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Deficit Irrigation-Nutrient Coupling on Growth, Yield, Fruit Quality and Water Use Efficiency of Indian Jujube

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Abstract

Sustainability of quality fruit production in Indian jujube is adversely affected by improper irrigation and nutrient management. A field study comprising of four irrigation levels (drip irrigation at 0.8, 0.6 and 0.4 of pan evaporation (E_0) and surface irrigation at 1.0 IW/CPE with 50 mm depth) and three nutrient levels (100% RDF, 75% RDF+25% RDF as vermicompost and 50% RDF+50% RDF as vermicompost) was conducted during 2018-19 (11 months) on jujube plant. Results showed that tallest tree (3.72 m), greatest tree circumference (0.32 m), maximum fruits tree^{-1} (563), highest fruit weight (15.5 g) and fruit yield tree^{-1} (8.42 kg) were recorded with drip irrigation at 0.8 E_0 with 100% RDF. Minimum growth, yield components and yield were found with drip irrigation at 0.4 E_0 with 50% RDF+50% RDF as vermicompost. Seasonal ETa was 373.6, 409.4 and 446.4 mm for drip irrigation at 0.4, 0.6 and 0.8 E_0, respectively and 694 mm for surface irrigation. Maximum CWUE of 18.87 g tree^{-1} mm^{-1} was obtained with drip irrigation at 0.8 E_0 with 100% RDF. About 55.7-75.5% water was saved by drip irrigations which could bring an additional area of 55.5-85.8% under drip irrigated jujube. Highest predicted yield of 9.02 kg tree^{-1} was accomplished with 278 mm irrigation water. This model approach could serve as a good guideline to yield potential decision in relation to limited irrigation water for jujube growers in the Indo-Gangetic plains or similar agro-climatic regions.

Keywords: Drip irrigation, jujube, nutrient, water use efficiency, yield

1. Introduction

Indian Jujube or ber (*Ziziphus mauritiana* Lamk.) is one of the very ancient and most important hardy fruit trees of tropical and sub-tropical climates of the world. It belongs to the genus Ziziphus of the family Rhamnaceae. It holds a prominent position in fruit kingdom in Asia, Middle-East countries and Africa, but ironically it is still considered a less privileged minor fruit crop in India. The cultivation of Jujube is gaining popularity in the arid and semi-arid regions of Indian states. It is extensively grown in plains of Maharashtra, Gujarat, Madhya Pradesh, Punjab, Haryana, Rajasthan, Bihar, Karnataka, Andhra Pradesh, Tamil Nadu, West Bengal and Assam. It has low maintenance cost, wider adaptability, low water requirement, early maturity, high yield potential, huge monetary returns, enormous scope for value addition and better suitability in all types of lands even in waste or marginal

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lands (Martinuzzo, 2006). India ranks second among Jujube growing countries in the world after China. India occupies an area of 90,000 ha under improved jujube cultivars with an average fruit productivity of 8.34 t ha^{-1} (Awasthi and More, 2009). It is a versatile tree plant providing fruits, fodder, fuel wood and fencing materials. It is considered as functional food because the fruits are rich source of minerals like P, K and Fe; constituents like carbohydrate, vitamin C, A and B complex and protein (Pareek and Yahia, 2013), besides having bioactive medicinal substances like triterpenic acid and flavonoids that have wide pharmacological effect on humans (Li et al., 2007; Boora and Bal, 2008; Al Zhao et al., 2008; Choi et al., 2011).

Water and nutrients are the most vital and critical environmental factors. The symbiotic association between these two essential resource inputs is determining the sustainability of irrigated agriculture (Hanumanth et al., 2016; Liu et al., 2017). Water is the major limiting factor in farm sector causing decreased available soil water status, depressed crop growth and yield (Tiwari et al., 2003). Though, the jujube tree is drought resistant, it is sensitive to moderate to severe soil water deficit during fruit maturation stage which negatively affects the absorption, utilization and translocation of nutrients and significant reduction in marketable fruit yield (Dayal et al*.,* 2010; Galindo et al., 2016). Under limited irrigation water sources, adoption of precise deficit irrigation strategy during some non-critical periods or all along the growth stages can prevent severe water stress and resulted in relatively higher yield, increased water use efficiency and saving of labour (Kang and Zhang, 2004). Drip irrigation is the modern tool of water saving technology where small quantity of water under low pressure at frequent interval in synchrony with crop and local atmospheric demand, is delivered directly in the root zone vicinity and has gained widespread acceptance as an efficient and economically viable irrigation method (Nalliah et al*.*, 2009; Rajurkar et al*.,* 2012). This method was more accessible than other methods of surface irrigation due to minimal soil evaporation, runoff and drainage losses (Feleafel and Mirdad, 2013; Deshmukh and Hardaha, 2014). Drip irrigation with correct scheduling approach is regarded as one of the solutions to save precarious water resource without placing the plants under water stress and can have direct bearing on tree health and fruit yield, size and quality (Meghwal and Kumar, 2014; Meena et al., 2015). Furthermore, the plant also requires the balanced supply of nutrients for proper vegetative and reproductive growth and fruit production. The deficiency of nutrients would restrain absorption and utilization of water and seriously retards the growth of crop. The indiscriminate and continuous conventional chemical fertilization deteriorates the physical, chemical and biological environment of soil, decreases soil microbial activity and creates health hazard to humans due to toxic residual effects (Dash et al., 2015). The organic manures as a supplement of chemical fertilizers can be used to meet the crop nutritional demand and curtail the cost of expensive synthetic fertilizers (Rodriguez et al., 2008). The judicious use of inorganic fertilizers and organic manures in right kind and proportion is a viable alternative to sustain the soil and crop productivity and economic profitability (Fan et al., 2009; Russo et al., 2010). The unscientific use of water and nutrients can pose a serious imbalance between water and nutrients in soil which has deleterious effect on growth, development and yield of crop (Liu et al., 2017).

In the Indo-Gangetic plains of West Bengal, Indian Jujube is a challenging and promising remunerative fruit tree. It has a high market demand all the year round because of its nutritional and medicinal values, but its supply chain is inadequate to meet the consumers' requirements. The farmers customarily follow the basin method to irrigate the plant, which is quite inefficient to enhance fruit yield and quality. The plant also experiences moderate to severe water stress between the irrigation interval periods. Less attention is paid to apply balanced supply of nutrients to plant resulting in depressed yield and monetary return. Most of the research studies are mainly focused on the influence of single factor, such as irrigation or, fertilizer nutrients on growth, fruit yield and economic benefits. Simultaneous application of proper irrigation and nutrient management may be encouraging to optimize yield and quality of produce. The state with its versatile soil and climatic conditions occupies a respectable position in terms of area and production. However, the information on the efficacy of different irrigation methods in association with nutrients manipulations for the plant is absent. Keeping all these points in view, the present investigation was planned with the objective of developing an appropriate irrigation-nutrient management schedule for improving the yield, quality and water use efficiency of Indian jujube.

2. Materials and Methods

2.1. Location, climate and soil

The field experiment was carried out on Indian Jujube tree during the growing season of 2018-19 at Central Research Farm, Regional Research Station, Bidhan Chandra Krishi Viswavidyalaya, Gayeshpur in Nadia district belonging to the lower Indo-Gangetic plains of West Bengal, India. The site is located at a latitude of $22^0$58'31'' N and longitude of $88^0$26'20'' E with an average altitude of 9.75 m above mean sea level. The climate is humid subtropical with an average annual rainfall of about 1500 mm. Of which, 75-80% is received during the four monsoon months of June through September. Sporadic rainfall during April-May and November-February is the common feature of the region. The wind speed velocity across the year varies from 0.2 to 3.69 kmph. The pan evaporation loss ranges from 0.9-1.4 mm day^{-1} during December-January and reaches as high as 4.2-4.6 mm day^{-1} during April-May. The mean monthly maximum and minimum temperature and maximum and minimum relative humidity ranged from

25.9 to 36.3°C and 10.9 to 26.7°C and 89.4 to 97.4% and 45.4 to 84.9%, respectively during the period of investigation (March 2018 to February 2019). The amount of rainfall during the growing season was recorded as 1043.9 mm. The plant experienced varying degrees of water stress across the growth stages except in the initial developmental stage (July). The soil is sandy loam in texture and classified as Typic Fluvaquept with good drainage and water transmission properties. The physical, hydrophysical and chemical properties of the experimental soil are presented in Tables 1 and 2.

2.2. Experimental details

2.2.1. Treatments and design layout

The treatments comprising of twelve treatment combinations with four irrigation levels (I_1: surface irrigation at 1.0 irrigation water to cumulative pan evaporation ratio (IW/CPE) at 50 mm depth treated as control, I_2: drip irrigation at 0.8 pan evaporation replenishment (E_0), I_3: drip irrigation at 0.6 E_0 and I_4: drip irrigation at 0.4 E_0) as main factors and three nutrient levels (F_1: 100% recommended dose of fertilizer (RDF) as chemical fertilizer, F_2: 75% RDF as chemical fertilizer+25% RDF as vermicompost and F_3: 50% RDF as chemical fertilizer+50% RDF as vermicompost) as sub-factors were laid out in a split plot design with three replications.

Table 1: Physical and hydrophysical properties of the experimental soil

Soil depth (cm)	Soil texture (%)			BD ($Mg\ m^{-3}$)	Ks ($mm\ hr^{-1}$)	Infiltration ($mm\ hr^{-1}$)	FC (%,w/w)	PWP (%,w/w)
	Sand	Silt	Clay					
0-15	70.17	15.75	14.08	1.49	23.5	18.2	23.64	11.16
15-30	72.41	16.24	11.35	1.53	22.3	14.5	21.38	10.74
30-45	78.92	12.27	8.81	1.58	23.1	12.3	19.52	9.43
45-60	74.56	14.01	11.36	1.51	21.9	11.6	22.53	10.57

BD: bulk density, Ks: hydraulic conductivity, FC: field capacity, PWP: permanent wilting point

Table 2: Chemical characteristics of the experimental soil

Soil depth (cm)	p^H (1:2.5)	EC ($dS\ m^{-1}$)	Organic C ($g\ kg^{-1}$)	Available N ($kg\ ha^{-1}$)	Available P ($kg\ ha^{-1}$)	Available K ($kg\ ha^{-1}$)
0-15	6.87	0.25	5.21	168.1	31.9	141.5
15-30	6.63	0.22	4.56	150.2	29.3	127.3
30-45	6.54	0.19	4.13	141.3	25.7	102.7
45-60	6.52	0.17	3.42	132.5	23.3	98.4

EC: electrical conductivity

2.2.2. Agronomic manipulations

The experimental field was partitioned into the 36 sub-plots according to the experimental design. The disease-free seedlings of jujube tree cv. Bau-1 were transplanted on 26 March 2018 at 5 m row to row and 5 m plant to plant distance accommodating 400 plants hectare^{-1}. The recommended dose of chemical fertilizers tree^{-1} year^{-1} was administered @ 400:200:100 g of N, P_2O_5 and K_2O in the form of urea, single superphosphate and muriate of potash, respectively. The fertilizers as per prescribed schedule were applied in three equal splits during mid-June, July and August. The measured quantity of vermicompost (2.5% N, 1.5% P_2O_5 and 1.2% K_2O on dry- weight basis) used as organic source of nutrients was incorporated as single basal dose in the pit during final land preparation and was thoroughly mixed up with the soil. The trees were pruned in late May by removing all primary branches leaving 40 cm from base of the trunk. The matured fruits were harvested manually in four pickings during 21-28 February 2019. During the experimentation, the necessary cultural operations like weeding, earthing-up and standard plant protection measures were equally adopted in all the treatments. The treatment wise and replication wise data on crop growth and yield characteristics viz., plant height, tree circumference, number of fruits tree^{-1}, fruit weight and fruit yield plant^{-1} were computed at harvest.

2.2.3. Irrigation scheduling

Irrigation treatments were imposed based on surface method of irrigation scheduling at 1.0 IW/CPE with 50 mm depth at 10-12 days interval in the dry period whereas drip irrigation was scheduled at 0.8, 0.6 and 0.4 of E_0 at 2 days interval. Eight (8) irrigations were applied in surface irrigation while 39 in gravity fed drip irrigation. A common irrigation of 20 mm depth was given just after planting to all sub-plots to establish the seedlings and maintain uniform soil moisture regime, thereafter irrigation was applied as per proposed irrigation schedules. In surface irrigations, when IW/CPE ratio reached the target level, the exact amount of water was applied. The amount of rainfall received during the crop growing period (from planting to harvesting) was 1043.7 mm. Irrigation was initiated on first week of April 2018 and continued up to second week of February 2019.

2.3. Estimation of irrigation water requirement

The amount of irrigation water applied to jujube tree by gravity drip irrigation system was calculated by the equation as, $I = E_p \times K_p \times K_c \times P - R_e$

where, I is the amount of irrigation water applied (mm), E_p is the open pan evaporation (mm), K_p is the pan coefficient or pan factor, K_c is the crop coefficient, P is the wetted area (%) and R_e is the effective rainfall (mm). The mean K_c value was adopted as 0.846 across the growth stages of plant. The lateral interval was assumed to be equal to the dripper interval for selected plot and P was taken as 100% to calculate the amount of irrigation to be applied (Karmeli and Keller, 1975). The daily evaporation data was measured from a USDA Weather Bureau Class A Pan Evaporimeter located adjacent to the experimental site on a wooden support base at a height of 15 cm above the soil surface. K_p value was taken as 0.75. In surface irrigation, water discharged from shallow tube well was measured by Parshall flume placed at the entrance of selected sub-plot. But in gravity fed drip irrigation system, groundwater was pumped out from a deep tubewell to a 500 L capacity over head tank placed at a height of 3.3 m from the local ground surface to facilitate water flow by gravitational force. Two drippers plant^{-1} were provided on either side of plant at 30 cm apart. The discharge rate of each dripper for gravity drip irrigation was 1.8 lph with operating pressure of 0.45 kg cm^{-2}. The lateral drip lines of 12 mm diameter were arranged in such a way that every row had two laterals at 30 cm interval. The amount of water intake was controlled by check valve arrangement in each lateral pipe. Groundwater was of good quality (EC 0.36 dS m^{-1}) and was used safely for irrigating the tree.

2.4. Estimation of seasonal crop water use

Seasonal crop water use or actual crop evapotranspiration (ETa) for jujube tree under the different irrigation treatments during the entire growing period was computed by the one-dimensional field water balance equation (Simsek et al., 2005) as, ETa = I+P-D+Cp–Rf±ΔS

where, ETa is the seasonal actual crop evapotranspiration (mm), I is the irrigation water applied (mm), P is the precipitation (mm), D is the drainage (mm), C_p is the contribution through capillary rise from groundwater (mm), Rf is the surface runoff (mm) and ±ΔS is the change in soil water storage in the profile between planting and harvest time (mm) in the 0-60 cm active rooting zone depth. The portion of rainfall retained in the active rooting depth which was used to meet the crop evaporative demand was considered effective rainfall i.e. Re=P–D. The capillary rise from groundwater (Cp) was assumed to be negligible as depth of water table was more than 5-6 m below ground surface. In this study, Rf was eliminated by providing suitable bund at 50 cm height around the sub-plot and the irrigation water applied carefully to prevent overflow. Thus, ETa =I+Re±ΔSW. The monthly and daily consumptive use of water (ETc) by jujube tree was computed and summarized in Table 3. It is evident from the data that daily and monthly water requirement was much higher in the month of October (peak reproductive or fruit setting stage) and lesser in January-February (fruit maturation stage).

Table 3: Monthly pan evaporation (PE), reference evapotranspiration (ET0) and crop evapotranspiration (ETc) of jujube plant at different days after planting

Month	PE (mm)	ET_0 (mm)	ETc (mm)	Daily ETc (mm day^{-1})
April'18	122.05	91.54	45.40	1.51
May'18	118.01	88.51	43.90	1.46
June'18	99.54	74.66	50.84	1.69
July'18	73.60	55.20	37.59	1.25
August'18	74.26	55.70	37.93	1.26
Sept'18	72.68	54.51	37.12	1.23
Oct'18	72.70	54.53	68.81	2.29
Nov'18	49.77	37.33	47.11	1.57
Dec'18	34.54	25.91	32.69	1.08
January'19	37.23	27.92	26.36	0.87
February'19	17.70	13.28	17.70	0.59
Total	772.08	579.06	445.45	14.8

PE: pan evaporation, ET0: reference evapotranspiration, ETc: crop evapotranspiration

2.5. Crop water use efficiency

Crop water use efficiency (CWUE) is considered one of the key water use indicators for sustainability of irrigated agriculture. It is calculated as the ratio of marketable yield to seasonal water depleted by the crop in the process of evapotranspiration (Howell, 2000) as CWUE = Y/ETa (kg tree^{-1} mm^{-1})

where, Y=Fruit yield (kg tree^{-1}) and ETa=Actual crop evapotranspiration (mm)

2.6. Computation of additional irrigated area

The additional irrigated area (x) i.e. the area that can be brought under irrigation network by using the water saved from drip irrigation was calculated by the equation as given below:

X=(Water saved from drip irrigation/Total water used for drip irrigation)×100

2.7. Statistical analysis

The data obtained for different plant growth, yield and quality characteristics of plant were subjected to analysis of variance (ANOVA) using software packages of MS Excel and SPSS 16.0 version. The appropriate standard error of mean (SEm±) was calculated in each case. Statistical significance between means of individual treatments was assessed using the least significant difference (LSD) test at p<0.05 (Gomez and Gomez, 1984).

3. Results and Discussion

3.1. Growth characteristics, yield components and yield

The growth characteristics, yield components and yield of Indian jujube were significantly influenced by the individual and combined effects of different irrigation and nutrient management (Table 4). A perusal of the data showed that among the adopted irrigation treatments, tallest plant (3.65 m), maximum tree circumference (0.28 m), greatest number of fruits tree^{-1} (544), heavier fruit weight (15.1 g) and highest fruit yield (7.93 kg tree^{-1}) were found with drip irrigation scheduling at 0.8 E_0 (I_2). These values were significantly superior over drip irrigation scheduling at 0.6 E_0 (I_3) and surface irrigation (I_1) with corresponding value of 2.96 m, 0.21 m, 525, 13.6 g and 7.41 kg tree^{-1} and 3.28 m, 0.24 m, 485, 14.7 g and 6.67 kg tree^{-1}, respectively. Conversely, significantly smaller plant height (2.32 m), minimum tree circumference (0.15 m), lowest number of fruits tree^{-1} (451), lighter fruit weight (12.3 g) and lowest fruit yield (5.98 kg tree^{-1}) were observed with drip irrigation scheduling at 0.4 E_0 (I_4). The increase in fruit yield over surface irrigation was 18.9% for I_2 and 11.1% for I_3. The results indicate that optimum supply of water by imposition of drip irrigation at 0.8 E_0 (I_2) had positive impacts on growth, yield components and yield of fruit crop. On the contrary, higher level of deficit drip irrigation scheduling at 0.4 E_0 applying relatively lower amount of irrigation water (I_4) as well as surface irrigation (I_1) with higher amount of water application had negative effects as a result of constant and intermittent water stress exposure across the physiological stages causing lesser growth and development of the plants and reduced yield. This clearly indicates that the tree plant is very sensitive to water stress and controlled low volume of water application by moderate deficit drip irrigation at 0.8 E_0 throughout the growth stages is pre-requisite for attaining maximum growth, yield characteristics and fruit yield.

With regard to the effect of the nutrient management, application of 100% RDF through mineral fertilizer (N_1) recorded significantly the tallest tree (3.18 m), highest tree circumference (0.25 m), maximum number of fruits tree^{-1} (518), heavier fruit weight (14.3 g) and maximum fruit yield (7.29 kg tree^{-1}) which were superior to the treatment providing 75% RDF as mineral fertilizer+25% RDF as vermicompost (N_1) except in fruit yield where N_1 and N_2 did not show any statistical variation. The combined application of nutrients through 50% RDF as mineral fertilizer+50% RDF as vermicompost (N_3) recorded the lowest growth characteristics, yield attributes and yield. This reveals to the fact that sole application of recommended dose of readily available mineral fertilizer nutrients in splits doses as compared with that of the integration of organic manure and inorganic fertilizers was much congenial for adequate plant nutrition. These results are in contrary to the findings of Meena et al. (2014) that

Table 4: Effect of different levels of irrigation and nutrient management on growth characteristics, yield components and fruit yield of jujube during 2018-19

Treatment	Tree height (m)	Tree circumstance (m)	No. of fruits tree^{-1}	Fruit weight (g)	Fruit yield (kg tree^{-1})
Irrigation (I)					
I_1	3.28	0.24	485	14.7	6.67
I_2	3.65	0.28	544	15.1	7.93
I_3	2.96	0.21	525	13.6	7.41
I_4	2.32	0.15	451	12.3	5.98
SEm±	0.013	0.005	1.41	0.09	0.02
LSD (p=0.05)	0.045	0.017	4.97	0.32	0.07
Nutrient (N)					
N_1	3.18	0.25	518	14.3	7.29
N_2	3.10	0.23	509	14.0	7.27
N_3	2.88	0.18	476	13.48	6.44
SEm±	0.017	0.004	1.18	0.09	0.021
LSD (p=0.05)	0.052	0.013	3.58	0.28	0.062
Interaction (I×N)					
I_1N_1	3.38	0.27	486	15.2	6.83
I_1N_2	3.31	0.25	493	14.7	6.96
I_1N_3	3.15	0.20	475	14.2	6.23
I_2N_1	3.72	0.32	563	15.5	8.42
I_2N_2	3.68	0.29	550	15.1	8.35
I_2N_3	3.55	0.23	520	14.7	7.02
I_3N_1	3.18	0.24	558	13.9	7.71
I_3N_2	3.09	0.22	542	13.7	7.67
I_3N_3	2.61	0.17	474	13.2	6.85
I_4N_1	2.42	0.17	465	12.6	6.18
I_4N_2	2.32	0.16	452	12.5	6.11
I_4N_3	2.22	0.12	435	11.8	5.66
	I×N N×I	I×N N×I	I×N N×I	I×N N×I	I×N N×I
SEm±	0.031 0.022	0.009 0.008	2.391 2.44	0.176 0.158	0.039 0.035
LSD (p=0.05)	0.095 0.106	NS NS	7.648 7.568	NS NS	0.124 0.13

I_1: surface irrigation @ 1.0 IW/CPE at 50 mm depth, I_2: drip irrigation at 0.8 E0 (evaporation replenishment), I_3: drip irrigation at 0.6 E0, I_4: drip irrigation at 0.4 E0; N_1: 100% RDF as mineral fertilizer, N_2: 75% as mineral fertilizer+25% RDF as vermicompost, N_3: 50% RDF as mineral fertilizer+50% RDF as vermicompost; NS: non-significant maximum yield of Indian jujube was found under integrated nutrient management schedule under jujube based horti-pasture system.

The coupling effects between irrigation and nutrient management showed that at each irrigation regime, there was consistent decrease in growth, yield variables and yield with incremental substitution of mineral nutrients by vermicompost substrate with some minor deviations. However, maximum tree height (3.72 m), greatest tree circumference (0.32 m), highest number of fruits tree^{-1} (563), maximum fruit weight (15.5 g) and fruit yield tree^{-1} (8.42 kg) was recorded with the treatment combination of moderate deficit drip irrigation scheduling at 0.8 E_0 with 100% RDF (I_2N_1) which was statistically at par with the treatment combination of drip irrigation at 0.8 E_0 with 75% RDF as mineral fertilizer+25% RDF as vermicompost (I_2N_2) with the corresponding value of 3.68 m, 0.29 m, 550, 15.1 g and 8.35 kg, respectively barring a few. The shortest trees (2.22 m), lowest tree circumference (0.12 m), minimum number of fruits tree^{-1} (435), lighter fruit weight (11.8 g) and lowest fruit yield tree^{-1} (5.66 kg) were obtained with higher deficit drip irrigation scheduling at 0.4 E_0 in conjunction with 50% RDF as mineral fertilizer+50% RDF as vermicompost (I_4N_3). On the other hand, surface irrigation in conjunction with 100% RDF as mineral fertilizer (I_1N_1) registered moderate values in respect of growth characters, yield constituents and fruit yield. These results pointed out to the fact that imposition of moderate deficit drip irrigation at 0.8 E_0 along with the application of 100% RDF as mineral fertilizer (I_2N_1) was found to be the best treatment combination for achieving the highest physiological growth, yield components and yield of jujube. The combination of moderate deficit drip irrigation at 0.8 E_0 in association with 75% RDF as mineral fertilizer plus 25% RDF as vermicompost (I_2N_2) was the alternative choice with almost comparable results. Neither excessive irrigation application by surface method of irrigation nor higher deficit irrigation scheduling by drip irrigation system in conjunction with integrated nutrient management was conducive for enhancing growth and development of jujube tree.

3.2. Seasonal crop water use and water use efficiency

The average data on water balance components, seasonal crop water use or actual crop evapotranspiration (ETa) and crop water use efficiency (CWUE) by jujube tree are furnished in Table 5. During the cropping period, the amount of irrigation water was scheduled based on different pan evapotranspiration replenishment (E_0) through drip irrigation system and 1.0 IW/CPE with 50 mm depth by surface irrigation system. The depth of irrigation water applied in surface irrigation was 420 mm whereas it was 103.0, 144.6 and 186.1 mm for drip irrigation scheduling at 0.4, 0.6 and 0.8 E_0, respectively. The effective rainfall during the experimental period ranged from 247.7 to 253.5 mm. The soil profile water contribution varied between 20.5 mm and 22.8 mm. This component was relatively higher in drip than in surface irrigation system and that too at lower irrigation regime than in higher irrigation regime. Thus the seasonal crop water use or actual crop evapotranspiration (ETa) was 373.6 mm, 409.4 mm and 446.4 mm for drip irrigation at 0.4 E_0 (I_4), 0.6 E_0 (I_3) and 0.8 E_0 (I_2) respectively. The corresponding value in surface irrigation (I_1) was 694.0 mm. The results showed that maximum CWUE (18.1 g tree^{-1} mm^{-1}) was recorded with drip irrigation at 0.6 E_0 followed by 0.8 E_0 (17.76 g tree^{-1} mm^{-1}) and 0.4 E_0 (16.01 kg tree^{-1} mm^{-1}), respectively; whereas minimum CWUE (9.61 g tree^{-1} mm^{-1}) was accomplished with surface irrigation. The application of water through drip irrigation system improved the CWUE by 84.8% for I_2, 88.3% for I_3 and 66.6% for I_4 as compared with surface irrigation (I_1) indicating the efficiency of drip irrigation system in the utilization of water for encouraging yield. Likewise, 100% RDF as mineral fertilizer (N_1) exhibited maximum CWUE (16.03 g tree^{-1} mm^{-1}) followed immediately by 75% RDF as mineral fertilizer+25% RDF as vermicompost (N_2) as 15.86 g tree^{-1} mm^{-1} and the least with 50% RDF as mineral fertilizer+50% RDF as vermicompost (N_3) as 14.23 g tree^{-1} mm^{-1}. This suggests that chemical fertilization was found better in water utilization for promoting yield, whereas the individual or combined application of mineral fertilizers and organic manures resulted in decreased water use and consequent yield depression. The coupling effect of irrigation and nutrient management showed that maximum CWUE of 18.87 g tree^{-1} mm^{-1} was obtained with treatment combination of drip irrigation at 0.8 E_0 and 100% RDF (I_2N_1) followed by 18.83 g tree^{-1} mm^{-1} for drip irrigation at 0.6 E_0 with 100% RDF(I_3N_1), 18.61 g tree^{-1} mm^{-1} for drip irrigation at 0.6 E_0 along with 75% RDF as mineral fertilizer+25% RDF as vermicompost (I_3N_2) and 18.60 g tree^{-1} mm^{-1} for drip irrigation at 0.8 E_0 along with 75% RDF as mineral fertilizer+25% RDF as vermicompost (I_2N_2). Higher CWUE with moderate to moderately high deficit irrigation schedule (i.e. 0.8 to 0.6 E_0) by drip irrigation system in association with 100% RDF or 75% RDF+25% RDF as vermicompost was particularly due to the proportional increase in fruit yield with relatively lesser amounts of water utilization by the plant. Comparatively low CWUE was observed with higher level of deficit drip irrigation scheduling at 0.4 E_0 in combination with different nutrient assembly was ascribed to disproportional increase in yield in response to per unit water use. The lower CWUE was recorded in surface irrigation along with different nutrient combinations indicating maximum losses of water by various mechanisms without influencing yield augmentation. These findings are in line with observations of Rajurkar et al. (2012) that higher water use efficiency and water saving in drip irrigation as compared to surface irrigation was the result of precise amount of water application directly in the root zone proximity at right time and minimum water losses in evaporation, runoff and deep percolation.

3.3. Water saving and water utilization

The data on water saving due to imposition of different drip irrigation schedules as compared with surface irrigation and

Table 5: Effect of different levels of drip irrigation and nutrient management on actual crop evapotranspiration (ETa) and crop water use efficiency (CWUE) of jujube during 2018-19

Treatment	Profile contribution (mm)	Effective rainfall (mm)	≠Irrigation water (mm)	ETa (mm)	Fruit yield (kg tree^{-1})	CWUE (kg tree^{-1} mm^{-1})	Water saving (%)	Additional area under drip irrigation
Irrigation (I)								
I_1	20.5	253.5	420.0	694.0	6.67	9.61	-	-
I_2	21.9	238.4	186.1	446.4	7.93	17.76	55.7	55.5
I_3	22.4	242.4	144.6	409.4	7.41	18.10	65.6	69.5
I_4	22.8	247.7	103.0	373.6	5.98	16.01	75.5	85.8
Nutrient (N)								
N_1	21.9	245.4	213.4	480.7	7.29	16.03		
N_2	22.4	247.8	213.4	483.6	7.27	15.86		
N_3	21.5	243.4	213.4	478.3	6.44	14.23		
Interaction (I × N)								
I_1N_1	20.4	253.6	420.0	694.0	6.83	9.84		
I_1N_2	20.9	255.8	420.0	696.7	6.96	9.99		
I_1N_3	20.2	251.2	420.0	691.4	6.23	9.01		
I_2N_1	21.9	238.2	186.1	446.2	8.42	18.87		
I_2N_2	22.2	240.6	186.1	448.9	8.35	18.60		
I_2N_3	21.6	236.4	186.1	444.1	7.02	15.81		
I_3N_1	22.4	242.5	144.6	409.5	7.71	18.83		
I_3N_2	23.2	244.4	144.6	412.2	7.67	18.61		
I_3N_3	21.7	240.2	144.6	406.5	6.85	16.85		
I_4N_1	22.8	247.3	103.0	373.1	6.18	16.56		
I_4N_2	23.2	250.2	103.0	376.4	6.11	16.23		
I_4N_3	22.5	245.7	103.0	371.2	5.66	15.25		

I_1: surface irrigation @ 1.0 IW/CPE at 50 mm depth, I_2: drip irrigation at 0.8 E0 (evaporation replenishment), I_3: drip irrigation at 0.6 E0, I_4: drip irrigation at 0.4 E0; N_1: 100% RDF as mineral fertilizer, N_2: 75% as mineral fertilizer+25% RDF as vermicompost, N_3: 50% RDF as mineral fertilizer+50% RDF as vermicompost; ; ≠ 20 mm depth of irrigation water applied in all plots for establishing uniform plant stand and irrigation regime in field

corresponding additional unirrigated area likely to be brought under drip irrigation network is presented in Table 5. The results indicated that higher deficit drip irrigation regime at 0.4 E_0 saved about 75.5% of water as compared to surface irrigation, which could bring about 85.8% of additional unirrigated cultivable area under drip irrigated crop with irrigation schedule at 0.4 E_0. Similarly, moderately high deficit drip irrigation at 0.6 E_0 could save as much as 65.6% of water in comparison with surface irrigation. On utilizing this amount of water, it was possible to cultivate an additional area of 69.5% under drip irrigation schedule at 0.6 E_0. Likewise, moderate deficit drip irrigation at 0.8 E_0 was found to save about 55.7% water as compared to surface irrigation which would bring an additional unirrigated area of 55.5% under drip irrigation following scheduling of 0.8 E_0 for jujube cultivation.

3.4. Water-yield production function

The relationship between jujube fruit yield and amount of irrigation water applied was computed by non-linear regression analysis. Fruit yield was taken as the dependent variable (y) and was plotted against the independent variable irrigation water (x) to derive a mathematical function (Figure 1). A second degree polynomial equation was best fitted between the data of fruit yield and irrigation water. The predicted regression equation is as follow,

$$y = -0.00009x^2 + 0.05093x + 1.81248 \quad \text{(i)}$$

The value of coefficient of determination (R^2) was estimated at 0.974, which was statistically highly significant. In this modular approach, all drip and surface irrigation treatments were taken into consideration for projecting the fruit yield. In the graph, the linear or upward effect indicates the marked

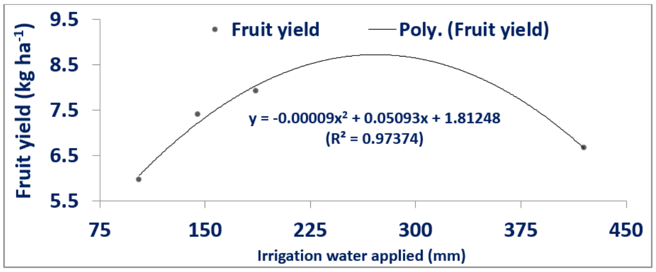

Figure 1: Relationship between jujube fruit yield and irrigation water applied

increase in fruit yield which was proportional to the increment of irrigation water applied because all the applied water was consumed by the plant, whereas the quadratic or downward effect displays the drastic reduction in yield with increasing amount of water application. This developed relationship can successfully be employed for projecting the marketable fruit yield under varying levels of irrigation water application. The predicted maximum fruit yield of 9.02 kg tree^{-1} was computed at the inflection point of the quadratic curve with 277.8 mm of irrigation water use. The projected decline in yield in the adopted irrigation treatment for surface irrigation at 1.0 IW/CPE, drip irrigation at 0.8 E_0, 0.6 E_0 and 0.4 E_0 were 26.1, 12.1, 17.8 and 33.7%, respectively. The highest reduction in fruit yield was found with higher level of deficit drip irrigation at 0.4 E_0 followed by surface irrigation which might be due to acute soil water stress all along the growth stages or some periods of growth stages, respectively resulting in more negative effect on crop growth and yield. Even the moderate or moderately high deficit drip irrigation schedules applying relatively higher amounts of irrigation water had adverse effects on plant in discouraging yields. These results reveal an interesting point for jujube growers from irrigation management point of view. Imposition of irrigation at 80% of pan evaporation replenishment (0.8 E_0) by drip irrigation scheduling at 2-day interval all through the physiological stages is inevitable for yield maximum. Thus in the present set of climatic variables and rainfall conditions, 278 mm of irrigation water could serve as a good platform for jujube growers in the Indo-Gangetic alluvial plains or similar agro-climatic regions for deriving maximum fruit yield and optimum utilization of available water resources. The equation can also be used as a better guideline to yield potential allocation decision related to limited irrigation water supply condition. The above results is in line with the findings of Bozkurt et al. (2006) who found significant second degree polynomial relationships between grain yield and irrigation water on hybrid corn under the Mediterranean condition.

4. Conclusion

Indian jujube is very responsive to irrigation and nutrient application. Drip irrigation at 0.8 E_0 coupled with 100% RDF produced maximum fruit yield, WUE and substantial water savings. Drip irrigation at 0.8 E_0 along with 75% RDF as chemical fertilizer+25% RDF as vermicompost could be the viable alternative. The predictive model can be used as guideline to yield potential in relation to limited irrigation water supply and useful to jujube growers of Indo-Gangetic plains or similar agro-climatic regions.

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