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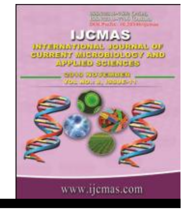

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Effect of Partial Root-Zone Drying (PRD) Irrigation in Fruit Crops: A Review

Santosh Kumar[1*], Kanchan Bhamini[1], Pushpa Kumari[1] and Rishav Raj[2]

[1]Department of Horticulture (Fruit & Fruit Technology), Bihar Agricultural University, Sabour, Bhagalpur (813210), Bihar, India
[2]Department of Agronomy, Bihar Agricultural University, Sabour, Bhagalpur (813210), Bihar, India

**Corresponding author*

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Controlled alternate partial root-zone irrigation (CAPRI), also known as partial root-zone drying (PRD), is a new irrigation technique where half of the root zone is irrigated while the other half is allowed to dry out. The treatment is then reversed, allowing the previously well-watered side of the system to dry down while fully irrigating the previously dry side. It may improve the water use efficiency (WUE) of crop without significant yield reduction. A successful PRD strategy reduces the tree water use through stomatal control of transpiration and also reduces the vegetative growth while maintaining the fruit size and yield of fruit.

Introduction

Food security is the main concern of recent agriculture throughout the world. To secure the food for 8 billion people by the end of 2025, irrigated area should be increased by more than 20% and the irrigated crop yield should be increased more than 40% (Lascano and Sojka, 2007). It can only be achieved by irrigated agriculture since irrigation on an average double the crop yield. Now, 60-80% of total agricultural water is consumed in irrigation (Huffaker and Hamilton, 2007). Hence, water shortage is the most important factor, constraining agricultural production all over the world. Deficit irrigation (DI) has been developed for more than 20 years ago and is able to increase both irrigation water use efficiency and crop water use efficiency of many crop species.

Water is the component through which fruit plant takes nutrients with the help of the well developed root system. In the absence of water, nutritional elements that found in soil can be used with difficulty from the root system (Zajmi *et al.,* 2014). During the last decade a novel irrigation strategy, PRD, has been developed. Controlled alternate partial root-zone irrigation (CAPRI) or partial root-zone drying (PRD) method is a new irrigation technique in which one-half of the root system into a drying phase while the other half is in irrigated phase (Kang and Zhang, 2004). This PRD method also used for minimizing water use with little or no negative effects on fruit growth but the cause of growth inhibition functional shoots (Kullaj, 2008). The wetted and dried sides of the root system alternate on a 10-14-day cycle.

The effective use of irrigation water has become a key component in the production of field crops and high-quality fruit crops in arid and semi-arid areas. Irrigation has been the major driving force for agricultural development in these areas for some time. Efficient water use has become an important issue in recent years because the lack of available water resources in some areas is increasingly becoming a serious problem (Kang and Zhang, 2004).

The concept of Partial Root-zone Drying (PRD)

The concept of PRD was first applied by Grimes *et al.,* in 1968 in USA on cotton field as an alternate of furrow irrigation. Sepaskhah and Sichani (1976) and Samadi and Sepaskhah (1984) were also applied PRD technique on beans through surface and subsurface drip irrigations in Iran. In 1999, vineyard of 70 ha area was established in California and completely operated with PRD. Later on, PRD technique was conducted in Australia for grapevines development through some extensive studies (Loveys *et al.,* 2000; Kriedmann and Goodwin, 2003). Now this technique is well adopted throughout the world in different fruit crops like citrus, pears and peaches with promising results.

Generally, fully irrigated plants have widely opened stomata through which plant can transpired maximum amount of water resulting maximum water loss through transpiration. However, a small narrowing of the stomata opening may reduce water loss substantially with little effect on photosynthesis (Jones, 1992). Now, part of the root system in drying soil can respond to deficit irrigation by sending a root-sourced signal to the shoots where stomata may be closed to reduce water loss (Davies and Zhang, 1991).

Design of PRD

PRD irrigation necessitates dual dripper lines. It can be targeted to a particular tree growth phase but would usually be maintained during an entire growing season. Wetting and drying cycles are not too short (not less than 3 days), nor too long (not more than 15 days).

Goodwin (2003) indicated that when soil water extraction from dry side is negligible, wetting should be changed from irrigated side to non irrigated side.

Furthermore, Liu *et al.,* (2008) stated that switching should be based on threshold soil water content in which the maximum abscisic acid concentration is produced.

Advantages of partial root-zone drying (PRD) in fruit crops

PRD leads to the preferential root growth.

It enhances the nutrient uptake from the soil zone.

Helps to increase water use efficiency (WUE) and fruit quality.

Save water upto 30-50% with no significant yield reduction.

Helps to advance the scheduled harvest date by 5–7 days which may results in getting better prices for farmers.

Limitations of PRD irrigation

Cost of implementing PRD irrigation system very high.

High-level management skills is required.

Faulty management may leads to loss of plant growth.

PRD effect on water use efficiency

Kang *et al.*, (2002) reported that the amount of water required under fully irrigated treatment is very high as compared to PRD irrigation. Hence, the irrigation water use efficiency (IWUE) under PRD system will increase which is also reported by different researchers in different crops like tomato, pear, grapevine and hot pepper (Dry *et al.*, 2003; Shahnazari *et al.*, 2007).

Effect of PRD on plant growth attributes on Citrus

PRDirrigated fruit plant had thicker root with high root tissue density. Bauerle *et al.*, (2008) concluded that the homogeneous root distribution and root structure in the wet and dry sides reflect the potential for internal hydraulic redistribution at night or hydraulic lift in citrus plant. Similar findings were also suggested by Dawson (1993).

But McCully (1999) showed such redistribution can alleviate drought conditions and it replenish any root xylem embolism which maintain plant root function (Williams *et al.*, 1993) and viability (Huang, 1999) of citrus plant. Similarly, Hultine *et al.*, (2003) showed that the internal hydraulic redistribution assist in sustaining water uptake of the entire root system by rehydrating roots in dry soil. A water redistribution process from wet to dry roots in response to water potential gradients can contribute to a decrease of ABA biosynthesis (Lovisolo *et al.*, 2010). This may have contributed to the lack of PRD treatment effects on root ABA since dry roots may not have experienced sufficient drought stress.

Effect of PRD on pomegranate fruit

PRD treated affected the fruit size of pomegranate fruit. The lower fruit weight in this treatment might be attributed to the smaller size of the fruits as indicated by the lower fruit diameter. On the other hand, PRD fruits exhibit the highest values of fruit weight, diameter and total soluble solids concentration. A possible explanation could be based the well-known negative effects of PRD strategy to lateral shoot growth, which in turn favors the accumulation of photosynthetic products in fruits (Beis and Patakas, 2015).

In Pomegranate fruit, titratable acidity, pH as well as juice percentage are not affected by differences in this irrigation methodology. Similar findings reported by Mena *et al.*, (2013) and Mellisho *et al.*, (2012). They showed that water stress did not affect the basic quality parameters of the pomegranate juice. In this reports a slight but significant reduction in pomegranate quality parameters was found only under severe water stress (12% of ETO).

Fruit cracking is considered as a major fruit disorder for pomegranate mainly associated with sudden changes in plant water status. It is believed that pomegranate is very sensitive to variation in soil moisture. When soil drought is followed by an increase in soil moisture content, the fruits pulp expands before the peel, causing the fruit cracking (Holland *et al.*, 2009).

Effect of PRD on banana fruit

PRD irrigation identifies reduction in photosynthesis rate as a higher consequence of the enzymatic activity or the stomatal closure. Higher leaf temperature increased transpiration and reduced instant water-use efficiency. The irrigation strategies with PRD maintain the gas exchanges of banana in variety 'BRS Princesa' (*Santos et al.*, 2017).

Effect of PRD on apple fruit

In Apple crop, PRD irrigation influences crop load and fruit size.PRD irrigated fruit had different quality attributes such as total soluble solids, treatable acidity at optimum maturity and harvesting stages. It provides higher soluble solids and lower titratable acidity in Apple fruit. It increases the red color percentage, fruit firmness and internal ethylene concentration in Apple. It also determines the flesh firmness, percentage and intensity of peel red color in Apple fruit. According to Lombardini *et al.,* (2004), sugar level of Apple fruit also increases in the moisture stress condition which is the major constituent of TSS in Apple fruit so, higher sugar is the reason of higher TSS content.

They also observed contrasting responses for apple fruit yield and quality, depending on the season, orchard location, and climatic conditions. In the similar way, they observed yield and fruit size of apple trees (Pink Lady apple) were reduced under PRD, when irrigation inputs equaled predicted crop evapotranspiration (O'Connell and Goodwin 2007). However, some other studies show that PRD does not affect apple fruit yield and quality (Caspari *et al.,* 2004; Einhorn and Caspari 2004; Van Hooijdonk *et al.*, 2004). PRD irrigation regime does not affect the starch pattern index and fruit maturation timing of Apple fruit (Lombardini *et al.*, 2004).

Effect of PRD on grape fruit

Anthocyanin pigmentation

PRD-treated fruit appear to have a direct effect on anthocyanin metabolism, which can occur even where berries receive equivalent levels of sunlight during their development. Field- grown vines imposes the distribution of the anthocyanins into a diverse range of anthocyanidin types in the presence of high levels of sun exposure (Haselgrove *et al.*, 2000) and also increase the effectiveness of the berry skin to photo-protection by absorption of a variety of wavelengths of radiation. It increases the radical scavenging capacity of the fruit in the protection against oxidative stress. This appears to be a response to increase the potential for oxidative damage within the fruit under high levels of light incidence, which would be exacerbated by the oxidative conditions caused by an additional water deficit brought in the PRD treatment. Haselgrove *et al.,* (2000) concluded that the response of grape berry anthocyanins to PRD requires sunlight, as demonstrated by the shading experiment, but is not exclusively mediated by increased levels of sunlight reaching PRD-treated fruit.

Aroma development

PRD irrigation increases the carotenoid concentration in the most abundant grape berry such as carotenoids lutein and β-carotene at berry maturity stages. Traditionally, increases in C13-norisoprenoid concentration have been associated with increased degradation of carotenoid precursors, leading to a reduction in the total pool of carotenoids (Marais *et al.*, 1991, Baumes *et al.,* 2002). However, an increase in the pool size of carotenoid precursor in response to water limitation was recently shown by Oliveira *et al.,* (2003), where non-irrigated treatment caused 60% increase in carotenoid concentration compared with an irrigated control. This finding indicated that water stress can result in an increase in the pool size of carotenoid precursors to theC13-norisoprenoids, and may in part account for the increase in certain C13-norisoprenoids in response to PRD. Lichtenthaler (1999) also showed that deficit irrigation has the potential to increase flux in the isoprenoid pathway, presumably toward increased synthesis of the stress hormone ABA via the carotenoids. This response to stress conditions experienced by the vine has the potential to increase the pool size of precursors to carotenoid-derived flavor compounds, which include the C13-norisoprenoids. This system has important implications for flavour development in grapes and wines, and deficit irrigation may become a significant tool to manipulate wine quality in the future. It is important to note that this increase in wine quality is independent of any change in berry size, or indeed yield per vine.

Effect of PRD irrigation on olive fruit

Ripeness index

PRD irrigated Olive fruit had higher ripeness index (RI). The olive ripeness seems to be precocious under PRD irrigation, which was probably due to the low yield induced by the water deficit (El Antari *et al.,* 2002).

Fruit size, weight and yield

This irrigation system improves fruit size, fresh weight (FW), stone weight (SW)and dimensions of the olive fruits. This improvement of olive fruit crop was probably due to a slightly lower olive production. Indeed our previous work showed that olive yield under PRD treatments was 78.7 (PRD_1), 74.5 (PRD_2) and 88.9 (PRD_3) kg/tree against 92.8 kg/tree for the control (Wahbi *et al.*, 2005). In fact, it was previously reported that the size of the fruit diminishes as olive tree production increases (Gomez-Rico *et al.*, 2005). Similarly, El Antari *et al.*, (2002) reported that low yields of olive were correlated with an increase in individual fruit weight and fruit dimensions under deficit irrigation. Wahbi *et al.,* (2005) resulted in an increase in water use efficiency by 60-70% under different treatments such as PRD_1 and PRD_2 and PRD_3 as compared to the control. They also assumed that the irrigation of the half root system could also be responsible for the precociousness of olive ripeness.

New irrigation strategies must be established to use the limited water resource more efficiently as PRD approximately save 50% irrigation water without significant yield loss, while may improve the quality. Implementation of the partial root-zone drying technique is simple, requiring only that irrigation systems are modified to allow alternate wetting and drying of part of the root-zone. PRD is recommended for irrigation of farms and orchards in arid and semi-arid areas which are suffering from lack of fresh water resources for fruit crop production.

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