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Deficit (Limited) Irrigation – A Method for Higher Water Profitability

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1. Introduction

Increasing world population and limitation of water and soil resources make the control of resource usage essential. Policymaking for the future must be based on a more profitable use of water and soil and it is necessary to consider economical, political and social aspects in order to reach a better condition in water and soil resources. Agricultural management, macro and micro policy should be based on sustainable use of limited water and soil resources. In some cases expanding farmlands needs vast investment while some times it is not possible. Plant production per given amount of water should be basis for organizing possibilities and invests to increase water profitability (Feres and Soriano, 2007; Blum, 2009). The necessity of planning to increase the water use efficiency is inevitable from world population growth and water amount.

Development pressure irrigation system, crop production based on crop rotation, plant nutrition and pest control are all for better use of water and soil resources.

Undoubtedly future water management should be based on more production per given amount of water. Deficit or limited irrigation is one of the irrigation methods which has been designed for more efficient use of water in some crops (English, 1990). Environmental conditions, type of crop and available possibilities have particular importance in water management regarding deficit irrigation (English, 1990).

In this method a plant won't encounter moisture deficiency during growth and development under normal condition, in other words, plant absorbs water requirements for metabolic functions easily. However, when a drought stress happens to a plant either in all its or at least in one of its growth stages, it won't be able to do metabolic functions due to water limitation or unbalanced water situation.

Drought stress is described by its intensity and duration which have interaction with plant growth stage (Samarah and Al-Issa, 2006; Farooq *et al.*, 2009). For example even a medium drought stress at anthesis time of wheat or barley causes more reductive effect on yield than a drought stress during grain filling (English and Nakamura, 1989; Martyniak, 2008; Katerij

et al 2009; Maleki farahani, 2009). Effect of severe short stress is more than a medium long stress, because under medium stress the plant is able to reduce bad effects of stress by stimulating some metabolic and morphologic mechanisms. Therefore it can be said that environmental stress including drought stress at any plant growth stage which has more contribution to the yield has determinant effects on yield reduction.

2. Deficit irrigation

Deficit irrigation is a water management method in which water will be saved with accepting little yield reduction without any severe damage to the plant (English 1990). Medium stress may be a delay in irrigation for a few days or reduced water consumption in each irrigation, but plant shouldn't encounter severe drought stress at any mentioned situation.

The principal attitude in deficit irrigation methods are using saved water for expanding farmlands, saving water for using in critical growth stage or using for cultivating of cash crops like summer plants.

3. Crop production response to given water

Generally yield increases sharply per given water unit in production curve. After a sharp incline in yield, there is a fairly increase until it reaches maximum yield and after that yield will be constant with more given water. The zone for applying deficit irrigation is when yield increases slowly with each given water unit. Selection of exact point for water amount in deficit irrigation depends on following factors:

1. Type of crop
2. Possibilities for farmland expansion
3. Energy usage per area unit for farmland preparation
4. Costs of sowing, cultivation operations and harvesting

4. Methods for application of deficit irrigation

Selecting the methods depends on available possibilities and soil texture. Considering soil conditions, deficit irrigation is possible in two ways:

In soils with light texture (sandy soil), soil doesn't have high water holding capacity, thus in such a situation irrigation periods may be constant or its frequency increases, however, in deficit irrigation the water amount reduces compared to normal irrigation in each irrigation (English, 1990).

Accordingly an experiment conducted by Jorat *et al* (2011) on two forage sorghum cultivars. The irrigation treatments consisted of IR₇₀: irrigation after 70mm accumulative evaporation from evaporation pan class A (control), IR₁₀₀: irrigation after 100mm accumulative evaporation from evaporation pan class A and IR₁₃₀: irrigation after 130mm accumulative evaporation from evaporation pan class A which were assigned to the main plots. The sowing density of 15, 20 and 25 plants per square meter and two sorghum varieties (Speedfeed and Pegah) were allocated as factorial arrangement to the subplots. The results

indicated that the highest forage yield was produced by Speedfeed variety at the control (IR₇₀), medium water stress (IR₇₀) and severe water stress (IR₇₀) treatments with 25 plants per square meter density. The plant height followed an increasing trend as sowing density increased and decreased as water stress got more severe. The stem and leaf dry matter followed the same trend as forage yield in response to water stress and sowing density. The leaf/stem ratio increased as sowing density increased.

Also in another study on chickpea the deficit irrigation was induced by reduction of volume of water in each consecutive irrigation. In this study which was conducted by Chaichi et al (2004), five chickpea accessions were treated by different irrigation gradient systems during generative growth stage. The irrigation gradient treatments were 5, 10, 15 and 20 percent of reduced water supplies compared to control (moisture kept at field capacity throughout the experimental period) at two-week intervals. Irrigation treatments started from flowering commencement and finished when plants reached physiological maturity. The volume of irrigation water in every other day intervals was determined by soil texture and soil moisture curve based on a preliminary experiment, which was 300 ml. Irrigation treatments were: 1: Control: soil moisture kept at field capacity level ($\pm 5\%$) throughout the experimental period by irrigating of 300 ml of water every other day, 2: Irrigation with 5% reduction of water supply compared to control in a two-week interval from flowering commencement to physiological maturity, 3: Irrigation with 10% reduction of water supply compared to control in a two-week interval from flowering commencement to physiological maturity, 4: Irrigation with 15% reduction of water supply compared to control in a two-week interval from flowering commencement to physiological maturity, 5: Irrigation with 20% reduction of water supply compared to control in a two-week interval from flowering commencement to physiological maturity.

Irrigation treatments were applied to simulate the pattern of available moisture reduction in dry land farming areas.

	First period	Second period	Third period	Fourth period	Fifth period
Irrigation	May, 10	May, 24	June, 7	June, 22	July, 5
Gradient	May, 23	June, 6	June, 21	July, 4	July, 18
Control	cc 300	cc 300	cc 300	cc 300	cc 300
5%	cc 285	270 cc	cc 255	240 cc	cc 225
10%	270 cc	240 cc	210cc	180 cc	150 cc
15%	255 cc	210 cc	165 cc	120 cc	75 cc
20%	240 cc	180 cc	120 cc	60 cc	0 cc

Table 1. Irrigation schedule and volume of irrigation water for chickpea accessions in 2001

Chickpea accessions were sown on March 6, 2001 outside the greenhouse and were normally irrigated to commencement of flowering. On May 10, 2001 pots were transferred to a controlled greenhouse and irrigation treatments were applied. Temperature and humidity was kept constant (temperature 23 ± 2 °C and humidity $65\% \pm 5\%$).

Seed production per plant was significantly ($P < 0.05$) affected by both chickpea genotypes and interaction of irrigation systems \times chickpea genotypes. Based on the mean seed production per plant, chickpea genotypes could be classified in three categories of high yielding accessions (4488 and 4283), medium yielding accession (5132 and 4348) and low yielding accessions (5436). The medium and low yielding accession produced 18 and 45 percent less seed yield per plant compared to high yielding ones, respectively.

At irrigation gradients of 5 and 10% there was 39% less seed production and at irrigation gradients of 15 and 20% there was a 54% reduction compared to control. Nonsignificant difference in seed production at 15 and 20% irrigation systems indicates that chickpea accessions have a relative tolerance to drought stress and can produce an acceptable minimum production under unfavorable moisture conditions. Accession No. 4283 was the best seed producer at control, however, it showed a severe sensitivity to water stress especially at irrigation system of 20% when it produced the least amount of seed among chickpea genotypes. Accession No. 4488 not only had the highest mean (over all irrigation system) seed production among all chickpea cultivars, it also had fairly stable seed production ability under all irrigation systems. By producing of bigger seeds with less number per pod, and producing more pods per plant, accession No. 4488 was the best seed producer among other genotypes. The lower number of branches provided with less leaf area ultimately reduced its evapotranspiration under stressed conditions. Accession No. 4488 was followed by No. 5132, which despite lower mean seed production had a better stability under all irrigation systems. This genotype followed the same vegetative and generative growth pattern of accession No. 4488.

Accessions No. 4283 and 4488 produced the most biomass and seed yield (respectively) averaged over all irrigation treatments. Accession No. 4283 showed a severe reaction to irrigation gradient compared to other accessions, while accession No. 4488 was more stable in biomass and seed production across all irrigation gradients.

In heavy texture soils (clay soil) with high water holding capacity, irrigation intervals should be scheduled so that irrigation intervals will be increased while the plant will not encounter severe drought stress. In heavy soils, deficit irrigation is also possible by reducing water amount in each irrigation if the irrigation intervals are kept constant.

In both methods, water consumption has to be less than normal condition per farm area unit. There are some factors which influence the efficiency of deficit irrigation including land leveling when irrigation is applied in surface and the existence of possibilities for conducting water in short time so that it can distribute uniformly in the farm.

In a study performed by Heidari Zooleh et al (2011) on Foxtail Millet they used alternate irrigation systems with different intervals in a pot experiment. Their treatments consisted of different irrigation methods and intervals. There were three irrigation intervals: I1: Control, irrigated every 2 days, I2: Mild water stress, Irrigated every 3 days, I3: Sever water stress, irrigated every 4 days, There were three methods of water application, viz: Conventional irrigation (M1): the whole root system was relatively evenly dried, Fixed irrigation (M2): fixed irrigation group by which water was always applied to one part of root system during the whole experimental period, Alternate irrigation (M3): watering was alternated between two halves of root system of the same pot. The watered and dried halves of root system were alternately replaced each irrigation interval. Irrigation intervals were determined

according to factors such as greenhouse temperature and humidity. At each irrigation event, enough water was allowed to be absorbed by the soil in each pot, and any excess water was allowed to drain. The pots were weighed before and after each irrigation event to determine the water consumption by the plant in each pot. They found The I1 had the highest dry forage yield, while I2 did not have significant difference compared with I1, but I3 had a significant reduction of dry forage yield compared with I1. For example under conventional irrigation, I2 and I3 had a dry biomass reduction of 5% and 34% compared with I1, respectively. Less water was used by M2I3 and M3I3 compared with M1I3 but dry forage yields were not affected. Under conventional irrigation, irrigation interval of 3 and 4 days had a dry biomass reduction of 5% and 34% compared with irrigation interval of 2 days, respectively. In addition, less water was used by M2I2 and M3I2 compared with M1I2 but dry forage yields were not affected. The most important point is that M2I2 significantly reduced dry forage yield compared with M3I1, while M3I2 did not have a significant reduction compared with M1I1, M2I1 and M3I1. These suggest that alternate irrigation of root is the best irrigation method among other irrigation methods. Also There was significant difference between M2I3 and M1I1 in terms of WUE and the difference among the other treatments were not significant. M2I3 had a WUE increase of 40% compared with M1I1. There was positive and significant correlation between WUE and leaf to stem ratio. By increasing irrigation interval, water consumption was reduced evident in the I2 in fixed and alternate irrigation. Reductions in water consumption, but not in biomass, with fixed and alternate irrigation compared with conventional irrigation method suggests that these two irrigation methods can be used for saving soil water. This is especially so with alternate irrigation under mild water stress (M3I2) that did not reduce forage dry weight when compared with M3I1. Under irrigation interval of 3 days, fixed and alternate irrigation used 29% and 20% less water compared with conventional irrigation, respectively. There was positive and significant correlation between water consumption and fresh forage yield, dry forage yield, plant height, leaf area, leaf dry weight, leaf relative water content (sampling stage 1, 2), root dry weight, root volume, root surface area and root length, while there was negative and significant correlation between water consumption and leaf to stem ratio and specific leaf weight (SLW). Overall their results showed that fresh and forage yield were reduced by increasing irrigation interval. Under conventional irrigation, irrigation interval of 3 and 4 days had a dry biomass reduction of 5% and 34% compared with irrigation interval of 2 days, respectively. Under irrigation interval of 3 and 4 days, less water was used by the alternate and fixed irrigation compared with conventional irrigation, but plant growth in terms of dry biomass, plant height, leaf to stem ratio, specific leaf weight, leaf area, root dry weight, root volume, root surface area and root length, was not affected. Under irrigation interval of 3 days, fixed and alternate irrigation used 29% and 20% less water compared with conventional irrigation, respectively. However, water stress increased specific leaf weight, but reduced leaf area, leaf dry weight and leaf relative water content. Root growth was less sensitive than shoot to water stress. Under mild water stress, alternate irrigation performed better than fixed irrigation compared with all irrigation methods under non-water stress, so they suggested to use alternate irrigation under mild water stress to achieve acceptable yield along with efficient use of water. In the other study water deficit irrigation systems applied on pearl millet (*Pennisetum americanum* L.) by reducing water amount in each time and irrigation times (Rostamza et al., 2011). The irrigation treatments were 40%, 60%, 80% and 100% depletion of available soil water (I₄₀, I₆₀, I₈₀ and I₁₀₀, respectively). The results indicated that water stress affected total dry matter (TDM), leaf

area index (LAI), water (WUE) and nitrogen utilization efficiency (NUE). The highest TDM of 21.45 t/ha was observed at I₄₀. Furthermore, NUE and LAI were higher at I₄₀. WUE increased as the water depletion increased and reached to a maximum of 3.44 kg DM m⁻³ at severe stress. In forage quality, TDN% reached to the highest value of 54.7% in non stress water treatment. However, CP% increased by soil water depletion and more N fertilizer application. The highest profit was observed when more water and N fertilizer was applied. They concluded pearl millet in semi-arid area can be cultivated with acceptable forage yield by saving irrigation water compared to traditional forms and reducing nitrogen supply.

5. Suitable crops for water management under deficit irrigation

Crop selecting has special importance in this method. As a general rule plants which their fresh yields are consumed are not eligible to apply deficit irrigation systems on them. Summer crops including sugarbeet, potato and some forage crops and vegetables are not suitable. While small grains including wheat, barley, triticale and drought stress tolerant oil seeds specially safflower and canola are important crops that applying deficit irrigation is possible for them and among industrial crops, the cotton can be indicated (English, 1990). However, it is necessary to notice that drought stress doesn't induce specially at pod setting stage by applying deficit irrigation.

6. Environmental conditions and deficit irrigation

Identification of environmental conditions is of great importance for applying deficit irrigation; some of these conditions are listed as following:

Soil: soil texture and structure along with topography have determinant role to apply deficit irrigation. In relatively light soils applying deficit irrigation is not as easy as heavy soils. As well as in soils without enough organic matter, this method is not applicable due to low water holding capacity.

Pressure irrigation equipments are most important factors when the farmland is unlevelled. In salty soil due to intensity of osmotic potential as a result of water deficiency the selection of irrigation method and type of crop have special importance.

7. Weather conditions

Drought stress is intensified by warm weather, as Maleki Farahani *et al* (2010b) found in their research that under deficit irrigation the barley 1000 seed weight decreased by 12% although in year with fairly higher temperature during grain filling 1000 seed weight decreased by 35%, thus applying deficit irrigation is more successful in autumn-winter crops than summer crops. Sanjani *et al* (2008) found yield of cow pea and sorghum decreased by about 50% in additive intercropping system of grain sorghum and cowpea under limited irrigation. The limited irrigation (moisture stress) treatments consisted of IR1: normal weekly irrigation (control), IR2: moderate moisture stress during vegetative and generative growth, IR3: moderate moisture stress during vegetative and severe during generative growth, IR4: severe moisture stress during vegetative and moderate during generative growth. Also Soltani *et al* (2007) evaluated 11 new corn hybrids under water

deficit irrigation by applying different amount of water including irrigation after 70, 100 and 130 mm evaporation from A evaporation pan. Their findings revealed that all hybrids produced significantly less yield after medium or severe water stress as average yield over 11 hybrids was 7.5, 5.4 and 4.9 t/ha in 70, 100 and 130 mm treatments respectively. However, corn seed inoculation by phosphate solubilizing microorganisms (*Arbuscular Mycorrhiza* and *Pseudomonas fluorescense*) showed satisfying results when applied along with above three irrigation levels (70, 100 and 130 mm) (Ehteshami et al., 2007). They stated that phosphate solubilizing microorganisms can interact positively in promoting plant growth as well as P uptake in corn plants, leading to plant tolerance improving under water deficit irrigation systems. Summer farming will be successful if the temperature doesn't rise over the required optimum plant temperature. In tropical weather condition because of salt transformation due to soil water evaporation, it may intensify the salinity and drought stress after applying deficit irrigation. As a general recommendation, this method is more successful in autumn- winter crops than summer crops because of salts being washed downward, lower evapotranspiration and higher precipitation.

8. Crop growth stage

Success in applying deficit irrigation is highly dependent on asynchronism of sensitive growth stages and drought stress (Kirda, 2000). Plant growth and development stages in which important yield components are determined shouldn't encounter drought stress. For example, spikelet differentiation and anthesis have important role in wheat yield, therefore for wheat cultivation, deficit irrigation should set in a manner to avoid drought stress in both mentioned stages (English and Nakamura, 1989; Ghodsi et al, 2005; Ghodsi et al., 2007). Irrigation frequency and irrigation time should be regulated based on crop growth stage and their sensitivity of them to drought stress. For example, it is suggested to perform two light irrigations at grain filling of wheat without producing optimal moisture condition.

There is a need to find detrimental effect of water stress in crops while limited irrigation is applied in different growth stages of crops. There are evidences that some experiments regarding deficit irrigation have been done in some crops like wheat, turnip, sorghum and etc. Ghodsi et al (2007) performed a field experiment on different bread wheat varieties to find the most critical growth stages to water stress. They conducted a field experiment in Torogh Agricultural Research Station (Mashhad, Iran) in 2000/01 and 2001/02 cropping seasons, using a split plot design based on a randomized complete block design with 3 replications. Main plots were assigned to 7 levels of water stress treatments D1, full irrigation; D2, cessation of watering from one leaf stage to floral initiation, and in other treatments, cessation of watering under rain shelter D3, one leaf stage to floral initiation; D4, floral initiation stage to early stem elongation; D5, early stem elongation stage to emergence of flag leaf; D6, emergence of flag leaf stage to anthesis; D7, anthesis stage to late grain filling (soft dough). Sub-plots were assigned to four bread wheat cultivars: Roshan, Ghods, Marvdasht and Chamran. Results of combined analysis of variance showed, biological yield, grain yield, yield components, harvest index and other traits were significantly affected by water stress treatments. Under D5, D6 and D7 treatments, grain yield decreased compared to D1 by 36.7, 22.8 and 45.6%, respectively. There were also significant differences between genotypes for yield and yield components. Significant correlation coefficients were found between grain yield and number of spike per m²,

number of grains per spike, harvest index, spike weight at anthesis and seed set percentage. Under water stress conditions, grain yield was more affected by number of grain per unit area. Results showed, susceptibility of developmental stages of bread wheat to water stress were different. Exposing to water stress in each developmental stages, lead to decrease in yield. Grain filling (D7) and stem elongation (D5) stages were the most critical stages under water stress conditions. The effect of water stress in early pre-anthesis (D6) and tillering (D3) stages was also considerable. The results of this study illustrated that imposing moisture stress in critical growth stages (Commencement of stem elongation, anthesis and grain filling) would significantly decrease grain yield; however, imposing moisture stress in initial growth stages would not have such a significant effect on grain yield. Furthermore, wheat cultivars reacted differently to different moisture stress treatments. Chamran cultivar had a higher grain yield and was more tolerant to moisture stress during critical growth stages. On the other hand, it was demonstrated that application of lower moisture stress treatments (D3 and D4) relatively increased water use efficiency (WUE), however, severe moisture stress treatments (D5, D6 and D7) decreased WUE. Genetic differences also played a significant role in variation in WUE among different cultivars. Roshan and Chamran cultivars exhibited the lowest and the highest WUE, respectively. It was also illustrated that there were some differences in moisture stress treatments for radiation use efficiency (RUE). D1, D2 and D3 treatments showed the highest RUE, while the lowest RUE belonged to D5 and D6 treatments.

In other study that has been conducted by Keshavarzafshar et al (2011) the reponse of forage turnip were evaluated to water deficit. In this study a field trial was conducted in Research Farm of College of Agriculture, University of Tehran, in Karaj/Iran (N 35°56", E 50°58"), during 2009. The climate type of this site was arid to semiarid with the annual average climate parameters as follows: air temperature 13.5°C, soil temperature 14.5°C, and with a rainfall of 262 mm per year. The soil texture of the experimental field was Clay loam (33% sand, 36% silt and 31% clay) with pH= 8.2 and $E_c = 3.41$ ds/m. The organic carbon content of the surface layer soil (0-15 cm) was 1.02 %. The soil had no salinity and drainage problem, and water table was more than 7 m deep. Turnip seeds were plantd on March 3rd, 2009. Plant to plant spacing was 10 cm and plant rows were 70 cm apart. The depth of sowing was 2 cm. The crop was harvested on June 15th, 2009. After elimination of border effects, one square meter area was hand harvested in each plot. After harvest, fresh yields of roots and leaves were measured and samples were dried in oven at 70° C to a constant weight for dry matter content. Three replicated samples of each treatment were taken for forage quality analysis.

Their results showed that highest tuber yield of 930.8 Kg/ha was produced at no water stress treatment (IR_N) while the lowest yield of 307 kg/ha was produced at control (IR_0). The most efficient irrigation regime in regard to tuber production was IR_1 causing 59% more tuber dry matter compared to control. As the severity of the water stress reduced, at IR_2 and IR_3 , the efficiency of extra water application followed a decreasing trend.

In the most severe water stress condition (IR_0), 100% F_{Ch} treatment demonstrated the best performance in tuber biomass production (almost five fold more than control). under favorable moisture condition (IR_N), application of integrated fertilizer (50% $F_{Ch}+F_{Bi}$) produced the highest tuber yield which was 18% more than control. In other irrigation levels, no significant difference between these two treatments, 100% F_{Ch} and 50% $F_{Ch}+F_{Bi}$

was observed. As the severity of water stress increased, the total biomass followed a decreasing trend. The highest biomass production of 3640 kg/ha was achieved by IR_N irrigation regime which was nearly five fold more than control (IR₀). The highest efficiency of biomass production per unit water utilization was achieved in IR₁ in which with only one irrigation at sowing time, the biomass production reached 2091 Kg/ha (100% increment compared to IR₀). In IR₂ by an extra irrigation at tuber formation stage, the added biomass was only 472 kg/ha more than IR₁, showing a much less efficiency in biomass production per unit water application.

Interaction effect of irrigation regimes and P fertilizers on total biomass yield of turnip was significant ($p < 0.01$). In IR₀ treatment, application of 100% F_{Ch} and 50% F_{Ch}+F_{Bi} increased biomass yield compared to control. Except for IR₀, in other irrigation regimes application of F_{Bi} treatment had no significant effect on biomass production of turnip.

The effects of irrigation regimes and P fertilizers on tuber protein yield of turnip were significant ($p < 0.01$). Water stress caused a significant decrement in crude protein yield. The highest yield of crude protein (129.4 kg/ha) was obtained by IR_N while the lowest yield (48.6 kg/ha) was obtained from IR₀ (nearly threefold increment). By one irrigation at sowing time (IR₁), the yield of crude protein highly increased (52 % increase compared to the control). However, the extra irrigation at tuber formation stage (IR₂) and third irrigation at stem elongation stage (IR₃) performed a lower efficiency in increasing the protein yield of turnip tuber.

As the water stress severity decreased, the digestibility of tuber dry matter followed an increasing trend. The lowest percent of DMD (62.9%) was obtained by IR₀ and the highest percent (66.9 and 68.5) was achieved by IR₃ and IR_N, respectively.

Application of phosphorous chemical fertilizer (100% F_{Ch}) had positive effect on dry matter digestibility of turnip tuber and increased it by more than 10 percent compared to control. However, other fertilizers had no significant effect on this trait.

By decreasing the severity of water stress, the ADF percent of turnip tuber followed a decreasing trend. The highest tuber ADF was observed in IR₀ (30%) and the lowest percent was achieved in IR_N (23.4 %).

The interaction effect of irrigation regimes and phosphorous fertilizers on ADF percent of turnip tuber was significant ($P < 0.01$). In the most severe water stress condition (IR₀), application of sole bio fertilizer (F_{Bi}) and integrated fertilizer (50% F_{Ch}+F_{Bi}) increased tuber ADF compared to control. However, in other irrigation regimes, application of 100% F_{Ch} and 50% F_{Ch}+F_{Bi} resulted in lower ADF percent compared to control. Overall, in all irrigation regimes, chemical P fertilizer had the most positive effect on decreasing ADF of turnip tuber.

Also as the water stress severity decreased, the tuber ME followed an increasing trend. The ME in IR₀ was 8.7 while in IR_N it was 9.6 MJ/kg dry matter.

Finally they concluded that turnip tuber yield was adversely affected by water stress and it is very sensitive to water stress at germination, establishment and early growth stages.

Considering to find most sensitive growth stages to water deficit, the following study was performed by Khalili et al (2006) on grain sorghum variety Kimia. The Experiment was

initiated in Research Farm of College of Agriculture, University of Tehran located in Karaj/Iran during summer 2004. The main plots were allocated to five different irrigation regimes which applied drought stress on sorghum (soil moisture approached wilting point before the next irrigation) at different vegetative and generative growth stages. The irrigation regimes comprised of: 1) Full irrigation (IR1) (control): The plots in this treatment were irrigated at weekly intervals up to the end of the growing period. 2) Moderate drought stress in both vegetative and generative stages (IR2): The plots allocated to this treatment were irrigated on weekly basis until the plants reached well establishment at 6 to 8-leaf growth stage and then the irrigation was ceased until 10 to 12-leaf stage where the plots received irrigation. Again irrigation was ceased until the early flowering stage (5 to 10% flowering) which the plant received another irrigation. The next irrigation was applied when the plants were in early milky grain stage and since then no irrigation was applied until the plants reached the physiological maturity. 3) Moderate drought stress in vegetative stage (after 6-8 leaf stage) and severe drought stress in generative stage (IR3): Irrigation treatment was identical to IR2 up to early flowering stage and then no irrigation was applied until plants reached the physiological maturity. 4) Severe drought stress at vegetative stage and moderate stress at generative stage (IR4): At vegetative growth stage the irrigation treatment was similar to IR2 except that no irrigation was applied at 10 to 12-leaf growth stage. However, the irrigation treatment followed exactly the same as IR2 in generative part of the plant growth. 5) Severe drought stress in both vegetative and generative growth stages (IR5): The Irrigation treatment followed the same trend as IR4 at vegetative and IR3 at generative stages of plant growth. 1 The statistical analysis of the data showed that there was a significant difference ($p < 0.01$) in grain yield production due to different irrigation regimes. The highest grain yield of 5871 kg/ha was obtained from control plots while the lowest grain yield of 500 kg/ha (less than ten times) was produced in severe drought stress both in vegetative and generative growth stages. As the drought stress in generative stage of the plant increased, grain yield followed a decreasing trend. In the severe drought stress regime in generative stage (IR3), the reduction of the kernel weight and one thousand kernel weight could be accounted for grain yield decrement. This shows the importance of water availability in generative stage of the plant growth (especially grain filling stage). The severe reduction of grain yield in irrigation regimes of IR2, IR3 and IR5 indicated the plant sensitivity to drought stress at different phenological stages. Grain production decreased over 50% in these treatments compared to control, however, in IR4 treatment, this reduction was only about 30%.

The results of this experiment indicate the importance of irrigation at early flowering and milky grain stages of the plant growth which could produce not only a proper grain yield, but also contribute in significant water conservation compared to control (full irrigation). The number of irrigations in IR4 treatment was reduced by 50% (from 18 to 9) compared to control, which from ecological and economical point of the views is very important in dry areas. The statistical evaluations showed that there is a statistically significant positive correlation between kernel weight, kernel length, one thousand kernel weight; biological yield and harvest index with grain yield production. Drought stress especially in generative growth stages caused a severe decrement in grain yield which could be because of decreasing of one thousand kernel weight, kernel length decrement and consequently decreasing the number of grains per kernel. Also the lower number of grains in

each kernel may be due to disordered pollination and finally decrement the number of fertilized flowers. By applying a regular irrigation on sorghum from germination to plant establishment stage (7-8 leaf) and then limited irrigations just at 10-12 leaf, early flowering and milky grain stages, the number of irrigations will be decreased from 18 to 9 times. Despite of 30% grain yield reduction in this system; still it is beneficial from ecological and economical point of the views for arid environments. So, Khalili et al (2008) suggested that by severe moisture stress at vegetative along with providing the minimum water requirements in generative growth stages of grain sorghum, the water consumption efficiency of the plant will be improved and a reasonable grain yield is achievable.

9. Economical aspect of deficit irrigation

Benefits: Beneficial effects of deficit irrigation are evaluated as different economic and social aspects. Researches have indicated that regardless to equal energy use either in normal or deficit irrigation, the amount of production per given water unit usually is more under deficit irrigation than normal irrigation. With water saving and providing possibilities for farmland expansion, the equipment use efficiency increases, therefore labor and machinery will be used in more efficient way (English and Raja, 1996).

Also the farmer income will increase by cultivating of high demanded vegetable and summer crops through saved water in deficit irrigation. Furthermore, results of applying deficit irrigation by reducing irrigation times have shown quality enhancement of subsequent produced seeds. Seeds which produced under deficit irrigation condition germinated earlier and had greater germination percentage in drought and salinity stress which induced either by polyethylene glycol or NaCl compared to seed produced under normal irrigation (Maleki Farahani *et al.*, 2010b). Moreover, the grain nutritional quality enhanced after implementing deficit irrigation (Maleki Farahani *et al.*, 2011). Deficit irrigation increased barley N content by 12% as well as Zn and Mn 27% and 7% compared to control. Also 4% increment was observed in P concentration an important element for seed germination.

In macro view, increment of agricultural production and efficiency of labor and machinery resulting from application of deficit irrigation can be assumed as benefits.

Disadvantages: Lack of knowledge about sensitive plant growth stages, insufficient planning for water use and distribution not only can affect the benefits of deficit irrigation but also can cause damage for the farmers. Drought stress in every critical growth stage will make irrecoverable damages for crop (English, 1990).

Deficit irrigation is not the same as complementary irrigation. In complimentary irrigation which is usually performed in dry land farming systems, one or two irrigations are applied at critical growth stages in which raining don't take place. However, in deficit irrigation the farmer's attitude should be based on relative reduction of water in an irrigated farming system. If the time and amount of water in this method are not determined properly, an irrecoverable damage will suffer the crop. More emphasis is on proper planning in this method to prevent probable damages.

10. The role of policymakers in development of deficit irrigation

Development and recommendation of new methods won't have favorable results if they aren't based on evaluation and planning. In first point of view, deficit irrigation won't be

welcome by farmers because of relative reduction of yield. In agricultural farming systems, which are managed by deficit irrigation, the net income is less than normal irrigation because expenses for land preparation and weed control are equal in both systems.

Generally, subsidizing and farmers supporting are not inevitable in case of policy for deficit irrigation. Subsidization may be indirect as providing of inputs like chemicals to the farmers who manage their farms with deficit irrigation method. Moreover water can be available with lower price for the mentioned farmers to compensate yield reduction.

In years which water source deficiency may take place because of lower precipitation, the development of deficit irrigation is a preference. Repetition of deficit irrigation in a long period of time may be set as farmers culture. Media plays key role in explaining deficit irrigation to be accepted by farmers. Planning for better use of water resources is inevitable.

11. Conclusion

Deficit irrigation methods are those irrigation methods that yield increases per given water unit (water productivity). Beside the water productivity, quality of the crop could be improved by more tolerance to drought and salt stress as well as more nutritional quality. The performance of these method is better in large lands and in years with lower precipitation which water is limited. In general it can be apply by either fixed irrigation frequency and reduced water in each irrigation or reduced irrigation frequency and fixed amount of water in each irrigation time. In both ways the basic principle is water usage reduction compared to normal irrigation, so that none of the critical plant growth stage encounters drought stress.

Soil texture, weather conditions, type and growth stage of plant and available possibilities have important role for applying and selecting of deficit irrigation method. Governmental support through subsidizing can play an important role in deficit irrigation development.

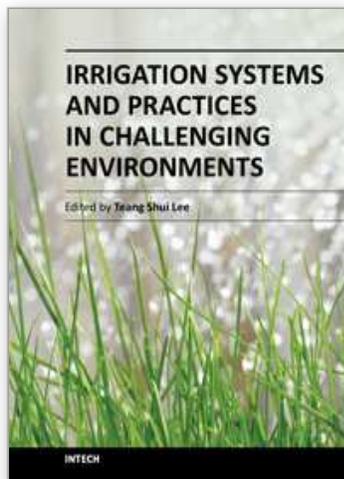
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The book *Irrigation Systems and Practices in Challenging Environments* is divided into two interesting sections, with the first section titled *Agricultural Water Productivity in Stressed Environments*, which consists of nine chapters technically crafted by experts in their own right in their fields of expertise. Topics range from effects of irrigation on the physiology of plants, deficit irrigation practices and the genetic manipulation, to creating drought tolerant variety and a host of interesting topics to cater for the those interested in the plant water soil atmosphere relationships and agronomic practices relevant in many challenging environments, more so with the onslaught of global warming, climate change and the accompanying agro-meteorological impacts. The second section, with eight chapters, deals with systems of irrigation practices around the world, covering different climate zones apart from showing casing practices for sustainable irrigation practices and more efficient ways of conveying irrigation waters - the life blood of agriculture, undoubtedly the most important sector in the world.

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