AgriCos e-Newsletter
ISSN: 2582-7049
AgriCos e-Newsletter
Open Access Multidisciplinary Monthly Online Magazine
Volume: 03 Issue: 05 May 2022 Article No: 09

Water Saving Techniques: Deficit and Partial Root-Zone Drying Irrigation

Sonal D. Jadhav[1], D. D. Nangare[2] and Vijaysinha Kakade[3]
[1]Young professional, ICAR- National Institute of Abiotic Stress Management, Pune, (M.S.)
[2] Scientist, ICAR-National Institute of Abiotic Stress Management, Pune, (M.S.)
[3]Scientist, ICAR-National Institute of Abiotic Stress Management, Pune, (M.S.)

SUMMARY

Due to climate changes and increased demands of different water users (agriculture, industry, domestic) water becomes scarce resources worldwide. Since irrigated agriculture is the one of the largest consumer of these resources. irrigation management must be shifted from maximal production per crop area to maximal production per unit of water used by crops. New irrigation strategies must be established to use the limited water resource more efficiently. Deficit irrigation (DI) has been developed for more than 20 years and is able to increase both irrigation water use efficiency and crop water use efficiency of many crop species. Partial root zone drying (PRD) is a further development of DI. The PRD approach is to use irrigation to alternately wet and dry (at least) two spatially prescribed parts of the plant root system. This new irrigation strategy allows the exploitation of drought-induced ABA-based root-to-shoot signaling system to water saving. These irrigation techniques particularly PRD are promising for application in drought-prone regions for saving water. In the last decade, scientists across the world, especially from arid to semi-arid countries, have extensively evaluated this irrigation as a water-saving irrigation strategy on agronomic and horticultural plants. The PRD irrigation is a novel improvement of deficit irrigation in which half of the root zone is irrigated alternatively in scheduled irrigation events. Overall, undern limited water resources where water is precious, PRD is a viable irrigation option to increase water productivity while margining the yield, rather than only increasing the economic yield without concerning the value of water in limited water environments. . These systems improve the water productivity (WP) and quality of produce in horticulture crops as well as in cereal crops.

INTRODUCTION

Drought is one of the most common environmental stresses that may limit agricultural production worldwide. However, in many countries as a consequence of global climate changes and environmental pollution, water use for agriculture is reduced. Water is also becoming scarce not only in arid and drought prone areas but also in regions where rainfall is abundant. Agriculture is therefore forced to find new approaches to cope with water scarcity but adopting sustainable water use issues. The sustainable use of water - resource conservation, environmental friendliness, appropriateness of technologies, economic viability, and social acceptability of development issues - is a priority for agriculture in water scarce regions. 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). 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. 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). 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. Other benefits of PRD include the maintenance of plant water potential, reduced shoot growth and decreased soil evaporation.

Deficit irrigation (DI)

Deficit irrigation is an optimization strategy in which irrigation is applied during drought-sensitive growth stages of a crop. The correct application of DI requires thorough understanding of the yield response to water (crop sensitivity to drought stress). In regions where water resources are restrictive it can be more profitable for a farmer to maximize crop water productivity instead of maximizing the harvest per unit land.

Advantages

- Maximizes the water productivity.
- Although a certain reduction in yield is observed but the quality of the yield (e.g. sugar content, grain size) observed to be equal or even superior to rain-fed or FI cultivation
- Allows economic planning and stable income due to a stabilization of the harvest in comparison with rainfed cultivation
- Decreases the risk of certain diseases linked to high humidity (e.g. fungi) in comparison with full irrigation
- Reducing irrigation applications over the crop cycle will also reduce nutrient loss through leaching from the root zone, resulting in improved ground water quality
- Lower fertilizers needs as compared to in full irrigation. DI reduced fertilizer application. Combining DI and optimum fertilizer application leads to a higher yield increase (higher WP) than the sum of the separate yield increases obtained by both factors
- Controls of vegetative growth and canopy density (reduce pruning in grapevine)
- Improvement of irrigation water use efficiency and saving water for irrigation
- Increases in nutrient use efficiency (especially N)
- Improvement of fruit or yield quality (potato, grape, tomato, pepper, apple, maize)
- Due to drought stress in particular growth stages, the length of the cropping cycle might change under rain-fed cultivation.

Constraints

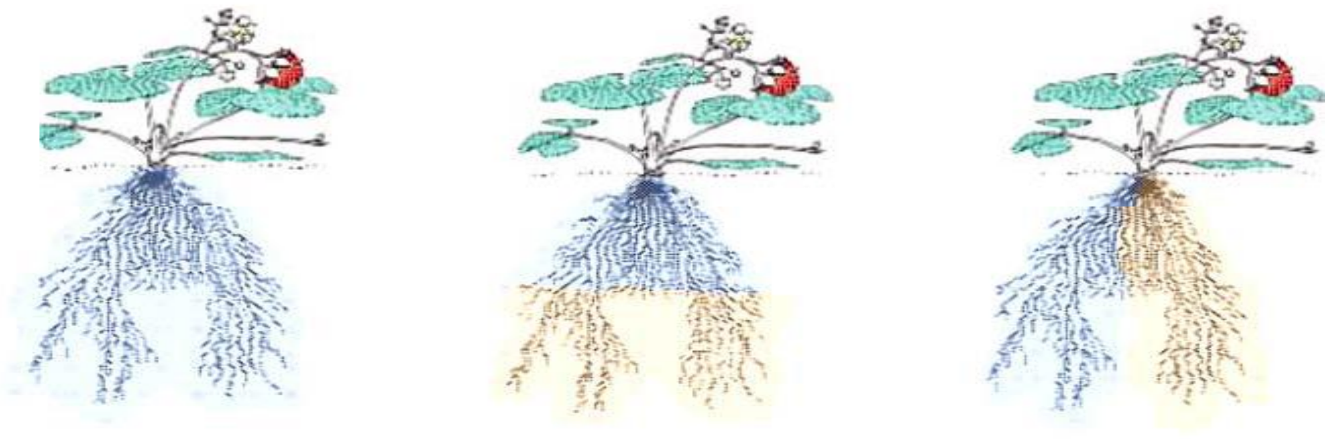
- Exact knowledge of the crop response to water stress is important.
- There should be sufficient flexibility in access to water during periods of high demand (drought sensitive stages of a crop).
- A minimum quantity of water should be guaranteed for the crop, below which DI has no significant beneficial effect.
- An individual farmer should consider the benefit for the total water users community (extra land can be irrigated with the saved water), when he faces a below-maximum yield
- Because irrigation is applied more efficiently, the risk for soil salinzation is higher under DI as compared to full irrigation.
- Determining optimal timing of irrigation applications is particularly difficult for crops with CWP functions in which maximal WP is found within a small optimum range of ET
- Irrigators should have unrestricted access to irrigation water during sensitive growth stages.

Partial root-zone drying irrigation (PRD)

Partial root-zone drying (PRD) is a modified form of deficit irrigation (DI) (English et al., 1990), which involves irrigating only one part of the root zone in each irrigation event, leaving another part to dry to certain soil water content before rewetting by shifting irrigation to the dry side; therefore, PRD is a novel irrigation strategy since half of the roots is placed in drying soil and the other half is growing in irrigated soil (Ahmadi et al., 2010a).

Principle of PRD

When a part of the root zone dries out, ABA produced in the roots in drying soils and is transported by water flow in xylem to the shoot for regulating the shoot physiology. The increase in abscisic acid in the xylem flow roots to leaves triggers the closure of stomata as response to water stress and reduced shoot growth and transpiration. After 10–15 days, the wet and the dry root zone are inverted. However, due to alternating wet and dry zones, roots have continuous access to water. Thus, the plant continues to grow and flowering and fruit development will not affect. Alternating the wet and dry zones of the roots means that repeated surges of ABA are delivered to the shoots, maintaining conditions of reduced shoot growth and reduced transpiration, but with no significant effects on flowering and fruit development (Fig 2)



Full irrigation **Deficit irrigation** **PRD**

Fig 1 : Schematic of the irrigation pattern in FI, DI, and PRD (Davies and Hartung, 2004).

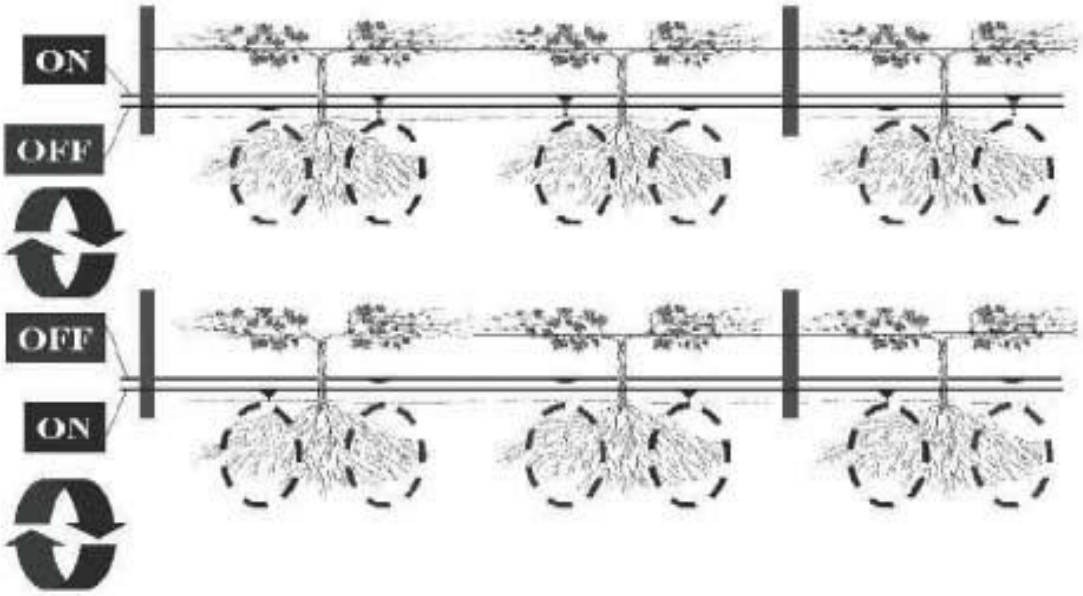


Fig 2 : Partial root zone drying using two above-ground drip lines in a vineyard

Chemical and hydraulic signaling in PRD

In drought, soil drying induces restriction of water supply and these results in a sequential reduction of tissue water content, growth and stomatal conductance. The plants have some mechanism for sensing the availability of water in the soil and regulating stomatal conductance and leaf growth accordingly. It has been termed non-hydraulic or chemical signaling. Hydraulic signaling, which represents transmission of reduced soil water availability *via* changes in the xylem sap tension. Roots in drying soil produce more ABA than under normal conditions and it is moved as an anti-stress root chemical signal to shoot through transpiration stream and limits the stomatal conductance. At mild water stress, ABA as a major chemical signal (CS) acts earlier than the change in plant water status i.e hydraulic signal, HS. However, under severe water stress, both CS and HS may be involved in regulating plant physiological processes. At severe water stress, the leaf water potential in mesophyll cells decreases and stomata will close to a greater extent that inhibits the photosynthetic rate (Taiz and Zeiger, 2006). In some plants, CS and HS occur independent of each other, while in others they take place dependently. A balance between CS and HS occur in PRD. In PRD, roots on the irrigated side absorb enough water to maintain high shoot water potential, and the roots on the non-irrigated side produce ABA for possible reduction in stomatal conductance. This mechanism optimizes water use and increase water productivity.

Advantages of PRD irrigation

PRD irrigation may have benefits on water use, WUE, fruit quality and nutrient uptake. It is important to assess how much water PRD can save in a growing season. Water-saving considerations have resulted in most PRD treatments receiving less water (usually 50%) than control plants. In addition to water savings, PRD has also been reported to have beneficial effects on fruit quality and nutrient uptake with no, or minimal, losses in yield (dos Santos *et al.*, 2003).

Fruit quality

PRD can improve the quality of fruits of several species; in grapes, cotton, tomato, and hot pepper. In grapes sugar content was increased by PRD (e.g. Stoll et al., 2000, dos Santos *et al.*, 2003). They have shown that this is largely a result of better control of vegetative growth of the grapevine. Also Dry et al., (2000) found that wine quality was consistently higher from PRD Wine yards.

Nutrient uptake

An extra benefit from PRD-induced new roots may be related to their function in nutrient uptake. The drying and rewetting cycle by PRD induced new roots, and this may make the nutrients in soil zone more available to the plants (Kang et al., 2001, dos Santos *et al.*, 2003).

Root development and water uptake

Root development and distribution are affected by spatial and temporal soil water distribution (Wang et al., 2006). Further, they affect water and nutrient uptake from the soil to maintain the physiological activities of the above-ground part of the crop. Mild water stress in soil leads to preferential root growth into the moist soil zone and water uptake through root system expansion and increasing root length density (RLD, cm root per cm3 soil) (Benjamin and Nielsen, 2006; Songsri et al., 2008). Earlier studies indicated that PRD enhanced the extension and inhibition of primary and secondary roots (Kang et al., 2000b), increased root growth (Dry et al., 2000) and root mass (Kang et al., 2000a; Mingo et al., 2004), improve ABA-induced root hydraulic conductivity (Glinka, 1980; Taiz and Zeiger, 2006; Thompson et al., 2007), and increased the nutrient uptake (Wang et al., 2009).

Disadvantages of PRD irrigation

PRD may be reducing biomass production as CO_2 uptake is partly restricted due to stomatal closure causing water savings. Biomass reductions are often in the range of 10% in cereal crops, while in fruit trees hardly any yield reduction has been found. The value of benefits from water savings should be balanced with value of yield reductions and cost of implementing PRD irrigation system compared with traditional systems. As PRD irrigation is in the research phase further experiences are needed to evaluate economical advantages of PRD irrigation.

Practical application of RDI and PRD: Irrigation management strategies

Before making irrigation plan it is important to know the characteristics of soil in the field including:

- Number and thickness of layers (identifying impermeable layers in the soil that may cause drainage and surface run-off problems)
- Soil texture,
- Soil structure
- Field water capacity, wilting point
- Rate of infiltration
- Rooting depth of plants that will be growing

• Soil chemical analyses to identify possible chemical/nutrient problems (e.g. acidity, salinity, nutrient deficiency).

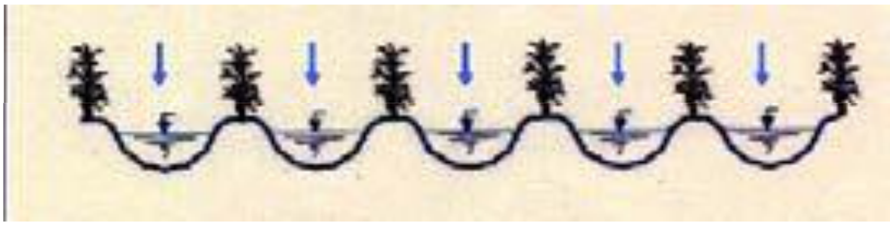
Irrigation methods for applying RDI and PRD

PRD and RDI could be applied in the field by different irrigation methods including:
• Furrow irrigation
• Drip irrigation

Furrow irrigation system

PRD System should be applied as the two rows configurations and the both furrows should be irrigated alternately. After the switching period, wetted furrow started to dry out and dry furrow will be irrigate

RDI System should be applied at the same time in all rows, but with 50-70% water amount needed for full treatment



In drip surface or subsurface for PRD irrigation two irrigation lines should be set up and operated separately with the distance between emitters of 60cm (for potato). This way lateral of one emitter will irrigate one part of the root system and emitters of other lateral will irrigate other half of root system. In FI and RDI irrigation one lateral is used for irrigation with the distance of 30 cm between emitters. Irrigation in FI and RDI should cover a total root area.

Precaution to be taken while implementing PRD

- Best PRD responses occur in soils with high values of readily available water (RAW). Shallow soils with low RAW can allow relatively small volumes of applied water to deplete rapidly. To some extent this can be overcome by more frequent irrigation.
- Use of PRD in soils with poor infiltration characteristics may also cause problems if sufficient water cannot be supplied through what is effectively 50% of the normal soil surface area.
- The amount and timing of irrigation applied to the ‘wet’ side should be sufficient to prevent the development of significant water deficits (soil moisture tension should remain higher than 50 kPa).
- If soil moisture monitoring is available, the irrigated side of the plant should be switched when water extraction from the “dry” side becomes negligible. In sandy soils and under hot dry conditions this may be only a few days. In soils with a higher water retention characteristic and under less stressful conditions, the cycle time may become several weeks.
- Use of PRD should not result in significant reduction in midday leaf water potential when compared with standard irrigation practice.
- When PRD is being implemented in an existing orchard, total soil area wetted by the irrigation system (wet plus dry sides) should not vary significantly from that wetted by the original irrigation system. For example, conversion from

flood to drip may wet only a small fraction of the available roots. The PRD irrigation system should aim to wet about half the roots at any one time.

- Correctly implemented PRD should not result in major effects on fruit quality. With Navel oranges, PRD using very low water application rates saw a reduction in fruit size in heavily cropped trees but this problem was not evident at higher water inputs. A reduction in water input, applied by flood or by drip, may result in a small but significant reduction in the percentage of juice and an increase in acid. There should be no effect on sugars and sugar/acid ratios may change accordingly.
- Response to PRD varies between species. It is still not known how some plants will respond.

CONCLUSION

In areas where the available water supply limits agricultural production, deficit irrigation will gain importance over time as farmers strive to increase the productivity of their limited land and water resources. Farmers must choose crops and irrigation strategies carefully to maximize the value of their crop and livestock production activities, while ensuring the sustainability of agriculture. Deficit irrigation will play an important role in farm-level water management strategies, with consequent increases in the output generated per unit of water used in agriculture. 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.

REFERENCES

Ahmadi, S.H., Andersen, M.N., Plauborg, F., Poulsen, R.T., Jensen, C.R., Sepaskhah, A.R., Hansen, S., (2010a) Effects of irrigation strategies and soils on field grown potatoes: Gas xchange and xylem [ABA]. Agri. Water Management, 97: 1486-1494.

Benjamin, J.G., Nielsen, D.C., (2006) Water deficit effects on root distribution of soybean, field pea and chickpea. Field Crops Research, 97: 248-253.

Davies WJ, Hartung W (2004) Has extrapolation from biochemistry to crop functioning worked to sustain plant production under water scarcity. In Proceeding of the fourth International crop Science Congress (Vol. 26, September).

Dos Santos TP, Lopes CM, Rodrigues ML, de Souza CR, Maroco JP, Pereira JS, Silva JR, Chaves MM. (2003) Partial rootzone drying: effects on fruit growth and quality of field grown grapevines (*Vitis vinifera*). Funct. Plant Biol. 30, 663–671.

Dry, P.R., Loveys, B.R., During, H., (2000) Partial drying of the rootzone of grape. II. Changes in the pattern of root development. Vitis, 39: 9-12.

English, M.J, Musick, J.T., Murty, V.V.N., (1990) Deficit irrigation. In: Management of farm irrigation systems (Hoffman, G.J., Howell, T.A., and Solomon, K.H., Editors). ASAE onograph no. 9. American Society of Agricultural Engineers publisher, 1020p.

Glinka Z (1980) Abscisic acid promotes both volume flow and ion release to the xylem in sunflower roots. Plant Physiol 65:537–540

Kang SZ, Liang ZS, Pan YH, Shi PZ, Zhang JH (2000a) Alternate furrow irrigation for maize production in an arid area. Agric Water Manag 45:267–274

Kang SZ, Shi P, Pan YH, Liang ZS, Hu XT, Zhang J (2000b) Soil water distribution, uniformity and water-use efficiency under alternate furrow irrigation in arid areas. Irrig Sci 19:181–190

Kang, S., Zhang, L., Hu, X., Li, Z., & Jerie, P. (2001). An improved water use efficiency for hot pepper grown under controlled alternate drip irrigation on partial roots. Scientia Horticulturae, 89(4), 257–267. https:// doi.org/10.1016/S0304-4238(00)00245-4

Kullaj, E. (2008). Ekofiziologjia e drufrutorëve. FBM. UBT. Tiranë. pp. 314

Mingo, D.M., Theobald, J., Bacon, M.A., Davies, W.J., Dodd, I.C., (2004) Biomass allocation in tomato (*Lycopersicon esculentum*) plants grown under partial rootzone drying: enhancement of root growth. Functional Plant Biology, 31: 971-978.

Songsri P, Jogloy S, Vorasoot N, Akkasaeng C, Patanothai A, Holbrook CC (2008) Root distribution of drought-resistant peanut genotypes in response to drought. J Agric Crop Sci 194:92–103

Stoll M, Loveys B, Dry P. (2000) Improving water use efficiency of irrigated horticultural crops. J. Exp. Bot. 51, 1627–1634.

Taiz L, Zeiger E (2006) Journal of Plant physiology. Sinauer Associates, Inc., Publishers, p 764

Thompson, A.J., Andrews, J., Mulholland, B.J., McKee, J.M.T., Hilton, H.W., Horridge, J.S., Farquhar, G.D., Smeeton, R.C., Smillie, I.R.A., Black, C.R., Taylor, I.B., (2007) Overproduction of Abscisic acid in tomato increases transpiration efficicency and root hydraulic conductivity and influences leaf expansion. Plant Physiology, 143: 1905-1917.

Wang H, Liu F, Andersen MN, Jensen CR (2009) Comparative effects of partial root-zone drying and deficit irrigation on nitrogen uptake in potatoes (Solanum tuberosum L.). Irrig Sci 27:443–447

Wang, F.X., Kang, Y., Liu, S.P., (2006) Effects of drip irrigation frequency on soil wetting pattern and potato growth in North China Plain. Agri. Water Management, 79: 248-264.

Zajmi A., Lepaja, K., Lepaja, L. (2014) Kultivimiidredhezes. Dija. Prishtine. Pp. 43-102.