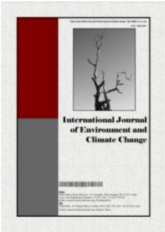

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Growth, Productivity, Economics, and Water Use Efficiency of *Rabi* Castor (*Ricinus communis*) as Influenced by Drip Fertigation

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

A field experiment was conducted in shallow Alfisols at Hyderabad for three consecutive years to evaluate the performance of castor on yield, water use efficiency, and economics for *rabi* castor cultivation under different irrigation schedules. The experiment was laid out in randomized block design and replicated thrice. The experiment comprised 100, 80, 60 percent of N and K applied through urea and K_2SO_4 through a drip in two schedules (0.6 and 0.8 Epan) compared with soil application of nutrients and flood irrigation. Significantly higher *rabi* castor seed yield (3,302 kg ha^{-1}), oil yield (1479 kg ha^{-1}), highest gross returns (₹1,25,489 ha^{-1}), net returns (₹86,754 ha^{-1}) and B:C ratio (3.65) were realized when irrigations were scheduled by drip at 0.8 Epan along with the supply of the full amount of N & K through fertigation. However, the highest water-use efficiency (4.85 kg ha^{-1} mm^{-1}) and water productivity (0.485 kg m^{-3}) were registered when irrigations were scheduled by drip at 0.6 Epan +100% N & K through fertigation.

Keywords: Castor yield; drip-fertigation; water productivity.

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1. INTRODUCTION

Castor bean (*Ricinus communis* L.) is a multipurpose crop; its oil has numerous applications worldwide and the last decade demonstrated a growing international demand [1]. "Castor bean is one of the main and promising agricultural crops for the production of biodiesel, castor oil and castor bean cake, which have high added value, especially the castor oil" [2].

"India is the world's largest producer of castor, castor seed oil, and its derivatives contribute to almost 80% share of total world production. Due to its varied and versatile uses in various industries, castor oil has a high level of demand in the world growing at 3 to 5% per annum. Castor is an ideal candidate for the production of high-value, industrial oil feedstock because of the high oil content (48-60%) of the seed, high levels of oil production with high levels of ricinoleic acid" [3,4].

"India holds a premier and dominant position in castor production and supplies in the world. Castor crop was grown in an area of 8.26 lakh ha, with 19.20 lakh tonnes production and a productivity of 2,300 kg ha^{-1} during 202-21. India meets more than 90% demand of castor oil globally, thereby enjoying dominant position in the world castor scenario. The global castor derivatives market is estimated to be over US$ 4.0 billion, and is highly dependent on India" [5]. Despite the phenomenal increase witnessed in production and productivity over the last two decades, there are wide regional disparities in the productivity of castor.

The productivity of castor during the *kharif* season is low in the southern states *viz.,* Telangana, Andhra Pradesh and Tamil Nadu and it varies from 311-568 kg ha^{-1} depending on rainfall pattern. Castor cultivation in southern states during *kharif* season is risky due to the incidence of botrytis grey rot (*Botrytis ricini*) and rainfed cultivation. Castor cultivation in *rabi* is safe, highly productive, and profitable bust essentially under irrigation. Raising castor during winter (*rabi)* season with assured irrigation using hybrids is a new dimension with the promise that provides greater stability and higher productivity and avoids many problems of *kharif* castor.

"The water requirement of castor may vary from 453 mm to 1178 mm ha^{-1} in the growing season" [6,7]. "The competition for water among various sectors is increasing and will continue to meet rising domestic demands for expanding population, industrial development, and environmental restrictions. Therefore, it is prudent to switch over to efficient irrigation systems which will increase the efficiencies and help to realize increased crop yields per drop of water. Drip irrigation is the frequent application of small quantities of water on (surface drip) or below the soil surface (subsurface drip) as drops by emitters are placed along a water delivery integral dripper line. It is a proven efficient irrigation management tool that allows precise control of water over the root zone of the crop resulting in consistently high yields" [3]. "Adequate and balanced nutrition is an important component in increasing the productivity of crops and achieving potential yields of hybrids under irrigated conditions. High cost of fertilizers and low use efficiency, wastage results in non-utilization of nutrients due to inadequate moisture, increased labor costs for split applications in long-duration crops like castor, drip fertigation is an effective and efficient opportunity to attempt achieving higher resource use efficiency (water, nutrient, and labour) through drip fertigation. In addition, better water and fertilizer management by drip through fertigation can help reduce fertilizer inputs, water needs, and runoff" [8]. The present investigation was conducted to evaluate the response to various drip irrigation/fertigation schedules and assess its influence on productivity, profitability and use efficiency of *rabi* castor.

2. MATERIALS AND METHODS

The field experiment was conducted in shallow Alfisols at Narkhoda Research Farm of IIOR, Hyderabad during *rabi* 2013-14 to 2015-16. The soil type was typical red chalka soil with shallow depth with the presence of hard pan/rocky substratum. Drip irrigation system along with fertigation was tailor-made for *rabi* castor (Hybrid-DCH-519) and fertigation treatments were super imposed in eight treatment combinations in Randomized Block Design with three replications. Adoption of RBD was possible due to customized drip system installation.

The eight treatment combinations comprised of I_1: Drip irrigation at 0.6Epan + 50% N & K through fertigation; I_2: Drip irrigation at 0.6Epan + 80% N & K through fertigation; I_3: Drip irrigation at 0.6Epan +100% N & K through fertigation; I_4: Drip irrigation at 0.8Epan + 50% N & K through fertigation; I_5: Drip irrigation at 0.8Epan + 80% N

& K through fertigation; I_6: Drip irrigation at 0.8Epan + 100% N & K through fertigation; I_7: Drip irrigation at 0.8Epan + 80% N & K through soil application; I_8: Surface method of irrigation in ridges and furrows at 0.8 IW CPE^{-1} ratio with an IW of 50 mm and 100% RDF (Plate 1). The full dose of phosphorus (40 kg P_2O_5/ha) was applied as basal in the form of single super phosphate and in fertigation, 50%, 80%, and 100% RDN and 30 kg RDK was applied in equal splits each, at ten-day intervals (RDF: - Recommended dose of fertilizer 80 kg N + 40 kg P_2O_5+ 30 kg K_2O/ha). A Gross plot size of 7.2 x 12.0 m was maintained. The crop was sown (Hybrid-DCH-519) with a seed rate of 5 kg ha^{-1} at 120 cm x 60 cm spacing. Other cultural practices and plant protection measures were followed as per recommendations.

2.1 Drip System Installation

A customized drip system was installed in the experimental field during 2013-14 Narkhoda farm and the experiment was continued in fixed plots till 2015-16 (Plate 1). The drip system was laid out in such a way that the main pipe was connected with the head unit. The line was divided into sub-main having separate controlling valves for each irrigation level (I_1-I_8) as per the treatment. Lateral lines connected with sub-main were laid out at a distance of 120 cm. The in-line drippers were spaced on lateral lines at a distance of 60 cm.

The drip irrigation treatments were given every 3rd day, based on the fraction of pan evaporation of three days. Daily pan evaporation (Epan) was measured with the help of the USDA Class-A pan evaporimeter. The data of evaporation and rainfall parameters recorded from the meteorological observatory of Narkhoda farm of IIOR were considered for calculating cumulative pan evaporation (CPE). Drippers were operated at 1.2 bar pressure for a required period as per treatment to deliver water at a flow rate of 4 liters per hour (LPH). The volume of water application during different crop growth stages was measured through water meters. The measured quantity of urea and K_2SO_4 (water-soluble) were dissolved in a plastic container and applied to the drip system through ventura. In the surface method of irrigation, an irrigation depth of 5.0 cm was applied at 0.8 IW CPE^{-1}. The relative water content (%) in leaves was assessed at 60 DAS before irrigation in each treatment. Water use efficiency (kg $ha^{-1}mm^{-1}$) was calculated by dividing the seed yield (kg) of castor by total water use (ha mm^{-1}). Water productivity (kg m^{-3}) was calculated by dividing the seed yield (kg) of castor by total water use (m^3). The oil content of seed was estimated by using Nuclear Magnetic Resonance (NMR) analyzer as per the procedures suggested by Yadav et al. [9] and was expressed as a percentage. Oil yield (kg ha^{-1}) was calculated by multiplying the oil content (%) in each treatment with the corresponding seed yield. The cost of cultivation included the cost of various inputs like cost towards land preparation, seeds, seed treatment, fertilizer, sowing, agro-chemicals, weeding, inter culture, harvesting, threshing, cleaning, and packing, etc. The cost of drip irrigation (Ci) included the cost of labor, electricity, and maintenance required for the irrigation application. The investment on the cost of irrigation was rationalized considering that the drip irrigation system was operational for 2 seasons per year for 10 years. The following expressions were used for assessing the economics [10,11].

$$C_t = C_c + C_i \text{ , } C_j = \frac{P \times i \times (1+i)^n}{2\{(1+i)^n - 1\}}$$

Where,

C_t = Total cost of cultivation (₹ $season^{-1}$ ha^{-1}); Cc = Cost of cultivation (₹ ha^{-1} $season^{-1}$); C_i = Cost of drip irrigation (₹ ha^{-1} $season^{-1}$); P = Cost of drip irrigation system, ₹ ha^{-1}; n = Life of the drip irrigation system, years; i = Prevailing rate of interest.

2.2 Soil Fertility and Water Quality

The initial soil fertility of the experimental site was: soil pH 7.23, organic carbon content 0.45%, low available N (201 kg ha^{-1}), medium in available P (32 kg ha^{-1}), and medium K (317 kg ha^{-1}) content. The DTPA-Zn content was sufficient (1.7 mg kg^{-1}) and S content was medium and ranged between 12-15 mg kg^{-1}.

"Irrigation water quality recorded a pH of 7.85; Ec-0.703 ds m^{-1}: Ca^{+2}- 6.02 m.eq l^{-1}; Mg^{+2} -1.35 m.eq l^{-1}; $Na^{+2;}$ Carbonates- 0.42 m.eq l^{-1}; bi-carbonates 2.31 m.eq l^{-1} and all were well within the permissible limits and was found to be safe for irrigation. Castor seed samples were analyzed for the determination of N, P_2O_5, and K_2O uptake as per the procedure suggested by Prasad" [12].

Plate 1. Imposition of drip fertigation (I_1-I_8) treatments

3. RESULTS AND DISCUSSION

3.1 Growth and Yield Attributes

The pooled analysis of results revealed that drip irrigation/fertigation significantly influenced plant height, the number of branches, spike length, capsules/plant, seed yield, stalk yield, and oil percent. However, 100-seeds weight was not influenced significantly due to different drip irrigation treatments (Table 1).

Plant height was significantly higher with drip irrigation at 0.8 Epan + 100% N & K through fertigation (I_6) (131 cm), was lower with surface irrigation (I_8) and drip irrigation at 0.6 Epan + 50% N&K through fertigation (90 cm and 105.6 cm); respectively). The significantly higher number of branches (8 plant^{-1}) were recorded with drip irrigation at 0.8 Epan +100% N&K through fertigation I_6. The lower number of branches/plant (5.50 no. plant^{-1}) were found with the surface method of irrigation and drip irrigation at 0.6 Epan + 50% N&K through fertigation (5.73 no. plant^{-1}). Significantly, longer spikes (84.4 cm) were recorded with drip irrigation at 0.8 Epan +100% N&K through fertigation (I_6) followed by drip irrigation at 0.8 Epan + 80% N&K through soil application (I_7) and the lowest was with the surface method of irrigation (I_8) and drip irrigation at 0.6 Epan + 50% N&K through fertigation (63.1 cm and 73 cm respectively). The lowest number of capsules (260 plant^{-1}) was found in the surface method of irrigation (I_8) and the highest was recorded with drip irrigation at 0.8 Epan +100% N&K through fertigation I_6 (387 plant^{-1}) followed by drip irrigation at 0.8 Epan +80% N&K through soil application I_7 (369 plant^{-1}).

The increase in growth and yield attributes under drip fertigation could be due to supply of water-soluble fertilizers at different crop growth stages as per crop demand and easy availability and uptake of nutrients leading to enhanced photosynthesis, expansion of leaves, and translocation of nutrients to reproductive parts compared to surface method irrigation along with soil application of nutrients. General losses due to leaching, volatilization, de-nitrification, etc. are avoided under controlled application of water through drip fertigation [13]. This mechanism was true even in castor as reported in previous studies conducted by Prasad [12] and Patel et al. [6].

3.2 Proportion of Male Flowers

The proportion of male flowers was found to be highest (38%) in the surface irrigation method. In general, drip irrigation at different fractions resulted in lower male flowers (3.2-25.2%) compared to surface irrigation. The proportion of male flowers was lowest (3.2%) in drip irrigation at 0.8 Epan +100% N&K through fertigation (I_6). Irrigation supply through drip irrigation/fertigation resulted in lower number of male flowers compared to surface/flood irrigation since castor is a cross-pollinated crop with monoecism and is sensitive to genotype-environment interactions. Abiotic stresses (nutrient and moisture) during critical stages promote more male flowers which in turn lead to reduction in castor crop yield. This situation is frequented in castor production in Alfisols further modified due to methods of irrigation. In surface irrigation due to variation in soil moisture content between cycles of irrigation coupled with air temperature lead to production of more male flowers. Whereas in drip fertigation the required water (3 day interval) and nutrients (10 day interval through fertigation) were supplied at frequent intervals which maintained a uniform wet regime and supply of nutrients throughout the crop growth cycle resulting in production of fewer male flowers and higher seed yield [14].

Table 1. Growth and yield attributes of *rabi* castor as influenced by drip-fertigation treatments (pooled means of 2013-14 to 15-16)

	Treatments	Plant height (cm)	Branches (no.)	Spike length (cm)	100-seed weight (cm)	Capsules $plant^{-1}$	Days to 50% flowering	Oil conten t (%)	Oil yield (Kg ha^{-1})	Proportion of male flowers $spike^{-1}$
I_1	Drip irrigation at 0.6Epan + 50% N & K through fertigation	105.6	5.73	73.0	29.06	222	52.0	45.80	1015	16.6
I_2	Drip irrigation at 0.6Epan + 80% N & K through fertigation	112.9	6.60	71.7	29.74	302	51.3	45.23	1104	15.4
I_3	Drip irrigation at 0.6Epan + 100% N & K through fertigation	118.6	6.93	75.1	30.86	334	51.7	45.86	1386	10.3
I_4	Drip irrigation at 0.8Epan + 50% N & K through fertigation	116.7	5.86	74.3	29.94	273	52.8	45.30	1144	25.2
I_5	Drip irrigation at 0.8Epan + 80% N & K through fertigation	128.0	6.66	76.9	30.77	363	51.2	45.60	1176	8.3
I_6	Drip irrigation at 0.8Epan + 100% N & K through fertigation	131.0	8.0	84.4	31.40	387	50.1	44.80	1479	3.2
I_7	Drip irrigation at 0.8Epan + 80% N & K through soil application	120.8	7.27	78.2	29.63	369	51.2	44.86	1142	5.2
I_8	Surface irrigation with RDF at 0.8 IW/CPE	90.0	5.50	63.1	28.51	260	50.5	44.61	911	38
	S Em ±	3.88	0.317	2.08	0.612	24.1	0.751	0.273		
	CD (P=0.05)	11.8	0.963	6.31	NS	73.3	NS	0.829		

Table 2. Seed yield, water-use-efficiency and profitability of *rabi* castor as influenced by drip-fertigation treatments (Pooled means of 2013-14 to 15-16)

	Treatments	**Seed yield (kg ha^{-1})**								**B:C Ratio**		
		2013-14	**2014-15**	**2015-16**	**Pooled mean**	**Stalk yield (Kg ha^{-1})**	**Harvest Index (%)**	**Water Use Efficiency (Kg $ha^{-1}mm^{-1}$)**	**Water productivity (Kg m^{-3})**	**Gross returns (₹ ha^{-1})**	**Net returns (₹ ha^{-1})**	**B:C ratio**
I_1	Drip irrigation at 0.6Epan + 50% N & K through fertigation	1846	2478	2324	2216	4311	51.4	3.55	0.355	84208	47840	2.29
I_2	Drip irrigation at 0.6Epan + 80% N & K through fertigation	1924	2754	2646	2441	4754	51.3	3.91	0.391	92771	54983	2.59
I_3	Drip irrigation at 0.6Epan + 100% N & K through fertigation	2050	3690	3328	3023	4957	61.0	4.85	0.485	114861	76126	3.34
I_4	Drip irrigation at 0.8Epan + 50% N & K through fertigation	2332	2523	2721	2525	4675	54.0	3.04	0.304	95963	59595	2.61
I_5	Drip irrigation at 0.8Epan + 80% N & K through fertigation	1946	2897	2893	2579	4893	52.7	3.10	0.310	97989	60201	2.74
I_6	Drip irrigation at 0.8Epan + 100% N & K through fertigation	2654	3786	3467	3302	5883	56.1	3.97	0.397	125489	86754	3.65
I_7	Drip irrigation at 0.8Epan + 80% N & K through soil application	1987	2670	2980	2546	5124	49.7	3.06	0.306	96735	58947	2.70
I_8	Surface irrigation with RDF at 0.8 IW/CPE	1812	2081	2232	2042	3921	52.1	2.46	0.246	77583	45848	2.61
	S Em ±	225	185	139	144	179						
	CD (P=0.05)	621	562	423	439	543						

3.3 Relative Water Content (%)

In general, the mean relative water content (%) was higher in drip-irrigated treatments compared to the surface method of irrigation. The relative water content ranged between 82.2-84% in different treatments. The highest relative water content (84%) was noticed in scheduling drip irrigation at 0.8Epan + 50% N & K through fertigation (I_4) and scheduling drip irrigation at 0.8Epan + 80% N & K through soil application (I_7) which was followed by scheduling drip irrigation at 0.8Epan + 80% N & K through fertigation (83.2%). The lowest mean relative water content (82.2%) was noticed in the surface method of irrigation at 0.8 IW/CPE ratio (Fig. 1). Favorable relative water content under drip irrigation scheduled at 0.8Epan treatments could be attributed to the maintenance of higher soil water potential contributing favorable plant water balance as compared to the crop in surface irrigation method with a longer frequency of applied irrigation water resulting in lower water potential and lower turgor.

3.4 Seed Yield

The results indicated that (Table 2) drip fertigation at 0.8 Epan + 100% N&K through fertigation (I_6) resulted in significantly higher seed yield of 2654, 3786 3467 and 3302 kg ha^{-1} during 2013-14, 2014-15, 2015-16 and pooled, respectively which remained at par with drip fertigation at 0.6 Epan +100% N&K through fertigation (I_3).During 2015-16, significantly highest seed yield (3467 kg ha^{-1}) was recorded with drip irrigation at 0.8 Epan +100% N&K through fertigation (I_6) which was at par with drip irrigation at 0.6 Epan + 100% N&K through fertigation (I_3) (3328 kg ha^{-1}). The lowest seed yield of 1812, 2081, 2232 and 2042 kg ha^{-1} was recorded in surface irrigation during 2013-14, 2014-15, 2015-16 and in pooled results, receptively. This was closely followed by drip irrigation at 0.6 Epan + 50-80% N&K through fertigation (I_1-I_2). The performance of drip irrigation at 0.8 Epan + 80% N&K through soil application (2546 kg ha^{-1}) was at par with that of drip irrigation at 0.8 Epan + 80% N&K through fertigation (2579 kg ha^{-1}) and 0.8 Epan + 50% N&K through fertigation (2525 kg ha^{-1}). The magnitude of per cent seed yield increased with 100% N&K through drip irrigation at 0.6 Epan (I_3) and 0.8 Epan (I_6) over surface method of irrigation (I_8) was to the tune of 32.4-38.1% in pooled results. The increase in seed yield under drip fertigation was due to maintenance of favourable soil moisture status in the root zone which in turn helped plants to maintain better relative water content, turgor pressure, thus utilized moisture as well as nutrients more efficiently from wetted area and ultimately enhanced vegetative as well as reproductive growth of the crop. Though, drip fertigation at 0.8 Epan + 100% N&K through fertigation (I_6) resulted in numerically higher seed yield, dry stalk yield over drip fertigation at 0.6 Epan + 100% N&K through fertigation (I_3) they were statistically at par. Relatively higher seed yield at 0.8 Epan was due to higher soil water content in the wetted portion of the plant root zone remains fairly constant because irrigation water is supplied slowly and frequently on daily basis as per the crop water requirement. Thus with high frequency drip irrigation the time-average soil water potential increases (soil water suction decreases) in the crop root zone and is restricted to a narrow range with elimination of the wide fluctuations in the soil water content, which typically result from conventional surface irrigation methods, as factors affecting plant growth and yield as was evident from variation in soil moisture content (based on crop ETc) in drip irrigated (I_6 and I_3) crop versus surface irrigated check basin (I_8). The maintenance of continuously high soil water potential, thus minimizing wide fluctuations in soil water content during the irrigation cycle, is an important and advantageous feature of drip irrigation (1). Other discussions [2,15] and [11] also imply that the best irrigation policy is to apply water as frequently as possible. Thus, maintained favourable soil water balance under I_6, I_3 and I_5 drip irrigation treatments as was evident from better soil moisture regimes which aided the crop plants to put forth improved performance over other treatments, since water plays a vital role in the carbohydrate metabolism, protein synthesis, cell wall synthesis and cell enlargement [16,2]. The main reason for realizing higher yields in drip fertigation treatments (I_6 and I_3) was due to the production of longer spikes and a higher number of capsules/plant (Plate 2).

A similar trend was noticed in stalk yield. Significantly highest stalk yield (5883 kg ha^{-1}) was recorded with drip irrigation at 0.8 Epan + 100% N&K through fertigation (I_6). The lowest stalk yield was recorded with the surface method of irrigation (3921 kg ha^{-1}). Studies conducted in Greece, the seed yield of 1080 kg ha^{-1} was observed on the hybrid Pronto with 147 mm of rain was increased to 4040 kg/ ha due to the addition of 363 mm of water through irrigation

[17]. The higher yields in drip fertigation treatments could also be attributed to the production of more female flowers. The proportion of male flowers in the surface method of irrigation was higher (38%) compared to minimal male flower production in drip fertigation plots (Table 2). Thus, a higher proportion of female flowers in relation to male flowers resulted in higher seed yield in drip irrigation/fertigation treatments.

3.5 Oil Content and Oil Yield

The oil content of *rabi* castor was significantly influenced due to different irrigation treatments. Significantly the highest oil content was recorded (45.86%) in drip irrigation at 0.6 Epan + 100% N&K through fertigation (I_3) and the lowest was recorded in surface irrigation (I_8) (44.61%). The oil content of other drip irrigation treatments was intermediate and ranged between 44.8-45.8%. The oil yield was the highest (1479 kg ha^{-1}) with drip irrigation at 0.8 Epan + 100% N&K through fertigation (I_6) followed by drip irrigation at 0.6 Epan + 100% N&K through fertigation (I_3) (1386 kg ha^{-1}) and the lowest oil yield (911 kg ha^{-1}) was recorded in surface irrigation (I_8). The recommended source of K fertilizer in surface irrigation was Muriate of Potash (MOP) which contains (62% K only). Whereas in drip irrigation/fertigation the recommended K fertilizer was Sulphate of Potash (K_2 SO_4) which contained about (53% K and 17% S) and was more water soluble and used in ferigation. Sulphur is an important secondary nutrient that has critical role in improving the oil content in oilseed crops. Additional supply of S through drip irrigation/fertigation might have improved the oil content of castor marginally in the present experiment.

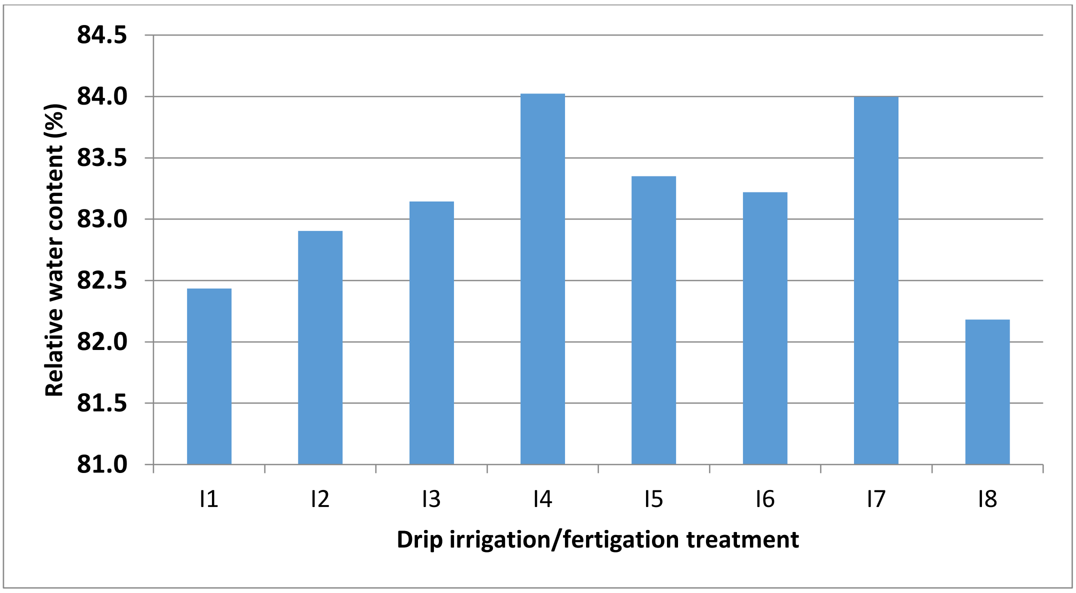

Fig. 1. Relative Water Content (RWC %) in castor leaves as influenced by drip fertigation treatments

Plate 2. Performance of castor (DCH-519) through drip fertigation

3.6 Water Use Efficiency and Water Productivity

Results further revealed that the highest water use efficiency of 4.85 kg ha^{-1} mm^{-1} and highest water productivity (0.485 kg m^{-3}) was recorded (Table 2) under drip irrigation at 0.6 Epan + 100% N&K through fertigation (I_3) followed by drip fertigation at 0.8 Epan + 100% N&K through fertigation (I_6) (3.97 kgha^{-1}mm^{-1}; 0.397 kg m^{-3}) compared to the surface method of irrigation (2.46 kg ha^{-1}mm^{-1}; 0.246 kg m^{-3}). Thus, water use efficiency was found to be higher when drip irrigation was scheduled under dry regime (0.6 Epan) than wet regime (0.8 Epan). Higher WUE at I_3 was due to better utilization of water at lower fractions, whereas at higher levels of water application, the rate of water losses through evapotranspiration and percolation were high and the relative increase in yield was not proportionate to the increasing rate of water application. Similar results were reported by Patel et al. [6]; Singh et al. [18] and Vagahasia et al. [11].

3.7 Economics

Raising *rabi* castor through drip irrigation at 0.8 Epan + 100% N&K through fertigation (I_6) resulted in the highest gross returns (₹125489 ha^{-1}), net returns (₹86754 ha^{-1}) and B: C ratio (3.65) followed by drip fertigation at 0.6 Epan + 100% N&K through fertigation (I_3) (gross returns ₹114861 ha^{-1}; net returns ₹76126 ha^{-1} and B: C ratio 3.34). Surface irrigation recorded the lowest profitability (Table 2). Similar results were also confirmed by Singh et al. (2012). The economic analysis suggested drip irrigation can be profitable even without Government subsidy. Under the scenario of the scarcity of water and depleting water table, the output would help in economizing water and nutrients leading to higher productivity and profitability for castor growers.

3.8 Nutrient Uptake in Castor

The uptake of nutrients was highest in I_6 (drip irrigation at 0.8 Epan + 100% N & K through fertigation) with 97.5 kg N, 13.6 kg P, and 17.5 kg K at 0.8 Epan due to improved NUE and the lowest uptake of NPK was noticed with Drip irrigation at 0.6 Epan + 50% N & K through fertigation (I_1) (Fig. 2).

Fertigation through micro-irrigation systems is very effective in both semi-arid/arid and humid areas where nutrients and other salts are leached to the perimeter of the wetted zone. Thus, crops almost always respond well to fertigation with micro-irrigation systems, especially on sandy soils and alfisols with low cation exchange capacities. Fertilizer applied through conventional methods may be unavailable to micro-irrigated crops in these areas unless it is placed within the irrigated zone.

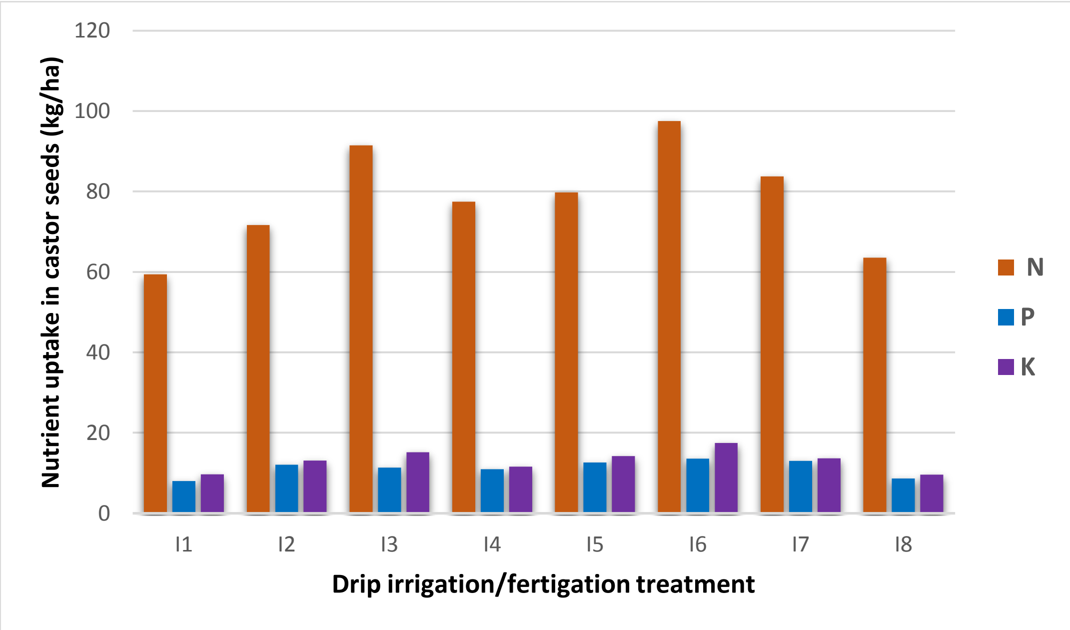

Fig. 2. Effect of drip fertigation on nutrient uptake in castor seeds

The potentiality of drip system for irrigation and fertigation in *kharif* grown castor was evaluated at Junagadh, Gujarat. The results revealed that drip irrigation scheduled at 0.6 CPE and fertigation of 100% dose of nitrogen significantly increased seed and stalk yield with remarkably higher water use efficiency and net returns as compared to surface irrigation and soil application of nitrogen. The results of field experiment conducted at Junagadh (Gujarat) in *kharif* indicated that drip fertigation at 0.8 PEF +75% RDN resulted in significantly higher seed yield of castor [11].

4. CONCLUSION

From these results, it could be concluded that on shallow Alfisols of Hyderabad, drip fertigation at 0.8 Epan + 100% N & K through fertigation at 10 days intervals resulted in higher seed yield (3302 kg ha-1) and oil yield (1479 kg ha-1) of *rabi* castor leading to higher profitability (B:C ratio 3.65).

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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