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Effect of partial root zone drying in fruit crops

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Abstract

Partial root zone drying (PRZD) is an advancement over traditional irrigation system. It is the process of irrigating the surface area of the plant sequentially one side after another side. In agriculture where 83 per cent of the total available water is used, adoption of such kind of technique is sure to curtail the requirement of water which is getting scarce day by day. PRZD in fruit crops can reduce irrigation water requirement up to 50 per cent and increase WUE to the extent of 90 per cent. Its usefulness has been proven in grapes, orange, pomegranate and apple. Having gone through literature, it vividly appeared that PRZD technique is worth adoption in view of better WUE. It has all merit of higher yield and quality per unit water consumed. Thus, it is environment friendly too which is much concerned in current day agriculture/horticulture production.

Key words: Deficit irrigation, fruit quality, PRZD mechanism, regulated deficit irrigation, WU

Introduction

Water is a limiting resource in the fruit production. The major challenge is to produce more and more produce of higher quality with limited use of water to feed the increasing population of the country. The highest proportion of water is consumed by agricultural crops which is called as blue water footprint and it is assumed that the water scarcity will increase in future in view of changing climate (Mancosu *et al.*, 2015). So, the efficient use of water without affecting crop productivity and its quality by adopting water saving irrigation techniques is the foremost need.

Generally, full irrigation is provided by farmers in crop production. Now-a-days, the use of full irrigation can be reduced without affecting the crop yield (Kang and Zhang, 2004) by the use of water saving irrigation techniques. These techniques are of different types such as regulated deficit irrigation and partial root zone drying which reduces the amount of irrigation water as compared to the full water requirement of crops. The amount of deficit irrigation depends upon crop, soil type, climate *etc.* and it is accompanied by without yield losses or a minor yield loss with increasing water use efficiency of crop (Ahmadi *et al.*, 2010).

Availability of water

Ground water is an important component of water availability. It is a major source of drinking water and also irrigation water. Ground water supplies about 80% of water for domestic purpose and 50% for industrial purposes. The irrigated agriculture depends on ground water, it has a significant role in food security of India. The availability of fresh water is decreasing day by day due to frequent climate changes and drought conditions. In year 1951, the availability of water per capita was 5177 m^3, but it is depleting continuously and up to 2025 it will be only 1341 m^3 per capita. The water level in wells has been deepened to 200 per cent. In year 2016, about 33 crores peoples of 9 states of the country gone through the water crises (Rajasthan Patrika, 10 July, 2018).

Water status of India

The average annual water generated mostly from rainfall and by snow melt in India is about 1869 billion cubic meters, whereas it is estimated that a little amount of this surface water (only 690 billion cubic meters) can actually be deployed. The reasons responsible for this are such as maximum flow of the Himalayas river takes place in a short duration and the storage reservoirs are also limited or not have that much potential to capture such resources. The average rainfall of India is 1170 mm. It varies from region to region such as in western desert region it is only 100 mm, whereas in Meghalaya in North-Eastern India it is about 11000 mm. Most of it falls in the June-September (rainy season), so it is necessary to create sufficient storage to collect maximum of this rainfall in rainy season. Ground water is the major source of irrigation water and an average 431 billion cubic meters water has been assessed rechargeable in India. About 30% of this ground water potential has been used for irrigation purpose and domestic use. In some states of India such as Punjab and Haryana have been exploited their 94% of ground water resources. Areas with depleting ground water table in India are Rajasthan, Gujarat, parts of western Uttar Pradesh and all Deccan states (Chatterjee, 2015). In India in year 2001, only 3% of tube-well owners used micro-irrigation or sprinkler irrigation and about 88% irrigated their crops through open channels by flooding irrigation method (according to India's third Minor Irrigation Census).

According to the Central Ground Water Board (CGWB), in India about 39% of the wells are showing a decline in groundwater level and out of 6,607 assessment units in about 1,071 units of 15 states and 2 union territories have been categorized under "over exploited" on the basis of the stage of groundwater withdrawal and long term decline in groundwater level (Dhawan, 2017).

Drought and drought prone regions in India

The period without effective rainfall, unavailability of proper soil water and in which atmospheric conditions also causes continuous loss of water through transpiration is called as drought stress. In India due to lack of monsoon rains water shortage is faced which results lower crop yield. The major drought prone regions in India are western Rajasthan, Southern and Eastern Maharashtra, Andhra Pradesh, Odisha (Eastern coast of India) and Telangana (South-eastern coast of India) (Fig. 1).

Some positive responses of plant by little drought stress

In the drought stress condition plant produces some symptoms that make it adaptable to adverse condition. Drought stress in plants helps in efficient use of water and nutrients and alters physiology of plants. Stress results in poor growth but increases quality (TSS, sweetness) and shorten juvenile phase, make them adaptable to semi-arid and dry areas. Thus, a little water stress may helpful in plants. Water stresses trigger a wide variety of plant responses, ranging from altered gene expression and cellular metabolism to changes in plant growth, leaf morphology and movement and root development and finally productivity (Kumar *et al*., 2019). Table 1 depicts the effect of water stress on plants at physiological, biochemical and molecular level, which are as follows:

Deficit irrigation techniques

Deficit irrigation techniques are the irrigation techniques which involves application of reduced amount of water to the crop as compared to the full irrigation. In these techniques the irrigation water is provided to the crop in a controlled manner at critical stages of crop growth and development such as at flowering stage, at fruit set stage, at

Water status of India

Particulars	Quantity
Geographical area	329 million ha.
Flood prone area	40 million ha.
Ultimate irrigation potential	140 million ha.
Total cultivable land area	184 million ha.
Net irrigated area	50 million ha
Natural runoff (surface water and ground water)	1869 Cubic km.
Estimated utilisable surface water potential	690 Cubic km.
Groundwater resource	432 Cubic km.
Available groundwater resource for irrigation	361 Cubic km.
Net utilisable groundwater resource for irrigation	325 Cubic km.

Source: Chatterjee, 2015.

Fig. 1. Drought affected areas in India (Source: Dhawan, 2017)

Table 1. Responses of plant to drought condition

Drought stress		
Physiological responses	Biochemical responses	Molecular responses
Reorganization of root signals	Decrease in photochemical efficiency	Increased expression in ABA biosynthesis
Decrease in stomata conductance and reduced transpiration	Decrease in efficiency of Rubisco enzyme	Expression of ABA responsive genes
Decrease in photosynthesis rate	Accumulation of stress metabolites	Synthesis of specific proteins such as LEA, dehydrins *etc.*
Reduced growth rate	Increase in antioxidants	Drought stress tolerance

Sources: Sepaskhah and Ahmadi (2010)

fruit maturity *etc.* in different fruit crops. The techniques of deficit irrigation are as follows:

1. Regulated deficit irrigation (RDI) and
2. Partial root-zone drying (PRZD).

Regulated deficit irrigation (RDI)

The term was first coined as a term during 1970s at Tatura in Victoria, and it was applied in the 1980s in peaches and pears which are mainly grown for canning in high density orchards in the Goulburn Valley. In regulated deficit irrigation technique a water deficit is applied to the plants to maintain water status in a closely controlled way over a critical period, *i.e.* at flowering stage, after fruit set, at fruit ripening *etc.* in this technique the water application is manipulated over time (Fig. 2). The main objective of this irrigation technique is to control vegetative growth and development with the reproductive growth of plant with improved water use efficiency. In regulated deficit irrigation the frequency of re-wetting should be determined by the prediction of a decrease in plant water potential below a certain level. The frequency of re-wetting should be based on plant water potential but it can also measured from soil moisture depletion or estimates of water used by plants based on evaporative conditions and on the basis of sap flow of plant.

Partial root zone drying (PRZD)

Partial root zone drying (PRZD) technique was introduced as a new irrigation strategy which can increase water use efficiency (WUE) and reduce vegetative growth without affecting the yield but improve quality in grapevines (Dry and Loveys, 1999). Partial root zone drying is a type of deficit irrigation technique in which irrigation is provided to the half root system of plant, while the other half is left dry. In this the wetted and dried sides of the root system of plant are alternated in different irrigation cycles. In this technique the shifting of irrigation is followed on the basis of soil, type of crop, stage of growing crop and soil water content. The main aim of this practice is to balance the vegetative and reproductive plant growth by improving the water use efficiency. In PRZD the alternate wetting and drying sides of root system is to done on a 10-14 days interval. Regulated deficit irrigation (RDI) and partial root zone drying (PRZD) are techniques jointly designed to increase the water use efficiency, improve quality of fruits and control the vegetative vigour of perennial plants such as grapevines and other fruit trees

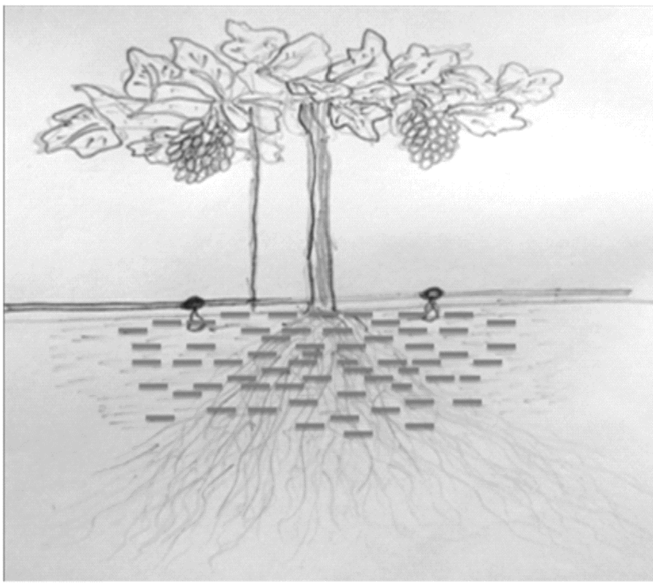

Fig. 2. Regulated deficit irrigation

RDI Versus PRZD

The basic differences in regulated deficit irrigation and partial root zone drying irrigation techniques are as follows in Table 2.

Types of partial root zone drying (PRZD)

Partial root zone drying is of two types:

1. Fixed partial root zone drying, in which the one half zone of root system is irrigated and another half is left for drying throughout the growing season.
2. Alternate partial root zone drying is another practice in which the irrigated and drying parts of root zone are changed. In alternate PRZD first irrigation is provided to half zone of root system and in next irrigation cycle the irrigation is shifted to the dry side of root system (Fig. 3.).

Mechanism involved in increase WUE through PRZD

The term water use efficiency (WUE) is a measure of plant's efficiency to produce maximally at the cost of per unit water.

Table 2. Physiological and molecular bases of drought stress tolerance

Regulated deficit irrigation (RDI)	Partial root zone drying (PRZD)
Deficit irrigation where only uppermost profile is re-wetted	Deficit irrigation where deeper wet/dry zones are spatially separated
Site is not responsive to irrigation	Site must be responsive to irrigation
RDI timing critical	PRD timing flexible
Can be used with furrow irrigation	Drip irrigation preferred, alternate row furrow possible
Potential for yield loss	No loss of yield
Lower root growth	Enhancement of root growth
Marginal water savings	Significant water savings
No irrigation hardware modification	Significant changes required.
Soil water monitoring recommended	High-level management skills required
Regulated deficit irrigation was originally developed on fine textured clay soils that provided a substantial reserve of plant available moisture.	Partial root zone drying technique can perform best in deep porous light sandy loam soil

Source: Shao *et al.,*(2008).

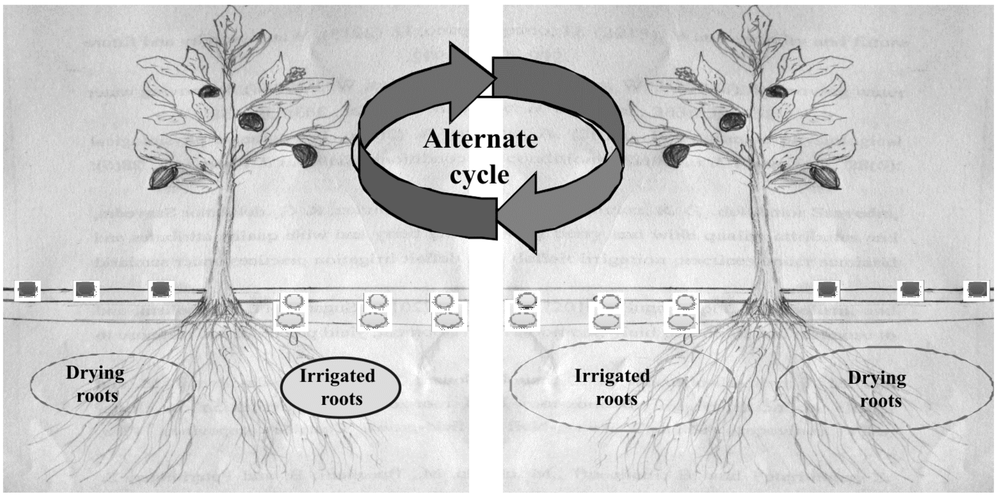

Fig. 3. Partial root zone drying

Basically, it is a ratio between two physiological processes; transpiration and photosynthesis (carbon assimilation). WUE is a complex character related to different physiological and biochemical processes which is involved in carbon-water uptake, in transpiration and controlled by many genes. In different environmental conditions, it is the challenge to balance between crop losses of water in transpiration and the higher efficiency of carbon uptake during photosynthesis, therefore the increase in WUE is not always associated with the increase in yield (Blum, 2009).

In partial root zone drying technique of irrigation, little water stress alter the physiology of plant by the production of ABA, closing the stomata and reducing the stomata conductance which affects the transpiration and increases the water use efficiency (Yan *et al.*, 2012). In the water stress condition given by partial root zone drying, ABA is produced in the dry side of roots and it transported to the leaves through the xylem sap. In the leaves ABA binds with some receptors which are present at the surface of the plasma membrane of the guard cells. These receptors activate many interconnecting pathways which raise the pH of cytocel, transfer the Ca2+ from vacuole to the cytosol. These stimulate the loss of NO3- , Cl- and K+ in the cell. The loss of these solutes in the cytosol reduces the osmotic pressure of the cell and the stomata is closed and finally the transpiration rate is reduced and losses of water is decreased which increase the water use efficiency of the crop.

Mechanism involved in quality improvement through PRZD

The plants in partial root zone drying are exposed to certain degree of water stress; there is the reaction towards the accumulation of stress metabolites. The chemical components which are mainly responsible for improved quality of fruits are primary and secondary metabolites produced during the stress condition in plants. In these sugars, lipids or minerals, proteins etc. are the primary metabolites and carotenoids, flavonoids, phenols etc. are the secondary metabolites. The water stress condition in plants may influence the secondary metabolism through two interactive mechanisms, which are the change of primary metabolite transport (which is the major sources of carotenoids and ascorbic acid biosynthesis) or by the oxidative stress which could affect the antioxidant compound biosynthesis. In case of the grape, berries responds to drought by altering its physiology and stimulating the production of secondary metabolites such as monoterpenes, phenyl-propanoids, zeaxanthin etc. which significantly influence grape berry composition, wine antioxidants and flavour also (Savoi *et al.*, 2016).

The improved colour of peel of apple fruit under partial root zone drying irrigation techniques was also noticed which may be due to the changes in canopy structure and increased WUE and nutrient efficiency. The accumulation of better total soluble solids (TSS) in the fruits may be due to metabolic changes or by the translocation of assimilate from the leaves to fruits (Francaviglia *et al.*, 2013) . The increased sugar level of fruits in partial root zone drying irrigation treatments is due to the accumulation of higher amount of ABA in the fruits which stimulates the activity of different enzymes such as enzyme invertase which increases the concentration of sugars hexose in the fruits (Ruan *et al.*, 2010). The change in ABA content under PRD improves the quality of grape berries by increasing anthocyanin content which is induced by the genes responsible for anthocyanin biosynthesis (Jeong et al., 2004). In PRD, the reduced vegetative growth increases the light penetration into the canopy with increased level of ABA and salicylic acid in berries at harvest, which might have effect on production of phenolic compounds. The increased activity of certain antioxidative enzymes like catalase, superoxide dismutase and guaiacol peroxidase in PRD plants (Lei *et al.*, 2009) indicates that certain degree of drought induces oxidative stress under condition of PRZD.

Present status of PRD in fruit crops

Nowadays partial root zone drying technique has been successfully applied to many horticultural as well as agricultural crops. This technique can save water up to 50% without much affecting the crop yield, increases crop water use efficiency as compared to full irrigation and also improves the quality of different fruits. Effect of partial root zone drying in different fruit crops is as follows:

Grape

In grape, there is increasing global demand of high quality produce such as raisins, wine etc. So, it is the challenge for grape growers to produce higher quality produce without yield loss. It maintains the appropriate balance between vegetative and reproductive growth of grapevine. A little water stress can reduce the vegetative growth and improve the quality of berries, because the vegetative growth of vine is more sensitive to water stress condition than the fruit growth. In case of wine grape cultivars it is important to control the berry size. Some grape growing countries are also facing the problem of water scarcity or drought condition. In such situations the application of irrigation water through partial root zone drying (PRZD) technique is the better option which increases water use efficiency and improves the quality of produce without affecting the yield of crop. The technique of PRZD can reduce 50% amount of irrigation water without any significant yield loss. The water use efficiency in partial root zone drying can be doubled as comparison to full irrigation to the crop (Santos et al., 2005). It improves the quality of berries in the terms of higher concentration of anthocynins, total soluble solids and total phenol content

Citrus

Citrus is an evergreen plant of tropical and sub-tropical regions which requires sufficient amount of water all round the year. In the condition of water stress, it can trigger some physiological responses in the plant that allows the plant to survive with reduced water availability (Hutton et al., 2007) without affecting its productivity. Irrigation through partial root zone drying techniques can be effective to the crop which increases the water use efficiency. Consoli *et al.* (2016) reported that the partial root zone drying with 50% of crop demand (crop evapo-transpiration) can increases 10-20% of crop yield as compared to the full irrigation treatment. The application of deficit irrigation by PRD with 60% of crop evapo-transpiration in citrus cv. Navel orange can save 25 to 40% of water and it increases the yield significantly (Lovatt and Faber, 2007).

Pomegranate

Pomegranate (Punica granatum L.) is one of the oldest known edible fruits, cultivated extensively in arid and semi-arid regions of the world. There is a major problem in pomegranate of fruit cracking which takes place due to moisture stress and after exposure of fruit to intense sunlight occurrence of sudden rainfall. Noitsakis et al. (2016) studied that the irrigation treatment of partial root drying (PRD_1) with 100% irrigation water of the demand of plant which was given to the half of the root system of each plant and another half zone of root system was exposed to soil drying. They found minimum fruit cracking of fruits were noticed in the treatment of PRD_1 with other parameters of yield and quality such as maximum fruit weight, fruit diameter, aril weight, juice percentage, TSS, and minimum titratable acid as compared to control irrigation treatment.

Apple

The apple growing areas is the temperate zones of India and other countries are situated at the high altitude which helps to meet the sufficient chilling hours during winter season (extending from Dec. to March). In such condition the measure problem is application of irrigation water, to maintain its yield and quality which can be overcome by applying partial root zone drying technique (PRZD) which can save up to 50% of irrigation water. Durovic *et al.* (2015) found that partial root zone drying technique has a positive effect on fruit firmness and weight loss during storage. It was also effective after 6 months of cold storage. The maximum flesh firmness was found in fruits from partial root zone drying treatment. PRD showed good effect on the fruit size and yield, compared with controlled irrigation and deficit irrigation treatment. The irrigation treatment with partial root zone drying can increase fruit quality. PRD application can save irrigation water up to 52% and it may improve FMA (Zegbe *et al.*, 2016).

Advantages

1. Plants under mild water stress condition, increase root growth (Liu *et al.*, 2011), which facilitate nutrient uptake.
2. The alternate wetting and drying cycles of root zones with partial root-zone irrigation method improve the ability of plants to acquire nutrients from the soil; the cycles facilitate the mineralization of soil organic nitrogen, which increases mineral nitrogen available to the plants.
3. The wetting and drying cycles with partial root zone irrigation method also enhance the activity of microorganisms with high microbial substrate availability that is partly responsible for the improvement of nitrogen mineralization in plants (Wang *et al.*, 2010).

Limitations

There are some limitations of partial root zone drying technique of irrigation such as PRZD systems which are more costly irrigation systems which allowed interchangeable wetting and drying of the root-zone part and the time of switching required in operating PRZD irrigation. In partial root zone drying there is the accumulation of certain reactive oxygen species (ROS) which causes cell damage in plants.

Application of deficit irrigation like partial root-zone drying with drip irrigation method in fruit crops can reduce irrigation water and increase water use efficiency. The challenge is also to understand hormonal signalling under changes of nutrient and water resources and particularly that of cytokinins. Because of limited available data, further research is needed to understand complex biosynthetic pathway and synthesis of nutritive and health-related metabolites and antioxidants in PRZD treated plants. Practical application and promotion of this knowledge will allow farmers in water scarce areas to adapt PRZD not only as a strategy for saving water, improving nutrient use, and increasing/sustaining yield but also for producing food with enhanced nutritive and health characteristics.

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