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Review article

Research review on Irrigation scheduling and water requirement in citrus

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ABSTRACT

Citrus is the main fruit group grown in tropical as well as sub-tropical climate of more than 150 countries in the world. Irrigation scheduling and water requirement of the citrus crops are one of the main concerns of the modem citrus fruit production irrespective of availability of natural resources. A large number of research findings have emerged world over on irrigation scheduling and water requirements of the citrus based on available soil water content and its depletion and based on pan evaporation replenishment. The research review of the literature has revealed best promising results on irrigation scheduling based on depletion patterns of soil available water content, irrigation schedules of various citrus crops and fertigation. Irrigation water management with proper water use is one of the prime concerns of modem horticulture irrespective of soil and water resource availability. A variety of recommendations have reviewed the world over on irrigation scheduling based on analysis of meteorological parameters, evapo-transpiration, depletion of available water content, soil and leaf water potential. The review of the literature has revealed best promising results on irrigation scheduling based on depletion patterns of soil available water content. Similarly, irrigation scheduling has shown good responses on growth, yield, and quality compared to calender method of irrigation schedules. The present status of the review of irrigation scheduling and water requirement of citrus cultivars is clearly presented in this research review article.

1. Introduction

The technology awareness coupled with technological developments and potential for export commodities has resulted in many folds increase in area and production of horticulture crops. In India, the total area under citrus crops is 0.86 M ha with a production of 0.923 M tonnes and a productivity of 10 tonnes per ha. Nagpur mandarin and acid lime occupy 40% and 25% of the total area under citrus cultivation in the country. One of the reason for low productivity is the lack of concern about the irrigation scheduling and management of soil moisture as the plants are sensitive to either less or excess availability of soil moisture status. Water is a national and natural resource, considered as a basic requirement for all developmental activities of living organisms. The demand for water is increasing with increase in population and economic activities. Irrigation potential in India has risen from 19.5 million ha in 1950 to 67.89 million ha. in 1985. The best estimates available indicate that the maximum amount of exploitable irrigation potential by all types of irrigation is 113.5 million ha. This could be sufficient for 50% of the total cultivable area of the country and 50% of the area would be left completely dependent on rainfed farming. Conjunctive use of rain and irrigation water offers a potential scope for optimizing water use in areas having problems of surface drainage during rainy season and water scarcity during the rest of the year. Success in commercial fruit culture largely depends upon availability of rains or supplemental irrigation, particularly during critical periods of tree growth. Commercial production of citrus fruits is being practised in areas having assured irrigation sources. Optimum use of available water determines the growth, vigour and productivity potential of the trees. Excess or scarcity of water at any stage affects the productivity in addition to quality of produce.The method of irrigation followed in the citrus orchards affects the distribution and availability of water to the plant which decide ultimately the nutrient uptake, growth,yield and fruit quality. The large scale drying of the citrus orchards is mainly due to scarce water resources, frequent drought and lowered water tables in mandarin growing areas of and Central India (Dass, 1989; Singh, 1999). The average yield of these orchards is 7 to 8 ton per ha, which is 3 to 4 times less than other citrus producing countries of the world (Shirgure et al., 1999; 2000c). Citrus plants are more extracting in their demand for irrigation. Water contact with the trunk of the trees adversely affects the plant growth. Citrus being an evergreen fruit crop, utilizes moisture constantly throughout the year, of course at a much slower rate during winter and faster in summer. There is a good amount of research available on irrigation water management of citrus from abroad but a little work has been done under Indian conditions.

The important factors which influence the soil water availability are soil structure, texture, nature of clay minerals, organic matter content, salt content and soil depth. The available soil water to plant ranges between field capacity and permanent wilting point and plant growth is very much influenced by percentage of water available in the form of capillary water. Based on the available water in the soil and plant requirement, the irrigation needs to be scheduled. Other parameters influencing the use of available water are plant character such as rooting habit, tolerance to moisture stress and stage and rate of growth. Weather parameters such as atmospheric temperature, humidity, wind velocity, sunshine etc. also determine evaporation demand.

For efficient water management of fruit trees, consideration should be given to (i) water requirement of the crop (ii) scheduling of irrigation (iii) irrigation method, and (iv) other practices such as in situ water harvesting and moisture conservation coupled with use of mulches, antitranspirants, modified layout, etc. Nutrient management programme aims at better fertilizer use efficiency which is governed by a dynamic inter - relationship of soil-water-nutrient-plant interaction over a given set of climatic conditions. The components such as a proper leaf and soil sampling method, availability of leaf nutrient indices to diagnose the nutrient constraint, fertilizer schedule suiting the crop requirement for pre bearing and bearing age of citrus orchards. The nutrient demand at various physiological growth stages and changes in soil available pool of nutrients using drip irrigation constitute an integral part of fertilizer use efficiency. The fertilizer like inputs account for 20-30 % of total cost of citrus cultivation. In case of plant moisture stress, the indirect method of measurement are canopy temperature, stomatal conductance or resistance, leaf water potential, spectral measurement, microwave measurement, where irrigation schedule is followed depending upon the magnitude of moisture stress in plants. There is a consistency in water saving to the extent of about 60 percent in earlier experiments and increased in the yield to the tune of 30 percent. These research findings synchronize the work done by Sivannapan et al. (1984). The drip system consists of the control head, showing pressure regulating valve, filter tank, pressure gauge and water meters extended with water conveyance and distribution system. The emitters or drippers were on the lateral line as per the requirement of crops. The fertilizer tank is replaced by the injection assembly or venturi. This system is further classified on the basis of type of emitters or drippers and their requirement, related to discharge and operating pressure. Every emitter has a rated discharge and an average discharge related to some standard pressure head which is often 10 m. The operating pressure influences both the average discharge and discharge variation.

The research on estimating the water requirements of the Nagpur mandarin and acid lime under sub-tropical conditions of the central India, the use of irrigation scheduling based on pan evaporation and depletion of available water and water requirement of citrus cultivars have been thoroughly investigated at National Research Centre for Citrus, Nagpur. The moisture conservation techniques using grass mulching and fertigation have also been given equal importance once from the water management point of view. The entire effort has been focused on irrigation management.

2. Irrigation scheduling in citrus

The research review of irrigation scheduling in citrus under Indian conditions abroad is thoroughly reviewed. Stolzy et al.(1963) found that the treatments irrigated at 20 kPa tensiometer readings as best compared to a calendar schedule. Hashemi and Gerber (1968) attempted correlation between actual evapo-transpiration (AET) and potential evapo-transpiration computed through Penman's model. Toledo et al. (1982) found that irrigation at 65 % field capacity caused drought injury symptoms, excessive defoliation, and less water consumption. Best results were obtained with irrigation at 85 % filed capacity. Evapo-transpiration ranged from 3.78 to 4.42 mm/day and 1.46 to 1.3 mm/day for 85% and 65% field capacity irrigation, respectively. Kelin (1983) compared drip irrigation scheduling according to soil water potential to class A pan evaporation in different horticultural crops using a crop factor. The study revealed that 12 to 23% water could be conserved by adopting the irrigation scheduling based on soil water potentials. Plessis (1987) also demonstrated that 690 liters of irrigation when tensiometer reading fell to -50kPa gave the highest net income. Use of tensiometer rather than evaporation pan scheduling saved 2000 m3 water per ha annually.

Barbera and Carimin (1988) studied the different levels of water stress on yield and quality of lemon trees and found that yield was lower in most stressed plots. The number of flower/m3 of the canopy was higher in most stressed treatment, indicating a definite relationship between severity of stress and flowering response. Plessis (1988) with a mature Valencia orange tree in a field experiment showed that the water use pattern over the entire season reached a maximum of 87 liter per day in January. Highest net income was obtained with tensiometer scheduling. Autkar et al.(1989) also studied the effect of pan evaporation, canopy size and tree age on daily irrigation water requirement of 1-5, 5-8 and above 8 years old Nagpur mandarin trees over 9 months (October-June) and concluded that the water requirement rose with age. The water requirement of citrus plants varies with species, season and age which were governed by different climatic conditions.

Plant growth retarded below a certain critical level of available moisture depending upon soil type, climatic factor and plant genetic makeup (Rajput, 1989). Sanehez et al. (1989) compared five flood irrigation treatments with daily drip irrigation at 0.475 Epan and concluded that the drip irrigation gave higher yields compared to flood irrigation. Plessis (1989) studied that lysimeter (13.4 m2, 50 t sail) was set up in an orange orchard with Valencia trees on rough lemon rootstocks at a spacing of 6.1 x 6.1 m apart and irrigated at a water depletion of 75 mm, class 'A' pan evaporation (Eo) was recorded daily for 5 seasons. Trees in similar orchards with a spacing of 5.8 x 6.7 m were subjected to five treatments viz; (i) 900, (ii) 450, (iii) 675 litres of water was applied per tree when 600 liters of water were used by each lysimeter, (iv) 990 liters per tree when pan evaporation indicated a 55 mm requirement or (v) 690 liters when tensiometer readings fell to -50 kPa. The crop factor f was determined as Et = evapo-transpiration by lysimeter/Eo. The lysimeter data showed that maximum water use occurred in phase 1 of the cell enlargement stage, whereas Eo peaked a few weeks earlier and that if raised considerably over 5 seasons, f factor did not necessarily corresponded with the period of greatest atmospheric demand. A comparison across several areas further showed that f factor varied widely, being much lower in summer having winter rainfall area than in summer rainfall area. Fruit growth rate and water use were closely correlated and fell from a high in January to a low in July. Crop yields in treatment (i) to (v) were 166, 143, 195, 179, and 209 Kg/tree, respectively, and water application rates were 34.6, 17.7, 26.4, 30.7, and 23.0 m3. Treatment involving 690 litres of irrigation with tensiometer reading below -50 kPa produced the highest net income.

Castel and Buj (1990) carried out trials on mature Satstuma orange trees grafted on sour orange rootstocks. Plants were irrigated with 60% of the estimated ET losses from a class A pan and 80% of the control throughout the year. Irrigation treatments affected both yield and fruit quality. Ray and Sharma (1990) studied the response of young Kinnow mandarin to irrigation. Irrigation was scheduled at -0.05, -0.1, -0.2, -0.4 and -0.8 MPa soil water potential , 0.8 IW/CPE ratio and irrigation to replenish estimated crop ET. The water use increased as the frequency of irrigation increased. The highest biomass per plant was obtained when irrigation was scheduled at -0.05 MPa soil water potential requiring 18-19 irrigations. The best tree growth in terms of trunk diameter, plant height, canopy volume, leaf number and shoot growth was also obtained at -0.05 MPa soil water potential using 182.4 cm water/tree/annum. Ray et al. (1990) stuided the effect of irrigation on plant water status and stomatal resistance in young Kinnow mandarin and found that the leaf water potential (LWP) and relative water content (RWC) declined considerably with reduction in soil moisture in rootzone due to differential irrigation schedules. Reduction in RWC was more conspicuous where soil moisture dropped below 11%. Leaf water potential measurements in early morning hours showed a significant curvilinear relationship with soil water status. Leaf stomatal values were lowest in September and highest in January.

Kanber et al.(1991) conducted an irrigation experiment on a 10 year old commercial marsh seedless grapefruit orchard at Yesilkent, Turkey during 1985-88. Irrigation applications were made at an intervals of 15 (I1) or 25 days (I2). The amount of irrigation water applied was based on pan coefficient of 0.60 (K1) and 1.00 (K2). During the trial period, I1K2 and I2K1 treatments used the most water. Average seasonal evapotranspiration for treatements I1K2 and I2K1 were calculated to be 1039 mm and 988 mm, respectively. The effective rootzones, as the depths at which 85% of the evapo-transpirational need was met for I1K1 and I2K2 were worked out to be 50 cm and 110 cm, respectively. Highest average pan coefficient (Et/Ep) for winter and spring was obtained with I1K2 (1.20) and for the irrigation season was obtained with I2K2 (0.75). There were no significant differences in grapefruit yield between irrigation treatments. However, with an irrigation interval of 15 days, the yield was slightly higher. Grapefruit trees exhibited periodicity, fruit yield and fruit number reduced by 45-52% and 77-85% respectively in low yielding years compared with normal years.The average fruit weight was 32% lower and the number of seeds was 2-4 times higher compared with the low yielding years. The highest water use efficiency was obtained from treatment I1K1 in normal yielding years.

Bacha et al.(1994) conducted a trail during 1984-90, irrigation at 4 days intervals produced the best results in terms of shoot growth, root growth, leaf chlorophyll content and fruit quality. Castel et al. (1994) stuided the response of four irrigation treatments viz.,50, 80, 110 and 140% of ETiy's through a drip irrigation system using clementina de Nales (clementine v. Nules) trees having 4 emitters for each tree. Maximum tree evaporation (ETiy's) was determined daily using a large weighing lysimeter. Irrigation frequency kept the same for all treatments which varied from 5 days/week in solution in weekly applications from April to September. Deep percolation and nitrate leaching in wetted zone were estimated by chloride balance and nitrate concentration in the soil solution at 45-60 cm depth. Although, tree growth and yield were not significantly affected by N application.The amount of irrigation and nitrate leaching losses varied according to treatments from over 200 Kg/N/ha for high irrigation to 70 Kg N/ha for low irrigation treatments. Germana (1994) found that the trees of orange cv. Tarocco were sprinkler-irrigated on a daily basis during the every 2 weeks. The irrigation volumes were determined using data from class 'A' evaporation pan and xylem potential values. The daily irrigation treatments reduced fruit drop, produced a greater increased stomatal conductance and transpiration rates. The daily irrigation regimes enhanced crop efficiency to application efficiency ratio as well as water use efficiency. There was no difference in fruit quality amongst treatments.

Sepaskhan and Kashefipour (1995)The evapo-transpiration (ET) and crop coefficient (KC) of sweet lime (Citrus limetta [C. limettiodies]) was determined and the relationship between ET and canopy to air temperature differential (Tc-Ta0C) established under drip irrigation treatments with different amount of water was studied. In the maximum value of the Kc for sweet lime under drip irrigation (1.17) was greater than those citrus trees under irrigation systems other than drip irrigation (0.75). The maximum value of evapo-transpiration to pan evaporation (ETp:Epan) for sweet lime under drip irrigation (0.7) was comparable with that of Valencia orange under drip irrigation in Arizona, USA. The equation for estimation of average 24 hr ET (Munld) by monitoring (Tc-Ta) is worked out to be, ET = 3.02-0.94 (Tc-Ta). The equation for estimation of ET-ETp = -0.43 (Tc-Tc*) in which Tc* is the temperature (0C) of well watered trees.

An experiment during 1991-95, was conducted in 2 citrus orchards in Taiwan planted with mandarin hybrid cv. Tankan or C. reticulata cv. Ponkan. Irrigation of selected trees was initiated during the growth stags before and after June, when soil moisture tension reached 30 or 60 bar. Soil water supplying capacity, determined by soil water-holding capacity, effective rooting depth and rainfall strongly influenced the canopy size and fruit yield in the two orchards. During March-June, soil moisture promoted spring flush and increased canopy size and fruit size, but during latter stages of fruit maturation, too much soil moisture reduced the accumulation of sugar and increased juice acidity. It was later suggested that irrigation was required to maintain soil moisture tension below 30 bar at 30 cm soil depth in March-June. Irrigation was required to keep soil moisture tension between 40 and 60 bar at 30 cm soil depth in June-October and irrigation needs to be controlled to keep soil moisture tension between 80 bar after October. The irrigation should be stopped during last month before harvest to avoid a decline in sugar content and an increase in juice acidity Huang et al. (1997).

Raina and Lakhanpal (1997) studied that the effect of different levels (40, 60 and 80% of available water) and frequencies (IW / CPE ratio of 0.3, 0.5, 0.7 and 0.9) of irrigation on sweet orange (CV. Pineapple) growing on Inceptisols at the Horticultural Regional Research Station, Dhaulakaun, Sirmaur, H.P., India. Irrigation at 80% available water content applied at IW/CPE ratio of 0.7 resulted in lowest incidence of fruit granulation. Further extrapolations revealed that citrus orchards having 10-15 irrigations per year produced fruits with the lowest of granulation in fruits. The controller based automatic pulse irrigation scheduling field experiment was conducted on 12-14 years old bearing Nagpur mandarin (Citrus reticulata Blanco) at National Research Center for Citrus, Nagpur during 2008-2011. The objective was to study the automatic 2-3 pulse irrigation scheduling daily as well as alternate day based on time schedule and potential evapo-transpiration through the drip irrigation. The treatments were consisted of Automatic daily irrigation daily with 60 minute interval three times (I1); Automatic irrigation daily with 90 minute interval two times (I2); Automatic irrigation at alternate day with 120 minutes three times (I3); and Automatic irrigation at alternate day with 180 minutes two times (I4) with six replications in Randomized Block Design. The automatic hybrid station controller E-6 (Rain Bird, USA) was used for micro-irrigation schedule setting the time for each treatment based on the water need of the plant and average open pan evaporation. The various scheduling treatment timings were programmed in A, B and C programs of the hybrid station controller. The sustainable production of Nagpur mandarin is possible with drip irrigation using automatic scheduling daily or on alternate days. The water use in October varied from 65.0-72.4 liters/day/plant and during May-June it was 133.0 - 147.7 liters/day/plant. Drip irrigation was scheduled to maintain automatically the soil moisture status above 25% (wet basis) during fruit growing period. The leaf nutrient status was high with automatic alternate day drip irrigation schedule. The canopy temperature was positively influenced with automatic drip irrigation schedules. The Nagpur mandarin fruit yield was highest (30.91 tones/ha) with irrigation on alternate day 120 minutes three times, followed by irrigation scheduled with 90 minute interval two times daily (30.11 tones/ha). Fruit weight (154.7 g), TSS (10.22 0Brix) and juice percent (40.77%) was found with automatic irrigation at alternate day with 120 minutes three times. The automatic drip irrigation scheduling can be a better substitute for manual drip irrigation operation and enhancing the water use efficiency (Shirgure et al., 2012b). To study the critical stages of irrigation water requirement of bearing Nagpur mandarin through the drip irrigation system a field experiment was conducted on 7-9 years old bearing Nagpur mandarin (Citrus reticulata Blanco) based on evaporation replenishment (ER) irrigation scheduling during 2009-12. The plant growing period was divided into 6 stages, 2 months each, starting from January to December and the effect on water use, tree growth, fruit yield and quality was studied. The irrigation water quantity given per day per plant under different treatments in various months varied from 21.3-158.5 liters per plant, 17.5-153.4 liters per plant and 20.9-164.5 liters per plant in different months during 2009-10, 2010-11 and 2011-12. The highest quantity of water was applied under the irrigation scheduled at 80 % evaporation replenishment (ER) treatment and it varied from 46.8-164.5 liters per plant in 2009-12. The average mandarin plant height was 4.57-4.83 m, stock girth was 51.5-56.3 cm and canopy volume 62.4-71.2 m3. The only canopy volume was found significantly between the various scheduling treatments. The fruit yield and quality were significantly affected under various evaporation replenishment (ER) based drip irrigation scheduling treatments. The highest fruit yield (17.25 and 21.48 tones per ha) higher TSS, juice percentage and lower acidity was observed under irrigation at 80 % ER in stages I-V and 30 % ER in stage VI during the study period. The highest TSS to acidity ratio (12.7 and 12.4) was found in the irrigation schedule with 80 % ER in stages I-V and 30 % ER in stage VI during 2010-12 (Shirgure et al., 2013).

3. Water requirement of Citrus

The review of work done in the past pertaining to water requirement in citrus has been presented. The growth of Valencia oranges slowed down with irrigation at 32 centibar and 55 centibar soil suctions at 30 cm depth in light and medium textured soil respectively (Hilgeman and Hewland , 1955). The preliminary study on the effect of soil management system on soil moisture in Sweet orange orchard was initiated by Randhawa et al. (1960). Koo (1968) advised Florida citrus growers to maintain soil moisture at 55 to 65% of field capacity from bloom to the young fruit exceeds 1 inch in diameter. Reitz (1968) estimated the water requirement of citrus at 40-45 inch per year. Richards and Warnke(1968) studied the irrigation systems to lemon and irrigation at 60 centibar and extrapolations to 150 centibar resulted in no measured differential response in tree growth and fruit yield under coastal conditions. Leyden (1977) found that 610 mm irrigation water applied via a drip system at 0, 200, 300 and 400 litres/tree gave the significant difference in total yield and fruit size distribution. Moreshet et al. (1983) compared the 100% and 40% of soil volume of irrigation in 'Shamouti' orange and found that partially irrigated plot was 66% of that of the fully irrigated one. Transpiration from the trees of partially irrigated plots was 72% of that of the fully irrigated plot and the evaporation from the soil surface was 58%. Fruit TSS and acid contents were higher in partially irrigated plots.

Makhija et al. (1986) obtained water need for 6 year old Kinnow mandarin which varied from 539 to 1276 mm depending upon the level of irritation with the average consumptive use of water as 61.5 cm in two years. Smajstrla et al. (1986) concluded that the tree growth of young Valencia orange was greatest when irrigation was scheduled at 20 centibar for no-grass and 40 centibar for the grass treatments. Randhawa and Srivastava (1986) emphasized on irrigation aspects in Citriculture in India. Mageed et al.(1988) carried the research on influence of irrigation and nitrogen on water use and growth of Kinnow mandarin receiving 4 levels of irrigation and three levels of nitrogen (0,115 or 230 kg N/tree). The consumptive use varied from 66.7 to 132.5 cm. Moreshet et al. (1988) studied on water use and yield of a mature 'Shamouti' orange orchard subjected to the root volume restriction and intensive canopy pruning.

Ghadekar et al. (1989) determined the consumptive use of water by citrus trees for the first time from a Modified Penman method for predicting potential ET, with the help of air temperature, relative humidity, wind velocity and solar radiation data, climatic data from 1946-85. Under clean cultivation, the water requirement of young, middle age and mature trees was work out to be 651.9, 849.0 and 997.8 mm per year respectively. An equation for daily water use was proposed for drip irrigation, to enable the adjustments and emitter discharge in order to replenish water loss through evapo-transpiration. An equation for daily water use was also proposed and it can be used for drip irrigation.

Cohen (1991) studied that a sap flow measurement in the trunk and potential transpiration computed from meteorological data were used during the irrigation seasons to determine the water requirement of grapefruit orchard (17 year old trees of cv. Marsh seedless on sour orange rootstock). Standard commercial irrigation was applied except for 2 trees, which were irrigated every 3 days to maintain unlimited soil water availability and used as reference trees. The measured transpiration was proportional to potential transpiration. The ratio between the two averages for all trees, was approximately 0.3 when soil water availability was not limiting falling to 0.2 when the soil water potential in the main root zone dropped to -90 KPa. This ratio was successfully used to schedule orchard irrigation at an arbitrary chosen reduction of 20% in the ratio as measured on the first day after irrigation correlated with their seasonally accumulated transpiration. Analysis of variability in transpiration between trees led to the conclusion that orchard transpiration could be determined with acceptable accuracy by this approach and could be used to schedule orchard irrigation.

Dettori and Filigheddu (1994) found that water requirement was measured from fruit set until ripeness in 1987-89 and 1992 in oranges given drip irrigation for 4-6 year old trees planted at 4.0 x 2.5 m. Seasonal water requirements ranged from 190 to 330 mm; the lysimeter tree used 7-28 litres per day. The crop coefficient reached a maximum at 130 days after planted at 4.0 x 5.0 m distance apart having, seasonal water requirement 223 mm; using 7-36 litres per day. Irrigation to replace 60% of the water consumed reduced tree growth, yield and fruit quality (thicker peel and lower juice content). Irrigating to replace 80% of the water used gave better yields and quality comparable to replacing 100% of the water consumed. Aiello et al. (1995) found that the irrigation water consumption by maize, silage maize, mixed pasture (Trifolium repens and Holium perenue), citrus and celery was determined at five plots in Sardinia, Italy and deficiencies or waste with respect to the actual crop water requirement were evaluated. It was concluded that the farmers tend to over-irrigate their cultivated land, the total irrigation water volume typically being 17% greater than the consumption by evapo-transpiration.

Eliadses (1998) conducted trials during 1986 to 1992 in the southwest coastal region of Cyprus using 6 year old Washington Navel orange trees grafted on sour orange rootstock sowing in a heavy (50% clay) soil and irrigated with the help of 4, 6 or 8 drippers per tree. The trees were supplied with varying amount of water ranging from 68 to 126 % of estimated water requirement. The results indicated that 780 mm of water was sufficient in normal year for optimum yield and tree growth. The amount corresponded to 56 % of class A pan evaporation. Reducing irrigation by 37 % decreased yield by 10.7 %, while further reduction to 26 % reduced the yield by 5.8 %. This yield reduction was mainly due to smaller fruit size and peel thickness increased with decreasing amount of water applied. Neither tree growth nor yield was affected by a number of diapers per tree.

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