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Research Paper

Drip irrigation in maize (*Zea mays*)-based cropping systems

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ABSTRACT

A field experiment was conducted during 2015–16 and 2016–17 at the Irrigation Water Management Research Centre (University of Agricultural Sciences, Dharwad, Karnataka) Dharwad, Karnataka to estimate the productivity of drip irrigation for which maize (*Zea mays* L.) was grown in the rainy (*kharif*) season, followed by chickpea (*Cicer arietinum* L.) or bread wheat (*Triticum aestivum* L.) or field bean (*Phaseolus vulgaris* L.) in winter (*rabi*) season. The treatments comprised 3 levels of irrigation for maize, viz. 1.0 ET0 (the reference evapotranspiration); 0.8 ET0; and surface flooding (control); and 0.6 ET0 for chickpea, 0.9 ET0 for wheat, and 0.6 ET0 for field bean. The grain yield of maize was significantly higher in 1.0 ET0 (11.93 t/ha) than 0.8 ET0 (11.16 t/ha or the control (9.73 t/ha). In the winter, yields with drip irrigation were significantly higher by 32.06% in chickpea, 16.46% in wheat, and 26.10% in field bean; in terms of maize-kernel equivalent yield, chickpea (20 t/ha) and wheat (18.4 t/ha) proved superior to field bean. The highest water productivity (21.84 kg/m^3) was recorded in the maize-chickpea combination, which fetched the highest returns (about 2 Lakhs, or \$2475/ha), giving a benefit: cost (B:C) ratio of 4.13.

Key words: Evapo-transpiration-based irrigation, Flood irrigation, Maize-based cropping systems, Maize-equivalent yield, Surface irritation water productivity

Malaprabha is one of the irrigation projects in Karnataka, although it offers no definite schedule or pattern for releasing water for irrigation. The quantity of water available for irrigation depends on the onset of the south-west monsoon, rainfall in the catchment area and the capacity of the reservoir. The most common cropping pattern in this command area comprises maize (early in *kharif*, or the rainy season, typically from June to September), followed by chickpea, wheat, safflower, sorghum, or sunflower (later in the *kharif* season), which, in turn, is followed by chickpea, wheat, sorghum, or safflower or a mixed/inter crop of chilli pepper, onion, and cotton. The main crop-growing period in the command area is from July to February: canal water for irrigation is usually available from the last week of August to December or, in a good season and if the dam is full, even up to the first half of January. Otherwise, water is available only for the winter (*rabi*) season, from September to December. In this agro-climatic zone (referred to as the Northern Dry Zone in India), it is possible to take an early crop if the area receives adequate (more than 100 mm) of rainfall from May to the first half of June; however, this is a gamble: the crops fail if the monsoon sets in late or weak in July and August, leading to a long, dry spell during the grand growth period of the crops at the time of peak water requirements.

Maize is the third most important food crop, after rice and wheat (USDA 2011), and considered a commercial crop with various industrial uses apart from its use as human food and also serves as feedstock for animals (Sarangi *et al*., 2020). Given the increasing demand for maize as both fresh and processed food, the challenge is to obtain higher yields from less water to maximize the crop's water productivity (WP). Proper scheduling of irrigation and applying fertilizers through drip irrigation (fertigation) are two major strategies to attain higher WP. Drip irrigation also known to have many advantages (Vijayakumar *et al*. 2010; Feleafel and Mirdad 2013; Deshmukh and Hardaha 2014), it saves water, expenditure on machinery, and labour, helps in applying fertilizers more accurately and uniformly, and increases the uptake of nutrients by roots. Zwart and Bastiaansen (2004) reported grain yields of maize as high as 1.1–2.7 kg/m^3 and attributed to climate, irrigation, and fertilizers. Their findings suggest that lowering irrigation volumes is the key to higher WP.

Despite such clear advantages of drip irrigation, no single system or design is available for drip irrigation suitable for the majority of crops grown by small farmers. The main reasons for drip irrigation not being popular among small farmers are its high initial cost and the difficulties

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posed by the network of pipes to cultural operations. The current available designs also require that the laterals and the drippers be changed for each crop. To overcome this constraint, a single system has been developed for the majority of crops grown in the study area (maize or sunflower followed by chickpea or wheat or field bean or groundnut or safflower or chilli + onion + cotton). The entire system remains above the ground so that it can be installed or dismantled easily and quickly.

With this background, new drip system was developed to be suitable for the majority of crops grown by the small farmers and was tested to quantify the benefits of drip irrigation for a maize-based cropping system in Karnataka, as applied in one catchment area, that served by the Malaprabha river and the reservoir fed by that river.

MATERIALS AND METHODS

A field experiment was conducted during 2015–16 and 2016–17 at the Irrigation Water Management Research Centre (15°342 N, 75°212 E and 578 m amsl) (University of Agricultural Sciences, Dharwad, Karnataka), Dharwad, Karnataka. The climate of the study site is semi-arid with annual precipitation of 560 mm and mean evaporation of 1626 mm (Table 1). The experimental fields had clayey soil (24.5% sand, 14.6% silt, and 60.9% clay) with an average bulk density of 1.4 Mg/m^3 to a depth of 90 cm, a *p*H of 8.5, and average electrical conductivity (EC) of 0.3 dS/m. The field capacity was 38.1% and the wilting point was 21.3%. The organic carbon content was 0.51%, available P was 37 kg/ha, and available K was 791 kg/ha

The irrigation lines rested on the soil surface and the network comprised sub-lines connected to the main line and laterals connected to the sub-lines. Each lateral was 10.8 m long, connected to the sub-line at intervals of 0.6 m, and was equipped with in-built emitters (discharging 4 litres of water per hour) spaced at intervals 0.4 m on the lateral lines.

Experimental design and treatments

The experiment was laid out in a strip plot design with 3 replications. Each main plot (the irrigation treatments) measured 68.04 m^2 and each subplot (the winter crops) was 22.68 m^2. The irrigation treatments for maize were 1.0 ET0 (I_1, the reference evapotranspiration), 0.8 ET0 (I_2), and surface irrigation (I_3, the farmers' method, which served as the control). After harvest of the maize crop, each main plot was divided into three subplots, one for each of the winter crops, namely chickpea, which was irrigated at 0.6 ET0; wheat, at 0.9 ET0; and field bean (as a relay crop) at 0.6 ET0 (ETo for this crops based on the experiments conducted and recommended from this centre). The dates of sowing and of harvest in both the years, 2015 and 2016,

Table 1. Rainfall and number of rainy days (in 2015 and 2016 and average values) at Irrigation Water Management Research, Belavatagi research station, Karnataka

Month	Normal rainfall 1985–2016	Normal no. of rainy days 1993–2016	Rainfall (mm) 2015	No. of rainy days 2015	Deficit/Excess rainfall (mm) 2015	Deficit (%) 2015	Rainfall (mm) 2016	No. of rainy days 2016	Deficit/Excess rainfall (mm) 2016	Deficit (%) 2016
Jan.	1.93	2.80	0.0	0.0	“1.93	100.00	0.0	0.0	“01.93	100.00
Feb.	1.36	0.27	0.0	0.0	“1.36	100.00	0.0	0.0	“01.36	100.00
Mar.	13.09	1.68	27.8	1.0	14.71	Excess	0.0	0.0	“13.09	100.00
Apr.	30.20	3.50	12.2	1.0	“18.00	59.60	09.4	1.0	“20.80	68.87
May	35.10	5.67	30.1	4.0	“05.00	14.24	88.2	9.0	53.10	Excess
June	86.23	4.44	120.2	7.0	33.97	Excess	78.2	4.0	“08.03	9.31
July	85.83	6.12	46.0	3.0	“39.83	46.40	62.7	10.0	“23.13	26.95
Aug.	80.53	5.84	35.0	7.0	“45.53	56.53	29.3	4.0	“51.23	63.62
Sept.	128.47	6.88	156.8	7.0	28.33	Excess	51.4	4.0	“77.07	59.99
Oct.	68.25	1.88	151.8	4.0	83.55	Excess	12.0	1.0	“56.25	82.42
Nov.	31.06	0.57	3.0	0.0	“28.06	90.30	0.0	0.0	“31.06	100.00
Dec.	4.91	0.63	0.0	0.0	“04.91	100.00	0.0	0.0	“04.91	100.00
Total	566.96	4.27	582.9	34.0	15.94	2.81% Excess	331.20	33.0	“235.76	41.58

are given in Table 2.

Fertilizers were applied to soil by conventional method of application as per the recommended doses (per hectare) for maize (150 kg of N, 76.5 kg of P_2O_5, and 67.5 kg of K_2O), chickpea (25 kg of N and 50 kg of P_2O_5), wheat (100 kg of N, 75 kg of P_2O_5, and 50 kg of K_2O), and field bean (25 kg of N and 50 kg of P_2O_5). Plant population was maintained at 100% during both the years. Maize was irrigated every 4 days in *kharif* and the other crops were irrigated every 7 days for *rabi* crops in all the drip irrigation treatments.

Each year, maize was irrigated 18 times and the winter crops were irrigated 12 times (Table 3). The total volume of water amounted (at 1.0 ETo) was 800 mm for the maize-chickpea system, 942 mm for the maize-wheat system, and 828 mm for the maize-field bean system. The corresponding amounts supplied through the surface method were 1013 mm, 1163 mm and 953 mm (pooled data). In both the yeas, the effective rainfall was 194, 92.7 mm received during *kharif* 2015 and 2016, and there was no rainfall during *rabi* seasons of both the years. Therefore, most of the rainfall received during the crop growth period was insufficient, and the crops were sustained by irrigation.

The amount of irrigation water applied through drip irrigation was calculated as:

$$Wa = \frac{\mathrm{IETo}}{\mathrm{Ea}} + \mathrm{LR}$$

where I, the empirical irrigation level (1.0 ET0 and 0.8 ET0, respectively, for the treatments I_1 and I_2); Ea, irrigation efficiency of the system determined at the beginning of the season as 0.8; and LR, the quantity required to compensate for water lost through leaching (assumed to 10% in each round of irrigation).

The reference crop evapo-transpiration (ET0) was calculated as:

ET0 = Ep. Kp

where, EP, the cumulative evaporation to be considered for choosing the irrigation interval and Kp, the pan evaporation coefficient (taken as 0.75 for the experimental site). Evaporation was measured daily from the standard Class A pan evaporation tank placed close to the experimental field.

The duration of irrigation was calculated as:

$$\mathrm{t} = \frac{\mathrm{Wa\ A}}{\mathrm{q}}$$

where, t, the duration of irrigation in hours; Wa, the depth of applied irrigation water in millimetres; A, the area, in square metres, wetted by emitters; and q, the rate of discharge of water from each emitter (litre/h).

Water productivity was determined to evaluate the benefit derived from irrigation and can be defined as the amount of grain yield a cubic metre of water may produce; the values of WP (kg/m^3) were determined by dividing the grain yield (kg/ha) by the total amount of irrigation water (m^3/ha) (Table 4). The data were subjected to analysis of variance, and mean values from the different treatments were compared using the test of least significant difference at 0.05 probability level (Gomez and Gomez, 1984).

RESULTS AND DISCUSSION

Grain yield

Maize grain yield (Table 4) in 1.0 ET0 was significantly higher than 0.8 ET0 and the control in both years. Pooled data for the two years shows that compared to the yield in the farmers' method, or the control, the yield in 1.0 ET0 was greater by 22.6% and the yield in 0.8 ET0 was higher by 14.6%. The same pattern was seen in the winter crops, the corresponding higher yields being 32.0% greater in chickpea, 16.5% in wheat, and 26.1% in field bean. The higher yields were due to easy access to moisture and nutrients enabled by the more controlled irrigation, which supplied the required quantity at frequent intervals to match the actual water needs of the crops at various stages. Although drip irrigation wetted only a small zone of the soil around the plant, the method ensured that soil moisture was always maintained close to field capacity. This continued supply also rendered ineffective most of the rainfall received during the crop growth period. Similar increases in the yield of maize with drip irrigation were reported by Islam *et al.,* (2006) and Anitta Fanish (2013).

Water productivity (WP)

Water productivity was significantly higher with drip irrigation in both seasons (Table 4). In maize, WUE

Table 2. Crops, cultivars and dates of sowing and harvest during 2015–16 and 2016–17

Crop and cultivar	2015–16		2016–17	
	Sowing	Harvesting	Sowing	Harvesting
Rainy season				
Maize (Cargil 900M)	10 Aug.	18 Nov.	13 July	4 Nov.
Winter season				
Chickpea (JG-11)	24 Nov.	12 Mar.	7 Nov.	20 Mar.
Wheat (UAS-334)	24 Nov.	12 Mar.	7 Nov.	28 Feb.
Field bean (Hebbal Avare)	29 Oct.	28 Feb.	21 Oct.	21 Feb.

Table 3. Total quantity of irrigation given through drip system and farmer's method (surface flooding)

Treatment (ETo is reference evapotranspiration)		No. of irrigation	Total amount of water applied (mm) (rainfall + drip)								
			Maize-chickpea @0.6 ETo			Maize-wheat @0.9 ETo			Maize-field bean @0.6 ETo		
			Maize	Chickpea	Total	Maize	Wheat	Total	Maize	Field bean	Total
Maize @1.0 ETo	2015	18 + 12	459	220	679	459	331	790	459	164	663
	2016	18 + 12	553	368	921	553	541	1094	676	355	1031
	Pooled	18 + 12	506	294	800	506	436	942	568	260	828
Maize @0.8 ETo	2015	18 + 12	409	220	629	409	331	740	409	164	573
	2016	18 + 12	469	368	837	469	541	1010	469	354	823
	Pooled	18 + 12	439	294	733	439	436	875	439	259	698
Maize (surface flooding)	2015	5 + 5	690	300	990	690	420	1110	690	240	930
	2016	5 + 5	676	360	1036	676	540	1216	676	300	976
	Pooled	5 + 5	683	330	1013	683	480	1163	683	270	953

Table 4. Yield and water productivity of crops irrigated by the drip method in maize-based cropping system in Malaprabha command area

Treatment (Horizontal strips) (ETo is reference evapotranspiration)	Yield							Water Productivity (kg/m³)						
	Maize (t/ha)			*Rabi* (kg/ha) (vertical strips)				Maize			*Rabi*			
	2015	2016	pooled	Crop	2015	2016	Pooled	2015	2016	Pooled	Crop	2015	2016	Pooled
Maize @1.0 ETo	9.96	13.97	11.93	Chickpea	2925	2776	2850	21.72ab	25.15ab	23.44ab	Chickpea	13.26	7.54	10.40
				Wheat	3530	4729	4130				Wheat	10.69	8.74	9.72
				Field bean	1517	1787	1652				Field bean	07.44	5.04	6.24
Maize @0.8 ETo	9.29	13.02	11.16	Chickpea	2796	233.9	2568	22.22 a	27.77 a	24.99 a	Chickpea	12.68	6. 38	9.53
				Wheat	3329	4430	3880				Wheat	10.09	8.19	9.14
				Field bean	1335	1636	1486				Field bean	6.55	4.62	5.58
Maize (Surface flooding)	8.05	11.3.	9.73	Chickpea	2207	2109	2158	11.73c	20.39c	16.06c	Chickpea	7.36	5.86	6.61
				Wheat	3176	3915	3546				Wheat	7.56	7.25	7.41
				Field bean	1203	1416	1310				Field bean	5.01	4.72	4.87
SEm±	0.25	0.34	0.28		58	177	97	T test	T test	T test	SEm±	0.23	0.403	0.48
CD (P=0.05)	0.89	1.19	0.99		175	350	291	S	S	S	CD (P=0.05)	0.68	1.17	2.47

Chickpea @0.6 ETo; wheat @0.9 ETo; and field bean @0.6 ETo. S, Significant.

Table 5. Yield, water use, water productivity, water saving and economics of maize in *kharif* followed by chickpea, wheat, or field bean in *rabi*

Treatment (ETo is reference evapotranspiration)	Maize grain equivalent yield (t/ha)	Total water use (mm)	Water Productivity (kg/m^3)	Water saving (%)	Net returns (/ha)	Benefit to cost ratio	Superiority over existing farmers' method
Horizontal strip: maize grown in *kharif* with different irrigation levels							
Maize @1.0 ETo	19.4	857	22.64	17.87	213,838	4.73	₹51,194 profit with 17.87% water saving over farmers' method
Maize @0.8 ETo	17.5	769	22.76	26.28	187,219	4.26	₹24,575 profit with 26.28% water saving over farmers' method
Maize (surface flooding)	15.7	1043	15.09	-	162,644	3.84	-
SEm±	0.33				4,642.29	0.08	
CD (P=0.05)	1.30				18,228	0.31	
Vertical strip: *rabi* crops grown after maize with different irrigation levels							
Maize-chickpea @ 0.6 ETo	18.5	849	21.84	14.76	196,805	4.13	₹11,940 profit over maize-wheat system with 14.76% saving of water
Maize-wheat @0.9 ETo	17.5	993	17.64	-	184,865	4.06	
Maize-field bean @0.6 ETo	16.5	826	20.08	20.21	182,031	4.62	₹2,834 profit over maize-wheat system with 20.21% saving of water
SEm±	0.40				5,650.76	0.10	
CD (P=0.05)	1.58				22,188	0.39	
Interactions effect of *kharif* followed by *rabi* crops (H × V)							
Maize-chickpea @ 0.6 ETo	20.6	800	25.83	19.00	226,459	4.61	₹65,227 over maize–wheat system and ₹ 57,055 profit over maize-chickpea, farmers' method under drip with 19–27.5% saving of water
Maize-wheat @0.9 ETo	19.1	942	20.37	27.50	208,226	4.45	
Maize-field bean @0.6 ETo	18.3	828	22.18	28.80	206,828	5.11	
Maize-chickpea @0.6 ETo	18.3	733	25.08	36.69	194,552	4.10	₹25,148 over maize-wheat system and ₹33,370 profit over maize-chickpea farmers' method under drip with 3.6.69–24.76% saving of water
Maize-wheat @0.9 ETo	17.5	875	20.05	24.76	185,186	4.07	
Maize-field bean @0.6 ETo	16.5	698	23.76	39.98	181,919	4.62	
Maize-chickpea (surface flooding)	16.5	1013	16.38		169,404	3.70	-
Maize-wheat (surface flooding)	15.8	1163	13.61		161,182	3.67	-
Maize-field bean (surface flooding)	14.8	953	15.56		157,346	4.13	
SEm±	0.15				2103	0.04	
CD (P=0.05)	0.49				6859	0.13	

recorded in 0.8 ET0 (24.99 kg/m^3) was higher than that in the control (16.06 kg/m^3). The same pattern was repeated in the winter crops. The higher WP was owing to the considerable saving of irrigation water, greater yields, and higher nutrient-use efficiency (Ramah, 2008). Increase in irrigation volume not only failed to elicit any corresponding increase in the marketable yield of crops but also lowered the production efficiency of irrigation significantly (Imtiyaz *et al*., 2000). Ardell (2006) reported that application of nitrogen and phosphorus usually results in higher yields, thereby increasing the crop WUE. Adequate levels of essential plant nutrients are needed for higher yields and higher WUE.

Maize-grain-equivalent yield and economic parameters

Overall, drip irrigation at 1.0 ET0 resulted in significantly higher maize-grain-equivalent yield (19.4 t/ha) compared to 0.8 ET0 (17.5 t/ha) and control (15.8 t/ha) (Table 5). The same pattern was seen among the three winter crops that followed maize. However, the result of the interaction between the level of irrigation and the crop showed that the highest equivalent yield (20.6 t/ha) obtained from maize with drip irrigation at 1.0 ET0 followed by chickpea at 0.6 ET0. This combination (maize-chickpea) is recommended for the region if water supply is limited. However, all the three winter crops are grown in the Malaprabha command area, and farmers can make their choice going by market demand and the availability of seeds and other resources, so long as they switch to drip irrigation.

The economics of drip fertigation in maize-based cropping systems are presented in Table 5. Although the initial capital investment was high for a drip fertigation system, the benefits outweigh the costs given the long life of the system. Secondly, although the cost of cultivation was generally higher with drip irrigation, so were the net returns per hectare from maize at 1.0 ET0 followed by chickpea at 0.6 ET0 (about ₹2 Lakhs, or $2475/ha), at a B:C ratio of 4.61 and 19% savings in the volume of water.

Drip fertigation uses both water and applied nutrients more efficiently, thereby achieving higher productivity. Drip irrigation is the need of the hour especially in areas with water deficit and can overcome the constraints posed by an uncertain monsoon and irregular release of water from dams. By storing water (*in situ*) in farm ponds and by supplying it through the drip system, farmers can grow two or three crops in a year. The drip system should not be viewed merely from the economic point of view. Given the shrinking availability of land for cultivation and the diversion of available water to non-agricultural uses, it is of paramount importance that water made available for agriculture be used as efficiently by adopting such techniques as drip irrigation. In areas of acute scarcity of water, drip irrigation is the only way to enhance crop productivity.

Switching from surface irrigation to drip irrigation increased the income from maize in the rainy season and wheat in winter by ₹ 65,227/ha; increased the amount of water saved by 27.5%; and earned a net profit of ₹ 57,055/ha. Growing either chickpea or field bean in winter also led to higher profits and greater savings of water. As all these crop combinations are common in the command area, the crop to follow maize can be chosen based on the market price to maximize profits.

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