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EFFECT OF FRUIT STAGE BASED IRRIGATION SCHEDULING ON YIELD, QUALITY AND IRRIGATION WATER USE EFFICIENCY OF LITCHI (*LITCHI CHINENSIS* SONN.) CV. SHAHI

S. S. MALI[1]*, B. DAS[1], A. K. SINGH[1] AND P. R. BHATNAGAR[2]
[1]ICAR Research Complex for Eastern Region, Research Centre Ranchi - 834 010
[2]Central Soil and Water Conservation Research & Training Institute, Research Centre, Vasad - 388 306
e-mail: santosh.icar@gmail.com

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***Corresponding author**

ABSTRACT
A field experiment was conducted to study the efficacy of deficit irrigation (DI) of the litchi crop under quantitative deficit (100, 60, 40 and 20 % of ETc) and temporal deficit irrigation with irrigations starting from 1st February (pre flowering), 1st March (flowering) and 1st April (fruit development)under basin (B) and drip (D) irrigation systems. Drip irrigation system recorded the highest fruit weight (22.6 g) at 60 % ETc with irrigation starting from flowering stage. The prolonged moisture stress between two irrigations under basin system resulted in lowest fruit length (3.4 mm), fruit diameter (2.8 mm) and highestfruit cracking percentage (10.2%). Deficit irrigation with drip system (60 % ETc) resulted in higher reducing sugar content (10.2 %) in the litchi pulp. Highest irrigation water use efficiency (57.1 g/m^3) was observed in case of drip irrigation having irrigation at 20 % of ETc and irrigation starting from fruit development stage (1st April). Deficit irrigation showed great potential to increase the irrigation water use efficiency of litchi production without affecting the fruit quality and with slight deviation in potential yield.

INTRODUCTION

Litchi (*Litchi chinensis Sonn.*) 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). Litchi is becoming more popular due to its distinct flavour, good taste, juicy aril giving cooling effect during hot summer (Chauhan *et al.*, 2008). Due to its high economic returns and ever increasing demand in thedomestic markets, the crop is also gaining momentum in Punjab, Himachal Pradesh,Assam, Tripura, and Orissa (Kumar *et al.*, 2014). Litchi is also economically important as it has excellent 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 the period which is characterized by soil water deficit, high temperature, low to no rainfall and low relative humidity. With increasing water scarcity, the available water resources should be effectively utilized through water saving irrigation technologies (Awasthy *et al.*, 2014). In the context of growing water sacristy, Deficit Irrigation (DI) can be a better option to reduce irrigation water use. The level of 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). 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 variety specific deficit irrigation practices needs to be standardized to achieve better litchi yields. In the litchi producing belt of India, no irrigation is given to the plants for the period after harvesting of a crop (May end) to onset of flowering in the next season (February). Farmers start irrigating the plants from the time of appearance of flowers on the litchi plants. The specific information on when to start irrigation and effect of different start times on fruit yield and quality is seriously lacking. This paper deals with the twin objectives of standardizing the irrigation start times after onset of litchi flowers and to optimize the level of deficit irrigation in litchi plants.

MATERIALS AND METHODS

A field experiment was carried during the fruiting season (February to May) 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. The 26 year old litchi plants (*litchi chinensis*, cv Shahi) planted at 10 x 10 m spacing were 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 (ñ) 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 (D20), 40 (D40) and 60(D60) percent of estimated full crop water requirement (ETc) while basin irrigation was done at 60 (B60) and 100(B100)% 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, start of irrigation was delayed at the intervals of one month. Treatments on temporal deficit included start of irrigation from 1st February (F)(pre flowering), 1st March (M) (flowering) and 1st April (A)(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 (ET0) 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 moisture 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 randomly from all directions of the tree.Determination of total sugar and reducing sugar were carried out using Lane and Eynon volumetric method as described by James (1995).Total soluble solid (TSS) was determined with the helpof digital refractometer. 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 parameters of the installed drip system (Table 1) showed that the system performed well for all three fruiting seasons. The mean total discharge (eight locations) of the systems A1 and A2 were about 82.1, 54.7 and 27.4 l h^{-1}, respectively. The coefficient of variation 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 there is slight variation in discharge of the emitters when micro tube based system is used. The distribution uniformity (DU) and statistical uniformity (SU) values were also within acceptable limits.

Quantity of water applied

The estimated crop evapotranspiration for February, 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 (16.45 m^3 per tree) while the treatment having 20 % of full irrigation and irrigations starting from the month of April required lowest quantity of water (2.59 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 lower indicating water stress to the plants. The high frequency applications under drip system (alternate day during February-March and Daily during April-May) maintained optimum 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.

Physical 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). Under drip irrigation system highest fruit weight (20.2 g) was observed when irrigation was applied at 20 % ETc with irrigations starting from 1st April. Deficit irrigation treatments did not show significant effect on fruit length. Application of deficit irrigation with drip irrigation showed increased stone weight. Drip irrigation treatments with water application at 40% of ETc and irrigation starting from February recorded highest average stone weight of 3.9 g. Treatments with irrigations starting from pre-flowering stage recorded higher stone weights implying that continuous irrigation of litchi plants will increase the proportion of non-edible part of the litchi.

Basin irrigation with full irrigation (B100) recorded lowest fruit length (3.4 mm), lowest fruit diameter (3.0 mm) and highest fruit cracking percentage (10.2 %). 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) which is the case with basin irrigation in which water was applied at 7 day interval. After the irrigation event plants undergo gradual water stress and addition of water to the root zone on eighth day after this prolonged water stress resulted in bulging of aril which consequently increased the fruit cracking. The fruit drop percentage varied from 65.6 % (B60A) to 78.58 % (B100F). Although the effect of treatments was found insignificant, the basin irrigation treatment with water application at 60% of ETc resulted in maximum fruit drop percentage.

Deficit irrigation under drip irrigation did not show significant effect on the fruit drop. The fruit drop may be attributed to nutrition and hormonal imbalance and/or infestation by insects or pests (Kumar *et al.*, 2010). The external factors like high temperature, low humidity and strong winds may also be responsible for the consistently higher fruit drop under all the treatments. It is also established that even after profuse flowering and fruit set there may be fruit drop between flowering and fruit maturity with only 2-18% flowers are carried to maturity in different cultivars (Singh *et al.*, 2012).

Chemical properties of fruits

Among the chemical properties the reducing sugar content was significantly affected by levels of irrigation deficit. Highest reducing sugar content (10.6%) was observed under drip irrigation treatments D60M while the lowest was under basin irrigation with 60 % of ETc and irrigation starting from February (5.3 %). 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 however, highest TSS (19.6 ^{0}B) was recorded under

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

PerformanceParameter	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

Table 2: Seasonal quantity of water applied (m^3/ tree) in different irrigation treatments

Irrigation(% of ETc)	Irrigation start time		
	1st Feb	1st Mar	1st Apr
100 (0) †	16.46	14.39	10.18
60 (40)	11.55	10.30	7.78
40 (60)	7.70	6.87	5.18
20 (80)	3.85	3.43	2.59

†figures in the parenthesis indicate level of irrigation deficit

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	Yieldkg/ 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

†Code explanation: D, B-Methods of Irrigation (D-Drip, B-Basin); Numbers100, 60, 40 and 20 - Percent of ET$_c$; Letters; F, M, A - Irrigation Start Time (F-February, M-March, A-April).

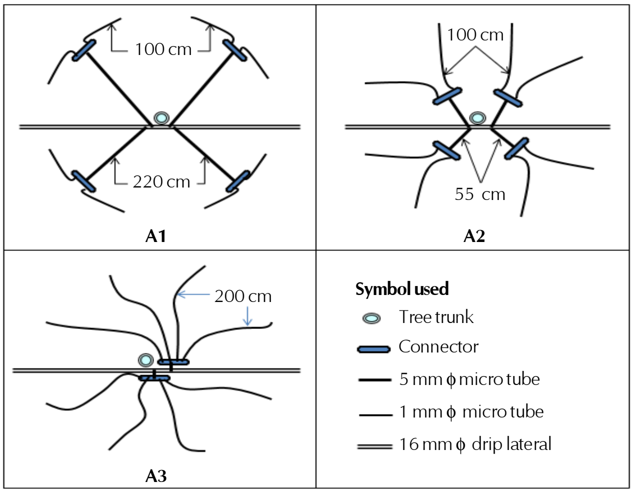

Figure 1: Micro tube based multi-location water drip emitting systems to apply water at 60 % ETc (A1), 40 % ETc (A2) and 20 % ETc (A3)

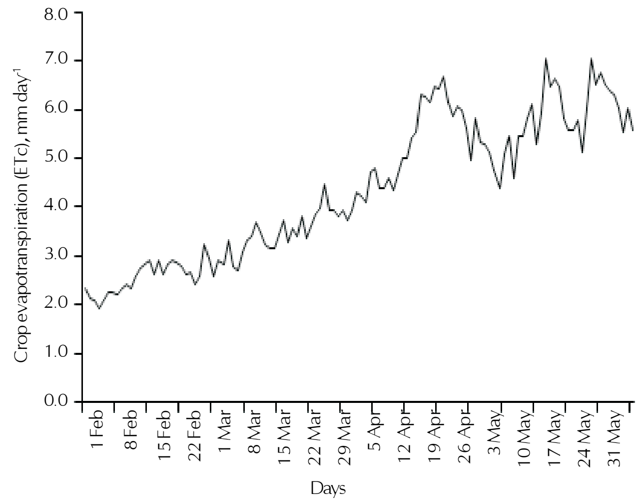

Figure 2: Estimated daily crop evapotranspiration of litchi for the period of study

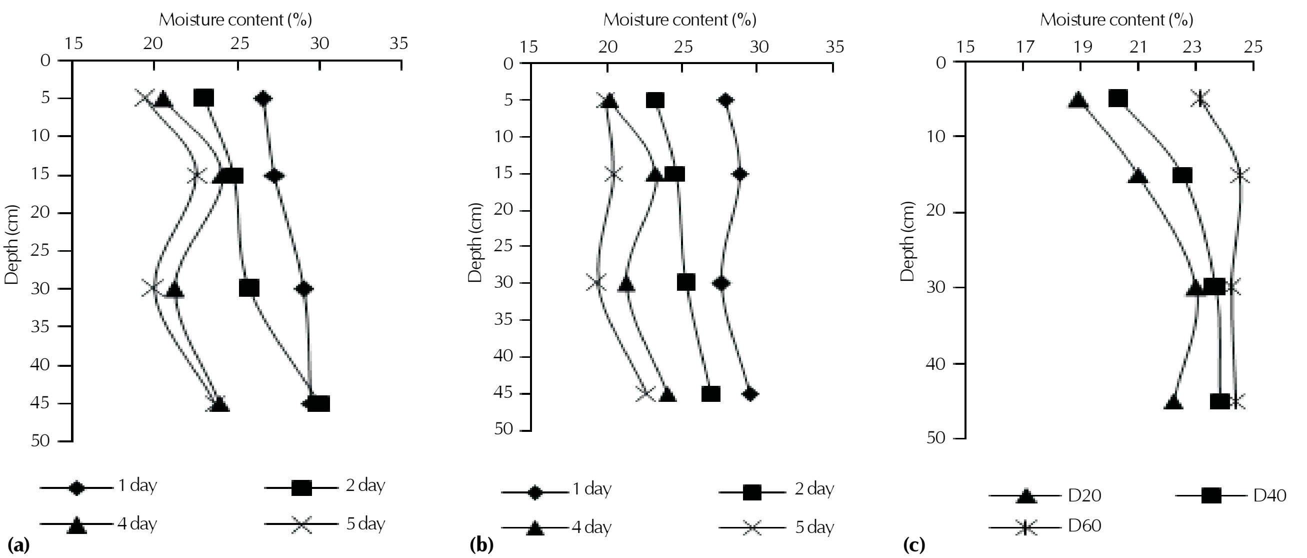

Figure 3: Soil moisture distribution under under basin irrigation with (a) 60 % ETc and (b) 100 % ETc on 1st, 2nd, 4th and 5th day of irrigation and (c) under drip irrigaiton with three DI levels (D20, D40 and D60)

the drip irrigation with irrigation at 20 % of ETc and starting from February, 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: It was interesting to observe that level of deficit irrigation did not affect the litchi fruit yields however, considerable saving in water was achieved under the treatment having 80 % irrigation deficit (i.e. irrigation at 20 % of ETc). Drip irrigation with irrigation at 40 % of ETc and irrigations starting from February showed the maximum fruit yield of 197.6 kg per plant. The average fruit yield recorded under all the treatments was 144.8 kg/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 and over the years these plants were irrigated using basin method. Because of the larger wetting are under basin system of irrigation the plants have developed an extensive root system which enables the plant to extract the soil water even at higher degree of stress. Therefore, 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 with 57.4 gram of litchi per $m^3$of water use 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. Comparative yields and high water use resulted in low IWUE under all the basin

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

irrigation treatment.

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.

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