EFFECT OF CONTROLLED DRAINAGE AND QUALITY OF IRRIGATION WATER ON CROP YIELD, WATER USE EFFICIENCY AND REDUCTION OF DRAINAGE WATER

EFFET DU DRAINAGE CONTROLE ET DE LA QUALITE DE L'EAU D'IRRIGATION SUR LE RENDEMENT AGRICOLE, L'EFFICIENCE DE L'UTILISATION DE L'EAU ET LA REDUCTION DES EAUX DE DRAINAGE

Negar Sharifi Mood[1] and Farhad Mirzaei[2]

ABSTRACT

In conventional drainage, water level in the root zone declines and salt is carried away from the root zone to other areas, where the environment deteriorates. Controlled drainage is one of management methods of controlling water table in root zone. In control methods, water exiting from the region will reduce making the rest available for plant use. The groundwater quality in such a case becomes an important issue of concern.

In order to address this concern, the influence of controlled drainage and quality of irrigation water were studied through simulation of a physical model as real farm conditions such as plant, soil, quality of irrigation water, and water level in drain. For this purpose, two treatments of drainage water level including free drainage (FD) and controlled drainage (CD) and three treatments of irrigation water quality including irrigation with 0.75 dS m^{-1}, 3.4 dS m^{-1} and 4.8 dS m^{-1} salinity in three replications were studied in 18 lysimeters to examine the corresponding crop yields. The results showed that unlike free drainage conditions in which soil moisture would be supplied only through irrigation water and hence before the next irrigation, the plant will face moisture stress. In controlled drainage treatments, capillary rise of water meets the plant water demand, leading to 3.5 times more yield in comparison to free drainage.

The mutual effect of water table and irrigation water salinity shows that higher moisture

1 Graduated MSc. student of Irrigation and Drainage, Academy Center of Soil & Water Engineering, Department of Irrigation & Reclamation, Faculty of Agriculture & Natural Resources, University of Tehran, Karaj, Iran. (Email: negar.irr80@gmail.com)

2 Assistant professor of Irrigation and Drainage, Academy Center of Soil & Water Engineering, Department of Irrigation & Reclamation, Faculty of Agriculture & Natural Resources, University of Tehran, Faculty St., 31587-11167, Karaj, Iran. PH (+98) 261-2241119.

conditions in controlled drainage treatments will diminish the effect of salt accumulation in comparison to free drainage conditions; therefore irrigation water salinity has not made its real effect.

Key words: *Controlled drainage, Irrigation water quality, Water use efficiency, Lysimeter.*

RESUME

Dans le drainage conventionnel, le niveau d'eau dans la zone racinaire s'abaisse et le sel est effectué hors de la zone racinaire à d'autres domaines, où l'environnement se détériore. Le drainage contrôlé est l'une des méthodes de la gestion pour contrôler la nappe phréatique dans la zone racinaire. Dans la méthode de contrôle, l'eau sortant de la zone se réduit permettant à utiliser le reste d'eau par les plantes. Dans un tel cas, la qualité des eaux souterraines devient une préoccupation importante.

Afin de répondre à cette préoccupation, l'influence du drainage contrôlé et la qualité de l'eau d'irrigation ont été étudiées par simulation d'un modèle physique en conditions agricoles réelles telles que les plantes, les sols, la qualité de l'eau d'irrigation, et le niveau d'eau du drainage. À cette fin, ont été étudiés deux traitements au niveau de l'eau de drainage, y compris le drainage libre (FD) et le drainage contrôlé (CD) et trois traitements sur la qualité de l'eau d'irrigation, y compris l'irrigation avec la salinité de 0,75 dS m^{-1}, 3,4 dS m^{-1} et 4,8 dS m^{-1} avec trois répétitions dans 18 lysimètres pour examiner le rendement agricole correspondant. Les résultats ont montré que, contrairement aux conditions de drainage libre dans lequel l'humidité du sol serait fournie par l'eau d'irrigation avant l'arrosage suivant, la plante fera face à un stress hydrique. Dans les traitements de drainage contrôlé, la hauteur d'ascension capillaire de l'eau satisfait la demande en eau des plantes, ce qui conduit à un rendement 3,5 fois élevé par rapport au drainage libre.

L'effet réciproque des nappes phréatiques et de la salinité de l'eau d'irrigation montre que les conditions d'humidité élevée dans les traitements de drainage contrôlé vont diminuer l'effet de l'accumulation du sel par rapport aux conditions de drainage libre. Donc la salinité de l'eau d'irrigation n'exercera pas un impact réel.

Mots clés : *drainage contrôlé, qualité de l'eau d'irrigation, efficience d'utilisation de l'eau, lysimètre.*

1. INTRODUCTION

About 17% of the entire lands all over the world are aquaculture lands and account for about 34% of production. In aquaculture, drainage is very important in controlling and adjusting salinity and waterlogging to improve plant environment. In conventional drainage, the level of water in root zone is lowered by drain and the soil salts are transferred with drainage effluent to another area, causing environment degradation to the effluent receiving areas. The problem associated with large area drainage is found in Khoozestan Agro-industrial Sugarcane farms. There is increasing public pressure to design drainage networks in a way that they do not become environmentally harmful to the surrounding habitat in terms of living condition, agriculture and other water uses. The issue of controlled drainage was put forward for the first time in humid regions and the research conducted in the field of controlled drainage in arid and semiarid region is not noticeable. Determining the depth of water table is the most important and the most difficult part in designing a water table controlling drainage system. The appropriate level for water table is achieved through the balance between effective depth of roots, upward capillary flux and inflow from the upstream. When the water is of good or permissible quality, the near-field capacity of root zone soil due to shallow and rising water table helps plant roots to up take water under minimal stress. This will also reduce drainage outflow from the land, irrigation requirement and environmental hazard to the effluent receiving lands.

Meyer et. al. (1980) showed that in loamy soil with groundwater table depth of 1 meter, wheat has managed to get 28% to 36% of its water need through groundwater.

Jia and Evance (2006) considered biodrainage and controlled drainage as the best management strategy to minimize the risk of salt transfer to surface water. The positive consequences of controlled drainage in arid and semi arid areas through reduction of drainage water and irrigation water storage have been shown in several studies made by Abbott et. al (2001).

Jia et al., (2006) conducted a comprehensive study on drainage systems in YinNan region in China and studied the possibility of controlled drainage in order to diminish negative consequences of drainage water in this area. Results showed that for most aquatic crops and rice, controlled drainage would lead to reduction in effluent discharge by 94%.

Khan et. al (2003), showed the adverse impact of deficit irrigation and large volume of drainage water inflow to agricultural lands in Mardan, Nowshera and Charsadda regions in Pakistan that led to substantial reduction in crop yield and troublesome reduction of underground water level. They used an underground collector in the outlet of drain to raise the level of water table and assessed the influence of groundwater level, depth of irrigation, crop yield, water use efficiency and water saving. Heavier irrigation was done in the regions with deeper water table, and lighter irrigation is done in the shallower water table region. Therefore water table depth of 1.1 m was taken as the basis of designing drainage system. Supplying moisture through optimum control of water table led to saving water from 23% to 129% and increasing water use efficiency up to 0.93 kg m^{-3} leading to increase of wheat yield up to 6.5 tone ha^{-1}.

Kahlown et. al. (2005) studied the effect of water table depth on the crop water need and considered the optimum water table depth of 1.5 to 2 meter for all crops except sugar beet as it is shown higher yield in water table of 2 meter or less. They also found that the groundwater table contribution in supplying plant water requirements is at the end of growth season when the plant has completely grown and developed.

2. MATERIALS AND METHODS

Construction of Physical Model and Water Table Control

A polyethylene barrel, 90 cm in height and 55 cm in diameter was chosen as a lysimeter. A rubber valve was installed in the drainage water exit pipe at 90 cm from soil surface for connecting, disconnecting and controlling exit. The other head of this valve was connected to a piezometer pipe as shows in Figure 1, enabling water table observation at any time as well as controlling lysimeter water level. Eighteen treatments (6 treatments in 3 replications) were adopted.

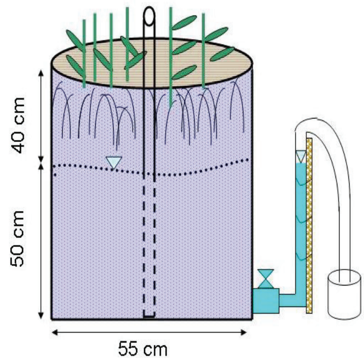

Fig. 1. Schematic of controlled drainage model (Schématique de drainage contrôlé modèle)

Since water table control is easier and quicker in coarse soil, in controlled drainage treatments lysimeters were filled with gravel up to 40 cm of the surface and then were filled by soil. To prevent soil particles entrance into the gravel bed below, two layers of burlap bags were used. Water table was stabilized at 40 cm in controlled drainage treatments with sorghum cultivation. By starting irrigation, rise and fall of water table before and after every irrigation event were read in each interval. To keep the water table stabilized, a valve was installed in drain exit place. For controlled drainage treatments, this valve was connected to a transparent vertical pipe of balance hose, which was connected to a wooden base and made it feasible to read the water table at any moment.

3. RESULTS AND DISCUSSION

The volume of irrigation was estimated based on NETWAT software data and provided to the plant in 2-day time intervals. Before starting application of treatments, equivalent irrigation was done in all lysimeters. After adjusting the water table and beginning application of treatments, 15 irrigations were made, the description of which are given in Tables 1 and 2.

Table 1. Irrigation depths in Free Drainage Treatments (des profondeurs d'irrigation dans traitements de drainage libre)

	irrigation(mm)																
Replication	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total	Average
FD 0.75-1	25	25	25	25	25	25	29	29	29	29	29	29	29	29	29	411	27.4
FD 0.75-2	25	25	25	25	25	25	29	29	29	29	29	29	29	29	29	411	27.4
FD 0.75-3	25	25	25	25	25	25	29	29	29	29	29	29	29	29	29	411	27.4
																1233	
FD 3.4-1	27	27	27	27	27	27	31	31	31	31	31	31	31	31	31	441	29.4
FD 3.4-2	27	27	27	27	27	27	31	31	31	31	31	31	31	31	31	441	29.4
FD 3.4-3	27	27	27	27	27	27	31	31	31	31	31	31	31	31	31	441	29.4
																1323	
FD 4.8-1	29	29	29	29	29	29	33	33	33	33	33	33	33	33	33	471	31.4
FD 4.8-2	29	29	29	29	29	29	33	33	33	33	33	33	33	33	33	471	31.4
FD 4.8-3	29	29	29	29	29	29	33	33	33	33	33	33	33	33	33	471	31.4
																1413	

Table 2. Irrigation depths in controlled drainage treatments (des profondeurs d'irrigation dans traitements de drainage contrôlé)

	irrigation(mm)																
Replication	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total	Average
CD 0.75-1	25	25	25	25	25	25	29	29	29	29	29	29	29	29	29	411	27.4
CD 0.75-2	25	25	25	25	25	25	29	29	29	29	29	29	29	29	29	411	27.4
CD 0.75-3	25	25	25	25	25	25	29	29	29	29	29	29	29	29	29	411	27.4
																1233	
CD 3.4-1	27	27	27	27	27	27	31	31	31	31	31	31	31	31	31	441	29.4
CD 3.4-2	27	27	27	27	27	27	31	31	31	31	31	31	31	31	31	441	29.4
CD 3.4-3	27	27	27	27	27	27	31	31	31	31	31	31	31	31	31	441	29.4
																1323	
CD 4.8-1	29	29	29	29	29	29	33	33	33	33	33	33	33	33	33	471	31.4
CD 4.8-2	29	29	29	29	29	29	33	33	33	33	33	33	33	33	33	471	31.4
CD 4.8-3	29	29	29	29	29	29	33	33	33	33	33	33	33	33	33	471	31.4
																1413	

In order to fix water level in controlled drainage treatments, water is added through a PVC pipe installed in middle of the lysimeter. During the growth season there were only four irrigations, and the water saved in soil profile through capillary rise was consumed by the plants (Table 3).

Table 3. Amounts of consuming water through Capillary Rising in Controlled Drainage Treatments (mm) (montants des consommation d'eau par remontées capillaires dans raitements de drainage contrôlé (mm))

Replication	1	2	3	4	Total	Average
CD 0.75-1	7.51	30.61	50.41	65.26	153.79	38.45
CD 0.75-2	61.96	38.86	38.86	33.91	173.59	43.4
CD 0.75-3	58.66	30.61	38.86	28.96	157.09	39.27
CD 3.4-1	43.81	43.81	37.21	32.26	157.09	39.27
CD 3.4-2	52.06	68.56	55.36	60.31	236.29	57.07
CD 3.4-3	83.41	61.96	61.96	57.01	264.34	66.09
CD 4.8-1	42.16	61.96	55.36	65.26	224.74	56.19
CD 4.8-2	32.26	52.06	48.76	43.81	176.89	44.22
CD 4.8-3	50.41	33.91	30.61	30.61	145.54	36.39

In controlled drainage treatments, due to proximity of water to the plant roots, we may possibly consider water consumption equivalent to potential evapotranspiration. Under deep water able and normal irrigation, there will be relative dryer soil moisture between irrigations when evapotranspiration will not take place at the potential rate. Table 4 shows that controlled drainage treatments have supplied almost one third of their water demand from shallow water table.

Table 4. Percent of water consumption through irrigation water and capillary rising in controlled drainage treatments (Percentage des consommation d'eau par l'eau d'irrigation de remontées capillaires dans raitements de drainage contrôlé)

treatments	Water consumption	
	Capillary rise	Irrigation Water
CD0.75	28.21%	71.79%
CD3.4	33.21%	66.79%
CD4.8	27.92%	72.09%

Crop Yield

Sorghum crop was harvested and the weight of total crop in each lysimeter was measured. Then by determining dry index, the amount of dry matter was calculated. Using MSTATC, treatments were statistically compared to each other. The results showed that water table control meaningfully has positive effect on crop yield and has led to yield increase.

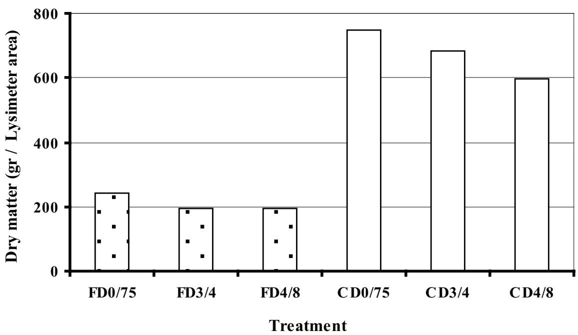

Fig. 2. Dry matter of crop in different treatments (matière sèche des cultures dans différents traitements)

As it is shown in Figure 2, the weight of dry matter is substantially higher in controlled drainage treatments. This shows that due to shallow water table and likelihood of water absorption in desired limit, growth was at potential level. In the other three cases, increase in irrigation water salinity has negatively influenced crop yield.

Water Use Efficiency (WUE)

By calculating total water consumption during plant growth period and crop yield, water use efficiency is evaluated in treatments. As it is observed in figure 3, water use efficiency in controlled drainage treatments is higher than free drainage conditions. On the other hand, water use efficiency showed a descending trend along with reduction of irrigation water quality. Readily access water in controlled drainage conditions is higher due to capillary rise and the plant has the potential of water absorption in potential rate.

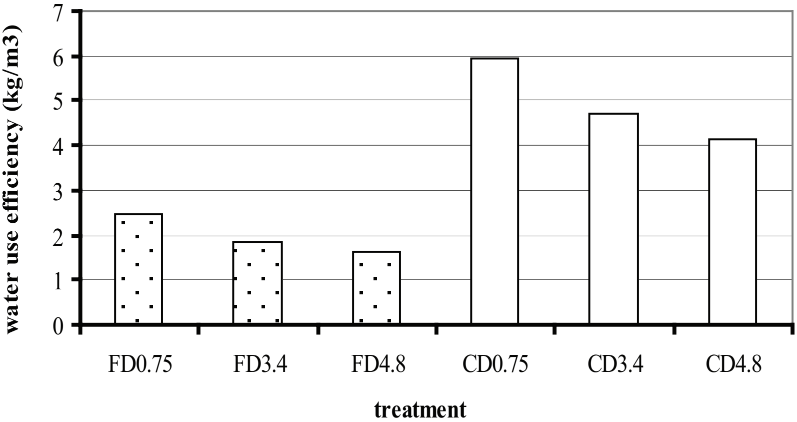

Fig. 3. Water use efficiency in different treatments (efficacité de l'utilisation de l'eau dans différents traitements)

In the meantime observations showed that salt accumulation in soil layers in controlled drainage conditions is higher than free drainage, which could negatively affect crop yield. But mutual effect of these two phenomena shows that the higher moisture condition in controlled drainage treatments has reduced the influence of salt accumulation in comparison to free drainage.

The result related to leaf-stem ratio in various treatments is shown in Figure 4. It can be seen that the leaf weight in both free and controlled drainage treatments is almost equal but stem weight is remarkably greater in CD treatments due to higher growth rate.

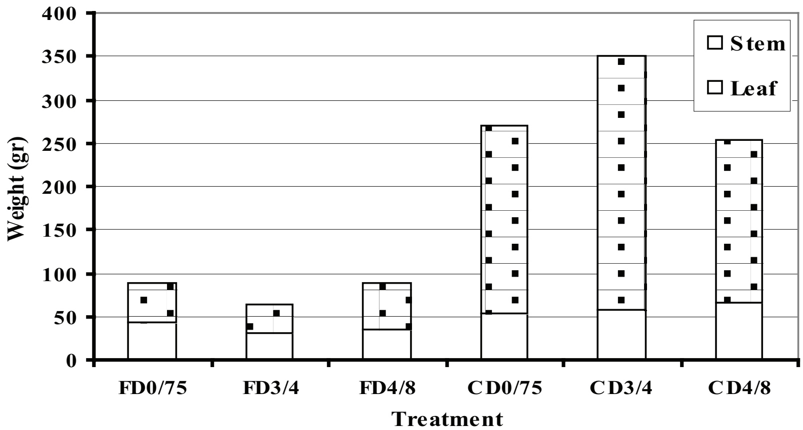

Fig. 4. Ratio of leaf and stem weight in different treatments (rapport des feuilles et des tiges de poids dans différents traitements)

It is obvious that the major part of water and nutrition is stored in leaf. Therefore water percentage that obtained from dry and wet weight difference shows that as ratio of leaf/stem increases, their water content percent will increase. This relationship is shown in figure 5.

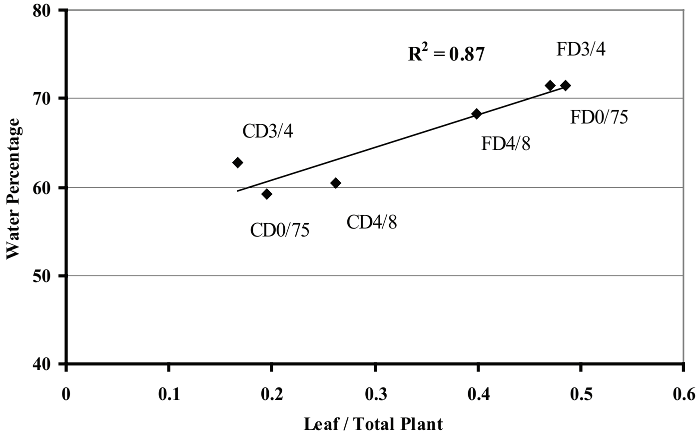

Fig. 5. Comparison of water percentage and ratio of leaf to total plant in different treatments (Comparaison du pourcentage d'eau des ratio de la feuille à l'ensemble des plantes dans différents traitements)

Regarding to qualitative and quantitative evaluation of yield, whereas quality of forage yield is assessed based on the amount of minerals in leaves, leaf weight is higher in controlled drainage treatments Therefore controlled drainage treatments are better option as concerns quality.

Salinity Changes in Controlled Drainage Soil Profile

Salinity in soil surface increased in controlled drainage treatments, although as irrigation water salinity increased, product decreased but salinity had no negative meaningful effect on crop yield. To explain this we can state that crop yield difference in free drainage and similar controlled drainage treatments is more related to water table than salinity. Also in controlled drainage, there is always an upward water flux from water table that has adjusted salinity to some extent in roots absorption area. These are shown in Figures 6 and 7.

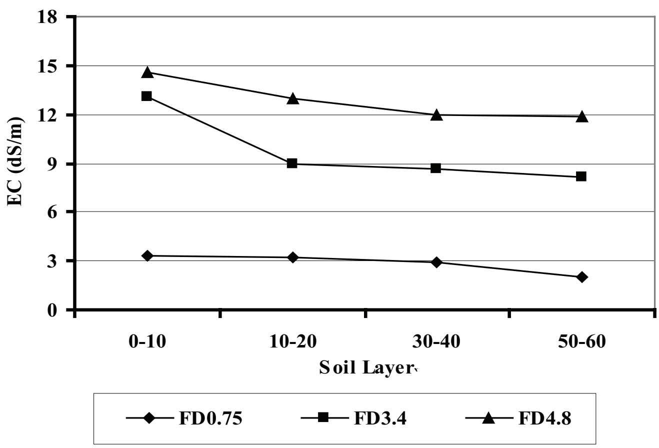

Fig. 6. Soil salinity in free drainage treatments (la salinité des sols dans traitement du drainage libre)

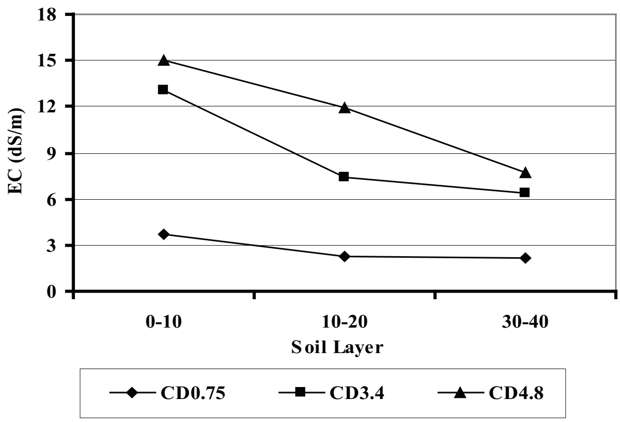

Fig. 7. Soil salinity in controlled drainage treatments ((la salinité des sols dans traitement du drainage contrôlé)

4. CONCLUSIONS

- Increase in amount of product in controlled drainage treatments compared to free drainage treatments, shows the influence of water table control methods.
- Unlike free drainage conditions in which soil moisture was supplied only through irrigation water and the plant would face lack of humidity in soil before next irrigation, regarding to supply of soil moisture through capillary rise, water absorption by plant has been reached to potential rate, which leads to double increase of yield.
- Results showed that controlled drainage treatments have supplied almost one third of their consumed water from water table, which is in fact drainage water.
- The mutual effect of water table and water salinity shows that higher humidity conditions in controlled drainage treatments have adjusted the influence of salts accumulation in comparison to free drainage conditions.

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