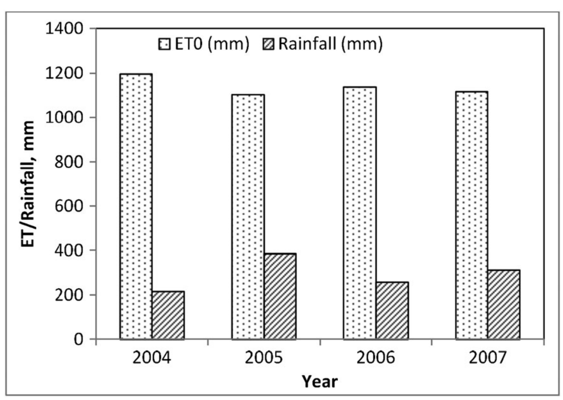

Figure 2. Annual rainfall and reference evapotranspiration for Abohar

monthly temperature, for the nine dry months, remains greater than 20 ^{0}C. Mean maximum and minimum temperature during the winter season (December to February) are 21.3 and 7.8 ^{0}C, respectively. The mean maximum and minimum temperature during summer (April to June) are 43.2 and 21.6 ^{0}C. The daily pan evaporation during the summer season varied between 10 and 12 mm.

Design and construction of service reservoir

Regular water supply is a prerequisite to derive maximum benefit from a micro-irrigation system. The research farm at CIPHET, Abohar, gets canal water from an outlet of the Panjawa minor of the Abohar distributor, which is a part of the Sirhind canal system (Figure 1). Since the canal water supply in the command is not regular or adequate, an auxiliary reservoir (dugout pond) of 1500 m^3 capacity was constructed and lined with LDPE film (agri-film) of 250-micron thickness to eliminate seepage losses. The reservoir obtained water from the adjacent canal and was subsequently supplied to the micro-irrigation system.

Though farmers get canal water supply once a week, the capacity of the reservoir was estimated on 2-week supply based upon crop water requirements. The same capacity was utilized for the purposes of estimation of cost of the auxiliary reservoir for economic analysis.

Installation of micro-irrigation systems for selected crops

Vegetables and fruit crops were considered for growing with micro-irrigation in place of the traditional cotton crop under possible crop diversification option.Selected vegetable crops were onion (*Allium cepa* L.), potato (*Solanum tuberosum* L.), tomato (*Lycopersicum esculentum* L.) and capsicum (*Capsicum annuum* L.); and fruit crops were pomegranate (*Punica granatum* L.), guava (*Psidium guajava* L.), and *kinnow* (*Citrus reticulata* Blanco.). Drip was planned for tomato, capsicum, and other selected fruit crops. Since potato and onion are closely spaced crops and do not flower, therefore, a micro-sprinkler system was also used along with the drip system. Performance of drip and micro sprinkler (MS) methods was compared with the surface irrigation method, i.e. furrow method in potato and border method for the rest of the crops. Irrigation interval for micro-sprinkler and drip was 2–3 days, while it was 6–10 days for the surface irrigation method. A minimum 4–5 cm depth of water was required to cover the entire plot using the surface irrigation method.

Layouts of the micro-sprinkler system for onion and potato crops were prepared, considering source of irrigation, slope, and shape of field. The field was divided into two parts with a sub-main of 90 mm diameter at the centre of the field and laterals of 16 mm diameter on the both sides of sub-main. The spacing between two micro-sprinklers for onion and potato was 3 m. Spacing for inline drip laterals was 0.9, 0.6, 0.8 and 0.5 m for tomato, potato, onion, and capsicum, respectively. Emitters were placed at a distance of 0.5 m for both crops. Crop geometry of potato, onion, tomato, and capsicum was 60×10, 15×10, 90×50 and 50×50 cm, respectively (Figure 3).

For pomegranate, guava and *kinnow*, the sub-main passed through the centre of the field and laterals of 16 mm were laid out on both sides of the sub-main along the row of fruit trees. Four emitters, each of 4 l h^{-1} discharge, were fixed around the tree stem in a circular loop, made of 12 mm lateral pipe, to maintain the emitters equidistant from each other. Plant to plant spacing of pomegranate, guava, and *kinnow* was 3.5×3.5, 6×6 and 6.5×6.5 m, respectively. A drip system was installed in a 1-year-old plantation of pomegranate and guava and in 3-year-old *kinnow*.

Irrigation scheduling of different crops in case of micro-irrigation

Irrigation scheduling of different crops was done on the basis of previous day pan evaporation data. Reference crop evapotranspiration was calculated using the FAO-24 pan evaporation method (Doorenbos and Pruit, 1977). The crop coefficient (K_c) for different growth stages of vegetable crops were considered on the basis of studies by Rajput and Patel (2001) in the northern part of India. The actual evapotranspiration was estimated by multiplying reference evapotranspiration and crop coefficients for different months based on growth stages. The daily net irrigation water requirement of different vegetable crops for drip irrigation system was estimated using the following relationship (Tiwari and Reddy, 1997):

$$V = (E_0.K_c.A) - (A.R_e) \tag{1}$$

where V is net irrigation water requirement on a volumetric basis (litre day^{-1} $plant^{-1}$); E_0 is reference crop evapotranspiration (mm day^{-1}), which was estimated as E_0 equal to pan evaporation (E_p) multiplied by pan factor (K_p); K_c is crop factor; A is area to be irrigated, m^2 (i.e. spacing between rows multiplied by spacing between plants); and R_e is effective rainfall (mm day^{-1}). Pan factor (K_p) for calculating reference crop evapotranspiration was adopted on the basis of Doorenbos and Pruit (1977), considering prevailing local conditions. For the drip system, the estimated amount of irrigation water was applied on alternate days during the hot summer (April, May, and June) and semi-weekly during the remaining part of the year. The same schedule was followed for the micro-sprinkler system.

For fruit crops, net water requirement on a volumetric basis for drip irrigation was estimated by using the following equation, where canopy coverage of the plant was considered:

$$V = (E_0.K_c.C_c.A) - (C_c.A.R_e) \tag{2}$$

where C_c is the canopy factor and the other parameters are the same as mentioned above. The C_c, for estimation of the crop water requirement, was taken as per Allen *et al*. (1998). Similarly, K_c for estimating the actual crop water demand for different fruit crops were considered on the basis of Allen *et al*. (1998); Rajput and Patel (2001) and Pandey *et al*. (2003). Irrigation was applied semi-weekly during April, May, and June and weekly during the remainder of the year to meet the water requirement as estimated by Equation (2).

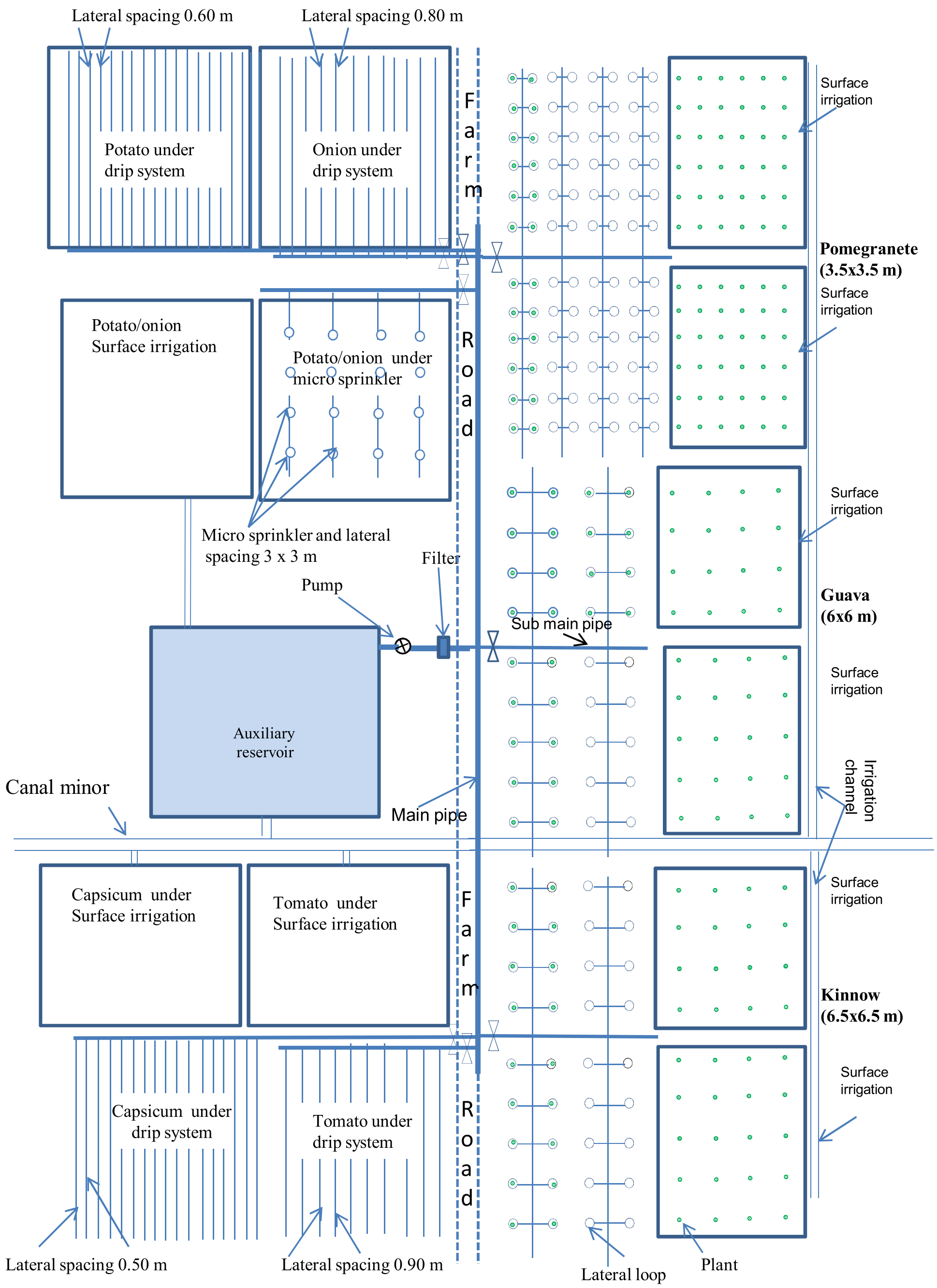

Figure 3. Layout of the experiments (not to scale). This figure is available in colour online at wileyonlinelibrary.com/journal/ird

Estimation of water productivity

Water productivity (WP) was estimated to assess the production per unit volume of water applied using the following relationship:

$$\text{Water productivity}\left(\text{kgm}^{-3}\right) = \frac{\text{Crop yield }\left(\text{kgha}^{-1}\right)}{\text{Irrigation water applied }\left(\text{m}^3\text{ha}^{-1}\right)} \tag{3}$$

Economic evaluation

Production cost, gross return, and net return of produce for different irrigation systems were estimated with the assumption that the salvage value of the different components of irrigation systems will be zero after their useful life. The useful life of the motor and sand filter was assumed as 12 yr, 20 yr for the storage water tank, and 8 yr for all other components of the irrigation system. The annual fixed costs of different components used for water storage, pumping, and irrigation systems were calculated using the approach of James and Lee (1971) as given below:

$$\mathrm{CRF} = \frac{i(1+i)^n}{(1+i)^n - 1} \quad (4)$$

where CRF = capital recovery factor, i = interest rate (fraction) at 9%, n = useful life of the component (yr). Annual fixed cost ha^{-1} was estimated by multiplying CRF by fixed cost ha^{-1}.

The operating cost included labour charges (system installation and agronomic practices such as land preparation, irrigation, planting, hoeing, application of fertilizers and chemicals, harvesting, etc.) land rent, fertilizers and chemicals, electricity charges, repair and maintenance. The gross return was calculated considering the produce yield and current wholesale price. Subsequently, the net return and benefit–cost ratio, and payback period were calculated considering the total cost of production (fixed and operating) and gross return. The payback period of this technological package was estimated as the number of years by which the net return equalled the establishment cost of the drip system in conjunction with service. Additional income was estimated as income from the drip system minus the income from the conventional system, which included income from the additional area cultivated with water saved by the drip system, as well as increase in yield as a result of adoption of the technology.

RESULTS AND DISCUSSION

Irrigation, yield, water productivity and economics for potato crop

The detailed results related to the techno-economic feasibility of an auxiliary reservoir along with the micro-irrigation system with reference to a potato crop are given in Table I. Results of the study revealed that approximately 24.6, 22.5, and 28.2 cm of irrigation water was applied to potato using micro-sprinkler, drip, and surface irrigation regimes, respectively, during the entire crop growing period. The potato yield was recorded as 32.2, 29.8, and 22.6 t ha^{-1}, respectively, for micro-sprinkler, drip, and surface irrigation methods. Cultivation of potato on an area of 1.13 and 1.20 ha was possible using the micro-sprinkler and drip system with the same amount of irrigation required for 1 ha crop using the regional standard irrigation practices. Water productivity value was recorded to be 12.5, 13.3, and 8.0 kg/m^3 for micro-sprinkler, drip, and surface method, respectively. Economic analysis of potato production with micro-sprinkler, drip, and surface irrigation methods is also presented in Table I. The cost of introducing micro-sprinkler and drip irrigation was about US\$3800 and 5160 ha^{-1}, respectively. Production cost was higher in micro-sprinkler and drip irrigation due to the initial investment required for construction of the auxiliary reservoir and installation of the micro-irrigation system. There was no comparable cost using the standard irrigation method. The gross return was highest in the micro-sprinkler, and lowest for surface-irrigated potato. The additional income due to micro-sprinkler and drip irrigation compared to the surface irrigation method was about US\$543 and 302 ha^{-1}, respectively, suggesting that micro-sprinkler is a better option for potato compared to drip irrigation. The payback period for micro-sprinkler was found to be 4 yr compared to 7 yr of a drip system for the potato crop.

Irrigation, yield, water productivity and economics for other vegetable crops

Tomato, potato, and onion are important vegetable crops in the area while capsicum is emerging as a most remunerative crop due to its higher market price. Use of drip irrigation in vegetable crops recorded saving of water, better growth among and higher fruit yield. Drip irrigation in conjunction with the auxiliary reservoir ensured small but frequent water application and recorded higher yields for all the vegetable crops than the surface method. It was found that the drip system produced 47, 30 and 32% higher tomato, capsicum and onion yield, respectively, as compared to the surface irrigation method. The drip system used for tomato production recorded savings of 39% water compared to the surface irrigation method and made it possible to cultivate tomato on an additional 39% area with the saved water. Similarly, the drip system resulted in a saving of irrigation water of 46% for capsicum and made it possible to grow crops on an additional 46% area with the saved water. Interestingly, the drip system recorded almost double the water productivity value, i.e. 7.32 and 13.1 kg m^{-3} for capsicum and tomato, respectively, while water productivity was 3.85 and 6.43 kg m^{-3} using the surface irrigation practice. The higher water productivity values for drip clearly suggested that canal water was utilized more efficiently with the drip system as compared to the conventional irrigation method (Bafna *et al*., 1993; Raina *et al*., 1999; Singh *et al*., 2009).

In case of the onion crop, irrigation water applied was recorded as 43.3, 47.8 and 49.4 cm, respectively, under micro-sprinkler, drip, and surface irrigation methods (see Table III). The onion yield was recorded as 34.9, 34.0, and 23.2 t ha^{-1}, respectively, for micro-sprinkler, drip, and surface irrigation methods. Small but frequent watering might have managed high water potential continuously, minimized soil moisture fluctuation in the effective root zone, and promised an increase in crop yield using the micro-sprinkler or drip system regime (Hanson *et al*., 1997).The micro-sprinkler and drip irrigated onion crop matured 7–15 days earlier than the surface irrigation method. Early maturity of the crop fetched a better market price, thus enhancing higher net

Table I. Economics of micro-sprinkler and drip in conjunction with auxiliary reservoir and surface irrigation system for potato

Sr. No.	Particulars	Potato		
		Type of irrigation system		
		Micro-sprinkler	Drip	Surface
1	Annual fixed cost (US$* ha^{-1})			
	(a) Water storage tank (capacity in m^3)	570	570	Nil
	(i) Initial investment	1753	1753	–
	(ii) Annual fixed cost (life 20 yr; interest @ 9%)	193	193	
	(iii) Repair and maintenance	88	88	
	Total annual fixed cost	*281*	*281*	
	(b) Pump and filtration unit			Nil
	(i) Initial investment	490	490	–
	(ii) Annual fixed cost (life 12 yr; interest @ 9%)	69	69	
	(iii) Repair and maintenance	25	25	
	Total annual fixed cost	*93*	*93*	
	(c) Micro-irrigation components (except filtration unit			Nil
	(i) Initial investment	1560	2920	–
	(ii) Annual fixed cost (life 8 yr; interest @ 9%)	281	526	
	(iii) Repair and maintenance	78	146	
	Total annual fixed cost	*359*	*672*	
	Grand total (a + b + c)	*732*	*1045*	
2	Seasonal fixed cost, US$ ha^{-1}	*244*	*348*	
3	Cost of energy for operation of drip irrigation	*25*	*22*	-
4	Cost of cultivation, US$ ha^{-1}	820	827	871
5	Total production cost (2 + 3 + 4), US$ ha^{-1}	1089	1197	871
6	Water applied (cm)	24.6	22.5	28.2
7	Yield (t ha^{-1})	32.2	29.8	22.6
8	Gross income from produce, US$ ha^{-1}	2116	1963	1487
9	Net income (8- 5) US$ ha^{-1}	1027	766	617
10	Gross benefit cost ratio (8/5)	1.94	1.64	1.71
11	Pay back period (season) 1(ai + bi + ci)/9	4	7	
12	Net profit per mm of water applied	4.2	3.4	2.2
13	Water productivity, kg m^{-3}	12.5	13.3	8.03
14	Additional area cultivated by saved water, ha	0.13	0.20	–
15	Total cost of production for additional area (US$)	142	239	–
16	Gross income from additional area (US$)	275	393	–
17	Net income from additional area (15 – 14), US$	133	153	–
18	Additional income (US$) with micro-sprinkler/drip irrigation system over surface irrigation system (16 + 9 MS-9 surface)	544	30	–

*1US$ = Rs.55/-.

returns. It was also important to note that the micro-sprinkler system recorded slightly higher water productivity than drip for onion (Table II). Holzapfel *et al.* (2000) also observed a higher yield of kiwi crop using micro-sprinkler compared to a drip system. Further, during the crop growing period of onion which coincided with cooler temperatures, the micro-sprinkler system might have protected the crop from damage from low temperature by sprinkling the irrigation water droplets on the crop that helped better growth during the early crop stage and consequently a higher yield. Spieler (1994) also reported that a micro-sprinkler protects crops from adverse climatic conditions, which helps better growth. Interestingly, the micro-sprinkler irrigation method was found to be the most appropriate technique to maximize the profit per unit onion cropped area by storing canal water in the auxiliary reservoir, as return per unit applied water was recorded to be US$2.23, 1.64 and 0.12, respectively, for micro-sprinkler, drip, and surface irrigation.

An investment of US$3740, 5030 and 5980 was estimated for installation of a drip system in conjunction with an auxiliary reservoir to store canal water for 1 ha block of tomato, capsicum and onion, respectively. Results clearly indicated that a drip irrigation system for vegetable production was profitable. Net returns for conventional irrigation varied from US$601 to 3240 per ha^{-1} with different vegetable

Table II. Feasibility analysis of different irrigation systems for capsicum, tomato and onion crops

		Capsicum		Tomato		Onion		
Sr. No.	Item	Drip	Surface	Drip	Surface	MS	Drip	Surface
1	Water productivity (kg m^{-3})	7.32	3.85	13.1	6.43	8.06	7.12	4.69
2	Total cost of cultivation (US\$ ha^{-1})	1760	1310	1370	1390	992	1120	697
3	Gross returns (US\$ ha^{-1})	5910	4550	3000	2050	1960	1910	1300
4	Net returns (US\$ ha^{-1})	4150	3240	1230	655	964	784	601
5	B: C ratio	3.36	3.47	1.69	1.47	1.97	1.70	1.86
6	Payback period (season)	2	–	4	–	5	8	–
7	Net profit per mm of water applied (US\$ mm^{-1})	2.44	0.93	9.35	4.96	2.23	1.64	0.12
8	Additional income (US\$) due to adoption of technology	2820	–	1050	–	498	207	–

MS: Micro sprinkler; Surface: existing irrigation practice.

crops, whereas for the same crops, drip irrigation resulted in significantly higher net returns (US\$784–4150 ha^{-1}). The additional income due to drip irrigation compared to the surface method was recorded as US\$1050 and 2820, respectively, for tomato and capsicum, while the payback period for was 2 and 4 yr respectively, for drip-irrigated tomato and capsicum (Table II).

The benefit–cost ratio for tomato was higher in the drip than the surface method, while slightly lower benefit–cost ratio values were recorded in drip as compare to the surface method in capsicum and onion (Table II).The slightly lower benefit–cost ratio in drip was due to the high initial investment involved, which led to significantly higher cost of production than the surface method in the canal command. Though the benefit–cost ratio influences investment decisions, other parameters such as economic returns and payback period also play an important role in deciding the adoption of any technology. The gross return and payback period recorded for these vegetables support the feasibility of adopting micro-irrigation with auxiliary reservoir. Secondly, non-tangible benefits such as additional income from the area brought under assured irrigation with saved water due to the adoption of the technology also indicate that adoption of drip or micro-sprinkler irrigation was justified. As irrigation water was not charged realistically, the saving of water did not have any economic importance. However, saving of water might be treated as creation of an additional resource of irrigation water and had economic importance.

Irrigation, yield and water productivity and economics for fruit crops

Assuming that horticultural orchards would have economic importance after fruit bearing, therefore, data for two years (i.e. 2006–2007) after fruit bearing were used for economic analysis of pomegranate, *kinnow* and guava and the details are summarized in Table III.

The effect of introducing a drip system in the canal command was evident as a significant amount of water was saved compared to the surface irrigation method. The drip system used about 32, 27, and 21% less canal water

Table III. Feasibility analysis of drip and surface irrigation for horticultural crops

		Pomegranate		*Kinnow*		Guava	
Sr. No.	Item	Drip	Surface	Drip	Surface	Drip	Surface
1	Water productivity (kg m^{-3})	5.32	2.92	8.45	5.26	4.78	2.27
2	Total cost of cultivation (US\$ ha^{-1})	1140	783	1670	1490	1470	1330
3	Gross returns (US\$ ha^{-1})	4330	3160	4820	3790	2750	1640
4	Net returns (US\$ ha^{-1})	3190	2380	3150	2300	1280	310
5	B : C ratio	3.80	4.04	2.89	2.55	1.88	1.23
6	Payback period (yr)	5	–	5	–	6	–
7	Net profit per mm of water applied (US\$ mm^{-1})	7.84	3.99	6.03	3.20	2.84	0.54
8	Additional income (US\$) due to adoption of drip system	2280	–	2050	–	1310	–

Note: Economics based on prevailing market price at the time of harvesting of the produce.

while irrigating pomegranate, *kinnow* and guava, respectively, as compared to surface irrigation. The saved water could be used to provide assured irrigation to more area under fruit plants using a drip system. Though fruit crops could withstand drought for a longer period, yield reduction was observed if water became limited in the root zone. In general, in this canal-irrigated dry ecosystem, water was a limiting resource rather than land. Hence, the fruit yield is mainly dependent on the canal water supply and its timely and adequate application. Field data revealed a positive effect of introducing drip along with an auxiliary reservoir on the yield of pomegranate, guava and *kinnow* (Table III). It was probably due to less water stress and efficient nutrient distribution in the case of the drip method which resulted in better crop growth and yield (Hansona *et al.*, 1997; Ram Asrey *et al.*, 2007). Pomegranate fruit cracking due to fluctuation in soil water availability was a severe problem in dry areas. The drip system reduced fruit cracking by 10–15% due to frequent watering and increased marketable yield. In the case of *kinnow*, the drip method provided adequate water to mitigate water stress during the peak summer period and produced a higher yield.

Under prevalent conditions, water shortage at the tail end of the canal commands during peak summer resulted in poor flowering and heavy fruit drop of *kinnow* due to its sensitivity to water stress particularly during flowering. Singh *et al.* (2001) also reported better response of *kinnow* under the drip irrigation method. Average fruit weight of *kinnow* (152 g) and size (3 Grade) was found in the case of the drip method as compared to fruit weight of 120 g and size of 5 Grade with the surface irrigation method. Hence, the drip system managed crop water demand according to climatic conditions to give better and uniform fruit retention. The number and size of fruit varied in the surface and drip methods and were responsible for variation in yield in the case of guava. Drip irrigation registered better guava yield than surface irrigation. Water productivity of pomegranate, *kinnow*, and guava was recorded as 5.32, 8.45 and 4.78 kg m^{-3}, respectively, with drip method compared to 2.92, 5.26 and 2.27 kg m^{-3}, respectively, with the surface irrigation method. The highest water productivity was observed under the drip regime. It might be due to the fact that the drip system in conjunction with the auxiliary reservoir managed crop water demand more efficiently and resulted in better growth and higher yield than the surface method. Higher water productivity favours the use of the drip system in conjunction with the auxiliary reservoir in this canal command.

An initial investment of US$2720, 1010 and 1920 was required to introduce a drip system along with an auxiliary reservoir in the case of pomegranate, guava and *kinnow*, respectively (Table III). Net income due to adoption of a drip system from 1 ha area varied from US$1280 to 3190 for different fruit crops compared to surface irrigation of US$310–2380. Economic analysis showed that the benefit–cost ratio varied from 1.88 to 3.80, the payback period from 5 to 6 yr and the additional income from US$1310 to US$2280, favouring the replacement of existing surface irrigation practices with a drip system in conjunction with an auxiliary reservoir.

Thus, growing vegetables and fruit in canal commands in arid regions of Punjab with the provision of an auxiliary reservoir and drip and micro-sprinkler methods emerged as a feasible option for crop diversification, which ensured water saving and higher water productivity.

Farmers' response to the technology

In south-west Punjab, western Haryana and northern Rajasthan canal water is limited.On the basis of interactions with farmers during field visits, farmers' meetings and visit by farmers to the experimental site at CIPHET, it was observed that farmers were convinced about the technological package. Some farmers took technical guidance from CIPHET to construct a plastic-lined auxiliary reservoir for storage of canal water and to install a drip irrigation system for horticultural crops (Kumar *et al.*, 2008; Kumar and Singh, 2010). Thus, the complete technological package is gaining importance since saline groundwater is prevalent in the region (Singh *et al.*, 2010). There is a chance that the technology will be well accepted among farmers in the region at a higher rate with financial support from respective state governments. There is need to provide incentives for farmers to save precious irrigation water, promote crop diversification and enhance water productivity.

CONCLUSIONS

On the basis of the results of the study on micro-irrigation in conjunction with an auxiliary reservoir in the canal command of the arid region of Punjab, shifting from conventional to micro-irrigation using an auxiliary reservoir is successful in saving a substantial amount of irrigation water (3–46%), improving crop yields, and almost doubling water productivity and increasing net profit per mm of irrigation water. These findings suggest that investment in this technological package (micro-irrigation in conjunction with an auxiliary reservoir) is technically feasible and economically viable. The study also showed that vegetable and fruit crops can emerge as viable crop diversification options to the traditional cotton crop, reducing risk to farmers. The groundwater quality in the area is saline and was not used in the experiment. However, saline groundwater, to some extent, could be mixed with limited canal water in the auxiliary reservoir and may be effectively used to increase the area under drip irrigation. Hence, there is potential to use poor quality groundwater after mixing through this system to overcome water shortages. The farmers' response to technology is also very encouraging.

With the support of the central and state governments, the technological package can overcome the problem of limited availability of irrigation water and canal operational timings, which do not match the critical stages of crops. Moreover, the technological package has the potential to provide self-employment for the rural youth.

ACKNOWLEDGEMENTS

The authors are grateful to the All India Coordinated Research Project on Application of Plastics in Agriculture (APA), Indian Council of Agricultural Research (ICAR), for financial assistance in carrying out this study. The authors are also grateful to two anonymous reviewers who improved the text by giving their frank and constructive views about the manuscript.

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