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Chapter 3

Irrigation Management Practices and Their Influence on Fruit Agroecosystem

Gaganpreet Kour and Parshant Bakshi

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http://dx.doi.org/10.5772/intechopen.79569

Abstract

Annual crops are highly sensitive to water stress, so efficient water management in orchards enhance the production and sustainability of fruit cultivation. The performance of fruit tree in terms of fruit yield, fruit size and quality and long term productivity is highly dependent on irrigation and different species respond to it differently, It is known fact that the amount of fresh water available for agriculture use is decreasing and there is a need to use water efficiently either by using water saving irrigation techniques or by scheduling irrigation as per the plant's need. The scheduling of irrigation in fruit crops has gained significant importance for last one decade due to viewed rise in temperature, changing pattern of rainfall and reduction of fresh water for irrigation purposes especially for farmers indulged in fruit culture. The recent research phenology and physiology of the fruit trees in orchard management with major emphasis on water management practices e.g. deficit irrigation can influence an optimal nutrient equilibrium in soil, improve irrigation efficiency and prevent soil erosions. On this basis, work on irrigation scheduling based on evapotranspiration demand was studied in fruit agroecosystem to maintain high yield and quality of fruit crop.

Keywords: peach, fruit crops, evapotranspiration, irrigation intervals and rainfed

1. Introduction

Irrigation is one of the major agricultural activities because the plant production is proportional to water use. It is becoming a limiting factor not only in Indian subtropics but its reduction has been observed globally. The current decrease of predicted water resources are leading to urgent need to adopt a strategy which could be applied to efficiently utilize water without affecting the growth, yield and quality of a plant in agroecosystem. In fruit agroecosystem,

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sometime introduced plants have different water needs than the ability of ecosystem provide for naturally. The water need of the fruit tree is governed by the annual phenological and soil-water-plant relationship. Fruit trees require frequent irrigation during fruit development and mismanagement of water supply to trees at critical stages leads to fruit drop, reduced fruit size and quality. So, proper irrigation is essential in maintaining a healthy and productive fruit orchard. Whereas over irrigation slow root growth, increases the potential for iron chlorosis in alkaline soils, and leaches nitrogen, sulfur and boron out of the root zone leading to nutrient deficiencies. It can also induce excessive vegetative vigor. Excessive soil moisture also provides an ideal environment for crown and collar rots in peach. On the other hands applying insufficient irrigation water results in drought stress and reduced fruit size and quality [1]. Many studies on irrigation management under different agroecological system on fruit crops e.g. peach [2–4], cherry [5], pummelo [6], olive [7, 8] and mango [9] reported that moderate water restriction do not effect morphological and physiological processes of tree. In fact, enhance the bearing, maturation and fruit tree features.

In irrigated agroecosystem, irrigation systems have been under pressure to produce more with lower supply of water. Majority of developed/developing countries implement technological, economical and regulative irrigation strategies for efficient use of hydro-resources and reusing wastewater in agriculture sector. Decreased water due to global warming along with uneven rainfall patterns have increased the requirement of optimum and efficient use of irrigation by means deficit irrigation practices. Deficit irrigation supplies reduced water volume depending upon evapotranspiration (Et) percentage throughout fruit crop irrigation season with the minimal impact on fruit production. Evapotranspiration is key factor in irrigation scheduling as a management tool, Et (actual, potential and reference) rate either directly measured or indirectly estimated are of crucial importance for determining crop water requirement. Among numerous indirect methods for Et estimation, initial Penman equation is probably the most modified one. Modified Penman-Monteith approach is the most used mathematical approach for Et determination accepted by research as well as in practice of water management and planning. The P-M method can be successfully applied for Et calculations and water management in field conditions [10].

2. Irrigation management practices, vegetative growth and fruit productivity

Considerable changes in weather and water availability during the last decade as expected, caused increase in temperature, frequencies and durations of summer drought events with changing precipitation patterns leading to enhanced rainfall during winter and spring, thereby adversely affecting the physiological performance, growth and competitive ability of trees [11]. Thus, the aim of this study was to understand the response of peach tree's morphological and biochemical characteristics, by supplying irrigation at T1 = 20 mm potential Et (PET), T2 = 30 mm potential Et (PET), T3 = 40 mm potential Et (treatment trees mulched with straw mulch), T4 = 50 mm potential Et (PET). The maximum soil water availability of the soil was 80 mm. The growth and quality characteristics of peach cultivars cultivated under rainfed conditions (control) were also evaluated. Irrigation water requirements (IWRs) for peach crop was calculated by subtracting effective rainfall (calculated using the CROPWAT Programme, [12]) from Etc, without taking account of the variation in soil water content during both experimental year. Estimation of crop coefficients (Kc1 = 0.20, Kc2 = 0.5, Kc3 = 0.7, Kc4 = 1.0) mean values given by [13] were used. Et requirement by the crop has been computed using the equation: Etc = Kc × Eto.

2.1. Effect of different irrigation levels on vegetative growth of crop

Water stress significantly reduces trunk growth and shoot extension growth of peach tree [14], so both vegetative characters was closely linked to irrigation volume and showed significant differences when compared under different trials. Shoot extension growth was measured on weekly bases, while trunk girth development measured at 15 days intervals in all the treatments. In both the year of study maximum trunk girth and shoot extension growth was attained by plants irrigated at 40 mm PET level, whereas minimum trunk girth and shoot extension growth observed under rainfed condition (**Figures 1** and **2**). Peach shoot growth reduced in proportion to the magnitude of the water deficit and with the replacement of 12.5% of the evaporation, there was more than 75% reduction in shoot weight [15]. Shoot growth and limb diameter were limited whenever water supply was restricted in Merrill Sundance cultivar of peach [16]. Water stress affected the growth and dry matter partitioning of young peach trees, whereas total dry matter production reduced with each incremental decrease in applied water and attributed to lower leaf conductance in the unirrigated conditions. Reduction or halting of lateral branching and new leaf production soon after water stress is the major factor that contributes to differences in tree biomass production [17]. Regulated deficit irrigation applied at stage II as well as combined regulated irrigation at stage II and postharvest stage

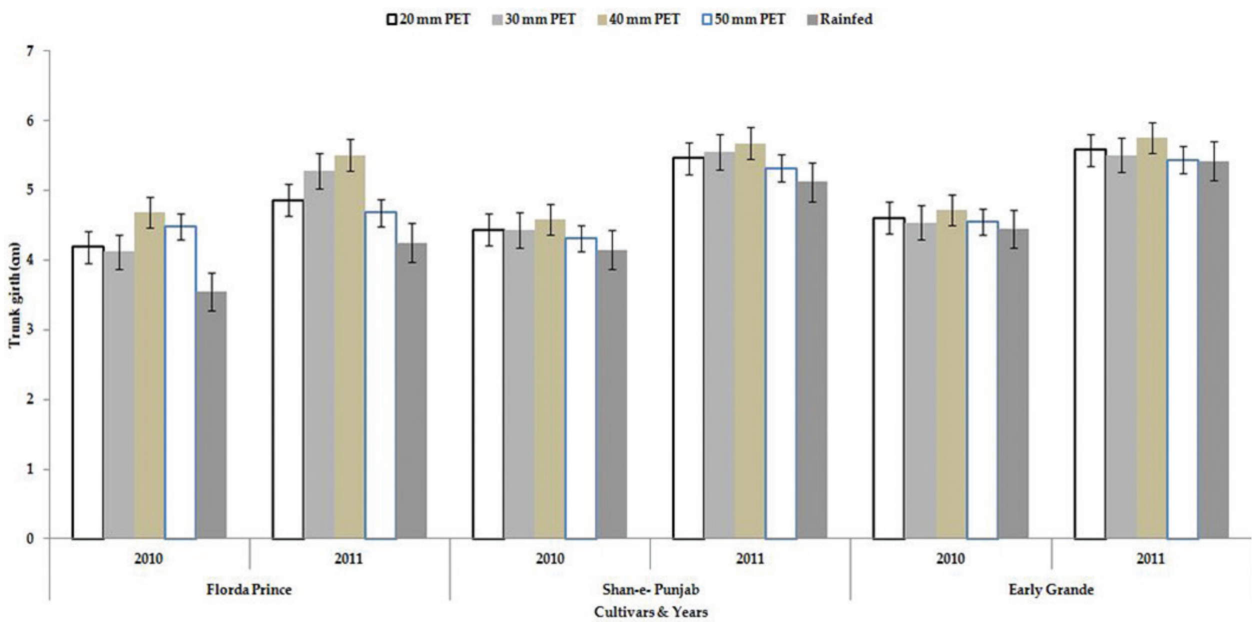

Figure 1. Effect of irrigation on trunk girth of peach cultivars.

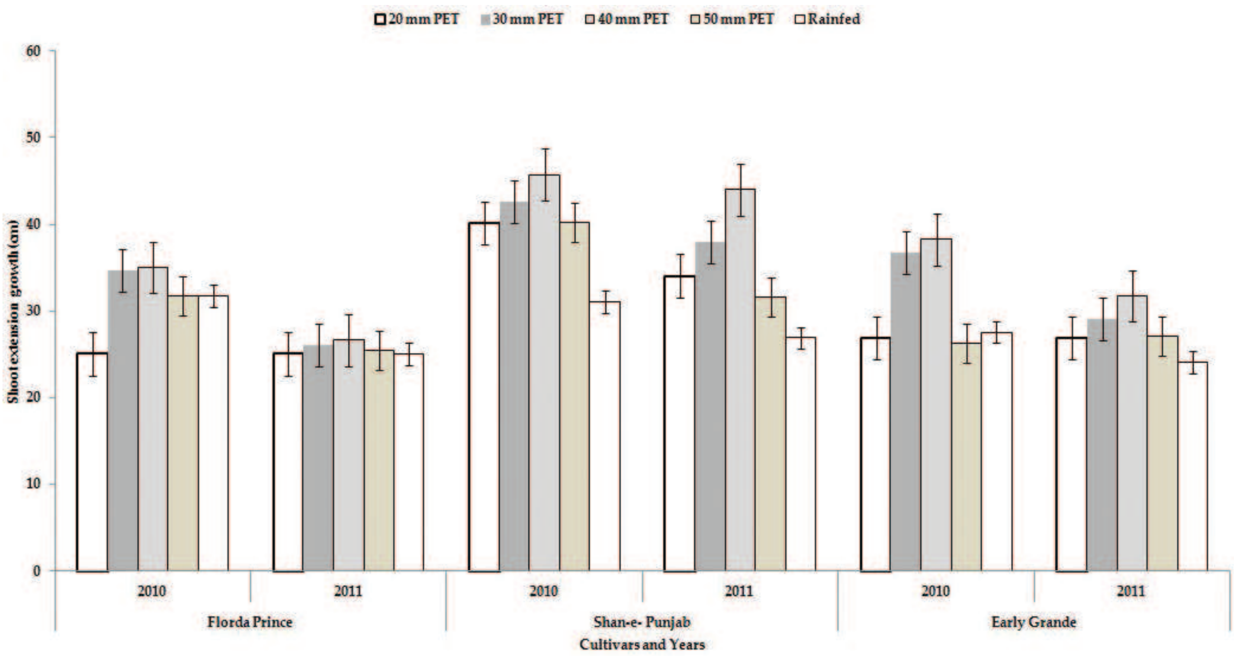

Figure 2. Effect of irrigation on shoot extension growth of peach cultivars.

reduced length of the shoots (>75 cm) inside the canopy in clingstone peaches [18]. Similarly, peach tree had reduced trunk radial growth and canopy shaded area when no irrigation was provided to the trees as compared to irrigated ones [19]. The range of maximum daily shrinkage was more pronounced in non-irrigated than the irrigated peach trees, because development of unirrigated plants was probably impaired by low values of stomatal conductance and CO_2 assimilation [20]. Trunk growth was maximum in 75% Etc based irrigation, followed by 50 and 25% Etc-based irrigation as compared to unirrigated in Larnaka pistachio [21]. Supplemental irrigation substantially increased trunk cross sectional area (TCA) of 1-year old Red Globe cultivar of peach as compared to tree supplied with no irrigation, whereas unirrigated trees were smaller than irrigated trees because of a lack of sufficient annual rainfall [22], a reduced increase in trunk diameter was observed due to limiting xylem deposition. The irrigated "Doyenne du Comice" pear trees had better trunk diameter development than water stress trees, with the intensification of water stress, there was a decrease in trunk fluctuations in non-irrigated rootstocks and related it to the low pluviometric precipitations and high ambient temperatures, which occurred at the time of experiment [23]. In grapefruit maximum relative growth of the trunk diameter at irrigation applied on 15 days with 1.00 pan evaporation (23% above the graft and 28% below the graft), whereas minimum relative growth rates, (10% above the graft and 12% below the graft), were observed in irrigation applied at 25 days interval with 1.00 pan evaporation [24]. Gemlik cv. of olive had highest trunk section area and canopy volume under full irrigation treatment at 100% evapotranspiration along with application of 400 g/tree phosphorous during initial developmental stage, potassium (500 g/tree) before endocarp hardening, and Nitrogen (40 g/tree) applied during each irrigation period. Canopy volume increased up to 10% with full irrigation treatment at 50% evapotranspiration and 25% with full irrigation at 100% evapotranspiration compared to rainfed conditions, whereas under full irrigation treatment at 50% evapotranspiration and full irrigation at 100% evapotranspiration 8 and 14% more trunk section area was recorded respectively [25]. Increased diurnal shrinkage of trunk in trees which did not get any irrigation over course of postharvest season reflected the progressive reduction in water potential. In a sub-humid climate, 'Z-900'/Gisela 5 young dwarf cherry trees had maximum values in terms of trunk cross-sectional area and volume of trees when irrigation was applied at 125% evaporation as compared to irrigation based on 75% pan evaporation wherein smallest trunk cross-sectional area was obtained [26].

2.1.1. Transpiration

Among the indicator used for monitoring water status transpiration is reliable, because transpiration and crop yield is linearly related in areas with higher solar radiations. The transpiration rates trends observed for all cultivars in 2010 and 2011 appeared to be mainly a function of the climatic factors in the different stages of growth. Rate of transpiration was low during 2010 due to moderate drought conditions (**Figure 3**). Overall transpiration rate in 2011 was higher at fruitset, maturity and post harvest in all irrigation levels as well as under rainfed conditions, whereas less transpiration rate in fruitset stage from plants irrigated at 20 mm Etc level. Similarly, the rate of transpiration was highest in well watered mango plants compared to the extremely stressed plants [27]. Small transpiration differences between control and irrigated or fertigated treatments which might be due to early season irrigation in grape Concord and Niagara vineyard observed [28]. Among various peach cultivars, Early Grande and Florda Prince transpired more at post harvest stage during both the years, whereas Shan-e-Punjab transpired more at maturity stage in 2010 and at post harvest stage in 2011. The variability was due to increased natural moisture because of rainfall during April and May.

2.1.2. Leaf area and traits

Fruit productivity is closely related to rate of leaf area development. As the amount of absorption of photosynthetically active radiation and dry matter accumulation depends on the area of leaf. Larger the leaf area, more the PAR is absorbed by plant and more dry matter accumulated, water is main factor responsible for leaf area development [29]. Thus, the purpose of study to understand the impact of irrigation on leaf area in low chilling peach cultivars. Leaf area in peach plant significantly increased with higher irrigation levels, however maximum leaf area recorded in plants irrigated at 30 mm PET level, due to better root establishment, efficient photosynthesis and production of more assimilates. Leaf area reduced in plants grown under rainfed conditions and irrigated at 50 mm PET level (**Figure 4**). Similarly, Korona cultivar of strawberry plants which received cent per cent water (100% water) supply differed significantly as compared to the water stressed plants, in terms of leaf expansion during fruit ripening [30]. The large reduction in leaf area with long term water stress is caused by a lower leaf elongation rate and earlier abscission of the old leaves. Whereas, Dashehari mango trees irrigated at 20 and 40% depletion of available soil moisture attained more spread and leaf area than those irrigated at 60% depletion of ASM and unirrigated [31]. In Thompson seedless cultivar of grape plant leaf area was higher in plants irrigated through drip irrigation followed by furrow irrigation than stressed plant [32]. Bell pepper had higher leaf area under irrigation applied after 3 days interval [33]. 16.8 laterals with leaf area of 122 cm^2/leaf, and leaf biomass

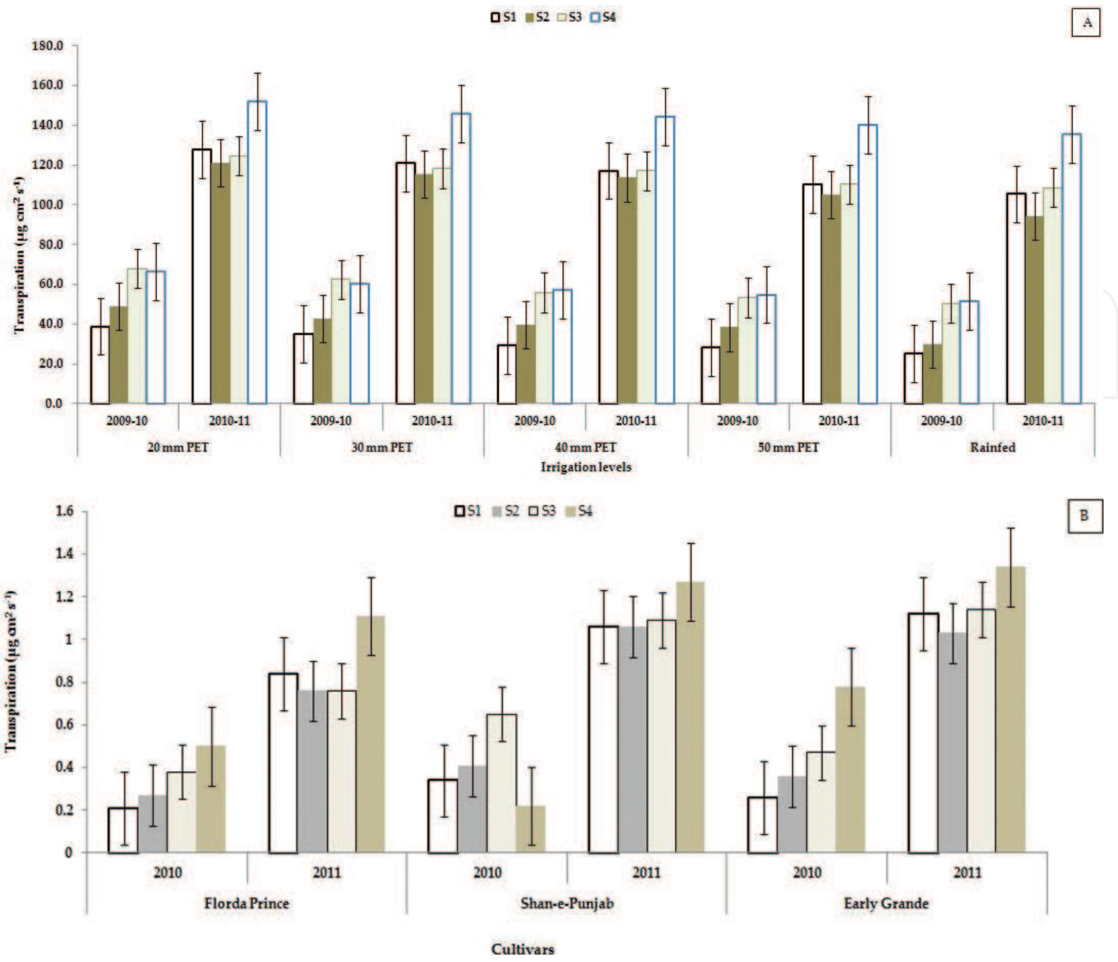

Figure 3. Graph showing average transpiration (a) in different irrigation levels (b) in three cultivars of low chilling peach at different stages of growth and development (stage 1: Fruitset, stage 2: Pit hardening, stage 3: Maturation and stage 4: Postharvest).

of 2.4 g/leaf was recorded when 20 L water was applied as compared to 2.5 L water application in purple passion fruit, wherein 11.3 laterals with leaf area of 106.5 cm^2/leaf and leaf biomass of 2.0 g/leaf was obtained [34]. Highest irrigation level of 15 m^3/tree/year increased leaf area, while lowest irrigation level of 7 m^3/tree/year decreased leaf area in 20-year old pomegranate trees [35].

2.1.2.1. Stomatal density

Stomatal features are known to affect transpiration, moderate water deficits had positive effects on stomatal number, but more sever deficits led to a reduction. The stomatal size obviously decreased with water deficit and stomatal density was positively correlated with stomatal conductance (gs), net CO_2 assimilation rate and water use efficiency [36]. Stomatal density of peach cultivars was maximum at 40 mm PET and 30 mm PET levels, whereas reduced stomatal density was recorded in plants grown under rainfed conditions as well as plants irrigated at 50 mm PET. The reduced stomatal density under stress conditions might be due to adaptation of plant to reduced water loss and cell division under certain degree of water stress, while stomatal density under surplus soil moisture conditions might be due to

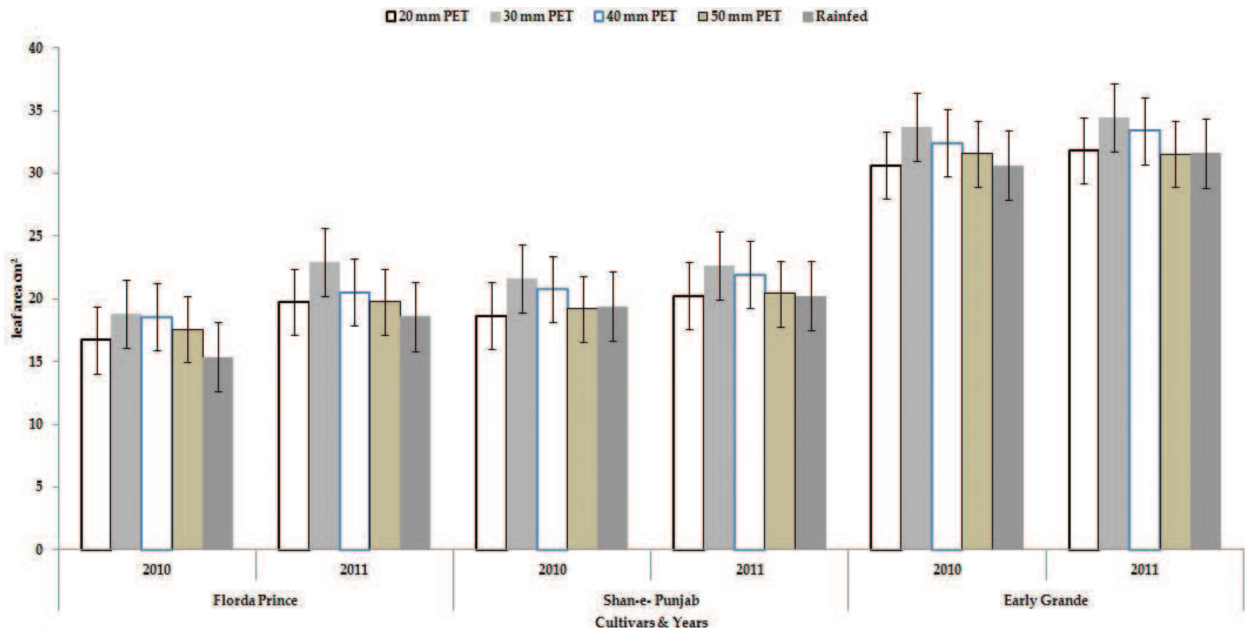

Figure 4. Leaf area development under different irrigation levels.

difference in stomatal number and size. Leaves from peach seedlings grown under both water stress and saturation conditions changed stomatal aperture and density as compared to leaves of seedling which received proper moisture [37], while water stress induced approximately 35% reductions in stomatal density in peach seedlings which is plant adaptation to water deficit conditions and lack of significant difference between stomatal density of leaves grown with excess and adequate soil moisture be caused primarily due to variation in stomatal number in each leaf. Stomatal density in 6-year-old apple was minimum under permanently irrigated trees and maximum in unirrigated trees, [38] concluded that stomatal density appeared to be predominantly affected by water status of the apple tree during vegetative growth period in spring. Hybrid peach seedling rootstocks (S-21, 42, 46, 47, 51 and 52) had highest stomatal density in soil moisture raised to 25% of the field capacity once in a week through irrigation and in saturated soil with irrigation once in a week, while lowest stomatal density was found in tree leaves when soil moisture was raised to 50 and 75% of the field capacity once in a week [39].

2.1.2.2. Chlorophyll content

Green color pigment chlorophyll is a light capturing molecule in photosystem and one of the key factors influencing photosynthetic capacity. Chlorophyll content in leaves was considered as a trait for crop production, drought stress during growth is negatively correlated with chlorophyll pigment in plants. Chlorophyll content of water-saturated grown peach leaves was minimum than that of leaves grown under stress and adequate soil moisture which attributed to the destruction or inhibition of chlorophyll synthesis in the leaves which resulted from water saturation conditions. In another study, [40] chlorophyll content of peach leaves from effluent treated watered trees was significantly higher than that of tree leaves from unirrigated, which could have been due to the significant increase in mineral contents, particularly Fe and N in effluent treated leaves. The chlorophyll content in peach leaves was another factor which was affected by the irrigation levels during the present investigation. Highest total chlorophyll content was in plants irrigated at 40 mm PET level and 30 mm PET. Reduced in plants irrigated at 20 mm PET and 50 mm PET as well as in plants under rainfed conditions. Decreased chlorophyll content under drought or water stress condition in Nectarin-8 cultivar reported [41]. Total chlorophyll content decreased with increased water stress among different rootstocks of grapes. The maximum total chlorophyll content was in 1103P leaves under water stress [42]. Similarly, in 6 months old mango rootstock seedlings, slight increase in chlorophyll content under water stress conditions, because chlorophyll A was more resistant to dehydration; it increased slightly with water stress, as compared to chlorophyll B, which remained constant, however slight increase in total chlorophyll under water stress suggest that the chlorophyll pigments in leaves were somewhat resistant to dehydration [27]. Chlorophyll A,B, and total chlorophyll reduced under drought stress conditions [43]. Leaves total chlorophyll content was higher under irrigation compared with rainfed condition in fig [44].

2.2. Fruit yield and quality

The sensitivity of fruit growth to soil water availability has been well documented, fruit growth depend on the accumulation of large quantities of osmotically active solutes and massive cell expansive growth and these processes require carbohydrates and its restriction under water-stressed crop decrease ability to accumulate water [14]. Maximum fruit size in peach was attained in the plants irrigated at 40 mm PET level as compared to fruit taken from plants provided with irrigation at different levels of evapotranspiration. However, the main contributed parameter in fruits, which was influenced by different levels of irrigation, is found to be diameter of the fruits in the present study. Bigger fruits harvested from the plant might be due to fulfillment of water requirement of that plant at that particular level of irrigation which in turn resulted into larger cell size rather than increase in the cell number and this cell expansion might have resulted in better uptake of mineral nutrient. In the present investigation, under water deficit condition, fruit size decreased probably due to reduction in availability of assimilate and lower stomatal conductance, whereas surplus water condition might have led to anaerobic conditions and reduced water and nutrient uptake, thus reduced the fruit size. Reduction observed in fruit weight of Nijisseiki Asian pear in late stress conditions compared to the well watered tree [45], whereas highest fruit weight under optimum irrigation and light water stress reported in Big-Top cv. of peach and the lowest average soluble solids percentages under water stress. When light water stress was applied; soluble solids percentages appeared to slightly decrease while peach weight remained relatively constant [46]. Peach fruit size increased with irrigation compared to no irrigation [47]. Water stress improved fruit size by 37% in low-chill peach cv. Florda Prince [48]. Nectarine fruit size distribution was shifted towards larger fruit with increased level and with decrease in crop load [49]. Larger fruit size in pear trees irrigated at amount 30% below (T 70, 1.7 × control irrigation rate) a presumed optimum rate (daily irrigated, control) of water than tree irrigated at 30% above (T130, 1.3 × control irrigation rate) or daily irrigated trees (control) [50]. Under regulated deficit irrigation, bigger average fruit size and a more favorable fruit size distribution in Chok Anan cultivar of mango was recorded [51]. In purple passion the fruit weight of 6016 g/plant was obtained from 20 L irrigation, which was greater than plants received 2.5 L water (505.5 g/plant) [34]. Pineapple fruit weight increased with irrigation volumes of 0.2, 0.3 and 0.4 pan evaporation, while irrigation volumes affected the polar and equatorial diameter of pineapple fruits with smallest fruit diameters in 0.1 pan evaporation (8.07 and 5.15 cm, respectively) as compared to other irrigation volumes [52]. The irrigation increases peach quality depending on the amount of water applied, cultivar and environmental conditions. The results of this study showed higher total soluble solids content in fruits harvested from plants under deficit water, while total soluble solids was lower in fruit from plant grown under optimum or excessive level of water and fruits from plants grown under rainfed conditions. Active increase in total soluble solids in the fruit by osmotic adjustment in low water level might be the mechanism through which the plant could have compensated for decrease in turgor potential and consequently attenuated the decrease in fruit growth, whereas decreased Total soluble solids under increased soil moisture might be due to dilution of the soluble solids under higher water content in fruit. Further studies on deficit irrigation and stress conditions revealed increased total soluble solids at harvest in 'O' Henry peaches as compared to optimum or fully irrigated trees [53–55, 65]. Increased level of total soluble (TSS) in Mihowase Satsuma under deficit irrigation compared to fruit grown under normal irrigation level with slight influence on peel color, titratable acidity (TA) and TSS/TA ratio was observed [56]. On other hand higher total soluble and glucose and fructose concentration obtained in the irrigated vines of Tempranillo grapes than in the unirrigated vines [57]. Andross cv. of peach had higher soluble solid content (12°Brix) under regulated deficit irrigation during stage II of fruit growth [2, 58], and also increased fruit firmness and total soluble solid under deficit irrigation during stage 3rd of growth observed [59] with higher total soluble solids and titratable acidity, coupled with small decreases in maturity index in citrus under deficit irrigation [60]. Total soluble solids in peach fruit increased under high water restriction as compared to control and light water restriction [61].

Relationship between water and yield demonstrated that in well watered cv. Ëlegant Lady "peach plants, tree water status is independent of crop load, whereas drought stress level increased with increasing crop load in trees receiving reduced irrigation [14]. The experiment conducted determine the yield response of the crop to different irrigation intervals. On an average maximum yield/plant was recorded when irrigation was applied at 40 mm PET level, in comparison to all treatment yield/plant was recorded lowest under rainfed condition. However, a significant decrease was noticed during the second year of the experimentation. Similarly strawberry yield reduced in water stressed plants because of a decreased mean fruit weight mainly caused by the reduction in individual fruit size [30]. Water restriction at stage III in peach reduced yield [20]. Pear-jujube yield under moderate and sever water deficit treatments at bud burst to leafing and fruit maturation stages increased fruit yield. Fruit yield under low water deficit at fruit growth and fruit maturation stages was similar to that of full irrigation treatment [62]. Yield comparison in case of variety Shan-e-Punjab had similar yield under different irrigation levels including rainfed treatment. Rainfall pattern in the second season is optimal for this cultivar needing least irrigation. Rainfall during sprouting phase gave positive response and rainfall during flowering phase gave negative response to yield and quality [63]. **Figure 5** represents yield (kg/plant) response of three peach cultivars to seasonal water use under different irrigation levels. Seasonal Etc (mm) of peach cultivars treatment wise in season first (2010) T1 = 202 mm, T2 = 168 mm, T3 = 127 mm, T4 = 121 mm & season second (2011) T1 = 216 mm, T2 = 173 mm, T3 = 158 mm, T4 = 152 mm.

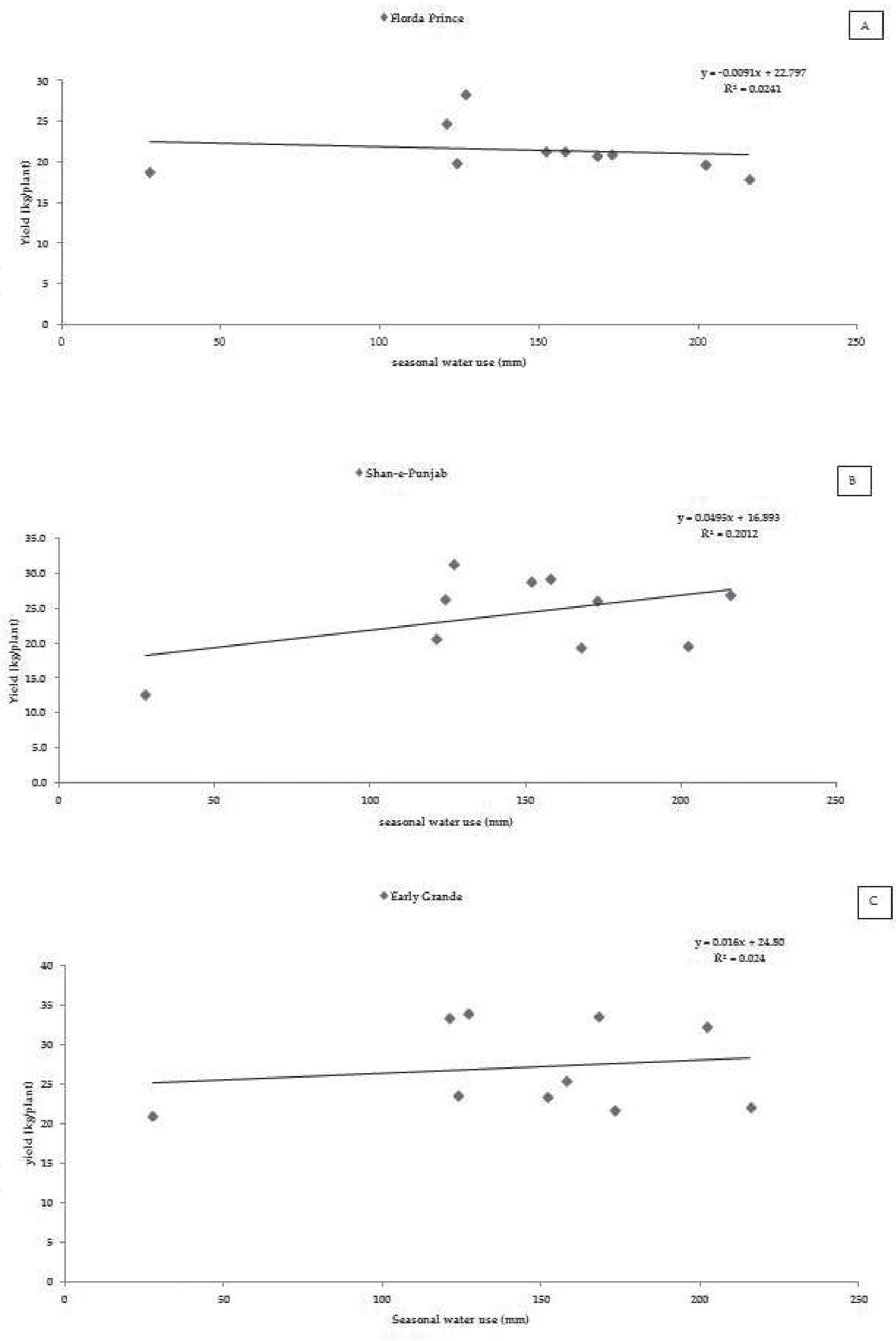

Figure 5. Response of different peach cultivars to seasonal water use [64].

3. Conclusion

Irrigation water is costly to farmers in most of the agroecosystem nowadays. The increasing environmental emergencies related to water scarcity, severely affected the performance of fruit plants in term of growth, yield, quality, storability and long term productivity. With an innovative and sustainable irrigation management, the effect of these environmental emergencies can be reduced. In fruit growing areas of world, environmental vagaries causes conditions like reduction of soil organic matter, groundwater contamination, soil deficiency of mineral elements (in particular phosphorus and nitrogen), alkalinization/salinization and nutritional imbalances in plants. As experimental works highlighted in this chapter, on morphological and biochemical characters (directly affected by water shortage) of fruit trees in orchards have revealed that sustainable and innovative irrigation management, with a particular emphasis on reduce irrigation, allow to obtain an optimal plant nutritional equilibrium, reduce nutrients leaching risks, improve irrigation efficiency and prevent soil erosion. The deficit irrigation technique based on reference evapotranspiration in fruit orchards are indispensable need for preserving tree quality and maintaining high yield and quality. With these information a fruit farmer can be informed of the field water loss occurring after the last rain or irrigation and taking into consideration the expected advised on the timing and quantum of irrigation. Optimization and innovation of sustainable irrigation technique with a low negative environmental impact, represent a major change in fruit agroecosystem by reducing needs or increase efficiency of water use and also enhance the value of water within ecosystem.

Acknowledgements

I express deep sense of gratitude to Dr. M.K. Khushu (Chief Scientist) and Dr. Mahendra Singh, (Associate Professor), Agrometeorology for their valuable suggestion and providing weather station and laboratory facilities at Agrometeorology Centre during the entire course of my research work.

Author details

Gaganpreet Kour* and Parshant Bakshi

*Address all correspondence to: gaprit05@gmail.com

Sher-e-Kashmir University of Agricultural Sciences and Technology, Jammu,
Jammu and Kashmir, India

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