Deficit Irrigation: For Reducing Agricultural Water Use

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Abstract- *Deficit irrigation refers to the application of water below full crop water requirement (Fereres, 2007). It is an optimizing strategy under which crops are deliberately allowed to sustain some degree of water deficit and yield reduction.The objectives of DI is to increase the WUE of a crop by eliminating irrigation that have little impact on yield, reduce the amount of water used for irrigating crops and improve the response of plants to certain degree of water deficit in a positive manner.Deficit irrigation is scheduled based on the yield response factor of each crops with seasonal and specific growth stages.The advantages of deficit irrigation are increased water use efficiency, enhanced root activity, improved nutrient use efficiency, improved product quality and increased plant yield. The basic rules for implementing deficit irrigation methods are practicing DI on relatively deep soils, use of drought resistant crops and varieties, increasing the contribution of precipitation, applying in the least sensitive growth stages, satisfying pre plant irrigation requirement, reducing irrigation losses and modifying cultural practices.As world's population is expected to increase in future, the additional food required to feed future generations is under enormous pressure and thus the fresh water sources also. Therefore, each drop of water is precious and has to be used efficiently. Deficit irrigation practice combined with other advanced agronomic practices like mulching, cover cropping, no-tillage, ridge-furrow planting can enhance water productivity.*

I. INTRODUCTION

About 70 percent of earth's surface is covered by water, but only 2.5 percent of it is fresh water. The majority of fresh water is trapped in glaciers, snow, and aquifers. All the fresh water in hydrological cycle constitutes only about 1 percent. Nowadays water shortage is becoming a threat in many parts of the world. Agriculture appears to be the largest consumer of freshwater resources. In many parts of the world, irrigation water has been over-exploited and over-used, and freshwater shortage is becoming critical in the arid and semiarid areas of the world.According to FAO (2010), in India, 71 percent of water withdrawal is by agriculture and livestock sector. As world's population is expected to increase in future, the additional food required to feed future generations is under enormous pressure and thus the fresh water sources also. Therefore, each drop of water is precious and has to be used efficiently. Recently, much emphasis has been given on the concept of water productivity; deficit irrigation is one of the methods designed to ensure the optimal use of allocated water (Shreedhar and Nithya, 2016).

II. DEFICIT IRRIGATION

Irrigation is usually done with three major goals which includes maximum profit, maximum yield per unit land and maximum yield per unit water (Vaux and Pruitt, 1983). When water becomes limited the focus must be shifted to the third goal, maximum yield per water i.e., water productivity. Under the present era of climate change and reduced water availability, it is important to increase the efficiency of irrigation systems as well as the water productivity of crops. Deficit irrigation refers to the application of water below full crop water requirement (Fereres, 2007). It is an optimizing strategy under which crops are deliberately allowed to sustain some degree of water deficit and yield reduction.The concept of deficit irrigation was born in the 1970s.In 1971, James et al., used the term DIin a book on the economics of water resource planning, and the first research into DI appeared in the early 80's

The objectives of DI is to increase the WUE of a crop by eliminating irrigation that have little impact on yield, reduce the amount of water used for irrigating crops and improve the response of plants to certain degree of water deficit in a positive manner. In regions where water is a limiting factor, deficit irrigation (DI) has been found as a valuable strategy.

III. MAIN APPAROCHES IN DEFICIT IRRIGATION

The three main approaches in DI are regulated/reduced deficit irrigation, partial root zone drying and sustained deficit irrigation (Chai *et al.*, 2015).

1. Regulated/reduced deficit irrigation (RDI)

It is growth stage based deficit irrigation strategy. The basic principle of this approach is that plant's demand to water stress, may not be equal in all the growth stages. Some stages will be highly sensitive to water stress while some others will be least sensitive. Here the less irrigation applied to the non-critical stages of the plant may not cause a significant negative impact on plant productivity even though it may reduce normal plant growth. This practice uses water stress to control vegetative and reproductive growth.Precision irrigation strategies like micro irrigation can also be utilized.For successful application of RDI, timing control and soil water level monitoring is required.Shreedhar and Nithya (2016) reported that sugarcane yield responses to deficit irrigation vary with crop growth stage.

2. Partial root zone drying (PRD)

English *et al.* (1990) stated that partial root-zone drying (PRD) is a modified form of deficit irrigation (DI). PRD involves irrigating only one part of the root zone in each irrigation event, leaving another part to remain dry for a certain degree. In PRD,roots on the irrigated side absorb enough water to maintain high shoot water potential, while roots on the non-irrigated side produce abscisic acid for a possible reduction in stomatal conductance. This mechanism optimizes water use and increases water productivity (Kang *et al*., 2000a).Topcu*et al.* (2007) studied the yield response of tomato grown under three different levels of irrigation ie.,full irrigation, PRD and 50 percent deficit irrigation .WUE was significantly higher for PRD and DI compared to full irrigation. Fruits under PRD matured earlier which gave a comparative market advantage of 7 to 10 days over other treatments.

Partial root zone drying is achieved through two approaches viz., alternate partial root zone irrigation and fixed partial root zone irrigation.

In alternate partial root-zone irrigation, one part of the root system is allowed to dry out, at the same time the other part is kept wet by irrigation. Later, irrigation is done in such a way that the former wet part of the root system is allowed to dry out and the former dry region is irrigated (Stoll et al., 2000).There are many studies to find out the effect of alternate partial root zone irrigation over full irrigation.Kang *et al.* (1998) reported that 34-36 percent of water was saved with a yield reduction of 6-10 percent in maize. In cotton 30 percent of water is saved with an yield reduction of 8 percent(Tang *et al*., 2005).Dorji*et al.* (2005) found that 50 percent of water is saved in hot pepper with an yield reduction of 20 percent. Topcu*et al.* (2007) found that 50 percent of water is saved and 20 percent of yield is reduced in tomato.

In fixed partial root-zone irrigation, approximately half of the root system is irrigated with normal amount of water and the remaining half is always exposed to drying during the entire growth period on each time when irrigation is carried out.

3. Sustained deficit irrigation (SDI)

Sustained deficit irrigation is application of a certain degree of constant water stress throughout crop growth, without considering its phenological period (Garcia-Tejero*et al.,* 2011).Goldhamer*et al.* (2005) studied the effect of different DI regimes on kernel yield in almond and concluded that sustained deficit irrigation has least detrimental effect on yield.

IV. SUB SURFACE IRRIGATION

Since Regulated/reduced deficit irrigation (RDI) and DI are used synonymously under most of the situations,subsurface irrigation is considered as the third DI practice which is used mainly in nursery systems and to a lesser extent, in the production of large scale field crops. In this method the above portion of root zone is kept dry. Irrigation water is supplied to plants by capillary movement from the bottom.Under field condition, subsurface drippers are used. The plants under subsurface irrigation maintains high leaf turgor potential that help plants to improve morphological strengthening, such as a thicker epidermis and more wax deposits on leaves and cuticle. According to Badr et al. (2010) in potato under four irrigation levels of 100, 80, 60 and 40 per cent of ETc, subsurface irrigated plants showed more yield than surface drip irrigated plants. The treatment with 80 percent ETc under subsurface drip gave comparable yield as full irrigation with surface drip.

V. DEFICIT IRRIGATION SCHEDULING

Stewart *et al.* (1975) has given the relationship between crop yield and water use through a simple equation where relative yield reduction is related to the corresponding relative reduction in evapotranspiration.

$$[1 - Y_a / Y_x] = K_y\,[1 - ET_a / ET_x]$$

(Y_x and Y_a are the maximum and actual yields, ET_x and ET_a are the maximum and actual evapotranspiration. K_y is the yield response factor which is crop specific and varies over the growing season according to growth stages).

$K_y>1$: crop response is very sensitive to water deficit. Larger yield reductions when water use is reduced because of stress.

K_y<1: crop is more tolerant to water deficit and recovers partially from stress. Yield reductions will be less with deficit.
K_y =1: yield reduction is directly proportional to reduced water use.

Thiyagarajan*et al.* (2014) conducted a study in groundnut to find the effects of deficit irrigation on yield and found that yield response factor was maximum under full deficit. He also reported that the pod formation and flowering stages were most sensitive to water stress and hence to be avoided from water stress.

VI. PHYSIOLOGICAL BASIS OF DEFICIT IRRIGATION

1. Leaf water content

A short period of mild water deficit under DI may promote plants to reduce leaf water potential substantially. Decreased leaf water potential acts as a hydraulic signal, triggering reduced leaf area expansion and partial closure of stomata.

2. Stomatal morphology

An important physiological response to drought stress associated with RDI is stomatal characteristics including stomatal closing and opening rhythms, the size of guard cells and stomatal density. Stomatal behavior of plants under DI is regulated by chemical signals that provide the shoot with some indication of water availability. The central component of signaling process involves plant hormone abscisic acid that is produced in shoots and roots and moved to leaves where it triggers stomatal closure.

3. Photosynthesis and transpiration

Plants under mild deficit associated with DI often express different levels of response to photosynthesis and transpiration. A number of studies showed that plants under partial root zone irrigation can improve leaf transpiration and enhance photosynthetic rate.Du *et al.*(2006) reported that irrigation methods and amount of water applied had little or no effect on photosynthesis rate but had significant impact on leaf respiration, seed yield and WUE in cotton. A low leaf transpiration rate with partial root zone irrigation allows plants to use more photosynthates, increase carboxylation efficiency and bundle sheath cell leakiness to CO_2. Increased leaf vapour pressure due to water deficit decreases the ratio of photosynthesis rate to transpiration rate, thus increasing transpiration efficiency (Shabani*et al.,* 2013).

VII. BIOCHEMICAL ASPECTS OF DEFICIT IRRIGATION

Plant hormones are molecules which regulate cellular processes in targeted cells, control the formation of flowers, stems and leaves and adjust the shedding of leaves and abscission of fruits. They act as signalling molecules, regulating a number of biochemical processes in plants and helping minimize the potential damage caused by DI induced water stress. Among the phyto hormones abscisic acid is well known.

Plants under DI can alter their cellular metabolism and invoke various defence mechanisms. A major defence mechanism is the increased activity of antioxidation enzymes, such as superoxide dismutase, catalase, ascorbate peroxidase, guaiacol peroxidase andlipoxygenase contents in roots and leaves (Hu *et al.*, 2010).

Another important defence mechanism with DI is the production of non enzymatic substances, which consists of low molecular weight substances such as soluble sugars, proline and malondialdehyde in leaves and in roots. These substances regulate osmotic potential in plants and reduce osmotic stress which enhances plant water holding capacity.

VIII. ADVANTAGES OF DEFICIT IRRIGATION

1. Increased water use efficiency

Water use efficiency is defined as yield of plant product (Y) per unit of crop water use (ET).

$$WUE = Y / ET$$

WUE=Water use efficiency (Kg/ha-cm or Kg/ha-mm) Y= Crop yield (kg) ET= Evapotranspiration (ha-cm or ha-mm)
The concept of water productivity is similar to WUE but it is defined as the ratio of the net benefits derived to the water applied. In areas where water is the limiting factor for crop production, maximizing WP by deficit irrigation is often economically more profitable for the farmer than maximizing yield. Kang *et al.* (2002) reported that in pear trees grown under alternate partial root zone drying and fixed root zone drying, water use is reduced by 12 and 28 per cent respectively, compared with conventional flood irrigation method. Greenhouse grown tomato showed that partial root zone drying saves 50 per cent water compared to fully irrigated (Topcu*et al.,* 2007).

A number of mechanisms are responsible for the reduced water use or increased WUE for the plants under DI induced water stress. Those plants under mild water deficit may be able to perform one or more of the following:

- Enhance guard cell signal transduction network that controls water loss from leaves through transpiration to the atmosphere (Schroeder *et al.,* 2001).
- Promote higher osmotic adjustment particularly when mild stress is applied in early growth stages (Yactayo*et al.,* 2013).
- Allow the development of drought hardiness by partial drought stimulations (Xu*et al.,* 2011)
- Optimize stomatal control over gas exchange (Wang *et al.,* 2010a).
- Reduce luxury transpiration loss with or without a minimum impact on photosynthesis (yang *et al.,*2012a).
- Improve moisture distribution across the soil profile and reduce potential evaporation due todecreased evaporative surface areas exposed by the partial root-zone irrigation approach (Xie*et al*., 2012).

2. Enhanced root activity

Deficit irrigation generally increases root to shoot ratio (Wang *et al.,* 2012), and increased root growth and root mass (Kang *et al.,* 2000a). Plant water uptake rate is enhanced after re-watering in water stress condition compared to full irrigation. PRD can greatly enhance the initiation and growth of lateral roots. Hence plant water uptake rate is enhanced after re-watering in water stress condition compared to full irrigation. Thus the newly formed roots may recover the sensitivity to the drying soil.

In a climate controlled environmental study, maize plants under alternate partial root-zone deficit irrigation produced 49 % more root biomass and increased root to shoot ratio by 54 %, compared to the fully irrigated control (Wang *et al.* 2012b). This is a typical example where mild water stress associated with DI has little or no effect on shoot biomass, but it promotes root growth significantly. Consequently, the increased root to shoot ratio provides benefits for water and nutrient uptake once full irrigation resumes.

3. Improved nutrient use efficiency

The increased secondary roots along with increased root to shoot ratio are beneficial for improving water absorption and enhancing soil nutrient uptake (Hu *et al.,* 2009). Reduction in irrigation will also reduce nutrient loss through leaching resulting in improved ground water quality and lower fertilizer needs in the field (Geerts and Raes, 2009).

A number of studies have shown that crops with DI can increase nutrient use efficiency through the promotion of nutrient recovery after a short period of water stress. In a maize–wheat rotation study, where full irrigation and partial root-zone deficit irrigation were compared, partial root-zone irrigation increased N recovery by 17 % compared to full irrigation in maize (Kirda*et al.,* 2005).

4. Improved product quality

The effects of DI on end-use quality of products are inconsistent, it varies with climate, crop species and the quality traits evaluated. Anthocyanin content of castelao grapes shown an increase under PRD and DI (Santos *et al.,* 2003). Farm managers will need to evaluate the effect of RDI on quality attributes for each particular product, hence minimize the trade-off between saving certain amounts of irrigation and decreasing the end-use quality of the product.

5. Maintained / Increased plant yield

Deficit irrigation applied at the early growth stage or partial root-zone deficit irrigation has been shown to maintain or even increase yields in many field crops. In an experiment done in cotton in arid northwest China, with conventional furrow, alternate furrow and fixed furrow irrigations, under three levels, i.e., 22.5, 30 and 45mm for each, resulted in an increased cotton yield by 13 to 20 per cent in alternate furrow irrigation (Du *et al.,* 2006).

The following are the factors that contribute to increased yield in DI :

a. Mild deficit at the seedling stage stimulates root development and increases root to shoot ratio, so that the plants are better equipped for soil water deficit at the later stages of growth.
b. Deficit irrigation at the vegetative stage increase the remobilization of pre- anthesis carbon reserved in the vegetative tissues to the grains (Xue*et al.,* 2006)
c. Water deficit reduces the growth redundancy of stem and leaves and promotes translocation of photosynthetic assimilates to the final products (Du *et al.,* 2008).

However, water deficit applied during reproductive stages typically decreases crop yield.

IX. ECONOMIC ANALYSIS OF DEFICIT IRRIGATION

The economic return to irrigation often involves more than the value of crop yield. The reduction in irrigation frequency permits the allocation of the given supply of irrigation water to a proportional larger area. Although yield per hectare is reduced under such deficit strategy compared to full irrigation, the reduction in irrigation cost and the opportunity cost of water more than compensates for the lower yield. Ali *et a*l. (2007) carried out economic evaluation of deficit irrigated wheat in both land limiting condition and water limiting conditions, and they found that deficit irrigation is effective in both conditions.

X. RULES FOR DEFICIT IRRIGATION

1. Practice deficit irrigation on relatively deep soils.
2. Use drought resistant crops and varieties.
3. Increase the contribution of precipitation
4. Apply DI in least sensitive growth stages
5. Pre plant irrigation requirement
6. Reduce irrigation losses
7. Modify cultural practices

1. Practice deficit irrigation on relatively deep soils.

Deep soils with high water holding capacity can retain more quantity of water and can sustain plant growth for longer periods. These soils may have ample time to adjust to low soil water matric pressure, and may remain unaffected by low soil water content. In contrast, shallow soils store only small amount of water and water stress develops quickly and increase yield reduction. Therefore, success with deficit irrigation is more probable in finely textured soils.

2. Use drought resistant crops and cultivars.

Some plants have capacity to grow well under irregular or inadequate water supply because they have well adopted mechanisms to withstand stress. Drought resistance is ability of plant to grow satisfactorily under water stress. Crops or crop cultivars that are most suitable for deficit irrigation are those with a short growing season. They complete lifecycle before stress develops (drought escape). Some plants maintain cell water potential even under stress by either increasing water uptake or reducing water loss (drought avoidance). Drought tolerant plants have the capacity to develop low osmotic potential through accumulation of solutes and thus maintain turgor pressure even under low soil water potential.

3. Increase the contribution of precipitation

In deficit irrigation practiced areas, precipitation can be effectively utilized to meet the part of crop ET demands and hence yield reduction can be minimized. The contribution of precipitation can be increased by adopting measures such as in-situ moisture conservation practices, rain water harvesting and recycling, partial wetting of soil profile during irrigation to allow some storage capacity for precipitation, and timely cut off irrigation at the end of crop season.

4. Apply DI at the least sensitive growth stages

Crop plants need water throughout lifespan but some crop stages are more sensitive to water stress. Hence less sensitive stages are to be identified for different crops as deficit irrigation applied at these stages will not affect crop yield adversely.

5. Reduce pre-plant irrigation requirement

Pre-plant irrigation is important for providing adequate moisture for seed germination or seedling establishment. Evaporation losses are more during these stages. Deficit irrigation have to be adjusted so that only adequate amount of water needed for seed germination is applied without much water loss.

6. Reduce irrigation losses

Deep percolation and runoff losses are more in uneven areas. In deficit irrigation, unnecessary water losses is not affordable.

7. Modify cultural practices

Under deficit irrigation, agronomic practices may require modification. Cultural practices like conservation tillage, adoption of flexible planting dates, anti transpirants, summer deep ploughing, mulching, moderate plant density, etc. can modify the water requirements of the crop with improved WUE.

XI. CHALLENGES IN DEFICIT IRRIGATION

- During sensitive stages, unrestricted water availability must be ensured. However, this may not be possible in periods of extreme shortage.
- Minimum quantity of water should always be available for application .This is difficult in extreme dry regions where water is scarce.
- Crop response to deficit changes widely with climate, soil, management practices, crop and growth stages.

XII. FURURE LINE OF WORK

The focus is primarily on water stress-induced responses of plants, mainly morphological, physiological, and biochemical responses as well as their influence on crop productivity. In addition, more applied techniques are required to facilitate application of deficit irrigation in large-scale agricultural systems. The real challenge is to establish DI on the basis of delivering sustained or increased crop productivity, while saving irrigation water and enhancing WUE. Many topics or subject areas are needed to be studied in the near future in which areas of signalling systems, physiological and biological responses, quantification of the magnitude of deficits and potential impact on soil quality attributes should be given top priorities.

XIII. CONCLUSION

Water is an increasingly scarce resource worldwide and irrigated agriculture remains one of the largest and most inefficient users of this resource. Many water saving practices have been adapted to tackle the critical issue of water shortage worldwide. Studies showed that deficit irrigation strategies like sustained deficit irrigation, regulated deficit irrigation and partial root drying can be successfully applied in field crops, trees, and vines in order to improve water use efficiency and save water. A mild water deficit applied at the early growth stages can provide large benefits to plant growth and development under certain conditions. In particular, a slowly increased water stress can induce internal physiological adjustments and regulations to protect plants from damage. Deficit irrigation practice combined with other advanced agronomic practices like mulching, cover cropping, no-tillage, ridge-furrow planting can enhance water productivity.

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