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Irrigation of pear
(A review)

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Summary: The plantation of intensive growing orchards and steady increase in yield is essential to return the growing cost by sale. Seasonal crop fluctuation of pear is increased by the frequently occurrence of drought and climatic changes. This study reviews genetic and growing factors determined the alternancy of pear and present the new knowledge concerning on water saving irrigation techniques. Use of dwarfing rootstocks, root pruning, branches pruning and new water saving irrigation make the changes in vegetative and generative growth that successfully improve the alternancy of pear growing. According to publications BA 29 of clonal quince rootstocks exhibited the best protection mechanism against to drought. Regulated deficit irrigation (RDI) applied during rapid shoot growth and slowly fruit growth result a decrease in shoot growth and 60% of water saving in pear orchard while there was no influence on harvested yield. Partial rootzone drying (PRD) microjet irrigation applied in pear orchard result 23–52% of decrease in water use, however concerning explorations are contradictory. Further investigations need to improve the efficiency of new irrigation technology adapted pear varieties based on monitoring of soil water status and measurement of stem water potential as stress indicators of plants.

Key words: pear, irrigation, regulated deficit irrigation, partial rootzone drying

Introduction

The pear crops are influenced by genetic, ecological and cultural factors. The ecological conditions have a determinant parts in economical pear production in which the ratio is 55% of precipitation, 20% of temperature and 25% of soil conditions, respectively (*Göndörné* 2000). In the area where the pear orchards concentrated, there is a water table ranging between 80 cm or less from the soil surface in the late winter and about 200 cm in midsummer (*Rossi Pisa & Venture* 1990). The water table levels of about 150 cm from the soil surface guarantee the best results in terms of vegetative growth and yield and the best efficiency in the use of precipitation. Water table depths between 150 cm and 200 cm may already allow the irrigation needs to be reduced (*Battilani* et al. 2004). Pear water requirement is high over 700 mm precipitation per year therefore the production can be safe only under balanced climatic conditions. The high temperature and low air humidity result yellow coloured leaves of trees, falling of leaves and small fruit size for this reason the areas for pear orchards are limited in Hungary. A total of 30 % of pear yield are produced in western part of Hungary where the precipitation is 700–800 mm per year and 17–20% of that around the Budapest. The third area of pear orchards (15–16%) can be found in northern part of Hungary where the microclimate of rivers Bodrog and Tisza have a good influence on pear production (*Göndörné*, 2000).

The frequently occurrence of drought makes the pear yield unbalanced in particularly South Europe. The climatic changes cause a risky in pear yield mostly at Hungarian lowland. The varieties should be revaluated and cultivars with large water demands might be crowded out the pear production. Use of drought tolerant varieties and up-to date technology could make the pear production profitable. The new aims of breeding programs are to improve the adaptability of pear varieties. Use of dwarf type of rootstocks with drought tolerance and the deficit irrigation technology are current objects for practice.

Water deficiency

The root manipulation techniques may access to increase the floral precocity of pear trees (*Webster*, 2002) and decrease of shoot length (*Maas*, 2007). Since the use of the chemical growth retardant chlormequat was forbidded thus root pruning has become common practice for controlling shoot growth in pear trees in the Netherlands. This may be a risky method because too strong pruning may result in reduced fruit size or decrease in fruit quality due to insufficient uptake capacity for water and nutrients by the remaining root system. *Wertheim* (2004) advised to apply the root pruning only in orchards in which trees can be irrigated because the root-pruned trees are more likely suffer from drought stress than irrigated ones. Others announced that root pruning without irrigation significantly decreased the tree growth but not effected on fruit growth (*Maas*, 2007).

The high pear yield can be only produced by irrigation in commercial orchards. *Shackels* et al., (1999) reported the water deprivation when only 65% of evaporation (ET) applied caused significant reductions in the tree growth and fruit growth. Proebsting and *Middleton*, (1980) reported abnormal fruit set in the year following a water stress periods, where leaf water potential was lower than -3.0 MPa and maintained for more than one month. Water deficit caused defoliation in pear varieties being sensitive to water stress and strong fruit falling of that disposed for dropping before ripening such as 'Hardenpont', 'Nemes Krasszán' and 'Diel' pear. The undropped fruit size is remained small as in 'Serres Oliver' and 'Esperes bergamott' varieties and the consumption quality of these fruits is decreased due to the development of stone cells in fruit flesh. In 'Williams' pear grown on a loamy sand soil and irrigated by mikrosprinkler the contribution of first and extra class fruits exceeded 82 and 85% when the lower limit of the optimum soil moisture was 50–60% of field water capacity (FWC). The decrease in soil moisture to 40% and 30% of FWC caused that the ratio of high quality pear yield also decreased to 77% and 68%, respectively (*Bošnjak* et al., 1997).

The water deficiency result a decrease in fruit size and yield and changes in the fruit quality during different stages of fruit development. Asian 'Nijisseiki' pear is more tolerant to water deficit than European pear cultivars because the water stress had no influence on the yield per trees and diameter of fruit neither at early stage (50–90 days after full bloom) nor late stage of development (109–130 days after full bloom). The early water stress coincided with a rapid vegetative growth and slow fruit growth. After 35 days of reduced irrigation, early stressed fruit had a high concentration of each carbohydrate involved the glucose fructose and sorbitol but decreased their Na, P, K, Ca and Mg contents (*Behboudian & Lawes*, 1994). Water stress conditions caused by withholding irrigation at full bloom and 30 days after full bloom resulted in remarkable increase of stone cells density in 'Niitaka' pear flesh. Stone cell content in pear flesh was the highest at 60 days after full bloom during water stress then it was decreased until the harvest. The water stress after bloom caused higher content of stone cells in the pear flesh than in the fruit of trees stressed before and during flowering (*Lee* et al., 2006). Contents of sugars and organic acids depended on genotypes are also influenced by the changes of soil and climatic conditions or technology in orchards such as fertilization, foliar nutrition, irrigation etc. (*Hudina & Stampar*, 2004, 2005). Fruits from non-irrigated trees were slightly less green and contained more sugars than irrigated trees. Root pruning applied without irrigation resulted in an even greater reduction in green background colour while further increased the sugar content of the fruits (*Maas* et al., 2007). Both fruit size and green colour decreased with a greater water stress whereas soluble solids and titratable acidity increased (*Ramos* et al., 1994).

Water relations of pear

The fruit trees with large canopy and deep root system endure better the drought than the smaller sized trees of intense orchards. The smaller root generally can be found close to the upper soil and cover small volume of soil hereby chance of water uptake is decreased.

The smaller canopy size is a relatively larger area for transpiration as compared to that of large trees and the root with small weight can hardly compensate the loss of water. Then the symptoms caused by water deficit are detected rapidly due to a less mobilizable reserve accumulated by small root and trunk.

Pear (*Pyrus communis* L.) has grown tall long-lived trees with wide spreading branches in the nature. The root density is usually small outside the canopy covering nevertheless the diameter of root is often more times that of crown canopy. The rootstock has an influence on growth of scions and the water supply and nutriment uptake. Roots of trees grafted on *Pyrus* seedlings grown deeply and lateral roots proliferate large area in the soil. The wild pear rootstocks are tolerant to lime soil and drought conditions. Quinces are very dwarfing and will induce early bearing but fruit yield and tree growth have in general, been fair to mediocre. The benefits used by quince rootstocks are decreased during drought; the fruit quality decline by the increase of stone cells density in the fruit flesh. Several pear cultivars such as 'Williams', Beure Bosc', 'Clapp's Favourit', Packam's Triumph are incompatible with quince rootstocks. The rootstocks produced by vegetative propagation have a less vigorous growth and restricted root distributions that can be found at depth of 10 to 60 cm in the soil (*Hrotkó*, 2000). EMH quince rootstock induces large fruit size in pear scions grafted or budded onto it. EMH is fully compatible with 'Conference' 'Comice' and 'Concorde' varieties (*APRC News* 2002).

Many attempts have been made to select the rootstocks which are highly adapted to environmental stresses (drought, poor soil and calcareous) and test the compatibility between some clones and scions. Clones of wild pear (*Pyrus syriaca*) were selected under lime soil and drought conditions were compatible with 'Spadona' (*Al Maarri* et al., 2007). The OHxF 87 and FOX 16 of rootstocks produced the most productive pear trees (*Loreti* et al., 2002) and these clonal rootstocks had moderate drought tolerance (*Hrotkó*, 2005). Under water deficiency conditions the productivity and fruit quality of pear can be improved by using of rootstocks with drought tolerance. 'Flemish Beaty'pear grafted on BA 29 quince rootstocks was more tolerant to water deficit than on other Quince rootstocks (Quince A, C). BA 29 of clonal quince rootstocks exhibited the best protection mechanism against oxidative damage by maintaining high proline contents of the leaves and strong antioxidant activity of super oxide dismutase and peroxidase (*Sharma & Sharma*, 2008).

The possibility to decrease the grow space of tree in the intense pear orchards is less than in apple ones. The increase of tree density over 1400–1800 tree/hectare demands a changes in rootstocks and improvement of water and nutriment supply. The spaces between the trees in the hedge could be decreased as small as 0.8 m and between hedge rows 2.5–4.0 m by use of dwarf rootstocks and training system (*Table 1*). *Bianco* et al. (2007) investigated the impact of V shape system on growth and fruit productivity of 'Williams' and 'Conference' grafted on BA 29 quince rootstock in spaced at 4 × 0.5 m row and tree spaces. In early stage of orchard life 'Williams' trees represent a more efficient option for pear cultivation using V-shape systems than 'Conference'. This could be explained by that 'Williams' pear has greater leaf area per tree however the deeper root system could exploit the soil water content and compensate the transpiration of large canopy. The root system of 'Conference' was shallower, wider and a smaller ratio of leaf /root surface resulted lower yield efficiency than 'Williams'.

Table 1 The shape systems in pear orchards (*Sansavini & Errani* 1998)

Shape system	Rootstocks	Space between row and trees (m)	Maximum of trees per hectare
Palmetta	Wild pear/Quince/OHF	5.0 × 2.5–3.0	800
Sloping hedge	Quince/OHF	4.0 × 2.5–3.5	1000
Slender spindle	Quince/OHF	4.0 × 1.5–2.0	1666
Y hedge	Quince/OHF	4.5 × 1.1	2020
Upright hedge	Quince C or Adams	4.0 × 1.0–2.0	2500

Pear is sensitive to movement of water table level in the soil; the airiness soil and the development of root system is hampered by up to 1.5 m of water table level on quince rootstock and 2.5 m of that on pear seedlings. The reactions of rootstocks to rise of water table level are different (*Tamura* et al., 2004). The growth ratio of canopy started to decrease from 190 cm water table in the soil for Conference grafted on Quince C. The growth of canopy of Conference self-rooted started to decrease from 240 cm water table level while no effect was observed on Williams self-rooted (*Battilani* et al., 2004). Conference/Quince C showed a reduction of 20% of the maximum observed marketable yield at high water table level but the decrease in the yield was higher (72%) in the case of water deficiency. This reduction yield was smaller in Conference self-rooted (16% of that in excess of water and 40% under water deficit, respectively) than Conference/Quince C. The Williams self-rooted was the least sensitive to changes of soil water levels (*Battilani* et al., 2004).

During bloom and 60 days after bloom the water deficiency of soil make a decrease in the root activity of 'Niitaka' pear. These roots were thinner and longer and the number of fibers roots was larger than under good water supply. The damages of roots and disturbance of water uptake impact on the water relations of leaves; when the leaf water potential is decreasing to –2.74 MPa the wilting and falling of leaves have been resulted (*Lee* et al., 2006). Under water deficiency the leaf necrosis and abscission occurred earlier and more seriously in the shad parts of the trees than those well-lit parts which due to the susceptibility of the varieties and osmoregulation of pear (*Neri* et al., 2003). Certain pear cultivars including 'Bartlett' having a weak stomatal control (*Bonany* et al., 1991, *Mitchell* et al., 1994) showed severe leaf burning and abscission caused by heavy drought stress conditions. The deep root and dense leaf vein system guarantee the active absorption of water and the adaptability to the drought in pears (*Kusnyirenko*, 1981). The results in the increase of drought tolerance of pear could be achieved by control of water uptake and monitoring of sap flow in the trunk and roots of tree (*Green* et al., 2003) and the control of water consumption, transpiration and investigation of compounds of osmoregulation (*Gao* et al., 2004, *Gomes* et al., 2004) rather than enhancement of water retention of tree.

Irrigation scheduling

The water status of tree and soil together determine the water balance of orchards. The soil moisture content and climatic factors influence the transpiration and the water use efficiency. The monitoring of water status in the soil is performed by estimation of water moisture at 20, 30, 40 and 60 cm depths. Sensors for soil water status are the most popular water stress indicators for irrigation scheduling (*Howell*, 1996; *Phene* et al., 1990). The conventional tensiometers detect changes in moist soils up to tension limit around 75 kPa. The "watermark" equipment between range 0–200 kPa tension operate more efficiency than traditional tensiometer, whereas gypsum blocks and granular matrix sensors operate reliably up to 1500 kPa tension (until wilting point) and are thus suitable for managing regulated deficit irrigation. The correlation between yield and soil water potential was higher than that reported for apple (*Naor* et al., 1995) thus monitoring trends of soil water potentials might be more useful for irrigation scheduling in pear than apple orchards (*Naor* et al., 2001). The yield of 'Williams' grown on sandy-loam soil was influenced by the soil moisture content before irrigation. The low limit of optimal soil moisture was at 50–60% of field water capacity below that the pear yield significantly decreased (*Bošnjak* et al., 1997).

Despite of many plant water status indicators, their use of practical application for irrigation scheduling has been limited. Trunk diameter fluctuations are a good parameter for the water status of tree. The degree of shrinkage of the trunk during daytime has been used in several species of fruit trees as a good parameter for control of irrigation (*Huguet* et al., 1992; *Bonany* et al., 2000). The trunk diameter started to decrease from 10 a.m. until 8 p.m. in summer when air temperature increased and the decreasing was lasted until the air temperature started to decline in 'Conference' pear orchard. The fluctuations of trunk diameter also influenced the fruit growth, the increase in fruit growth ceased as soon as trunk diameter started to decrease and increased again after trunk diameter started to increase (*Maas*, 2007). The leaf water potential and stem water potential as the plant water stress indicators are better shown the water deficiency of trees than the change of soil water potential. The greater variability of soil water potential could be attributed to non-uniform soil moisture content within the root zone of a single tree in turn could be due to non-uniformity of water application especially for drip irrigation (*Naor* et al., 2006).

Predawn and midday leaf water potentials as like the plant water status characters are proposed for irrigation scheduling in orchards. The leaf water potentials have been influenced by the wind and sunlight and their position in the crown. The latest researches considered the midday stem water potential of fruit trees included the pear the most reliable indicator for irrigation scheduling (*Marsal* et al., 2002/b; *Naor* et al., 2000; *Ramos* et al., 1994). The measurement of midday stem water potential is widely used for irrigation scheduling of deciduous orchards in Israel. The growers select about five trees in each commercial plot in close proximity to one another to enable the technician to take the means per day. The sample size is important to get a stable average where the smaller samples were sufficient to present stem and leaf water potentials (4, 5 and 8 trees of apple, nectarine and pear, respectively) but the larger samples were required for maximum daily trunk shrinkage as 16 and 17 trees for nectarine and apple, respectively and 21 tree for pear needed to measure the soil water potential (*Naor* et al., 2006). During water stress a minimum of two week period was necessary to recover leaf gas exchange when stem water potential (ψ stem) values exceeded –3.5 MPa. The leaf necrotic mottling due to tissue dehydration appeared at ψ stem values of –3.9 MPa (*Marsal* et al., 2002/a). The occurrence of leaf turgor loss closed to these thresholds therefore it could be used to establish a critical value for irrigation scheduling of pear orchards in drought.

Soil type and atmosphere influence on the water demands of trees hereby the productivity of orchards. The daily water use is called evapotranspiration (ET) which is the amount of water evaporating off the soil surface plus the water used (transpired) by the tree. Taking the grass crops cover of the orchard into consideration, the grass reference evapotranspiration (ETo) is generally estimated with the modified Penman-Monteith equation (*Allen* et al., 1998) in order to the actual transpiration of trees should be estimated. During the day the evapotranspiration increases due to enhance of solar radiation and increase of temperatures in plant and soil. The water requirement of plant is increased by the rising of air temperature and decrease of humidity. On hot days evaporation at the leaf surface, through the stomatal apertures, causes a large potential differences between the stomata and the roots that pulls water to the top of the tree. When the evaporation of soil surface is decreased by various cover crops to minimum, the climatic factors such as radiation, temperature, wind speed etc. affect the plant transpiration. Stomatal conductance was correlated with leaf water potentials (r^2=0.54) but a much better correlation was showed with stem water potential (r^2=0.80) in mature 'Spadona' pear variety. In addition, the midday stem water potential was highly correlated with the yields of fruit exceeding 55, 60 and 65 mm in diameters (*Naor* et al., 2001). These results show the irrigation scheduling of pear orchards is efficient by use of midday stem water potential as a plant water status indicator as well as the monitoring of soil water potential.

Water requirements of pear

The pear has large water requirement therefore the planting of high density and grass covered pear orchards is needed irrigation conditions in Hungary. The air temperature is important fact in water use and water uptake of pear because the water use increase at high temperature and the soil moisture content influence the water and nutriment supply. The soil moisture content the only of root zone could be taken into consideration for establishment of water use. The available water for plants depends on the soil water capacity (*Table 2*). The high water capacity of soil save not only the precipitation but contribute the use of irrigated water is to be more efficient. The pear trees grafted on quince have small extended and shallow root systems whereas have a large transpiration surface due to the large tree pieces per unit area. These orchards have great water requirements and are sensitive to drought. The irrigation should be performed more times with small doses in pear orchards grafted on quince with shallow root system (*Papp*, 2000).

Table 2 Hydraulic properties of different soil types (*Tóth*, 1995)

Soil type	Field water holding capacity	Wilting point	Available water depletion
		mm/10cm layer	
Sandy	<15	<5	5–10
Sandy loam	15–25	5–10	10–15
Loam/Silt loam	25–35	10–20	15–22
Clay loamy	35–42	20–27	12–17
Clay	42–50	27–35	10–15

From budburst to flowering and fertility is the first period of pear development needed large water demands. Following dry winter the irrigation may be used this time but it is often applied as the prevention of freezing. The occurrence of drought periods is frequently in June, July and August when the water supply have to be satisfied of the orchard. The second critical period concerning on water requirements of pear is coincided with the rapid growth of fruits and fertile bud formation in August and September.

From the start of the growing season to picking the water requirements of pear 'Williams' on loamy sand soil were 470-480 mm (*Bošnjak* et al., 1997). The water deficiency is particularly the low soil moisture content diminish the fruit quality during fruit growth. The average daily water use of pear orchard grown under good water supply varied between 3 and 5 mm however it could exceed 7 mm/day on warm days (*Papp*, 2000). Average daily consumptive water use of pear trees in an orchard was 6 mm on 0–89 days after blooming (*Kang* et al. 2003) and the water use was 479 mm during fruit development (*Kang* et al., 2002).

Summer ripening varieties have usually lower water requirements than that of autumnal and winter ones. There are differences in tolerance to water deficiency among the varieties. 'Conference' pear variety is very sensitive to water deficit. Under this condition their leaves have already been dropped by middle of August and the growth of fruits is stopped. The varieties preferred the cool climate with high moisture have been wilting and drying or dropping of leaves in response to high daily temperature with low humidity (50–60%) in summer months. At high temperature the transpiration is intensified which causes larger water losses of tree than in spite of the high soil moisture content it could be supplement from the soil. The fruit sizes characterized by varieties have been decreasing due to the permanently low air humidity. 'Conference' variety is very sensitive both water deficiency and high temperature. At the beginning there is a necrosis symptom expanding from the edge to middle of the leaves then the drying of leaves caused by heat scorch expand from the inside of the foliage to outside which result at least whole defoliation of the 'Conference' trees. 'Williams' Packam's Triumph' and 'Bosc' varieties are considered to be a high drought tolerance (*Soltész*, 2004).

Irrigation strategies in pear orchards

Irrigation procedures

The irrigation is the most frequently used as the complementary irrigation in pear orchards but it is applied to reduce the spring frost risks or cooling and conditioning irrigations, respectively. Nowadays the use of fertigation is also extended.

Complementary irrigation is applied to increase of yield with monitoring of soil moisture content and water status of pear trees. The water supplement is used effectively as surface irrigation on relative even ground and good soil structure. The amount of irrigation water is less adjustable with surface irrigation therefore it can be used only in the case of sufficient water resources. The flooded irrigation used for pear orchard is mostly wide-spreaded in the countries being rich in water resources for irrigation. The efficiency of surface irrigation is about 40–60%.

Sprinkler irrigation can be used for supplemental irrigation and other special objects if there are moderate water resources. When the stable sprinkler irrigation system is carried out the irrigated tubes have to be placed below the rows into the soil before planting of trees. Another application of sprinkler irrigation is the computerized one with small output emitters placed above the crown that used for cooling, colouring and frost prevented irrigation in high density intensive orchards. Emmitters placed by the rows or more row distances guarantee the uniform water distribution. The velocity of the wind has a large influence on uniformity of irrigation therefore it should be interrupted over the speed of 5 m/s (18 km/h) wind.

The water use efficiency is less favourable (25–40%) of sprinkler irrigation because of the large evaporation loss but that can be decreased by night irrigation. Applying as cooling irrigation improve the colouration of fruits. Trees of 'Sensation' Red Bartlett were evaporatively with over tree sprinkler irrigation that result an increase in hue of fruit colour and fruits from cooled trees matured earlier than that of no-irrigated trees (*Dussi* et al., 1994). The sprinkler irrigation with emitters above the crown level is efficiently in prevention of frost damages. Thus the trees can be protected against the spring frost when the cooling of 6–8 °C however its efficiency is influenced by the development stage of flowers. The use of sprinkler irrigation is extended for the frost protection in the apple and pear orchards in the South Tyrol. Here the irrigation is started when the temperature is –7 °C at green buds stage, –4 °C at the burstbud stage, –2 °C at redbud stage and 0.5 °C at the beginning of blooming and 0 °C in full blooming, respectively. The irrigated water is 2–4 mm (20–40m^3/ha/hour) depended on the degree of cooling (*Soltész* et al., 2006).

Microsprinkler irrigation used by emitters with plastic locking-lamina or rotary is wide-spreaded in orchards. The size of wetted area is limited by the range of micro-emitter radius. Microjet irrigation set up below the crown could protect the orchard against the frost near the soil. Solanelles (1993) showed that under tree microsprinkler system with low application rates is suitable to protect a slight frost (–6 °C). 'Conference' pear have smaller damage (10–30%) in flowers and/or fruits from 1 m to the top of the tree that is about 3 m high from the soil surface than the bottom of tree when the lower application rates (2.9 mm/hour) was used. In larger danger of frost such as -8 °C during burstbud and –2 °C in full bloom the permanently applied microsprinkler with higher output as 12 mm/hour provide satisfactory defense (*Gonda*, 2005).

Drip irrigation spread in the orchards is due to the 70–90% of water use efficiency. It is relative easy operated and regulated because small ration of water can be applied more times a day. The drip irrigation is a good delivery system because it allows doing the agricultural procedures between the rows in the orchards and providing the water and nutriment used by fertigation to reach the high density root zone. The wing lines running from the head line are set up fixed on the stay system or on the soil in the tree rows and their emitters output 1–5 l/hour. The distances between the emitters on the hose are chosen accordance with planting of trees in the rows. Larger output emitters or higher water pressure should be applied when we want to increase the diameter size of wetted soil. This type of irrigation is only used for supplement of water and nutrient in pear orchards because it has no influence on the air humidity during hot days.

Fertigation, where the water and nutrient supply carried out at the same time, is most effectively executed by state-up the art drip irrigation systems. The only fully soluble fertilizers are suitable for the fertigation. To receive the right concentration and application rates of nutrient solution through fertigation should take into consideration the tolerance to salinity of plants. The high accumulation of sodium and chloride reached a toxic level in the plant organs that result a decrease in net assimilation and in consequence the yield. The lower level of salinity (1.5 dS/m) stimulated growth while higher levels (5.0 dS/m) reduced shoot elongation and dry weight of one-year-old trees of 'Abbe Fétel' independently the type of rootstocks and grafted. The accumulation of sodium in leaves was rapid and depended upon the genotypes and salinity level. Trees on both quinces Sydo and EMC significantly increased the uptake of Na^+ when irrigated with saline water, while there was no significant effect of saline water on Na^+ and Cl^- uptake of own-rooted tress and of trees grafted on OHF 40 (*Musacchi* et al., 2002, 2006). Subsurface drip irrigation used saline water resulted 30–40% higher pear yields when emitters located at a depth of 30 cm below the soil surface than for on-surface irrigation. Saline water application with subsurface irrigation significantly increased the sugar content and acidity of the fruit simultaneously (*Oron* et al., 1999, 2002). The overdosage of nutrient supply should be avoided in pear orchards. The fertigation should be performed during shoot elongation in young pear orchards and during intensive shoot and fruit development in mature orchards.

Water saving irrigation

High density, intensive orchards have been increasing requirements of water and nutrients. The ecological demands of pear are regarded for planting however the irrigated water is often limited for practice even if the soil has a good water management. The global climatic changes and occurrence of frequently drought periods caused that researchers intensively attend to the monitoring of water requirements and supply of fruit trees due to. The development of different water saving irrigation is to be urgent by the lack of available water recourses all of World. The research teams of USA, China and New Zealand have been working on the improvement of deficit irrigation techniques that satisfy the demands of plants for water without loss of fruit yields. The regulated deficit irrigation based on the more frequent irrigation with smaller doses which result in less water percolating through the root-zone (*Green* et al., 2003) and larger water use efficiency.

In Australia there is 75–85 t/ha yield of pear orchards applied flooded irrigation. This luxury irrigation is changed by *Regulated Deficit Irrigation* (RDI) among the Australian pear growers. The RDI irrigation, however used flood irrigation in furrow the water saving was 2ML/ha compared with the whole surface flood irrigation (*Kriedemann & Goodwin*, 2003).The application of RDI improves 60% of water use efficiency (WUE) in peach and pear that is due to largely the reductions in transpiration (*Boland* et al., 1993, *Goodwin & Boland*, 2002). WUE increased from 12.5 to 22 t/Ml under RDI in 'William Bon Chretien' pears that yielded approximately 90 t/ha in the orchards (*Kriedemann & Goodwin*, 2003).

The partial root-zone drying (PRD) is a new irrigation technique for improvement of regulated deficit irrigation (RDI) system to increase the tolerance to drought stress in fruit trees. PRD provide an alternate water supply in root zone that decrease the really irrigated water use and reduce fruit tree water use significantly. This is due to that the part of the root system in drying soil responds to drying by sending a root-sourced signal to the shoots where the stomata are closed to reduce water loss of plants. After switch on irrigation the wetted root zone is sending the sign to the stomata to open. PRD irrigation was applied alternately two poly-tube lines, each with an independent valve, have been installed on trees at each row. Irrigation was switched from one side of root system to the other at approximately 2-week interval (*Núnez-Elisea* et al., 2004).

The largest water use was in conventional flood irrigation (STD) and alternate partial root zone drying (*Table 3*) and the latter was applied alternately to west or east side of the tree lines during consecutive watering periods. Considering the precipitation, the water use efficiency of pear (fruit yield/water consumed) was the best in FPRD (24.83 t/ML) where only the west side of each tree line received water (*Table 4*). In the latter case less of water use (343 mm) resulted large fruit yield.

Table 3 Water input and water consumed by pear trees under different irrigation treatments (Based on *Kang* et al., 2002)

Irrigation treatment*	Irrigation applied (mm)	Rain (mm)	Total input (mm)	Orchard ET (mm)
STD	291	172	463	479
FPRD	141	172	313	343
APRD	223	172	395	424

* Orchard ET = orchard evaporation was inferred from comprehensive measurements of soil moisture, STD = standard flood irrigation, FPRD = fixed partial rootzone drying, APRD = alternate partial root zone drying

Table 4 Productivity and apparent water use efficiency by pear trees under different irrigation treatments (Based on *Kang* et al., 2002)

Irrigation treatment*	Pear yield (t/ha)	Fruit yield/ water consumed (t/ML)	Fruit yield/ irrigation applied (t/ML)
STD	81.3	16.97	27.93
FPRD	85.3	24.83	60.48
APRD	79.0	18.62	35.41

* STD= standard flood irrigation, FPRD= fixed partial root zone drying, APRD=alternate partial root zone drying

Despite of some disadvantage, the drip irrigation improves the water use efficiency (WUE) of plants. A well designed microjet or drip irrigation system may result 70–90% of water use.

Regulated deficit irrigation (RDI) computerized by switch on/of emitters eliminates the disadvantages of traditional drip irrigation. According to Californian researchers this irrigation technique is advantageous for growth, mineral nutrient, yield and grape quality in vineyard. RDI with drip irrigation system was also efficient in pear orchards (*Goodwin & Boland*, 2002). RDI was developed to improve control of vegetative vigour in high-density orchards in order to optimize fruit size, fruitfulness and fruit quality. It is usually applied in the midway between bloom and harvest for pear when the fruit are growing slowly and shoot growth is rapid. However, it can also be applied after harvest in early-maturing varieties.

The RDI system with 100% of replenishment of crop evapotranspiration (RDI_{100}) used from vegetative growth to harvest resulted fruit yield increased by 57%, fruit weight by

16% in 'Conference' orchard planted on a silty loam soil, in comparison with the non-irrigated control (*Anconelli & Mannini*, 2002). There was a positive reduction in growth of trees irrigated with this technology and the more ample flowering resulted larger quantity of fruits. The limited irrigation regime (RDI_{50}), that is equivalent the half of water requirements of trees, result a 64% of water saving compared to optimal crop evaporation (Etc_{100}) while the fruit weight and fruit number per tree did not decrease. Analyzing the economy of RDI *Anconelli & Mannini* (2002) suggested that the regulated deficit irrigation (RDI_{50}) extending from 60 days after flowering to harvest time could only be applied in pear orchard in cases of truly limited, or costly, water supplies.

Total seasonal irrigation inputs with microjet irrigation were 470 mm/ha for fully watered trees and 250 mm/ha for partial rootzone drying (PRD_{50}) trees. PRD_{50} irrigation was carried out one side of tree for one week then other side for second week, it was alternated every 14-days (*O'Connell & Goodwin*, 2004). These data highlight that the traditional irrigation practice for pear orchards of applying 600 mm/ha (*Boland* et al. 2001) is excessive in orchards with low effective canopy cover. The PRD_{50} trees tended to have lower stoma conductance during the 14-day cycle that was attributed to lower stem water potential (from-2.0 to-2.5MPa) resulted a water stress in orchard. There was no indication of stomata control for transpiration in the trees received water supply for 100% of crop evaporation with PRD technique (*O'Connell & Goodwin*, 2004).

There are contradictory views for effectiveness of PRD irrigation technique applied in pear orchards. *Loveys* et al., (2003) reported the PRD drip irrigation had no effect on pear yield and fruit size however it was only a small influence on water status of tree. *O'Connell & Goodwin* (2007) also don't advice to use of deficit PRD irrigation with microjet technique on fine-grained soils in pear orchards because it increase the fruit dropping and decrease the fruit size which was not suitable for commercial demands. Others (*Kang* et al., 2003, *Kang & Zhang*, 2004) showed 23–52% water saving under PRD without a yield or fruit size penalty in pear orchard. The foregoing suggested that partial rootzone drying micro irrigation technique should be revised particularly for fruit yield in pear growing.

Recommendations for practice

The plantation of drought tolerance rootstock/varieties and the irrigation scheduling is very important for increasing of water management and productivity in pear orchards. The soil moisture must be monitored and the water stress indicators of varieties must be measured at different phonological stages in order to design and scheduling of irrigation. During the procedures we should identify the developmental periods of varieties such as time of bloom-setting, growth, full growth, ripening periods and the degree of canopy cover. When the evaporation pan is not at disposal the evapotranspiration (ET0) can be estimated by Penman-Monteith methods using of meteorological data. The recommendations are normative for irrigation scheduling in pear orchard during regulated deficit irrigation period and fruit growth (*Kriedemann & Goodwin*, 2003).

General techniques

1. Measure fruit and shoot growth to determine the regulated deficit irrigation period for fruit varieties in an orchard.
2. Excavate one side of a tree to determine root distribution in order to have information on rootzone width and depth.
3. Determine the wetting pattern of the irrigation system and estimate wetted rootzone.
4. Develop a season irrigation plan for run time and interval based on soil type, wetting pattern and average pan evaporation.
5. Install soil water sensors; preferred measure is soil water tension using gypsum blocks at 30 cm and bottom of rootzone in shallow soil, at 30 cm, 60 cm and bottom of rootzone in deep soil, respectively.

Recommendation during regulated deficit irrigation period

1. Measure and record soil water tension and irrigate when the entire rootzone dries out to a minimum of 200 kPa.
2. Irrigate to wet the top 30 cm of the rootzone.
3. Measure and record soil water 6 to 12 hours after irrigation and, if necessary, adjust the amount applied in previous irrigations to wet soil to 30 cm depth.
4. Irrigate when the wetted rootzone soil at 30 cm depth dries out to 200 kPa.
5. Measure pan evaporation between irrigations, and irrigate in future years based on this cumulative evaporation.

Recommendation during rapid fruit growth

1. Irrigate to wet at least the top 60 cm of rootzone.
2. Measure and record soil suction 6 to 12 hours after irrigation and, if the soil drier than 30 kPa (sandy soil) or 50 kPa (clay soil) at 60 cm, apply more irrigation.
3. Irrigate when the wetted rootzone soil water tension at 30 cm depth dries out to 30 or 50 kPa.
4. Measure pan evaporation between irrigations, and irrigate in future years based on this cumulative evaporation.

The water requirement of varieties grafted on different rootstocks and irrigation plan based on above-mentioned should be determined.

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