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Review article

Micro-irrigation systems, automation and fertigation in citrus

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A B S T R A C T

Citrus is number one group of fruits grown in more than 140 countries in the world. Micro-irrigation systems and fertigation management is one of the main concerns of the modem citrus fruit production irrespective of availability of soil, water and fertilizer resources. A variety of recommendations have emerged world over on irrigation systems and fertigation based on soil and leaf analysis of the nutrients, evapo-transpiration and water use pattern. The research review of literature has revealed best promising results on irrigation scheduling based on depletion pattern of soil available water content, irrigation systems and fertigation. Various micro-irrigation systems have established their superiority over traditionally used flood irrigation with micro-jets having little edge over rest of the others. Similarly, fertigation has shown good responses on growth, yield, quality and uniform distribution pattern of applied nutrients within the plant rootzone compared to band placement involving comparatively localized fertilization. Automated fertigation in citrus orchards is a new concept, which would be the only solitary choice amongst many irrigation monitoring methods in near future. The present status of the review on micro-irrigation and fertigation in citrus cultivars is clearly indicated in this article.

1. Introduction

Citrus which is largest grown fruit in world and third largest fruit crop grown in India, originates from the wet tropics in Southeast Asia. The large-scale commercial production is found in the subtropics under irrigation The most commonly cultivated citrus species in India are *Citrus reticulata* (mandarin), *Citrus sinensis* (sweet orange), *Citrus aurantifolia* (acid lime), *Citrus aurantium* (sour or Seville orange), *Citrus grandis* (pummelo, shaddock), *Citrus limon* (lemon), *Citrus medica* (citron), and *Citrus paradisi* (grapefruit). The area under citrus in India is 0.86 million ha. with production of 0.923 million tonnes of fresh fruit, of which 34 percent is sweet orange, 26 percent mandarin, 34 percent is lime and, 5 percent citron, tangerine, lemon and grapefruit. In India the acid lime is mainly cultivated in arid and semi-arid climate. The cultivation of mandarin fruit is in 0.316 Mha area with the production of 2.57 M tonnes. Citrus is cultivated between 40°N and 40°S, up to 1800 m altitude in the tropics and up to 750 m altitude in the subtropics. For large-scale production geared toward export markets the crop is not suited to humid tropics because in addition to the difficulty of achieving the right fruit colour, humidity increases the incidence of pests and diseases. Only mandarins will tolerate humid conditions to a certain extent. The optimum mean daily temperature for growth is 23 to 30°C, it is markedly reduced above 38°C and below 13°C. Active root growth occurs when soil temperatures are higher than 12 °C. Citrus is grown on soils that are sufficiently aerated and deep to allow tap roots to penetrate to the desired depths (1-2 m). Light to medium textured soils, free from stagnant water and sticky impervious layers are preferred. Areas with a high water table should be avoided. Soil physical structure is of greater importance than the chemical properties, provided sufficient magnesium and minor elements such as zinc, copper and manganese are present in an available form. Soils with pH between 5 and 8 are preferred. The annual fertilizer requirements of citrus are 600 g/plant N, 200 g/plant P and 300 g/plant K. Adequate fertility is important for both fruit quality and yield. Citrus trees are sensitive to a high salt concentration in the soil. The citrus yield decreases due to soil salinity are : 0% at ECe 1.7, 10% at 2.3, 25% at 3.3, 50% at 4.8, and 100% at ECe 8 mmhos/cm. In addition to fresh fruit and juice, citrus is grown for production of oil and citric acid. Citrus trees normally start bearing fruit from the third year after planting, but economic yields are generally obtained from the fifth year onward. For flowering in spring a period of rest or reduced growth is needed. In the subtropics the low winter temperature induce:, this rest period, but in the absence of sufficient chilling, the rest period can be induced by water deficits. Fruits take 7 to 14 months from flowering to maturity, corresponding to a harvest season from October /November to May/June in the northern hemisphere and from April/May to November/December in the southern hemisphere. Lemons, however, have a longer flowering period and are harvested throughout the year. For most cultivars, pollination is necessary for fruit development.

Water is the basic component of plant cell tissue. It is water, above all, which controls the growth and development of citrus trees. Most of the water absorbed by the plant comes from the soil. Nutrients present in the soil are dissolved in water, taken up by the tree, and supplied to all parts of plant through translocation. Water is needed by the plant for transpiration. An adequate water supply during the growth stage has a significant influence on plant development, fruit quality and yield. In most citrus-growing areas, rainfall is unevenly distributed at different parts of the year, with marked dry and wet seasons. To stabilize fruit production and quality, it is necessary to supply adequate irrigation in the dry season, and proper drainage during the wet season. It is important to provide the right amount of water and fertilizers at different growth stages not only enhances the growth of citrus trees, but also improves yield and fruit quality (Shirgure *et al.,* 2000a). The common methods of applying water to the orchards are basin, border strip, furrow, sprinkler, and drip irrigation. Ring basin is generally followed in early establishment phase of fruit trees. Micro-irrigation to citrus is common in developed countries. Drip and micro-jet irrigation has the advantage over surface irrigation methods, due to more uniform and complete wetting of the soil surface and adaptability on a sloppy terrain (Shirgure *et al.,* 2000b; 2000c; 2001a and economically profitable (Shirgure *et al.,* 2002).

2. Micro-irrigation systems in citrus

The most common surface irrigation methods are furrow irrigation (several furrows between the tree rows), check irrigation (basins containing one or more trees) or flood irrigation (where citrus trees are planted on beds or ridges). Because of uneven water distribution and the difficulty of applying small amounts of water the importance of surface irrigation for citrus is decreasing. Sprinkler irrigation may provide a more uniform distribution of water and the possibility of applying the exact depth of required water. With the drip or micro-jet systems, water savings may be obtained because water is applied only to the root zone, leaving the remaining part of the soil dry. Sprinkler irrigation is also frequently used for frost protection. Faton (1970) observed better tree growth and yield, less weed growth, evaporation and leaching with 16 gallon water applied through drip to each 4 years old lime trees at two weeks interval compared to 320 gallon water in flood irrigation. Fritz (1970) observed that all applied water is transferred directly to rootzone of plants and 20-50 % water saving is reported depending on soil and climate. Raciti and Scuderi (1977) compared drip irrigation with the basin and found that the fruits under drip system were more acid and lower maturity ratio. Rondey *et al.* (1977) observed better tree growth and less water consumption in Valencia orange under drip irrigation in sandy soil. Simpson (1978) found that there is a shift from furrow irrigation and over head sprinkler irrigation systems to under tree systems like microjets. Slack *et al.*(1978) demonstrated that trickle irrigation on young orange trees used 5400 litres of water compared to 23400 litres of water per tree for dragline. Scuderi and Raciti (1978) compared basin irrigation with different combination of drip irrigation and measured number, weight and quality of fruits in Valencia orange and found drip irrigation providing the highest yields.

Raciti and Barbagallo (1982) found that the yield of lemon was more with localized irrigation amounting to 227.23 q/ha and 213.2 q/ha for basin irrigation. Ozsan *et al.*(1983) compared furrow, under tree, over tree and drip irrigation in lemons. Amounts of water applied were greatest (1286 mm) with under tree method and least (207 mm) with drip irrigation system. Yield was more with over tree sprinkling and least with furrow. Water use efficiency was high in drip irrigation. Cevik and Yazar (1985) demonstrated that a new irrigation system i.e. bubbler irrigation for the orchards. They further observed that under tree sprinkling and drip irrigation had the best pomological effects. Amounts of water applied per tree for over sprinkling, under sprinkling and drip irrigation were 22.01, 17.04, and 10.33 cu. m per season. Pyle (1985) appraised the use of micro-irrigation in citrus especially drip irrigation. Except the higher cost, the advantages include saving in labour, water and power, better orchard uniformity , and immediate response to crop need, better soil-water relationship, rooting environment, in addition to better yield and quality. Tashbe Kov *et al.*(1986) studied different irrigation methods. Drip irrigation and under tree sprinkling produced the highest yield with the least water requirements. The application rate for drip irrigation of 4 year old lemon trees was 7400 m^3/ha annually. Capra and Nicosia (1987) studied flooding, sprinkler and sub-irrigation with sprays and concluded that the rates of water application affected the rate of fruit growth. Autkar *et al.* (1988) studied the distribution of active roots of Nagpur mandarin as it can be useful in planning irrigation nutrition, laying planting density, and drainage management strategy. The root depth and radial extension for1- 4 year aged trees was 7.5 - 8.0 cm deep and 5 -12.5 cm, respectively with accordingly 2 - 3 m and 80 -90 cm for 10 year old trees. Increased tree growth and yield were recorded in young Valencia orange under drip irrigation method with emitter placed at distance of 1 meter from the trunk (Azzena *et al.,* 1988). Grieve (1988) concluded that under tree microsprinklers increased yield by 12% and reduced water application by 9.3% compared to conventional full ground cover. Intrigliolo and Raciti (1989) demonstrated that water saving with sub-surface irrigation was 32% over the traditional basin irrigation. The yield was higher but fruit quality was not much different. Marler and Davies (1989) studied the effect of micro-sprinkler irrigation scheduling on growth of young Hamlin orange trees and found that growth was not affected by pattern of irrigation, suggesting that 90% of root dry weight within 80 cm from the trunk, emitters are enough for root system. Zekri and Parsons (1989) studied drip, micro-sprinkler and overhead sprinkler irrigation at two water application rate and found that fruit size and tree canopy area were 9 to 20% greater in the overhead sprinkler treatments. Marler and Davies (1990) studied the growth response of micro-irrigation on growth of young Hamlin orange and found that more than 90% of root dry weight was within 80 cm of the trunk at the end of first growing season. Rumayor and Bravo (1991) studied three irrigation systems (drip, microsprinkler and flooding) and found that yields were higher in sprinkler irrigated trees and the fruits were smaller in flood irrigation.

Smajstrla *et al.*(1984) obtained greatest yields using spray-jet trickle irrigation. Yield increases were not linear with the volume of rootzone irrigated, but ranged from 39% under the drip irrigation treatments which irrigated 5-10% of the area beneath the tree canopies to 64% for two spray jet per tree, which irrigated as much as 50.7% of the areas beneath the tree canopies. Plessis (1985) observed the highest yields (190 kg/tree) coupled with largest increase in average fruit size with irrigation at a crop factor of 0.9 on a 3 day cycle. With this consumption micro-irrigation gave better results than drip irrigation. Grieve (1988) observed that a full ground cover, mid row mini-sprinkler system, and a micro-irrigation system using 100 liter/hr micro-sprinkler wetted about 2/3 of the soil area under the canopy in the tree line, in a mature Valencia orange orchard at Wateron, NSW. The two systems were operated at 14 and 17 days intervals, respectively, during Nov.-Dec. Under-tree micro-sprinkler increased the yield by 12% and reduced water application by 9.8% compared to the conventional full ground cover system resulting in increased in water use efficiency by 22%.

Castel *et al*. (1989) carried out a trial during 1981-85 with 30 year old trees planted at 6.25 x 5 m spacing. In 1980, the plot was observed into 2 parts, one part continued to be border irrigated and other was drip irrigated. No marked differences between the two treatments were observed with regard to average yield (52-53 t/ha), fruit weight (153-154 g), number of fruits/tree (1100-1106) and fruit quality. However, water use was about 15% less under drip than border irrigation. Madrid *et al*.(1989) reported that the response of 21 year old trees receiving microjet or flood irrigation on various quality parameters. The fruit physical parameters viz.; weight of fruit, peel and juice, area, volume and area: volume ratio was higher under microjet irrigation when compared with responses with flood irrigation. Jaspal Singh *et al.* (1990) observed that microsprinkler is a low volume sprinkler which operates at low pressure, requires less energy than conventional sprinklers and is less susceptible to clogging than a drip emitter. System performance was evaluated by estimating flow variation in lateral lines and field emission uniformity. The discharge pressure relation equation was developed based on actual field observations. Boman and Brain (1992) reported through a three years field study conducted to determine the effects of combinations of irrigation depletion levels at growth stages of fruit production and juice quantity of young Navel oranges. Microsprinklers were operated to initiate irrigations at earlier a high depletion level at 35-45 (bar H)) or a low depletion level at 10-15 (bar (c)). Growth stages were harvest through flowering (S_1), fruit set stages early development (S_2) and development through harvest (S_3), eight combinations of depletion level and growth stages were included in the experiment. No differences in yield per tree were attributed due to the treatments. In each of the years, the brix: acid ratio was higher for the LHH treatment. Trees with the low depletion level during all three seasons had the largest average fruit weight in 1988 and 1990. Trees with high depletion levels during the S_2 and S_3 growth stages had the highest fruit drop. Smajstrala (1993) reported that the popularity of micro-irrigation for Florida citrus production is primarily due to the many production benefits. Government regulations encourage micro-irrigation system use by limiting the volume of water allocated to growers through water use permits. Severe frosts that have damaged much of the Naval citrus belts have encouraged the use of micro-irrigation. Newly developed citrus orchards are almost always irrigated by micro-irrigation due to the lower initial system and pumping cost, rapid young tree growth, frost protection and water conservation. Combinations of sandy soils, climate, and geological factors, such as salt water intrusion have led to widespread use of micro-irrigation in the Florida to avoid emitter clogging and increased management intensity. Castel *et al.*(1994) observed that the growth, evapo-transpiration, water relations , and yield components of clementine trees (*cv.* Clementinea de Nules) subjected to differential drip - irrigation treatments were investigated during two seasons of 1990-92. Irrigation treatments were applied in a factorial design of 2 or 4 emitters per tree and 4 amounts of water (50, 80, 110 or 140 %) of tree evapo-transpiration measured by a large weighing lysimeter was 290 and 397 mm per year for 1990 and 1991, respectively and the corresponding crop coefficient values were 0.25 and 0.31. Soil evaporation during selected periods of 1991 ranged from about 50% of evapo-transpiration in the months with frequent rainfall to 8-30% in rainless months. The number of emitters per tree did not significantly affect soil matrix tension, the water status or tree growth, or flowering fruit set or yield. Irrigation rate, however significantly affected all these varieties. Irrigation with 50% ET, was insufficient in both the seasons, producing high water stress and reducing the tree growth. Yield was also reduced by a reduction in fruit number per tree. Optimum tree growth was obtained with irrigation at 110 % ET which did not differ from that at 140%.

Kumar and Bojappa (1994) conducted an experiment in the citrus orchards. Irrigation methods were compared for three effects on the yield and quality of sweet oranges, *cv.* Sathgudi on rough lemon rootstocks. Treatments were drip irrigation at 6 litre/tree/day with 1 emitter (T_1) or 2 emitter (T_2); drip irrigation at 12 litre/tree day with 1 emitter (T_3) or 2 emitter (T_4); irrigation via. 1 pot (T_5) or 2 pots (T_6) buried beside the tree (with the pots refilled as and when water was exhausted); and flood irrigation with 250 litre/tree at fortnightly intervals (T_7), and control. Parameters measured were number of fruits and fruit weight per tree, fruit fresh and dry weight, fruit volume, rind and pulp weight, rind thickness, juice content, chemical composition of the fruit juice and quality. Treatments resulted in the lowering of average fruit weight per tree (3.08 Kg). Compared with control, the drip irrigated trees (T_1-T_4) which yielded 4.38 - 5.97 Kg/tree, produced fruits with a significantly higher FW, DW, Volume, rind thickness, pulp weight and juice content. Treatment 3 and 4 were associated with a superior fruit quality and gave the best overall performance. Drip irrigation proved more economical than traditional flood irrigation besides using less water was used with treatments 1-6 respectively. Dasberg (1995) reported that the most of citrus orchards in Israel are grown with irrigation. Spray irrigation is prevalent on the lighter soil of the coastal area and drip irrigation assured on the alluvial soils of the interior valley and loam of the southern plain. The water balance of typical citrus orchard through long term experiments comparing the use of drip and spray irrigation was computed. Partial wetting of the surface never decreased or increased the yield. No water saving was achieved by partial watting. Water losses by evaporation from bare soil and by deep drainage could be minimised by water application below the tree canopy and by proper management of drip, microjet, and spray irrigation. Garcia Petillo (1995) carried out an experiment in 4 years trials with Valencia and Washington Navel oranges, mandarins and lemons, grafted on Poncirus trifoliatata rootstock. Trees were irrigated (1) throughout the growing season; (2) from flowering up to June drop, (3) from June drop to harvest or (4) no irrigation was applied in treatments 1, 2 and 3 were 481, 93 and 388 mm, respectively. The best yield increase compared with controls was obtained in treatment - 1, closely followed by treatment -3, their average of 41% in Valencia, 20% in Washington Navel, and 29% in lemons. The results for the mandarin were less consistent. Irrigation also increased fruit size and quality (improved juice content, brix, citric acid ratio and thickness of peel). Vegetative growth (trunk circumference increment) was not significantly influenced by various irrigation treatments.

Genestar and Castel (1995) reported that stem diameter changes of drip-irrigated clementina du Nules citrus trees (clementenes) were recorded continuously during 1994 using LVDT dendrometers in 4-6 trees per treatment in a well irrigated (control) treatments and in 3 under stress treatments. The stress treatments were: Irrigation during the whole year at 50% of the evapo-transpiration measured in a weighing lysimeter (SSO); supression of irrigation from 1st March to 25 July (S_1); suppression of irrigation from 4 June to 7 Sept. (S_2). During the rest of the year the treatments S_1 and S_2 were irrigated like control. Two parameters were obtained from dendrometer reading, amplitude of daily contraction (ADC) and changes in daily maximum stem diameter (DM) and compared to leaf water potential measurement performed at down (UP). The ADC value varied with evaporative demand and were highly variable typically (20-30%) both between trees as well as between different days in any treatment. Maximum ADC for the control trees was about 350 mm. At the beginning of water stress, ADC values on the severely stressed trees (S_1 and S_2) were on most of the occasions significantly higher than those for the control and the differences increased as stress progressed. The stress reversed before rewatering, suggesting the occurance of depletion of the tree water. When irrigation was recommended, UP increased quickly and stem growth increased, with their ADC values becoming similar to those of the control in treatment S_2 or even lower than in treatment S_1. In treatment SSO, ADC became significantly higher than control during summer months when the stem growth stopped and minimum UP values were reached. Change in DM appeared more clearly related to water stress development and the inflexion point in the different stress treatments occurred at UP values of about 0.6 to 0.8 MPa. The results obtained indicate that changes in DM can be used as an index of water stress in citrus. Madrid *et al.* (1995) carried out a trial during 1990-91, 21 year old trees at Sagunto, Valencia irrigated using drip or flood system to study their response on changes in juice biochemical parameters during ripening, including brix, acidity, pH and protein. Initially, similar with both irrigation methods, brix, acidity (g citric acid/100 ml) and protein and ascorbic acid contents tended to be higher with flood irrigation, where as localized drip irrigation tended to favour nutrient uptake in particular. The brix : acidity relationship indicated that fruits reached ripeness 185 days after fruit set, as the beginning of possible harvesting.

Xin *et al*. (1995) developed a prototype of real-time expert system (CIMS) for citrus microirrigation management. The system was developed to manage irrigation scheduling and control; database and stimulation. The hardware for CIMS consisted of soil mositure sensor, personal computer, automated weather station, and irrigation control system. The system is being tested at the conservation II water reuse project, Florida, USA. Dasberg and Erner.(1996) carried out an experiment in 10 year old mineola tangelo grove on the coastal plain of Israel over 6 years comparing three irrigation treatments (microsprinkler 70 litre/hr or trickle irrigation) or 2 drip laterals per tree or row 3.5 or 2.6 litre/hr. The N fertigation at 100, 200 or 300 Kg N/ha was also tested for their effects on the tree growth, yield, and fruit quality. Tree growth decreased when less water was applied at the end of irrigation season, although yield was less affected. The fruit of the stressed tree were smaller and had higher sugar and acid contents, low N rate (100 Kg N/ha) cause a gradual decline in fruit yield and its leaf N content, but produced larger fruits with thinner rinds as compared with 200 and 300 Kg N/ha. Trickle irrigation with two laterals produced greater tree growth and higher yields than trickle irrigation with one lateral or micro-sprinkler irrigation. Kanber *et al.* (1996) observed that the effect of trickle irrigation and micro-sprinkler irrigation was compared in an orange *cv.* Washingtion Navel grove during 1981-87. The soil moisture content in sprinkler irrigated plots was brought to field capacity by application at 40-50 % of available soil moisture at a depth of 90 cm with trickle irrigation. The amount of irrigation was calculated using free water surface evaporation and 4 pan coefficient ranging from 0.60 to 1.20. Irrigation was applied at 2 days intervals. For both irrigation methods, yield increased from year to year. The final year, yields were 1344 Kg/ha with sprinkler and 534-771 Kg/ha with trickle irrigation. There were no significant differences in the yield between the trickle irrigation treatments. Evapo-transpiration rates were 29-44 % lower with trickle irrigation system. Water use efficiency was 4.5-6.2 kg/m^3 with trickle irrigation, compared to 1.6 kg/m^3 with sprinkler irrigation. The amount of the roots decreased with distance from trickle and the soil depth. The highest root concentration was found near the lateral pipe in the upper soil layer with more than 80 % of roots in the 0 - 60 cm soil layer with better irrigation methods using drip irrigation.

Tuzcu *et al.* (1997) investigated the effect of irrigation system (drip, furrow, mini-sprinkler or overhead) on root growth in 13 year old lemons *cv.* Kutdiken, grafted on sour orange rootstock and planted at a spacing of 8 x 4 m and grown in clay loam soils in Aduna, Turkey. Root distribution was determined down to 160 cm of soil depth. While, 40% of total amount of roots were found in the first 20 cm of the soil in the drip irrigation treatment that proportion was 39%, 2% and 24% in furrow, mini-sprinkler, and overhead treatments respectively. Irrigation system had no significant effect on root distribution at a depth of 40 cm. The per cent of root that grew deeper than 1m were 8%, 4% and 1% for drip, furrow, mini-sprinkler and overhead irrigation treatment respectively. Boman and Parsons (1998) studied the combinations of micro-sprinkler emission devices, discharge rates and coverage. Many factors should be considered when selecting the approximate micro-sprinkler design for a particular installation. Improper selection may result in an inefficient system in terms of both cost and performance. Boman and Parsons (1998) later summarized several factors, which related to application uniformity, freeze protection, clogging, problem, wear and wetting patterns in citrus. Favetta (1998) reported that the analysis of current expansion of citrus irrigation schemes and the most popular commercial equipment revealed a trend towards selecting alternatives with lower operational costs, such as localized irrigation. Such alternatives generally have lower water and energy requirements and are easier to install. Selection of the appropriate equipments and management techniques are tools that enable producers to increase their profit margins and competitiveness in the market place. Plant spacing and choice of cultivars are other important considerations while deciding upon an appropriate irrigation system.

The investigation was done to evaluate the potential effect of different degree under tree automatic micro-jet irrigation on growth, yield and fruit quality of bearing Nagpur mandarin during 2003-2006. The quantity of water applied using in micro-jet irrigation systems varied from 97.6 to 151.1 litres/day/plant and 95.4 to 158.2 litres/day/plant during 2004-05 and 2005-06. The moisture distribution was observed higher under irrigation with 180^0 Fan type micro-jet (2/plant) and irrigation with 180^0 Ray type micro-jet (2/plant). The highest average increase in canopy volume and stock girth of Nagpur mandarin was recorded in micro-jet 180^0 (Fanjet) (93.68 m^3) and micro-jet 180^0 (Rayjet) (90.65 m^3). The highest fruit yield of mandarin was recorded with irrigation system of micro-jet 180^0 (Fanjet) (2/plant) irrigation system (40.33 t/ha) followed by irrigation with 270^0 micro-jet (Rayjet) (2/plant) (39.89 t/ha), whereas the lowest fruit yield was observed in irrigation with 300^0 Ray type micro-jet (2/plant) (35.10 t/ha). The highest TSS (10.12^o Brix) and juice content (43.05 %) was found in micro-jet 180^0 (Fanjet) and micro-jet 300^0 (Rayjet) respectively (Shirgure *et al.,* 2003a).

3. Automation of the micro-irrigation systems

With the shortage of the manpower in citrus cultivation manual drip irrigation operation is not economical, so it is being converted into the automatic controller based micro-irrigation as well as fertigation systems in citrus crops whole over the world. The details of this review related to these aspects are presented her. Choate and Harrison (1968) described the accounting method of citrus irrigation. In this method, daily moisture use represents withdrawals and rainfall, and irrigation represents deposits. The use of this daily accounting system requires information on available and usable soil moisture capacities and potential daily moisture requirements of citrus. Marsh (1968) described the system consisting of tensiometers installed at two depths in the rootzone of trees when the shallow depth reaches predetermined soil dryness, a short irrigation is applied which does not increase moisture in deeper regions. A long irrigation is later applied in response to a predetermined level of dryness in the lower soil. The system has been successfully automated in the turf grass orchards equipped with solid jet permanent sprinkler irrigation system. Irrigation of Florida citrus groves consumes more energy than any other production or harvesting operation. A computerized approach to irrigation timings allows growers to know when critical moisture levels are expected to occur. The computer enables rapid analysis of a number of variables and the system used in simple, reliable and accurate. Grower inputs are minimal, namely, monitoring rainfall, irrigation levels and determining the soil moisture depletion level for the grove. Citrus growers are provided with a projected data when tree stress will start, but decide them when to start irrigation (Jackson and Ferguson, 1981). Bolden *et al*. (1985) studied the computer based feed back system in citrus groves. Information on soil moisture and fertilized levels is registered by sensors and fed into a micro-computer, which initiates, controls, and terminates irrigation or fertigation. Eight to ten year old trees cv. Valancia on Citrus aurantium rootstocks planted at 8 x 4 m apart in red loamy soil in Cuba were irrigated at 65, 75, 85 or the conventional 80% of field moisture capacity or they were not irrigated. The highest yield was produced by irrigation at 85% moisture capacity which improved the fruit quality.

Cavazza (1991) assessed the value of automatic irrigation systems in reducing labour and water consumption costs by considering three levels of automation comprsing : (i) local automation control, (ii) cyclic automation and (iii) central programming automation. The differences between data command transmission automation of irrigation in greenhouse crops were highlighted using the above method. A simplified irrigation schedule for citrus growers in the Mediterranean was also developed on a citrus farm in Sicily, Italy. The programme was based on the balance between ET and PET. The automatic system could be implemented using a meteorological station, a personal computer, field units and electrodes. Daily gross requirements were calculated from the net requirement and application efficiency. Reference ET was calculated as the emergence between the value obtained by applying the formula of Hargreaves-Samani and the readings obtained in a class A evaporation pan. A survey of the Florida (USA) citrus industry conducted in 1996, revealed that 49% of respondents used computers for grove management, an increase from 26% in 1986. Larger operations continue to be more likely to use a computer than smaller operations. If they are use computers, the largest citrus operations are also more likely to use more specialised software applications for production automated citrus production as decision aids and accessing weather information. This suggests that larger citrus operations may enjoy a competitive edge over smaller scale operations. It is also noted that owner or manager growers are least likely interested in the management types to use these specialized applications and this group may be a disadvantaged relative to professional managers. Sardo (1992) considered the main advantages and disadvantages of the system used are considered. Control systems, both simple and sophisticated, one examining current irrigation management system are critisized and techniques based on historic weather record tensiometer readings or evaporation monitoring are promoted.

Sagee *et al.* (1995) reported a low cost, mini-lysimeter system assembled by connecting 2 electronic weighing scale of a data recorder. Each lysimeter had a surface area of $0.15m^2$ and rested on a sensitive electronic load cell capable of measuring upto 30 Kg with a precision of 25 g. The electronic signals were monitored every minute by a Campbell data aquisition and control system. Using this system, the transpiration rate of orange *cv.* Shamouti trees on 4 different rootstocks (Volkameriana lemon [C. Volkameriana], C. Sunki, citrumelo *cv.* Swingle and poncirus trifoliate) were compared. Two 18 months old trees in 6-litre plastic bags filled with equal amounts of sand, perlite and peat were placed on each scale. Leaves were removed as necessary to maintain equal leaf areas. Weight loss due to transpiration was up to 30% higher in trees on C. volkameriana than in those on C. sunki and upto 38% higher in trees on Citrumelo than in those on P. trifoliata. The system was also tested for monitoring transpiration in commercial green houses and was used effectively to establish irrigation regimes for different scion-rootstock combinations. Sardo (1996) observed a simplified irrigation schedule for citrus growers in the Mediterranian was developed on a citrus farm in Sicily, Italy. The simplified programme was based on the balance between evapo-transpiration and precipitation. The automatic system could be implemented using a meterological station, a personal computer; field units and electrovalves. Daily gross requirements were calculated from the net requirements and the application efficiency. Reference evapo-transpiration was calculated as the average between the value obtained by applying the formula of Hargreaves - Somani and the reading obtained in a class A evaporation pan. Muller *et al.* (1998) observed that as both water and the energy are particularly scarce resources in Egypt, a photovoltaic driven low pressure drip irrigation system was developed. Results of a test in a 1.7 ha citrus orchard are reported. A 530 W solar generator was installed to operate the drip irrigation system. The efficiency of conversion from solar to hydraulic energy was 3%. By watching the solar generator to the load profile of the pump and by regular cleaning of the modules from air borne dust, the efficiency of the system could be increased considerably. Shirgure *et al.* (2000a) converted the drip system existing in one acre Nagpur mandarin orchard to automatic drip irrigation system using 4 station Hybrid Station Controller, aquamiser, and 100 PGA Solenoid Valve along with soil moisture sensors. The 1.0 HP electrical pump as well as 1" Solenoid valve is remotely started as per the program scheduled into the controller. The Extra Simple Programming (ESP) with self display made the controller easy to program, read and work. Two independent programs with 3 start times and system water budgeting from 10-200 % made the seasonal adjustments easy. Programmable 7 – day watering schedule was later developed to meet varying irrigation requirement with the precision of 1 minute increment. The aquamiser monitors and soil moisture levels, and overrides controller to prevented unnecessary irrigation. The automatic drip system in Nagpur mandarin operated daily on 3 timings with irrigation time of 40-60 minutes keeping the system water budgeting from 70-120 % of the time. With this conversion from drip system to automatic drip irrigation system, the plants are irrigated daily 3 times. The soil moisture content 26.5 % (vol.) and leaf water potential 2.07 MPa and leaf canopy temperature 25.17 ^{0}C have been observed on an average at 25.2 ^{0}C ambient temperature during December, 1999. With the automatic irrigation system the growth and vigor of the Nagpur mandarin plant is maintained to the desired level.

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 (I_1); Automatic irrigation daily with 90 minute interval two times (I_2); Automatic irrigation at alternate day with 120 minute three times (I_3); and Automatic irrigation at alternate day with 180 minute two times (I_4) 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 minutes interval two times daily (30.11 tones/ha). Fruit weight (154.7 g), TSS (10.22 ^{0}Brix) and juice percent (40.77%) was found with automatic irrigation at alternate day with 120 minute three times. The automatic drip irrigation scheduling can be better substitute for manual drip irrigation operation and enhancing the water use efficiency (Shirgure *et al.,* 2012).

4. Fertigation research in citrus

Citrus production depends upon the application of water and fertilizers in appropriate amount at proper time. The market prices of fertilizers required for citrus crops are rising up day-by-day and farmers cannot afford to buy the required fertilizers. Therefore, it is the time need to apply fertilizers efficiently at proper time when plant needs. The application of fertilizers through basin irrigation goes waste (40 to 50% fertilizers) through leaching, evaporation and fixation in the soil. Fertigation is application of water soluble solids as well as liquid fertilizers through the irrigation on weekly/monthly basis so as to reach each and every plant regularly and uniformly. Use of proper quantity of fertilizer at appropriate time can be achieved through fertigation. Fertilizers are applied in the effective root zone at plants requirement through drip irrigation system. Nowadays liquid fertilizers are available in the market. They may be single or compound with micro-nutrients. In conventional method of irrigation, the fertilizers are applied with band placement and that is also three times in a year. But, with the adoption of the trickle irrigation system the fertilization schedule to the citrus orchards can be changed to more precise and frequent using fertigation technology. It is the most effective and convenient means of maintaining optimum fertility level and water supply according to the specific requirement of each crop. In the area of scarce water resource and insufficient rainfall, fertigation offers the best and sometimes the only way of ensuring the nutrients enter the root zone of acid lime (Shirgure, 1999; 2001c). It has many advantages like increasing fertilizer-use efficiency, ensured supply of water and nutrients, labour saving and improvement in growth, yield and quality. It is a very new technique under Indian conditions but getting popular along with adoption of drip irrigation system. The research related to injection of fertilizers through the drip irrigation was started by Smith during 1979. Koo (1981) appraised the potential advantages of micro-irrigation systems and its usefulness to fertigation. Bielorai (1984) advocated use of fertigation technology in citrus as it resulted in higher production of good quality

Shamouti oranges. He compared N fertigation at 100, 170 and 310 Kg/ha with broadcast application at 170 Kg/ha through irrigation system. Phosphatic and potash fertilizers were given at same rate by conventional method in all the treatments. Average yields for 4 years were 62, 73 and 82 Kg/ha with 100, 170 and 310 kg N/ha, through fertigation. Koo and Smajstrala (1984) supplied 15% and 30% of crop N and K requirements through fertigation and rest through conventional method to Valencia orange. Partial fertigation of N and K resulted in lower N contents of leaves. TSS and acid concentration in juice was also reduced but yield was not affected. Haynes (1985) discussed the principles of fertilizer use for trickle irrigated crops. In another study Haynes (1988) studied the comparison of fertigation with broadcast applications of urea on levels of available soil nutrients and on growth and yield of trickle irrigated peppers. He found that growth and yields were greatest at the low rate of N applied as fertigation or as a combination of broadcast plus fertigation.

Fouche and Bester (1986) tried various fertilizer combinations through fertigation on 13 years old Navel oranges. Fertigation was given with a soluble fertilizer 'Triosol' (3:1:5) + 350 g urea by broadcast, fertigation of N and K with broadcast of single super- phosphate and NPK through broadcast. Highest yield was obtained with fertigation of NPK through Triosol or by complete broadcasting of NPK fertilizers. No significant difference was observed as fruit size, acidity percent juice content and TSS among treatments. Beridze (1990) conducted trial on 5 year old lemon tree and fertilized 150 Kg N + 120 Kg P_2O_5 + 90 Kg K_2O per ha. as basal dressing. The highest yield of 6.6 ton per ha. was obtained from trees fertilized with basal dressing + 250 Kg peat per tree as a mulch + FYM at 25 ton per ha. Ferguson *et al.* (1990) studied the fertigation as growth of Sunburst tangerine trees. Two years old *citrus reticulata* x *C. paradisi cv.* Sunburst was fertilized with 0.66 or 1.32 lb N/tree during 1988-89 and it was 0.52 or 1.05 lb N/tree during 1990. Leaf analysis showed that low to deficient concentrations of N, K, Mn and Zn with both N treatments. Intrigliolo *et al.*(1992) reported that Valencia orange trees were irrigated either by drip irrigation using laterals along the rows or rings around the trees with 3 to 5 drippers per tree, or semilocalized sprays and each plot received nutrients either continously throughout irrigation or annually with single application in April. Xylem water potential, CO_2 exchange rate, transpiration rate, stomatal resistance and leaf temperature were monitored. Continuos fertigation provided significantly improved water, nutritional and physiological plant status compound with annual application, particularly with drip system. In the drip treatments, ring with 5 drippers produced the best result. Leaf N concentration was significantly higher with continuos fertigation, the highest concentration being found in leaf P or K concentrations. Water consumption was 21% lower for the drip system and 10% lower with the semi-localized sprays in comparision to annual irrigation. Lombard (1994) observed that stem circumference was greatest with double line trickle fertigation, followed by single line trickle fertigation, micro-fertigation and finally microjet irrigation with hand fertilization in the first season of a fertigation trial on Valencia orange at Addo Research Station. Weekly fertigation was inferior to fortnightly application but superior to monthly fertilization with KNO_3 resulted in increased K in 0 to 300 mm soil zone, especially with single line trickle fertigation. Zekri and Koo (1994 a) tried micro-nutrients through fertigation with different sources of various rates. Inorganic forms (NO_3^- and SO_4^{2-}) were ineffective in evaluating micro elements levels in oranges. But chelated sources of Fe, Mn, Zn and Cu were very effective and their rates of application were comparable with rates through foliar applications. Zekri and Koo (1994 b) studied that the use of conventional soil and foliar spray applications to correct micronutrient deficiency in citrus has not been completely satisfactory. The effectiveness of micronutrient application through micro-irrigation (fertigation) at rates similar to those recommended for foliar spray application was, therefore investigated. Three field experiments were conducted on orange, *cv.* Valencia trees to study the absorption of Fe, Mn, Zn and Cu by periodically analysing leaf samples. Details are provided of fertilizer rates and sources. The effectiveness of fertigation with micronutrients was found to depend on the fertilizer source. Application of chelated Fe, Mn and Zn through irrigation system increased the concentration of these micronutrients in the leaves. The nitrate forms of Fe, Mn and Zn were ineffective, as was the sulphate form of Zn. The sulphate form of Mn was occassionally effective, but the sulphate form of Cu was very effective. The application of chelated micronutrients through fertilization showed promise in central Florida. Berreda et al. (1996) in a study during 1995 on the use of herbigation in Spanish citrus orchards with trickle irrigation found that only 10% of 92 surveyed farmers used herbigation. Bromacil, Diuron, Oxyfluorfen, Nonflurazon, Simazine Terbuthylazine and Terhacil were the major herbicides applied by this technique. Complementary weed control treatments were necessary in non-treated areas. A serious drawback was the poor drip discharge uniformity in many orchards. Because, herbicide degradation is faster in the bulb zone, injection was usually applied more than 3 time a year. Syvertsen and Smith (1996) studied the nitrogen uptake efficiency and leaching losses from lysimeter grown trees fertilized at three nitrogen rates. The average N uptake efficiency decreased with increased

N application rates, overall canopy volume and leaf N concentration increased with N rate, but there was no effect of N rate on fibrous root dry weight. Foguet et al.(1998) showed that the growth of Valencia orange trees was positively influenced by irrigation and not so much by nitrogen fertilization in the province of Tucuman, Argentina. Two irrigation systems were tested, micro-sprays and trickle irrigation. Good results were obtained with both systems.

A field experiment was conducted on Nagpur mandarin (*C. reticulata*) during 1998-2000 at NRC for Citrus, Nagpur. The treatments were 4 levels of irrigation (10 %, 20 %, 30 % and 40 % depletion of available water content) and 3 levels of fertigation (600, 200 and 100 g; 500, 140 and 70 g and 400, 80 and 40 g N, P and K /plant). The incremental plant height (0.46 m), girth (19.9 cm) and canopy volume (14.3 m^3) was more with irrigation scheduled at 20 % depletion of available water and 500, 140 and 70 g N, P and K /plant fertigation. The fruit yield (26.1 kg/ tree), fruit weight (135.1 g), total soluble solids in fruits and juice percentage (47.32 %) were higher with irrigation scheduled at 20 % and 500, 140 and 70 g N, P and K /plant fertigation (Shirgure *et al.,* 2001b). The incremental height (0.40 - 0.60 m), stock girth (4.07 - 4.26 cm) and canopy volume (6.93 m^3) of bearing acid lime was more in irrigation scheduled at 30 % depletion of available water content with 500:140:70 fertigation. The combined effect of irrigation at 30 % depletion of available water content and fertigation with 500:140:70 gave better growth and yield of acid lime. The average fruit yield was 15.83 kg/ tree in 30 % depletion of available water content. The average fruit weight and total soluble solids were 30.1 g and 8.1 % in irrigation scheduled at 30 % depletion of available water content with 500: 140: 70 fertigation. The juice percent and acidity with irrigation scheduled at 30 % depletion of available water content and 500:140:70 fertigation was more (42.5% and 7.0%) as compared to other treatments (Shirgure *et al*., 2001d; 2003b; 2004a; 2004b; 2004c; Srivastava *et al.,* 2003).

Potassium is one such essential nutrient known for improving the fruit quality. Conventional method of fertilization suffers from not producing the consistent response of fertilizers application. The fertilization using drip irrigation has proved very effective in sustaining the quality production of Nagpur mandarin. For evaluation of the potash (K) fertigation dose, and to evaluate the effects of different potassium fertilizers applied through drip irrigation system a field experiment was conducted on 11-14 years Nagpur mandarin during 2003-06. The treatment consisted of fertigation with 20 g K_2O/plant/month, fertigation with 30 g K_2O/plant/month, fertigation with 40 g K_2O/plant/month, fertigation with 50 g K_2O/plant/month. Nitrogen and phosphorous were given from October to January and all N, P and K as per the treatments were given during February to June. The leaf nutrients status was highest in fertigation with sulphate of potash (40 g K_2O/plant) at 30 days interval from February to June. The fruit yield was highest (25.52 t/ha) with sulphate of potash fertigation followed by fertigation with 50 g K_2O/plant at 30 days interval (23.67 t/ha). The fruit quality was influenced with different potassic fertilizers. Maximum juice TSS (9.63 ^{0}Brix) and fruit weight (163.3 g) was observed with K fertigation with 40 g K_2O/plant at 30 days interval. The highest TSS/acidity ratio was observed with K fertigation with 40 g K_2O/plant at 30 days interval (10.0). Fertigation with 40 g K_2O/plant at 30 days interval using sulphate of potash fertilizer through micro-irrigation proved to be very effective for better fruit yield and quality of Nagpur mandarin (Shirgure *et al*., 2006b). In the treatments of evaluation of different potash fertilizers in K fertigation for Nagpur mandarin consisted of fertigation with potassium chloride, potassium nitrate, sulphate of potash and mono potassium phosphate with dose as 150 g k_2O/plant. The fertigation was scheduled at 15 days interval and fruit yield and quality were measured at harvest. The Nagpur mandarin yield was highest (31.13 t/ha) with fertigation of mono potassium phosphate (150 g K_2O/plant) followed by fertigation with potassium nitrate (150 g k_2O/plant) at 15 days interval (29.4 t/ha).The fruit quality is also affected with different potash fertilizers. Highest fruit TSS (10.54 ^{0}Brix) and fruit weight (159.28 g) was observed in fertigation with potassium nitrate (150 g k_2O/plant) at 15 days interval. The highest TSS / acidity ratio was observed in fertigation of mono potassium phosphate (13.7) followed by potassium sulphate (13.1). Therefore, the use of micro-irrigation and K fertigation technique will be a sustainable solution for increasing the productivity as well as fruit quality of Nagpur mandarin orchards (Shirgure *et al*., 2006a).

Climate is likely the most important determinate of improved tree performance related to fertigation. Specifically, rainfall amount and seasonal distribution affects root distribution. In arid or semiarid regions roots are concentrated around irrigation emitters allowing concentration of nutrients in the root zone. In areas with high rainfall, roots are naturally more widely distributed and consequently fertigation of a portion of the root zone does not improve tree growth or yields. Adequate coverage (60-70%) of the root zone using drippers or micro sprinklers is also likely related to effectiveness of fertigation. Coverage patterns are related to soil texture and irrigation emitter type. Micro sprinklers typically cover more area than drippers, particularly in well drained sandy soils, although trickle irrigation is effective in heavy soils if multiple drippers are used.

5. Conclusion

The adoption of micro-irrigation along with automation and fertigation is getting more popular in various citrus cultivars. Due to the scarcity of soil resources, water, manpower and energy the citrus cultivation as well as production of quality fruits is becoming very difficult and un-economical. The various advance methods of irrigation coupled with automation and fertigation is reviewed in this article and this has immense importance to the researchers of the citrus crops in the various countries.

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