RELATIONSHIP BETWEEN PLOWING METHODS AND SURGE IRRIGATION AND ITS EFFECT ON WATER RATIONALIZATION

BY

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بسم الله الرحمن الرحيم

﴿وآية لهم الأرض الميتة أحييناها وأخرجنا منها حباً فمنه يأكلون﴾

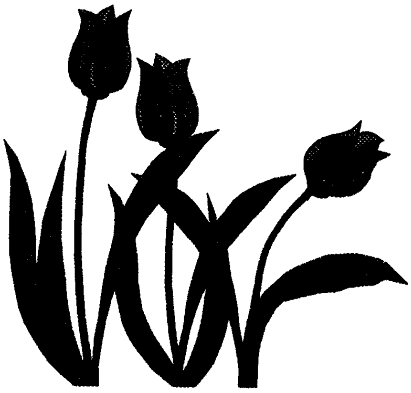
(سورة يس : آية ٣٢)

DEDICATE

to

my parents,

my brother and my sisters



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In the name of Allah most Gracious, most Merciful "For him who puts his faith in God, He will be all sufficient, for God will attain his purpose, and God has assigned its destiny to every thing". (Surat Al-Talak, Ayah 3, Koran)

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CONTENTS

CONTENTS continued

CONTENTS continued

CONTENTS continued

LIST OF TABLES

LIST OF FIGURES

1-INTRODUCTION

Water is the source of life. As a matter of fact it includes all life with its aspects. In recent times, the world is threatened by shortage of water and agriculture itself consumes the highest rate of water. This serious case attractes the attention of scientists and makes them to do their bests for solving this problem. Therefore, shortage of water becomes one of the principle elements of poverty and starvation in the world. We must inquire if all sources are exploited economically to prevent wasting water.

So, irrigation is vital to insure the essential moisture for plant growth. In the same direction, Egypt is a unique case concerning irrigation all over the world in which, all agricultural lands are under irrigation.

Although increased emphasis has been placed on sprinkler and trickle irrigation systems during recent years for a shortage of water but they have high cost of structure and energy, surface irrigation will remain popular and most extensive method for crops.

Surface irrigation is the oldest method. It is practiced as flooding the soil surface (border and basin irrigation) or running the water in small ditches (furrows). It uses open channel flow to spread water over a field. Gravity is the driving force in such systems.

Generally, surface irrigation efficiency is the lowest. It is due to high run off and deep percolation losses that are cited as prime problems. This inefficiency is a result of improper management, inadequate equipment and accordingly, irrigator's inability to control the water completely.

The main goal of surface irrigation design and management is generally to complete the advance phase of the irrigation as quickly as possible so that differences in intake opportunity time are minimized. Hence, the advance phase plays an important role in the application of the soil and the distribution of water in the soil root zone.

Over years, minor changes have been made to increase the efficiency of surface irrigation through surge flow irrigation.

Surge flow furrow irrigation is a new irrigation technique. **Trout (1991)** reported that surge irrigation was the intermittent application of surface irrigation water. Under some conditions, the technique reduces the application time and volume required advancing flows across the field surface and thus improving irrigation water distribution uniformity.

These intermittent water applications lead to a discontinuity in the infiltration process. Its result is often a reduction in surface layer permeability. However, this effect is widely variable depending on soil compaction and its prior wetting history, surface water velocities and duration of on / off **(Stringham and Keller, 1979)**.

- The main objectives of the present study are:

1- Study the effect of surge flow irrigation technique on water advance time phase, water saving comparing with conventional continuous flow under different ploughing systems.

2- Selection of the best on-off time for the surge flow irrigation system.

3- Study infiltration behavior for surge flow irrigation technique comparing with conventional continuous flow under different ploughing systems.

4- Evaluation of the efficiency of water use.

2- REVIEW OF LITERATURE

2.1. Definition of irrigation:

Plants are living beings and do require water and air for their revival as do human beings require. Their requirement of water varies with their type. Different types of plants require different quantities of water, till they grow up completely. Irrigation may, therefore, be defined as the science of artificial application of water to the land, in accordance with the "Crop requirement" throughout the "Crop period" **(Garg, 1984)**.

Depending on source of water, type of crop to be irrigated, quantity and quality of water crops from surface, subsurface, under pressure (sprinkler) or in drops (drip irrigation) **(Lenka, 1991)**.

2.2. Surface irrigation:

Surface irrigation method is still the most widely used. Water is spread across the land surface using basin, border and furrow methods. More than 95% of all irrigation is done in this way and is likely to remain so for the foreseeable future. Many types of surface irrigation schemes have been developed to suit different agricultural systems and communities **(Key, 1986).**

Surface irrigation systems generally require a smaller initial investment (except when extensive land smoothing is needed), are more labor intensive, and apply water less efficiently than other types of irrigation systems. Surface irrigation systems are best suited to soils with moderate to low infiltration capacities and land with relatively uniform terrain and slops less than 2 percent. **(James, 1988)**

2.2.1. Theory of surface irrigation:

Merriam and Keller (1978) explained the four phases of surface irrigation by plotting the time and distance relationship of water as it advances down the strip as follows (Fig.1):

1) Advance phase:

It is the time required for water leading front reaches the other end of the field. The rate of advance down a field is affected by find major factors normally, unit inflow, field slop, field roughness, soil infiltration characteristics and channel shape. This may vary throughout the irrigation process or remain constant. The slop of the field determines the rate at which energy is added to the flowing water.

The forces restraining flow are those due to roughness from both the soil surface and vegetation. The soil surface roughness changes during irrigation and between irrigation.

The vegetative roughness is a function of the type of vegetation involved as well as stems rigidity, length, diameter and density in the presence of leaves.

Infiltration characteristics of the soil, varies with time (during and between irrigation) and space (location within the field).

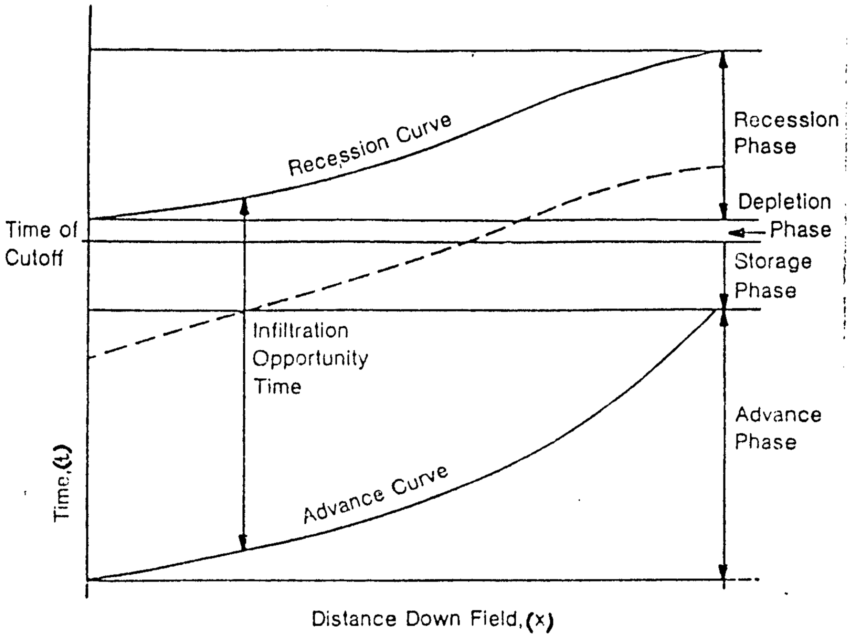

Fig. 1: Representation of the phases of surface irrigation **(Merriam and Keller, 1978)**.

Channel shape is the find variable affecting the advance phase. The cross-sectional shape of the channel is usually considered wide and shallow rectangular.

2) Storage phase:

The time from the leading front reaches the other end of the field and until the end of irrigation. In this phase, the infiltration rate is generally high. However, the infiltration rate rapidly declines to some relatively constant value. Thus, when the water reaches the end of field, the infiltration rate is constant or decreasing at every point within the field. The tail end of the field may have a dam over which the water can not pass, thus water begins to accumulate on the surface. This phase, during which water covers the entire soil surface, is known as the "storage phase". The storage phase ends when inflow ceases (time T_{co}).

3) Depletion phase:

At some appreciable time after turning the water off the pounded water at the upper end disappears by infiltration and movement on down the field. This interval of time between turn off and disappearance is known as the "depletion phase".

4) Recession phase:

The water that once covered the surface has either entered the soil or flowed to a lower level of the field. This is known as the "recession phase". Ideally this recession of water from the surface begins at some appreciable time after turning the water off, the pounded at the head end and progresses down the filed until the water either enters the soil or runs off. When the pounded water has been absorbed by the soil, the irrigation is complete.

2.2.2. Methods of surface irrigation:

Key (1986) mentioned that surface (gravity) irrigation methods used to spread water as uniformly as possible in the soil to irrigate the crops are mainly three: basin, border and furrow irrigation.

2.2.2a. Level basin irrigation:

Michael (1978) reported that the level basin irrigation is the simplest in principle of all methods of irrigation. There are many ways of applying the method, but all involve dividing the field into smaller areas so that each has a nearly level surface. Ridges are constructed around the areas forming basing within which the irrigation water can be controlled.

Clemmens *et al.* (1981) showed that the level basin method has a number of advantages. They concluded:

(i) Uniform application of water and associated high application efficiencies, which reduce farm water requirement and decrease nutrient and fertilizer loss form excessive deep percolation;

(ii) Elimination of run off, which reduces soil erosion and eliminates water reuse systems; and

(iii) Better control of the irrigation water, thus reducing labor requirement.

Also, they indicated that the development of laser-controlled land leveling equipment has greatly improved the achievable efficiencies for level basins.

2.2.2b. Border irrigation:

Michael (1978) explained that the border method of irrigation makes use of parallel ridges to guide sheet flowing water as it moves down the slope. The land is divided into a number of long parallel strips called borders that are separated by low ridges. The border strip has little or no cross slope but has a uniform gentle slope in the direction of irrigation.

Lenka (1991) showed that the border strip method is suitable for irrigation most of the close growing crops. Its chief advantages are:
(i) Can be constructed with cheap farm equipment,
(ii) Irrigation labor requirement is greatly reduced,
(iii) Uniform distribution of water and high water use efficiency, and
(iv) Large irrigation streams can be efficiently used.

2.2.2c. Furrow irrigation:

Woodward (1971) explained that the commonly accepted criteria for designing a furrow irrigation system is that the furrow stream be large enough for it to reach the lower end of the furrow in one fourth the time needed for the planned depth of water to penetrate the soil. The method provides high irrigation efficiencies.

Garg (1984) noted that the long furrows might result in too much percolation near the upper end and too little water near the down-slope end.

Key (1986) reported that the furrow could usually be longer on clay soils than on sandy soils. It can be longer when a larger stream size is used for irrigation and a larger irrigation depth is applied. It is usually shorter on steeper sloping land to prevent erosion.
He also, added that there are several ways in which irrigators can reduce run off losses. One way is a allow some water to pond at the end of a furrow and to back up into adjacent furrows. Another way is to reduce the stream size and

relax the quarter time rule. A third method is to reduce the stream size once the flow has reached the end of the furrow. This is called the cutback method.

Lenka (1991) showed that the chief advantages of furrow irrigation are:

(i) Economic use of water and increased water use efficiency due to lateral and downward flow of water into the root zone,

(ii) Evaporation loss is reduced for lesser contact zone in the furrow,

(iii) Reduces pudding and crusting of the ridge since zone of wetting is only 1/3 – 1/5 of the total furrow depth,

(iv) Cultural operations become easy,

(v) The furrow can be used as drainage channels, and

(vi) During water scarcity alternate furrow can be irrigated to save water. The hazard to crops can be reduced.

Schwab *et al.* (1993) reported that while in the flooding methods water covers the entire surface, irrigation by furrows submerges only from one fifth to one half the surface, resulting in less evaporation and less puddling of the soil, and permitting cultivation sooner after irrigation.

Furrows vary in size and are up and down the slope or on the contour. Small, shallow furrows, called corrugations, are particularly suitable for relatively irregular topography and close-growing crops, such as meadow and small grains.

Furrows 80 to 200 mm deep are especially suited to row crops since the furrow can be constructed with normal tillage. Contour furrow irrigation may be practiced on slopes up to 12 percent, depending on the crop, the erodibility of the soil, and the size of the irrigation stream.

2.2.3. Hydraulic of surface irrigation:

The forces restraining flow are those due to resistance both from the soil surface and vegetation. The soil changes during irrigation and between irrigations.

Linderman and Stegman (1971) stated that of the factors influencing hydraulic behavior of irrigated units, the following parameters are probably most dominant: (a) size of irrigation stream, (b) infiltration rate, (c) soil moisture deficit, (d) length of run, (e) slope, and (f) flow retardance.

Katopodes *et al.* (1990) reported that surface irrigation factors could be classified into three categories. The first group consists of geometrical factors, such as field dimensions and elevations and furrow or border cross-sectional shape. In general, these parameters are determined during design of the system. The second set of parameters represents the soil and crop factors, infiltration and roughness. Infiltration has a significant influence on the water advance and recession relation, as well as the infiltrated profile. Roughness affects the advance and recession, but generally does not influence directly the infiltrated profile. The third set of parameters represents the management alternatives available to the irrigator. These include the inflow hydrograph, typically represented by inflow rate and cutoff time, and the soil moisture deficit at the time of irrigation, or the management allowed deficit (MAD).

2.2.3a. Field length:

Ley and Clyma (1981) showed that although furrow lengths ranging from 175-725 m were observed, the majority of observed lengths fall between 350-650 m. Depending on the farm size and farm boundaries, fields generally were laid out between established roadways or traditional farm roadways.

The results show that while marginally acceptable designs can be achieved for the longer run lengths from 400m to 800m, improved system performance can be attained on the run lengths of 400m or less.

2.2.3b. Field slope:

Key (1986) mentioned that this is a measure of the difference in ground level between tow places in a field and is referred to as a percentage (%). It is the number of meters difference in elevation for each 100 m of horizontal distance. As water will only flow downhill it is important to know which way the land is sloping when setting out new channels and field irrigation methods. This may seem obvious but in areas where surface irrigation is used the land slopes are usually very small (0-2 %) and are not easily detected by eye. Special survey instruments are needed to determine slope.

2.2.3c. Surface roughness:

Heermann *et al.* (1969) stated that the surface roughness and related resistance to flow affect rate of water advance, rate of recession, and indirectly infiltration depth. Efficient irrigation by surface application can be accomplished only by the proper combination of these three factors. Quantification of surface roughness and associated hydraulic-flow resistance is a necessary step in reaching retional design criteria.

Ley and Clyma (1981) stated that furrow roughness was characterized using Manning's n. Values ranging from 0.010 to 0.047 were observed. Roughness was found to vary significantly along a single furrow and from irrigation to irrigation through the season.

Key (1986) showed that the bed and sides of a channel can de quite rough and this slows down the flow in the same way as friction slows down an object as it is pushed across some rough surface. Weeds growing in badly maintained channel will greatly increase roughness and can stop the flow completely.

2.2.3d. Infiltration:

Lai and Pandya (1972) stated that the infiltration is defined as the entry of water into the soil due to gravitational and surface tension forces. Soil properties, fluid properties and hydraulic gradient influence it. Knowledge of infiltration is essential for determining the time required for given quantity of water to fill the root zone and for optimizing the length of run and percolation losses in surface irrigation.

Furrow infiltration measurement can be made by using blocking furrow infiltrometer **(Bondurant, 1957)**, a by-pass furrow infiltrometer **(Shull, 1961)** or an inflow-outflow method **(Nance and Lambert, 1970)**.

Hansen *et al.* (1979) showed that intake rate varies with many factors, including depth of water on the surface, temperature of water and soil, soil structure and texture, and moisture and salinity content of the soil. Retarding layers of soil will greatly influence the rate. Configuration of the surface such as furrow shape and size, as well as the method of application, will be influencing factors also. Hence, intake rate varies from place to place on a field and it also varies with time.

Key (1986) reported that when the soil is dry, water infiltrates quickly. After 20-30 minutes this decreases as the air spaces in the soil become filled with water. After a period of 1-2 hours water infiltrates at a slow steady rate. It is used to describe different soil types from an irrigation point of view.

Fonteh and Podmore (1994) present a model that accounts for infiltration variability along the furrow, which should lead to improvements in the design and management of the irrigation system. If efficiency is to be improved without sacrificing application uniformity and crop yield, good real-time management should be achieved by controlling the furrow inflow rates according to the respective infiltration rates at the soil surface under unrestricted water supply. This infiltration rate is a function of time and depends also on site conditions such as roughness, surface sealing, furrow cross-section and wetted perimeter.

- Infiltration equation

The historical orders of appearance of some widely applied infiltration rate equations that describe the process of infiltration are either physical or empirical.

As an example of physical equation of **Green and Ampt (1911)** as follows:

$$i = i_c + \left(b/I\right) \qquad 2.1$$

Where:

i = Infiltration rate;

i_c = Final constant infiltration rate;

b = Characterizing constant and

I = Cumulative infiltration.

Serralheiro (1995) describe infiltration in irrigation furrow using Kostiakov empirical equation is more appropriate.

$$Z = K\,t^{a} \qquad 2.2$$

Where:

Z = Cumulative infiltration;

t = The elapsed time of infiltration and

K, a = Constants which vary with the type of soil and its condition.

Elliott and Walker (1982) present one of the equations, which has been used to characterize infiltration in furrow, is the modified Kostiakov or Kostiakov-Lewis equation.

$$Z = K\,t^{a} + f_{o}\,t \qquad 2.3$$

Where:

Z = Cumulative infiltration in units of volume per unit length per unit width;

t = Infiltration opportunity time;

K, a = Empirical constants which must be determined experimentally and

f_o = Final (stabilized) infiltration rate.

A physically-based approach to infiltration has been discussed by **Philip (1969)** who presented equation for water movement in the soil profile. The Philip equation is given by

$$Z = S\,t^{0.5} + c\,t \qquad 2.4$$

Where:

Z = Cumulative infiltration;

S = The parameter which Philip called sorptivity;

c = The hydraulic conductivity of the saturated soil and

t = The elapsed time of infiltration.

Serralheiro (1995) noted that the infiltration equation obtained with a short length might not represent well the spatial variability of the soil infiltration characteristics.

2.2.4. Performance measurement of irrigation:

Farm irrigation systems are designed and operated to supply the individual irrigation requirements of each field on the farm while controlling deep percolation, run off, evaporation, and operational losses. The performance of farm irrigation system is determined by the efficiency with which water is diverted, conveyed, and applied, and by the adequacy and uniformity of application in each field on the farm **(James, 1988)**.

2.2.4a. Water-conveyance efficiency:

This term is used to measure the efficiency of water conveyance systems associated with the canal network, watercourses and field channels from the well to the individual fields. It is expressed by **(Michael, 1978)** as follows:

$$E_c = \frac{W_f}{W_d} \times 100 \qquad 2.5$$

Where:

E_c = Water-conveyance efficiency, percent;
W_f = Water delivered to the irrigated plot and
W_d = Water diverted to from the source.

2.2.4b. Water-application efficiency:

After the water reaches the field supply channel, it is important to apply the water as efficiently as possible. Therefore, the water application efficiency is the ratio of the average depth of irrigation water infiltrated and stored in the root zone, to the average depth of irrigation applied water **(Michael, 1978)**.

Willardsone and Bishop (1967) reported that in surface irrigation, water-application efficiency is influenced principally by the amount of water applied, the intake characteristics of the soil, and the rate of advance of water over the soil surface. An under standing of how these variables affect the water-application efficiency is important in the design of surface irrigation systems.

Hansen *et al.* (1979) showed that in normal irrigation practice, surface irrigation efficiencies of application are in the range of 60 percent, where as well designed sprinkler irrigation systems efficiencies are generally considered to be approximately 75 percent. Water-application efficiencies below 100 percent are due to seepage losses from the field, distribution channels, deep-percolation below crop root zone and run-off losses at the end of the field. In general water application efficiency decreases as the amount of water applied during each irrigation increases.

2.2.4c. Water-storage efficiency:

Water-storage efficiency becomes important when water supplies are limited or when excessive time is required to secure adequate penetration of water into the soil. The concept of water-storage efficiency relates how completely the water needed prior to irrigation has been stored in the root zone during irrigation. It is defined by **(Michael, 1978)** as follows:

$$E_s = \frac{W_s}{W_n} \times 100 \qquad 2.6$$

Where:

E_s = Water-storage efficiency, percent;

W_s = Water stored in the root zone during irrigation and

W_n = Water needed in the root zone prior to irrigation.

2.2.4d. Water-distribution efficiency:

Smerdon and Glass (1965) showed that the desirable water-distribution efficiency requires collection data relating water-distribution efficiency to those variables, which influence the irrigation operation. These variables include type of surface irrigation, whether furrows or borders, length of irrigation runs, stream size, slope and roughness of irrigated surface, and infiltration characteristics of the soil.

Not only the application of the right amount of water to the field, but also its distribution uniformity over the field is important. Permissible length of irrigation runs are controlled, to a large extent, by the uniformity of water-distribution and irrigation management practice. Water-distribution efficiency indicates the extent to which water is uniformly distributed along the run **Micheal (1978)**.

2.2.4e. Water use efficiency:

The water utilization by the crop is generally described in terms of water use efficiency (Kg/ha .cm). Therefore, It can be defined in the following ways:

(i) *Crop water use efficiency.*

It is the ratio of crop yield (**Y**) to the amount of water depleted by the crop in the process of evapotranspiration (**ET**)

$$\text{Water use efficiency} = \frac{Y}{ET} \qquad 2.7$$

(ii)*Field water use Efficiency.*

It is the ratio of crop yield to the total amount of water used in the field.

Crop yield itself can be defined in terms of total growth (i.e., dry matter production) or in terms of marketable product. Of the two indices for water use efficiency, the concept of crop water use efficiency is of fundamental interest while field water use efficiency is of greater practical importance **(Micheal, 1978)**.

2.2.5. Surge flow irrigation:

Surge flow irrigation is considered one mean to improve the surface irrigation system. The intermittent application of irrigation to surface irrigation systems is distinctly different than with either sprinkle or trickle systems.

Surge flow has been defined by **Bishop *et al.* (1981)** as "The intermittent application of irrigation water to furrow or border creating a series of on and off conditions of constant or variable time spans at the furrow inlet".
They defined the cycle time as "The period required for a complete on/off cycle", i.e., the time between the beginning of one surge to the beginning of the next. The cycle time may be of any desired duration and can vary from a few seconds to hours, but present experience indicates a typical cycle time 10 min – 60 min.

Also, they defined the cycle ratio as "The ratio of the on time to cycle time". With conventional irrigation, no off time, making the cycle ratio equal to one (continuous flow).

Measurements by **Stringham and Keller (1979)** showed that the flow at the end of the furrow was relatively steady. The behavior of pulsed furrow inflow was better characterized by surge hydraulics.

2.2.5a. The advantages of surge irrigation:

Many authors and investigators i.e. **Bishop** ***et al.*****, (1981); Ismail** ***et al.*****, (1985); Izuno** ***et al.*****, (1985); Ghallab (1987); Guirguis (1988); Zein El-Abedin (1988); Osman (1991) and Moustafa (1992)** summarized the potential benefits of using surge rather than continuous irrigation, as follows:

1- Faster advance, which results in more uniform water distribution. The accelerated advance rates and accompanying reductions in water volume necessary for the completion of one irrigation attributed to a reduction in the infiltration rate.

2- Less water used or more acres irrigated with the same amount of water.

3- Reduction in the total irrigation times.

4- Less water lost to deep percolation, and less opportunity for leaching of nutrients, and less run off at the end of the fields.

5- Increased distribution uniformity, thus greater opportunity for increased yield.

6- Reduced erosion with surge flow.

7- More energy efficient and decreased labor for management.

8- Possibility of automation.

2.2.5b. Design and management of surge irrigation:

Surface irrigation design and management objectives are generally to complete the advance phase of the irrigation as quickly as possible to minimize these differences in intake opportunity time.

To accomplish this, large streams have been recommended for the advance phase with cutback streams or run off recovery systems to minimize the run off and deep percolation losses during the intake phase **(Bishop *et al.*, 1981)**.

Proper design and management run off and deep percolation can be reduced, which increases application efficiencies. Special surge valves are available to facilitate surge irrigation. These valves alternate the flow between two sets of furrows to form the surges. The water is delivered to the furrows through gated pipe connected to the surge valves **(Schwab *et al.*, 1993)**.

Good design provides a satisfactory uniformity of distribution with a minimum operating cost including deep percolation, power, and labor cost.

Stringham and Keller (1979) first suggested the automatic system.

One device used to control water is an automatic drop gate by **Ismail et al. (1985)**. The gate opens automatically when the water level on its upstream side rises to a predetermined elevation and remains open until the water surface drops to a lower predetermined level. The gate then returns automatically to its normally closed position by action of a counter balance weight.

The management parameters for surge irrigation are the stream size, number of surges, on-times, off-times, cutback time, cutback method, and total irrigation time. The appropriate values of these parameters are dependent upon run length, soil characteristics and surface debris.

Bishop *et al.* **(1981)** reported that in a surge furrow irrigation experiment with a cycle time of 2, 5, 10 and 20 minute and with cycle ratio of 0.5 and discharge of 1.26 l/s, surge flow irrigation was more effective during the first irrigation than in the second one. They also showed that surge flow alters the basic intake characteristics of the furrow by developing a thin surface seal in the bottom, which is compacted by tension forces, which build up in the furrow during the drainage period between surges.

Izuno *et al.* **(1985)** stated that in every test in 1982 and 1983, completion of the advance phase required less time in the surge irrigated furrows than in those irrigated continuously when equal instantaneous inflow rate were used. Advance in the surge irrigated soft furrows required only 28 % as much applied water, as that required for the continuously irrigated soft furrows. Completion of advance in the surge irrigated hard furrows averaged 60 % of water required for completion of advance in the continuously irrigated hard furrows.

Miller *et al.* **(1987)** in their study on evaluating the combined effects of wheat and corn residues and surge flow irrigation on furrow erosion and irrigation uniformity, showed that residues were hand-placed in clean furrows.

Testezlaf *et al.* **(1987)** showed that surge flow has achieved popularity because it often results in a more rapid advance rate for the wetting front. This in turn can lead to a decrease in water losses due to deep percolation. By controlling the on-off cycle and the flow rate, run off at the lower end of the field can be reduced.

Awady *et al.* (1988) found that the reduction in water volume required during the season for surge irrigation was 23 % less than for the continuous irrigation under the same condition.

Purkey and Wallender (1989) reported that although the instantaneous flow was the same for surge and continuous irrigation, 17.8 % less total on time was needed to complete advance under surge irrigation.

In their study on advance trajectories of each surge normalized relative to the start of the surge, for the first surge, water advanced to 95 m prior to cut off at the field inlet and there after advanced to 115 m simultaneous with rear end recession. For the second surge, advance was much faster than the first surge over the first 95 m, slowed slightly between 95 m to 115 m and was even slower over the dry soil beyond 115 m. The reduction in advance time was less in the section wetted after cut off (95 m to 115 m) possibly because wetting, up the sides of the furrow, was not complete during the first surge. Continued surging reduced wet furrow advance time.

Izadi *et al.* (1990) listed six possible causes for the faster advance rate under surge irrigation include:

1- Decreased furrow roughness and a more stable cross-section during infiltration of water between pluses.
2- Redistribution of water during the time that water is turned off, which causes a decrease in the hydraulic gradient in the top soil layer for the next surge.
3- Hysteresis in the soil water content vs. pressure head relationship.
4- Air entry and entrapment occurring between pluses.
5- Surface sealing and consolidation of the soil matrix near the soil surface, which decreases the hydraulic conductivity of the top soil layer.

6- Change in the hydraulic properties of the soil profile between pluses.

Osman (1991) reported that surge flow furrow irrigation with cycle ratio of 1/3, reduces the advance time by 51 % of the advance time for continuous irrigation at Sakha and by 53 % at the Abis. Also surge irrigation (1/3) used 58.18 % of total amount of applied water for continuous irrigation, this leads to save 41.82 % (1462 m^3/fed., where one feddan [fed.] = 4200.83 m^2) of total amount of applied water for continuous irrigation at Sakha. While at Abis farm, surge irrigation (1/3) used 64.96 % of total amount of applied water for continuous irrigation therefore this saving 35.04 % (1015 m^3/fed.) of total water for continuous irrigation.

He also, added that the water drained from continuous irrigation was11.61cm and reduces to 0.5 cm for surge irrigation (1/3) along the season at Sakha. At Abis farm water drained from continuous irrigation was 6.4 cm and reduces to zero for surge irrigation (1/3).

Moustafa (1992) stated that surge flow in furrow irrigation system can be used efficiently in new land "light textured soils" by using conventional or concrete channels with siphon tubes or automatic gate pipes for distributing irrigation water.

Gomaa (1995) on silty-clay-loam soil with 1.5 l/s inflow; 0.05 % slope; and 100m long furrow, compared the continuous irrigation with three different cycle ratio of 0.75 (30 min on - 10 min off), 0.67 (20 min on – 10 min off), and 0.6 (15 min on – 10 min off). His results showed that the advance time and water required to reach to the end of the furrow decrease under surge irrigation. Minimum values of advancement time and water per furrow were 334min and 3.1m^3 (about 186 m^3/fed.). Also, water under surge irrigation can be saved with about 24, 38 and 42 % for cr treatment of 0.75, 0.67 and 0.60, respectively, than continuous irrigation.

Morcos ***et al.*** **(1996a)** reported that in border irrigation, the surge flow of (5 min on –5 min off), (10 min on –10 min off), and (15 min on –15 min off) reported the total net advance time by about 29.6, 33.3 and 32 % compared with the continuous flow. This means that the surge flow reduced 12.78, 14.4 and 13.8 m^3/border form the amount needed for continuous.

They also, added that in furrow irrigation, the surge flow of (5 min on –5 min off), (10 min on –10 min off), and (15min on -15min off) reduced the total net by about 29.4, 34.2 and 28.6 % compared with the continuous flow. This means that the surge flow reduced 2.26, 2.56 and 2.16 m^3/furrow from the amount needed for continuous.

El-Saadawy (1997) showed that the surge flow with its cycle 5/15 (T_4) (5 min on – 15 min off) gives the best result comparing its continuous flow (T_1), 5/5 (T_2) and 5/10 (T_3). The average advanced time of water applied to reach the end of the furrow (90m) were 83.83, 72.17, 56.67 and 44.83 min for T_1, T_2, T_3 and T_4, respectively. The total amounts of water applied were 86.69, 69.35 and 59.78 % by surge for T_2, T_3 and T_4 of the water applied by continuous flow.

Eid (1998) reported that surge flow had the highest water advance rate, either under dead or traditional levelling i.e. surge flow saved 22 and 18 % of the time required for continuous flow to complete the irrigation, under dead and traditional levelling, respectively.

He also, indicated that surge flow irrigation used less amount of water than in continuous one. It could save water on average for all treatment by about 19.1

and 16.5 % of the continuous flow irrigation under dead and traditional levelling, respectively. The best treatment (20 min on and 20 min off) could save water with an average of 28.2 % (959.4 m^3/fed.) and 23.9 % (911.4 m^3/fed.) of the applied water to corn crop under dead and traditional levelling, respectively.

2.2.5c. Effect of surge flow irrigation on infiltration rate:

Izuno *et al.* (1985) reported that the surge infiltration function appeared to undergo a step reduction from the time dependent rate to the basic rate after one complete wetting and dewatering cycle. This infiltration rate reduction led to reduced amounts of time and water necessary to complete advance when surged applications were used instead of continuous application. The surge infiltration phenomenon also caused a reduction in advance time differences between successive irrigations as well as between furrows with different degrees of compaction.

They also, added that three distinct phases of infiltration occur under surged furrow irrigation. These phases are (a) infiltration into initially dry soil, (b) infiltration into previously wetted soil, and (c) a transition infiltration regime caused by increased wetted perimeters occurring after the first wetting of a furrow section.

Samani *et al.* (1985) showed that the two basic phenomena which affect infiltration that take place during the intermittent off-time of surge flow irrigation are redistribution of the infiltration water in the soil profile and particle sealing of the wetted soil surface.

They also, reported that the intermittent application of water would increase the instantaneous intake rate of the soil if the soil's bulk density does not change during the off-time. If the soil's bulk density changes during the off-time due to the consolidation of the soil caused by the development of negative pressure. Increasing the off-time in surge flow will increase the reduction of intake rate for some time, but the process will be limited.

Evans ***et al.*** **(1987)** studied the crop residue effects on surge furrow irrigation hydraulics. They reported that surge irrigation reduced infiltrated depths along of the furrow compared to the continuous flow treatments with the same residue levels. Because of the increased uniformity of application under various levels of crop residues, surge flow is preferable to continuous flow furrow irrigation.

Testezlaf ***et al.*** **(1987)** investigated the infiltration behavior of three soil (fine sandy loam, loam and clay loam soils) for continuous flow and three different surge flow conditions (cycle times of 20, 40 and 60min). They reported that surging reduced the quasi-steady infiltration rate by one-third to two-thirds bellow that measured for continuous flow condition of the three soil's studied, despite shorter opportunity times for the surge treatments. The fine sandy loam soil exhibited greater reductions in quasi-steady infiltration than did the loam and clay loam soils. With the surge flow treatments, the infiltration rate increased, or "rebounded", at the beginning of each new surge cycle, but then quickly declined.

Kemper ***et al.*** **(1988)** reported that the mechanisms causing this infiltration reduction include: (a) consolidation of soil in the furrow beds as tension develops in the soil water during interruption of the flow; (b) filling of cracks, which form in the furrow bed during supply interruption by bed load when water reenters the furrows; (c) sealing of the furrow during each supply interruption enters the soil and deposits its fine sediments in the large pores or as a fine seal on absorbing surfaces; and (d) more complete disintegration of soil particles in the wetted perimeter as a result of faster wetting.

Purkey and Wallender (1989) reported that mean and variability of infiltration depth under surge irrigation were smaller than under continuous irrigation. Higher uniformity under surge irrigation resulted from reduced dependence of infiltration on IOT and from reduced spatial variability of the infiltration rate. To conclude, surging not only reduces water application depth but also reduces variability of water application depth along a furrow compared to continuous irrigation.

El-Amir (1991) showed that under surge flow irrigation and in the absence of surface sealing, there are two mechanisms involved in reducing the hydraulic conductivity. The first is soil surface consolidation and the second is the air entrapment. The dominance of one mechanism depends on the history of the soil. In partially consolidated soil, before tillage or at the end of the growing season, the dominant mechanism is air entrapment, where as in freshly tilled soil the two mechanisms are instrumental.

Allen and Schneider (1992) reported that the furrow compaction by tractor traffic and surge flow both reduced water intake on a fine-textured clay loam during graded furrow irrigation. An intake reduction of about 20 to 25 % occurred when the soil surface was loose after primary tillage. After surface soil consolidation from previous irrigation and rainfall, the effects continued during the later season irrigation of grain sorghum by reducing the intake from 15 to 20 %. When irrigation intake is excessive relative to storage capacity, the treatments tested are effective in reducing loss to deep percolation beneath the root zone. However, continued use of surge may reduce intake below acceptable levels after the first application. Furrow flow rate had a negligible effect on irrigation intake. The tillage layer density to about 200mm deep has a major controlling effect on intake with this soil.

Morcos ***et al.*** **(1996b)** showed that the experimental data of the infiltration curve, could also be expressed in a mathematical equation relating the basic infiltration rate as a function of the elapsed time, which will be equal to the total continuous period of explosion time of the soil to irrigation water. Also, the experimental data of infiltration rate for surge flow could be expressed in a mathematical equations relating the surge infiltration rate as a function the basic infiltration rate, elapsed time, number of the pulse, and the ratio of on-time to cycle time.

Zin El-Abedin and Ismail (1998) reported that the quasi-steady infiltration rate was reduced significantly below that measured for continuous flow conditions. The greatest reductions were observed on a sandy clay soil. It was, also, observed that best cycle time is 5/20 where the infiltration rate for continuous flow is basically high and the opportunity time is shorter. Therefore higher off-time with lower on-time improved the infiltration rate.

2.2.5d. Effect of surge flow irrigation on application efficiency and distribution uniformity:

Ismail ***et al.*** **(1985)** reported that the surge flow treatments showed a higher distribution uniformity, which indicates that the depth of water infiltration was more uniform than for continuous flow. Surge flow irrigation also had a higher potential application efficiency than continuous irrigation under the same inflow, which indicates that surge flow used less water to achieve the same efficiency or used the same amount of water at a higher efficiency. The higher efficiency of surge flow can be attributed to the rapid advance of the water front.

Guirguis (1988) found that the water application efficiency at inflow rate of 1.45 l/s was 43.9, 87.8, 90.1 and 88.8 % for continuous flow and for surge flow of 5/5, 5/10 and 5/15 minutes receptively. The higher efficiency of surge flow can be attribute to the surface seal that is caused by the intermitted wetting and the surface hydraulic roughness of the wet advance is less than the surface hydraulic roughness after dry advance.

Zaghloul (1988) reported that surge flow efficiency was high than that of continuous flow. T he highest efficiencies were obtained at cycle ratio of 0.8, while less efficiencies was obtained at cycle ratio of 0.2. These efficiencies increased with increases in slope of soil and flow rate.

Izadi *et al.* (1991) showed that the highest intake furrow for smaller flow rates or the lowest intake furrow for larger flow rates determines the maximum application efficiency. The cutback flow management option is preferred, since high application efficiency values are achieved over a wide rang of flow rates. The surge flow management option is recommended for highly erodible soils during the early part of the irrigation season, where high intake rates are observed. Cutback and surge flow simulations resulted in 5 % to 7 % savings in applied volume of water when compared to continuous flow simulation.

Moustafa (1992) showed that, as a results of surge irrigation compared to continuous irrigation treatments in sandy loam soil, application efficiency was increased by about 3 to 35 % and distribution uniformity was increased by about 2 to 11 %.

El-Zaher ***et al.*** **(1996)** reported that the values of water application efficiency were increased in case of surge flow irrigation than continuous flow irrigation under similar condition. The average values of water application efficiency were 73.39, 79.12, 82.82 and 91.02 %; 65.71, 71.70,74.26 and 80.01 % for continuous flow and for surge flow of 5/5, 5/10, and 5/15 on/off time, at El-Kaher and El-Nasser, respectively. The 5/15 on/off time treatment was the best treatment due to the lowest deep percolation comparing with all other treatments.

Abd El-Maksoud and Khater (1997) stated that surge irrigation water distribution efficiency did not exceed 89.12 %, which may be attributed to less number of surges applied.

2.2.5e. Effect of surge Flow irrigation on the yield and water relations of crops:

Ghallab (1987) compared continuous flow irrigation (T_1) with three different surge irrigation treatments of cycle rates 1/2 (T_2), 1/3 (T_3) and 1/4 (T_4), to evaluate the surge flow irrigation for different field crops. He found that the grain yields for corn were 4.27, 4.47, 5.23 and 5.59 Mg/ha respectively for T_1, T_2, T_3 and T_4. The values of water consumptive use were 3.36, 3.18, 3.18 and 3.00 mm/day and the water use efficiencies were 0.575, 0.796, 0.928 and 0.998 kg/m^3 respectively for T_1, T_2, T_3 and T_4.

Zaghloul (1988) carried out field studies on wheat during three growing seasons to compare surge flow border strip irrigation with conventional continuous flow in the clay soil. He added that the grain yield increases with increase of cycle ratio, slope and inflow rate and decrease by increasing the number of pulses per irrigation. The maximum increase in yield is found for cycle ratio 0.8. These results may be attributed to the higher water distribution efficiency and less water losses by deep percolation.

Osman (1991) reported that surge furrow irrigation a cycle rate of 1/3 increased corn yield by 0.46 Mg/fed. at Sakha and by 0.8 Mg /fed. at Abis compared with continuous flow. This may be due to improved good aeration conditions and did not removed the most plant nutrients from the root zone. He also, added that surge irrigation (1 on/ 3 off) leads to increase water use efficiency by 0.695 kg/m^3 at Sakha farm and by 0.99 kg/m^3 at Abis than water use efficiency for continuous irrigation.

Gomaa (1995) reported that the surge irrigation improves the water use efficiency. Highest values of the yield and the water use efficiency are obtained with the surge irrigation treatment of the cycle ratio of 0.6. They are about 2770 kg/fed. and 2.1 kg/m^3 of total water applied, respectively. The best cycle ratio is 0.6 at furrow length of 100m, slope of 0.05 %, and inflow rate of 1.5 l/s; which saves water with about 42 % and increases yield and water use efficiency with about 833 kg/fed. and 0.65 kg/m^3 of water respectively than continuous irrigation.

El-Saadawy (1997) reported that the surge treatment (5 min on/15 min) off recorded the highest yield (1.183 Mg/fed.). The values of water use efficiency were 0.4764, 0.617, 0.8381 and 1.0888 kg/m^3 for continuous flow and for surge flow of 5/5, 5/10 and 5/15, respectively. Also, it could be seen that 5/5 treatment produced the highest yield per m^3 of water consumed, this means that more water saved and achieved good production, while the continuous treatment produced the lowest value.

Eid (1998) showed that the increment in corn grain yield under the surge flow treatment of 0.5 cycle ratio were 14.1 and 15 % above the yield of the continuous irrigation, for the 1st and 2nd season, respectively.
He also, added that the overall average of water utilization efficiency values (average of the two seasons) of continuous flow irrigation were 0.9 and 0.83 kg/m^3 under dead and traditional levelling, respectively. While the best surge flow treatment was that of 0.5 cycle ratio, It had the highest water utilization efficiency values of 1.52 and 1.22 kg/m^3 for the dead and traditional levelling, respectively.

2.3. Effect of tillage operation on some soil physical properties:

2.3.1. Soil bulk density and total porosity:

The bulk density of a soil influences soil strength for structural purposes and for trafficability of vehicles, animals, and humans. It affects plant growth, water infiltration into soil and drainage from soil, power required to till soil, and performance of tillage tools. So, soil bulk density is one of the best indicator value for measuring soil physical conditions.

Korayem and Hindey (1974) carried out a comparative study on ploughing quality of moldboard, disk, and chisel ploughs. They reported that the chisel plow leaves unplowed area of about 14 %. Although this plow produces the largest increase in soil volume (gain in porosity), the distribution of these pores is very poor because it leaves separated large chunks of soil density variation, (d1- d2)/d1 for the chisel plough, was 14.05 %.

El-Gohary (1978) showed that the ploughing process caused a pronounced increase in the values of total porosity and bulk density decreased by increasing the ploughing depth.

Zien Al-Din (1985) found that soil density generally decrease due to tillage with all treatment expects that with no-tillage. The reduction in soil density increased by increasing plowing depth. At the top layer (0-10 cm), the maximum reduction (33 %) was obtained by the rotary plow at 20cm plowing depth. At the bottom layer (20-30 cm) the reduction was less than in the top and middle layers.

El-Gohary *et al.* (1988) reported that bulk density (g/cm^3) was after ploughing as compared with that before ploughing. The values were also relatively lower with the use of moldboard as compared with the values of chisel plough mainly was in depth of 15-30 cm. Therefore, total porosity (%) has an opposite trend to bulk density.

Hamad *et al.* (1992) found that dry bulk density increased with increasing the forward speed of tillage. Also, they indicated that the rotary plough had the highest mean dry bulk density than chisel and moldboard ploughs, respectively.

El-Beily (1995) showed that bulk density increased with increasing ploughing forward speed and it increased with increasing depth at all treatments. He also, added that the moldboard plough gave the most pronounced decrease in bulk density than other treatments after ploughing it gave the most pronounced increase in total porosity after ploughing operations than other treatments.

Taieb (1998) reported that soil bulk density was decreased after tillage operations. The reduction was more when the ploughing depth was 5cm and less reduction was found to be when the ploughing depth was 20cm. Such decrease in soil bulk density after tillage may be to the breakdown of soil compaction, because plouging increases pore spaces and therefore reduces soil bulk density.

2.3.2. Soil moisture characteristics:

It is well know that the amount of water retained by a soil is affected by the physical characteristics of the wetted part of soil.

Ayers and Perumpral (1982) found that the specific moisture content depends on the soil type and increased as increasing the percentage of clay in the soil.

Erbach *et al.* (1986) indicated that soil water content the (0-20 cm) soil layer increased in the following order: fall moldboard plow< spring disk< no-tillage. In the growing season for maize, the fall plowed-soil was warmer than the disked soil.

Zein Al-Din (1985) reported that the reduction in soil moisture content due to tillage operations increased by increasing the plowing depth all the plows. The minimum reduction was obtained with no-tillage where the reduction was about 5-10 %. At the top layer (0-10 cm) maximum reduction was obtained with the chisel plow. At the bottom layer (20-30 cm) the maximum reduction was obtained with the rotary plow at 20 cm plowing depth.

Erbach (1987) showed that the moisture content of surface soil influence plant growth, performance of tillage, planting, and chemical application equipment, soil conditions created by tillage, equipment trafficability and bulk density changes caused by equipment and animals

El-Beily (1995) reported that the minimum values of moisture content were obtained on soils treated by rotary plough than treatments after ploughing operations. However, increasing ploughing depth tends to slightly decrease moisture content for all the types and ploughing forward speeds and after ploughing operations. Those results are due to increasing the total porosity.

2.3.3. Hydraulic conductivity:

The hydraulic conductivity of a soil in mm/h or cm/day defines the volume of water, which will pass through unit cross sectional area of a soil in unit time.

El-Gohary (1978) reported that the deep ploughing greatly increased the hydraulic conductivity coefficient. This mainly due to the higher soil porosity and less soil compactness obtained by deep ploughing. Also, be observed that the hydraulic conductivity coefficient values decreased with the depth within the profile in all soil treatments running parallel to decrease of porosity.

Ohu *et al.* (1985) reported those higher compaction levels to increase penetration resistance, increase bulk density, decrease available water to crops, and decrease saturated hydraulic conductivity of the soils. The effects of these soil physical characteristics might prevent the roots from proliferating to obtain the essential nutrients from the soil for proper growth.

El-Beily (1995) showed that the moldboard plough gave the most pronounced increase in hydraulic conductivity after ploughing operations than chisel plough and rotary plough.

2.3.4. Infiltration rate:

El-Gohary (1978) showed that constant values of infiltration rate increased with increasing of the ploughing depth.

Zein Al-Din (1985) reported that deep plowing increases the infiltration rate specially with the moldboard and disk plows.

El-Gohary ***et al.*** **(1988)** reported that the infiltration rate was found to be higher after using moldboard plough as compared with that resulted from chisel plough. This may be due to the higher soil porosity and less soil compactness obtained by deep ploughing resulted from moldboard plough. In general, the infiltration rates of the different treatments were greater than before ploughing.

El-Beily (1995) reported that the moldboard plough gave the highest values of basic infiltration rate after ploughing operations compared with the chisel and rotary ploughs. He also added that increasing the ploughing depth tends to increase the basic infiltration rate at all plough types.

3- MATERIALS AND METHODS

3.1. Experimental site:

Field experiments were carried out at Zarzora Agricultural Research Station near Etay El-Baroud, Beheira Governorate, Egypt during 1998/1999 growing season.

The experimental site located near to the main open drain and was served by surface open channel using an electric pump.

3.2. Layout and experimental design:

Field experiments were carried out on maize (*zea mays L.*). The area was divided into three large plots; each plot was 17 m wide and 95 m long. Each plot was divided into 4 strips. Each strip was considered as one treatment. The area of each strip was 332.5 m^2. Each treatment involved 5 furrows; the first, the third, and the fifth were used as replicates and the other furrows were as non-irrigated furrows. Buffer furrows (1m spacing) separated the treatments.

The field experiment layout is shown in Fig. 2.

Mechanical analysis of the soil is shown in Table 1, and the soil type is clay loam soil.

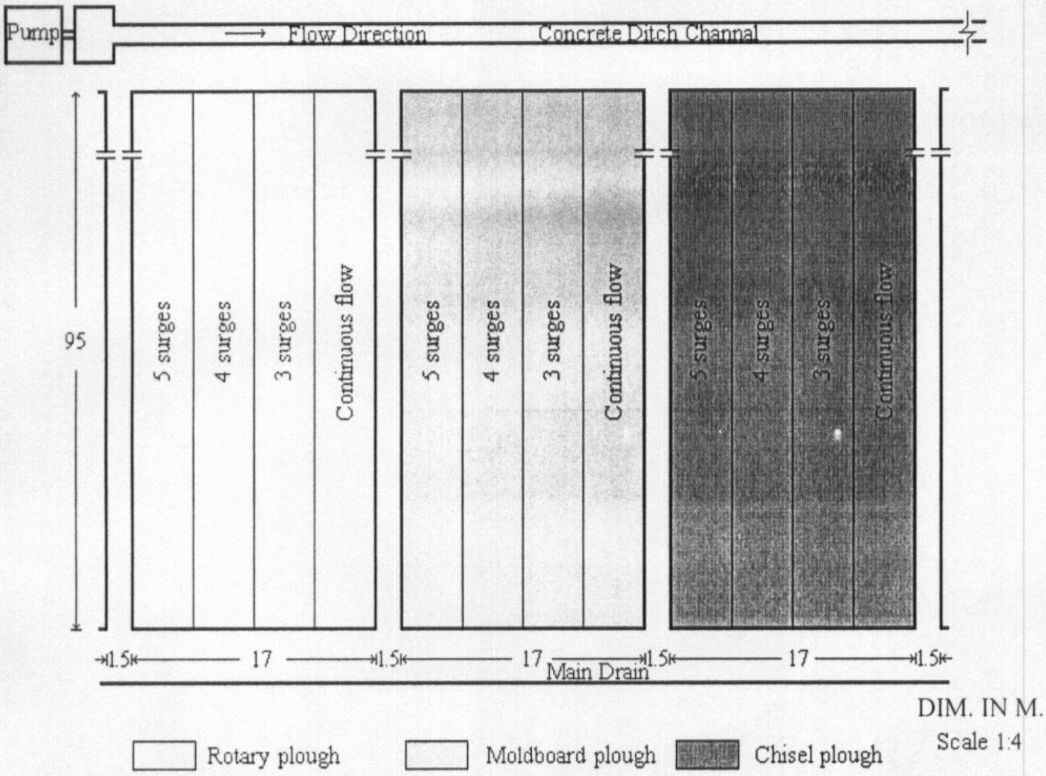

Fig. 2: Schematic diagram showing the distribution of tillage, irrigation treatments as related to the layout of the experiment.

Table 1: Soil mechanical analysis of experimental site.

Soil depth, Cm	Particle size distribution			Texture soil
	Sand, %	Silt, %	Clay, %	
0 – 30	36	35	29	Clay loam
30 – 60	29	40	31	Clay loam

The test was conducted on 95 meter long furrows having slope of 0.04%. The value of Manning's roughness (n) was 0.037 according to **Guirguis (1988)** and **Zin El-Abdin (1988)**. The furrow spacing was designed to be 0.70 meter in order to suit the flow rate used for testing and planting maize. The furrows were irrigated alternately with different tillage systems.

The inflow rate was constant over the irrigation period in all treatment. The inflow rate used in this test was 1.5 l/s. The water was applied in pluses until it reached the tail end of the furrow. The crop received five irrigations through growing season.

3.2.1. Cultural practices for maize:

Zea Maize (Giza 10 variety) was planted on June 1998. The soil was plowed and levelled (Laser levelling). Three seeds were planted (Maize planter) in a hole 15 cm intervals in half of the ridge. All agricultural operations as thinning, hoeing and pest control were practiced through the growing season.

The ploughs were mounted types. The moldboard and chisel plough were mounted on Ford tractor 7610 of 56.72 kW (76 hp) while the rotary type was mounted on Nasr tractor of 48.51 kW (65 hp), which is used also for planting.

The ploughing optimum depths of moldboard, chisel, and rotary were 25 cm, 20 cm and 12 cm, respectively.

3.2.1a. Agricultural tractors:

A- Ford "7610" tractor:

Ford 7610, four cylinders, diesel engine, water cooling system, 56.67kW (76 hp). The tractor mass is about 3.363 Mg, 2 × 4. Rear tyres are 18.4-34 in size. This was used for primary and secondary tillages of moldboard and chisel.

B- Nasr "65" tractor:

Nasr 65, four cylinders, diesel engine, water cooling system, 48.47 kW (65 hp). The tractor mass is about two and half Mg, 2 × 4. Rear and front tyres are 14.8-28 and 12.8-16.8 in size, respectively. This tractor was used for tillage of rotary and operating planter.

3.2.1b. Agricultural equipment:

A- Moldboard plough:

A three mounted bottoms moldboard plough was used. It was manufactured locally, composed of three bottoms fixed on frame 60 cm high and manufactured from square cross section of 10.16 cm width and thickness of six mm. The bottoms have an advantage by adding a small scraper at front of bottom to penetrate soil easier. The bottom height is 50 cm and the net cutting width of the bottom is 35 cm, the total cutting width of plow is 105 cm. The shares are imported from Italy. The plough mass is about 600 kg as shown in Fig. 3.

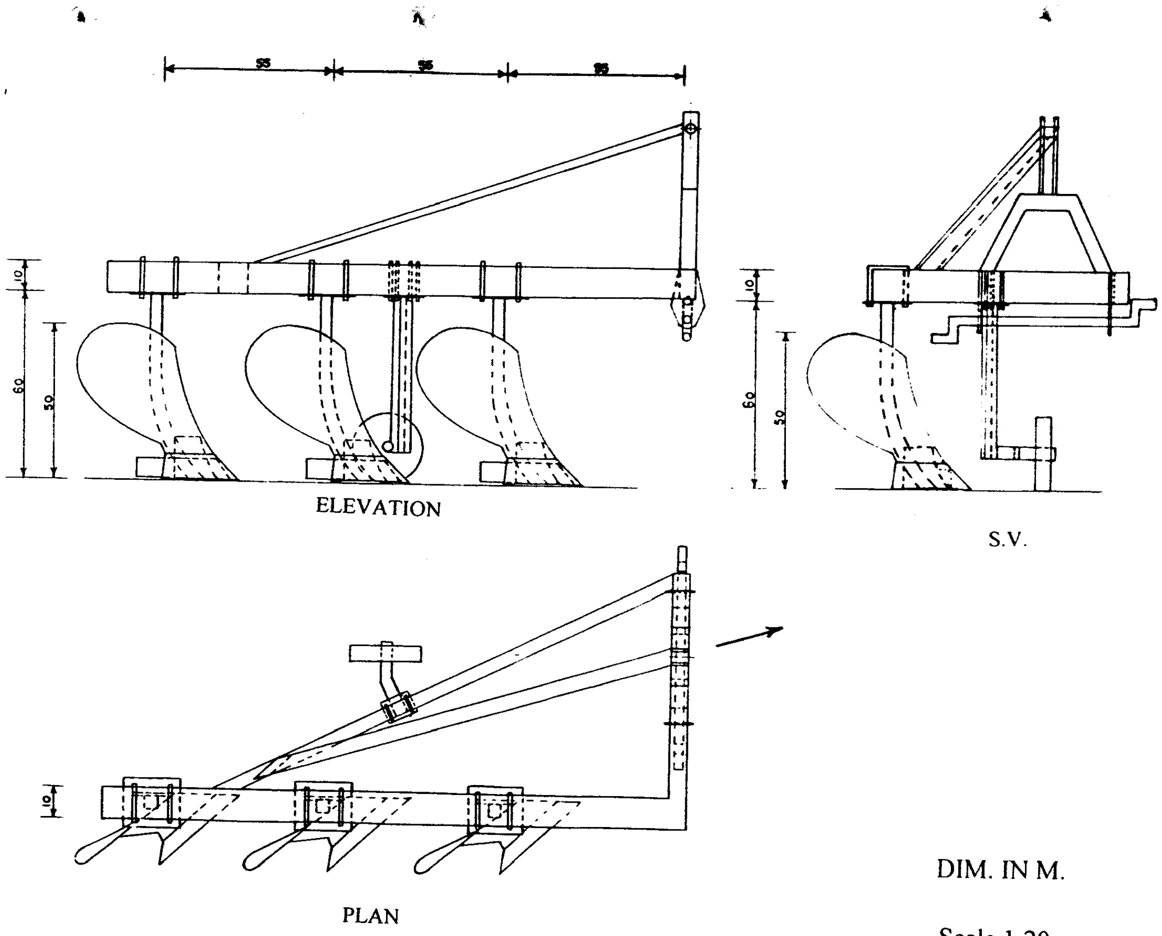

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Fig. 3 : Moldboard plough three bottom.

B- Chisel plough:

A seven mounted shares chisel plough was used. It was manufactured locally, composed of three rows at 50 cm spacing between rows. The shares distribution on rows is 2, 2 and 3 from front to rear at 50 cm spacing between each two shares on the same row. The share beam height is 50 cm. The share beam has a sheer bolt to absorb the chocks from soil and clods and to protect the share beam. The shares are imported from Germany. The plough mass is about 400 kg as shown in Fig. 4.

C- Rotary plough:

In the right end of the flanges, three blades of L-type were bolted in one direction only. However, on the other seven flanges, the blades were mounted with three right hand and three left hand blades per flange. The distance between flanges was 25 cm. The working width of the rotary plough was 190 cm. The length of the adjustable rear shied was 195 cm and the width was 50 cm. The diameter of the rotor shaft was 7.64 cm. The depth shoe was present for adjustment of the depth of cut. The rotary plough is shown in Fig. 5.

D- Maize planter:

A planter was used to plant the mechanical plots. It consists of four planting units at 70 cm spacing between units. Each planting unit has one seed plate. Each seed plate includes 26 cells.

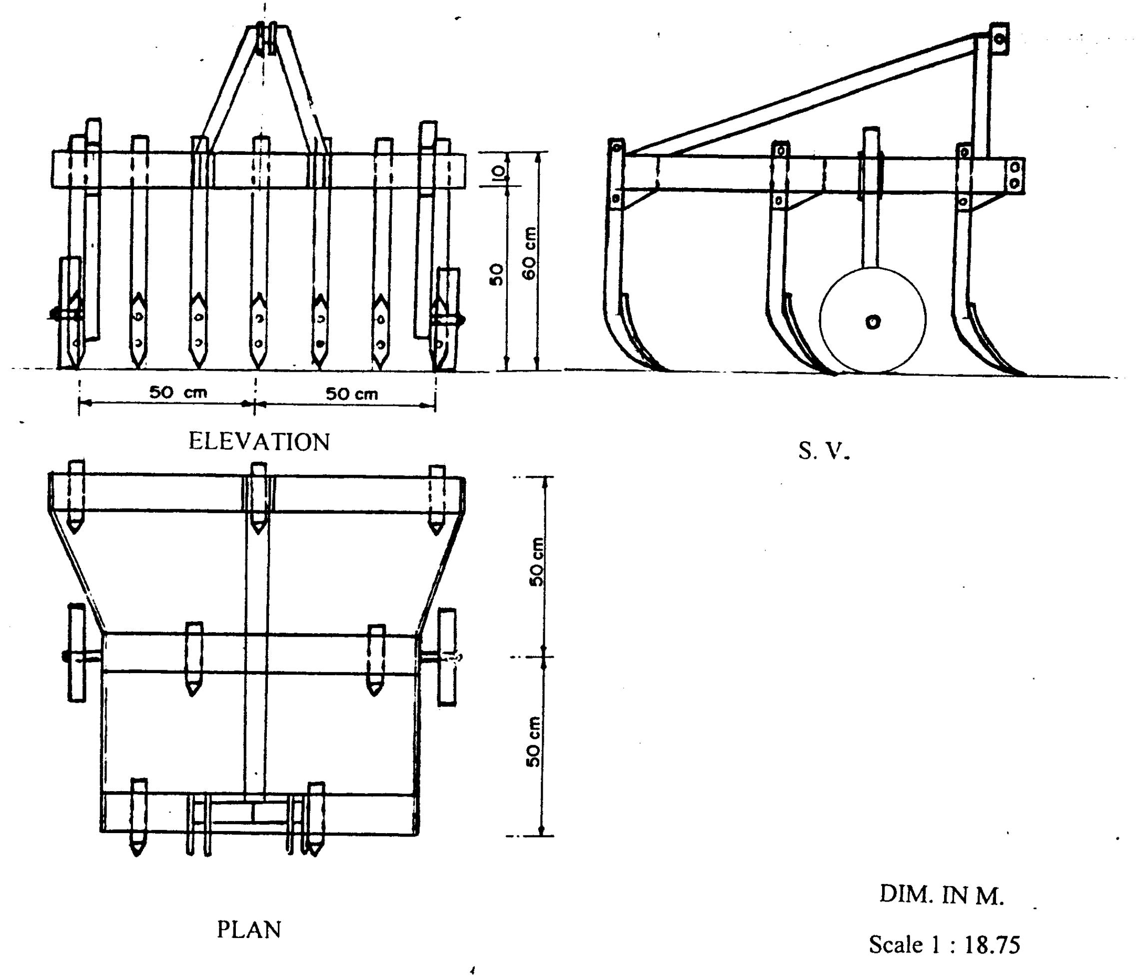

Fig. 4 : Chisel plough 7 shares arranged in three rows.

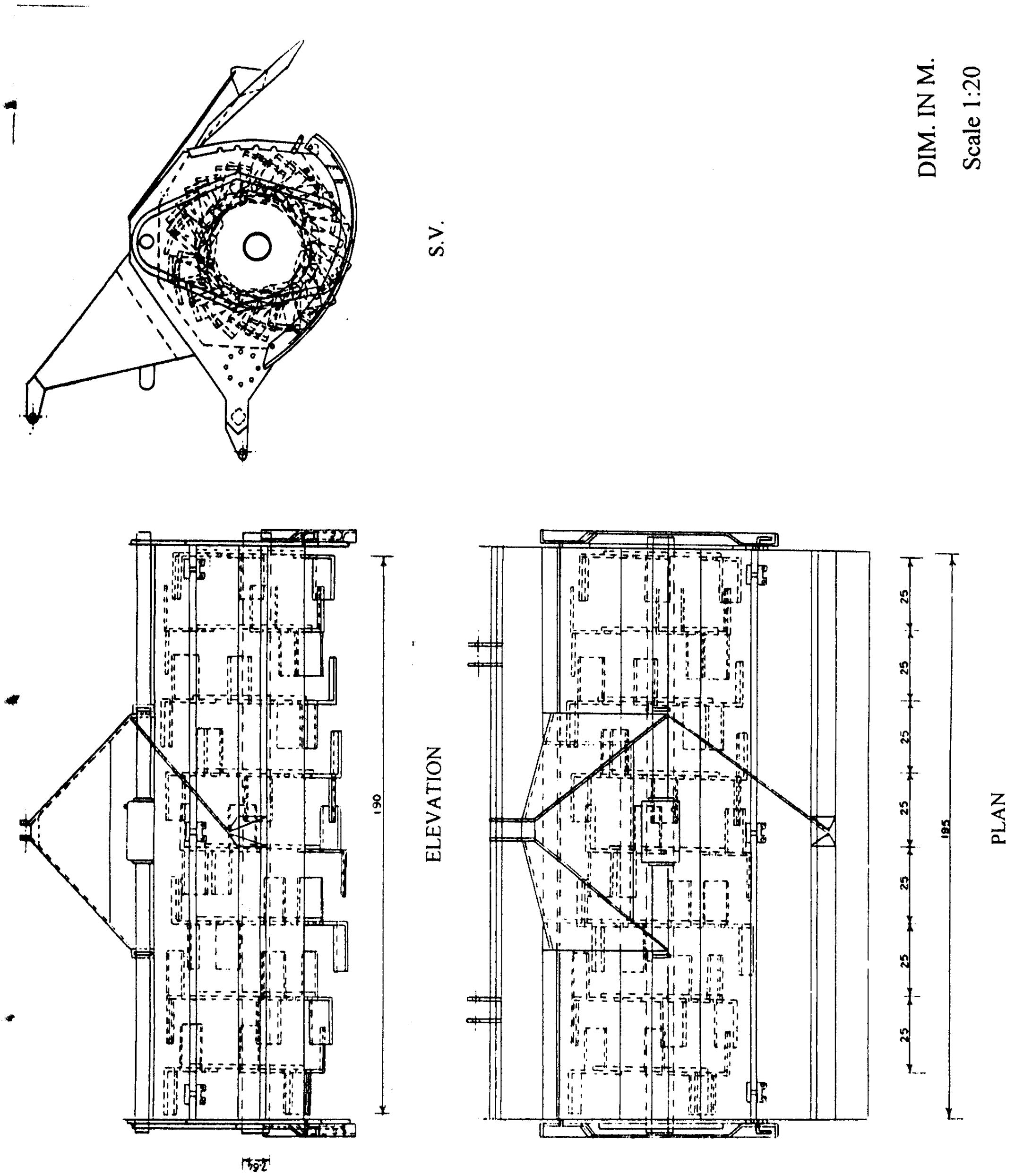

Fig. 5 : Rotary plough.

3.2.2. Treatments:

Two treatments were studied and tested in this work.

3.2.2a. Ploughing treatments:

1- Moldboard plough (ploughing optimum depth 25 cm).
2- Chisel plough (ploughing optimum depth 20 cm).
3- Rotary plough (ploughing optimum depth 12 cm).

3.2.2b. Irrigation treatments:

Four irrigation treatments were applied manually after sowing. These treatments are:

A- Continuous flow (control).
B- Surge irrigation with 3 surges, on-time (10 – 19 – 25 minutes) and off-time 20 minutes between the surges; total on-time 54 minutes.
C- Surge irrigation with 4 surges, on-time (6 – 11 – 15 – 18 minutes) and off-time 15 minutes between the surges; total on-time 50 minutes.
D- Surge irrigation with 5 surges, on-time (4 – 8 – 10 – 12 – 13 minutes) and off-time 10 minutes between the surges; total on-time 47 minutes.

The on-time factor (**OTF**) and on-time cycle (**OTC**) were determined according to **Yonts and Eisenhauor (1991),** as follows:

$$\mathrm{OTF} = [\mathrm{CN}]^{1.52} - [\mathrm{CN} - 1]^{1.52} \qquad \mathbf{3.1}$$

$$\mathrm{OTC} = \mathrm{OTF} \times \mathrm{OTC}_1 \qquad \mathbf{3.2}$$

Where:

CN = Cycle number and
OTC_1 = On-time for the first cycle.

3.2.3. Statistical design:

A split plot design was carried out. The three plough treatments were considered as the main plots and the four irrigation treatments were considered as the sub-main plots. Therefore, each irrigation treatment was replicated three times with three plough systems. The continuous flow irrigation treatments were considered as the control. Stakes were placed at regular intervals (10 m) along each furrow until 80 m from length furrow.

3.3. Data collection:

3.3.1. Calibration siphon:

Inflow rates were measured by calibrated siphon tubes. Siphon tubes were 2 meters in length and 50 mm in diameter. Siphon tubes were calibrated by using a bucket and a stopwatch was used to collect a constant volume of water, which were delivered from siphon at different times. This work was repeated many times. For calculating rate of discharge, the constant volume of water was divided into the average values of times. The rate of discharge which, was used in this study was 1.5 l/s for furrow.

3.3.2. Flow advance and recession (distance and time):

The water advance and recession times were recorded at ten points along each furrow. These points were called stations. The on-off cycle time was controlled by means of stopwatch. The time needed for water to advance the entire furrow was recorded and irrigation was terminated.

3.3.3. Maize yield:

A plot of one furrow with five meters length at the beginning, middle, and end of the furrow was chosen for average yield determination for maize.

3.3.4. Laboratory infiltration rate:

The laboratory infiltrometer consists of a glass cylinder, a control valve, a filter paper, two holders, a Mariotte tube and a plastic hose, as shown in Fig. 6 . It was used to measure the infiltration rate of the soil in the laboratory. This method was modified from **Abd El-Latif (1978)** and **Zoharb *et al.* (1985)**.

The cylinder diameter was 5 cm and its length was 30 cm. It was designed to carry 25 cm height soil sample. The glass nipple was mounted in a 0.4 cm diameter hole drilled at the center of the bottom of cylinder cap. The filter paper, used as a porous plate, was placed under the soil sample. This provided a port for preventing air trapped inside the soil sample. A 0.5 cm hole, drilled at the side of the cylinder and connected with a plastic hose, was used as a port for draining the water head during the off-time. A Mariotte tube, of the construction with 150 cm length, was used to keep a constant head of water over the soil surface.

Laboratory experiments were conducted to measure the water infiltration rates under continuous and surge application of water. Disturbed dry soil samples were collected from a cultivated field. The soil samples were dried in air, pounded and sieved to have a homogenous structure less consistency. When soil of certain structure was desired, large clods were partially loosened by pounding, then finer clods of the desired range were separated by sieving. The dry soil samples were placed inside the glass cylinder and compacted in layers to achieve the same bulk densities as measured in the field until the desired height (below the opening hole at the cylinder side) was reached. The glass cylinder was connected to the Mariotte tube filled with water.

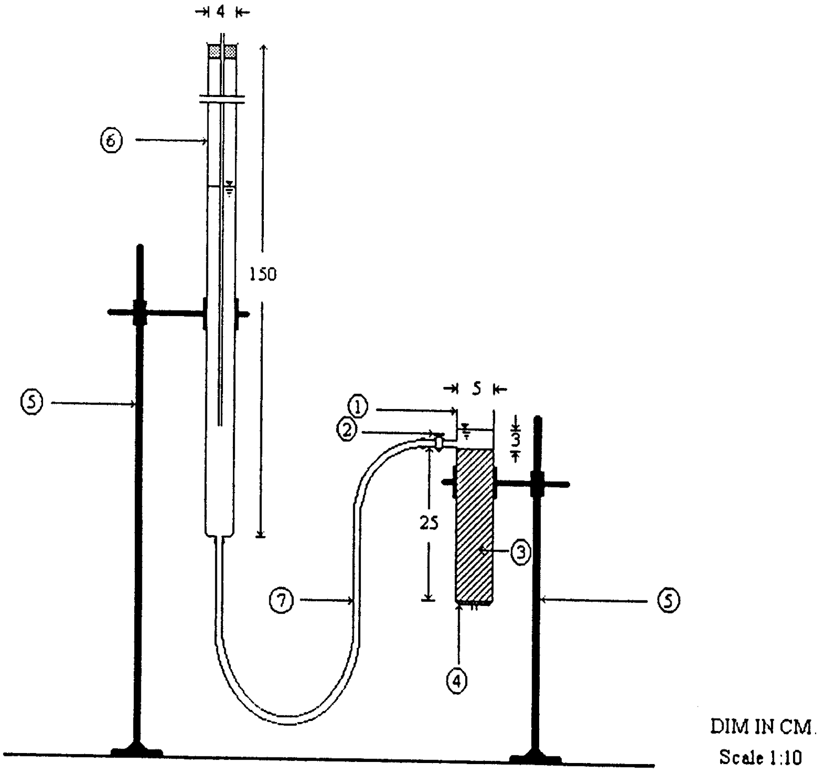

Fig. 6 : Schematic diagram for laboratory infiltrometer set.

1- Glass cylinder.
2- Valve.
3- Soil sample.
4- Filter paper.
5- Holder.
6- Mariotte tube.
7- Plastic hose.

Water was applied to the top of the soil sample to maintain a constant water level of 3cm by adjusting the level of water inside the Mariotte tube. This level was recorded. For example, after one minute a certain volume of water infiltrated inside the soil sample, the new level of water inside the Mariotte tube was recorded and the difference between readings gave the volume of water, which infiltrated in the soil sample during the specified time interval. The volumes of water infiltrated at different time increments were measured.

The infiltrated depth in the soil sample could be calculated at any time by measuring the volume of water in the Mariotte tube in the on-time. When off-time began the depth of water above the soil sample inside the cylinder was drained by lowering the Mariotte tube. This work was repeated several times for each cycle time selected inside each treatment. The readings, which were recorded from the Mariotte tube against time, were used to calculate the constants of infiltration equations for each on-time. This equation was Kostiakov's infiltration equation **(Serralheiro, 1995)** as follows:

$$Z = K\,t^{a} \qquad 3.3$$

Where:

Z = Cumulative infiltration;

t = Elapsed time of infiltration and

K, a = Empirical constants.

3.4. Methods of calculations of the parameters:

3.4.1. Time of irrigation:

The total on-time under continuous and surge flow irrigation was calculated using a stopwatch.

3.4.2. Advance time function:

All of the advance data were fitted to a power function of the following from to represent the relationship between the distance that water has advanced across the furrow and time, the approach of **James (1988)** was used as:

$$X = p\,t^{r} \qquad 3.4$$

Where:

X = Distance that water has advanced across the furrow, m;

t = Time since the start of advance, min and

p, r = Fitted parameter.

3.4.3. Water-application efficiency (E_a), %:

It was calculated according to **Micheal (1978)** as follows:

$$E_a = \frac{W_s}{W_f} \times 100 \qquad 3.5$$

Where:

W_s = Water stored in the root zone of the plants and

W_f = Water delivered to each treatment.

3.4.4. Water-distribution efficiency (E_d), %:

It was determined as defined by **Micheal (1978)** as follows:

$$E_d = \left(1 - \frac{\bar{y}}{\bar{d}}\right) \times 100 \qquad 3.6$$

Where:

$\bar{d}$ = Average depth of water stored along the run during the irrigation and

$\bar{y}$ = Average numerical deviation from $\bar{d}$.

3.4.5. Field water-use efficiency (E_t), kg/m^3:

It was determined as defined by **Micheal (1978)** as field water-use efficiency:

$$E_t = \frac{Y}{WR} \qquad 3.7$$

Where:

Y = Total crop yield, kg/fed and

WR = Total amount of water use in the field, m^3/fed.

4- RESULTS AND DISCUSSION

4.1. Effect of surge flow irrigation on advance rate and total amount applied water under different tillage treatments:

The obtained data were collected on field during the 1998/1999 irrigation seasons. The field was composed of a clay loam soil, precision levelled to a longitudinal slope of 0.04 % according to **Key (1986)**. This is needed to ensure that water will flow down the furrow, any excess water can be drained, and prevent erosion occurring. Maize was irrigated through furrows of 95 meter length with 0.70 meter width.

4.1.1. Advance rate:

The advance of water in surface irrigation plays an important when water applied and its distribution in the soil root zone. Table 2 and Fig. 7 illustrate the average advance time for continuous flow treatment (inflow rate 1.5 l/s for furrow) for the three different tillage systems.

The average values of time required for water to advance to the end of the furrow in case of continuous flow treatment were 75.1, 64.8 and 63.3 minutes using moldboard, chisel and rotary plough, respectively. This indicates that water advance rate was the fastest under rotary plough. The fastest water advance rate was under rotary plough. This may be due to the highest the bulk density (1.25 g/cm^3) and the lowest total porosity (52.83 %) when rotary plough used comparing with others according to **Hamad *et al.* (1992)**.

Table 2: Advance time (min), advance equation ($X = pt^r$) and total amount of applied water (m^3/fed.) with continuous and surge flow irrigation under three different ploughs during the experiment period.

Plough treatments	Irrigation treatments	Advance time, min									Advance equation $X = pt^r$			Total amount of applied water	
		Distance, m													
		10	20	30	40	50	60	70	80	95	p	r	R^2	m^3/fed.	% of cont.
Moldboard plough	Continuous	5.00	10.40	16.85	24.90	33.40	43.00	53.50	62.80	75.10	0.269	1.236	0.997	2129.09	100
	3 surges	2.50	6.30	14.70	19.45	26.40	32.95	45.30	50.00	58.50	0.095	1.434	0.993	1658.48	77.90
	4 surges	2.90	5.85	11.95	17.60	28.30	34.70	47.50	55.00	64.30	0.088	1.460	0.992	1822.91	85.62
	5 surges	3.00	9.50	12.27	18.70	22.05	32.50	35.50	53.00	60.65	0.162	1.292	0.987	1719.43	80.76
Chisel plough	Continuous	4.30	8.80	14.70	22.40	30.00	36.50	42.90	50.60	64.80	0.244	1.220	0.998	1837.08	100
	3 surges	3.25	6.40	9.60	17.20	19.20	24.00	28.70	45.50	51.30	0.165	1.240	0.982	1454.36	79.17
	4 surges	2.75	5.60	11.80	17.40	27.20	33.05	46.30	53.25	61.00	0.084	1.462	0.992	1729.35	94.14
	5 surges	2.70	7.40	10.37	18.15	21.80	29.35	32.00	35.00	59.10	0.141	1.294	0.989	1675.49	91.20
Rotary plough	Continuous	4.00	8.25	13.45	19.45	26.20	33.80	42.00	50.30	63.30	0.209	1.244	0.997	1794.56	100
	3 surges	2.80	5.60	8.40	11.20	17.40	21.40	26.05	31.20	47.25	0.144	1.228	0.984	1339.54	74.64
	4 surges	2.40	4.80	10.73	14.00	17.50	27.08	31.33	36.00	52.70	0.092	1.372	0.991	1494.05	83.25
	5 surges	2.30	4.65	10.20	17.80	21.60	25.47	28.80	30.88	54.00	0.094	1.368	0.981	1530.90	85.31

X = distance, m.

t = advance time, min.

p, r = fitted parameters.

R^2 = coefficient of determination.

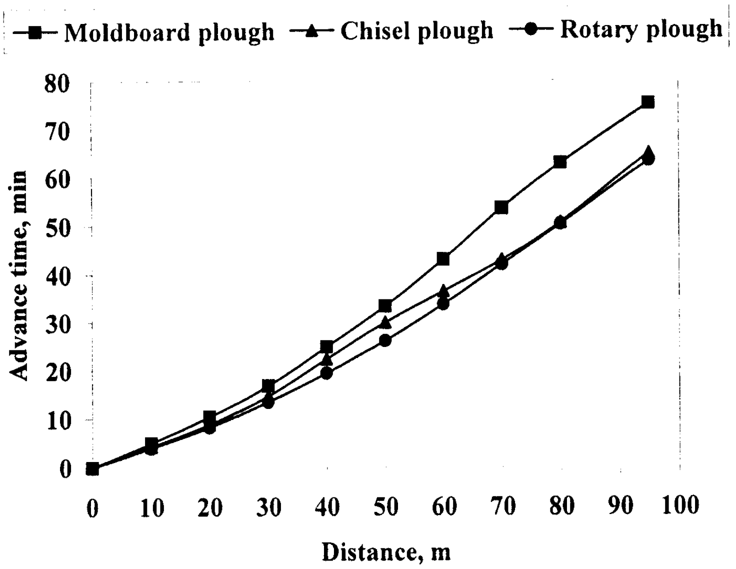

Fig. 7 : Advance time for continuous flow irrigation with three different ploughs.

On the other hand, the rotary plough did not cause enough soil aeration around root system than other plough systems.

Table 2 and Fig. 8 show the effect of different tillage treatments on the advance time for continuous and 3, 4 and 5 surges treatments. The average values of time required for water advance to reach the end of the furrow for 3, 4 and 5 surges treatments were 58.50, 64.30 and 60.65 minutes (average of 61.15 min.) for the moldboard plough, respectively. The corresponding values for the chisel plough were 51.30, 61.00 and 59.10 minutes (average of 57.13 min.) for 3, 4 and 5 surges treatments, respectively. Also, the corresponding values for the rotary plough were 47.25, 52.70 and 54.00 minutes (average of 51.32 min.) for 3, 4 and 5 surges treatments, respectively.

Therefore, in these treatments (surge irrigation treatments under moldboard, chisel, and rotary plough) water reached the end of the furrow in about 81.42, 88.16 and 81.07% of the time required for continuous flow treatment, respectively. This means those mentioned, surge irrigation treatments, saved 18.58, 11.84 and 18.93% of the time required for continuous flow treatment to complete the advance phase for the moldboard, chisel, and rotary ploughs, respectively.

On the other hand, for each plough system, the 3 surges treatment was the fastest advance rate. It may be due to increasing the off-time that reduced infiltration rate according to **Samani *et al.* (1985)**.

Accordingly, these results indicted that the surge flow treatments had faster advance rate than the continuous ones. This may be attributed to the redistribution of the infiltrated water in the soil profile during the off-time,

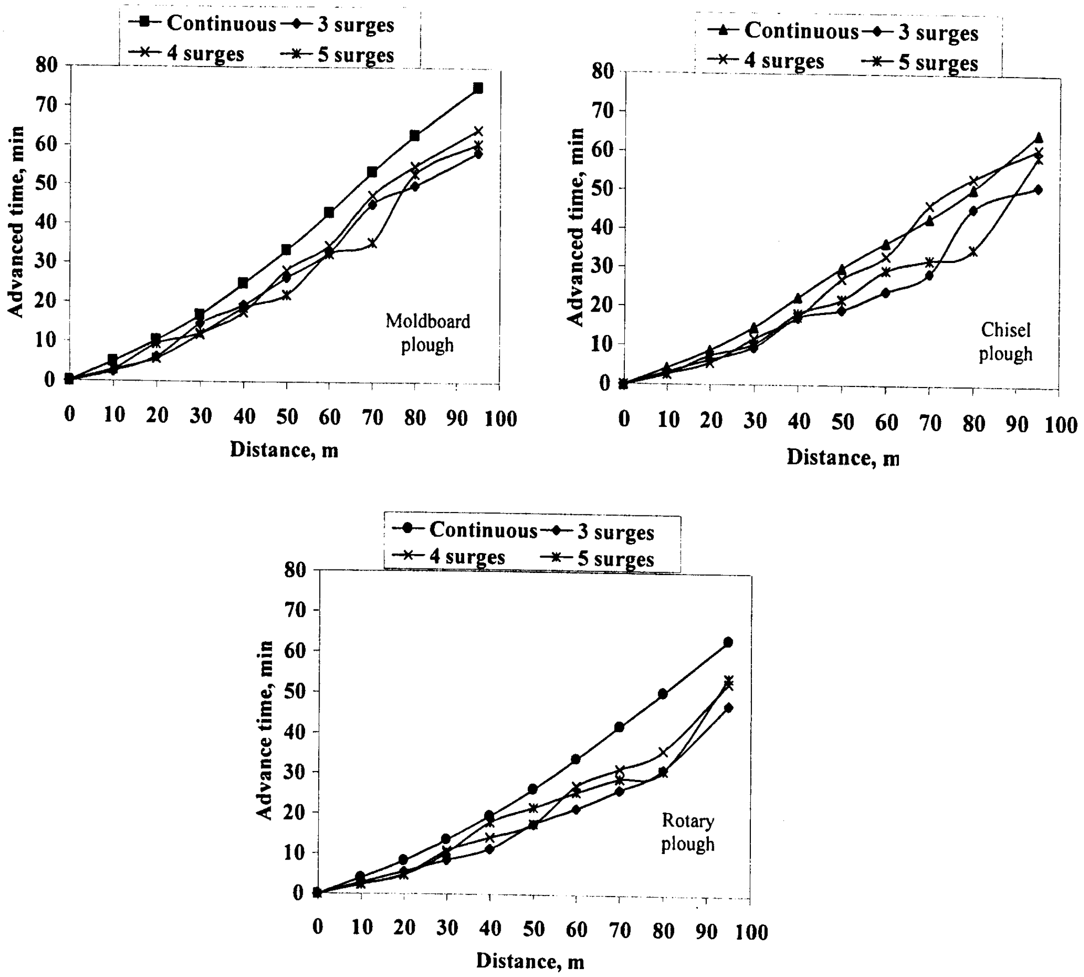

Fig. 8 : Advance time differences for continuous and surge flow irrigation under three different ploughs.

and partical sealing of the wetted soil surface according to **Samani *et al.* (1985) and Izadi *et al.* (1990)**.

On the other hand, the fit of the advance time is a power function $X = pt^r$ (where X distance, m.; t advance time, min.; and p, r constant), in accordance with **James (1988)**. The values of advance time are plotted against the values of advance distance for all different treatments illustrated in Fig. 9 . The advance rate data equation as well as the irrigation time (total on-time), for all different treatments are tabulated in Table 2. The advance time equations were statistically obtained by simple regression for irrigation runs.

The analysis indicated that coefficient of determination (R^2) values generally were highly significant. This means that the obtained difference are due to regression, while the duration from regression (error) was vary small in most of them and nothing in the others.

4.1.2. Amount of water applied:

During the growing season there were six irrigations including the sowing irrigation. The total amounts of water applied to different treatments are given in Table 2.

The total amounts of water added to continuous flow treatment were 2129.09, 1837.08 and 1794.56 m^3/fed. for moldboard, chisel and rotary plough, respectively. The total amounts of applied water by surge flow treatments (3, 4 and 5 surges) were 1658.48, 1822.91 and 1719.43 m^3/fed; 1454.36, 1729.35 and 1675.49 m^3/fed; and 1339.54, 1494.05 and 1530.90 m^3/fed. under moldboard, chisel, and rotary plough, respectively. The total amount of applied water by 3, 4 and 5 surges treatments were 77.90, 85.62

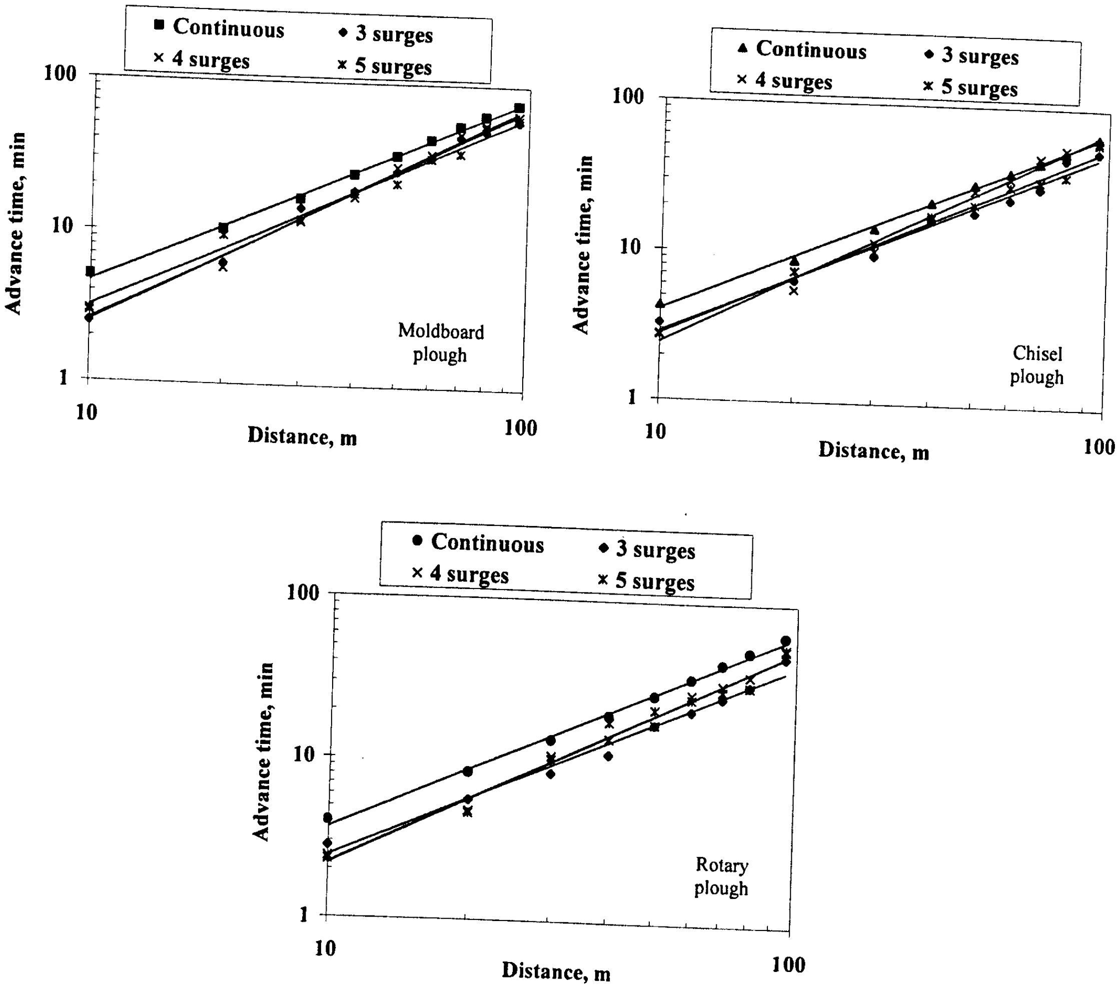

Fig. 9 : Relationship between advance time and distance for continuous and surge flow irrigation under three different ploughs.

and 80.76% of the water applied by continuous treatment under moldboard plough, respectively. The corresponding values under chisel plough were 79.17, 94.14 and 91.20 % for 3, 4 and 5 surges treatments, respectively. Also, the corresponding values under rotary plough were 74.64, 83.25 and 85.31 % for 3, 4 and 5 surges treatments, respectively.

These results showed considerable reductions in water applied by using 3, 4 and 5 surges treatments of 22.10, 14.38 and 19.24 % of water applied to continuous flow treatment under moldboard plough, respectively. The corresponding values reduction of the applied water under chisel plough were 20.83, 5.86 and 8.80 % for 3, 4 and 5 surges treatments, respectively. Also, under rotary plough, the corresponding values reduction of the applied water were 25.36, 16.75 and 14.69 % for 3, 4 and 5 surges treatments, respectively.

Therefore, surge flow technique caused a great reduction in total water volume used compared to the volume used by the continuous flow technique. This reduction is in close agreement with that given by **Eid (1998), Osman *et al.* (1996), Moustafa (1992), and Osman (1991).**

The best irrigation treatment for each plough system was 3 surges treatment, the saving of the applied irrigation water to maize crop. Reduction up to 18.58, 11.84 and 18.93 %, as previously mentioned in advanced time, were experienced for moldboard, chisel, and rotary plough under surge flow irrigation, respectively. This means that rotary plough emphasized the saving of the applied irrigation water to maize crop.

4.2. Infiltration behavior for continuous and surge flow under different tillage treatments:

Laboratory infiltrometer was used to investigate the infiltration behavior of the soil after using three plough treatments for continuous flow and the different surge flow treatments. The infiltration water depth for the tested soil was calculated using infiltration equations. These equations indicate soil characteristics, similar to that used by Kostiakov $Z = Kt^a$ [where Z was cumulative infiltration, mm.; t was elapsed time, min.; and (K and a) were empirical constants] to express the cumulative intake as a function of time. Different coefficients of Kostiakov's equation were computed according to the method suggested in the section on materials and methods.

4.2.1. Infiltration equation for continuous flow irrigation:

Tables 3, 4 and 5; and Fig.10 show the relation between cumulative infiltration and infiltration opportunity time for three plough treatments under continuous flow. In the same time, it shows the relation between infiltration rate and infiltration opportunity time.

The highest cumulative infiltrated water and infiltration rate at any time was with ploughing by moldboard comparing with chisel and rotary types. This may be due to the lowest bulk density (1.11 g/cm^3) and the highest total porosity (58.11 %) for moldboard plough, while rotary plough caused the highest bulk density (1.25 g/cm^3) and the lowest total porosity (52.83 %).

For each plough treatment, infiltration starts with the greatest rate of increase when the soil was relatively dry, dropped to a much lower infiltration rate after a period of time, and become lower and almost constant after a

Table 3: Laboratory infiltration test for continuous flow under moldboard plough conditions.

Elapsed time (t), min	Difference in time (dt), min	Cumulative infiltration (Z), mm	Difference in cum. inf. (dZ), mm	Infiltration rate (I), mm/h	Kostiakov equation $Z = Kt^a$
0	--	0	--	--	$Z = 3.154\,t^{0.6782}$
1	1	2.713	2.713	162.780	
2	1	5.050	2.337	140.220	
3	1	6.899	1.849	110.940	
5	2	9.951	3.052	91.560	
7	2	12.633	2.682	80.460	
9	2	14.952	2.319	69.570	
12	3	17.789	2.837	56.740	
15	3	20.191	2.402	48.040	
20	5	24.013	3.822	45.864	
25	5	27.610	3.597	43.164	
30	5	31.045	3.435	41.220	
40	10	37.630	6.585	39.510	
50	10	43.981	6.351	38.106	
65	15	52.718	8.737	34.948	
80	15	60.715	7.997	31.988	
100	20	70.397	9.682	29.046	
120	20	79.472	9.075	27.225	

K, a = empirical constants.

Table 4: Laboratory infiltration test for continuous flow under chisel plough conditions.

Elapsed time (t), min	Difference in time (dt), min	Cumulative infiltration (Z), mm	Difference in cum. inf. (dZ), mm	Infiltration rate (I), mm/h	Kostiakov equation $Z = Kt^a$
0	--	0	--	--	$Z = 2.2599\ t^{0.6988}$
1	1	2.018	2.018	121.080	
2	1	3.575	1.557	93.420	
3	1	5.076	1.501	90.060	
5	2	7.193	2.117	63.510	
7	2	9.074	1.881	56.430	
9	2	10.889	1.815	54.450	
12	3	13.271	2.382	47.640	
15	3	15.491	2.220	44.400	
20	5	18.921	3.430	41.160	
25	5	21.860	2.939	35.268	
30	5	24.614	2.754	33.048	
40	10	29.788	5.174	31.044	
50	10	34.424	4.636	27.816	
65	15	40.789	6.365	25.460	
80	15	46.904	6.115	24.460	
100	20	54.588	7.684	23.052	
120	20	61.948	7.360	22.080	

K, a = empirical constants.

Table 5: Laboratory infiltration test for continuous flow under rotary plough conditions.

Elapsed time (t), min	Difference in time (dt), min	Cumulative infiltration (Z), mm	Difference in cum. inf. (dZ), mm	Infiltration rate (I), mm/h	Kostiakov equation $Z = Kt^a$
0	--	0	--	--	$Z = 2.0768\ t^{0.5852}$
1	1	1.757	1.757	105.42	
2	1	3.050	1.293	77.580	
3	1	4.075	1.025	61.500	
5	2	5.655	1.580	47.400	
7	2	6.966	1.311	39.330	
9	2	8.025	1.059	31.770	
12	3	9.356	1.331	26.620	
15	3	10.451	1.095	21.900	
20	5	12.190	1.739	20.868	
25	5	13.840	1.650	19.800	
30	5	15.384	1.544	18.528	
40	10	17.971	2.587	15.522	
50	10	20.323	2.352	14.112	
65	15	23.381	3.058	12.232	
80	15	26.203	2.822	11.288	
100	20	29.373	3.170	9.510	
120	20	32.240	2.867	8.601	

K, a = empirical constants.

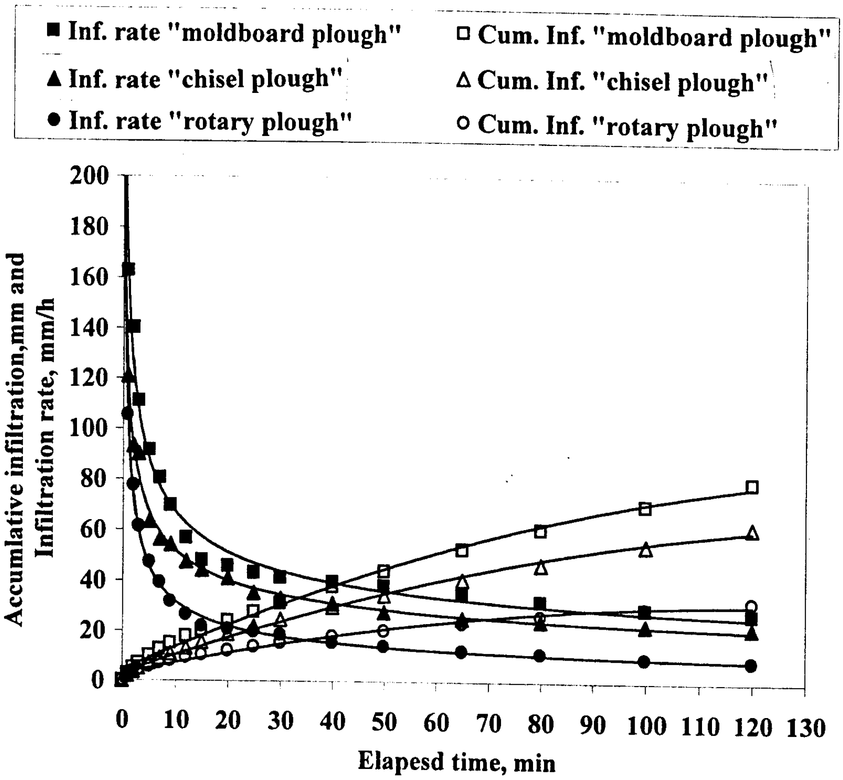

Fig. 10: Cumulative infiltration and infiltration rate vs. elapsed time for continuous flow under three different ploughs conditions.

period of time, as the soil sample gets more saturated with water (Tables 3, 4 and 5; and Fig.10).

The sealing of the soil surface and the formation of soil crusts, which is an important element in the reduction of infiltration from high rate, is caused partly by wetting and subsequent dry of the soil.

By plotting the data on a log-log paper as shown in Fig. 11, it was found the Kostiakov equation was fitted to the cumulative infiltration data from the continuous flow treatment for different plough systems as presented in Tables 3, 4 and 5.

4.2.2. Infiltration equation for surge flow irrigation:

Table 6 presents the data of average infiltration and elapsed time for 4 surges treatment under moldboard plough and other treatments are presented in Appendix A. Comparing the 4 surge flow treatments with the continuous flow treatment under moldboard plough, infiltration rate is plotted against elapsed time only excluding the surge off-time as shown in Fig.12 .

Evident in Fig.12 (4 surges treatment for moldboard plough) is during the first surge, the infiltration rate starts high 222.600 mm/h and drops to 70.530 mm/h in 6 minutes on-time. In other treatments, the infiltration rate starts high 215.940, 175.740 and 116.100 mm/h and drops to 61.160, 51.740 and 29.160 mm/h in 10 minutes on-time for 3 surges treatment under moldboard, chisel and rotary plough, respectively. The corresponding values for 4 surges treatment the infiltration rate starts high 191.280, and 125.700 mm/h and drops to 56.460, and 35.280 mm/h in 6 minutes under chisel and rotary plough, respectively. Also, The corresponding values for 5 surges treatment

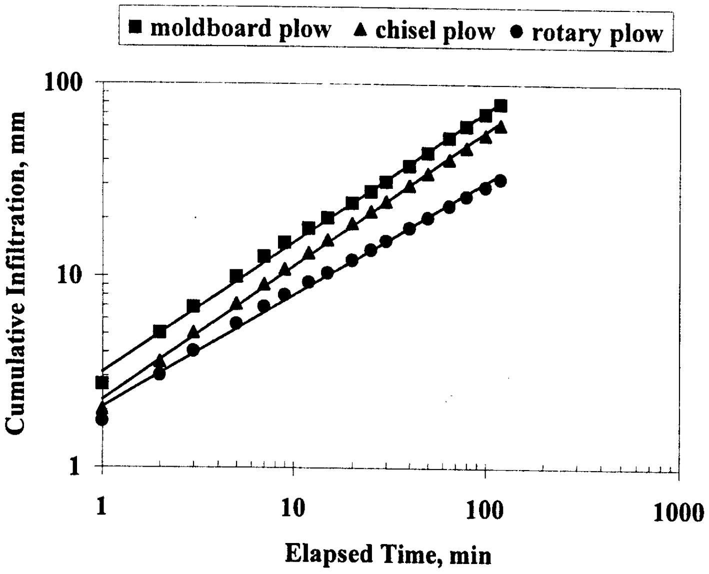

Fig. 11: Relationship between cumulative infiltration and elapsed time for continuous flow under three different ploughs conditions.

the infiltration rate starts high 265.980, 225.960 and 111.780 mm/h and drops to 84.480, 70.620 and 52.200 mm/h in 4 minutes under moldboard, chisel and rotary plough, respectively, as shown in Appendix B.

In Fig. 12 , a rebound or jump phenomenon, where the initial infiltration rate following the off-time is higher than the infiltration rate measured at the end of the preceding surge. This initial rate even exceeds the infiltration rate for continuous flow at the same opportunity time. As the surge cycle proceeds, however, the infiltration rate rapidly declines. The rebound effect is evident across all three ploughs and all three surge flow treatments, as shown in Appendix B.

Fig. 12 reflects the step drop in infiltration rate from 70.530 mm/h to 21.904 mm/h during off and on-times after the first surge. This discontinuity in infiltration rate accounted for the accelerated advance rates that occurred in surge irrigation after one complete cycle. Also, in other treatments, for 3 surges treatment are the step drops in infiltration rate from 61.160, 51.740 and 29.160 mm/h to 22.516, 18.945 and 8.400 mm/h under moldboard, chisel and rotary plough, respectively. The corresponding values for 4 surges treatment are the step drops in infiltration rate from 56.460 and 35.280 mm/h to 14.600 and 5.854 mm/h under chisel and rotary plough, respectively. For 4 surges treatment, the corresponding values are the step drops in infiltration rate from 84.480, 70.620 and 52.200 mm/h to 19.848, 14.303 and 4.590 mm/h under moldboard, chisel and rotary plough, respectively.

In most cases, the last infiltration rates measured were lower with surge flow than with continuous flow, despite shorter opportunity times in the case of surge (Table 7 and Appendix A). Since infiltration rates had become fairly

Table 6: Laboratory infiltration test for 4 surges under moldboard plough conditions.

No. of surges	Elapsed time (t), min	Difference in time (dt), min	Cumulative infiltration (Z), mm	Difference in cum. inf. (dZ), mm	Infiltration rate (I), mm/h	Kostiakov equation $Z = Kt^a$
1st	0	--	0	--	--	$Z = 3.8032\ t^{0.6446}$
	1	1	3.710	3.710	222.600	
	2	1	6.065	2.355	141.300	
	3	1	7.947	1.882	112.920	
	4	1	9.358	1.411	84.660	
	6	2	11.709	2.351	70.530	
2nd	2	2	2.011	2.011	60.330	$Z = 1.1276\ t^{0.8455}$
	4	2	3.671	1.660	49.800	
	6	2	5.164	1.493	44.790	
	8	2	6.561	1.397	41.910	
	11	3	8.480	1.919	38.380	
3rd	2	2	1.404	1.404	42.120	$Z = 0.7682\ t^{0.8896}$
	4	2	2.674	1.270	38.100	
	6	2	3.808	1.134	34.020	
	9	3	5.456	1.648	32.960	
	12	3	6.993	1.537	30.740	
	15	3	8.454	1.461	29.220	
4th	2	2	1.248	1.248	37.440	$Z = 0.705\ t^{0.8624}$
	4	2	2.364	1.116	33.480	
	6	2	3.353	0.989	29.670	
	9	3	4.733	1.380	27.60	
	12	3	6.066	1.333	26.660	
	16	4	7.731	1.665	24.975	
	20	4	9.324	1.593	23.895	
	25	5	11.239	1.915	22.980	
	32.3	7.3	13.901	2.662	21.904	

K, a = empirical constants.

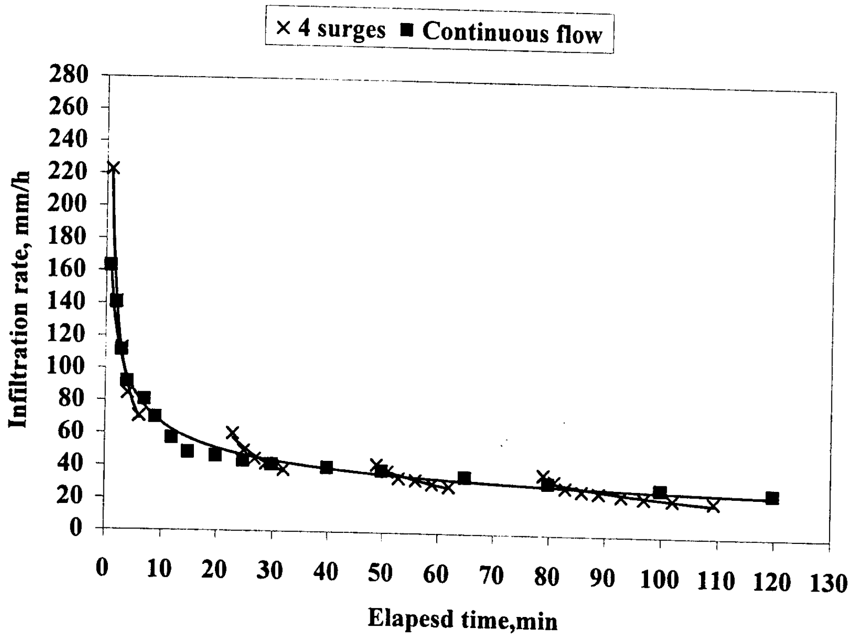

Fig. 12 : Comparison of infiltration rates for 4 surges and continuous flow under moldboard plough conditions.

Table 7: Measured infiltration rates (mm/h) and corresponding opportunity times (min) at the end of the Laboratory infiltration tests.

Treatment	Moldboard plough			Chisel plough			Rotary plough		
	Opp. Time, min	Inf. rate, mm/h	Reduction, %	Opp. Time, min	Inf. rate, mm/h	Reduction, %	Opp. Time, min	Inf. rate, mm/h	Reduction, %
Continuous	120.00	27.225	--	120.00	22.080	--	120.00	8.601	--
3 surges	58.50	22.516	17.30	51.30	18.945	14.20	47.25	8.400	2.34
4 surges	64.30	21.904	19.54	61.00	14.600	33.88	52.70	5.854	31.94
5 surges	60.65	19.848	27.10	59.10	14.303	35.22	54.00	4.590	46.63

constant by the end of most of the tests, the infiltration rates may be termed quasi-steady. This is according to **Bautista and Wallender (1985), and Testezlaf *et al.* (1987)**.

The data indicate that 3, 4 and 5 surges treatments reduced the quasi-steady infiltration rate by 17.30, 19.54 and 27.10%; 14.20, 33.88 and 35.22; and 2.34, 31.94 and 46.63% compared by the continuous flow treatment by using moldboard, chisel and rotary plough, respectively. The greatest reductions were observed when the rotary plough was used. This may be due to the highest bulk density (1.25 g/cm^3) and the lowest total porosity (52.83 %).

The typical power function curves that can be characterized by the Kostiakov relationship is plotted and fitted in Fig. 13 to the cumulative infiltration data for 4 surges treatment under moldboard plough. The same procedure is followed for each treatment in Appendix C.

4.3. Infiltration depth for continuous and surge flow under different tillage treatments:

4.3.1. Infiltration depth for continuous flow irrigation:

In Table 8 and Fig. 14 , at each station on the furrow for three plough treatments, the opportunity time was difference between the advance and recession time. The infiltration depth was found from the typical power function curve as shown in Fig. 11 .

In Table 9, the infiltration depth for each station was calculated and tabulated by using the opportunity times with Kostiakov equation for the cumulative infiltration depth. The depth of infiltration at every station for

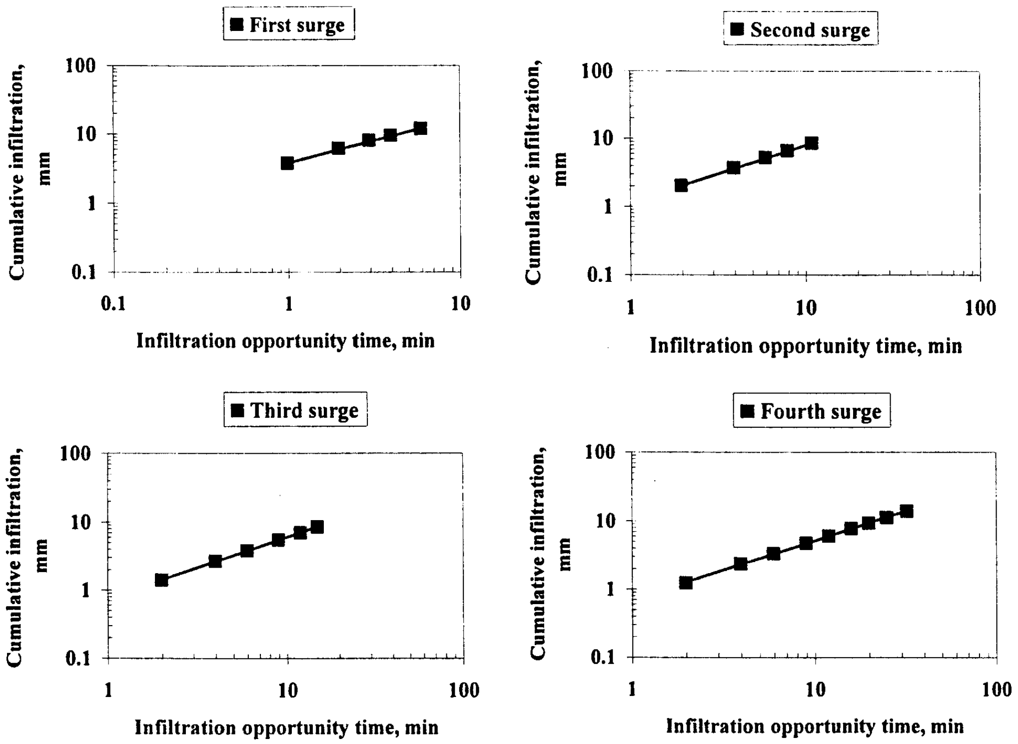

Fig. 13: Relationship between cumulative infiltration and infiltration opportunity time with typical infiltration for 4 surges under moldboard plough conditions.

Table 8: Advance time (min), recession time (min), and infiltration opportunity time (min) for continuous flow under three different ploughs during the experiment period.

Distance, m	Moldboard plough			Chisel plough			Rotary plough		
	A.T., min	R.T., min	IOT, min	A.T., min	R.T., min	IOT, min	A.T., min	R.T., min	IOT, min
0	0	86.30	86.30	0	68.50	68.50	0	77.20	77.20
10	5.00	86.40	81.40	4.30	70.75	66.45	4.00	79.65	75.65
20	10.40	86.65	76.25	8.80	73.15	64.35	8.25	82.10	73.85
30	16.85	87.70	70.85	14.70	76.45	61.75	13.45	84.45	71.00
40	24.90	89.70	64.80	22.40	80.35	57.95	19.45	86.85	67.40
50	33.40	91.70	58.30	30.00	84.00	54.00	26.20	89.30	63.10
60	43.00	93.30	50.30	36.50	86.30	49.80	33.80	91.65	57.85
70	53.50	94.85	41.35	42.90	88.20	45.30	42.00	94.10	52.10
80	62.80	96.65	33.85	50.60	90.10	39.50	50.30	96.70	46.40
95	75.10	99.80	24.70	64.80	93.00	28.20	63.30	101.00	37.70

A.T. = advance time, min.
R.T. = recession time, min.
IOT = infiltration opportunity time, min.

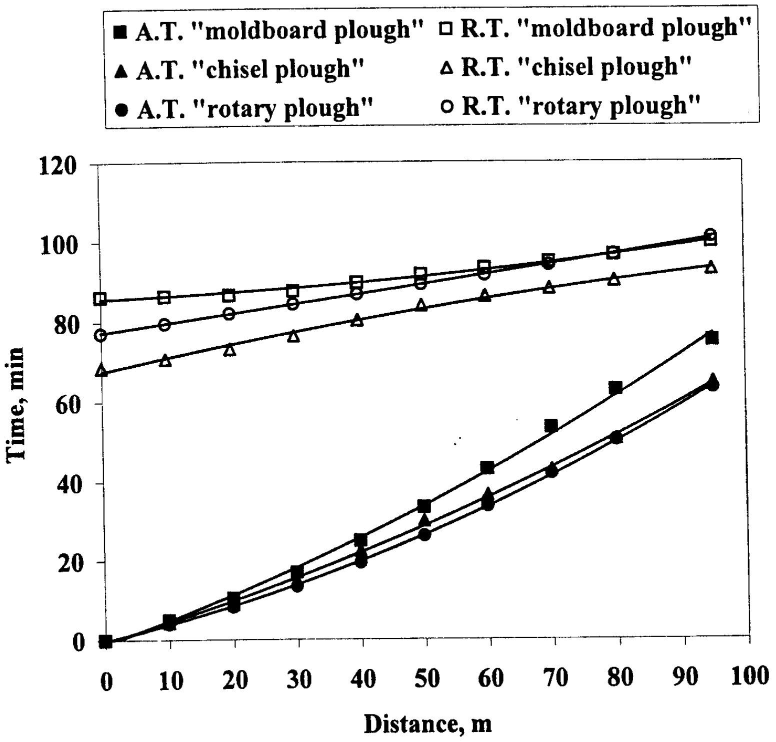

Fig. 14 : Advance and recession times for continuous flow irrigation with three different ploughs.

Table 9: Infiltration opportunity time and corresponding infiltrated depth for continuous flow under three different ploughs.

Distance, m	Moldboard plough		Chisel plough		Rotary plough	
	IOT, min	Inf. dep., mm	IOT, min	Inf. dep., mm	IOT, min	Inf. dep., mm
0	86.30	64.84	68.50	43.34	77.20	26.43
10	81.40	62.32	66.45	42.43	75.65	26.11
20	76.25	59.62	64.35	41.49	73.85	25.75
30	70.85	56.72	61.75	40.31	71.00	25.16
40	64.80	53.39	57.95	38.56	67.40	24.41
50	58.30	49.70	54.00	36.70	63.10	23.48
60	50.30	44.96	49.80	34.68	57.85	22.32
70	41.35	39.37	45.30	32.46	52.10	20.99
80	33.85	34.37	39.50	29.50	46.40	19.62
95	24.70	27.76	28.20	23.31	37.70	17.37

IOT = infiltration opportunity time, min.
Inf. dep. = infiltrated depth, mm.

plough treatments is drawn in Fig. 15. This is according to **Merriam and Keller (1978)**.

4.3.2. Infiltration depth for surge flow irrigation:

In Table 10 and Fig. 16, the 4 surges treatment showed that the opportunity time was found by measuring the difference between the advance and recession time for each surge. The advance and recession time for each treatment are tabulated and drawn in Appendix D. Also, Fig. 16 showed that 4 surges treatment is compared to the continuous flow treatment for moldboard plough.

The infiltration depth was found from the typical power function curves as shown in Fig. 13. The typical depth for each station is calculated and tabulated in Table 11.

To check the infiltration depth for each station, the average typical infiltration depths was compared with the depth of water applied in each surge. Therefore, the coefficient "K" of Kostiakov equation was adjusted to become "K`" where as, the exponent constant "a" still as it is. This had been done for all treatments, as presented in Table 12.

In each surge, the adjusted infiltrated depth at each station and the average of infiltrated depths among stations were computed as a check for the adjusted equation as shown in Table 11. The average of infiltrated depths was found to equal to the depth of inflow. The adjusted infiltration depths at each location along the furrow are plotted in Fig. 17 and also the infiltration depths for continuous flow are drawn in the same figure.

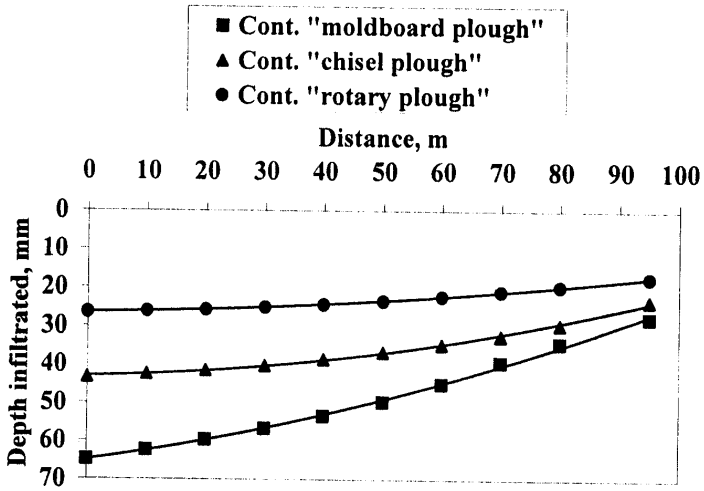

Fig. 15 : Infiltrated water distribution curves for continuous flow under three different ploughs.

Table 10: Advanced time (min), recession time (min), and infiltration opportunity time (min) for 4 surges under moldboard plough during the experiment period.

Distance, m	First surge			Second surge			Third surge			Fourth surge		
	A.T., min	R.T., min	IOT, min	A.T., min	R.T., min	IOT, min	A.T., min	R.T., min	IOT, min	A.T., min	R.T., min	IOT, min
0	0	8.25	8.25	21.00	34.10	13.10	47.00	64.00	17.00	77.00	113.30	36.30
10	2.90	8.47	5.57	22.30	35.40	13.10	47.15	67.35	20.20	77.38	115.30	37.92
20	5.85	8.62	2.77	23.77	36.68	12.91	47.60	70.60	23.00	77.85	118.30	40.45
30				26.95	37.67	10.72	49.80	72.65	22.85	78.45	120.52	42.07
40				32.60	36.40	3.80	53.70	72.60	18.90	79.00	118.50	39.50
50							58.30	71.00	12.70	81.90	116.50	34.60
60							64.70	69.30	4.60	86.95	115.85	28.90
70										92.50	115.73	23.23
80										100.00	114.38	14.38
95										109.30	113.80	4.50

A.T. = advance time, min.
R.T. = recession time, min.
IOT = infiltration opportunity time, min.

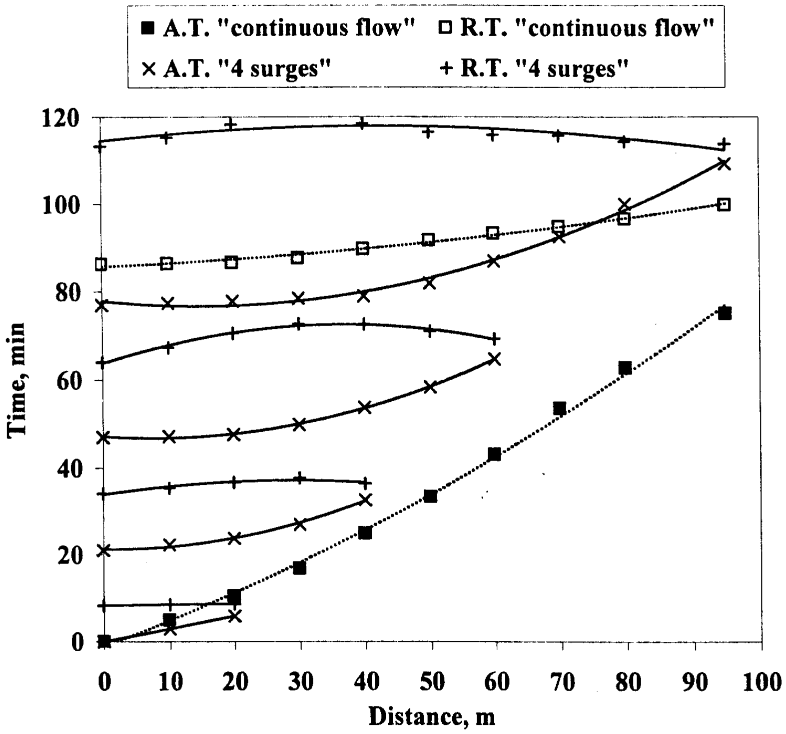

Fig. 16 : Comparison of Advance and recession times for continuous flow and 4 surges under moldboard plough.

Table 11: Infiltration opportunity time and corresponding typical and adjusted depth infiltrated for 4 surges under moldboard plough.

Distance, m	First surge			Second surge			Third surge			Fourth surge		
	IOT, min	Typ. inf. dep., mm	Adj. inf. dep., mm	IOT, min	Typ. inf. dep., mm	Adj. inf. dep., mm	IOT, min	Typ. inf. dep., mm	Adj. inf. dep., mm	IOT, min	Typ. inf. dep., mm	Adj. inf. dep., mm
0	8.25	14.82	49.25	13.10	9.93	30.27	17.00	9.55	10.49	36.30	15.61	16.14
10	5.57	11.51	38.23	13.10	9.93	30.27	20.20	11.14	12.22	37.92	16.21	16.76
20	2.77	7.33	24.37	12.91	9.80	29.90	23.00	12.50	13.72	40.45	17.14	17.72
30				10.72	17.55	58.31	22.85	15.89	48.46	42.07	21.39	23.48
40				3.80	8.99	29.88	18.90	12.93	41.27	39.50	20.22	22.20
50							12.70	19.57	65.04	34.60	22.57	68.82
60							4.60	11.55	33.80	28.90	19.38	59.10
70										23.23	28.89	95.99
80										14.38	21.21	70.46
95										4.50	10.03	33.32

IOT = infiltration opportunity time, min.
Typ. inf. dep. = typical infiltrated depth, mm.
Adj. inf. dep. = adjusted infiltrated depth, mm.

Table 12: Adjusted parameters for the fit of the Kostiakov's infiltration equation to surges treatments data ($Z = K`t^a$ with Z in mm and t in min) for different treatments.

Treatment	Moldboard plough		Chisel plough		Rotary plough	
	K`	a	K`	a	K`	a
3 surges	10.5038	0.6711	10.1112	0.6394	7.7888	0.6431
	0.6783	0.9471	0.4940	0.9904	1.2081	0.8141
	0.5594	0.9506	1.0791	0.9165	0.6396	0.7492
4 surges	12.6381	0.6446	11.1630	0.6271	8.8342	0.6311
	3.4389	0.8455	2.6598	0.8535	3.9180	0.6458
	0.8433	0.8896	1.2958	0.9015	1.2727	0.6532
	0.7288	0.8624	0.8746	0.7658	2.3996	0.5713
5 surges	13.4500	0.6072	14.2702	0.5866	9.2352	0.7246
	3.6629	0.7996	1.4041	0.8262	5.7622	0.6933
	1.6103	0.8235	2.6878	0.7835	1.1951	0.6452
	2.2546	0.8810	0.9126	0.8404	0.7640	0.5844
	0.8464	0.8315	1.1830	0.8069	2.8424	0.5697

K`= adjusted constant.
a = empirical constant.

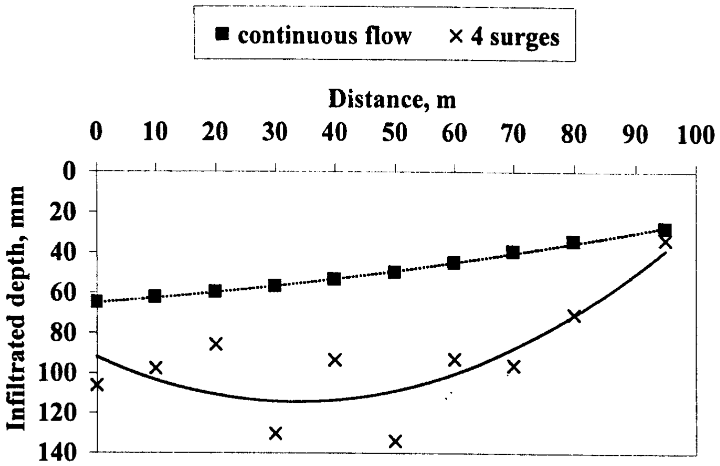

Fig. 17 : Infiltrated water distribution curves for continuous flow and 4 surges under moldboard plough.

The same procedure was followed for each treatment and these are shown in Appendix E.

4.4. Effect of surge flow on water-application efficiency and water-distribution efficiency under different tillage treatments:

4.4.1. Water-application efficiency (E_a):

Water-application efficiency becomes more important as demands on irrigation water increase. The water-application efficiency is shown in Fig. 18.

The E_a values [equation No. (3.4) in the section materials and methods] for continuous flow treatments were 48.51, 41.37 and 27.04 % under moldboard, chisel, and rotary plough, respectively. The corresponding values for 3, 4 and 5 surges treatments were 93.56, 98.49 and 97.84 % (average of 96.63 %); 93.47, 98.05 and 93.46 % (average of 94.99 %); and 88.12, 92.84 and 92.05 % (average of 91.00 %) under moldboard, chisel and rotary plough, respectively. Excess of 48.12, 53.63 and 63.96 % were experienced for moldboard, chisel and rotary plough under surge flow irrigation, respectively.

The results indicated that the E_a values for surge flow treatments were higher than that for continuous ones. It can be attributed to the rapid advance of waterfront for surge flow treatments. This is an agreement with **Ismail *et al.* (1985), Guirguis (1988), Osman (1991), and Eid (1998)**.

On the other hand, the E_a value for 4 surges treatment under moldboard plough was the highest. It might be due to the moldboard caused the lowest bulk density (1.11 g/cm^3) and the highest total porosity (58.11 %) more than others.

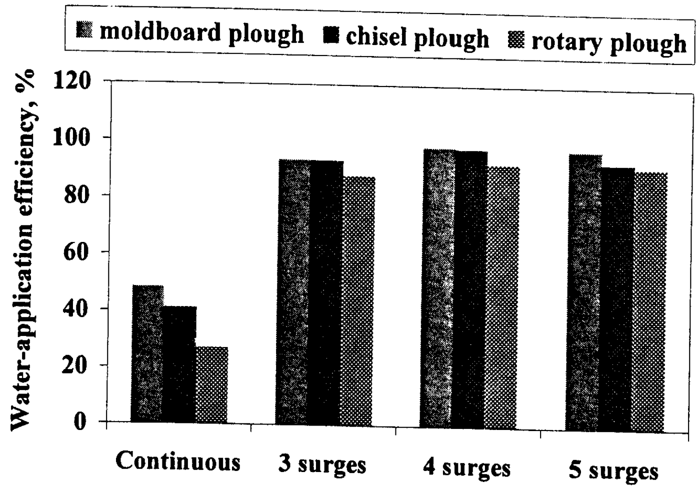

Fig. 18 : Water-application efficiency for continuous and surge flow irrigation under three different ploughs.

4.4.2. Water-distribution efficiency (E_d):

Water-distribution efficiency is shown in Fig. 19 for continuous flow and surge flow treatments under different tillage systems.

The E_d values [equation No. (3.5) in the section materials and methods] for continuous flow treatments were 79.41, 86.13 and 89.33 % under moldboard, chisel and rotary plough, respectively. The corresponding values for 3, 4 and 5 surges treatments were 79.42, 79.99 and 67.40 % (average of 75.60 %); 78.44, 76.36 and 73.87 % (average of 76.22 %); and 82.23, 83.90 and 79.47 % (average of 81.86 %) under moldboard, chisel, and rotary plough respectively.

From these obtained data, it can be concluded that, the average values of E_d for surge flow treatments gave the lowest values comparing with continuous flow treatments. **Guirguis (1988) and Zein El-Abdin (1988)** in agreement with those obtain tendencies of these results. This might be that the soil is glycollic and it is able to save water in a high level.

But, this is not a true indicator because water-distribution efficiency depends on deviation of water depths values from its mean regardless whether it is around root system region or not. So, it may be found furrow with high water-distribution efficiency in a zone not around root system where water is required. On the other side, it may be found another furrow with low water-distribution efficiency despite water needed around root system is available.

On other hand, the E_d values in case of rotary plough were the highest. This may be attributed to the highest bulk density (1.25 g/cm^3) and the lowest total porosity (52.83 %). Also, a trend is observed from Fig. 19 that is, in

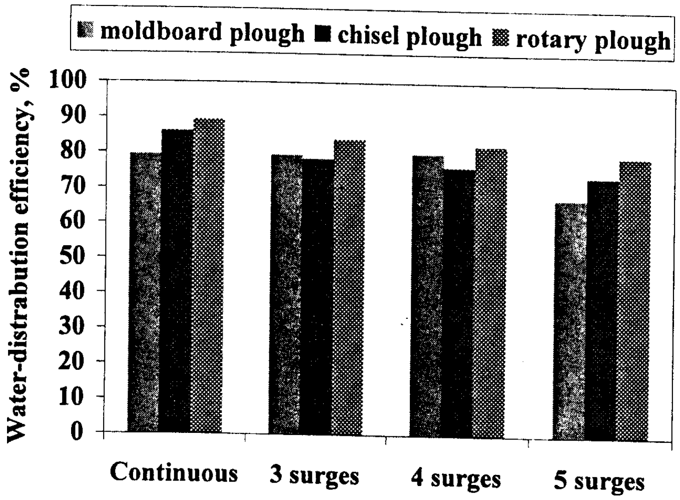

Fig. 19 : Water-distribution efficiency for continuous and surge flow irrigation under three different ploughs.

surge flow treatments, the E_d value of 3 surges treatment for rotary plough method was the highest due to increasing the off-time (20 min.).

4.5. Effect of surge flow on yield and field water-use efficiency under different tillage treatments:

4.5.1. Yield (Y):

The grain yield of maize for continuous and surge irrigation treatments and different tillage systems is shown in Table 13 and Fig. 20.

Maize grain yields for continuous flow treatments were 3181.60, 3836.00 and 2679.40 kg/fed. under moldboard, chisel and rotary plough, respectively. The corresponding values for 3, 4 and 5 surges treatments varied between 3562.00 to 3777.65 kg/fed. (average of 3644.35 kg/fed.), between 3859.80 to 4372.40 kg/fed. (average of 4049.87 kg/fed.), and between 2843.80 to 3384.60 kg/fed. (average of 3160.80 kg/fed.) under moldboard, chisel and rotary plough, respectively.

The 3 surges treatment recorded the highest yield for each plough method. The yield increased by 15.78, 12.27 and 20.84 % comparing by the yield of the continuous irrigation, for moldboard, chisel, and rotary plough, respectively. But, the chisel plough achieved the highest grain yield values. This may be due to its value, which is not low or high for water-application efficiency and water-distribution efficiency compare with both of other plough treatments.

Generally, surge flow irrigation had higher grain yield values than that of continuous flow irrigation. The highest production in surge irrigation may be attributed to increasing soil aeration with relatively fewer amounts of applied

Table 13: Yield and Field water-use efficiency for continuous and surge flow irrigation under three different ploughs.

Treatment	Moldboard plough			Chisel plough			Rotary plough		
	Yield, kg/fed.	App. water, m^3/fed.	E_t, kg/m^3	Yield, kg/fed.	App. water, m^3/fed.	E_t, kg/m^3	Yield, kg/fed.	App. water, m^3/fed.	E_t, kg/m^3
Continuous	3181.60	2129.09	1.49	3836.00	1837.08	2.09	2679.40	1794.56	1.49
3 surges	3777.65	1658.48	2.28	4372.40	1454.36	3.01	3384.60	1339.54	2.53
4 surges	3593.40	1822.91	1.97	3917.40	1729.35	2.27	3254.00	1494.05	2.18
5 surges	3562.00	1719.43	2.07	3859.80	1675.49	2.30	2843.80	1530.90	1.86

E_t = field water-use efficiency, kg/m^3.

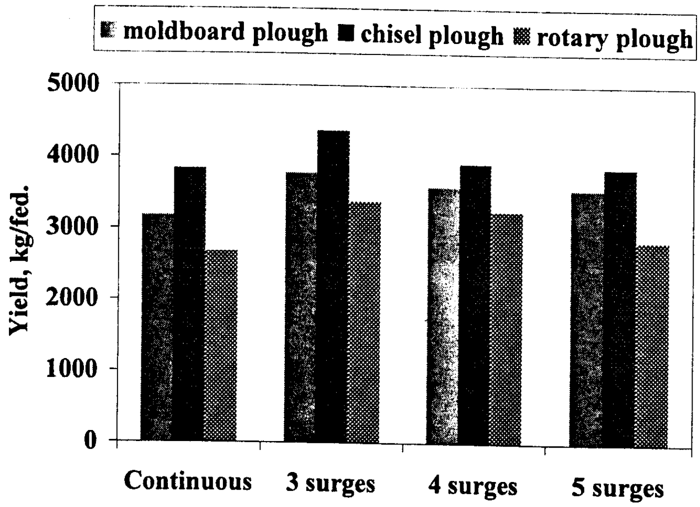

Fig. 20: Yield for continuous and surge flow irrigation under three different ploughs.

irrigation water. But under continuous irrigation the maize yield may be decrease due to the leaching of nutrients from the soil profile as a result of high amount of drained water. These results are similar to that found by **Osman (1991), El-Zaher *et al.* (1996), El-Saadawy (1997), and Eid (1998).**

4.5.2. Field water-use efficiency (E_t):

Field water-use efficiency for different treatments are presented in Table 13 and shown in Fig. 21. The E_t can be increased either by increasing crop productivity or by decreasing water losses. Therefore, one main objective of the water management studies is to maximizing of crop yield per each unit of applied water.

The E_t values for continuous flow treatments were 1.49, 2.09 and 1.49 kg/m^3 when the moldboard, chisel, and rotary plough were used, respectively. The corresponding values for 3, 4 and 5 surges treatments varied from 1.97 to 2.28 kg/m^3 (average of 2.11 kg/m^3), from 2.27 to 3.01 kg/m^3 (average of 2.53 kg/m^3), and from 1.86 to 2.53 kg/m^3 (average of 2.19 kg/m^3) under moldboard, chisel and rotary plough, respectively.

The results showed that surge flow irrigation improved the E_t comparing by the continuous flow irrigation. Highest value of Et was when the 3 surges treatment applied and chisel plough used. It can be attributed to a more rapid advance rate for the wetting front, the lowest amount of irrigation water applied through growing season, and the highest production for maize crop. These trends of results are similar to the E_t obtained by **Osman (1991), El-Zaher *et al.* (1996), El-Saadawy (1997), and Eid (1998).**

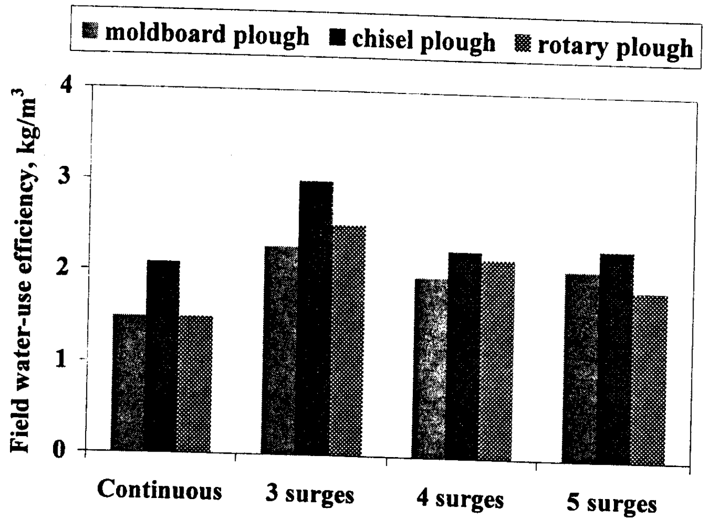

Fig. 21: Field water-use efficiency for continuous and surge flow irrigation under three different ploughs.

5- SUMMARY AND CONCLUSION

Surge flow furrow irrigation is a new irrigation technique for controlling furrow irrigation. The main purpose of this study was to investigate the effect of surge furrow irrigation comparing with continuous irrigation on water management and yield of maize with different ploughing methods.

Field experiments were carried out at Zarzora Agricultural Research Station, Etay El-Baroud, Beheira Governorate, Egypt during 1998/1999 growing season. It was divided into three main plots; each plot was 17 m wide and 95 m long. The main plot was assigned to plowing systems. Each plot was divided into four strips (sub-main plots). The area of each strip was 332.5m^2. The sub-main plot was assigned to irrigation treatments.

The soil type is clay loam soil. The furrow has 95 m length, and 0.70 m width, 0.04% slope, and 0.037 Manning's roughness (n).

The treatments were studied and tested in this work as follows:

- Ploughing treatments (main plot):
    1- Moldboard plough (ploughing optimum depth 25 cm).
    2- Chisel plough (ploughing optimum depth 20 cm).
    3- Rotary plough (ploughing optimum depth 12 cm).

- Irrigation treatments (sub-main plot):
    A- Continuous flow (control).

B- Surge irrigation with 3 surges, on-time (10 – 19 – 25) minutes and off-time 20 minutes between the surges; total on-time 54 minutes.

C- Surge irrigation with 4 surges, on-time (6 – 11 – 15 – 18) minutes and off- time 15 minutes between the surges; total on-time 50 minutes.

D- Surge irrigation with 5 surges, on-time (4 – 8 – 10 – 12 – 13) minutes and off-time 10 minutes between the surges; total on-time 47 minutes.

Irrigation water was applied to each furrow through a plastic siphon, (2 meters length, 50 mm diameter) and inflow rate 1.5 l/s for each furrow.

Laboratory experiments were conducted to measure the water infiltration rates under continuous and surge application of water by The laboratory infiltrometer which consisted of: glass cylinder, holder, Mariotte tube, filter paper, plastic hose, and valve.

The field and laboratory measurements were recorded during the growing season as follows:

1- The water advance and recession times for stations (10 m intervals) along each furrow.
2- Yield of maize crop at the beginning, middle, and end of the furrow.
3- Cumulative infiltration depths against opportunity infiltration time for every treatment.

The parameters for different treatments were calculated as follows:

1- The total water on-time to each treatment.
2- The total amount of water applied to each treatment.
3- Water-application efficiency (E_a).
4- Water-distribution efficiency (E_d).

5- Field water-use efficiency (E_t).

According to the obtained results, it may be concluded that:

1- Surge flow treatments required less time completion of the advance phase than in those continuous flow treatments.

2- The 3 surges treatment for rotary plough was the fastest advance rate. It reduced the advance time 25.36 % than the advance time for continuous irrigation.

3- The percentage of water saving by using surge technique were 11.84, 18.58 and 18.93% of water applied to maize crop to compared by continuous flow with chisel, moldboard and rotary plough, respectively.

4- The 3 surges treatment for rotary plough irrigated less total amount of applied water (1339.54 m^3/fed.) about 74.64 % of total amount of applied water for continuous irrigation at the same condition.

5- The surge flow caused reduction in the quasi-steady infiltration rates of the three studied ploughs, despite shorter opportunity times for the surge treatments.

6- The 4 surges treatment for moldboard plough gave the highest water-application efficiency (E_a) (98.49 %).

7- Water-distribution efficiency (E_d) for surge flow treatments gave the lowest values comparing with continuous flow treatments.

8- In surge flow treatments, the 3 surges treatment for rotary plough had the highest water-distribution efficiency ($E_d = 83.90$ %).

9- The highest value of maize grain yield (4372.40 kg/fed.) accomplished the 3 surges treatment for chisel plough.

10- The 3 surges treatment for chisel plough also, recorded the highest value of field water-use efficiency ($E_t = 3.01$ kg/m^3).

Finally, future studies' recommendations are:

1- More investigations need to study the effects of surge irrigation on the advance rates related to soil type, furrow shape and slope; and stream flow rates.

2- Effect of cycling water on sediment, transportation and erosion in the furrows.

3- Studies should be evaluate other applications of the surge flow system (border and basin irrigation) at different ploughing systems.

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APPENDIX A

Table 1: Laboratory infiltration test for 3 surges under moldboard plough conditions.

No. of surges	Elapsed time (t), min	Difference in time (dt), min	Cumulative infiltration (Z), mm	Difference in cum. inf. (dZ), mm	Infiltration rate (I), mm/h	Kostiakov equation $Z = Kt^a$
1st	0	--	0	--	--	$Z = 3.7527\ t^{0.6711}$
	1	1	3.599	3.599	215.940	
	2	1	6.186	2.587	155.220	
	3	1	8.067	1.881	112.860	
	5	2	11.125	3.058	91.740	
	7	2	13.947	2.822	84.660	
	10	3	17.005	3.058	61.160	
2nd	1	1	0.569	0.569	34.140	$Z = 0.5754\ t^{0.9471}$
	3	2	1.657	1.088	32.640	
	5	2	2.657	1.000	30.000	
	7	2	3.635	0.978	29.340	
	10	3	5.081	1.446	28.920	
	13	3	6.513	1.432	28.640	
	16	3	7.934	1.421	28.420	
	19	3	9.333	1.399	27.980	
3rd	1	1	0.465	0.465	27.900	$Z = 0.4707\ t^{0.9506}$
	3	2	1.346	0.881	26.430	
	5	2	2.193	0.847	25.410	
	7	2	3.012	0.819	24.570	
	10	3	4.218	1.206	24.120	
	13	3	5.391	1.173	23.460	
	16	3	6.554	1.163	23.260	
	20	4	8.091	1.537	23.055	
	24	4	9.621	1.530	22.950	
	29.5	5.5	11.688	2.067	22.516	

K, a = empirical constants.

Table 2: Laboratory infiltration test for 3 surges under chisel plough conditions.

No. of surges	Elapsed time (t), min	Difference in time (dt), min	Cumulative infiltration (Z), mm	Difference in cum. inf. (dZ), mm	Infiltration rate (I), mm/h	Kostiakov equation $Z = Kt^a$
1^{st}	0	--	0	--	--	$Z = 3.0974\, t^{0.6394}$
	1	1	2.929	2.929	175.740	
	2	1	5.046	2.117	127.020	
	3	1	6.575	1.529	91.740	
	5	2	8.691	2.116	63.480	
	7	2	10.573	1.882	56.460	
	10	3	13.160	2.587	51.740	
2^{nd}	1	1	0.462	0.462	27.720	$Z = 0.4632\, t^{0.9904}$
	3	2	1.378	0.916	27.480	
	5	2	2.286	0.908	27.240	
	7	2	3.186	0.900	27.000	
	10	3	4.532	1.346	26.920	
	13	3	5.873	1.341	26.820	
	16	3	7.209	1.336	26.720	
	19	3	8.544	1.335	26.700	
3^{rd}	1	1	0.465	0.465	27.900	$Z = 0.4698\, t^{0.9165}$
	3	2	1.292	0.827	24.810	
	5	2	2.067	0.775	23.250	
	7	2	2.813	0.746	22.380	
	10	3	3.909	1.096	21.920	
	13	3	4.949	1.040	20.800	
	16	3	5.959	1.010	20.200	
	19	3	6.943	0.984	19.680	
	22.3	3.3	7.985	1.042	18.945	

K, a = empirical constants

Table 3: Laboratory infiltration test for 3 surges under rotary plough conditions.

No. of surges	Elapsed time (t), min	Difference in time (dt), min	Cumulative infiltration (Z), mm	Difference in cum. inf. (dZ), mm	Infiltration rate (I), mm/h	Kostiakov equation $Z = Kt^a$
1st	0	--	0	--	--	$Z = 3.0137\ t^{0.6431}$
	1	1	1.935	1.935	116.100	
	2	1	3.212	1.277	76.620	
	3	1	4.241	1.029	61.740	
	5	2	5.749	1.508	45.240	
	7	2	7.067	1.318	39.540	
	10	3	8.525	1.458	29.160	
2nd	1	1	0.502	0.502	30.120	$Z = 0.5084\ t^{0.8141}$
	3	2	1.255	0.753	22.590	
	5	2	1.898	0.643	19.290	
	7	2	2.503	0.605	18.150	
	10	3	3.329	0.826	16.520	
	13	3	4.110	0.781	15.620	
	16	3	4.826	0.716	14.320	
	19	3	5.518	0.692	13.840	
3rd	1	1	0.442	0.442	26.520	$Z = 0.4500\ t^{0.7492}$
	3	2	1.043	0.601	18.030	
	5	2	1.510	0.467	14.010	
	7	2	1.948	0.438	13.140	
	9	2	2.351	0.403	12.090	
	12	3	2.912	0.561	11.220	
	15	3	3.418	0.506	10.120	
	18.25	3.25	3.873	0.455	8.400	

K, a = empirical constants

Table 4: Laboratory infiltration test for 4 surges under chisel plough conditions.

No. of surges	Elapsed time (t), min	Difference in time (dt), min	Cumulative infiltration (Z), mm	Difference in cum. inf. (dZ), mm	Infiltration rate (I), mm/h	Kostiakov equation $Z = Kt^a$
1st	0	--	0	--	--	$Z = 3.2711\ t^{0.6271}$
	1	1	3.188	3.188	191.280	
	2	1	5.164	1.976	118.560	
	3	1	6.693	1.529	91.740	
	4	1	7.869	1.176	70.560	
	6	2	9.751	1.882	56.460	
2nd	2	2	1.643	1.643	49.290	$Z = 0.9208\ t^{0.8535}$
	4	2	3.055	1.412	42.360	
	6	2	4.287	1.232	36.960	
	8	2	5.420	1.133	33.990	
	11	3	7.053	1.633	32.660	
3rd	2	2	1.236	1.236	37.080	$Z = 0.6664\ t^{0.9015}$
	4	2	2.346	1.110	33.300	
	6	2	3.363	1.017	30.510	
	9	3	4.827	1.464	29.280	
	12	3	6.260	1.433	28.660	
	15	3	7.625	1.365	27.300	
4th	2	2	1.276	1.276	38.280	$Z = 0.7746\ t^{0.7658}$
	4	2	2.242	0.966	28.980	
	6	2	3.099	0.857	25.710	
	9	3	4.265	1.166	23.320	
	12	3	5.343	1.078	21.560	
	15	3	6.261	0.918	18.360	
	19	4	7.397	1.136	17.040	
	23	4	8.397	1.000	15.000	
	29	6	9.857	1.460	14.600	

K, a = empirical constants.

Table 5: Laboratory infiltration test for 4 surges under rotary plough conditions.

No. of surges	Elapsed time (t), min	Difference in time (dt), min	Cumulative infiltration (Z), mm	Difference in cum. inf. (dZ), mm	Infiltration rate (I), mm/h	Kostiakov equation $Z = Kt^a$
1st	0	--	0	--	--	$Z = 2.1368\ t^{0.6311}$
	1	1	2.095	2.095	125.700	
	2	1	3.343	1.248	74.880	
	3	1	4.378	1.035	62.100	
	4	1	5.225	0.847	50.820	
	6	2	6.401	1.176	35.280	
2nd	2	2	1.581	1.581	47.430	$Z = 1.0249\ t^{0.6458}$
	4	2	2.526	0.945	28.350	
	6	2	3.326	0.800	24.000	
	8	2	3.985	0.659	19.770	
	11	3	4.690	0.705	14.100	
3rd	2	2	1.119	1.119	33.570	$Z = 0.7292\ t^{0.6532}$
	4	2	1.826	0.707	21.210	
	6	2	2.414	0.588	17.640	
	9	3	3.119	0.705	14.100	
	12	3	3.684	0.565	11.300	
	15	3	4.154	0.470	9.400	
4th	2	2	1.234	1.234	37.020	$Z = 0.8500\ t^{0.5713}$
	4	2	1.849	0.615	18.450	
	6	2	2.392	0.543	16.290	
	8	2	2.909	0.517	15.510	
	11	3	3.464	0.555	11.100	
	14	3	3.905	0.441	8.820	
	17	3	4.210	0.305	6.100	
	20.7	3.7	4.571	0.361	5.854	

K, a = empirical constants.

Table 6: Laboratory infiltration test for 5 surges under moldboard plough conditions.

No. of surges	Elapsed time (t), min	Difference in time (dt), min	Cumulative infiltration (Z), mm	Difference in cum. inf. (dZ), mm	Infiltration rate (I), mm/h	Kostiakov equation $Z = Kt^a$
1st	0	--	0	--	--	$Z = 4.4790\,t^{0.6072}$
	1	1	4.433	4.433	265.980	
	2	1	6.935	2.502	150.120	
	3	1	8.817	1.882	112.920	
	4	1	10.225	1.408	84.480	
2nd	1	1	1.497	1.497	89.820	$Z = 1.5014\,t^{0.7996}$
	3	2	3.616	2.119	63.570	
	5	2	5.498	1.882	56.460	
	8	3	7.850	2.352	47.040	
3rd	1	1	1.073	1.073	64.380	$Z = 1.0824\,t^{0.8235}$
	3	2	2.703	1.630	48.900	
	5	2	4.133	1.430	42.900	
	7	2	5.321	1.188	35.640	
	10	3	7.163	1.842	36.840	
4th	2	2	1.515	1.515	45.450	$Z = 0.8309\,t^{0.8810}$
	4	2	2.845	1.330	39.900	
	6	2	4.074	1.229	36.870	
	9	3	5.751	1.677	33.540	
	12	3	7.348	1.597	31.940	
5th	2	2	1.239	1.239	37.170	$Z = 0.7273\,t^{0.8315}$
	4	2	2.354	1.115	33.450	
	6	2	3.303	0.949	28.470	
	8	2	4.177	0.874	26.220	
	10	2	5.016	0.839	25.170	
	13	3	6.167	1.151	23.020	
	17	4	7.623	1.456	21.840	
	21	4	9.023	1.400	21.000	
	26.65	5.65	10.892	1.869	19.848	

K, a = empirical constants.

Table 7: Laboratory infiltration test for 5 surges under chisel plough conditions.

No. of surges	Elapsed time (t), min	Difference in time (dt), min	Cumulative infiltration (Z), mm	Difference in cum. Inf. (dZ), mm	Infiltration rate (I), mm/h	Kostiakov equation $Z = Kt^a$
1st	0	--	0	--	--	$Z = 3.8199\ t^{0.5866}$
	1	1	3.766	3.766	225.960	
	2	1	5.892	2.126	127.560	
	3	1	7.300	1.408	84.480	
	4	1	8.477	1.177	70.620	
2nd	1	1	1.161	1.161	69.660	$Z = 1.1646\ t^{0.8262}$
	3	2	2.903	1.742	52.260	
	5	2	4.420	1.517	45.510	
	8	3	6.452	2.032	40.640	
3rd	1	1	1.008	1.008	60.480	$Z = 1.0164\ t^{0.7835}$
	3	2	2.432	1.424	42.720	
	5	2	3.607	1.175	35.250	
	7	2	4.685	1.078	32.340	
	10	3	6.096	1.411	28.220	
4th	2	2	1.274	1.274	38.220	$Z = 0.7187\ t^{0.8404}$
	4	2	2.327	1.053	31.590	
	6	2	3.267	0.940	28.200	
	9	3	4.562	1.295	25.900	
	12	3	5.740	1.178	23.560	
5th	2	2	1.000	1.000	30.000	$Z = 0.5941\ t^{0.8069}$
	4	2	1.867	0.867	26.010	
	6	2	2.570	0.703	21.090	
	8	2	3.215	0.645	19.350	
	10	2	3.844	0.629	18.870	
	13	3	4.736	0.892	17.840	
	16	3	5.575	0.839	16.780	
	19	3	6.357	0.782	15.640	
	22	3	7.119	0.762	15.240	
	25.1	3.1	7.858	0.739	14.303	

K, a = empirical constants.

Table 8: Laboratory infiltration test for 5 surges under rotary plough conditions.

No. of surges	Elapsed time (t), min	Difference in time (dt), min	Cumulative infiltration (Z), mm	Difference in cum. Inf. (dZ), mm	Infiltration rate (I), mm/h	Kostiakov equation $Z = Kt^a$
1st	0	--	0	--	--	$Z = 1.8771\ t^{0.7246}$
	1	1	1.863	1.863	111.780	
	2	1	3.137	1.274	76.440	
	3	1	4.194	1.057	63.420	
	4	1	5.064	0.870	52.200	
2nd	1	1	1.190	1.190	71.400	$Z = 1.2007\ t^{0.6933}$
	3	2	2.611	1.421	42.630	
	5	2	3.693	1.082	32.460	
	8	3	5.006	1.313	26.260	
3rd	1	1	0.940	0.940	56.400	$Z = 0.9399\ t^{0.6452}$
	3	2	1.879	0.939	28.170	
	5	2	2.703	0.824	24.720	
	7	2	3.361	0.658	19.740	
	10	3	4.067	0.706	14.120	
4th	2	2	1.023	1.023	30.690	$Z = 0.7017\ t^{0.5844}$
	4	2	1.619	0.596	17.880	
	6	2	2.065	0.446	13.380	
	9	3	2.534	0.469	9.380	
	12	3	2.911	0.377	7.540	
5th	2	2	0.879	0.879	26.370	$Z = 0.6184\ t^{0.5697}$
	4	2	1.387	0.508	15.240	
	6	2	1.777	0.390	11.700	
	9	3	2.221	0.444	8.880	
	12	3	2.590	0.369	7.380	
	16	4	2.963	0.373	5.595	
	20	4	3.269	0.306	4.590	

K, a = empirical constants.

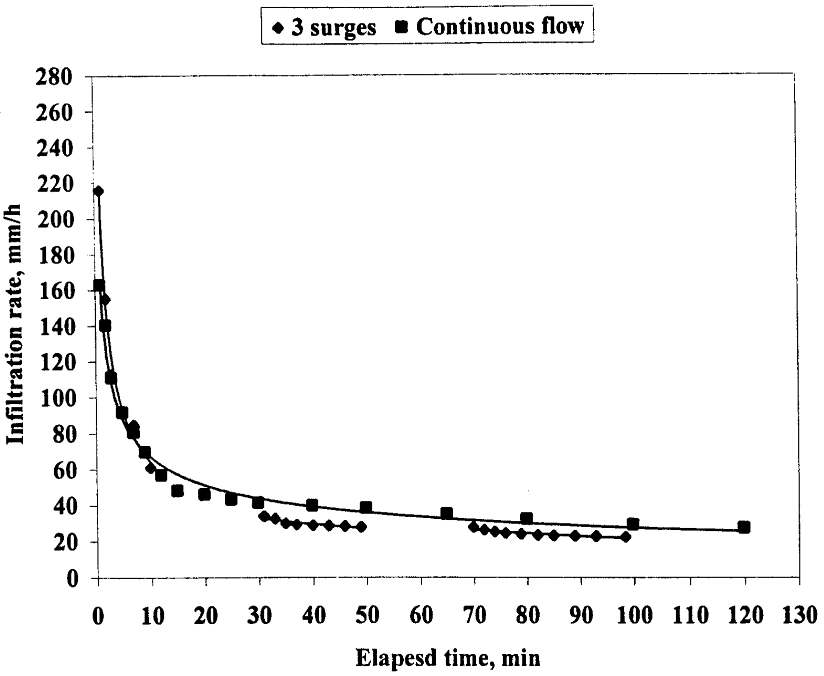

Fig. 1: Comparison of infiltration rates for 3 surges and continuous flow under moldboard plough conditions.

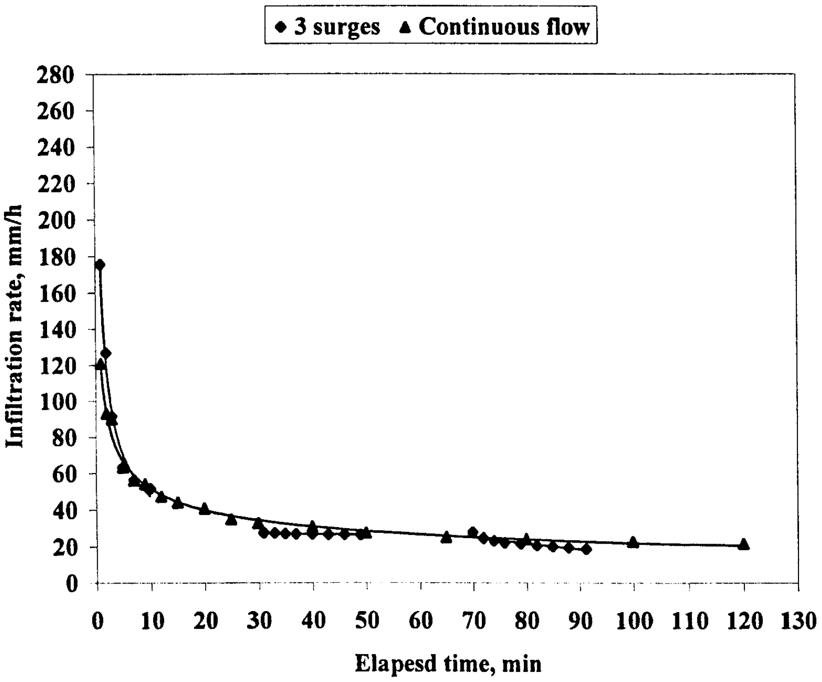

Fig. 2: Comparison of infiltration rates for 3 surges and continuous flow under chisel plough conditions.

APPENDIX B

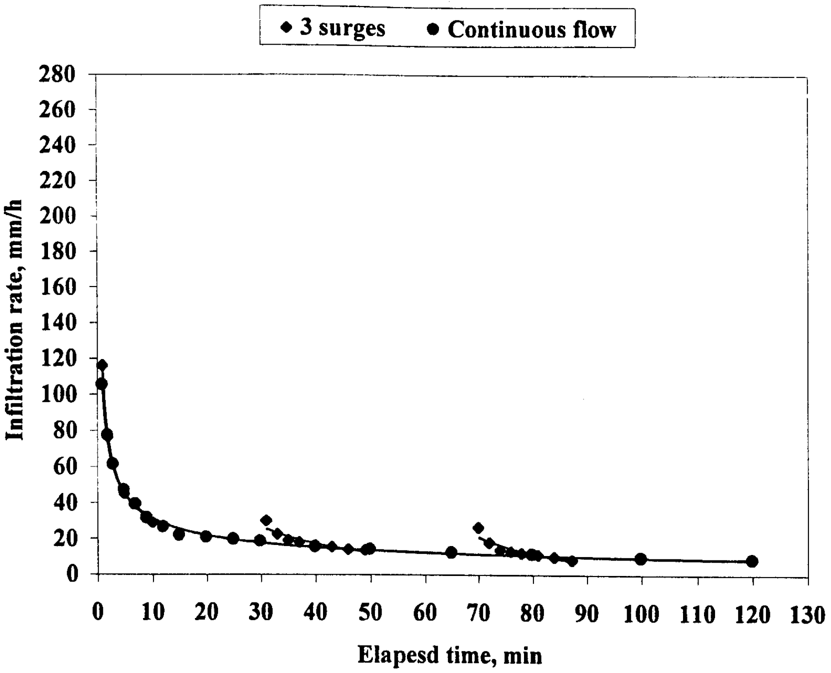

Fig. 3: Comparison of infiltration rates for 3 surges and continuous flow under rotary plough conditions.

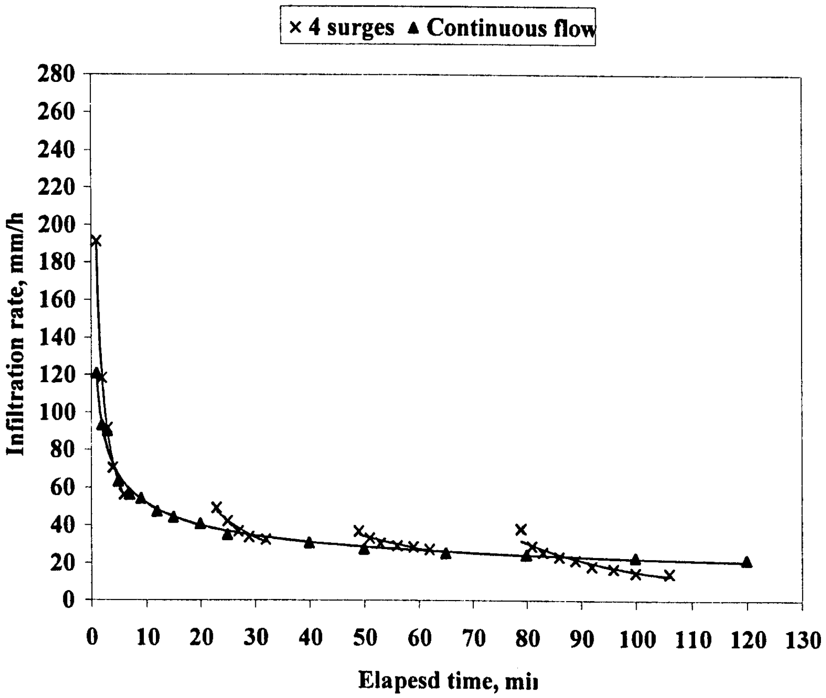

Fig. 4: Comparison of infiltration rates for 4 surges and continuous flow under chisel plough conditions.

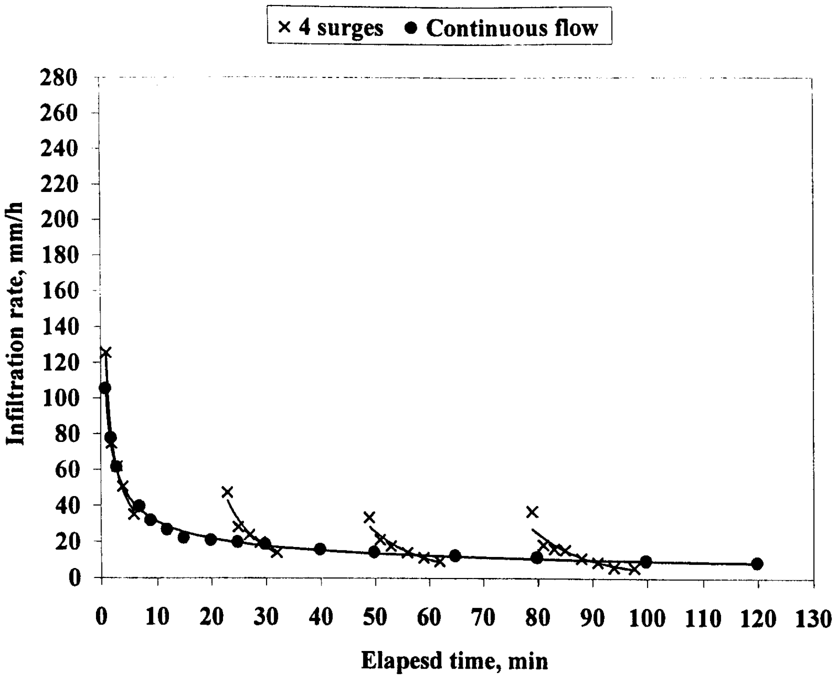

Fig. 5: Comparison of infiltration rates for 4 surges and continuous flow under rotary plough conditions

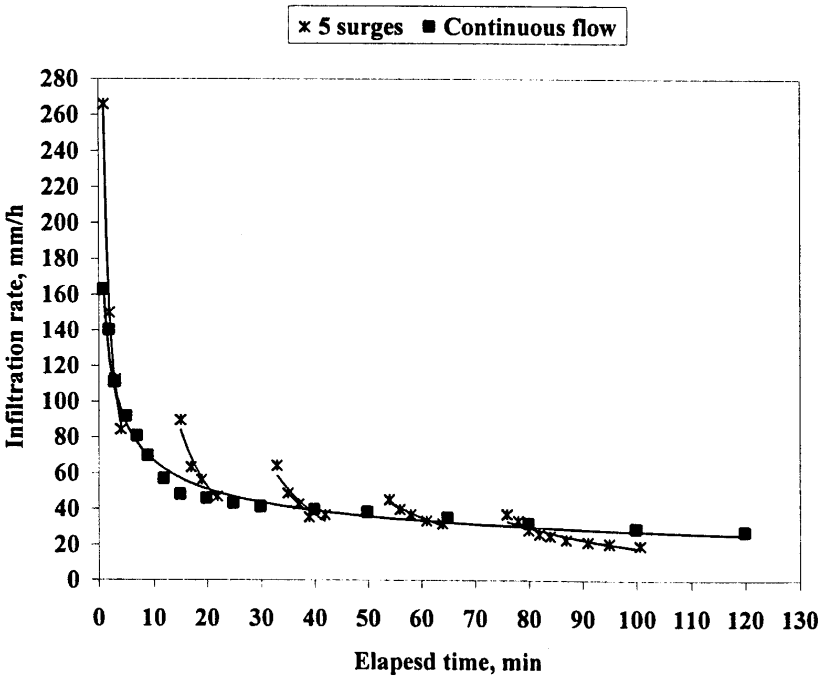

Fig. 6: Comparison of infiltration rates for 5 surges and continuous flow under moldboard plough conditions.

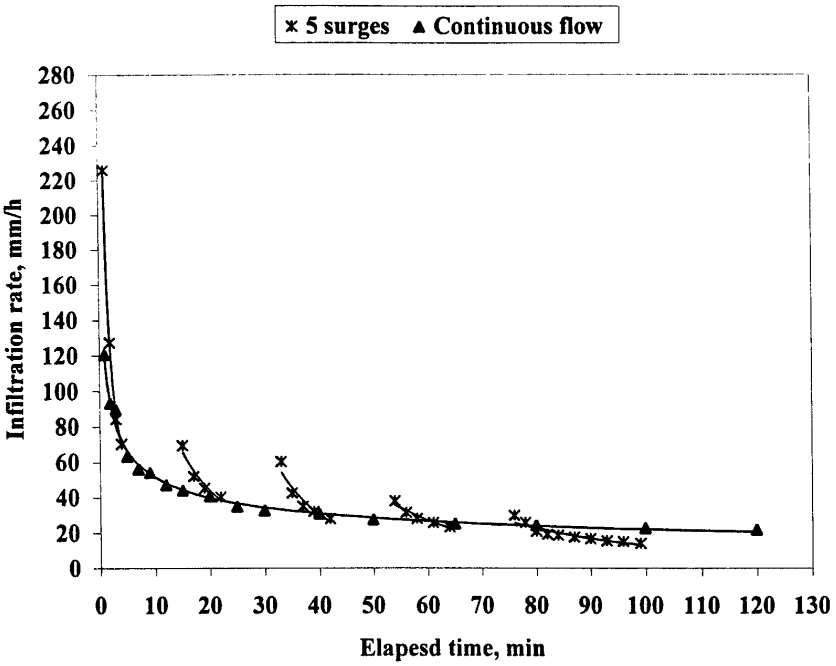

Fig. 7: Comparison of infiltration rates for 5 surges and continuous flow under chisel plough conditions.

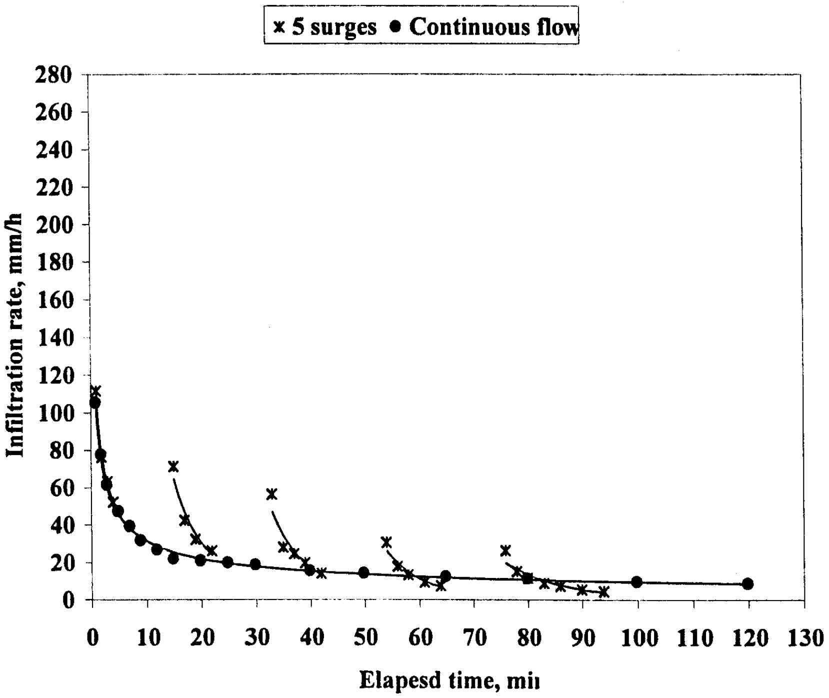

Fig. 8: Comparison of infiltration rates for 5 surges and continuous flow under rotary plough conditions.

APPENDIX C

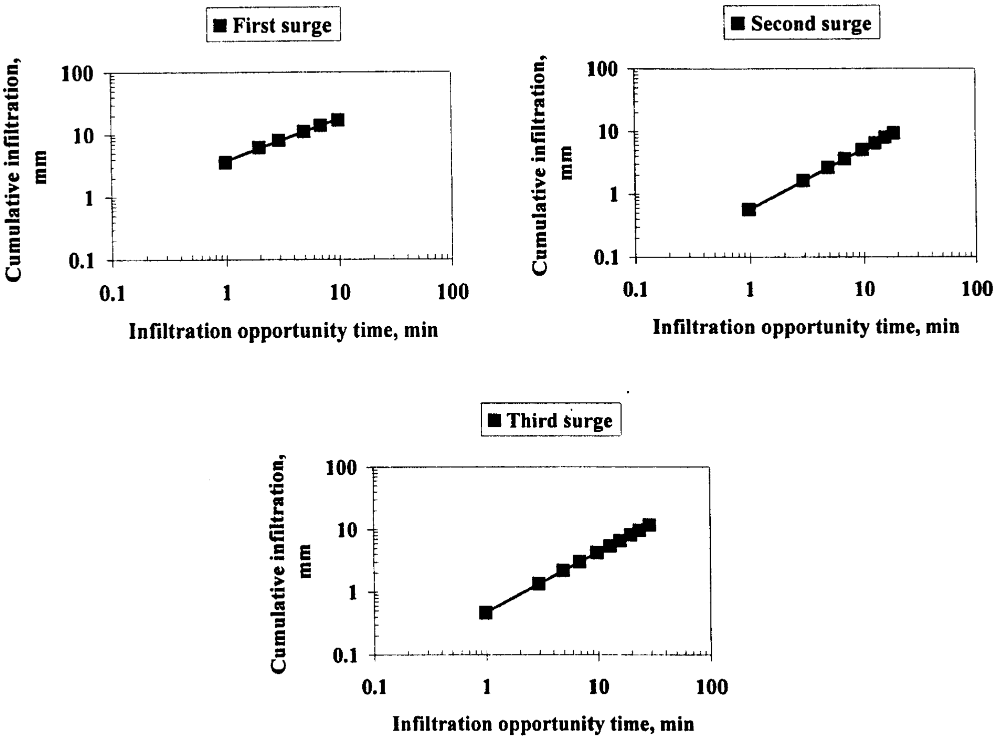

Fig. 1: Relationship between cumulative infiltration and infiltration opportunity time with typical infiltration for 3 surges under moldboard plough conditions.

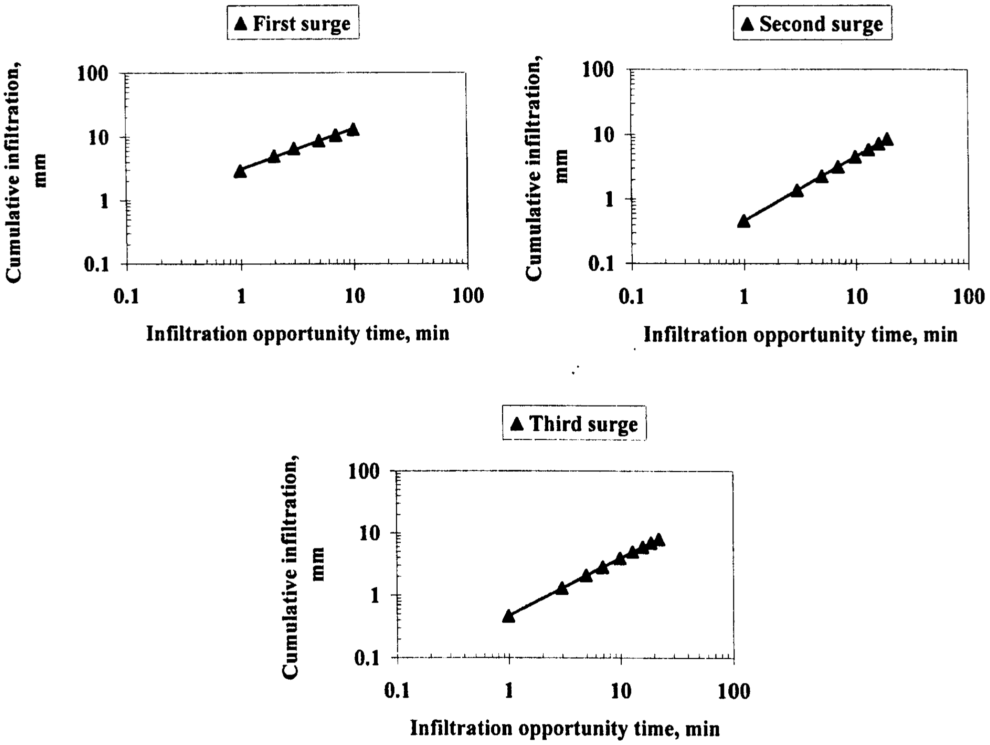

Fig. 2: Relationship between cumulative infiltration and infiltration opportunity time with typical infiltration for 3 surges under chisel plough conditions.

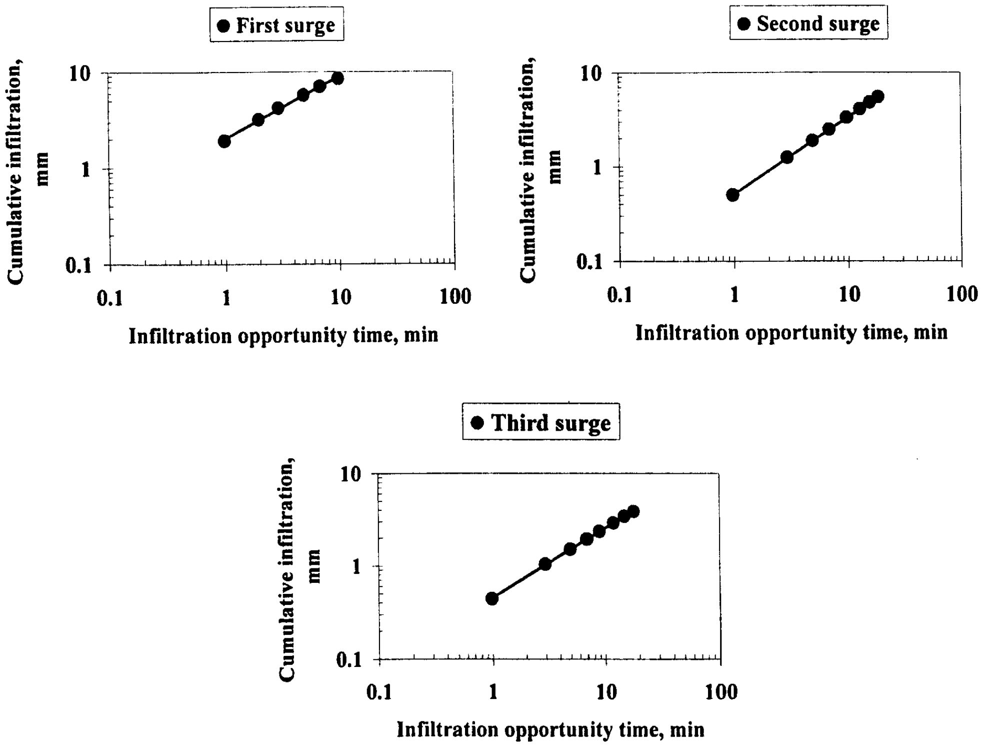

Fig. 3: Relationship between cumulative infiltration and infiltration opportunity time with typical infiltration for 3 surges under rotary plough conditions.

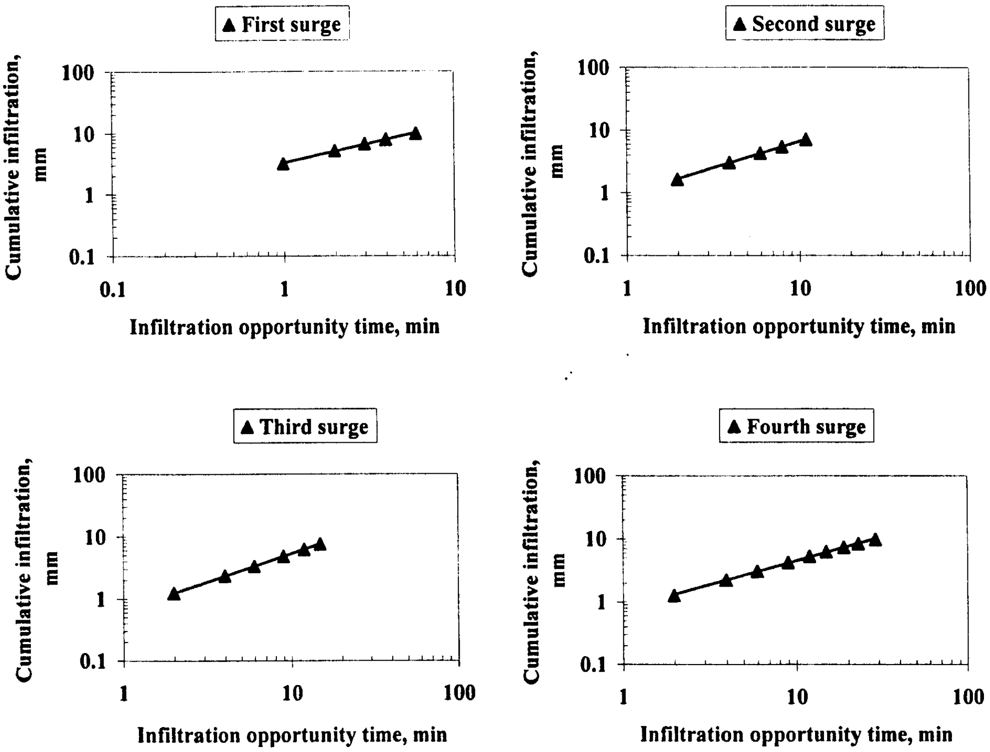

Fig. 4: Relationship between cumulative infiltration and infiltration opportunity time with typical infiltration for 4 surges under chisel plough conditions.

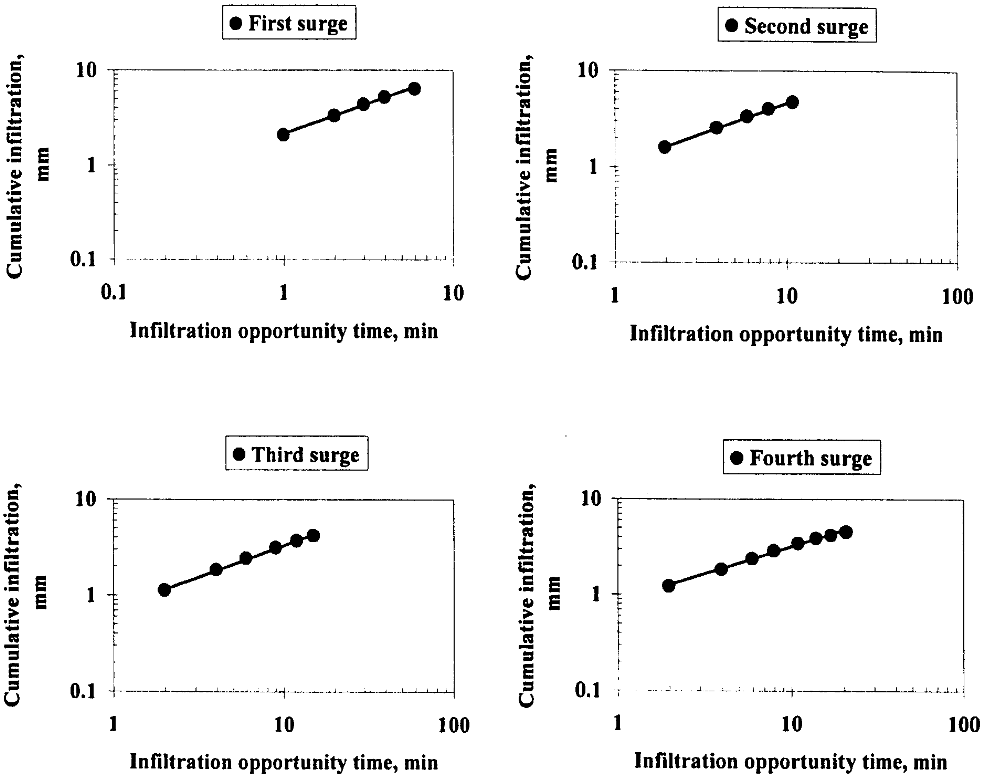

Fig. 5: Relationship between cumulative infiltration and infiltration opportunity time with typical infiltration for 4 surges under rotary plough conditions.

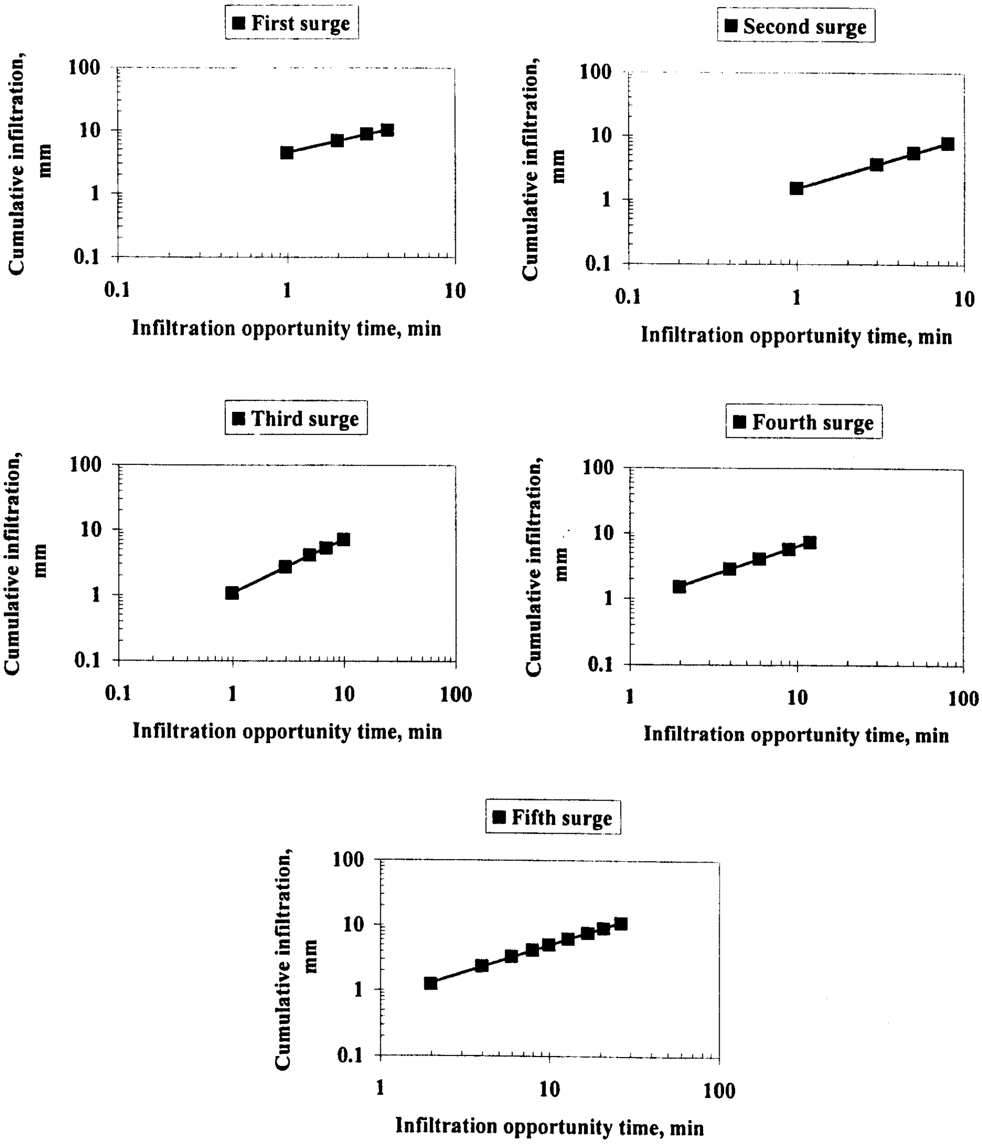

Fig. 6: Relationship between cumulative infiltration and infiltration opportunity time with typical infiltration for 5 surges under moldboard plough conditions.

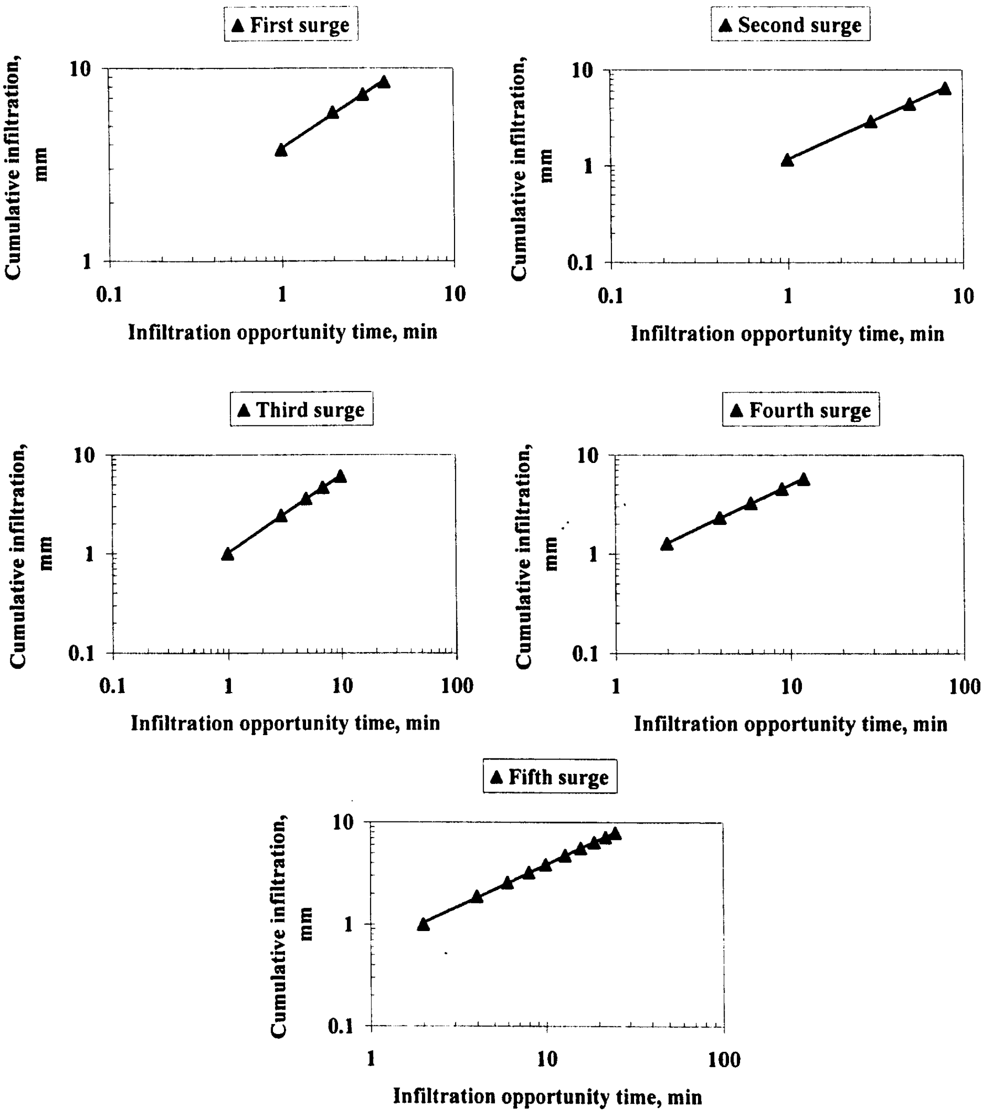

Fig. 7: Relationship between cumulative infiltration and infiltration opportunity time with typical infiltration for 5 surges under chisel plough conditions.

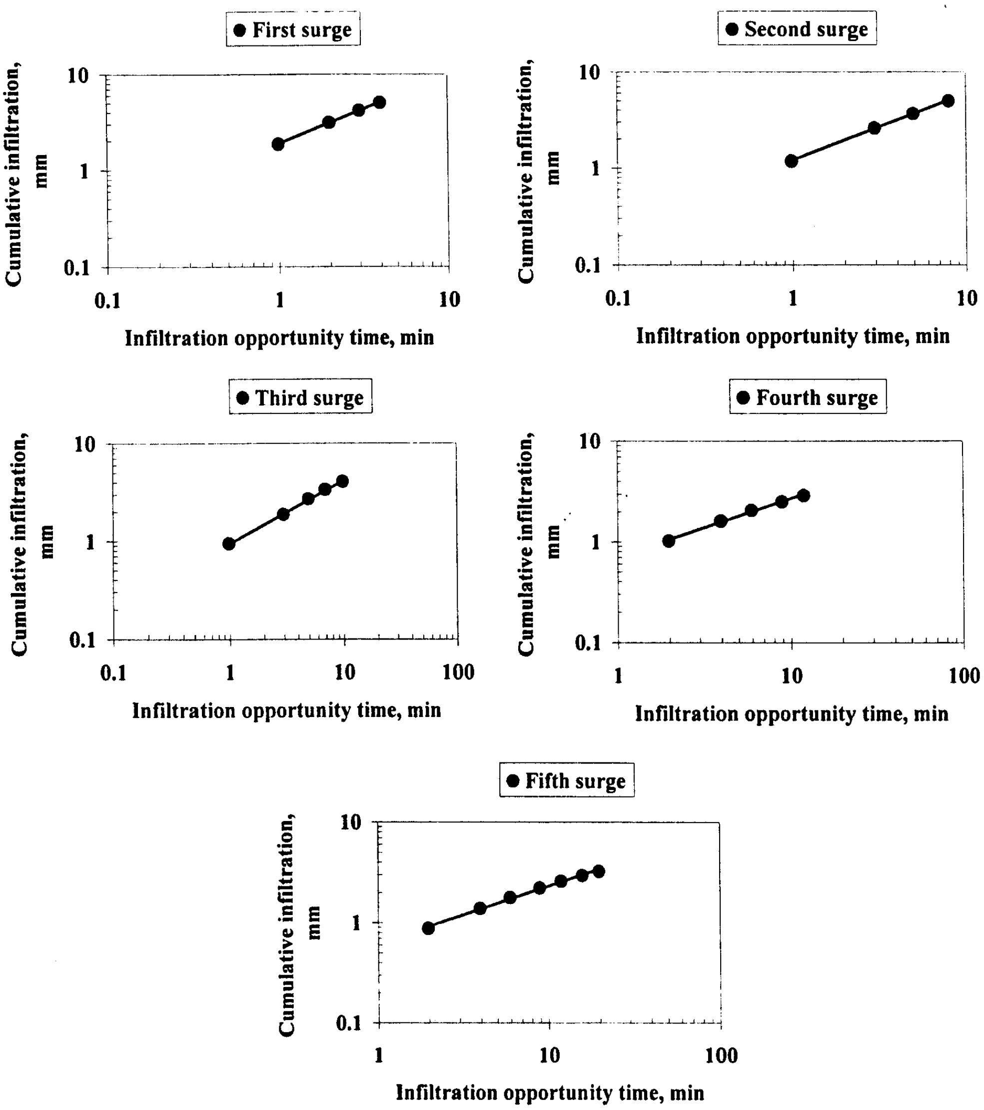

Fig. 8: Relationship between cumulative infiltration and infiltration opportunity time with typical infiltration for 5 surges under rotary plough conditions.

APPENDIX D

Table 1: Advance time (min), recession time (min), and infiltration opportunity time (min) for 3 surges under moldboard plough during the experiment period.

Distance, m	First surge			Second surge			Third surge		
	A.T., min	R.T., min	IOT, min	A.T., min	R.T., min	IOT, min	A.T., min	R.T., min	IOT, min
0	0	12.20	12.20	30.00	54.80	24.80	69.00	104.30	35.30
10	2.50	13.25	10.75	30.70	56.50	25.80	69.50	108.05	38.55
20	6.30	14.30	8.00	31.75	57.80	26.05	70.15	111.65	41.50
30				34.70	58.70	24.00	70.85	114.60	43.75
40				39.45	58.15	18.70	71.50	116.90	45.40
50				46.40	57.13	10.73	73.30	117.00	43.70
60				52.95	56.80	3.85	77.20	114.50	37.30
70							85.30	109.00	23.70
80							90.00	108.00	18.00
95							98.50	105.50	7.00

A.T. = advance time, min.
R.T. = recession time, min.
IOT = infiltration opportunity time, min.

Table 2: Advance time (min), recession time (min), and infiltration opportunity time (min) for 3 surges under chisel plough during the experiment period.

Distance, m	First surge			Second surge			Third surge		
	A.T., min	R.T., min	IOT, min	A.T., min	R.T., min	IOT, min	A.T., min	R.T., min	IOT, min
0	0	12.20	12.20	30.00	54.60	24.60	69.00	97.90	28.90
10	3.25	13.30	10.05	30.85	57.00	26.15	69.60	101.15	31.55
20	6.40	14.45	8.05	31.80	59.75	27.95	70.20	103.50	33.30
30	9.60	15.55	5.95	33.35	61.60	28.25	70.75	106.05	35.35
40				37.20	59.65	22.45	71.30	109.05	37.75
50				39.20	58.05	18.85	72.40	109.60	37.20
60				44.00	57.55	13.55	74.40	106.50	32.10
70				48.70	55.50	6.80	77.20	104.10	26.90
80							8.50	99.20	13.70
95							91.30	98.10	6.80

A.T. = advance time, min.
R.T. = recession time, min.
IOT = infiltration opportunity time, min.

Table 3: Advance time (min), recession time (min), and infiltration opportunity time (min) for 3 surges under rotary plough during the experiment period.

Distance, m	First surge			Second surge			Third surge		
	A.T., min	R.T., min	IOT, min	A.T., min	R.T., min	IOT, min	A.T., min	R.T., min	IOT, min
0	0	13.00	13.00	30.00	54.30	24.30	69.00	98.90	29.90
10	2.80	13.75	10.95	30.55	56.25	25.70	69.40	102.50	33.10
20	5.60	14.45	8.85	30.65	58.10	27.45	69.85	106.00	36.15
30	8.40	15.17	6.77	32.05	59.35	27.30	70.60	108.85	38.25
40	11.20	15.88	4.68	34.30	60.20	25.90	71.40	111.15	39.75
50				37.40	60.60	23.20	72.40	109.80	37.40
60				41.40	60.45	19.05	73.20	108.85	35.65
70				46.05	59.97	13.92	74.45	107.45	33.00
80				51.20	59.27	8.07	77.90	104.60	26.70
95							87.25	100.60	13.35

A.T. = advance time, min.
R.T. = recession time, min.
IOT = infiltration opportunity time, min.

Table 4: Advance time (min), recession time (min), and infiltration opportunity time (min) for 4 surges under chisel plough during the experiment period.

Distance, m	First surge A.T., min	First surge R.T., min	First surge IOT, min	Second surge A.T., min	Second surge R.T., min	Second surge IOT, min	Third surge A.T., min	Third surge R.T., min	Third surge IOT, min	Fourth surge A.T., min	Fourth surge R.T., min	Fourth surge IOT, min
0	0	8.20	8.20	21.00	35.20	14.20	47.00	64.00	17.00	77.00	110.00	33.00
10	2.75	8.70	5.95	22.60	37.70	15.10	47.10	68.05	20.95	77.30	114.26	36.96
20	5.60	9.12	3.52	23.70	39.15	15.45	47.45	71.80	24.35	77.65	117.20	39.55
30				26.80	39.55	12.75	49.45	73.20	23.75	78.15	119.05	40.90
40				32.40	38.50	6.10	52.85	72.30	19.45	78.45	117.15	38.70
50							57.20	70.50	13.30	81.10	114.50	33.40
60							63.05	69.35	6.30	85.00	114.10	29.10
70										91.30	112.70	21.40
80										98.25	111.40	13.15
95										106.00	111.00	5.00

A.T. = advance time, min.
R.T. = recession time, min.
IOT = infiltration opportunity time, min.

Table 5: Advance time (min), recession time (min), and infiltration opportunity time (min) for 4 surges under rotary plough during the experiment period.

Distance, m	First surge			Second surge			Third surge			Fourth surge		
	A.T., min	R.T., min	IOT, min	A.T., min	R.T., min	IOT, min	A.T., min	R.T., min	IOT, min	A.T., min	R.T., min	IOT, min
0	0	8.70	8.70	21.00	35.80	14.80	47.00	66.20	19.20	77.00	107.70	30.70
10	2.40	9.55	7.15	22.15	36.90	14.75	47.30	68.77	21.47	77.27	110.25	32.98
20	4.80	10.30	5.50	23.40	37.90	14.50	47.70	71.23	23.53	77.55	112.65	35.10
30				25.73	38.27	12.54	49.90	73.05	23.15	78.10	114.55	36.45
40				29.00	37.90	8.90	50.75	72.25	21.50	78.88	115.00	36.12
50				32.50	37.50	5.00	53.40	72.90	19.50	80.00	114.00	34.00
60							57.08	71.85	14.77	81.27	112.55	31.28
70							61.33	70.40	9.07	83.15	110.00	26.85
80							66.00	69.65	3.65	87.20	109.40	22.20
95										97.70	108.13	10.43

A.T. = advance time, min.
R.T. = recession time, min.
IOT = infiltration opportunity time, min.

Table 6: Advanced time (min), recession time (min), and infiltration opportunity time (min) for 5 surges under moldboard plough during the experiment period.

Distance, m	First surge			Second surge			Third surge			Fourth surge			Fifth surge		
	A.T., min	R.T., min	IOT, min	A.T., min	R.T., min	IOT, min	A.T., min	R.T., min	IOT, min	A.T., min	R.T., min	IOT, min	A.T., min	R.T., min	IOT, min
0	0	6.65	6.65	14.00	24.95	10.95	32.00	45.20	13.20	52.00	65.70	13.70	74.00	103.80	29.80
10	3.00	7.13	4.13	16.75	26.20	9.45	32.80	46.75	13.95	52.40	67.00	14.60	74.20	104.77	30.57
15.60	4.70	7.40	2.70	18.25	26.35	8.10	33.20	47.08	13.88	52.60	69.15	16.55	74.28	105.33	31.05
20				19.50	26.45	6.95	33.70	47.27	13.57	52.85	68.28	15.43	74.45	105.73	31.28
30				22.27	26.40	4.13	35.65	46.45	10.80	54.20	68.47	14.27	75.25	106.38	31.13
40							38.70	46.33	7.63	56.25	68.60	12.35	76.48	106.75	30.27
50							42.05	45.10	3.05	58.90	68.65	9.75	78.40	106.90	28.50
60										62.50	67.62	5.12	83.50	105.77	22.27
70										65.50	66.55	1.05	87.00	105.00	18.00
80													93.00	104.70	11.70
95													100.65	104.00	3.35

A.T. = advanced time, min.
R.T. = recession time, min.
IOT = infiltration opportunity time, min.

Table 7: Advance time (min), recession time (min), and infiltration opportunity time (min) for 5 surges under chisel plough during the experiment period.

Distance, m	First surge			Second surge			Third surge			Fourth surge			Fifth surge		
	A.T., min	R.T., min	IOT, min	A.T., min	R.T., min	IOT, min	A.T., min	R.T., min	IOT, min	A.T., min	R.T., min	IOT, min	A.T., min	R.T., min	IOT, min
0	0	5.40	5.40	14.00	25.25	11.25	32.00	45.80	13.80	52.00	66.15	14.15	74.00	106.60	32.60
10	2.70	5.80	3.10	15.27	25.85	10.58	32.40	46.63	14.23	52.40	66.53	14.13	74.25	109.00	34.75
19.20	5.20	6.20	1.00	17.24	26.40	9.16	32.85	47.35	14.50	52.75	66.85	14.10	74.50	111.00	36.50
20				17.40	26.48	9.08	32.95	47.40	14.45	72.80	66.88	14.08	74.55	111.20	36.65
30				20.37	26.40	6.03	34.95	47.57	12.62	53.75	67.08	13.33	75.10	112.88	37.78
40							38.15	47.13	8.98	55.17	67.16	11.99	75.77	114.05	38.28
50							41.80	46.50	4.70	57.00	67.10	10.10	77.20	113.70	36.50
60										59.35	66.90	7.55	79.73	112.85	33.12
70										62.00	66.60	4.60	83.20	112.52	29.32
80										65.00	66.22	1.22	88.20	111.80	23.60
95													99.10	107.50	8.40

A.T. = advance time, min.
R.T. = recession time, min.
IOT = infiltration opportunity time, min.

Table 8: Advance time (min), recession time (min), and infiltration opportunity time (min) for 5 surges under rotary plough during the experiment period.

Distance, m	First surge			Second surge			Third surge			Fourth surge			Fifth surge		
	A.T., min	R.T., min	IOT, min	A.T., min	R.T., min	IOT, min	A.T., min	R.T., min	IOT, min	A.T., min	R.T., min	IOT, min	A.T., min	R.T., min	IOT, min
0	0	6.70	6.70	14.00	24.20	10.20	32.00	46.20	14.20	52.00	65.00	13.00	74.00	99.30	25.30
10	2.30	6.78	4.48	15.73	25.07	9.34	32.28	47.15	14.87	66.20	66.20	14.00	74.28	102.78	28.50
20	4.65	6.88	2.23	17.50	25.93	8.43	32.75	48.05	15.30	52.45	67.35	14.90	74.57	104.08	29.51
30				20.20	26.23	6.03	34.60	48.35	13.75	53.08	68.15	15.07	75.00	105.92	30.92
40							37.80	48.13	10.33	54.05	67.00	12.95	75.75	104.22	28.47
50							41.60	47.70	6.10	55.30	66.70	11.40	76.80	103.10	26.30
60							45.47	46.55	1.08	56.92	66.00	9.08	78.20	102.48	24.28
70										58.80	65.60	6.80	80.20	101.45	21.25
80										60.88	65.32	4.44	84.10	101.15	17.05
95													94.00	99.45	5.45

A.T. = advance time, min.
R.T. = recession time, min.
IOT = infiltration opportunity time, min.

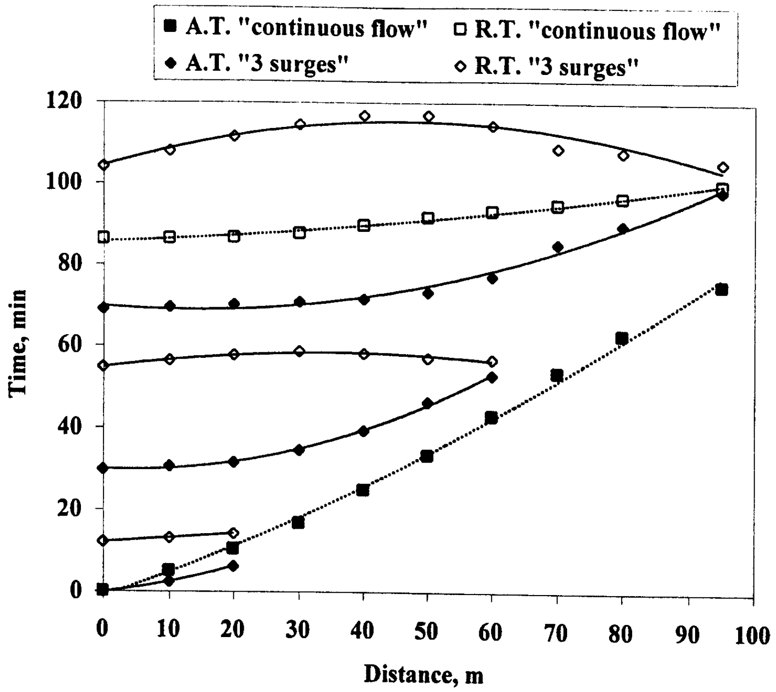

Fig. 1: Comparison of Advance and recession times for 3 surges and continuous flow under moldboard plough.

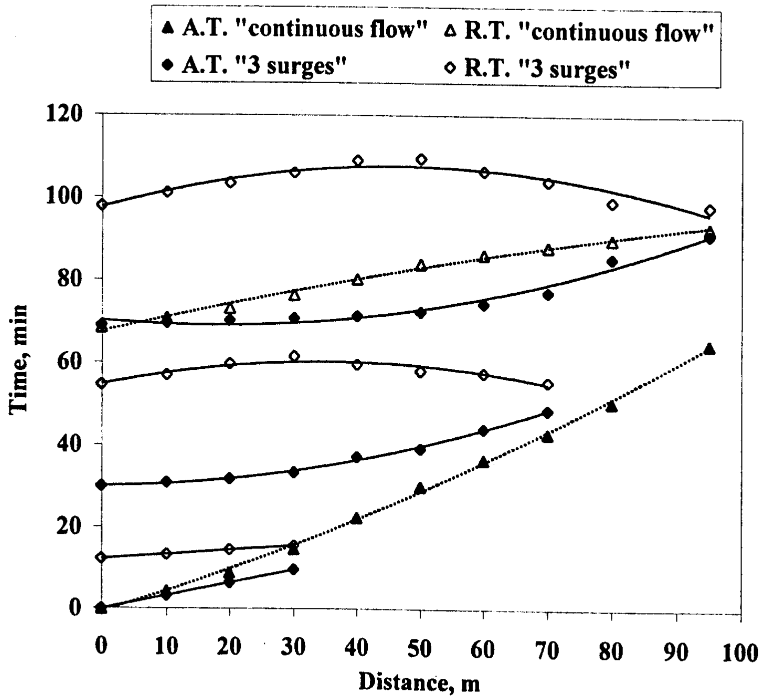

Fig. 2: Comparison of Advance and recession times for 3 surges and continuous flow under chisel plough.

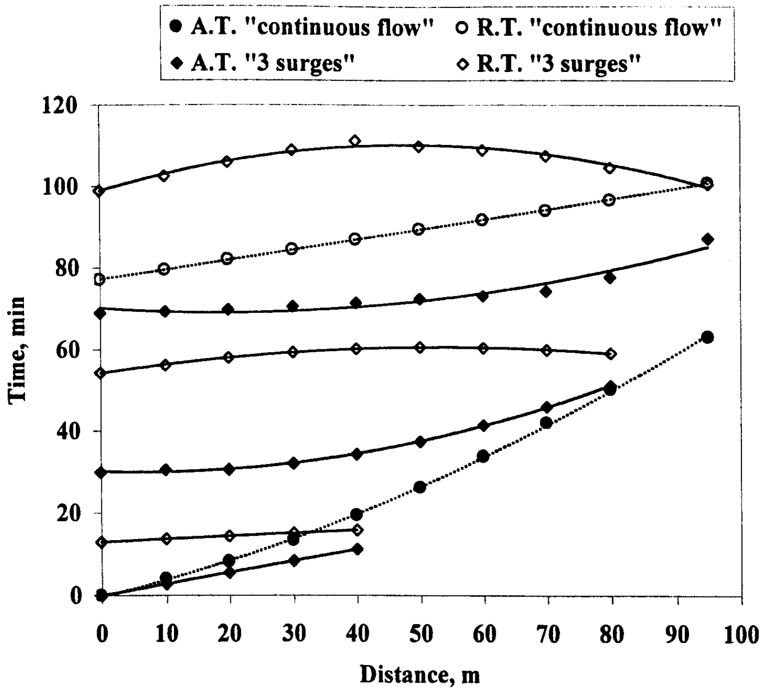

Fig. 3: Comparison of Advance and recession times for 3 surges and continuous flow under rotary plough.

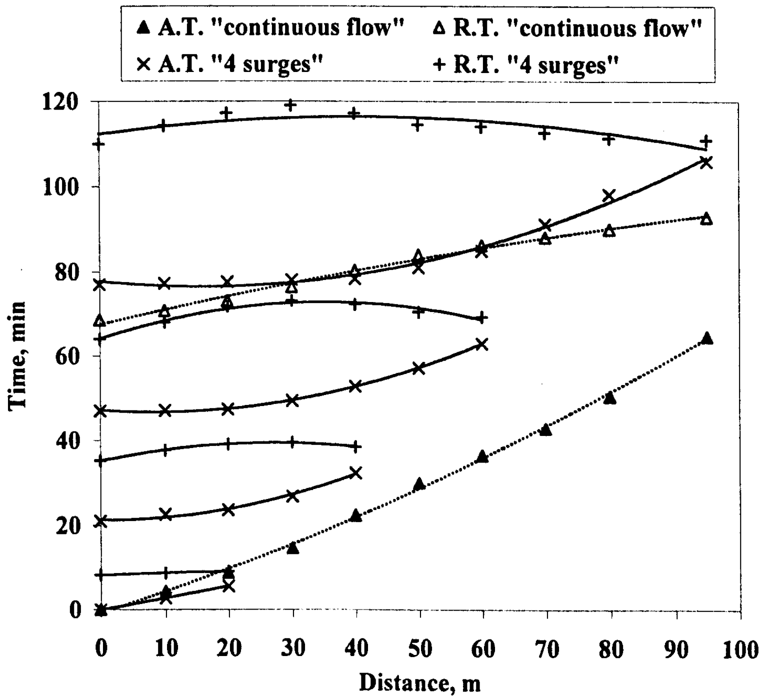

Fig. 4: Comparison of Advance and recession times for 4 surges and continuous flow under chisel plough.

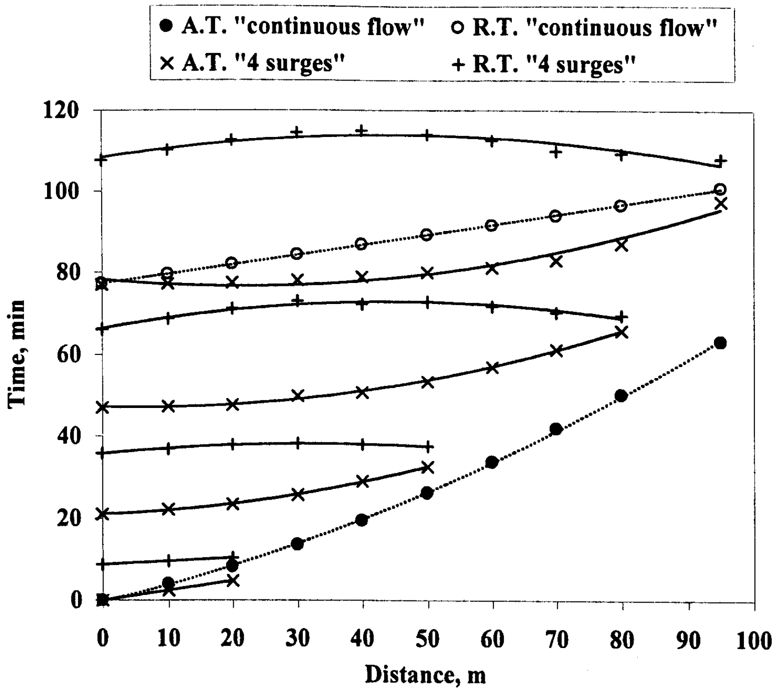

Fig. 5: Comparison of Advance and recession times for 4 surges and continuous flow under rotary plough.

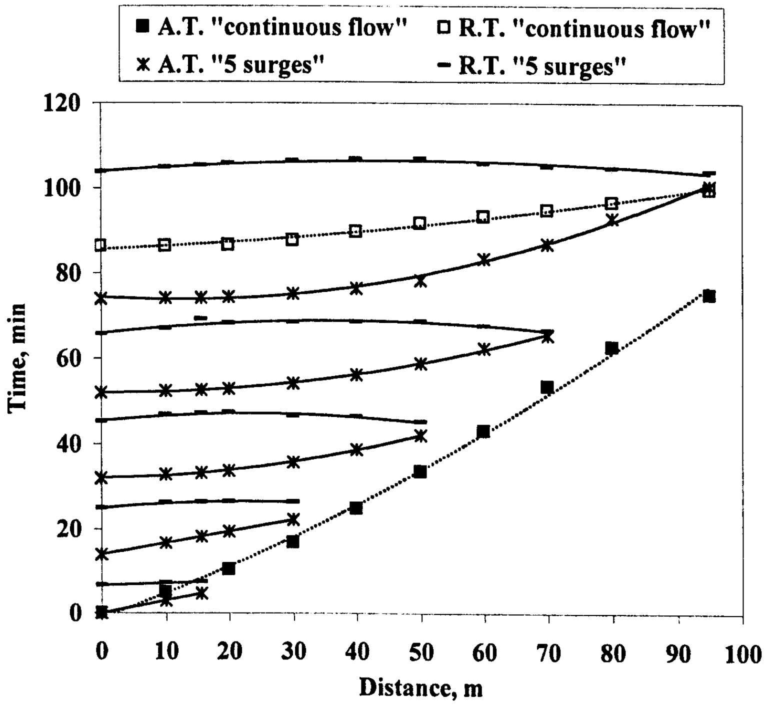

Fig. 6: Comparison of Advance and recession times for 5 surges and continuous flow under moldboard plough.

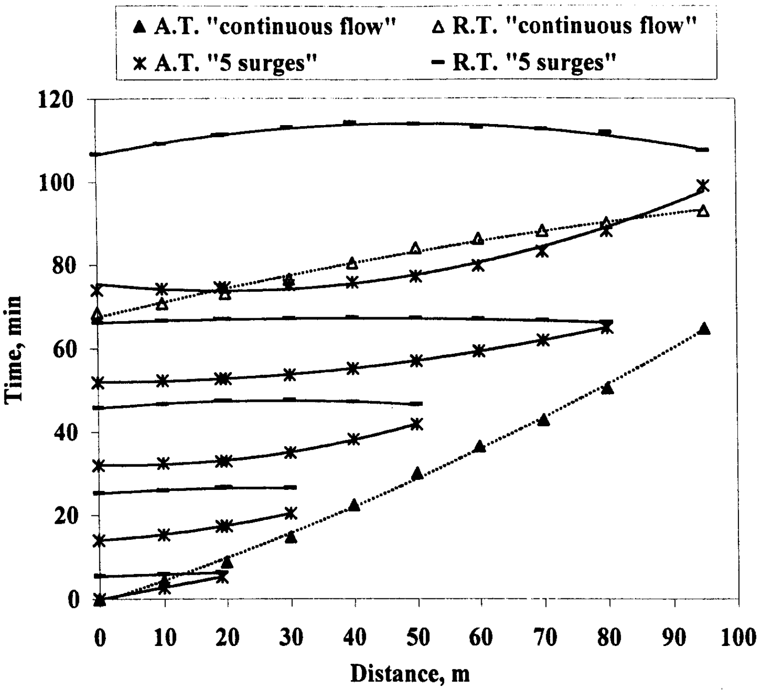

Fig. 7: Comparison of Advance and recession times for 5 surges and continuous flow under chisel plough.

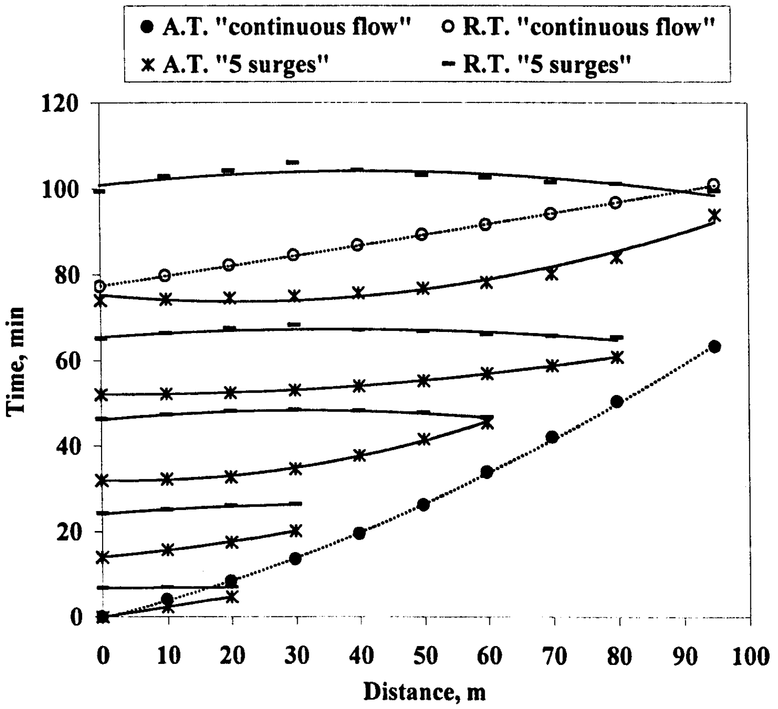

Fig. 8: Comparison of Advance and recession times for 5 surges and continuous flow under rotary plough.

APPENDIX E

Table 1: Infiltration opportunity time and corresponding typical and adjusted depth infiltrated for 3 surges under moldboard plough.

Distance, m	First surge			Second surge			Third surge		
	IOT, min	Typ. inf. dep., mm	Adj. inf. dep., mm	IOT, min	Typ. inf. dep., mm	Adj. inf. dep., mm	IOT, min	Typ. inf. dep., mm	Adj. inf. dep., mm
0	12.20	20.11	56.29	24.80	12.04	14.19	35.30	13.93	16.56
10	10.75	18.47	51.70	25.80	12.50	14.74	38.55	15.15	18.00
20	8.00	15.15	42.40	26.05	12.61	14.87	41.50	16.25	19.31
30				24.00	31.67	88.64	43.75	20.61	24.30
40				18.70	26.78	74.97	45.40	21.35	25.17
50				10.73	18.45	51.64	43.70	20.59	24.27
60				3.85	9.27	25.96	37.30	17.72	20.89
70							23.70	31.40	87.89
80							18.00	26.11	73.07
95							7.00	13.85	38.77

IOT = infiltration opportunity time, min.
Typ. inf. dep. = typical infiltrated depth, mm.
Adj. inf. dep. = adjusted infiltrated depth, mm.

Table 2: Infiltration opportunity time and corresponding typical and adjusted depth infiltrated for 3 surges under chisel plough.

Distance, m	First surge			Second surge			Third surge		
	IOT, min	Typ. inf. dep., mm	Adj. inf. dep., mm	IOT, min	Typ. inf. dep., mm	Adj. inf. dep., mm	IOT, min	Typ. inf. dep., mm	Adj. inf. dep., mm
0	12.20	15.33	50.05	24.60	11.05	11.78	28.90	10.25	23.55
10	10.05	13.55	44.22	26.15	11.74	12.52	31.55	11.11	25.52
20	8.05	11.75	38.37	27.95	12.54	13.37	33.30	11.67	26.81
30	5.95	9.69	31.62	28.25	12.67	13.51	35.35	12.32	28.29
40				22.45	22.64	73.92	37.75	16.89	18.01
50				18.85	20.25	66.11	37.20	16.64	17.75
60				13.55	16.40	53.53	32.10	14.38	15.34
70				6.80	10.55	34.44	26.90	12.07	12.87
80							13.70	16.51	53.90
95							6.80	10.55	34.44

IOT = infiltration opportunity time, min.
Typ. inf. dep. = typical infiltrated depth, mm.
Adj. inf. dep. = adjusted infiltrated depth, mm.

Table 3: Infiltration opportunity time and corresponding typical and adjusted depth infiltrated for 3 surges under rotary plough.

Distance, m	First surge			Second surge			Third surge		
	IOT, min	Typ. inf. dep., mm	Adj. inf. dep., mm	IOT, min	Typ. inf. dep., mm	Adj. inf. dep., mm	IOT, min	Typ. inf. dep., mm	Adj. inf. dep., mm
0	13.00	10.48	40.54	24.30	6.83	16.22	29.90	5.74	8.16
10	10.95	9.39	36.30	25.70	7.15	16.98	33.10	6.19	8.80
20	8.85	8.18	31.66	27.45	7.54	17.91	36.15	6.62	9.40
30	6.77	6.89	26.65	27.30	7.51	17.83	38.25	6.90	9.81
40	4.68	5.43	21.01	25.90	7.19	17.09	39.75	7.10	10.10
50				23.20	15.21	58.83	37.40	9.70	23.04
60				19.05	13.40	51.83	35.65	9.33	22.16
70				13.92	10.95	42.36	33.00	8.76	20.81
80				8.07	7.71	29.83	26.70	7.37	17.52
95							13.35	10.66	41.24

IOT = infiltration opportunity time, min.
Typ. inf. dep. = typical infiltrated depth, mm.
Adj. inf. dep. = adjusted infiltrated depth, mm.

Table 4: Infiltration opportunity time and corresponding typical and adjusted depth infiltrated for 4 surges under chisel plough.

Distance, m	First surge			Second surge			Third surge			Fourth surge		
	IOT, min	Typ. inf. dep., mm	Adj. inf. dep., mm	IOT, min	Typ. inf. dep., mm	Adj. inf. dep., mm	IOT, min	Typ. inf. dep., mm	Adj. inf. dep., mm	IOT, min	Typ. inf. dep., mm	Adj. inf. dep., mm
0	8.20	12.24	41.77	14.20	8.86	25.61	17.00	8.57	16.66	33.00	11.27	12.73
10	5.95	10.01	34.16	15.10	9.34	26.98	20.95	10.35	20.12	36.96	12.29	13.88
20	3.52	7.20	24.58	15.45	9.53	27.52	24.35	11.85	23.04	39.55	12.95	14.62
30				12.75	16.14	55.09	23.75	13.75	39.72	40.90	18.91	36.77
40				6.10	10.17	34.69	19.45	11.59	33.49	38.70	17.99	34.98
50							13.30	16.58	56.57	33.40	18.39	53.13
60							6.30	10.37	35.40	29.10	16.35	47.24
70										21.40	22.34	76.22
80										13.15	16.46	56.16
95										5.00	8.97	30.63

IOT = infiltration opportunity time, min.
Typ. inf. dep. = typical infiltrated depth, mm.
Adj. inf. dep. = adjusted infiltrated depth, mm.

Table 5: Infiltration opportunity time and corresponding typical and adjusted depth infiltrated for 4 surges under rotary plough.

Distance, m	First surge			Second surge			Third surge			Fourth surge		
	IOT, min	Typ. inf. dep., mm	Adj. inf. dep., mm	IOT, min	Typ. inf. dep., mm	Adj. inf. dep., mm	IOT, min	Typ. inf. dep., mm	Adj. inf. dep., mm	IOT, min	Typ. inf. dep., mm	Adj. inf. dep., mm
0	8.70	8.37	34.60	14.80	5.84	22.33	19.20	5.02	8.77	30.70	6.01	16.97
10	7.15	7.39	30.57	14.75	5.83	22.28	21.47	5.41	9.43	32.98	6.26	17.68
20	5.50	6.27	25.91	14.50	5.76	22.03	23.53	5.74	10.02	35.10	6.49	18.32
30				12.54	10.54	43.58	23.15	7.80	29.81	36.45	7.64	13.33
40				8.90	8.49	35.10	21.50	7.43	28.42	36.12	7.59	13.25
50				5.00	5.90	24.39	19.50	6.98	26.68	34.00	7.30	12.74
60							14.77	11.69	48.32	31.28	9.47	36.20
70							9.07	8.59	35.52	26.85	8.58	32.80
80							3.65	4.84	20.00	22.20	7.59	29.01
95										10.43	9.38	38.80

IOT = infiltration opportunity time, min.
Typ. inf. dep. = typical infiltrated depth, mm.
Adj. inf. dep. = adjusted infiltrated depth, mm.

Table 6: Infiltration opportunity time and corresponding typical and adjusted depth infiltrated for 5 surges under moldboard plough.

Distance, m	First surge			Second surge			Third surge			Fourth surge			Fifth surge		
	IOT, min	Typ. inf. dep., mm	Adj. inf. dep., mm	IOT, min	Typ. inf. dep., mm	Adj. inf. dep., mm	IOT, min	Typ. inf. dep., mm	Adj. inf. dep., mm	IOT, min	Typ. inf. dep., mm	Adj. inf. dep., mm	IOT, min	Typ. inf. dep., mm	Adj. inf. dep., mm
0	6.65	14.15	42.50	10.95	10.18	24.83	13.20	9.06	13.48	13.70	8.34	22.62	29.80	12.23	14.24
10	4.13	10.60	31.82	9.45	9.05	22.07	13.95	9.48	14.11	14.60	8.82	23.93	30.57	12.50	14.54
20				6.95	14.54	43.65	13.57	12.08	29.47	15.43	10.30	15.33	31.28	17.25	46.82
30				4.13	10.60	31.82	10.80	10.07	24.56	14.27	9.66	14.37	31.13	17.18	46.62
40							7.63	15.38	46.19	12.35	11.20	27.34	30.27	17.95	26.70
50							3.05	8.82	26.47	9.75	9.27	22.63	28.50	17.08	25.41
60										5.12	12.07	36.26	22.27	17.95	43.80
70										1.05	4.61	13.85	18.00	15.14	36.94
80													11.70	19.94	59.89
95													3.35	9.33	28.02

IOT = infiltration opportunity time, min.
Typ. inf. dep. = typical infiltrated depth, mm.
Adj. inf. dep. = adjusted infiltrated depth, mm.

Table 7: Infiltration opportunity time and corresponding typical and adjusted depth infiltrated for 5 surges under chisel plough.

Distance, m	First surge			Second surge			Third surge			Fourth surge			Fifth surge		
	IOT, min	Typ. inf. dep., mm	Adj. inf. dep., mm	IOT, min	Typ. inf. dep., mm	Adj. inf. dep., mm	IOT, min	Typ. inf. dep., mm	Adj. inf. dep., mm	IOT, min	Typ. inf. dep., mm	Adj. inf. dep., mm	IOT, min	Typ. inf. dep., mm	Adj. inf. dep., mm
0	5.40	10.27	38.38	11.25	8.60	10.37	13.80	7.95	21.01	14.15	6.66	8.46	32.62	9.88	19.68
10	3.10	7.42	27.71	10.58	8.18	9.86	14.23	8.14	21.52	14.13	6.65	8.45	34.75	10.41	20.72
20				9.08	13.93	52.05	14.45	10.58	12.76	14.08	8.07	21.35	36.65	14.83	18.82
30				6.03	10.96	40.94	12.62	9.46	11.41	13.33	7.73	20.45	37.78	15.21	19.31
40							8.98	13.84	51.72	11.99	9.07	10.93	38.28	17.67	46.74
50							4.70	9.47	35.38	10.10	7.87	9.49	36.50	17.03	45.03
60										7.55	12.50	46.71	33.12	20.99	25.31
70										4.60	9.35	34.93	29.32	18.98	22.89
80										1.22	4.29	16.04	23.60	15.87	19.13
95													8.40	13.31	49.73

IOT = infiltration opportunity time, min.
Typ. inf. dep. = typical infiltrated depth, mm.
Adj. inf. dep. = adjusted infiltrated depth, mm.

Table 8: Infiltration opportunity time and corresponding typical and adjusted depth infiltrated for 5 surges under rotary plough.

Distance, m	First surge			Second surge			Third surge			Fourth surge			Fifth surge		
	IOT, min	Typ. inf. dep., mm	Adj. inf. dep., mm	IOT, min	Typ. inf. dep., mm	Adj. inf. dep., mm	IOT, min	Typ. inf. dep., mm	Adj. inf. dep., mm	IOT, min	Typ. inf. dep., mm	Adj. inf. dep., mm	IOT, min	Typ. inf. dep., mm	Adj. inf. dep., mm
0	6.70	7.45	36.65	10.20	6.01	28.83	14.20	5.21	6.62	13.00	3.14	3.42	25.30	3.90	17.91
10	4.48	5.56	27.38	9.34	5.65	27.12	14.87	5.36	6.82	14.00	3.28	3.57	28.50	4.17	19.17
20	2.23	3.36	16.51	8.43	5.26	25.26	15.30	5.46	6.95	14.90	3.40	3.70	29.51	4.25	19.55
30				6.03	6.90	33.95	13.75	7.39	35.46	15.07	5.41	6.88	30.92	5.21	5.68
40							10.33	10.19	50.15	12.95	7.09	34.02	28.47	8.10	10.37
50							6.10	6.96	34.24	11.40	6.49	31.14	26.30	7.70	9.85
60							1.08	1.98	9.76	9.08	5.54	26.60	24.28	7.31	9.36
70										6.80	7.53	37.04	21.25	9.99	47.96
80										4.44	5.53	27.20	17.05	8.58	41.17
95													5.45	6.41	31.55

IOT = infiltration opportunity time, min.
Typ. inf. dep. = typical infiltrated depth, mm.
Adj. inf. dep. = adjusted infiltrated depth, mm.

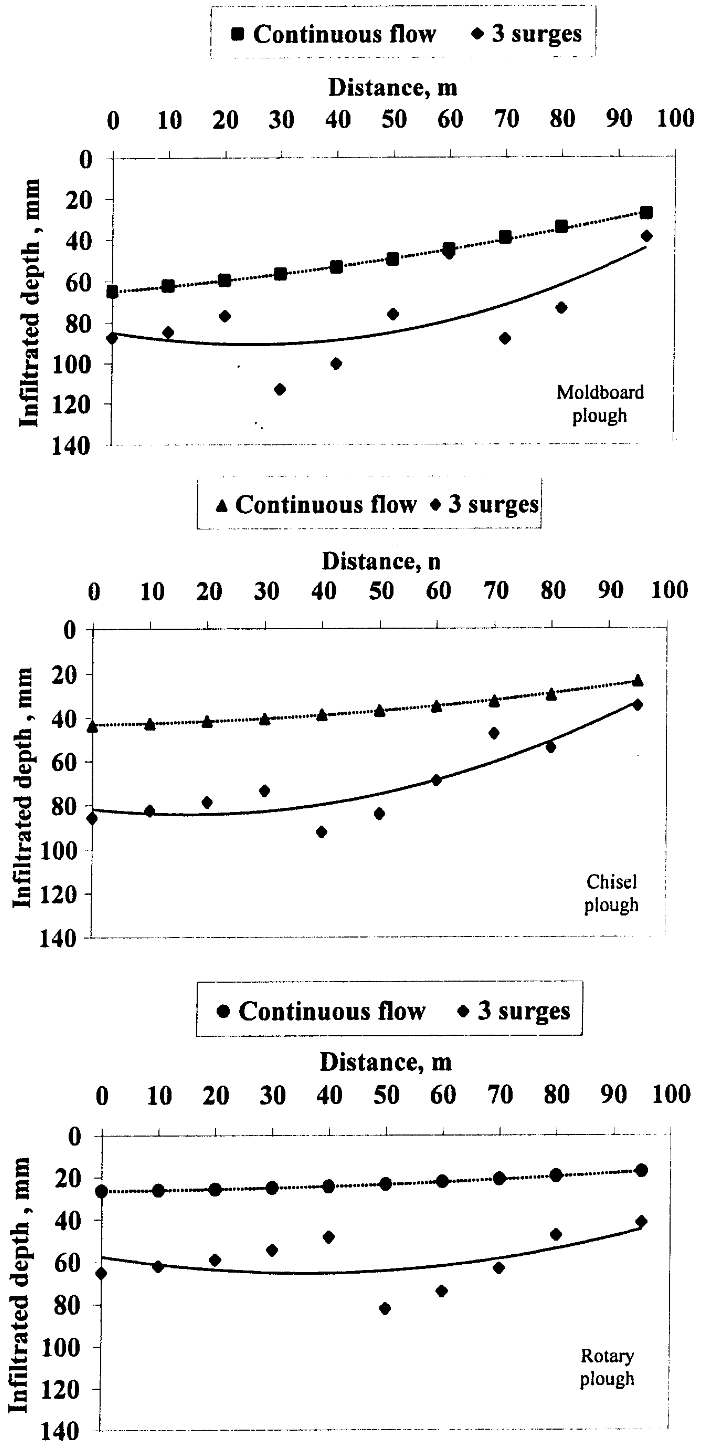

Fig. 1: Infiltrated water distribution curves for 3 surges and continuous flow under three different ploughs

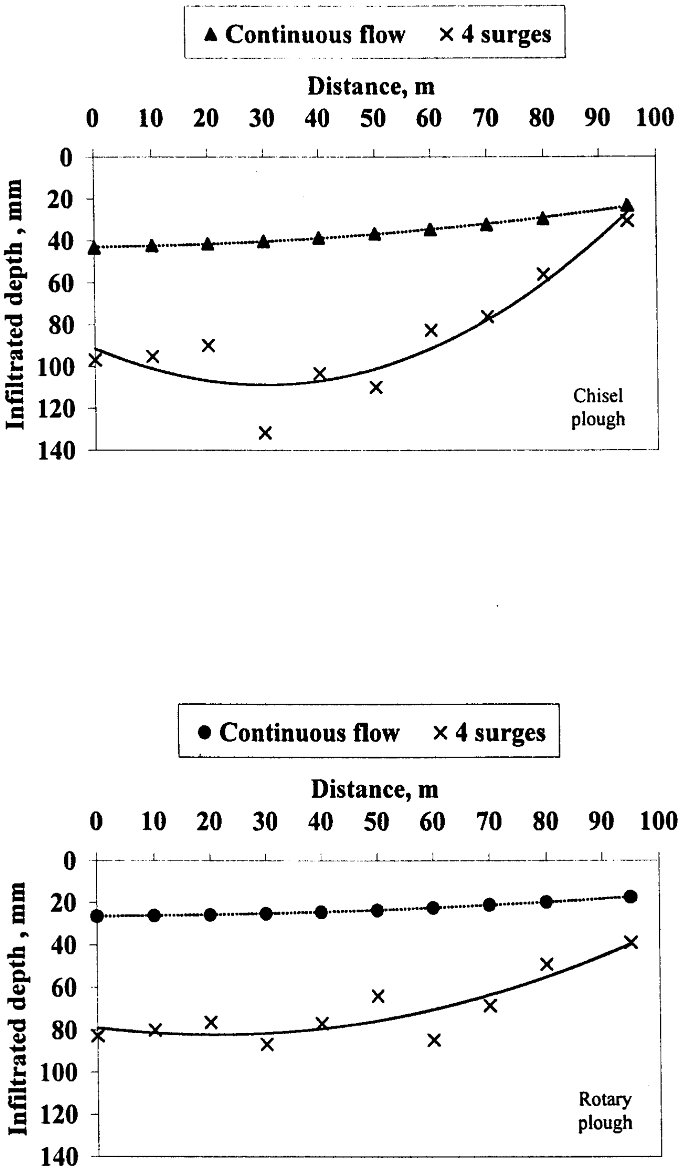

Fig. 2: Infiltrated water distribution curves for 4 surges and continuous flow under chisel and rotary ploughs.

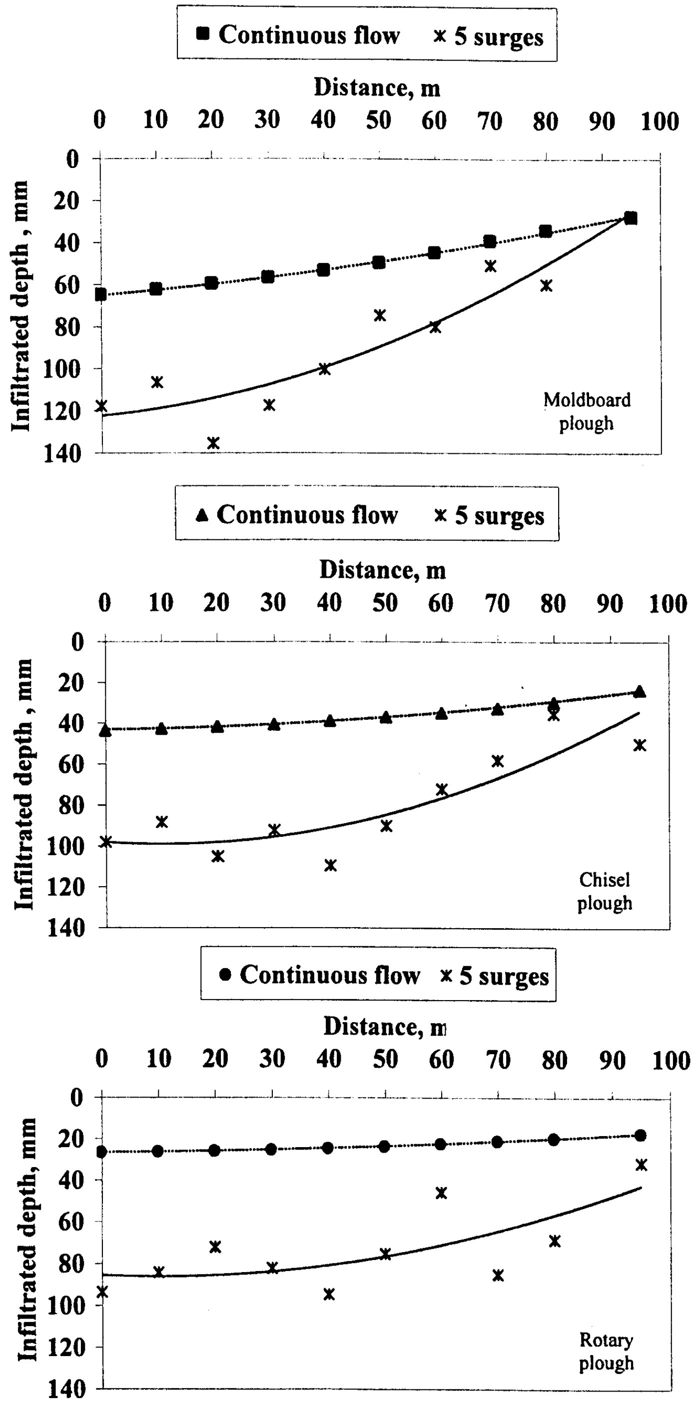

Fig. 3: Infiltrated water distribution curves for 5 surges and continuous flow under three different ploughs.

ARABIC SUMMARY

الملخص العربى

الرى النبضى للخطوط هو تقنية جديدة للتحكم فى رى الخطوط. والهدف الرئيسى من هذا البحث هو دراسة تأثير الرى النبضى والرى المستمر للخطوط على إدارة المياه وإنتاجية محصول الذرة مع طرق الحرث المختلفة.

وقد أجريت التجارب الحقلية فى محطة البحوث الزراعية بزرزورة - إيتاى البارود - محافظة البحيرة - مصر ، خلال موسم ١٩٩٨/١٩٩٩م. وقسمت أرض التجربة إلى ثلاث قطع رئيسية ، كل قطعة بطول ٩٥ متراً وعرض ١٧ متراً ، ومخصصة لأنظمة الحرث المستخدمة. وقد قسمت كل منها لأربع شرائح (تحت رئيسية) ، بمساحة ٣٣٢,٥ م^2 ، مخصصة لمعاملات الرى المستمر و النبضى.

والتربة تحت الدراسة طينية طفلية ،أخذت فيها الخطوط بطول ٩٥ متراً وعرض ٠,٧٠ متراً وميل ٠,٠٤٪ ومعامل الخشونة لماننيج ٠,٠٣٧.

وكانت المعاملات المدروسة كالأتى :

أ - معاملات الحرث (القطع الرئيسية) :

١- محراث قلاب مطرحى بعمق حرث أمثل ٢٥ سم.

٢- محراث حفار بعمق حرث أمثل ٢٠ سم.

٣- محراث دورانى بعمق حرث أمثل ١٢ سم.

ب - معاملات الرى (القطع تحت رئيسية):

١- رى مستمر.

٢- رى نبضى (٣ نبضات) بزمن فتح للمياه ١٠ - ١٩ - ٢٥ دقيقة على التوالى وزمن غلق المياه ٢٠ دقيقة بين كل منها ، وزمن إجمالى لفتح المياه ٥٤ دقيقة.

٣- رى نبضى (٤ نبضات) بزمن فتح للمياه ٦ - ١١ - ١٥ - ١٨ دقيقة على التوالى وزمن غلق المياه ١٥ دقيقة بين كل منها ، وزمن إجمالى لفتح المياه ٥٠ دقيقة.

٤- رى نبضى (٥ نبضات) بزمن فتح للمياه ٤ - ٨ - ١٠ - ١٢ - ١٣ دقيقة على التوالى وزمن غلق المياه ١٠ دقائق بين كل منها ، وزمن إجمالى لفتح المياه ٤٧ دقيقة.

وتم إضافة ماء الرى لكل خط من خلال أنابيب السيفون البلاستيكية ، بأطوال ٢ متر وبأقطار ٥٠ مليمتر ، وأستعمل معدل تصرف ١,٥ لتر/ث للخط الواحد ، وثبت هذا التصرف داخل الخطوط طوال فترة التجربة لمختلف المعاملات.

وتم إجراء التجارب المعملية لقياس معدلات التسرب للإضافات المستمرة والنبضية للماء وذلك باستخدام جهاز التسرب ، والذى يتكون من اسطوانة زجاجية و صمام تحكم وورق ترشيح وحاملين و أنبوبة ماريوت وخرطوم بلاستيكي.

وقد سجلت القياسات الحقلية والمعملية أثناء الموسم كما يلي :

١- أزمنة التقدم والانحسار للمياه للمحطات (مسافة ١٠ أمتار بين كل محطة) على طول كل خط.

٢- إنتاجية محصول الذرة عند بداية ووسط ونهاية الخط.

٣- أعماق التسرب التراكمى والزمن المنقضى لها لكل معاملة.

وكانت المؤشرات المحسوبة للمعاملات المختلفة كما يلي :

١- الزمن الكلى لفتح المياه لكل معاملة.

٢- كمية المياه المضافة لكل معاملة.

٣- كفاءة إضافة المياه.

٤- كفاءة توزيع المياه.

٥- كفاءة استخدام المياه.

ومن النتائج المتحصل عليها فى هذه الدراسة ، يمكن أن نحصل على الخلاصة الآتية :

١- تتطلب معاملات الرى النبضى زمناً أقل لإكمال جبهة التقدم عن التى فى معاملات الرى المستمر.

٢- أعطت معاملة ٣ نبضات رى مع الحرث بالمحراث الدورانى معدلاً أسرع لتقدم المياه عن باقى المعاملات الأخرى ، وخفضت الزمن اللازم لتقدم المياه لها ٢٥,٣٦ ٪ مقارنة بالرى المستمر.

٣- وفر السريان النبضى ١١,٨٤ و ١٨,٥٨ و ١٨,٩٣ ٪ من المياه المضافة لمحصول الذرة للسريان المستمر تحت المحراث الحفار والقلاب المطرحى والدورانى على الترتيب.

٤- أدى الرى باستخدام ٣ نبضات مع الحرث بالمحراث الدورانى أقل كمية للمياه الكلية المضافة (١٣٣٩,٥٤ م^{٣}/فدان) حيث استعملت ٧٤.٦٤ ٪ من كمية المياه الكلية المضافة للرى المستمر.

٥- سبب الرى النبضى انخفاضاً فى معدلات التسرب الشبه الثابتة للمياه مع كل من المحاريث الثلاثة المستخدمة فى هذه الدراسة رغم قصر أزمنة فرصة التسرب للرى النبضى عن الرى المستمر.

٦- تفوقت معاملة ٤ نبضات رى مع الحرث بالمحراث القلاب المطرحى عن باقى المعاملات حيث أعطت أعلى قيمة لكفاءة إضافة المياه (٩٨,٤٩ ٪).

٧- أعطت معاملات السريان النبضى القيم الأقل لكفاءة توزيع المياه مقارنة بمعاملات السريان المستمر.

٨- فى المعاملات النبضية ، أعطت معاملة ٣ نبضات للمحراث الدورانى أعلى قيمة لكفاءة توزيع المياه (٨٣,٩٠ ٪).

٩- كانت أعلى قيمة لإنتاجية محصول الذرة (٤٣٧٢,٤٠ كج/فدان) للمعاملة ٣ نبضات مع المحراث الحفار.

١٠- كذلك سجلت معاملة ٣ نبضات مع المحراث الحفار أعلى قيمة لكفاءة استخدام المياه لمحصول الذرة (٣,٠١ كج/م^{٣}).

وأخيراً ، فإن التوصيات للدراسات المستقبلية هى كالآتى :

١- الاحتياج لكثير من البحث فى دراسة تأثير الرى النبضى على معدلات التقدم للمياه التى لها علاقة بنوع التربة وشكل وميل الخط ومعدلات تصرف سريان المياه.

٢- تأثير الإضافات النبضية للمياه على الترسيب والنقل والنحر فى الخط.

٣- يجب عمل دراسات لتقييم الاستخدامات الأخرى لنظام الرى النبضى (رى الشرائح والأحواض) مع أنظمة الحرث المختلفة.

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رسالة مقدمة من

محمد عبد العزيز محمد مطر

للحصول على درجة الماجستير للعلوم الزراعية فى الميكنة الزراعية

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التاريخ: / / ٢٠٠١م

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كجزء من المتطلبات للحصول على درجة

الماجستير للعلوم الزراعية

فى

الميكنة الزراعية

قسم الميكنة الزراعية
كلية الزراعة بكفر الشيخ
جامعة طنطا

٢٠٠١