IMPACT OF IRRIGATION REGIME AND LAND LEVELLING ON INFILTRATION CHARACTERISTICS, WATER RELATIONS AND YIELD OF WHEAT AND CORN IN CLAY SOILS

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ABSTRACT

Field experiments were carried out during four successive winter and summer seasons at Sakha Agricultural Research Station, Kafr El-Sheikh, Egypt. These experiments aimed to evaluate the impact of border and furrow irrigation systems, under different land levelling practices, on infiltration characteristics of the soil, water relations and yield of wheat and corn. Experiments were arranged for each crop in split plot design with three replicates. Main plots were assigned to land levelling practices (dead and traditional levelling), while the subplot treatments were the continuous flow irrigation and four cycle ratios of surge flow irrigation.

Obtained data showed that water infiltration rate of the soil is reduced and bulk density of surface layers increased using surge flow irrigation. This was more pronounced under the dead levelling than under the traditional one. Reducing infiltration rate with surge flow irrigation was advantageous in several aspects. Surge flow irrigation, especially under dead levelling, gave lower water advance times, lower amounts of applied water, higher water application efficiency and higher water distribution efficiency than that continuous flow irrigation. Average values of water distribution efficiency (WDE) under continuous flow irrigation were 75.4 and 71.5% for wheat, 85.4 and 77.1% for corn under dead and traditional land levelling respectively. Corresponding values for surge flow irrigation varied for wheat from 78.8 to 90.6% and from 72.4 to 84.3%: and for corn varied from 87.5 to 95.3% and from 79.4 to 90.4%, respectively.

Results revealed also that the values of water consumptive use of wheat and corn, were higher for continuous flow irrigation than that for surge flow one. The water consumptive use is reduced with increasing the off-time in surge flow irrigation. The mean grain yield under surge flow irrigation varied from 2.25 to 2.76 ton/fed for wheat, and from 3.03 to 3.60 ton/fed for corn. The corresponding values under continuous flow irrigation, were 2.38 ton/fed for wheat and 3.0 ton/fed for corn. The dead levelling achieved higher grain yield (for both wheat and corn) than that traditional levelling. The average values of water utilization efficiency for continuous flow irrigation for wheat, were 0.78 and 0.61 Kg/m^3, and for corn were 0.90 and 0.75 Kg/m^3, under dead and traditional land levelling, respectively. The corresponding values for surge flow treatments varied from 0.82 to 1.21 Kg/m^3, and from 0.62 to 0.85 Kg/m^3

for wheat; and from 1.03 to 1.46 and from 0.80 to 1.14 Kg/m^3 for corn, respectively. Effective water management could be achieved using surge flow irrigation in clay soils. For all the studied parameters, the surge flow irrigation with cycle ratio of 0.5 (20 min. on and 20 min. off) gave the best results.

Key words: Infiltration- clay soils- border and furrow irrigation- surge flow irrigation- land levelling- irrigation efficiency- crop yield.

INTRODUCTION

For an efficient soil water management under irrigated land agriculture, knowledge of the soil physical properties and the infiltration characteristics under different irrigation regimes is of vital importance. Surface flooding irrigation, by borders and furrows, is still the most widely used irrigation method in clay soils of Nile Delta. Over years, many researches have been carried out to improve the efficiency of surface irrigation. Land smoothing, cutback technology and tail water reuse, along with proper irrigation scheduling, are used to reduce water losses and increasing water use efficiency.

The latest improved surface irrigation method, is through surge flow irrigation (James, 1988). Surge flow irrigation is the intermittent application of irrigation water to borders or furrows in a series of surges of constant or variable duration. Such method of irrigation was suggested to allow further advance of water, to reduce the infiltrated water through soil and to achieve better soil moisture distribution uniformity (Humphreys, 1989). The present study was carried out, on clay soils of northern Nile Delta, to evaluate the impact of continuous flow irrigation and surge flow irrigation with different cycle ratios , under different land leveling practices, on :

- Soil physical properties, especially the infiltration characteristics;
- Water relations and yield of wheat and corn.

The study aimed also to define the best surge flow irrigation practices for wheat and corn crops owing to optimize the water utilization efficiency.

MATERIALS AND METHODS

Field experiments were carried out at Sakha Agricultural Research Station, Kafr El-Sheikh Governorate, northern Nile Delta, during four successive winter and summer seasons. The soil of the experimental site is non-saline and clayey in texture. Some physical and chemical characteristics of the experimental soil are given in table (1). Wheat (*Triticum aestivum* L.) as winter crop followed by corn (*Zea mays* L.) as summer crop were sown in an agricultural rotation. This rotation was repeated for two years (1996 and 1997). All cultural practices were the same as recommended for the area, except the levelling and the irrigation treatments under study. The experiment was arranged in split plot design, for each crop, with three replicates. Each plot was 3.5 x 80 m= 280 m^2 = 1/15 feddan). Eight stations (S_1 to S_8) were arranged

Table 1: Physical and chemical characteristics of the soil of the experimental site.

Soil Depth	Particle size Distribution			Bulk density	FC W%	PWP w%	EC_e	Cation c mole/kg soil				Anion c mole/kg soil			pH
	Sand	Silt	Clay	Mg/m^3			dS/m	Na^+	K^+	Ca^{++}	Mg^{++}	HCO_3^-	Cl^-	$SO_4^=$	
0-15	15.18	18.85	65.97	1.09	47.2	25.38	1.50	0.76	0.02	0.30	0.10	0.55	0.21	0.46	8.15
15-30	19.90	13.80	66.30	1.15	40.5	21.85	1.57	0.79	0.02	0.31	0.10	0.57	0.22	0.48	8.00
30-45	16.59	16.97	66.94	1.24	39.0	21.19	1.65	0.89	0.02	0.34	0.10	0.65	0.23	0.50	8.00
45-60	12.65	15.24	67.12	1.26	38.5	20.81	2.78	1.25	0.03	0.84	0.27	0.45	0.23	1.71	7.90

every 10 m along the border (for wheat) and the furrow (for corn), to measure the flow advance pattern. The treatments were as follows:

Main treatment (land levelling):

A. Dead levelling (0.0%) B.Traditional method of land levelling.

Sub treatments: five irrigation treatments were applied after sowing:

Ir1: Represent a continuous flow irrigation (control),

Ir2: Surge irrigation with cycle ratio of 0.8 (20 min on and 5 min off),

Ir3: Surge irrigation with cycle ratio of 0.67 (20 min on and 10 min off),

Ir4: Surge irrigation with cycle ratio of 0.57 (20 min on and 15 min off), and

Ir5: Surge irrigation with cycle ratio of 0.5 (20 min on and 20 min off).

Irrigation intervals were twenty one days, after the first post irrigation (El-Mohaya) for the winter crop (wheat), while they were 15 days for the summer crop (corn). The cycle ratios were chosen according to the possible applicability. The amount of water in each application was added whatever number of surges needed until reaching 95% of the run length (75 m). The irrigation water was conveyed to the experimental plots through an open channel, using a centrifugal pump, with a water meter to measure the total volume of applied water. The inflow rate was about 5.4 L/sec. The advance time of the water flowing in border and furrow of each treatment was recorded, when the water front was reached each station, along the border or furrow. The on-off cycle time was controlled by means of stop watch. The number of surges needed until the water reached 95% of the border or furrow length were recorded, and the irrigation time was determined. The applied irrigation water to each experimental plot was measured using spile tubes. The effective head of water above the cross section center of irrigation spile was measured several times during irrigation, the averaged value was 6 cm. Water in the canal was controlled to maintain a constant head, by means of fixed sliding type gates.

The amount of water delivered through a spile of 10 cm inner diameter was calculated by the equation: $q = CA$

Where: q = Discharge rate of irrigation water (L/sec),

C = Coefficient of discharge = 0.64 according to Osman 1991, g = Gravity acceleration, 980 cm/S^2, A = Inner cross section area of irrigation spile,

h = Average effective head,cm; D = Inside diameter of the spile tube, cm.

The volume of water for each strip (3.5 x 80 = 280 m^2) was calculated by substituting Q in the following equation: **Q = q x T x n**

Where: Q = Water volume m^3/strip, q = Discharge rate m^3/min, T = Total time of irrigation (min) and n = Number of spile tube per each strip.

The total on-time under continuos and surge flow irrigation was calculated using a stop watch. To evaluate the flow advance rate for different treatments the approach of Christiansen *et al.*, 1966 was used as: $L = a\ t^b$

In which: L = Length of advance, t = Time of advance, a and b = Empirical constants.

Soil samples were taken from five selected stations along the border or furrow of two replicates, before and 2 days after each irrigation and immediately before harvesting, from four depths (0-15, 15-30, 30-45, 45-60 cm). Their moisture content on the dry weight basis were determined. Soil moisture depletion (SMD) for the 60 cm top soil (or actual water consumptive use) was computed for all irrigations, from planting up to harvest, according to Hansen et al. (1979)

For border irrigation of wheat, infiltration rate was determined using double cylinder infiltrometer. While, for furrow irrigation of corn, blocked furrow infiltrometer was used, as described by Garcia (1978) and Michael (1978). The measurements were taken at three sites (20, 40 and 60 m) along the borders or furrows in three replicates for each treatment. The infiltration rate was calculated using Kostiakov equation (Garcia, 1978): $I = k\ t^n$

Where: I = Infiltration rate; t = Infiltration time; k and n = Empirical constants.

At the end of each season, undisturbed soil samples were collected using cores under each treatment from the successive soil depths 0-15, 15-30, 30-45 and 45-60 cm. The soil bulk density was determined according to Vomocil (1957). After harvesting the grain yield of wheat and corn were determined. Water application efficiency (WAE) was calculated according to Michael (1978). Water distribution efficiency (WDE) was calculated according to James (1988). The water utilization efficiency was calculated according to Michael (1978) as follows: $WU_tE = Y/Wa$

In which: WU_tE = Water utilization efficiency (kg/m^3),

Y = Total yield produced kg/fed., and Wa = Total applied water m^3/fed.

The collected data for grain yield were subjected to the statistical analysis according to Snedecor and Cochran (1967) and the mean values were compared by L.S.D. test and Duncan multiple range test (DMRT) according to Duncan, 1955. Regression analyses were done for the relation between infiltration rate and some studied parameters (soil bulk density, water advance time and speed, water consumptive use and water application efficiency). Correlation coefficients were calculated according to the method given by Snedecor and Cochran (1967).

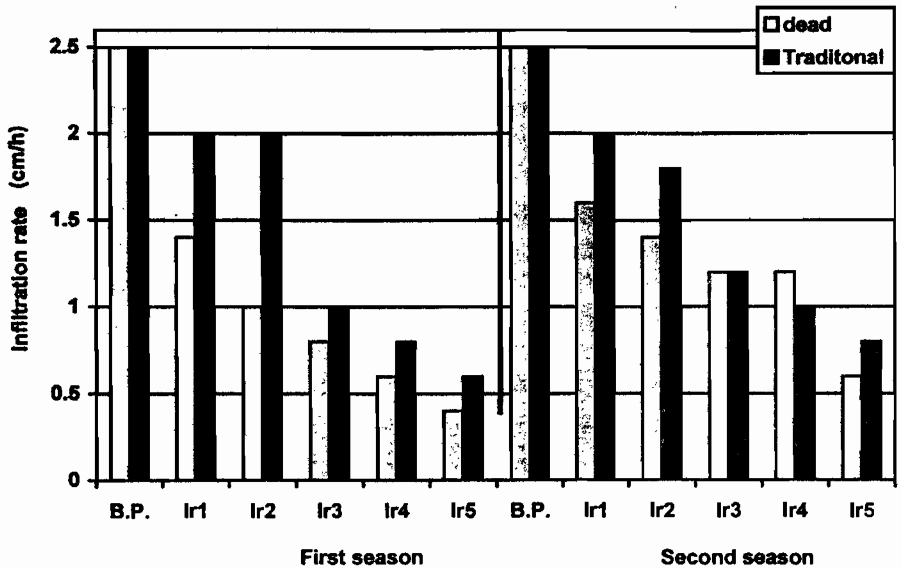
RESULTS AND DISCUSSION

1. Infiltration rate (IR):

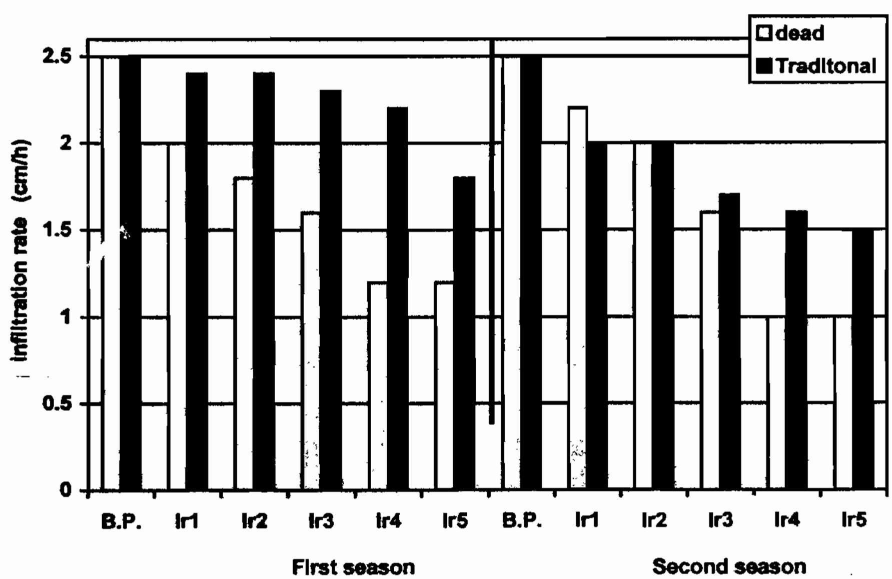
Infiltration rate decreased with time until it nearly reached the basic infiltration rate (IR) of the soil. The basic IR of the experimental site before planting was 2.5 cm/h. Fig. (1) illustrates the data of basic IR after harvesting the crop. These data indicated that basic IR values after harvesting of the crop were lower than that before planting. Surge flow treatments reduced the basic IR compared with the continuous irrigation due to the intermittent wetting and dewatering process. Mechanisms by which surge flow irrigation reduce the infiltration rates include: (a) air entrapment between successive rewetting (Izadi *et al.*, 1995 and El-Amir, 1991), (b) a combination of surface sealing and consolidation of the soil matrix near the surface (Samani *et al.*, 1985; El-Amir, 1991 and Trout, 1991) and (c) reduction of the hydraulic gradient within the soil surface layer (Coolidge *et al.*, 1982). The data collected, also, indicated that basic IR decreased with the increasing of the off-time. The lowest basic IR of 0.4-0.6 cm/h was recorded under treatment Ir5 after wheat harvesting and 1.0-1.2 cm/h after corn harvesting. Trends of these results are in agreement with those of Guirguis (1988). Regarding the effect of land levelling on the basic IR, data illustrated in Fig (1) indicated that dead levelling treatment reduced the basic IR markedly, compared with the traditional one under both continuous and surge flow irrigation treatments. This means that the precision land levelling (dead level 0.0%) altered the infiltration opportunities. This may be attributed to smoothing the soil surface, destroy the macropores and soil compaction due to the heavy machine used to implement the land levelling.

Results showed that the values of cumulative infiltration (Cum.I), for both continuous and surge flow treatments, reduced with the reducing of the distance from water inlet, especially under dead levelling (Figs. 2 and 3). This could be attributed to the greater number of surges at the head than that at the end of border or furrow. The reduction of Cum.I at the head was more pronounced for continuous flow compared with surge flow irrigation treatments. This is due to the more uniformity water distribution along the border or furrow under surge flow irrigation, whereas water content is greater at the head than that at the tail of the field under the continuous irrigation. Coolidge *et al.* (1982) reported the same trend of results.

Finally, it was noticed that both basic IR and Cum.I values differed from one season to another. This could be attributed to that infiltration characteristics vary with many factors such as, water depth on the soil surface, water and soil temperature, surface permeability, soil structure and texture, moisture content of soil and degree of swelling of soil colloids (Israelson and Hansen, 1962 and Hillel, 1971). Generally, the Cum.I values after winter crop



Wheat



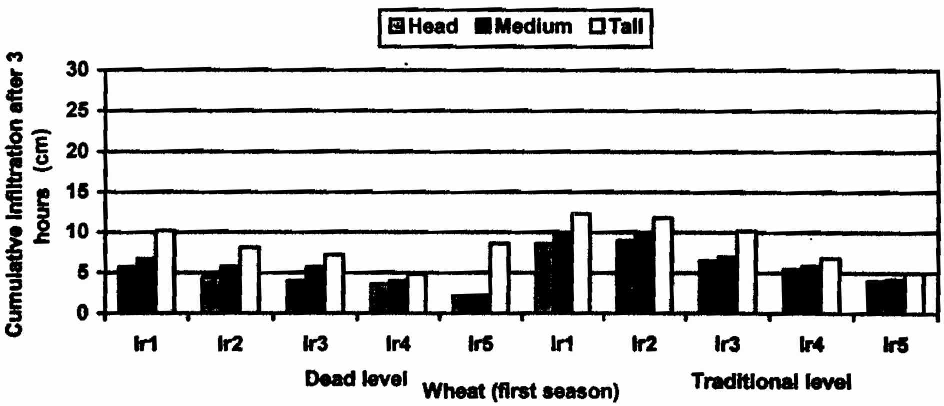
Corn

Fig. 1: Basic infiltration rates under different irrigation treatments after the harvesting of wheat and corn crops and before soil preparation (B.P.).

(wheat) were lower than that obtained for summer season crop (corn). This may be due to the effect of cropping system, with different rooting systems, on the aggregates formation and degeneration (Omar, 1983).

2. Soil bulk density:

Values of bulk density under different treatments are presented in Tables (2 and 3). Bulk density increased with the increasing of soil depth. Surge flow irrigation increased the values of soil bulk density particularly in surface layer, the values increased with increasing of the off- time. On the other hand, the increase of bulk density values was more pronounced under the dead levelling than under the traditional one. The highest increase was obtained under the treatment of Ir5 (20 min on and 20 min off). Mean values, for the two seasons after harvesting the wheat crop (table 2), were 1.205 and 1.16 Mg/m^3 for dead and traditional levelling, respectively under continuous irrigation. The corresponding values for the surge flow irrigation treatments varied from 1.205 to 1.34 Mg/m^3 and from 1.20 to 1.31 Mg/m^3, respectively.



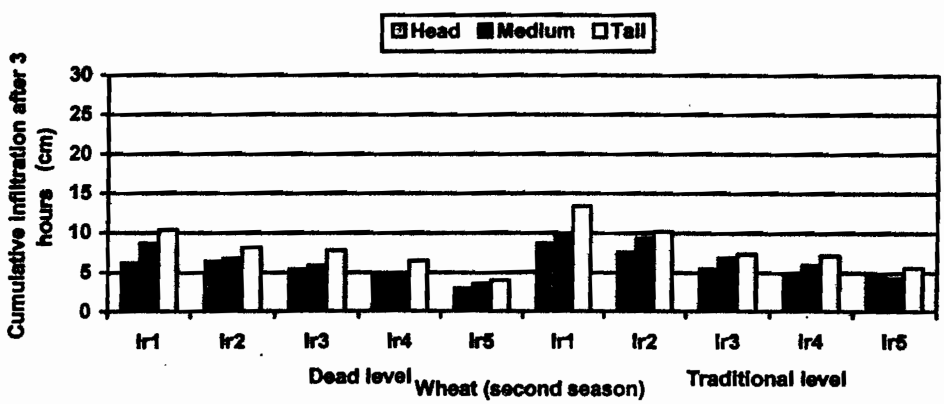


Fig. 2: Cumulative infiltration after 3 hr at different sites along the border at the end of wheat season under dead levelling and traditional levelling.

Concerning the bulk density after harvesting the corn crop, data in table (3) showed that mean values of the bulk density under continuous irrigation were 1.24 and 1.18 Mg/m^3 for dead and traditional levelling, respectively. Corresponding values for the surge flow irrigation varied from 1.26 to 1.32 with an average of 1.29 Mg/m^3 and from 1.22 to 1.30, with an average of 1.25 Mg/m^3, respectively. Such increase of bulk density under surge flow irrigation, could be attributed to the consolidation of the previously wetted soil, which takes place during the off-time. These results are in harmony with those previously obtained for the infiltration rate. Samani *et al.*(1985), Farahani *et al.* (1990) and El-Amir (1991) reported the same trend of the results. In this

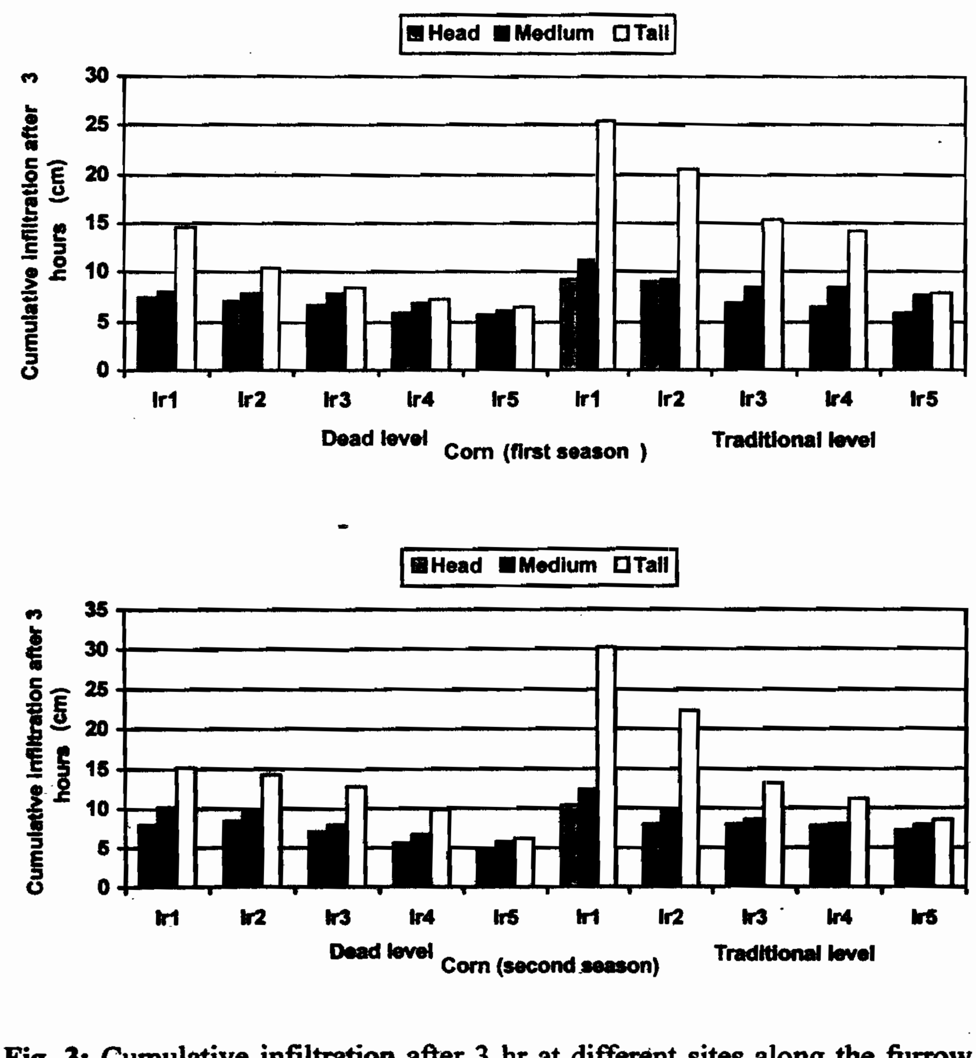


Fig. 3: Cumulative infiltration after 3 hr at different sites along the furrow at the end of corn season under dead levelling and traditional levelling.

Table (2): Bulk density values in Mg/m^3 for different irrigation and land levelling treatments under wheat during the two growing seasons.

Depth Cm	Dead levelling					Traditional levelling				
	Ir1	Ir2	Ir3	Ir4	Ir5	Ir1	Ir2	Ir3	Ir4	Ir5
	At the end of the first season									
0-15	1.13	1.13	1.16	1.32	1.35	1.03	1.21	1.20	1.26	1.30
15-30	1.16	1.17	1.26	1.31	1.41	1.11	1.11	1.14	1.30	1.32
30-45	1.24	1.24	1.25	1.31	1.32	1.15	1.25	1.24	1.30	1.31
45-60	1.29	1.29	1.29	1.32	1.30	1.32	1.29	1.26	1.30	1.32
0-60	1.21	1.21	1.24	1.31	1.34	1.15	1.20	1.21	1.29	1.31
	At the end of the second season									
0-15	1.20	1.20	1.22	1.20	1.24	1.10	1.06	1.10	1.12	1.20
15-30	1.12	1.16	1.18	1.20	1.25	1.12	1.12	1.20	1.22	1.26
30-45	1.25	1.22	1.25	1.30	1.33	1.15	1.22	1.23	1.25	1.32
45-60	1.24	1.23	1.24	1.32	1.33	1.32	1.33	1.34	1.33	1.33
0-60	1.20	1.20	1.22	1.25	1.29	1.17	1.20	1.21	1.23	1.278
Average	1 .205	1.205	1.23	1.28	1.31	1.16	1.20	1.21	1.26	1.29

Table (3): Bulk density values in Mg/m^3 for different irrigation and land levelling treatments under corn during the two growing seasons.

Depth Cm	Dead levelling					Traditional levelling				
	Ir1	Ir2	Ir3	Ir4	Ir5	Ir1	Ir2	Ir3	Ir4	Ir5
	At the end of the first season									
0-15	1.20	1.16	1.18	1.20	1.32	1.06	1.13	1.17	1.20	1.25
15-30	1.20	1.25	1.26	1.28	1.31	1.19	1.28	1.25	1.26	1.32
30-45	1.31	1.33	1.32	1.30	1.31	1.23	1.25	1.30	1.31	1.33
45-60	1.31	1.33	1.33	1.32	1.32	1.32	1.34	1.33	1.32	1.30
0-60	1.25	1.27	1.29	1.30	1.31	1.20	1.25	1.26	1.27	1.30
	At the end of the second season									
0-15	1.20	1.20	1.18	1.25	1.30	1.10	1.06	1.12	1.20	1.24
15-30	1.18	1.20	1.23	1.30	1.40	1.10	1.16	1.22	1.22	1.28
30-45	1.27	1.30	1.31	1.35	1.33	1.17	1.25	1.23	1.28	1.30
45-60	1.31	1.32	1.34	1.35	1.35	1.32	1.33	1.34	1.30	1.33
0-60	1.24	1.26	1.27	1.31	1.34	1.17	1.20	1.22	1.25	1.28
Average	1.24	1.26	1.28	1.30	1.32	1.18	1.22	1.24	1.26	1.29

concern, Si-Tusong *et al.* (1994) reported that under surge irrigation, infiltration rate reduced, bulk density increased and roughness decreased as soil clods partially dissolved and formed a silty, slick surface. In other words, increasing the bulk density and reduction in infiltration rate, under surge or intermittent flow, is attributed to the increase of aggregates breakdown and of sediment erosion and deposition.

3. Flow advance (time and speed):

Surge flow treatments had lower advance time and higher water advance speed, either under dead or traditional levelling, compared with the continuous flow irrigation treatments. The water advance speed increased with decreasing the cycle ratio and was higher under dead levelling than under the traditional levelling treatments (tables 4 and 5). The mean time required for water advance to reach the end of the border (for wheat) varied from 72.3 to 109.3 min and from 97.5 to 130 min for surge flow treatments, under dead and traditional levelling respectively. Corresponding values for the continuous flow were 115 and 139.7 min, respectively. While for corn, the mean time required for water advance to reach the end of the furrow varied from 64.3 to 87.6 min and from 85.6 to 106.3 min for surge flow treatments, under dead and traditional levelling respectively. The corresponding values for the continuous flow were 97.3 and 115.2 min, respectively.

Table (4): Irrigation time, speed of advance, volume of applied water, water application efficiency (WAE), water consumptive use (WCU) and water utilization efficiency WUtE) for border irrigation of wheat.

Season	Treat.	Irrig. time (min)	Speed of advance (m/min)	Applied water M^3/fed	WUC m^3/fed	WAE %	WDE %	WUtE Kg/m^3
First	A* Ir1	114.5	0.66	2877	1696.8	60.4	73.5	0.77
	Ir2	109.5	0.68	2709	1646.4	64.4	78.8	0.82
	Ir3	91	0.82	2427.6	1570.8	69	80.5	0.91
	Ir4	82	0.91	2230.2	1478.4	72	84.2	1.02
	Ir5	75.5	0.99	2091.6	1348.2	81	86.6	1.12
	B** Ir1	138.3	0.54	3499.4	1780.8	55.8	70.2	0.62
	Ir2	130	0.58	3318	1696.8	56	72.4	0.62
	Ir3	120.3	0.62	3154.2	1604.4	58.9	76.6	0.65
	Ir4	111.3	0.67	2973.6	1528.8	61.5	80.1	0.74
	Ir5	100.5	0.75	2759.4	1436.4	64.3	82.4	0.78
Second	A* Ir1	115.5	0.65	2923.2	1604.4	58.9	77.3	0.80
	Ir2	107.5	0.70	2772	1570.8	62.8	80.4	0.85
	Ir3	89.3	0.84	2410.8	1520.4	72.1	83.8	0.97
	Ir4	76.5	0.98	2179.8	1402.8	76.6	86.8	1.11
	Ir5	72.3	1.04	2070.6	1276.8	80.3	90.6	1.21
	B** Ir1	141	0.53	3532.2	1856.4	54.5	72.8	0.61
	Ir2	125.8	0.60	3267.6	1822.8	55.2	74.8	0.66
	Ir3	111.5	0.67	2981	1780.8	59.9	78.8	0.72
	Ir4	104.3	0.72	2847.6	1612.8	64.4	82.4	0.79
	Ir5	97.5	0.77	2717.4	1528.8	68.5	84.3	0.85

A* = Dead levelling B** = Traditional levelling

Table (5): Irrigation time, speed of advance, volume of applied water, water application efficiency (WAE), water consumptive use (WCU) and water utilization efficiency WUtE) for furrow irrigation of corn.

Season	Treat.	Irrig. time (min)	Speed of advance (m/min)	Applied water M^3/fed	WUC m^3/fed	WAE %	WDE %	WUtE) Kg/m^3
First	A* Ir1	97.8	0.77	3435.6	2175.6	64.8	84.4	0.91
	Ir2	87.6	0.86	3137.4	2028.6	67.5	87.5	1.03
	Ir3	81.5	0.92	2952.6	1955.5	70.5	91	1.13
	Ir4	75.5	0.99	2780.4	1867.7	74.6	92.6	1.25
	Ir5	68	1.09	2585	1790	83.3	94.6	1.39
	B** Ir1	116.2	0.65	4082.4	2293.2	52	75.5	0.73
	Ir2	106.3	0.71	3780	2209.2	54	79.4	0.80
	Ir3	96.2	0.78	3465	2024.4	60.6	83.4	0.91
	Ir4	89.8	0.84	3288.6	1948.8	65.5	86.3	0.99
	Ir5	85.6	0.88	3133.2	1915.2	72.8	89.9	1.07
Second	A* Ir1	96.8	0.77	3368.4	2070.6	61.3	86.3	0.90
	Ir2	85	0.88	3011.4	1999.2	69.6	88.5	1.04
	Ir3	77	0.97	2713.2	1902.6	70.8	93.2	1.15
	Ir4	70.5	1.06	2423.9	1814.4	75.3	94.6	1.33
	Ir5	64.3	1.17	2310	1705.2	85	95.3	1.46
	B** Ir1	114.2	0.66	3544.8	2200.8	51	78.6	0.78
	Ir2	105.8	0.71	3259.2	2116.8	53.5	79.8	0.86
	Ir3	99.2	0.76	3057.6	1986.6	63.7	84.6	0.96
	Ir4	93.3	0.80	2818.2	1906.8	67.3	86.2	1.05
	Ir5	85.8	0.87	2675.4	1898.4	74	90.4	1.14

A* = Dead levelling B** = Traditional levelling

Advance times in relation to the distances from water inlet were plotted for all treatments. A typical advance data are presented in Fig. (4) for surge furrow irrigation for corn under dead leveling. The irrigation is completed faster when surge flow irrigation technique is used. Such saving of irrigation time under surge flow was mainly because of the faster water advance rate, due to lower infiltration rate. The best treatment was that of 0.5 cycle ratio (Ir5, 20 min on and 20 min off). Increasing the off-time in surge flow reduced infiltration rate and resulted in greater advance on wetted area. The trend of these results is in accordance with those obtained by Goldhamer et al. (1987), Guirguis (1988), Moustafa (1992) and Osman *et al.* (1996). Data in Fig. (4) showed also that, the greatest reductions in advance time with surge flow irrigation were observed during the first irrigation (Fig. 4 A), while advance time was less variable in the subsequent irrigation (last irrigation, Fig. 4 B). These results are similar to those obtained by Oyonarte et al. (2002).

4. Soil moisture depletion (SMD):

Average percentages of soil moisture depletion from different soil layers are given in table (6) for wheat and in table (7) for corn. Data indicated that most of water consumed by wheat and corn was removed from the surface soil layer (0-15 cm) then decreased with soil depth. Such trend was common for all treatments. The water extraction from the upper 15 cm soil layer was high under the continuous flow treatment than those under surge flow treatments. This may be as a result of excess irrigation water added to continuous flow treatment and due to higher evaporation from soil surface. The opposite trend was observed for the deepest soil layer (45-60 cm). Deepest soil layers had relatively higher values of SMD under surge flow than that under continuous flow irrigation, this may be attributed to the good aeration which is expected in the case of surge flow irrigation. These results are in agreement with those of Ghalleb (1987). In this concern, Ibrahim (1999) reported that more water was depleted by wheat, grown in clay soils at North Nile Delta,

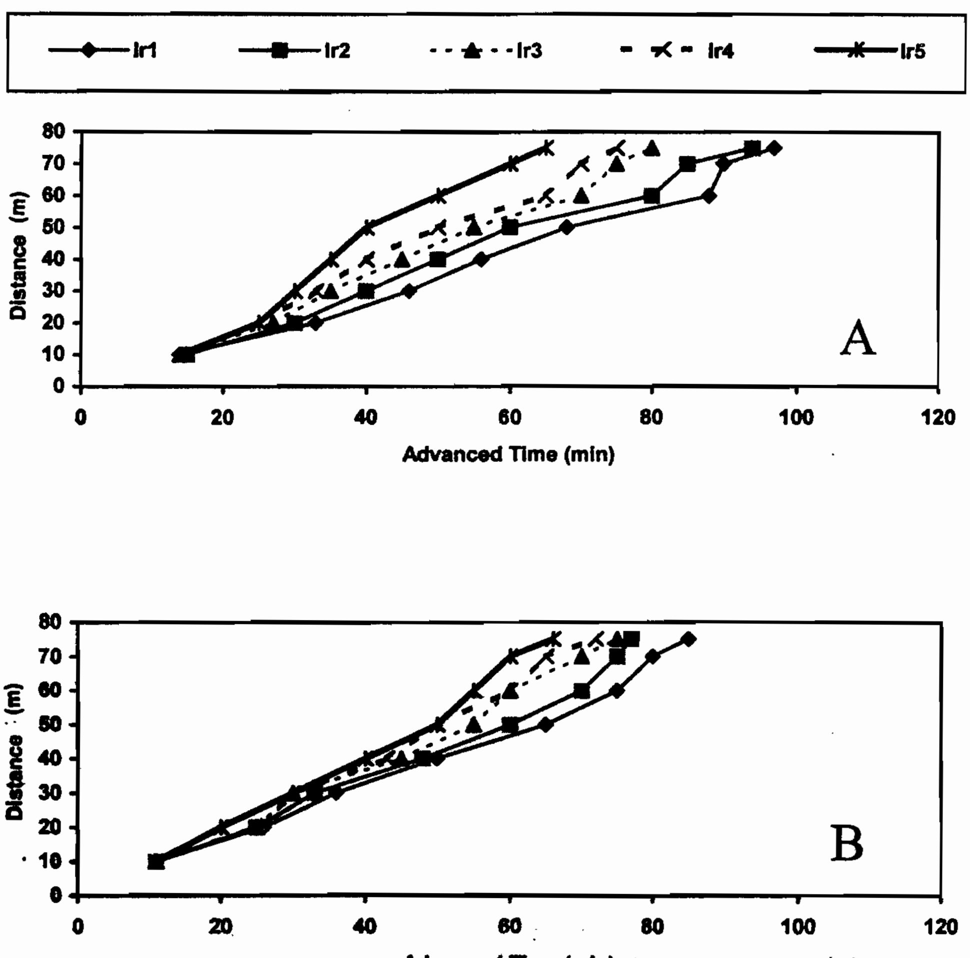


Fig. 4: Advance time for the first (A) and last (B) irrigation runs for different irrigation treatments for corn under dead levelling during the second growing season.

from the lower soil depth (45-60 cm) under limited irrigation. Water table contribution to wheat water requirement increased from about 10% to 20% and 37% for four, three and two irrigation treatments, respectively.

Table (6): Average percentage of soil moisture depletion by wheat roots for different soil layers during the two growing seasons.

Levelling	Cycle On	Cycle Off	0-15 First	0-15 Second	15-30 First	15-30 Second	30-45 First	30-45 Second	45-60 First	45-60 Second
Dead Levelling	Cont.	0	45.6	45.8	25.4	25.3	19.0	18.7	10.0	10.2
	20	5	44.3	42.4	26.3	27.8	19.4	19.4	10.0	10.4
	20	10	41.2	40.3	20.3	29.6	19.4	18.5	9.1	11.6
	20	15	40.3	39.9	30.4	30.8	18.4	15.5	10.9	13.8
	20	20	38.7	39.6	32.5	30.9	15.3	15.5	13.5	14.0
Traditional Levelling	Cont.	0	48.6	48.6	22.3	22.8	20.4	17.2	8.7	11.4
	20	5	45.8	46.3	25.4	24.6	19.8	18.9	9.0	10.2
	20	10	42.6	43.2	28.7	26.3	20.8	17.9	7.9	12.6
	20	15	42.3	43.2	28.4	28.3	19.9	15.3	9.4	13.2
	20	20	40.6	42.6	30.6	29.6	18.3	15.2	10.5	12.6

Table (7): Average percentage of soil moisture depletion by corn roots for different soil layers during the two growing seasons.

Levelling	Cycle On	Cycle Off	0-15 First	0-15 Second	15-30 First	15-30 Second	30-45 First	30-45 Second	45-60 First	45-60 Second
Dead Levelling	Cont.	0	50.8	48.7	25.8	24.3	19.0	18.3	4.4	8.7
	20	5	50.7	48.7	26.3	25.6	19.4	18.7	3.6	7.0
	20	10	49.3	49.1	24.3	23.3	21.4	20.5	5.0	7.1
	20	15	46.9	45.6	23.4	22.8	21.4	20.9	8.3	10.7
	20	20	46.3	44.5	22.3	26.3	20.0	19.2	11.4	10.0
Traditional Levelling	Cont.	0	52.6	50.4	20.3	22.9	20.4	19.5	6.7	7.2
	20	5	50.8	48.7	21.4	25.3	19.8	19.0	8.0	7.0
	20	10	50.6	49.2	22.4	23.3	20.8	19.8	6.2	7.7
	20	15	49.3	48.6	23.4	25.4	19.9	20.2	7.4	5.8
	20	20	48.6	48.0	24.6	22.9	19.3	21.2	7.5	7.9

5. Applied irrigation water and water consumptive use (WCU):

The amount of the applied water to each treatments are given in tables (4 and 5). Total amount of applied water varied according to the differences in irrigation treatments. All tested cycle ratios of surge treatments used less amount of water than that continuous one. Surge flow irrigation of wheat saved water, on average for all treatments, by about 17% and 14% of the continuous flow irrigation, under dead and traditional levelling, respectively. The corresponding values for corn were 19.1% and 16.5%, respectively. The best treatment in saving water was that of Ir5. Trends of these results are in accordance with those obtained by Ghalleb (1987) and Osman (1991). On the other hand, the soil under traditional method of land levelling received higher amount of irrigation water than that under dead levelling. These results are in a harmony with those obtained by El-Mowelhi *et al.* (1995).

As shown in tables (4 and 5) values of water consumptive use (WCU) for wheat varied from 1276.8 to 1646.4 m^3/fed and from 1436.4 to 1822.8 m^3/fed for the surge flow irrigation treatments under dead and traditional levelling, respectively. The corresponding values for the continuous irrigation treatment were 1650.6 and 1818.6 m^3/fed, respectively. The values of WCU for corn varied from 1705.2 to 2028.6 m^3/fed and from 1898.4 to 2209.2 m^3/fed for surge flow irrigation treatments under dead and traditional levelling, respectively. The corresponding values for the continuous irrigation treatment were 2123.1 and 2247 m^3/fed, respectively. Increasing the off-time in surge flow results in reducing the water consumptive use of wheat and corn. The tendency of these results are in agreement with those obtained by Musick *et al.* (1987) and Ghalleb (1987). The surge flow treatments Ir5 recorded the lowest values of WCU; average of 1312.5 and 1482.6 m^3/fed for wheat, 1747.6 and 1906.8 m^3/fed for corn; under the dead and traditional levelling, respectively.

6. Water application efficiency (WAE) and water distribution efficiency (WDE):

Surge flow irrigation had higher values of water application efficiency (WAE) compared with the continuous flow irrigation (tables 4 and 5). The mean WAE values for continuous flow irrigation of wheat were 59.7% and 55.2%, under dead and traditional levelling, respectively. Corresponding values for surge flow irrigation treatments varied from 62.8% to 81%, and from 55.2% to 68.5%, respectively. While mean WAE values for continuous flow irrigation of corn were 63.1% and 51.5%, under dead and traditional levelling, respectively. The corresponding values for surge flow irrigation treatments varied from 67.5% to 85%, and from 53.5% to 74%, respectively. The high efficiency of surge flow irrigation can be attributed to the surface sealing that caused by the intermitted wetting and the decrease of surface hydraulic roughness of the wet advance (Guirguis ,1988). It was found that WAE increased with the decrease of the cycle ratio or the increase of off-time. The best treatment was that of 0.5 cycle ratio (Ir5). It had the highest value of

80.7% and 66.4% for wheat and of 84% and 73% for corn as average of the two seasons, under dead and traditional levelling, respectively.

Surge flow technique, for wheat and corn, recorded also higher values of water distribution efficiency (WDE), compared with continuous flow irrigation, either under dead or traditional levelling (tables 4 and 5). It was found that WDE values increased whenever the cycle ratio decreased. The best treatment was that of 0.5 cycle ratio (Ir5). It had the highest values of 88.6 and 83.4% for wheat, 94.7% and 90.2% for corn under dead and traditional levelling, respectively. Trends of these data are in agreement with those obtained by Moustafa (1992) and Evans *et al.* (1995) who mentioned that use of surge flow was superior to continuous flow furrow irrigation for maintaining acceptable application uniformity.

Regression analyses showed a negative significant relation between infiltration rate and soil bulk density of surface layer, 0-15 cm (table 8). Also, negative significant correlation was found between infiltration rate and each of water advance speed and water application efficiency. While a positive significant relation was obtained between infiltration rate and both of water advance time and water consumptive use. These data reveal that, reducing infiltration rate with surge flow irrigation has a favorable effect on optimizing water use under clay soil conditions.

Table (8): Correlation coefficient (r) and constant for the relation between infiltration rate and each of bulk density (d_B), advance time and speed, water consumptive use (WCU) and water application efficiency (WAE).

	d_B	Time	Speed	WCU	WAE
r	0.50356**	0.3807*	0.37714*	0.85849**	0.58038**
Constant	- 0.0829	13.3868	- 0.1072	9.4017	- 9.2907

7. Grain yield and water utilization efficiency (WU_tE):

Data in tables (9 and 10) showed that, surge flow irrigation had higher wheat and corn grain yield than that the continuous one, either under dead or traditional levelling. The overall average of grain yield under surge flow treatments varied for wheat from 2.36 to 2.57 ton/fed and from 2.41 to 2.62 ton/fed, for the first and second seasons, respectively. And for corn varied from 3.15 to 3.48 ton/fed and from 3.09 to 3.40 ton/fed, respectively. The corresponding values under the continuous treatment were 2.35 and 2.4 ton/fed for wheat; 3.05 and 2.98 ton/fed for corn, respectively. Dead levelling treatments achieved higher grain yield values than that the traditional levelling ones. It had an average values of 2.55 and 2.60 ton/fed for wheat; 3.35 and 3.26 ton/fed for corn, for the first and second seasons, respectively. The corresponding values under the traditional levelling were 2.32 and 2.35 ton/fed for wheat; 3.17 and 3.10 ton/fed for corn, respectively. The statistical analysis showed significant differences between treatment of 20 min on/20 min off (Ir5) and other treatments. The high grain yield of wheat and corn under surge irrigation compared with continuous one may be attributed to the improvement of soil aeration conditions, more uniformity water distribution along the field and maintenance of nutrients. These results are in agreement with Ghalleb (1987), Zaghloul (1988) and Osman (1991).

Table (9): Grain yield of wheat (ton/fed) in the two growing seasons as affected by irrigation treatments and land levelling practices.

Cycle ratio		First season			Second season		
On	Off	Dead Levelling	Traditional Levelling	Mean	Dead Levelling	Traditional Levelling	Mean
Cont.	0	2.457 CD	2.247 E	2.352 C	2.506 E	2.291 H	2.398 E
20	5	2.478 CD	2.238 E	2.358 C	2.527 D	2.282 I	2.405 D
20	10	2.499 C	2.247 E	2.373 C	2.548 C	2.291 H	2.419 C
20	15	2.604 B	2.420 D	2.512 B	2.656 B	2.399 CC	2.528 B
20	20	2.709 A	2.436 CD	2.573 A	2.763 A	2.484 F	2.624 A
Means		2.549	2.318		2.600	2.349	
L.S.D. at 5% = 0.015					L.S.D. at 5% = 0.003		

Table (10): Grain yield (ton/fed) of corn in the two growing seasons as affected by irrigation treatments and land levelling practices.

Cycle ratio		First season			Second season		
On	Off	Dead Levelling	Traditional Levelling	Mean	Dead Levelling	Traditional Levelling	Mean
Cont.	0	3.110 CD	3.00 D	3.055 D	3.000 EF	2.960 F	2.980 D
20	5	3.260 BCD	3.040 CD	3.150 CD	3.150 CD	3.030 DEF	3.090 C
20	10	3.340 ABC	3.170 CD	3.255 BC	3.220 BC	3.110 CDE	3.165 C
20	15	3.480 AB	3.270 BCD	3.375 B	3.430 A	3.150 CD	3.290 B
20	20	3.600 A	3.360 ABC	3.480 A	3.530 A	3.270 B	3.400 A
Mean		3.358	3.168		3.266	3.104	
L.S.D. at 5% = 0.323					L.S.D. at 5% = 0.1136		

Surge flow treatments had higher values of water utilization efficiency (WU_tE) than those of continuous flow. WU_tE values were higher under dead levelling than that under the traditional levelling (tables 4 and 5). Mean WU_tE values for wheat under continuous flow irrigation were 0.79 and 0.61 kg/m^3 under dead and traditional levelling, respectively. Corresponding values for surge flow treatments varied from 0.82 to 1.21 kg/m^3 and from 0.62 to 0.85 kg/m^3, respectively. While for corn, these values were 0.9 and 0.76 kg/m^3 for continuous flow irrigation under dead and traditional levelling, respectively. Corresponding values for surge flow treatments varied from 1.03 to 1.46 kg/m^3 and from 0.80 to 1.14 kg/m^3, respectively. The best treatment was that of 0.5 cycle ratio (Ir5), it had the highest WU_tE value of 1.21 and 0.85 for wheat; 1.46 and 1.14 kg/m^3 for corn, under dead and traditional levelling, respectively. The explanation of these results, as mentioned before is that surge flow irrigation especially with dead levelling leads to higher water distribution uniformity, less water losses by deep percolation and less amount of applied water during the irrigation.

Conclusion: Surge flow irrigation in clay soils could be recommended as a mean to improve the efficiency of surface irrigation and water saving. Under the conditions of the pressent study, surge flow irrigation for wheat and corn with cycle ratio of 0.5 (20 min on and 20 min off) is the best irrigation treatment.

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تأثير أسلوب الري وتسوية الأرض على خصائص الرشح والعلاقات المائية ومحصول القمح والذرة في الأراضي الطينية

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أجـريت دراسات حقلية خلال أربع مواسم شتوية وصيفية متتالية بمحطة البحوث الزراعية بسـخا محافظـة كفـر الشيخ. تهدف هذه الدراسات إلى تقييم تأثير الري السطحي في أحواض وفي خطـوط تحـت ظروف تسوية مختلفة على رشح الأرض للمياه والعلاقات المائية ومحصول القمح والـذرة فـي الأراضي الطينية. ولقد استخدم تصميم القطع المنشقة (لكل محصول) بثلاثة مكررات وكـانت المعـاملات الرئيسية هي عمليات التسوية (التسوية الدقيقة صفر%، التسوية العادية). بينما كـانت المعـاملات الـتحت رئيسية هي معاملات الري وهي الري المستمر وأربع معاملات للري النبضي تمثل أربع نسب دورات مختلفة هي ٠,٨ (٢٠ دقيقة فتح، ٥ دقائق غلق)، ٠,٦٧ (٢٠ دقيقة فـتح، ١٠ دقـائق غلق)، ٠,٥٧ (٢٠ دقيقة فتح، ١٥ دقيقة غلق)، ٠,٥٠ (٢٠ دقيقة فتح، ٢٠ دقيقة غلق).

ولقـد أوضـحت النـتائج أن معـدل رشح الأرض للماء يقل بينما الكثافة الظاهرية للطبقة السـطحية للأرض تزداد باستعمال نظام الري النبضي (المتقطع). ويكون ذلك بصورة أوضح تحت نظام التسوية الدقيقة. ويلاحظ أن انخفاض معدل الرشح باستعمال الري النبضي له فوائد عديدة. حيث نظام الري النبضي خاصة مع استعمال التسوية الدقيقة يعطى زمن أقل لتقدم جبهة المياه وكميات أقل من مياه الري المستعملة وكفاءة أعلى لتوزيع المياه- وذلك مقارنة بمعاملات الري المستمر. وتزداد كفـاءة توزيع المياه باستعمال الري النبضي حيث تكون القيم المتوسطة لها باستعمال الري المستمر ٧٥,٤ ، ٧١,٥ % للقمح و ٨٥,٤ ، ٧٧,١ % للذرة تحت التسوية الدقيقة والعادية على التوالي. بينما القيـم المماثلة باستعمال الري النبضي تتراوح بين ٧٨,٨ إلي ٩٠,٦ % و ٧٢,٤ إلى ٨٤,٣ % في حالة القمح ومن ٨٧,٥ إلى ٩٥,٣ % ومن ٧٩,٤ إلى ٩٠,٤ % في حالة الذرة علي التوالي.

ولقد أوضحت النتائج أيضا أن الاستهلاك المائي للقمح والذرة يكون أعلى تحت نظام الري المسـتمر بالمقارنـة بالري النبضي. وينخفض الاستهلاك المائي بنقص نسبة الدورة أو بزيادة زمن الغـلق (off-time) في حالة الري النبضي. ويتراوح محصول الحبوب تحت الري النبضي ما بين ٢,٢٥ و ٢,٧٦ طن / فدان للقمح وبين ٣,٠٣ و ٣,٦٠ طن / فدان للذرة. بينما القيم المماثلة تحت الري المسـتمر فهـي ٢,٣٨ طن / فدان للقمح و ٣,٠ طن / فدان للذرة على التوالي. وتعطي معاملات التسوية الدقيقة محصول حبوب أعلى (للقمح والذرة) من معاملات التسوية العادية. وأوضحت النتائج أيضـا أن القيم المتوسطة لكفاءة استخدام المياه تحت الري المستمر تعادل ٠,٧٨ ، ٠,٦١ كجم / م٣ لـلقمح ، ٠,٩٠ ، ٠,٧٥ كجـم / م٣ لـلذرة تحت التسوية الدقيقة والعادية على التوالي. بينما القيم المماثـلة لمعاملات الري النبضي فتتراوح بين ٠,٨٢ ــ ١,٢١ كجم / م٣ ، ٠,٦٢ ــ ٠,٨٥ كجم / م٣ فـي حالـة القمح وبين ١,٠٣ ــ ١,٤٦ كجم / م٣ ، ٠,٨٠ ــ ١,١٤ كجم / م٣ في حالة الذرة تحت التسوية الدقيقة والعادية علي التوالي.

وعـلى ضـوء نتائج هذه الدراسة يمكننا أن نوصى باستعمال الري النبضي في حالة زراعة القمح والـذرة فـي الأراضي الطينية بشمال الدلتا. ولقد وجد أنه لكل المقاييس المدروسة فإن معاملة الري النبضي بنسبة دورة قدرها ٠,٥ (٢٠ دقيقة فتح ، ٢٠ دقيقة غلق) تعطي أفضل النتائج.