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Gravity-Fed Drip-Fertigation: An Efficient Water and Nutrient Management Tool for High Valued Crops in a Deep Tube Well Command of West Bengal

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Abstract: Drip-fertigation with proper irrigation scheduling can be an efficient and viable technology alternative to traditional irrigation and fertilizer management for enhancing crop productivity, water and nutrient use efficiency and economics. The gravity-fed drip fertigation with moderately deficit or optimum irrigation resulted in maximum yield (9.9-43.3 t ha^{-1}), water use efficiency (19.7-73.54 kg $ha^{-1}mm^{-1}$), fertilizer use efficiency (9-312 kg increase kg^{-1} NPK added), income (₹46250-₹144748 ha^{-1}) and BCR (2.05-4.41) for several high-value crops. The increase in yield, water-saving and income was 11.0-42.9%, 20.1-68.1% and 18.8-59.5%, respectively over farmers' traditional practices. Inclusion of partly pre-plant fertilization, plastic mulching for soil water conservation and vermicompost in the nitrogen management had additional influences in promoting the parameters studied.

Keywords: Drip irrigation, Fertigation, Yield, Water use efficiency, Water-saving, Income

Water is one the major environmental constraints affecting the sustainability of irrigated agriculture (Shamshiri et al 2011). Rapid population growth, increasing competitive demand from agricultural, industrial and domestic sectors, improved standard of living, decreasing water availability due to water pollution and groundwater mining and climatic variability have exacerbated the water crisis in the world (Dhiman et al 2015). The farmers' conventional surface method of irrigation is quite inefficient for input utilization and non-remunerative (Pramanik and Patra 2016). In this challenged situation in agriculture, many improved water-saving technologies have been developed and adopted around the world for efficient and economic utilization of precious irrigation water resources for maximum crop production while minimizing adverse impact on environment (Fereres and Soriano 2007, Kumari et al 2014). Deficit irrigation is a water management strategy which can cope with the risk of excessive water and nutrient leaching in one hand and simultaneously produce higher yield and input use efficiency on the other (Chai et al 2016, Filho et al 2020). However, drip irrigation is a modern and economically viable irrigation method and proves its superiority over other methods of irrigation because of its unique ability to supply precise but frequent water under low pressure in synchrony of crop evapotranspirative demand directly in the root zone of each plant (Rajurkar et al 2012, Abd El-Wahed and Ali 2013). Drip irrigation with proper scheduling is considered the best solution to save precarious water resources with increased yield and water use efficiency especially in the areas where water is either expensive or scarce or the soils are coarse textured (Deshmukh and Hardaha 2014). It is preferred for vegetable and fruit crops having high commercial value so that its high initial investment cost can be recovered with high economic return. The use of plastic mulch is an eco-friendly approach to conserve soil water, suppress weed growth, reduce disease and pest infestation, improve soil condition, moderate soil hydrothermal regime, reduce nutrient loss and increase yield and water use efficiency of crop (Bakshi et al 2015, Kader et al 2019).

Plant nutrients are also the most critical inputs for a resilient and sustainable agricultural production and quality improvement. Traditional fertilizer broadcasting across the surface of crop field is inefficient with low nutrient use efficiency and crop productivity (Rahman and Zhang 2018). Chemical farming especially the continued and indiscriminate use of nitrogen fertilizers have a hidden danger because of its adverse impacts on soil quality, human health, atmospheric and groundwater pollution as a result of nitrogen losses through leaching, ammonia volatilization and denitrification (Bishnoi 2018). Proper management of fertilizer application is thus very important to register higher fertilizer use efficiency. Adjustment of nitrogen fertilizer through balanced use of organic manure and inorganic fertilizer is an alternative for deriving higher soil and crop productivity and nutrient use efficiency (Singh et al 2014, Kumar et al 2019). Since both water and fertilizer are costly inputs, their optimum utilization is imperative for increase in yield. Drip fertigation which combines drip irrigation with soluble fertilizers as per crop requirement is the most effective and convenient way to achieve the target of higher water and fertilizer use efficiency (Sureshkumar et al 2016). In this perspective, the objective of the present paper was to evaluate the feasibility of gravity-fed drip-fertigation vis-à-vis farmers' practice on yield, water and fertilizer use efficiencies, water-saving and economics from high-value crops in a sandy loam soil.

MATERIAL AND METHODS

Experimental site: The experimental site is located between 22^{0}58'31'' N latitude and 88^{0}26'20'' E longitude with an altitude of 9.75 m above mean sea level in a humid sub-tropical climatic belt. Average annual rainfall was 1450 mm, of which nearly 75% being received during June through September. Intermittent rainfall showers during November-February and April-May were experienced. The weather was hot and humid during summer (May-June) and dry and cold during winter (December-January). Mean monthly temperature ranged between 9.5 to 23.7 ^{0}C in winter and 25.4 to 37.6^{0}C in summer. Mean relative humidity around the year fluctuated between 70 to 95%. Wind speed ranged from 0.2 to 3.69 kmph. Pan evaporation loss varied from 0.9 to 1.4 mm/day during December-January and 4.2 to 4.6 mm/day during April-May. Depth of watertable ranged from 5.6 to 6.8 m bgl. The soil (Typic Fluvaquept) was sandy loam in texture. Gravimetric soil water content at field capacity (-1/3 bar) and permanent wilting point (-15 bar) was 32.1 and 11.2% w/w, respectively on dry weight basis. Plant available soil water was 30.5 cm/m. The monthly rainfall and evaporation pattern of the experimental site and relevant soil properties are presented in Figure 1 and Table 1, respectively.

Data collection and methodologies adopted: A number of field experiments on gravity-fed drip-fertigation were conducted during the period 2006-07 to 2014-15 with the initiatives of AICRP-Irrigation Water Management, BCKV center, West Bengal to optimize irrigation water and fertilizer requirements for several high-value crops. The selected data for the designated crops were collected from the Annual Reports of 2009-2017. The standard methodologies for design layout, agronomic manipulations, proper irrigation scheduling as per crop water need and graded dose of N, P and K through drip-fertigation were adopted for each test crop. Some other interventions like integrated nitrogen management incorporating vermicompost as a source of nitrogen in the fertilization schedule and black polyethylene film of 80 µ thickness as mulch material were accommodated in the experimentation. All soluble N, P and K nutrients in the form of urea, acidified single super phosphate and muriate of potash at very low concentrations in multiple splits were applied by drip irrigation as per prescribed schedules. In some treatments, 50% NPK or, 100% PK or 50% N as vermicompost of the recommended dose of fertilizer (RDF) was incorporated as pre plant and the remaining dose was fertigated through drip irrigation. The amount and number of splitting for N, P and K doses for fertigation varied according to the type of crops, duration and critical growth stages. The required amount of fertilizer nutrients selected was dissolved in 10 L of water and the stock fertilizer solution was prepared. The desired amounts of nutrients were mixed in a 500 L capacity overhead tank placed at a height of 3.3 m above local ground surface to facilitate water movement on gravitational force. The irrigation water along with nutrients was applied in the drip-fertigation treatments. The evaporation data was recorded daily from a USWB Class A Pan located inside the experimental site. The reference evapotranspiration (ET_0) was determined by multiplying pan evaporation (E_p) with pan coefficient (K_p). The crop evapotranspiration (ET_c) was estimated by multiplying ET_0

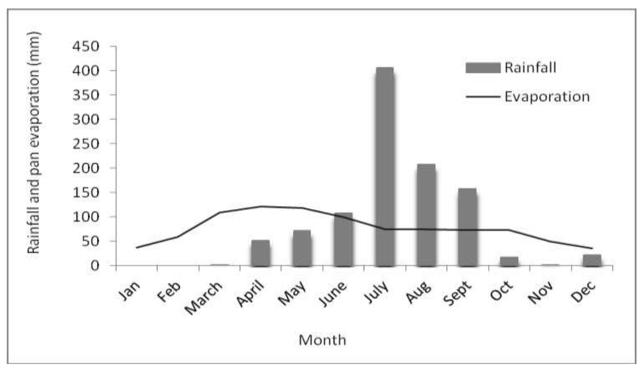

Fig. 1. Rainfall and evaporation pattern at the experimental site

Table 1. Important properties of the experimental soil

Parameter	Value
Sand (%)	69.8
Silt (%)	15.5
Clay (%)	14.7
Bulk density (Mg m^{-3})	1.49
pH (1:2.5)	6.9
EC (dS m^{-1})	0.37
CEC [cmol (p^+) kg^{-1}]	15.6
Organic carbon (g kg^{-1})	5.6
Available N (kg ha^{-1})	183.7
Available P (kg ha^{-1})	35.8
Available K (kg ha^{-1})	187.6

with crop coefficient (K_c) for different crop growth stages (Allen et al 1998). The amounts of irrigation and actual crop water use, marketable yield, water use efficiency (WUE), fertilizer use efficiency (FUE), water-saving and income gain from several test crops due to imposition of different adaptable drip-fertigation technique vis-à-vis farmers' traditional water and fertilizer management practice (control) were estimated. The economic assessment in terms of income and benefit-cost ratio (BCR) based on the prevailing market values of the produce and the inputs used for the experimentation were computed.

RESULTS AND DISCUSSION

Brinjal: Drip-irrigation at 100% ET_0 with 50% NPK as basal and remaining 50% NPK of RDF through fertigation recorded maximum fruit yield (14.42 t/ha), WUE (62.65 kg/ha/mm), FUE (9.0 kg increase/kg NPK) and income (₹50520/ha) with BCR as 2.05. The increase in yield, water-saving and income was 20.3, 21.43 and 26.5%, respectively over the farmer's practices (Table 2). The drip-irrigation at 100% ET_c with 100% PK as basal and 125% N of recommended dose (RD) as fertigation demonstrated highest fruit yield (16.65 t/ha), WUE (73.54 kg/ha/mm), FUE (11.52 kg increase/kg NPK) and income (₹46250/ha) with BCR as 2.64. The enhancement in yield, water-saving and income was 23.0, 28.65 and 29.6%, respectively over the conventional practices.

Guava: Imposition of drip-irrigation at 100% ET_c with 100% PK as basal and 100% N of RD through fertigation increased fruit yield by 11.0% (21.2 t/ha), WUE (19.7 kg/ha/mm), FUE (85.5 kg increase/kg NPK), water-saving by 20.1% and income by 18.8% (₹118400/ha) with BCR 3.03 over the traditional practices.

Broccoli-okra-cowpea cropping sequence: Application of moderately deficit drip-irrigation at 80% ET_c coupled with

Table 2. Effects of different irrigation scheduling and fertigation through drip system on yield, water and fertilizer use efficiencies, water-saving and income for various crops

Crop, variety and season	Drip irrigation schedule with/without mulch	Fertigation schedule	Recommended dose of fertilizer (kg ha^{-1})	Yield (t ha^{-1})	Yield increase (%)	WUE (kg ha^{-1} mm^{-1})	FUE (kg increase Kg^{-1} NPK)	Water - saving (%)	Income (₹ ha^{-1})	Income increase (%)	BCR
Brinjal cv. Muktakeshi (Rabi)	Drip irrigation at 1.0 ET_0 (irrigation 198 mm at 2-day interval and total crop water use 230 mm)	50% NPK as basal and 50% NPK as fertigation in 10 splits at 7-day interval	120:60:90	14.42	20.3	62.65	9.0	21.43	50520	26.5	2.05
Brinjal cv. Muktakeshi (Rabi)	Drip irrigation at 1.0 ET_c (irrigation 205 mm at 2-day interval and total crop water use 226 mm)	100% PK as basal and 125% N as fertigation in 10 splits at 7-day interval	120:60:90	16.65	23.0	73.54	11.52	28.65	46250	29.6	2.64
Guava cv. Khaja	Drip irrigation at 1.0 ET_c (irrigation 576 mm at 6-day interval and total crop water use 1074 mm)	100% PK as 2-splits and 100% N in 10 splits at 10-day interval as fertigation	200:160:260 g/plant	21.2	11.0	19.7	85.5	20.1	118400	18.8	3.03
Broccoli cv. Green magic-Okra cv. Pankaj –Cowpea cv. Local	Drip irrigation at 0.8 ET_c (irrigation 238 mm at 2-day interval and total crop water use 668 mm) with BPM	100% PK as basal and 100% N as fertigation in 6-7 splits in broccoli and okra and 2 splits in cowpea	Broccoli-100:60:60 Okra-90:60:40 Cowpea-20:40:40	33.4 broccoli eq.	23.34	50.0	15.96	68.1	362609	59.5	4.41
Gladiolus cv. American beauty (Rabi)	Drip irrigation at 0.8 ET_c (irrigation 115 mm at 3-day interval and total crop water use 158 mm)	100% PK and 50% N through vermicompost as basal and 50% N as fertigation in 6 splits	100:60:60	9.9 (fresh spike yield)	34.1	62.41	6.52	66.4	80000	33.4	2.78
Banana *cv.* Martaman (AAB, Silk)	Drip irrigation at 0.8 ET_0 (irrigation 318 mm at 3-day interval in summer and 5-day interval in winter and total crop water use 721 mm)	100% N in 20-splits, P in 2 splits and K in 9 splits as fertigation at 10-30 days interval	200:50:250 g/plant	43.3	42.9	60.1	312	66.9	144748	19.8	2.07

ET_0: Reference pan evaporation, ET_C: crop evapotranspiration, BPM: black polythene mulch

100% RD of PK as basal application and 100% RDN through fertigation under black polyethylene mulch condition enhanced broccoli equivalent yield by 23.34% (33.4 t/ha), WUE (50 kg/ha/mm), FUE (15.96 kg increase/kg NPK) and water-saving by 68.1% over the usual irrigation and soil fertilization without mulching. The corresponding income increase was 59.5% (₹362609/ha) with BCR 4.41 over the farmers' practice.

Gladiolus: Moderately deficit drip-irrigation scheduling of 80% ET_c with basal application of 100% RD of PK + 50% RDN through vermicompost and 50% RDN through fertigation increased the fresh spike yield by 34.1% (9.9 t/ha), WUE (62.41 kg/ha/mm), FUE (6.52 kg increase/kg NPK), water-saving by 66.4%, income by 33.4% (₹80000/ha) with BCR 2.78 over the existing surface irrigation and soil fertilization.

Banana: Moderately deficit watering through drip-irrigation at 80% ET_0 with 100% RDF through fertigation increased fruit yield by 42.9% (43.3 t/ha), WUE (60.1 kg/ha/mm), FUE (312 kg increase/kg NPK) and water-saving by 66.9.1% over the traditional practices of flood irrigation and soil fertilization. The corresponding income increase was 19.8% (₹144748/ha) with BCR 2.07.

The increase in yield of different crops and cultivars under drip-fertigation ranged between 11.0 to 42.9% as compared with conventional irrigation and soil fertilization. These results are in consistent with those of earlier researchers (Brahma et al 2010, Vijayakumar et al 2010, Deshmukh and Hardaha 2014, Kumari et al 2014, Debbarma et al 2018). The water use efficiency and fertilizer use efficiency obtained in drip-fertigation, irrespective of crop and water and nutrient scheduling adopted, varied widely ranging from 19.7 to 73.54 and 9 to 312 kg increase/kg NPK added, respectively with increase in water-saving of 20.1 to 68.1% and income of 18.8 to 59.5% over farmers' conventional practices. This improvement could be largely due to steady movement of water and nutrients both laterally and vertically as a result of precise and controlled watering at higher frequency with several splits application of fertilizers through drip-irrigation according to the growth stage specific crop requirements. The drip fertigation enabled more favorable and uniform distribution of water and nutrients in the vicinity of active root zone across the growth stages which encourages better root growth and development and more absorption of water and nutrients from soil and subsequent translocation of assimilates from source to sink resulting in higher marketable yield and input use efficiency (Sureshkumar et al 2016, Debbarma et al 2018). Drip-fertigation reduces losses of water and nutrients in deep percolation and leaching in one hand and allows efficient and appropriate use of water and nutrients by plants on the other which ensures better resource use efficiency (Chai et al 2016, Filho et al 2020). In contrarily, the soil water and nutrient distribution down the layers of the soil profile throughout the growing season was uneven and inconsistent or asymmetrical under conventional irrigation and soil fertilization, permitting excessive leaching and deep percolation losses and subsequently causing lesser availability in soil for root absorption and the plants suffer from acute soil water and nutrient stresses for a longer period which adversely affected the plant with depressed yield and poor input use efficiency (Pawar and Dingre 2013, Pramanik and Patra 2016).

CONCLUSIONS

Gravity-fed drip fertigation with moderately deficit or optimum irrigation scheduling recorded maximum yield, water and fertilizer use efficiency, water-savings and economic return as compared with farmers' conventional water and fertilizer practices. Based on the resource availability, imposition of fertilization partly as pre-plant and rest through fertigation or full drip-fertigation, integrated nitrogen management and plastic mulching as soil water conservation were found to be techno-economically feasible for the farmers of deep tube well command in West Bengal or similar agro-climatic conditions. However, the commission of the system is costlier and requires more skill and expertise for operation and maintenance.

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