International Journal of Chemical Studies

P-ISSN: 2349–8528
E-ISSN: 2321–4902
IJCS 2018; 6(2): 900-903

Received: 19-01-2018
Accepted: 22-02-2018

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Partial root-zone drying technique in fruit crops: A review paper

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Abstract
Now a day resources of fresh water are going to be an ever-increasing pressure because of extensive agricultural water demand for fruit crop cultivation. Long-term perspectives in shortage of available water resources, especially in arid and semi-arid area, urgent need solution for innovative irrigation technique and agricultural water management. In this review article the applications of the partial root-zone drying irrigation (PRD) on important fruit crop species. The partial root-zone drying technique is a novel irrigation technique of deficit irrigation in which half of the root-zone is irrigated alternatively in scheduled irrigation events. In the recent years, scientists were conducted research across the world, especially from arid to semi-arid countries, have extensively evaluated this irrigation as (50-75 %) water-saving irrigation technique on fruit crops. This review paper focuses mainly on the production quantity and quality of fruit aspects of partial root-zone drying on plants and its ultimate impact on yield and water productivity. Under limited water resources where water is precious PRD is viable irrigation option to increase water use efficiency while margining the yield, rather than only increasing the economic yield without concerning the value of water in limited water environments.

Keywords: Partial root-zone drying technique, mango, citrus, grape, pomegranate, apple, strawberry

Introduction
Partial root-zone drying is a modified form of deficit irrigation method which involves irrigating only one half of the root-zone in each irrigation event, leaving another half of root-zone to dry to certain soil water content before rewetting by shifting irrigation to the dry side. Water management in agriculture is crucial to food security, and environmental protection. From the last few years the global boom in groundwater use for irrigation in regions subjected to extended dry seasons has led to water shortages for agriculture. This is particularly true for rain–fed, arid and semiarid regions where trees are grown and their irrigation is essential for meeting high yields and adequate fruit quality standards (Behboudian *et al*., 2011). Many investigations have been conducted to gain experiences in irrigation of crops to maximize performances, efficiency and profitability. However, investigations in water-saving irrigation still are continued (Spreer *et al*., 2007) [7]. Full irrigation (FI) is used by farmers in non-limited or even water-limited areas. In this method, crops receive full evapo-transpiration requirements to result the maximum yield. Now a day's full irrigation is considered a luxury use of water that can be reduced with minor or no effect on profitable yield. Water-saving irrigations are used to improve the water productivity (WP) in recent years. Deficit irrigation (DI) and partial root-zone drying irrigation (PRD) are the water-saving irrigation methods that cut down 50% irrigation amounts of full irrigation to crops. The amounts of irrigation reduction is crop-dependent and generally accompanied by no or minor yield loss that increases the water productivity. Partial root-zone drying (PRD) is an irrigation strategy developed for saving water. PRD has been successfully applied to apples, strawberry, grape, mango, pomegranate and citrus without compromising yield while saving water.

During PRD, soil drying is expected to stimulate root to leaf biochemical signalling that reduces stomatal conductance and transpiration. Other benefits of PRD include the maintenance of plant water potential, reduced shoot growth and decreased soil evaporation. PRD is thought to reduce plant water consumption by enhancing abscisic acid production in the dry half of the roots (Stoll *et al.*, 2000) [15], a hormonal signal that reduces stomatal aperture and thus transpiration of the leaves (Davies *et al.*, 2000) [3]. Water use efficiency (WUE) is increased because the well-watered half of the root-zone ensures the maintenance of fruit growth, while vegetative growth is reduced (Dry *et al.*, 2000) [5].

The effect of water stress on plants at physiological, biochemical and molecular levels a crop that is imposed to PRD as a water-saving irrigation may show diverse responses to water stress in terms of these three responses levels according to the severity and timing of the water stress. However, in this review article much is focused on the effects of water stress at the physiological and morphological levels which play important roles in regulation of crop reproductive development, which directly relate to quantitative and qualitative properties of yield (Liu *et al.,* 2005) [7].

Mango

Mango belongs to family anacardiace and has been called in the orient, "king of fruit". Mango is rightly known as 'National Fruit of India', owing to its nutritional richness, unique taste and flavour, religious and medicinal importance. It is the third widely produced fruit crop of the tropics after banana and citrus. It is originated from south East Asia, in the foot hills of the Himalayas. Spreer *et al*., (2007) [12]. They conducted experiment to evaluate the influence of different deficit irrigation technique on ten year old "*Chok Anan*" Mango tree cultivated at spacing of 4 x 4 m In the years 2004 and 2005, 196 ten-year-old '*Chok Anan*' mango trees were assigned to different irrigation treatments in 2004 are as followed a)100% irrigation according to ETc by use of micro sprinkler method (Full irrigation); b) Deficit irrigation with 50% of Etc by use of drip method (DI50%); c) PRD with 50% of ETc by use of drip method (PRD); d) No irrigation (NI). In PRD treatment the irrigated part of the root system alternated every two weeks in 2004 and for 2005 three modifications of the experimental setup were made, treatment with 75% of Etc (DI75%) got introduced. To exclude a potential influence of the application technique, half of the DI50% and PRD trees were irrigated with drippers and micro-sprinklers, respectively. In PRD the irrigated sides were altered as soon as drought stress was detectable through increased stomatal resistance in the afternoon. Experiment was conducted at an orchard of Mae Jo University, Chiang Mai, Thailand. And result revealed that different deficit irrigation application influence on yield more than doubled yield in the dry year 2004 and 36.2% increase in 2005, when little rainfall occurred prior to harvest, the beneficial effect and necessity of irrigation in mango production could be proved significantly. Even though differences were only significant in 2004, in both years simple cutting down irrigation volume by half (DI50%) resulted in yield loss, whereas under dry conditions (2004) the same volume of water applied as PRD had no negative impact on yield, but increased WUE by 96.7 %; more than twice the difference in efficiency between DI50% and FI. Under conditions with some natural precipitation, like 2005, PRD, even if not statistically significant from FI, seemed to be less effective in obtaining maximum yield, however still reached the highest WUE value of irrigation regimes. The newly introduced DI75% treatment on the other hand showed a tendency towards even higher yield response compared to FI parallel to the same considerable increase in WUE of around 30%, as achieved by DI50%, but without yield loss. Looking into the reasons for higher yields in various treatments it can be concluded that the main positive effect of irrigation was on number of fruit per tree rather than beneficially influencing fruit size development. So losses by preterm fruit drop were significantly reduced by FI and PRD treatment in 2004 because no rain and smaller variability within the measurements, especially during afternoon hours, stomatal aperture under PRD presented the same diurnal pattern as FI, not showing any increase during the course of the day. Overall, under the changing weather conditions of this year, with occasional rainfall, differences in stomatal resistance between the treatments were insignificant and thus ineligible to securely indicate drought stress. Srikasetsarakul *et al.,* (2011) studied the effects of partial root-zone drying irrigation on proline content and yield of mango in a commercial orchard at Phrao district, Chiang Mai, Thailand. Irrigation treatments are (a) Full irrigation (FI) with 100% of ETc, evenly distributed over the root-zone, (b) Partial root-zone drying (PRD) with 50% of ETc on alternating sides of the trunk, and result reported that deficit irrigation strategies partial root-zone drying with irrigation of 50% Etc on alternating sides of the trunk and all trees were equipped with one micro-sprinkler were developed to increase water use efficiency and solve the problem of fruit weight reduction during development. However, partial root-zone drying might cause drought stress response, producing proline to balance cell solution and affects to fruit development. In addition, PRD might be affect tree vigour and yield in the long-term.

Citrus

Citrus fruits have a prominent place among popular and extensive growing tropical and sub-tropical fruits. India is sixth largest producer of citrus in the world contributing 4.8 per cent share in production. Citrus species do not tolerate freezing temperatures or poorly drained soils very well, so most citrus trees are grown in warm climates with soils that have a low water-holding capacity and also frequent irrigation is needed to development of quality fruit but in arid and semi-arid region condition there is shortage of irrigation water in that condition one can go for deficit irrigation method in which one of the best method is PRD which can give 90% water use efficiency. To reduce water use in navel orange production the experiment was conducted at California citrus industry by Lovatt and Faber (2007) [8]. They took six treatments *viz.* (a) well-watered as a control (based on evaporative demand); (b) 75% PRD, (c) 60% PRD trees have an emitter on each side, which alternate in delivery to one side of the tree, then next irrigation in other side; (d) 75% CI-RR and (e) 60% CI-RR trees have an emitter on each side so that both sides of the tree are wet. The result revealed that application of deficient irrigation citrus *cv.* Navel orange can save 25 to 40% water. And significantly higher yield was reported in PRD 60% as compare to PRD 75%. Dzingai *et al*., (2010) [6] they conducted experiment with six irrigation treatments *viz*, 1) Control: One drip line, one side of the tree irrigated according to ETo data from the automatic weather station. 2) Current practice: Single drip line, scheduled according to grower. 3) PRD 2 drip lines applying half of control 4) Control at flowering or fruit set and PRD 50% at stage 2. 5) Control at flowering or fruit set and PRD 50% at stage 3, 6) Control at flowering or fruit set and PRD 75% at stage 2 and 7) PRD 50% at stage 3, in October 2009, each treatment comprised of one single row with ten trees each. The ten trees were selected such that the outermost rows were excluded to eliminate edge effects; treatments were replicated once such that each treatment will have two rows. The effects of the different PRD treatments were evaluated against the current practice and the control. Before the treatments were established, all the citrus trees were being irrigated according to the grower's practice. The grower's practice is where by all the trees in the orchard watered using a single drip line was running close to the main stem. It is assumed to replace 100% of the crop evapotranspiration. During the 2009/2010 season

the trees were subjected to an irrigation cycle that changed the daily duration of each irrigation event. It was depended on the growth stage of it was observed that lowest citrus fruit drop in PRD 60% as compare to all other treatment, even though conventional irrigation required rate 75% and control irrigation

Pomegranate

Pomegranate (*Punica granatum* L.) belongs to family Punicaceae and is one of the oldest knowing edible fruits, cultivated extensively in India. Pomegranate widely distributed in the tropical and sub tropical regions of the world. Pomegranate is sold as whole fruits, but in some case fruit cracking takes place because of moister stress and long period exposure of the fruit to intense sunlight and sudden irrigation leads to damage of fruit, which render the fruit unmarketable. Noitsakis *et al.*, (2016) [10] studied the pomegranate physiological responses to partial root drying under field condition at Aristotle university of Thessaloniki, Greece. The following irrigation regimes were applied: fully-irrigated control plants (C) in which the plants were irrigated at both sides of the root system in order to establish 100% of the estimated crop evapotranspiration; partial root drying (PRD1) with half of the root system of each plant exposed to soil drying while the other half received 100% irrigation water of the irrigation water volume applied to control plants; partial root drying (PRD2) with half of the root system of each plant exposed to soil drying while the other half received only 50% irrigation water of that applied to control plants and found that maximum fruit weight, fruit diameter, aril weight, juice percentage, TSS, pH, and minimum fruit cracking and titratable acid recorded in PRD 100% treatment as compare to control irrigation treatment.

Grape

The grape commonly called as grapevine (*Vitis vinifera* L.) belongs to the family Vitaceae and also it has a historically important fruit plant. Traditionally grape has a great demand for wine making, raisin preparation and it has important source of medicine as well as nutrition's. In grape cultivation water is play an important role, because grape quality is defend on the water availability. Some part of country has facing water scarcity or drought condition in such a condition we can manage water problem by applying PRD system of irrigation it increase water use efficiency of crop without losing their quality and quantity. Santos *et al.*, (2005) [11] study was carried out during the 2002 growing season in a commercial vineyard at the Centro Experimental de Pegoes, southern Portugal. The treatments are fully irrigated (FI, minimum water deficit, 100 % of the ETc, half of the water amount supplied by drippers, deficit irrigated (DI, 50% of the ETc, half of the amount of water supplied to each side of the row by drippers); partial root drying (PRD, 50% of ETc periodically supplied to only one side of the vine by drippers, while the other side tried); non-irrigated (NI, rain-fed). In PRD the first change of the irrigation side of the vine was done after 1 month and then alternating sides every 15 days. Vines were watered twice a week, from fruit-set (mid-June) until one Week before harvest (September 3). The total amount of water supplied to FI plants vine). The PRD and the DI vines received half of this amount. And noticed that as result of the 50% reduction in the amount of water applied without any significant yield reduction, water use efficiency was double in PRD and deficient irrigation treatments compared to full irrigation. And also improve fruit quality was recorded in partial root-zone drying vine due to the higher concentration of anthocyanins, total soluble solids and total phenols. Bindon *et al.*, (2008) [2] they conducted experiment on two treatment 1) full irrigation 2) PRD 50% of ETc irrigation system on grapevine and revealed that there is no significant yield reduction in partial root-zone drying, however maximum bunch number per vine, berry number per bunch, total soluble solids and pH, and also minimum concentration tartaric acid was reduced in partial root-zone drying. Taisheng *et al*., (2008) [16] field experiments were carried out on a cultivated table grape (*Vitis vinifera* L. cv Rizamat) grown in a 1.75ha vineyard during the year 2005-2006 in Shiyang River Basin, which locates in the typical continental temperate arid zone of northwest China Three partial root-zone drip irrigation methods were included, i.e. CDI (conventional drip irrigation, irrigated on both sides of the root system as the control), ADI (alternate partial root-zone drip irrigation, irrigated with 50% of the control, alternatively on the two sides of the root system during consecutive watering), FDI (fixed partial root-zone drip irrigation, irrigated with 50% of the control on only one side of the root system). In the drip irrigation system, irrigation water was applied with pressure compensated drip emitters, two emitters per tree for CDI and one emitter per tree for ADI or FDI, operating at 4 L $h^{-}1$ and positioned 40 cm from the vine trunk. they revealed that partial root-zone drying increased water use efficiency by 26.7-46.4% of edible grape by 3.88-5.78%, vitamin C content in the fruit by 15.3-42.2% and compare to all other treatments and maximum yield (17.30t /ha), bunch number (25.30 /tree), berry number (66.08 /bunch) and total soluble solids (13.65° Brix) were recorded maximum and saved irrigation water up to 40-50% for same treatment.

Apple

Apple is botanically (*Malus X domestica.* Family: *Rosaceae*) the most important temperate fruit of the north-western Himalayan region in India. It is predominantly grown in Jammu and Kashmir (leading apple producing state), Himachal Pradesh (known as Apple bowl of India) and hills of Uttar Pradesh; its cultivation has also been extended to Arunachal Pradesh, Sikkim, Nagaland, and Meghalaya in north-eastern region and Nilgiri hills in Tamil Nadu. The agro climatic conditions in these states are not as conducive as in north-western Himalayan region. Early and continuous rains from April onwards do not favour the production of quality fruits besides resulting in high incidence of diseases. The apple-growing areas in India do not fall in the temperate zone of the world but the prevailing temperate climate of the region is primarily due to snow covered in Himalayan ranges and high altitude which helps to meet the chilling requirement during winter season extending from mid-December to mid-March in this condition major problem is irrigation water this can be over-come by applying Partial root-zone drying (PRD) technique which save 50% of irrigation water. (Zegbe *et al.*, 2008) [17] they conducted two experiments on different irrigation system for high water use efficiency on apple cv. Specific at *Hort Science* Group, INR 433, Massey University, Palmerstone North, New Zealand. Treatments are 1) commercial irrigation (CI) as control and partial root-zone drying (PRD). In control irrigation was applied by the grower following commercial practice. The PRD irrigation was applied by alternating the irrigation from the wetted side to the dry side when the volumetric soil water content and reported that PRD and CI fruit had similar quality attributes at

harvest and after storage except that the former had lower weight loss during storage in Exp. 1 and a lower firmness after storage in Exp. 2 compared with CI, PRD saved water by 50% in both the exp. Mark and Goodwin (2007) [9] studied the responses of Pink Lady apple to deficit irrigation and partial root-zone drying at Australia. By using different treatment were (1) conventional irrigation (CI, commercial grower practice, irrigated on both sides of the tree) (2) a partial root-zone drying treatment (PRD) which received 50% of CI on alternating sides of the tree and (3) a deficit treatment (DI) which received 50% of conventional irrigation on a fixed side of the tree. They reported that no significant yield of fruit dry weight difference was measured in both the years between PRD and CI regime. However water use efficiency and flesh firmness were recorded maximum in PRD in both the year of with respect to TSS. PRD reported maximum and similar concentration of TSS compare to other treatment in 1st and 2nd year respectively, in apple *cv.* Pink lady.

Strawberry

The modern cultivated strawberry (*Fragaria* x *ananassa* Duch.) is a hybrid of two largely dioecious octoploid species, *Fragaria chelonesis* Duch and *Fragaria varginiana* Duch. Basically, it is herbaceous perennial and short day plant grows predominantly in the temperate climate. Strawberry is an attractive, luscious, tasty and nutritious fruit with a distinct and pleasant aroma, and delicate flavor. It has a unique place among cultivated berry fruits. Rich in vitamin C, ellagic acid and iron, it is mainly consumed as fresh. Jam and syrup are also prepared from strawberry. It is cultivated in tropical and subtropical hills areas round the year. It is cultivated commercially in Himachal Pradesh., Uttar Pradesh, Maharashtra, West Bengal, Nilgiri hills, Delhi, Haryana, Punjab and Rajasthan. Owing to wide climatic and soil adaptation and high returns, it has tremendous potential in world for its antioxidant in human nutrition, enhancement of the immune system and reduce the risk of cardiovascular diseases and some form of cancer. Ellagic acid (EA) is a phenolic secondary metabolite that exhibits anti oxidant, ant mutagenic, and ant carcinogenic and possible antimicrobial properties (Vattem and Shetty, 2005). Fruit concentration of both As A and EA can be influence by pre-harvest environmental conditions and cultural practice. Dodds *et al.* (2007) [4] conducted experiment to determine if the irrigation management techniques RDI and PRD could be used to increase the concentration of the antioxidants ascorbic acid and ellagic acid in strawberry at east malling research, New Road east malling, kent, UK. Treatments were 1) Well watered control (WW) 120% ETP, 2) Regulated deficit irrigation (RDI) 60% ETP, 3) Regulated deficit irrigation (RDI) 80% ETP, 4) Regulated deficit irrigation (RDI) 100% ETP, 5) Partial root zone drying (PRD) 60% ETP, 6) Partial root zone drying (PRD) 80% ETP, 7) Partial root zone drying (PRD) 100% ETP. And they reported that the mean in fruit weight was unaffected by all deficient irrigation regimes except PRD60 and compare to control As A and EA concentration were increased (55% and 270%) respectively under PRD80 and PRD60 regime respectively. and no other different irrigation treatment significant effected fruit As A concentration compare to control and all deficient irrigation treatment except PRD100 helped to increase fruit EA concentration compared to control.

Conclusion

Application of deficit irrigation like partial root-zone drying with drip irrigation method in fruit crops can reduced irrigation water up to 50% of the commercial irrigation, and water use efficiency increased up to 80-92%. In mango partial root-zone drying 50% treatment increase the percentage of fruit mesocarp, fruit weight and unmarketable fruit can be reduced per tree, so one can adapt this practice in arid and semiarid zone area for mango production. In Citrus utilization of PRD 60% irrigation can avoid the fruit drops, and get good quality fruit and increase the water use efficiency and reduced 40% water loss so it is potential to use in the region where water scare. Alternate root-zone drying in grape cultivation maintains good balance between vegetative to reproductive growth, produced good quality and composition of berry, improve the fruit dry weight, Total soluble solids and flesh firmness of apple. PRD apple can store up to 10 to 15 week without any affect on quality of fruit. When PRD applied in the strawberry substantial water saving, reduced vegetative vigour, and increase productivity and alter chemical composition produce antioxidant and ascorbic acid. In pomegranate partial root-zone drying reduces the fruit cracking and increase the fruit quality.

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