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Drip Fertigation Technology for Enhancing Water and Nutrient Use Efficiency in Arid Agro-ecosystem of Irrigated North-Western Rajasthan

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Abstract: Field experiments were conducted from 2002 to 2012 in AICRP on IWM at Agricultural Research Station, Sriganganagar to find out optimum crop geometry under drip system, optimum drip irrigation schedule and optimum fertigation schedule for American cotton (hybrid *hirsutum* cotton), Bt cotton, sugarcane and brinjal. The pooled results of the trials revealed that paired planting in Bt cotton, sugarcane and brinjal was found cost effective without any yield loss. In American cotton paired planting gave significantly higher seed cotton yield over single row planting. Drip irrigation schedule at 1.0 ET_c, 1.0 ET_c, 80% PE and 1.0 ET_c was found optimum for American cotton, Bt cotton, sugarcane and brinjal, respectively. The increase in yield of respective crops was 24.2, 31.0, 26.4 and 30.9% and saving of water was 13.3, 32.9, 17.1 and 29.6% over conventional practice. Drip irrigation also improved the quality of produce by increasing fibre length and fineness in cotton lint and commercial cane sugar to the extent of 35.8% over conventional practice. Drip irrigation also suppressed the pest population in cotton. The fertigation schedule 150 kg N and 20 kg K_2O ha^{-1} (40 kg P_2O_5 ha^{-1} as basal) in 6 equal splits at an interval of 15 days for American cotton, 120 kg N, 32 kg P_2O_5 and 16 kg K_2O ha^{-1} in 6 equal splits at an interval of 15 days and 2% foliar spray of KNO_3 at 90 and 105 days after sowing for Bt cotton, 112.5 kg N and 30 K_2O ha^{-1} (40 kg P_2O_5 ha^{-1} as basal) in 9 equal splits at an interval of 20 days for sugarcane and 96 kg N and 48 K_2O ha^{-1} (80 kg P_2O_5 ha^{-1} as basal) in 12 equal splits at an interval of 10 days for brinjal was found optimum. The increase in yield of respective crops due to optimum fertigation schedule was 49.8, 15.6, 20.7 and 30.6% and water saving was 13.3, 24.3, 25.0 and 29.6% and fertilizer saving was 0, 20, 25 and 20% over conventional practice of irrigation and fertilizer application. In both drip irrigation and fertigation water expense efficiency increased by 43.3 to 85.9% over that of conventional practice. Thus, drip irrigation with fertigation was found a better option to increase water and nutrient use efficiency in arid agro-ecosystem of Irrigated North Western Rajasthan.

Key word: American cotton, brinjal, Bt cotton, crop geometry, drip irrigation, fertigation, quality, sugarcane, yield, water expense efficiency.

Irrigated North-Western Plain Zone of Rajasthan, comprising of Sriganganagar and Hanumangarh districts, is a part of the vast arid tract of Thar Desert. The geographical area and net cultivable area of the zone is 2.06 and 1.71 m ha, respectively. Most of the soils in the region come under *Torrisamments* and *Torrifluvents* groups. These soils are light textured having low organic carbon and poor water holding capacity. The climate of the area is hostile. The rainfall is very low and erratic. The average annual rainfall varies from 250 to 350 mm. During summer maximum temperature goes as high as 46 to 48°C and during winters the minimum temperature goes as low as 1 to 2°C. Humidity remains low throughout the year except during rainy season. The mean annual pan evaporation is 1825 mm. There is wide gap between rainfall and pan evaporation throughout the year. The ground water in general is brackish. Thus, the crop production is mainly dependant on canal irrigation. The water availability in canal (Gang, Bhakra and Indira Gandhi) command is inadequate and uncertain. There is no match of water availability with crop water requirements. The farmers also face the inequitable distribution of water when canal is closed without completing its cycle due to one or other reason. The requirement of warabandi,

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although in terms of equity is full filled to a certain extent, but in practice the farmers at head reaches get more water as compared to tail enders. The government is encouraging the farmers for construction of secondary water reservoirs (Diggies) in their fields and about 10,000 water reservoirs have been constructed in the canal command. The problem of water shortage is likely to be more aggressive for agriculture in years to come mainly due to continuously increasing demand for water in domestic, industrial and energy sectors.

Drip system is highly precise irrigation method applying water directly to the root zone. Irrigation scheduling through drip can be managed precisely to meet crop water demands, holding the promise of increased yield and quality (Desai *et al*., 2008; Mishra and Paul, 2009). Agricultural chemicals can be applied more efficiently with drip irrigation. Since only the crop root zone is irrigated, nitrogen already in the soil is less subject to leaching losses, and applied fertilizer N can be used more efficiently. Nutrient use efficiency in fertigation increases as a result of controlled and regular application of fertilizers (Kumar and Singh, 2002). An effort has been made in AICRP on Irrigation Water Management to generate information on optimum irrigation schedule, fertigation schedule and optimum crop geometry for drip irrigation in major crops of Irrigated North-Western Plain Zone of Rajasthan.

Materials and Methods

The experiments on crop geometry, drip irrigation and drip fertigation were conducted on American cotton i.e. hybrid *hirsutum* cotton (LHH 144), Bt cotton (JKCH 1947), sugarcane (Co 6617) and brinjal (Nishant), in AICRP on Irrigation Water Management at Agricultural Research Station, Sriganganagar during 2002 to 2012. The experimental soil was sandy loam in texture, low in organic carbon (0.18 to 0.24%), medium in available phosphorus (34 to 45 kg P_2O_5 ha^{-1}) and high in available potash (350 to 420 kg K_2O ha^{-1}) with a pH of 8.1 to 8.3. The average values for volumetric moisture content in the soil at field capacity and permanent wilting point were 0.198 and 0.072 m^3 m^{-3}, respectively. The experiments were laid out in randomized block design. Drip lines having in line drippers at 30 cm distance with water discharge of 2 LPH were used in the study. In the experiments on crop geometry, different crop geometries of single and paired planting under drip irrigation system were tested to evaluate their performance. In paired planting drip line was placed within the pair and in single row plantings, drip line was placed along the row. Alternate day irrigation schedule was followed. In the experiments on irrigation scheduling, different levels of drip irrigation based on crop evapo-transpiration were evaluated with recommended practice of surface irrigation for that crop. Irrigation was applied on alternate day by drip irrigation as per treatment. In the experiments on fertigation, graded levels of fertigation with different timings of application were tested with conventional practice of recommended fertilizer dose and surface irrigation. In fertigation experiments, traditional as well as water soluble fertilizers were used for nutrient application. Treatment wise yield, yield attributing parameters, water use and water expense efficiency in all the experiments were recorded. The data were statistically analyzed and inferences were drawn accordingly.

Results and Discussion

Crop geometry

Different crop geometries including recommended crop geometry in conventional surface irrigation, wider row spacing as well as paired row planting have been evaluated under drip system of irrigation in American cotton, Bt cotton, sugarcane and brinjal at Agricultural Research Station, Sriganganagar. Drip lines were placed along the row in single row planting and within the pair in paired row planting. Irrigation water was applied equal in all the drip layouts for the particular crop. Paired planting (60 cm x 120 cm) in American cotton gave significantly higher seed cotton yield in comparison to single row planting of 90 cm. The higher seed cotton yield in paired planting was attributed to numerically higher number of bolls and more boll weight as a result of better aeration and effective spray of pesticides in the crop (Yadav and Chauhan, 2013). Aujla *et al*. (2005) also reported superiority of paired planting in American cotton than normal planting under drip irrigation at Bathinda in Southern Punjab. In Bt cotton paired planting (60 cm x 120 cm) gave at par seed cotton yield

Table 1. Effect of crop geometry on yield of different crops (pooled data of 3 years)

Crop geometry (cm)	American cotton	Bt cotton	Sugarcane	Brinjal
	Seed cotton yield (q ha^{-1})	Seed cotton yield (q ha^{-1})	Cane yield (t ha^{-1})	Fruit yield (q ha^{-1})
Single row planting*	17.56	31.65	119.80	547.37
Paired planting**	18.88	30.85	115.18	511.82
CD at 5%	0.54	NS	NS	NS

*Row to row distance for American cotton, Bt cotton, sugarcane and brinjal was 90, 90, 75 and 60 cm, respectively.
**Paired planting for American cotton, Bt cotton, sugarcane and brinjal was 60 x 120, 60 x 120, 60 x 90 and 60 x 120 cm, respectively.

with single row planting of 90, 108 and 120 cm (Chauhan *et al*., 2014). In sugarcane paired planting 60 cm x 90 cm gave at par cane yield with single row planting of 75 cm and 90 cm (Yadav *et al*., 2014). In brinjal paired planting of 60 cm x 120 cm and 60 cm x 75 cm gave at par fruit yield with single row planting of 60 cm (Yadav and Chauhan, 2013). Thus, paired planting was found at par or superior than conventional recommended single row planting in the experimental results (Table 1). Desai *et al*. (2008) reported the superiority of paired planting in tomato under drip irrigation at Navsari in Gujarat. In paired planting cost of installation of drip system was lower due to wider spacing of drip lines (Yadav and Chauhan, 2013). Bhatia *et al*. (2001) also suggested paired row planting system to reduce the installation cost of drip system and to make the system economically viable while reviewing the drip irrigation for Indian arid region.

Irrigation schedules

American cotton: Different irrigation schedules applied to American cotton significantly influenced plant population, plant height, number of bolls per plant and seed cotton yield in sandy loam soils of Sriganganagar (Table 2). The plant population was significantly decreased in flood and furrow irrigation treatments in comparison to drip irrigation treatments. Under drip irrigation due to availability of water on alternate day sufficient moisture remained in soil and soil surface temperature remained lower as a result minimum plant mortality was observed under drip irrigation treatments. Plant height at 100 DAS was significantly higher in drip irrigation at 0.8 and 1.0 ET_c in comparison to flood and furrow irrigation treatments. The seed cotton yield and number of bolls per plant increased with increasing the level of drip irrigation from 0.6 to 1.0 ET_c. Irrigation at 1.0 ET_c gave 24.2% higher seed cotton yield over that obtained with flood irrigation. Irrigation at 1.0 ET_c through drip saved 105 mm irrigation water in comparison to flood irrigation. The higher seed cotton yield in drip irrigated crop was attributed to its higher plant population, better growth and higher number of bolls per plant in comparison to conventional flood irrigation. Shelke *et al*. (1999) reported 23% increase in seed cotton yield with drip irrigation at 0.8 ET_c in comparison to surface irrigation in Vertisols of Maharashtra. The water expense efficiency in drip irrigated treatment at 1.0 ET_c was 43.3% higher than that of flood irrigation treatment.

Irrigation through drip also improved the quality of cotton lint in comparison to flood irrigation (Yadav *et al*., 2006). Span lengh and fibre strength of the lint were more in drip irrigated treatments in comparison to flood

Table 2. Effect of irrigation schedules on growth, yield and water use in American cotton (pooled data of 3 years)

Irrigation schedule	Plant population/ ha at 60 DAS	Plant height (cm) at 100 DAS	No. of bolls per plant	Seed cotton yield (kg ha^{-1})	Total water use (mm)	WEE (kg ha^{-1} mm)
0.6 ET_c (drip)	16631	131.1	31.1	1610	480	3.35
0.8 ET_c (drip)	16657	137.5	35.8	1939	582	3.33
1.0 ET_c (drip)	16368	143.0	37.6	2113	680	3.11
Flood irrigation	14766	131.4	31.5	1701	785	2.17
Furrow irrigation	14314	129.9	30.1	1711	527	3.25
S. Em ±	116	1.7	0.9	32	-	-
CD at 5%	333	4.7	2.6	91	-	-

Source: Yadav *et al.* (2006).

Table 3. Effect of different irrigation treatments on yield, water use and expense efficiency in Bt cotton (pooled data of 3 years)

Irrigation schedule	Seed cotton yield (q ha^{-1})	No of bolls $plant^{-1}$	Total water use (mm)	WEE (kg ha^{-1} mm^{-1})
0.6 ET_c (drip)	23.60	57.05	602	3.92
0.8 ET_c (drip)	26.26	60.20	660	3.98
1.0 ET_c (drip)	30.93	63.98	736	4.21
1.2 ET_c (drip)	30.96	63.51	802	3.86
Flood irrigation	23.61	55.17	978	2.41
S Ed	0.72	3.65	-	-
CD at 5%	1.57	7.93	-	-

Source: Chauhan *et al*. (2014).

irrigation. Drip irrigation also reduced short fibre content in the lint in comparison to flood irrigation. The infestation of spotted bollworm was significantly lower and incidence of whitefly was numerically lower in drip irrigated crop (1.0 ET_c) in comparison to flood irrigated crop (Yadav and Chauhan, 2013).

Bt Cotton: The maximum seed cotton yield of Bt cotton was recorded when drip irrigation was scheduled at 1.2 ET_c, however, it was at par with seed cotton yield obtained at 1.0 ET_c (Table 3). Seed cotton yield at 0.8 and 0.6 ET_c was significantly lower than that of 1.0 and 1.2 ET_c treatments. Thus, drip irrigation to Bt cotton at 1.0 ET_c was found optimum. This treatment gave 31.0% higher seed cotton yield and saved 32.9% of irrigation water over conventional flood irrigation. The water expense efficiency obtained with this treatment was 74.7% higher as compared to that of flood irrigation. The maximum water expense efficiency of 4.21 kg ha^{-1} mm^{-1} was recorded at 1.0 ET_c under drip as against 2.41 kg ha^{-1} mm^{-1} in flood irrigation treatment.

Sugarcane: Different irrigation schedules significantly influenced yield and quality parameters of sugarcane**.** The highest cane yield was recorded with drip irrigation at 100% PE treatment, however, highest poll percentage and commercial cane sugar percentage was recorded at 80% PE treatment (Table 4). Drip irrigation at 60% PE gave highest water use efficiency (89.0 kg ha^{-1} mm^{-1}) followed by 80% PE treatment (78.9 kg ha^{-1} mm^{-1}). Drip irrigation at 80% PE to sugarcane was found optimum irrigation schedule. Drip irrigation at 80% PE gave at par commercial cane sugar (11.88 t ha^{-1}) with 100% PE treatment (12.81 t ha^{-1}). It increased cane yield by 26.4%, commercial cane sugar by 35.8% and saved water by 17.1% over that of surface irrigation. The water expense efficiency in this treatment was 52.9% higher than that of surface irrigation.

Brinjal: The fruit yield of brinjal recorded with drip irrigation at 1.0 ET_c (814.0 q ha^{-1}) was statistically at par with that of 1.2 ET_c (821.3 q ha^{-1}) and significantly higher than other treatments tested in the study (Table 4). Thus, drip irrigation at 1.0 ET_c was found optimum irrigation schedule for brinjal. It gave 30.9% higher fruit yield of brinjal and saved 29.6% irrigation water over conventional surface irrigation. Mishra and Paul (2009) also observed the highest yield of brinjal under drip irrigation at 100% irrigation requirement treatment in sandy loam soil of coastal Orissa. The water expense efficiency was 85.9% higher at 1.0 ET_c as compared to that of flood irrigation. The maximum water expense efficiency of 119.0 kg

Table 4. Effect of irrigation schedule on cane yield, quality and water use efficiency in sugarcane (pooled data of 3 years)

Irrigation schedule	Cane yield (t ha^{-1})	CCS (t ha^{-1})	Juice (%)	Poll (%)	CCS (%)	WEE (kg ha^{-1} mm^{-1})
Surface irrigation	88.74	8.75	35.98	13.96	9.67	51.6
100% PE (drip)	128.29	12.81	38.60	14.24	9.77	75.7
80% PE (drip)	112.21	11.88	37.98	14.93	10.42	78.9
60% PE (drip)	101.54	10.07	36.18	14.03	9.68	89.0
S. Em.$\pm$	2.98	0.40	0.64	0.25	0.21	-
CD at 5%	8.62	1.22	1.93	0.75	0.65	-

Source: Bhati *et al*. (2014), Yadav *et al*. (2014a).

Table 5. Effect of drip irrigation on fruit yield, water use, water expense efficiency and benefit cost ratio in brinjal (pooled data of 3 years)

Irrigation schedule	Fruit yield (q ha^{-1})	Water use (mm)	WEE (kg ha^{-1} mm^{-1})	B:C ratio	ICBR
0.6 ETc (drip)	556.5	467.5	119.0	3.04	1.29
0.8 ETc (drip)	657.4	588.6	111.7	3.78	2.75
1.0 ETc (drip)	814.0	709.4	114.7	4.92	5.87
1.2 ETc (drip)	821.3	790.4	103.9	4.97	6.48
Flood irrigation	621.6	1007.8	61.7	4.44	-
S Ed	22.1	-	-	-	-
CD at 5%	48.1	-	-	-	-

Source: Chauhan *et al*. (2013).

ha^{-1} mm^{-1} was recorded with 0.6 ET_c followed by 114.7 kg ha^{-1} mm^{-1} with 1.0 ET_c by drip irrigation. It is pertinent to mention here that brinjal under low tunnel started fruiting about 20 to 25 days earlier than the crop without low tunnel. Thus, advance picking of fruits under low tunnel gave higher returns due to more selling price. Moreover, cotton may be grown timely after brinjal crop raised under low tunnel. The highest B:C ratio of 4.97 was recorded when the irrigation was scheduled at 1.2 ET_c closely followed by 4.92 at 1.0 ET_c as against 4.44 under flood irrigation (Table 5). The incremental cost benefit ratio of irrigation scheduling at 1.0 and 1.2 ET_c was 5.87 and 6.48, respectively.

Fertigation schedules

American cotton: Different fertigation treatments significantly influenced seed cotton yield and other yield attributes (Table 6). The minimum plant mortality was observed in drip fertigated treatments due to alternate day irrigation which counteracted the adverse effect of high temperature. The application of 100% RD of N and K in six equal splits significantly increased plant population, plant height, number of bolls/plant, seed cotton yield and quality of cotton lint in comparison to recommendation practice of surface irrigation and fertilizer application. This treatment increased 49.8% seed cotton yield and saved 13.3% water over recommended practice.

Increase in growth and yield attributes as a result of optimum moisture and nutrition to the crop through drip fertigation was due to increased photosynthates and translocation of more assimilates from source to sink (Raskar, 2004; Veeraputhiran and Chinnusamy, 2009). The incidence of whitefly and per cent infestation of spotted bollworm were lower in fertigation treatments in comparison to recommended flood irrigation.

Bt Cotton: The maximum seed cotton yield was recorded at 120% RD of fertilizers, however, it was at par with 100% and 80% RD of fertilizers with 2% KNO_3 spray (Table 7). Application of 80% RD of NPK in 6 equal splits each at an interval of 15 days and foliar spray of 2% KNO_3 at 90 and 105 DAS was found optimum dose of fertigation for Bt cotton. This

Table 6. Effect of fertigation on plant population, growth, yield and quality of American cotton (pooled data of 3 years)

Fertigation schedule	Plant population ha^{-1} at 60 DAS	Plant height (cm) at 100 DAS	No. of bolls $plant^{-1}$	Seed cotton yield (kg ha^{-1})	2.5% SL	MIC value	SFC%
100% RD* in 4 splits	16898	142.6	39.13	2398	28.7	4.3	6.3
100% RD in 6 splits	16966	145.8	41.82	2573	27.9	4.6	8.8
75% RD in 4 splits	16700	138.5	38.40	2238	27.6	4.5	9.5
75% RD in 6 splits	16772	139.6	38.83	2385	27.7	4.3	8.5
RP**	15508	136.3	31.99	1718	26.4	3.5	11.6
S. Em. ±	174	1.8	1.03	42	--	--	--
CD at 5%	501	5.2	2.96	120	--	--	--

*RD = Recommended dose of fertilizers i.e. 150 kg N, 40 kg P_2O_5 and 20 kg K_2O ha^{-1}.
**RP = Recommended practice of flood irrigation with recommended dose of fertilizers.
Source: Yadav *et al*. (2014b).

Table 7. Effect of different irrigation treatments yield and water expense efficiency (pooled data of 3 years)

Fertigation schedule	Seed Cotton yield (q ha^{-1})	No of bolls $plant^{-1}$	Total water use (mm)	WEE (kg ha^{-1} mm^{-1})
120% RD*	29.96	65.87	759	3.95
100% RD + 2% KNO_3	29.40	64.08	759	3.87
80% RD + 2% KNO_3	28.72	64.92	759	3.78
60% RD + 2% KNO_3	24.44	58.25	759	3.22
RP**	24.85	55.24	1003	2.48
S Ed	0.67	4.32	-	-
CD at 5%	1.46	9.41	-	-

*RD = Recommended dose of fertilizers for Bt cotton was 150 kg N, 40 kg P_2O_5 and 20 kg K_2O ha^{-1}
**RP = Recommended practice of flood irrigation with recommended dose of fertilizers
Source: Chauhan *et al.* (2014).

treatment increased 15.6% seed cotton yield, saved 24.3% water and increased 52.7% water expense efficiency over conventional method of fertilizer application and irrigation.

Sugarcane: Different doses of fertilizers (75, 100 and 125% recommended dose of fertilizers through drip) did not influence cane yield and yield attributes (Yadav *et al*., 2015). Thus, fertigation at 75% recommended dose of N and K was sufficient to meet the requirement of the crop. Phosphorus @ 40 kg P_2O_5 ha^{-1} was applied as basal application in all the treatments. Time of fertilizer application also did not influence the yield and yield attributes of sugarcane. However, numerically higher cane yield was recorded with 9 splits of N and K at 20 days interval in comparison to 12 splits at 15 days interval (Yadav *et al*., 2015). Therefore, 75% recommended dose of fertilizers (112.5 kg N and 30 kg K_2O ha^{-1}) in 9 equal splits each at an interval of 20 days has been recommended for sugarcane. It gave 20.7% higher cane yield and saved 25% fertilizers in comparison to conventional practice of flood irrigation and recommended dose of fertilizers.

Brinjal: The maximum yield of brinjal was recorded with the application of 80% recommended dose of N and K in 12 equal splits at an interval of 10 days and it was at par with the same dose in 9 equal splits in 13 days interval but significantly superior than rest of the treatments (Table 8). Phosphorus @ 80 kg P_2O_5 ha^{-1} has been applied as basal in all the treatments. The water expense efficiency was 85.5% higher in the 80% RD (12) drip fertigated treatment as compared to that of flood irrigation treatment. The maximum water expense efficiency of 120.2 kg ha^{-1}mm was recorded under 80% RD in 12 splits, followed by 114.4 kg ha^{-1} mm^{-1} under 80% RD in 9 splits. The maximum B:C ratio 6.43 was recorded with 80% recommended dose of N and K in 12 equal splits followed by 6.08 recorded at the same dose of fertilizer in 9 equal splits as against 4.71 under flood irrigation with recommended fertilizer dose. The incremental benefit cost ratio under fertigation at 80% recommended dose of N and K in 12 equal splits and 9 equal splits was 13.24 and 11.51, respectively. Therefore, 80% recommended dose of N and K of fertilizers (96 kg N and 48 kg P_2O_5 ha^{-1}) in

Table 8. Effect of fertigation on fruit yield, water use and water expense efficiency in brinjal (pooled data of 3 years)

Fertigation schedule	Fruit yield (q ha^{-1})	Water Use (mm)	WEE (kg ha^{-1} mm^{-1})	B:C ratio	IBCR
80% RD* in 9 splits	811.6	709.4	114.4	6.08	11.51
80% RD in 12 splits	852.4	709.4	120.2	6.43	13.24
60% RD in 9 splits	697.7	709.4	98.4	5.18	7.16
60% RD in 12 splits	675.6	709.4	95.2	4.98	6.13
RP**	652.7	1007.8	64.8	4.71	--
S Ed	22.9	--	--	--	--
CD at 5%	49.9	--	--	--	--

*RD = Recommended dose of fertilizers for brinjal was 120 kg N, 80 kg P_2O_5 and 60 kg K_2O ha^{-1}, respectively.
**RP = Recommended practice of flood irrigation and recommended dose of fertilizer application.
Source : Chauhan *et al.* (2013).

12 equal splits each at an interval of 10 days has been recommended for brinjal. It increased 30.6% fruit yield of brinjal, saved 29.6% water and 20% fertilizers over conventional practice of flood irrigation and fertilizer application.

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