International Scholars Journals

International Journal of Irrigation and Water Management ISSN 5423-5294 Vol. 2 (1), pp. 001-007, January, 2015. Available online at www.internationalscholarsjournals.org © International Scholars Journals

Full length Research paper

Effect of water application method and deficit irrigation on yield, quality and irrigation water use efficiency of litchi (*Litchi Chinensis Sonn.*) cv Shahi

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Accepted 13 October, 2013

A field experiment was conducted to study the efficacy of deficit irrigation on litchi crop under two deficit irrigation (DI) strategies viz. reducing the quantity applied (Quantitative Deficit) and prolonging the period without irrigation (Temporal Deficit). Under quantitative deficit water was applied at 60, 40 and 20 % of ETc, where ETc is crop evapotranspiration. Temporal deficit was achieved through different irrigation start times viz. from 1stFebruary (pre flowering), 1stMarch (start of fruiting) and 1stApril (start of fruit development stage). Results showed that comparable litchi yields can be obtained even with deficit irrigation. Drip irrigation system recorded highest fruit weight (22.6 g) at 60 % ETc and irrigation starting from 1stMarch. The prolonged moisture stress between two irrigations under basin system resulted in lowest fruit length, smallest fruit diameter and higher fruit cracking percentage. Deficit water application under drip system resulted in higher reducing sugar content (7.5 %) of litchi fruits. Highest IWUE (57.1 g/m3) was observed in case of drip irrigation having 20 % ETc level and irrigation starting from 1stApril. Deficit irrigation showed great potential to increase the irrigation water use efficiency of litchi production with slight deviation in potential yield.

Key Words: Deficit irrigation, water use efficiency, litchi, drip irrigation.

INTRODUCTION

Litchi (*Litchi chinensisSonn*) is a sub-tropical fruit crop cultivated in northern and north eastern states of India with over 0.80 lakh ha area under cultivation yielding 5.38 lakh MT of litchi (NHB, 2013). The major litchi growing areas are located in tarai and bhavar regions of Indo-Gangetic plains. The five states of India viz. Bihar, West Bengal, Jharkhand, Chhatisgarh and Orissa, collectively known as litchi growing belt of India, contribute about 79.22 % to the total litchi production in India (NHB, 2013). Litchi is becoming more and more popular due to its distinct flavour, good taste, juicy aril giving cooling effect during hot summer (Chauhan *et al*, 2008). Litchi is also economically important as it has excellent domestic market as well as good export potential.

The litchi flowers in mid-February and fruits mature in the month of May (Yadav, 2011). The entire phenological sequence from flowering to fruit maturity takes place during February to May. In litchi growing areas this period of the year is characterized by soil water deficit, high temperature, low to no rainfall and low relative humidity. Absence of irrigation for prolonged time during this period may lead to severe decrease in litchi yields. Since, water scarcity is real threat to litchi production, efficient water management practices are required to ensure litchi production under limited water supplies. Irrigation plays an important role in raising and stabilizing yield and maintaining quality of litchi grown in tropical or sub-tropical climate.

The practice of deficit irrigation is been used in case of many fruit plants and has the potential to reduce the water use without reducing the crop yields significantly. In the context of growing water shortages, Deficit Irrigation (DI) can be a better option to reduce irrigation water use. Under deficit irrigation a moderate water stress is applied at particular phenological stage of the crop in order to reduce the total water use with no or little effect on overall plant health and crop yields. The quantity of irrigation and time of application are the two important decision variables in deficit irrigation. Although litchi is a hardy plant species able to tolerate drought fairly well during vegetative period,

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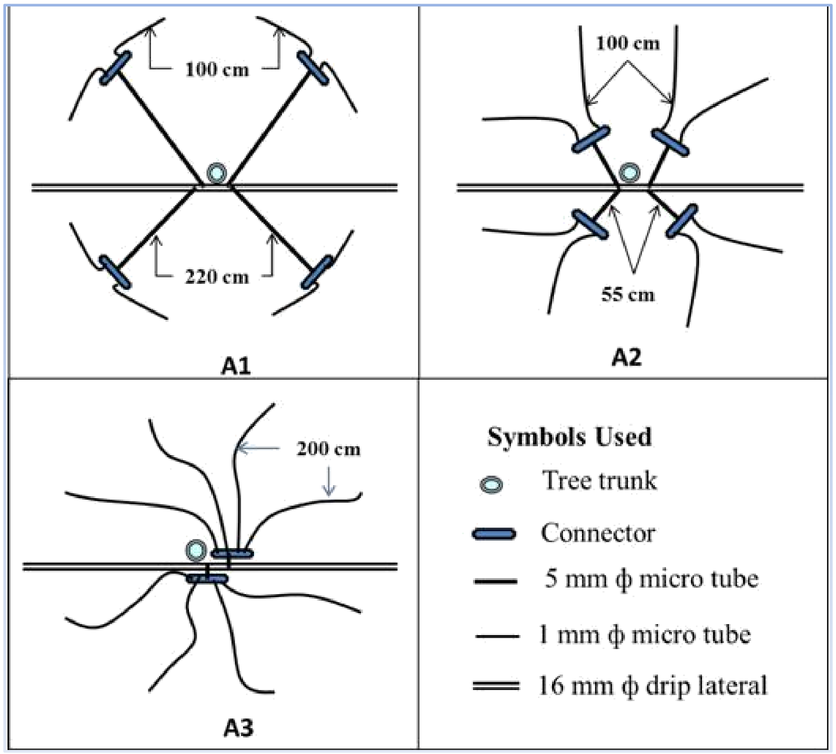


Figure 1. Micro tube based multi-location water drip emitting systems to apply water at 60 % ETc (A1), 40 % ETc (A2) and 20 % ETc (A3).

water stress during inflorescences and fruit setting irrigation is essential to achieve the optimum crop yield and quality. Since, crop health, fruit quality and yield are sensitive to level of soil moisture, imparting water stress to crops due to under-irrigation or prolonging the period with 'no-irrigation' is essentially an agronomic and economic decision (Pereira, 2005). Since, the yield and fruit quality of litchi is highly sensitive to water deficit, the practice of DI needs to be carefully designed (Spreer *et al,* 2007) so that crop health is not severely affected and litchi yield and quality is within acceptable limits.

High degree of water stress under DI may adversely affect the fruit development and aggravate the fruit cracking and shorten the postharvest life of litchi fruits (Joshi 2011, Mitra and Pathak 2010). The water deficit, obtained by prolonging the irrigation interval, is responsible for decreased calcium content of the fruit which reduces the skin strength making it more susceptible to cracking (Rab and Haq, 2012). Ray *et al*, (2005) concluded that soil moisture status was better correlated with fruit cracking than atmospheric humidity. The sensitivity of cracking, fruit drops and chemical attributes of litchi fruits to soil moisture emphasize that site and crop variety specific deficit irrigation levels needs to be standardized to get better litchi yields under limited water supply and. In the litchi production belt of India, the plants are generally not irrigated after litchi harvesting in is completed in last week of May to onset of flowering in the next season. Farmers start irrigating the plants from the time of visual appearance of flowers on the litchi plants. In order to schedule the water applications under deficit irrigation, the specific information on optimum irrigation start times and effect of different irrigation start times on fruit yield and quality is seriously lacking. Also, keeping in mind sensitivity of the litchi plants to water stress, it is necessary evolve the deficit irrigation strategies under limited water supplies. This experiment was planned with the twin objective to standardise the deficit irrigation practice for litchi production and to study the effect of deficit irrigation on litchi yield and quality.

MATERIALS AND METHODS

A field experiments were carried during the fruiting season (February to May) of 2007-08 in experimental litchi orchards located at Ranchi, Jharkhand, India. The climate of the area is sub-tropical with hot and dry summers and cool winters. Average rainfall of Ranchi is about 1350 mm out of which about 80 % is received during monsoon months (June-September). The 26 year old adult bearing litchi (*litchi chinensis*, cv Shahi) planted at 10 x 10 m spacing was considered for the treatments on deficit irrigation. The soil in experimental plot was silt loam with neutral p^H (6.5-7.5) and had field capacity and wilting point values of about 24.2 % and 10.5 % respectively. Soil was well drained and bulk density (ρ) of the soil in top 30 cm was 1.59 g/cc. Drip and Ring basin methods of irrigation were considered in the present study. Drip irrigation levels were planned at 20, 40 and 60

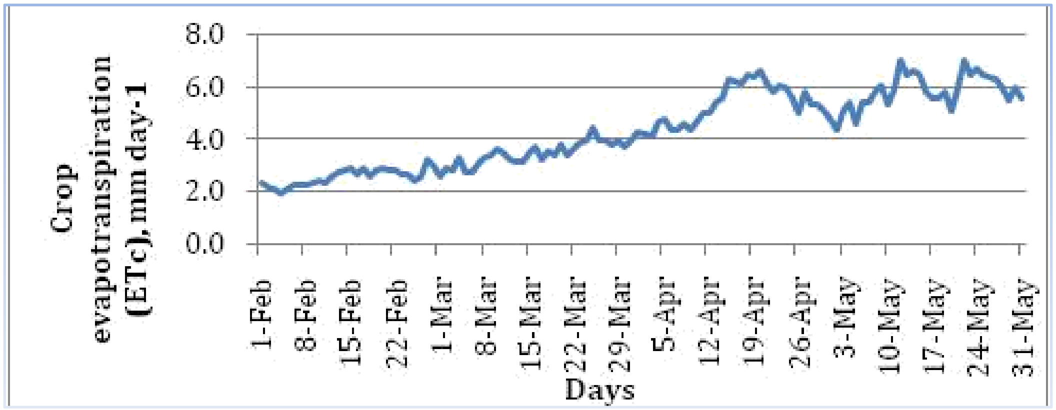


Figure 2.Estimated daily crop evapotranspiration.

Table 1. Mean discharge (l h^{-1}) and performance parameters of the drip emitting systems.

Performance Parameter	**Emitting system**		
	A1 (60 %ETc)	**A2 (40 %ETc)**	**A3 (20%ETc)**
Mean	10.19	6.81	3.27
SD	1.68	0.87	0.51
CV	0.165	0.130	0.156
DU	76.18	85.02	81.06
SU	83.50	87.19	84.40

percent of estimated full crop water requirement (ETc) while basin irrigation was done at 60 and 100 % of ETc. The treatment B100 (full irrigation) was considered as control treatment for comparison with other deficit irrigation treatments. To achieve the temporal irrigation deficit, starting of irrigation from 1st February (pre flowering), 1st March (flowering) and 1st April (fruit development) was considered in the study. There were 15 treatments resulting from five quantitative deficit and three temporal deficit levels. Each treatment was replicated three times. Completely randomized design was adopted for allocation of treatments to individual plants.

In case of drip irrigation, three micro-tube based emitting systems (A1, A2 and A3) were developed such that they can apply 60, 40 and 20 % of full crop water requirement within same irrigation 'ON' time. The combination of 5 mm and 1 mm diameter micro tubes was used and their lengths were standardised to get the desired application rate. These emitting systems were designed to apply water at eight locations around the tree trunk (Fig 1). Under basin irrigation system, the basins of 1.4 m inner and 2.2 m outer radius having bund height of 12 cm were constructed to store the applied water.

Reference crop evapotranspiration (ET_0) was estimated from pan evaporation (Ep) (ET0 = Ep x Kp). Pan evaporation data was collected from the field meteorological observatory located at about 150 m away from the experimental site. The actual crop evapotranspiration was estimated by multiplying reference crop evapotranspiration with crop coefficient (ETc = ET0 × Kc) (Allen *et al*, 1998). Where, Kc is the crop coefficient. The pan coefficient value of 0.75 was adopted to convert pan evaporation in to reference crop evapotranspiration as suggested in FAO-56. The uniform K_c value of 0.85 throughout the fruiting season was adopted for the for 26 year old litchi trees (Bredell, 1971). Estimated daily crop evapotranspiration for growing season is presented in Fig 2. In present study, 60 % of the canopy area was considered as wetted area. Under drip system, irrigation frequency was set at 2 day during February and March and 'daily' in the months of April and May. Basin irrigation was applied once a week which is common irrigation practice fallowed by the farmers in the region.

Soil water content was measured at 5, 15, 30 and 45 cm below the soil surface using time domain reflectometry (TDR). Under each treatment, ten fruits per replication were randomly selected from each of the two previously tagged secondary branches and the fruit parameters like fruit diameter, fruit volume, fruit weight, aril weight and peel weight were measured in the laboratory. Percentage fruit drop was determined by dividing number of fruits dropped by total number of fruits. Fruit cracking percentage was determined by dividing the number of fruits cracked from the tagged branches by total number of fruits on them. A sample of five fruits per treatment per replication was collected ran-

Table 3. Physiochemical properties of litchi fruits under deficit irrigation.

Treatment	Physical Properties							Chemical Properties			
	Fruit Wt (g)	Length (mm)	Diameter (mm)	Aril Wt (g)	Stone Wt (g)	Cracking %	Drop %	TSS	RS	TS	Yield kg/ plant
D20F†	19.2	3.6	3.2	12.7	3.5	1.5	67.6	18.2	8.2	14.5	115.6
D20M	19.5	3.5	3.1	13.5	3.5	6.0	74.9	20.1	10.2	14.3	155.0
D20A	20.2	3.5	3.1	14.4	3.6	2.7	72.1	20.0	8.9	13.4	149.0
D40F	19.3	3.5	3.2	12.8	3.9	2.5	70.8	19.5	8.6	13.6	197.6
D40M	19.7	3.5	3.1	13.5	3.5	5.0	69.2	19.4	9.7	12.9	126.6
D40A	18.6	3.4	3.1	13.4	3.1	3.4	73.8	20.1	9.4	16.7	161.3
D60F†	19.2	3.5	3.1	13.8	3.1	4.2	75.9	18.9	9.9	14.5	119.0
D60M	19.7	3.5	3.1	13.3	3.6	2.3	66.4	19.0	10.4	12.5	134.3
D60A	17.4	3.4	3.0	12.1	3.1	3.3	66.4	19.0	9.0	14.7	128.0
B60F	19.9	3.5	3.1	13.5	3.6	8.4	78.5	17.8	8.1	13.7	138.3
B60M	18.8	3.5	3.1	12.7	3.4	1.2	72.3	18.5	9.2	13.3	145.6
B60A	17.8	3.4	3.0	12.9	3.0	4.9	65.5	19.6	9.2	14.2	153.0
B100F	19.6	3.5	2.8	13.4	3.7	4.2	78.5	20.1	8.9	12.9	172.0
B100M	18.5	3.4	3.0	13.2	3.1	10.2	67.1	20.5	10.1	14.4	156.3
B100A	19.2	3.5	3.0	14.0	3.0	5.9	68.9	20.1	10.2	13.2	121.6
SE(M)	1.35	3.41	3.01	1.2	0.34	3.08	6.0	0.9	0.6	2	32.6
CD	NS	NS	NS	NS	NS	NS	NS	NS	1.25	NS	NS

Table 2.Seasonal quantity of water applied (m3/ tree) in different irrigation treatments.

Irrigation (% of ETc)	Irrigation start time: 1^{st} Feb	1^{st} Mar	1^{st} Apr
100 (0) †	16466.2	14391.8	10181.1
60 (40)	11551.7	10307.1	7780.7
40 (60)	7701.2	6871.4	5187.1
20 (80)	3850.6	3435.7	2593.6

†figures in the parenthesis indicate level of irrigation deficit.

domly from all directions of the tree. Total soluble solids (^{0}Brix), total sugar (%) and reducing sugar (%) content in the litchi fruit juice were assessed using standard methods of analysis. At harvest, all fruits from each experimental tree were harvested and weighed to get the fresh fruit yield per tree. The irrigation water use efficiency (g/m^3) was determined as ratio between fresh fruit yield (g) and total quantity of irrigation water applied (m^3).

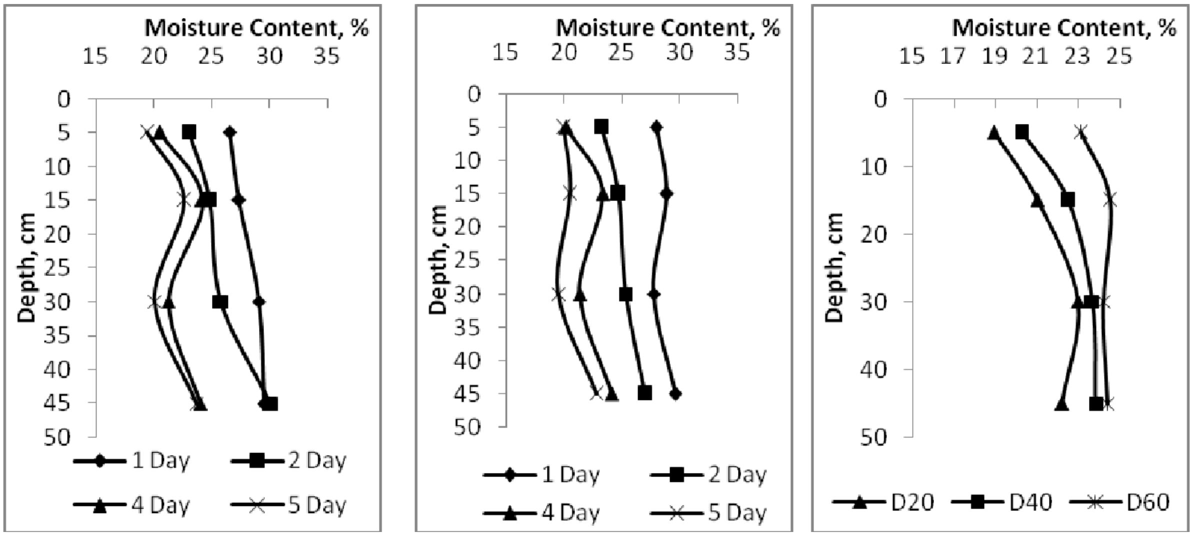
RESULTS AND DISCUSSION

Uniformity of drip system

Performance evaluation of the customized drip irrigation system (Table 1) showed that the system performed well at all the three levels of water application. The mean total discharge (eight locations) of the designs A1 and A2 was about 82.1, 54.7 and 27.4 l h^{-1}, respectively. The coefficient of variation (CV) for A1, A2 and A3 (0.14 to 0.16, 0.12 to 0.13 and 0.12 to 0.15, respectively) were slightly higher than the recommended value of 0.10. This shows that although the micro tubes used were of same length, there is variation in the internal friction encountered by water particles inside the micro tube which resulted in variation in discharge of the emitters. The distribution uniformity (DU) and statistical uniformity (SU) values, although lower than the recommended values for excellent performance, were also within acceptable limits of good performance parameters.

Quantity of water applied

The estimated evapotranspiration of litchi for February,



a. Basin irrigation (B60) b. Basin Irrigation (B100) c. Drip Irrigation

Figure 3.Soil moisture distribution under under basin irrigation with (a) 60 % ETc and (b) 100 % ETc on 1st, 2nd, 4th and 5th day of irrigation and (c) under drip irrigaiton with three DI levels (D20, D40 and D60).

March, April and May was 50.0, 101.4, 144.6 and 167.8 mm respectively. The treatment with full irrigation required highest amount of water (19252.9 m^3 per tree) while the treatment having 20 % of ETc and irrigations starting from the month of April required lowest quantity of water (2433.5 m^3 per tree) for the entire fruiting season (Table 2).

Soil moisture distribution

Under both the methods of water application, soil water content on the day of irrigation was higher and uniform. However, it was more than field capacity (26.5-29.4% and 27.7-29.6%) under B60 and B100 treatments, respectively (Fig. 3-a, 3-b). Soil moisture in excess of field capacity indicates occurrence of deep percolation loss under basin irrigation. Moisture content under drip irrigation treatments was more uniform and was close to field capacity. In top 30 cm of the root zone moisture content under B20 was considerably below the field capacity and increased with depth (Fig. 2-c). Under basin irrigation treatments the moisture content approached field capacity on second day of irrigation (29 h after irrigation). On 5th day, the soil moisture under basin treatments was considerably low which indicates water stress to the plants. The high frequency applications under drip system (alternate day during February-March and Daily during April-May) maintained optimum level of soil moisture in the root zone throughout the season. The soil water content under D60 was slightly more than that observed under D40 and D20 (Fig. 3-c). In general there was increase in soil water content with depth in all treatments and at same level of deficit drip system maintained better wetting in the soil profile.

Physiochemical properties of fruits

Fruit weight, fruit length, fruit diameter, aril weight and fruit cracking were not affected by quantitative or temporal irrigation deficit (Table 3). Average fruit weight varied from 19.3 (D40F) to 23.6 (B60F). Under drip irrigation system highest fruit weight (22.6 g) was observed when irrigation was done at 60 % ETc and irrigation started from 1st March. Fruit length did not show significant variation among the treatments. Drip irrigation treatments B40F and B20F with start of irrigation from February resulted in highest (4.3 g) stone weight while the lowest stone weight (3.5 g) was observed in case of basin irrigation with full irrigation and irrigation starting from March. This shows that continuous irrigation right from the flowering results in increased the stone weight in litchi fruits. The treatment which resulted in significantly higher stone weight (D40F) showed lowest aril weight (11.8 g). This confirms that stone weight and aril weight are complimentary to each other.

Basin irrigation with full irrigation (B100) recorded lowest fruit length (3.5 mm), lowest fruit diameter (31.3 mm) and highest fruit cracking percentage (8.5 %). Fruit cracking occurs when the aril grows rapidly than the fruit skin. This situation occurs when water is applied after a prolonged stress (Rab and Haq, 2012). Under basin irrigation water was applied at 7 day interval. Prior to each of the basin irrigation event, plants were under moisture stress. Application water in higher amounts after this prolonged water stress resulted in bulging of aril which consequently increased fruit cracking under basin treatments. The fruit drop percentage varied from 65.57 % (B60A) to 78.58 % (B100F).

Table 4.Irrigation water use efficiency (g/m^3) under different methods, levels of irrigation deficit and irrigation start times.

Treatment	Start of irrigation schedule		
	February	March	April
D20	30.0	45.1	57.4†
D40	25.7	18.4	31.1
D60	12.0	14.1	19.7
B60	10.5	13.0	16.5
B100	10.2*	10.9	12.0

†highest and *lowest value of IWUE.

†Code explanation: D- Drip irrigation method, B-Basin irrigation method; Numbers- 100, 60, 40 and 20 indicate irrigation amount as percent of ET_C; Letters F, M, A represent irrigation Start Time (F-February, M- March, A-April); NS-not significant; *Maximum value ; ^{x} Minimum value.

Reducing sugar content was significantly affected by levels of irrigation deficit. Highest reducing sugar content (7.5 %) was observed under drip irrigation treatments D60A and D40F while the lowest (5.3 %) was under D40A. This confirms the findings that with increasing level of deficit the reducing sugar content increases. Skipping the irrigations during February and March increased the reducing sugar content under basin treatments. Drip system showed highest reducing sugar content (10.2, 9.7 and 10.4 %) under 20, 40 and 60 % ETc irrigation levels and irrigations starting from March. Irrigation treatments did not show any significant effect on total soluble solids (TSS) and total sugar (TS) content of litchi aril. Highest TSS (19.6 ^{0}B) was recorded under the treatment D20F, which is highest level of irrigation deficit, and the lowest value was observed under B60M. The treatment B60A recorded highest total sugar content in litchi aril.

Yield and water use efficiency

In present study, effect of different levels of irrigation deficit and different start times does not affect the fruit yields significantly; however considerable saving in water was achieved under the treatment having 80 % irrigation deficit (i.e. irrigation at 20 % of ETc). Treatment D40F showed the maximum fruit yield of 197.6 kg per plant. Generally with increasing level of irrigation deficit the fruit yield decreases in young bearing (6-10 year) or adult bearing (11-20 year) plants (Zhou *et al*, 2002; Hasan *et al*, 2002). The plants used in the present study were 26 year old. Since, over the years the experimental orchard was irrigated using basin method, the plants have developed an extensive root system. So, sudden switch over to drip irrigation or introduction irrigation deficit did not affect the plant yields significantly.

Joshi *et al*, (2012) also showed that the fruit yield, fruit physical and chemical properties remained unaffected when quantity of water applied per irrigation was reduced to 50 and 75 % of the estimated crop water requirement (100%). Highest IWUE (57.41 g/m^3) was observed in case of drip irrigation having 20 % ETc level and irrigation starting from April (Table 4). As compared to other treatments, the basin treatment with full irrigation and irrigation events starting from February resulted in lowest IWUE. Highest water use relatively similar yields under resulted in low IWUE under this treatment.

CONCLUSIONS

Increased level of quantitative or temporal deficit irrigation (DI) of adult bearing litchi plants did not show significant effect on litchi fruit yield. The well-developed root system of the mature litchi plants was capable of extracting the required soil moisture even at 80% irrigation deficit without affecting yield and quality attributes. Irrigation to restore 20, 40 and 60% of ET resulted in fruit yields statistically at par with that of 100% ET. Effect of DI on most of the physical and chemical properties of fruit was not significant; however the reducing sugar content was significantly high under high level of irrigation deficit. Deficit irrigation resulted in considerable saving in water which improved the irrigation water use efficiency of litchi production to great extent.

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