EFFECT OF CYCLE RATIO ON FURROW SURGE IRRIGATION EFFICIENCY USING A HYDROFLUME (GATED-PIPE)

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DEDICATION

To my sister’s soul, my beloved father, mother, brothers, sisters my family and to all those to whom I belong with love.

Saleh
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ABSTRACT

The practical part of the study was conducted at the University of Khartoum top farm, in Shambat during the period "2004-2005". To involve the investigation and evaluation of surge irrigation cycles on irrigation efficiencies, advance and recession times, advance velocities and opportunity time. The study as well measured the effect of surge irrigation technique, soil depth and location along the furrow on soil moisture content and infiltration rate. Application, distribution and storage efficiencies for all cycle ratios were determined. Soil moisture content down the profile at depths 0-20, 20-40 and 40-60 and along the furrow run at 10m, 40m and 70m were determined. Furrow length was 80m and the flow rate was 1 liter/second. The advancing front of water reached the end of furrow in 28 minutes. The treatments included four-cycle ratios under surge irrigation using a hydroflume (gated pipe). These cycle ratios were 1, ¾, ½ and ¼ of the cycle time. The cycles were tested under four furrows and each treatment was repeated four times in any irrigation set.

The results showed that the moisture content at all locations had no significant between them but near the upper end of the furrow (10m) had high values followed by locations at 40m and then the locations at 70m so moisture content decreased with increasing distance along the furrow with all cycle ratios. The results of advance and recession phases for all cycle ratios showed that water advance for ½ cycle ratio was very rapid and it reached the lower end of the furrow in a shorter time as compared to the other cycle ratios, followed by cycle ratio ¾ and cycle ratio ¼ which resulted in longer time than the continuous time. The results of recession phases showed that the cycle ratios were in a descending order. The results
also showed that the highest opportunity time was obtained with cycle ratio \(\frac{1}{2}\) at the upper end of the furrow. The highest application efficiency of 98% was recorded with cycle ratio \(\frac{3}{4}\). Whereas the lowest application efficiency of 63% was obtained by cycle ratio \(\frac{1}{4}\).

However, results of distribution efficiencies showed that the highest distribution efficiency of 89% was obtained with cycle ratio 1, while the lowest distribution efficiency of 86% was recorded by cycle ratio \(\frac{1}{4}\). Whereas the highest storage efficiency of 78% was obtained with cycle ratio \(\frac{1}{2}\), whereas the lowest storage efficiency of 71% was recorded under cycle ratio \(\frac{1}{4}\).
بسم الله الرحمن الرحيم

خلاصة الأطروحة

أجريت هذه الدراسة بمزرعة جامعة الخرطوم- كلية الزراعة شمبات أثناء الفترة من 2004-2005م و اشتملت التجربة على اختيار أربعة دورات من زمن دورة الري تحت الري النبضي باستخدام الهيدروفولوم وهذه الدراسة احتوت على تقييم أثر تقنية الري النبضي، عمل التربة والموقع على طول السرارة على المحتوى الرطبي ومعدل التخلل.

كما اشتملت أيضا الدراسة على تقديم كفاءة الإضافات، التوزيع والتخزين لكل الدورات. هذه الدورات كالآتي دورة كاملا 1/4, 1/3, و من زمن دورة الري. أختبرت هذه الدورات في أربعة سرابات وزوّرت على التوالي كل دورة في سرارة في أربعة مكررات في كل رية، كان طول السرارة 80م. أشتملت الدراسة على تقييم أثر دورات الري على كفاءة الري النبضي، تحديد زمن التلمس زمن التقدم والانحسار.

أوضحت النتائج أن المحتوى الرطبي أظهر فروقات معنوية في الجهة العليا من السراب ويقل بزيادة طول السرارة لكل الدورات، كما وضحت النتائج أن دورة الري 1/2 كان لها أسرع منحنى تقدم وانحسار مقارنة بالدورات الأخرى ووصلت نهاية السرارة في زمن أقل من الدورات الأخرى وتبعتها دورة الري 4/4 لدورة الكاملة ثم دورة الري 4/4 كان زمن تقدمها ووصولها نهاية السرارة أكثر من زمن منحنى تقدم الري المتواصل.

أيضاً أوضحت النتائج أن عمق التربة ذا أثر معنوي على محتوى الريوتوبية وأعلى زمن تلمس كان لدورة الري 1/2 عند النهاية العليا للسريحة.

في هذه التجربة أعلى كفاءة إضافه كانت 98% أمكن الحصول عليها مع دوره الري 4/4 في حين أن أقل كفاءة إضافه 63% سجلت مع دوره الري 4/4 أظهرت نتائج كفاءة التوزيع أن أعلى كفاءة للتوزيع كانت 89% أمكن الحصول عليها مع دوره
الري الكاملة 1و أقل كفاءة للتوزيع 86%سجلت مع دورة الري ¼، أنتجت أعلى كفاءة تخزين 78%ففي حين أن أقل كفاءة للتخزين سجلت مع دورة الري ½.
CHAPTER ONE

INTRODUCTION

Surface irrigation is the most common irrigation method in the world. Throughout the world, irrigation is probably the most important use of water. Almost 60 percent of all the world's freshwater withdrawals go towards irrigation uses. Large-scale farming could not provide food for the world's large populations without the irrigation of crop fields by water gotten from rivers, lakes, reservoirs, and wells. Irrigation water is the most important input for agricultural production in the arid and semiarid regions; therefore, efficient use and appropriate management practices of this input should be developed and adopted.

Surface irrigation is the application of water by gravity flow to the surface of the field. Either the entire field is flooded (basin irrigation) or the water is fed into small channels (furrows) or strips of land (borders). An adequate water supply is important for plant growth. When rainfall is not sufficient, plants must receive additional water from irrigation. Various methods can be used to supply irrigation water to the plants. Each method has its advantages and disadvantages. These should be taken into account when choosing the method that is best suited to the local conditions.

Furrows are small channels, which carry water down the land slope between the crop rows. Water infiltrates into the soil as it moves along the slope. The crop is usually grown on the ridges between the furrows. This method is suitable for all row crops and for crops that cannot stand in water for long periods. Irrigation water flows from the field channel into the furrows by opening up the bank of the channel, or by means of siphons or spiels. Sometimes, instead of the field canal with siphons or spiles, a gated pipe is
used. Types of surface irrigation include furrow, border, and basin irrigation. Surface irrigation involves flowing water across the soil surface, thus using the soil to convey water along the field length. This results in a low capital cost. However, using the soil surface to convey water across the field introduces problems to its design and management. Both design and management depend to a high degree on the soil properties such as infiltration rate and surface roughness. These properties can be difficult to measure thus requiring a trial-and-error approach to develop proper design and management strategies.

A surface irrigation event is composed of four phases: advance, wetting or storage, depletion and recession. When water is applied to the field, it 'advances' across the surface until the water extends over the entire area. It may or may not directly wet the entire surface, but all of the flow paths have been completed. Then the irrigation water either runs off the field or begins to pond on its surface. The interval between the end of the advance and when the inflow is cut off is called the wetting or ponding phase. The volume of water on the surface begins to decline after the water is no longer being applied. It either drains from the surface (runoff) or infiltrates into the soil. For the purposes of describing the hydraulics of the surface flows, the drainage period is segregated into the depletion phase (vertical recession) and the recession phase (horizontal recession). Depletion is the interval between cut off and the appearance of the first bare soil under the water. Recession begins at that point (at the bottom end of the furrow) and continues until the surface is drained (at the upper end of the furrow). There are some suggestions to improve the efficiencies of surface irrigation such as land smoothing, reuse of tail-water that runs off the down stream end of surface irrigation fields, surge flow, cut-back and cut-off irrigation
techniques. Therefore, the objectives of this study were:

1. To evaluate the effect of cycle ratios on completing advance phase to know the time which needed to complete the irrigation?

2. To examine the effect of using hydroflume on surface irrigation systems efficiency by saving water and high control of adding.

3. To determine the opportunity time using surge irrigation technique by determining the advance and recession fronts at different stations along the run.

4. To evaluate the effect of surge irrigation on irrigation efficiencies by measuring at many locations.
Chapter Two

Literature Review

2.1 Water Application Methods:

The main objective of irrigation is to supply the essential moisture for plant growth and leach or dilute salts in the soil. The method and timing of irrigation have significant effects on crop production. Irrigation management is often designed to maximize efficiencies and minimize the labor and capital requirements (Walker, 1987). Farm irrigation systems must supply water at rates, in quantities, and at times needed to meet farm irrigation requirements and schedules. They divert water from a water source, convey it to the cropped area of the farm, and distribute it over the area being irrigated (James, 1988). Irrigation water may be applied to crops by flooding it on the field surface (surface irrigation), by applying it beneath the soil surface (subsurface irrigation), by spraying it under pressure (sprinkler) or by applying it in drops (drip) (Michael, 1978).

2.2 Surface irrigation methods:

Surface irrigation is the oldest and most commonly used method of irrigation. In the surface methods of irrigation, water is applied directly to the soil surface from a channel located at the upper reach of the field. Surface irrigation systems convey water from the source to fields in lined or unlined open channels and/or low head pipelines. Basins, borders, and furrows are the primary methods of applying irrigation water. Other surface irrigation methods include water spreading and contour ditch irrigation (Israelsen and Hansen, 1962; Michael, 1978; Bassett et al., 1980; Walker, 1987). Two general requirements of prime importance to obtain high efficiency in surface methods of irrigation are properly constructed water
distribution systems to provide adequate control of water to the fields and proper land preparation to permit uniform distribution of water over the field (Michael, 1978). Surface irrigation methods are classified by the slope of the field (each system suitable for suitable slope), the size and shape of the field, the end conditions and how water flows into and over the field (Walker, 1987). Surface irrigation uses open channels flow to spread water over a field. The driving force in such systems is gravity and hence the alternate term, gravity flooding. Surface irrigation systems generally require a smaller initial investment than do other types of irrigation systems (Hart et al., 1980).

2.2.1 Furrow irrigation:

The furrow method of irrigation is used in the irrigation of row crops with furrows developed between the crop rows in the planting and cultivating processes. The size and shape of the furrow depends on the crop grown, equipment used spacing between crop rows (Michael, 1978). Furrows can be made by ridge tillage, which results in relatively uniform distribution of water in the field along the length of run. Furrows are used for nearly all row crops that are irrigated by surface methods (Unger and Musick, 1990). Furrow irrigation avoids flooding the entire field surface by channeling the flow along the primary direction of the field using furrows, creases or corrugations. Furrows are often employed in basins and borders to reduce the effects of topographical variations and crust. Furrows provide a better flexibility on farm water management under many surface irrigation conditions. Also, furrows provide the irrigator with more opportunity to manage irrigation toward higher efficiencies as field conditions change for each irrigation throughout a season (Walker, 1989). Infiltration occurs laterally and vertically through the wetting perimeter of the furrow
The enormous variability of parameters such as soil infiltration, soil surface roughness, soil water holding capacity, field slope and furrow geometry make field testing slow, tedious and expensive (Holzapfel, et al., 1984).

2.2.2 Water flow in furrows:

Water is diverted into furrows from open ditches or pipes. Two of the most common methods of introducing water into furrows from open ditches are siphon tubes and forebays with spiels (Criddle et al., 1956; James, 1988). James (1988) added those portable gated pipes and single or multiple outlet risers are two popular ways of distribution of water from low pressure underground pipes. Water infiltrates from the bottom and sides of furrows moving laterally and downward to wet the soil carrying with it soluble salts, fertilizers and herbicides. Under normal conditions flow continues until the advancing front reaches the lower end of the furrow. When surface flow and infiltration reduce the depth of water at the upper end to zero, a recession front proceeds down stream until it reaches the lower end of the furrow. At this time the irrigation is completed (Bassett et al., 1980).

2.2.3 Furrow classification:

Irrigation furrows may be classified into two general types based on their alignment. These are straight furrows, and contour furrows. Based on their size and spacing, furrows may be classified as deep furrows and corrugations (Michael 1978), whereas, James (1988) classified furrows as level and contour or graded ones.

(a) Straight furrows:

Straight furrows are best suited to sites where the land slope doesn’t exceed 0.75 percent. In areas of intense rainfall; however, the furrow grade should not exceed 0.5 percent so as minimize the erosion hazard (Michael,
(b) Contour furrows:

Contour furrows are curved to fit the topography of the land. Contour furrow method can be successfully used in nearly all irrigable soils (Michael, 1978).

2.2.4 Design of furrow system:

Efficient irrigation by the furrow method is obtained by selecting proper combinations of spacing, length and slope of furrow and suitable size of the irrigation stream and duration of the water application (Michael, 1978). A furrow system may be designed only after gathering information about soils, crops, topography, size and shape of the area to be irrigated. Most furrows in row crops are either parabolic in cross section or have flat bottoms or about 2:1 side slopes (Hart et al., 1980). Furrow irrigation designs are often needed either for new irrigation schemes or existing projects where improvements are needed (Walker, 1987). Furthermore, it was reported that there are three primary furrow designs, namely, furrow without cut back, the cut back system and the tail water recycled system. These systems should be flexible to irrigate the field adequately in which the surface roughness and intake rates vary widely from irrigation event to another.

a. Furrow spacing:

Furrow can be spaced to fit the crops grown and the type of machines used for planting and cultivation. Furrows should be spaced close enough to ensure that water spreads to the sides into the ridge and the root zone of the crop to replenish the soil moisture uniformly. The lateral movement of water in soils with uniform profiles depends primarily upon the texture of the soil. The spacing in clay soils more than the spacing in sandy soils (Michael, 1978). The spacing of furrows depends on the crop to be irrigated, the type
of tillage machinery and the wetting pattern which can be obtained by lateral movement of water in the soil (Booher, 1974). Whereas James (1988) mentioned that standard furrow spacing is often used for a number of different crops that make use of the same farm equipment. Sandy soils that tend to have a vertical wetted pattern should have closer furrow spacing than clay or loam soils. Soils with non uniform profiles will generally have greater lateral movement of water than soils lying above less permeable layers or above abrupt changes in soils texture.

**b. Furrow length:**

The optimum length of a furrow is usually the longest furrow that can be safely and efficiently irrigated. Proper furrow length depends largely on the hydraulic conductivity of the soil. The length of furrow which can be efficiently irrigated may be as short as 45 m for irrigating soils which take up water rapidly, or as much as 300m or longer on soils with low infiltration rates (Michael, 1978). Solomon (1988) stated that optimal furrow length is primarily controlled by the intake rate of the soil and the stream size. The length of furrows varies from 30 meters or less for gardens to as much as 450 meters for field crops and furrow lengths of 90 meters to 200 meters are common (Israelsen and Hansen, 1962). Relatively short furrows are required on sands and other soils with rapid infiltration characteristics and low water holding capacities. Furrow length can normally be increased as average depths of application become larger. (James, 1988) mentioned that furrows can be much longer for deep rooted crops on clay soils than shallow rooted crops grown in sandy soils, while Booher (1974) recommended that furrow length should be adjusted according to soil type and slope in fields with large soil and slope variations.
c. **Furrow slope:**

The slope or grade of furrow is important because it controls the speed at which water flows down the furrow. A minimum furrow grade of 0.05 percent is needed to ensure surface drainage (Michael, 1978). Recommended safe limits of land slopes in furrows are 0.25% to 0.6% for sandy loam to sandy soils, 0.2% for medium loam soils and 0.05 to 0.2% clay loam soil.

**d. Furrow stream size:**

The size of the furrow stream is one factor which can be varied after the furrow irrigation system was installed. The size of the furrow stream usually varies from 0.5 to 2.5 liters per second (Michael, 1978). Criddle *et al.*, (1956) mentioned that the maximum stream need not always be used for good irrigation. A smaller stream will be satisfactory if it will reach the lower end of a field with" one-fourth time” criterion. Furrow stream sizes must be carefully selected to obtain the desired blend of irrigation effectiveness and convenience of operation (James, 1988). Furrow stream size must not exceed the maximum non-erosive stream size determined in field trials. The maximum non-erosive flow rate in furrow is estimated by the following empirical equation:

\[
q_{\text{max}} = \frac{0.6}{s} 
\]

\[\text{In which:}\]

\[
q = \text{maximum non-erosive stream, lit/sec.}
\]

\[
S = \text{slope of furrow expressed as percent.}
\]

The following equation, (James, 1988; Phelan and Criddle, 1954) provides guidance in selecting stream sizes for field trials:-
\[
\frac{k}{Q_{\text{max}}} = s, \quad \ldots \ldots \ldots \quad (2.2)
\]

Where:

- \(Q_{\text{max}}\) = irrigation maximum non-erosive stream size (L/min).
- \(K\) = a constant of a volume of 40 for \(Q_{\text{max}}\) in L/min.
- \(S\) = furrow slope in the direction of flow (percent).

Michael (1978) reported that the average depth of water applied during irrigation can be calculated from the following relationship:

\[
d = \frac{q \times 360 \times t}{W \times L} \quad \ldots \ldots \ldots \quad (2.3)
\]

Where:

- \(d\) = depth of water (cm).
- \(q\) = discharge in (l/sec).
- \(t\) = time to complete irrigation (hours).
- \(W\) = width of furrow (m).
- \(L\) = length of furrow (m).

**e. Furrow shape and size:**

The size and shape of the furrow depend on the crop grown, equipment used and spacing between crop rows (Michael, 1978). Furrow systems may be designed with a variety of shapes and spacing (Solomon, 1988). Furrows vary in shape and size and most furrows in row crops are either parabolic in cross section or have flat bottoms and about 2:1 side slope (Hart et al., 1980). The shape of furrow can have considerable influence on the adequacy and efficiency of irrigation. The cross section of the furrow should be sufficient to carry the amount of water needed to obtain uniform distribution throughout the furrow. Increasing the wetted perimeter provides a greater
area for the water to move into the soil (Booher, 1974). Michael (1978) stated that different furrow shapes might be used for different purposes depending on the crop grown. Shallow furrows should have a uniform depth and shape along the length of the field to prevent overtopping. Broad-based furrows promote infiltration by increasing the wetted perimeter. Deep furrows require a large volume of water to adequately irrigate the upper portion of the root zone. On the other hand, deep furrows minimize the adverse effects caused by water logging of the root zone in high rainfall areas. Furrow shapes are normally modified by water flow. On steep slopes narrow channels tend to farm, whereas on flatter slopes broader channel usually result. These tendencies are greater on sandy soils than on clay soils (James, 1988). Erosion created by furrow irrigation is a serious problem, which can reduce crop yields.

2.5 Water flow measurement:

Water is the most valuable asset of irrigated agriculture. Accurate measurement of irrigation water reduces excessive waste and allows the water to be distributed among users according to their needs and rights. Water is measured under two conditions at rest and in motion. Water at rest is measured in units of volume such as liters, cubic meters and hectare-centimeter or meter and in motion is expressed in rate of flow units that is volume per unit time such as liters per hour or cubic meters per second. For on farm monitoring and evaluation the most commonly used devices for measuring water are weirs, flumes, orifices and meter gates (Michael, 1978; Replogle et al., 1980; Walker, 1987). There are many useful devices available for measuring water as part of surface irrigation evaluation. For on farm monitoring and evaluation the most commonly used devices for measuring water are weirs, flumes, orifices and metergates (Michael, 1978;
Israelsen and Hansen, 1962; James, 1988; Walker, 1987). Effective irrigation management and maintenance programmes require acknowledgement of the amount and rate of water use. All irrigation systems should include measuring devices for determining system flow (James, 1988). Efficient use of irrigation water depends on the measurement of water and information concerning the relationship between water, soil, and plants will be of no value in irrigation practice without measurement of water (Israelsen and Hansen, 1962). Flumes include the parshall flume, the H-flume and the trapezoidal flume (Walker, 1987). For accurate measurement the flume must be carefully leveled and installed as reported by Merriam (1977).

2.5.1 The Parshall flume:

The Parshall flumes may be made of sheet metal, concrete, galvanized sheet metal or other materials (James, 1988; Michael, 1978). The parshall flume is the most commonly used flow measuring device in irrigation systems (Walker, 1987). It is designed as a measuring device with which the discharge is obtained by measuring the loss in head caused by forcing a stream of water through a throat or converged section of the flume with the depressed bottom (Israelsen and Hansen, 1962). The size of flume is determined by the width of its throat. The discharge through the flume can occur under either free flow or submerged flow conditions. Where the elevation of the water surface downstream from the flume is high enough to determine the discharge two scales, Ha and Hb are provided at the upstream and downstream sections of the flume (Michael, 1978). The flow depth downstream of the throat may not affect the rate of flow through a parshall flume. Free flow conditions exist when the tail water depth is not high enough to affect flow, but it is considered to be submerged when tail water
depth is sufficient to affect flow (James, 1988). Under free flow condition only Ha need to be measured (Michael, 1978). Submergence ratio is determined using the following equation:

\[
S = \frac{H_b}{H_a} \quad \text{(2.4)}
\]

Where:

- \(S\) = Submergence ratio.
- \(H_b\) = Head downstream of throat (cm).
- \(H_a\) = Head upstream of throat (cm).

When the flow is free Ha is used to determine the flows from certain tables. Discharge (Q) is determined by using the following equation suggested by James (1988) for submerged flow:

\[
Q = 25.733(H_a - H_b)^{1.55} \quad \text{(2.5)}
\]

Where:

- \(Q\) = discharge in (lit/sec).

2.5.2 System components:

a. The hydroflume:

Gated pipe irrigation is a type of surface irrigation in which the conventional main ditch and field lateral ditch or siphons are replaced by an above ground pipeline and gated pipe. Irrigation water flows from gates which are regularly spaced along the pipeline.

The gated pipe gave water saving of 25-28%, a 19-29% increase in water use efficiency and 25% of electricity energy saving compared to conventional basin irrigation, this for the closed of the pipe. Economic analysis indicated that the PVC gated pipe system has lower investment and higher irrigation efficiency among the conventional ditches, underground
pipe, aluminum gated pipe and hand move sprinkler irrigation system. Commercialization and widely extension of this gated pipe irrigation system could reduce agricultural water use.

Hydroflume is available in 5 sizes; it is made of VU and thermal protected low density Polyethylene of 700 micron wall thickness for maximum service life time in hot and tropical conditions. It is flexible so that no alluvial clings to its wall. Gated pipes are portable lines with uniformly spaced outlets used for releasing irrigation water to furrows, border strips or check basins. Gated pipes are usually constructed of aluminum, light weight steel tubing or rubber materials. The spacing of the gates is usually the same as the spacing of the furrows so that the water is discharged directly into them. A portable end plug with a locking device is fitted at the end of the line. The gates are placed on one side of the system and operate with outlets fixed with caps to control the discharge. The flow through them is a function of the pressure within the pipe and the size of the opening. A pressure of 30 to 150 cm of water usually required at the hydrant to operate the gated pipe. The velocity of flow in the pipe depends on the pipe size, the initial flow in the pipe and the number of gates opens upstream from a given point. There would be no velocity in the pipe at the last gate of a line (Micheal, 1978 and Walker, 1987). Their diameter ranges from 10 to 45 cm. The system consists of the riser, hydroflume and outlets (Micheal, 1978).

To divert water from a large diameter irrigation pipeline to a smaller diameter plastic gated pipe so called "Hydroflume", a pipe turnout was designed and built. This pipe turnout not only conveys water but it also dissipates the excess energy. Gated pipe has many advantages and these are:

1. **Improve the water conveyance efficiency:** The gated pipe system uses the solid aluminum pipeline to deliver water from the source (riser) to
the field boundary, so there is nearly no water loss like seepage and evaporation.

2. **Better distribution uniformity:** The uniformity for surface irrigation system is more commonly characterized by the distribution uniformity, and it is a main parameter to evaluate a system.

3. **Water, irrigation time and energy saving:** Compared with conventional basin and border strip method, the gated pipe system can reduce the irrigation quota, save time and energy and irrigation water infiltration depth in root zone.

**b. Joiner:**

It is used to join rolls together. It is made of hot galvanized iron sheet for corrosion protection. It is delivered open and may be ready to use by attached screw and nuts in field.

**c. Clamps:**

Clamp consists of the belt which is made of stainless steel and screw mechanism made of anodized iron pieces. It is used to fix hydroflume on joiners.

**d. End clamp:**

End clamp is made of strong iron profile and hot galvanized for corrosion protection; it is used to close end of line or to control flow of water.

**e. Outlets:**

Outlet consists of two parts, the base made of flexible PVC, and cap made of Polypropylene. It may be easily installed in any point of the path. Outlet is adjustable and water discharge rate may vary up to 4.5 liters per sec. (At water pressure of 100 cm). If the cap is removed discharge will exceed 7 Lit/Sec.

Outlets structures are necessary to provide controlled delivery of water to the fields at any desired location. These should be easy to open and close, be of proper size to provide the flow required, and be so constructed that the water
released will not cause soil erosion. It consists of value and an attached value to control the flow of water. The diameter of the riser is usually the same as the diameter of hydroflume. The flow through them is a function of the pressure within the pipe and the riser of the opening. A pressure of 30 to 150 of water is usually required at the riser to operate the gated pipes.

f. Punch:

Punch consists of base and cap made of Polypropylene and cutting head made of stainless steel. This tool is used to make holes on hydroflume to install outlets.

g. Riser:

It is made of metal, bricks or any other materials used to maintain a constant head.

2.6 Soil physical properties:

The most important soil properties influencing irrigation are its infiltration characteristics and water holding capacity. Other properties include soil structure, capillary conductivity and soil profile conditions (Micheal, 1978).

2.6.1 Soil bulk density:

The bulk density, or bulk specific weight, of a soil mass is the dry weight of soil per unit bulk volume which is expressed in g/cm³. Measurements of bulk specific weight are commonly made by extracting a soil samples, then measuring the bulk volume, and drying the sample in an oven to determine the soil moisture content. Soil bulk density is defined as the ratio of mass of solid to its volume i.e. bulk density is a mass/unit volume of individual soil particles including pore spaces and total soil volume. Bulk density is a highly variable quantity since it depends upon the degrees of aggregation and porosity of the soil. The usual method of
determining the bulk density or apparent specific gravity of a soil is to obtain an uncompacted soil sample of known volume (Michael, 1978). The apparent specific gravity is the ratio of the weight of a given volume of dry soil, air space included, to the weight of an equal volume of water. This ratio is known also as the “volume weight” or bulk density (Israelsen and Hansen, 1962).

2.6.2 Field capacity:

The field capacity of a soil is the water content after gravitational water has become slow and water content becomes relatively stable (Israelsen and Hansen, 1962). Field capacity of a soil is the upper limit of soil water that is available to plants. The water content when the soil is at field capacity is less than saturation. As the soil dewateres, the matric forces steadily increase (negatively) to contribute to a steadily declining outflow rate. This continues until the rate of water movement through the soil becomes negligible. This situation occurs at field capacity (James, 1988). Field capacity is the water content in a field soil after the drainage rate has become small and it is an estimate of the amount of water that may be temporarily stored in the soil profile for plant use (Skaggs, et al., 1980). The field capacity is determined by ponding water on the soil surface in an area of about 1 to 5 square meters and permitting it to drain for one to three days with surface evaporation prevented (Micheal, 1978). It was assumed that an application of a given amount of water would wet a soil to field capacity (Skaggs et al., 1980). Also field capacity can be defined as the soil water content corresponding to a matric potential ranging from 0.1 bars for sands to 0.5 bars or more for very fine textured soils. A matric potential of 0.33 bars is used to define field capacity for most soils (Israelsen and Hansen, 1956; Micheal, 1978; Skaggs et al., 1980 and James, 1988).
2.6.3 Soil moisture content measurements:

The primary concern with water in irrigated agriculture is the replenishment of soil moisture in the plant root zone (Walker, 1987). The soil water content is determined either by direct measurement or inference from measurements of other soil parameters such as soil water potential or electrical conductivity (James, 1988). The standard method for determining soil moisture content is the gravimetric sampling method. The samples are usually collected from the field over some depths interval. The soil sample is weighted and placed in an oven maintained at 105°C. Usually, the soil samples are left in the oven for 24 hours and reweighed after drying it to a constant weight (Walker, 1987). The results are expressed as a ratio of the mass of water lost to the mass of dry soil. The required drying time depends upon the soil texture, soil wetness, loading of oven, sample size, whether the oven is a forced draft or convection type and other factors. Moisture content on dry mass basis is multiplied by the apparent specific gravity, which numerically equals the bulk density to obtain moisture content on volume basis (Isrealson and Hansen, 1962; Micheal, 1978; Skaggs et al., 1980 and James, 1988).

2.7 Infiltration concept:

Infiltration is the most important process in surface irrigation. It essentially controls the amount of water entering the soil reservoir, as well as the advance and recession of the overland flow (Walker, 1987). Infiltration is the total amount of water that enters the soil in a given time. Rate of entry of water into the soil under field conditions is called intake rate (Isrealson and Hansen, 1962). Skaggs et al., (1980) stated that infiltration is usually defined as the entry of water into the soil profile. Matric as well as gravitational forces cause the water entry into soil. Two and three
dimensional movements are considered briefly since they are also of interest in the field. The matric forces usually predominate over the gravitational forces during the early stages of water entry into soil so that many conclusions that are reached concerning the early infiltration are valid in the absence of gravity (Baver et al., 1972). For surface irrigation, the most efficient furrow or border length depends on the infiltration and factors affecting it which are important to design and operate systems (James, 1988; Skaggs et al., 1980). El Ramlawi (1992) stated that there are many factors affecting the infiltration behavior of a soil. These include:

1- Initial soil moisture.
2- Soil texture and structure.
3- Subsurface strata.
4- Soil cracking.
5- Soil surface compaction.
6- Surface sealing.

Infiltration characteristic of a soil may change from one point to another (spatial variability) due to heterogeneity of the soil. It may also change during the irrigation season (temporal variability) due to the difference in the moisture content, compaction and surface soil conditions (Hart et al., 1980).

2.7.1 Infiltration rate:

Infiltration rate and cumulative infiltration are the two parameters commonly used in evaluating infiltration characteristics of soil (Micheal, 1978; Skaggs et al., 1980, and Walker, 1987). Infiltration rate is the characteristic determining the rate at which water enters the soil vertical downwards under specific conditions (Micheal, 1978). The infiltration rate is greater during the first irrigation event than in subsequent ones (Abdel Nour, 1988). It is normally expressed in units of length per unit time or volume per
unit area per unit time (e.g. cm/h, mm/h). Whereas, cumulative infiltration is the total amount of water infiltrated at any time (Michael, 1978).

2.7.2 Infiltration functions:

There are different functional forms to characterize the infiltration behavior of a soil including theoretical (physical) and empirical equations. The empirical methods are most often used in the field (Clemmens, 1981). The intake rate during a normal irrigation is plotted on log-log paper on the vertical axis and time on the horizontal axis; the resultant curve has a general shape indicated by the Kostiakov formula (Israelsen and Hansen, 1962):

$$ I = kt^n \quad \cdots \cdots \quad (2.6) $$

Where:
- $I =$ Intake rate.
- $T =$ Time contact (time that water is on the surface of the soil).
- $K =$ Constant (intake rate intercept at unit time).
- $n =$ slope of the line.

As the observation of intake extends over long periods, a better representation of the data can usually be obtained by using the modified Kostiakov equation:

$$ I = kt^n + b \quad \ldots \ldots \quad (2.7) $$

Since $(n)$ is negative, $(I)$ decreases with an increase in $(T)$. Therefore, the intake rate $(I)$ will approach a constant value $(b)$ as time increases (Israelsen and Hansen, 1962). Furthermore, the cumulative infiltration $(D)$ is the total amount of water that enters the soil in a given time and can be represented by the accumulated depth of water that has entered the soil. This amount is represented by the integral of equation.

$$ D = \frac{KT}{N+1} + bt \quad \ldots \ldots \quad (2.8) $$
Holzapfel et al., (1984) stated that several functional forms have represented cumulative soil infiltration. If “D” is volume of water infiltration per unit of area and “T” is the time that water has been in contact with the soil, then “D” can be represented by one of the following equations:

1. The Kostiakov equation:
   \[ D = kt^n \] \hspace{1cm} (2.9)

2. The modified Kostiakov equation:
   \[ D = kt^n + bt \] \hspace{1cm} (2.10)

3. Philips equation:
   \[ D = kt^n + ct \] \hspace{1cm} (2.11)

In which k, n, b and c are constants.

The Kostiakov equation is often selected over the other equations for two reasons:

a. It is a linear function in the logarithmic domain which simplifies certain mathematical application.

b. Much data from field and laboratory infiltration tests are accurately represented by this equation (Smerdon et al., 1956). The Kostiakov infiltration parameters k and n can be determined by plotting time “T” versus depth “D” on a log-log paper.

The parameters “k” describes the initial infiltration rate and “n” represents the incremental rate of the accumulated infiltration. The two parameters can be influenced by the type of crop, irrigation methods and measuring methods of the water infiltration rate (Yoo, 1987)

2.7.3 Infiltration measurement:

Infiltration data are collected with ring infiltrometers, the ponding method, the blocked furrow technique, the inflow/ outflow method, and
recirculating infiltrometers. Infiltration characteristics can also be determined from advance data using the two-point method (James, 1988 and Walker, 1989).

**a. Ring infiltrometers:**

The cylinders are driven in the soil using a driving plate set on the top of the infiltrometer and a heavy hammer. The infiltration rate is estimated the rate at which water is added to the inside by cylinder, (Micheal, 1978; Skaggs, *et al.*, 1980; James, 1988 and Walker, 1987). Double ring infiltrometer is the most commonly used method for determining infiltration rate as described by Haise *et al.*, (1956), and Micheal (1978). A double ring infiltrometer consists of two concentric rings usually about 25 cm deep and are formed of 2 mm rolled steel. The inner cylinder, from which the infiltration measurements are taken, is usually 30 cm in diameter. The outer one 60 cm in diameter provides a buffer pond of water that minimizes the lateral movement of water from the inner ring when the wetting front has penetrated below the bottom of the rings. The ring infiltrometer data may not agree with the actual amount of infiltration that occurs during irrigation, they are often adjusted utilizing measured inflow, runoff, advance and recession data (James, 1988). The results obtained with cylinders are indicative of the rate to be expected during irrigation and considerable departure usually occurs when furrows or sprinklers apply the irrigation water. Hence, the cylinders are generally used to obtain an index from which design values can be obtained on the basis of local experience (Israelsen and Hansen, 1962).

**b. The inflow- outflow method:**

Inflow-outflow methods for determining infiltration provide good measures of total infiltration (Walker, 1989). In the inflow- outflow method the infiltration rate is determined by measuring the rates of flow into and out
of a section of a furrow when the depth of flow in the furrow is changing slowly, the infiltration equals the difference between the inflow and outflow rates. Flumes or weir plates can be used for measuring inflow and outflow (Micheal, 1978; Skaggs et al., 1980 and James, 1988).

c. The blocked furrow method:

With blocked furrow technique, the furrow cross-section must be measured. Thus the cumulative infiltration function is developed in the same way as for cylinder and pond measurements (Walker, 1987). The blocked furrow method involves installing cutoff plates at the up and down stream ends of test sections in three adjacent furrows. Infiltration is measured in the center furrow by measuring the volume of water required to maintain a constant water level. The furrows on each side of the test furrow provide a buffer that improves accuracy. The depth of infiltration is computed by dividing the measured infiltration volume by the product of furrow spacing times the length of the test section (James, 1988).

d. The pounding method:

Ponds can be created using earth bunds or dykes around an area on the ground surface and operated in the same manner and by using the same procedures as for cylinders (Schwab et al., 1981 and Walker, 1989).

The disadvantage of this technique is that edge effect can be significant (Walker, 1989).

e. Recirculating infiltrometer:

Recirculating infiltrometer is an inflow-outflow device. It is used for evaluating infiltration primarily in furrows. The primary advantage of this device is that both the geometric and hydraulic conditions in the field furrow are simulated during the test (James, 1988 and Walker, 1987).
2.8 Furrow intake rate:

Intake in a furrow or corrugations, unlike other surface irrigation methods where the entire soil surface is in contact with water, occurs through only a portion of the soil surface. This portion is limited to the wetted perimeter, which is independent of the furrow spacing (Hart et al., 1980). The rate at which the soil absorbs water usually decreases rather rapidly after the start of irrigation (Criddle et al., 1956).

Infiltration under furrow irrigation involves soil water movement in both vertical and lateral directions. Because the rate of infiltration depends on the size and shape of the furrow, the rate at which water moves into the soil is often called “intake rate”. Generally the inflow–outflow method is the most commonly used method of infiltration measurement in furrows (Skaggs et al., 1980). Field evaluations of furrow intake–time relationships require measurement of hydrographs of inflow and outflow from a furrow with a minimum length of 60-90 meters for high and 150-180 meters for low intake rate soils. The furrow cross-section and grade between inflow and outflow measuring points should be reasonably uniform (Hart et al., 1980). The intake measurement is done by measuring the inflow and outflow rates at two stations. Suitable flow measuring devices are set in several furrows having different typical flow rates.

2.9 Determination of evapotranspiration:

Evapotranspiration is the process by which water is transferred from the surface and plant to the atmosphere. It includes evaporation of liquid or solid water from soil and plant surfaces plus transpiration of liquid water through plant tissues expressed as the latent heat transfer per unit area or its equivalent depth of per unit area (Criddle et al., 1956 and Burman et al., 1980). Micheal (1978) mentioned that evapotranspiration, or consumptive
use, denotes the quantity of water transpired by plants during their growth, or retained in the plant tissue, plus the moisture evaporated from the surface of the soil and the vegetation. Transpiration is the process by which water vapor leaves the living plant body and enters the atmosphere. Potential evapotranspiration (PET) concept was suggested by Thornthwaite (1948) as the evapotranspiration from a large vegetation covered land surface with adequate moisture at all times. Penman (1947) defined (PET) as the evapotranspiration from an actively growing short green vegetation completely shading the ground and never short of moisture. Jensen (1980) assumed (PET) as the upper limit of (ET) that would occur with a well watered agricultural crop having an aerodynamically rough surface such as Lucerne with 30 to 50 cm of top growth. Evapotranspiration (ET) is dependent upon climate, crop variety and stage of growth, soil moisture depletion and various physical and chemical properties of the soil temperature and the wind. There are two procedures generally followed in estimating (ET) and these are:

1. The seasonal distribution of reference crop potential evapotranspiration (ETo).

2. The (ETo) is adjusted for crop variety and stage of growth.

There are many methods for calculating evapotranspiration ranging from the Blaney-Criddle method using primarily mean monthly temperature to the Penman method requiring radiation, temperature, wind velocity, humidity and other factors. Doorenbos and Pruit (1977) modified Penman formula to determine reference crop evapotranspiration. They gave the following form:

\[ \text{ET} = C \left( W \cdot Rn + (1-W) \cdot f(u) \cdot (ea-ed) \right) \text{mm/day} \ldots \ldots (2.12) \]

Where:

\[ \text{ET} = \text{reference crop evapotranspiration (mm/day)}. \]
W = temperature related weighing factor.

\( \text{Rn} \) = net radiation in equivalent evaporation in mm/day.

\( f(u) \) = Wind related function.

\((ea-ed)\) = vapor pressure deficit as difference between saturation vapor pressure at mean air temperature and the mean actual vapor pressure of air both in (mb).

\( C \) = adjustment factor to compensate for the effect of day and night weather conditions. The adjustment for day and night weather conditions and wind function term are the most important modifications made on the original formula.

All methods for computing crop evapotranspiration (ET) involve the following equation:

\[ \text{ET}_c = k_c \text{ET}_o \quad \text{......... (2.13)} \]

Where:

\( \text{ET}_c \) = evapotranspiration for a specific crop (mm/day).

\( \text{ET}_o \) = potential ET or reference crop ET (mm/day).

\( k_c \) = crop coefficient.

Air temperature, solar radiation and pan evaporation are the most commonly used parameters.

Many simple methods for estimating parameters controlling ET have been developed.

Reference evapotranspiration (ET) can be calculated by any one of the prediction methods as the modified Blaney-Criddle or Penman evaporation methods (James, 1988 and Walker, 1989).

The principal methods for direct measurement of evapotranspiration are
lysimeters, field experimental plots, soil moisture depletion studies, and water balance (Israelsen and Hansen, 1962). The most widely used direct measurement techniques are based on the principle of conservation of mass (James, 1988).

2.10 Irrigation efficiencies:

Irrigation efficiencies indicate how efficiently the available water supply is being used based on different methods of evaluation. The design of the irrigation system, the degree of land preparation, and the skill and care of the irrigator are the principal factors influencing irrigation efficiency. Loss of irrigation water occurs in the conveyance and distribution system, non-uniform distribution of water over the field, percolation below crop root zone. In case of large fields loss may occur by run-off at the end of irrigation borders and furrows. The losses can be held to a minimum by adequate planning and proper design of the irrigation system, adequate land preparation and efficient operation of the system.

2.10.1 Water application efficiency:

It is important to apply the water as efficiently as possible. A measure of how efficiently this is done is the water application efficiency, defined as follows:

\[ Ea\% = \frac{WS}{Wf} \times 100 \quad (2.14) \]

In which:

- \( Ea\% \) = water application efficiency, percent.
- \( WS \) = water stored in the root zone of the plants during irrigation.
- \( Wf \) = water delivered to the field.

Water application efficiencies below 100% are due to seepage losses from
the field distribution channels and deep percolation below the root zone. In case of long field runoff losses may occur.

2.10.2 Water storage efficiency:

The concept of water storage efficiency shows how completely the water needed prior to irrigation has been stored in the root zone during irrigation. It is defined as follows:

\[
Es\% = \frac{Ws}{Wn} \times 100 \quad \text{……… (2.15)}
\]

In which:

\[Es\% = \text{water storage efficiency, percent.}\]
\[Ws = \text{water stored in the root zone during irrigation.}\]
\[Wn = \text{water needed in the root zone prior to irrigation.}\]

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. Also, when salt problems exist, the water storage efficiency should be kept high to maintain a favorable salt balance.

2.10.3 Water distribution efficiency:

Not only is the application of the right amount of water to the field but also its uniform distribution over the field important. Water distribution efficiency indicates the extent to which water is uniformly distributed along the run. It is defined as:

\[
Ed\% = \frac{1 - \bar{y}}{d} \times 100 \quad \text{……… (2.16)}
\]

In which:

\[Ed\% = \text{water distribution efficiency, percent.}\]
\[d = \text{average depth of water stored along the run during the irrigation.}\]
\[\bar{y} = \text{average numerical deviation from } d.\]
2.11 surface irrigation phases:

Surface irrigation event is composed of four phases. The complete surface irrigation process diagrammed is divided into the advance, storage, depletion and recession phases. These phases are named according to the most noticeable process that occurs during the phase (James, 1988 and Walker, 1987).

2.11.1 Advance phase:

When water is applied to the field, it advances across the surface until the water extends over the entire area (Walker, 1987). While Bassett et al, (1980) reported that the advance phase is that portion of the total irrigation time during which water advances in overland flow from the upstream end of the field towards the lower field boundary. The advance phase ends when water reaches the downstream end of the field. During advance a sharply defined water front with water on the inflow side of the front and dry field on the other side moves across the field (James, 1988). Walker (1987) mentioned that there are two important measurements necessary during the advance phase and these are:

a. The discharge hydrograph into the field or into the test furrows.

b. The elapse time from introduction of the water until the advancing front reaches each of the stations along the direction of flow.

The rate of advance decreases with time as the wetted area behind the water front increases.

2.11.2 Storage phase:

This phase begins when the advance phase is completed and ends when the irrigation water supply is cut off. While Walker (1987) stated that the interval between the end of the advance and when the inflow is cut off could be called the wetting or pounding phase (storage phase). It occurs only if the
inflow to the field continues after water has advanced to the down stream end of the field (Bassett et al., 1980 and James, 1988).

2.11.3 Depletion phase:

The depletion phase begins at the time of cutoff and ends when any portion of the ground surface is bare of water (Walker, 1987). James (1988) stated that the depletion phase begins when the storage phase ends and ends when the depth of flow at the inflow end of the field becomes zero.

2.11.4 Recession phase:

For surface irrigated fields the recession phase ends when surface water disappears at each measuring station. The interval during which water will infiltrate at a specific location is called the intake opportunity time. It begins when the water flow first reaches the point (advance) and ends when the water eventually drains from that point (recession). Because infiltration is assumed to be uniform over the field, the variation in intake opportunity time is also an indication of application uniformity (Walker, 1987). James (1988) stated that recession phase begins when the depletion phase ends, A drying front moves from the inflow to the down stream end of the field. Recession continues until either the dry front reaches the end of the field or it encounters a receding front moving towards the inflow end of the field.

2.12 Evaluation of surface irrigation systems:

The principal objective of evaluating an irrigation system is to identify alternatives that may be both effective and feasible in improving the system's performance. An evaluation may show that higher efficiencies are possible by reducing the duration of the inflow to an interval required to apply the depth that would refill the root zone. The evaluation may also show opportunities for improving performance through changes in filed size and topography. There are two aspects of evaluation. The first is the field
infiltration relationship and the second is the evaluation of the efficiency of the irrigation event studied (Walker, 1987). As reported by Walker (1987) field measurements outlines provide the following elements in a field evaluation:-

a. The inflow hydrograph (per furrow).
b. The advance and recession of the water over the field surface.
c. The run off hydrograph (if the field is not dyked).
d. The soil moisture depletion during the irrigation.
e. The volume of water on the soil surface at various times.
f. Infiltration and water holding capacities of the soil.
g. The geometry of the cross sectional flow area.

Also Merriam et al., (1980) stated that the purpose of evaluating irrigation systems is four fold and these are:-

a. To determine the efficiency of the system as it is being used.
b. To determine how effectively the system can be operated and whether it can be improved.
c. To obtain information that will assist engineers in designing other systems.
d. To obtain information to enable comparing various methods, systems and operating procedures as basis for economic decisions.

2.12.1 Managing the furrow method:

In order to achieve uniform water application. The advancing water front should cover the field during a short interval. Certainly not longer than required to infiltrate a depth equal to the soil moisture depletion. A quarter-time rule of thump was first proposed in published form by Criddle et al., (1956) and has shown promise in some field situations. Although rapid advance is recommended, it imposes serious problems on fields that allow
tailwater to flow out of the system. Surface irrigation performance can be improved by managing the field surface. Where the grade is irregular, causing dry spots and excessive depression storage. Land leveling is an important practice. Furrowing, borders or basins also reduce the effect of topographical variations. Surface irrigation systems involve a number of structural elements which control the rate of flow and its energy. To achieve efficient use of the water on the field, these elements should provide a steady, reliable discharge and be capable of effective operation under a number of adverse conditions. Most surface irrigation systems at the farm level supply water from open canal systems operated by irrigation districts, companies, or corporations. Variations include piped delivery systems and groundwater supplies (Walker, 1987). Water is lost in furrow irrigation either as run off or as deep percolation. Tailwater stream runoff begins to contribute to the losses after the water reaches the end of the run and continues until the irrigation event is completed (Willardson and Bishop, 1967). Hart et al., (1980) mentioned that water is applied at one end of the furrow at a rate that will provide coverage of the entire length in a relative short time. The water is then pounded until it infiltrates. The inflow rate should be large enough to advance to the end in not greater than 1.5 times the net opportunity time required for the design application. The rates must not exceed the flow capacity of the furrow, no result in excessive erosion. Erosion created by furrow irrigation is a problem and has resulted in reduced crop yields. Erosion rate should decrease with distance from the head (inflow) end of the furrow. Erosion rates on the upper quarter of a uniformly slope furrow were 6-20 times greater than average rates from the field (Trout, 1996). Runoff and uniformity of the depth of water infiltrated along the furrow are related to the velocity of water reaching the lower end (time
of advance) and the total time of irrigation. If a large stream is turned into the furrow it will reach the lower end quickly if the length is reasonable. The water will be on the upper end only a little longer than at the lower end and a very uniform irrigation will result. There is a number of ways that affect the advance rate and deep percolation losses and the losses can be kept small with furrow than with any other method because water advanced across the field quickly for many flow rates and intake opportunity times during advance. Therefore, infiltration during post advance phases is significant and largely cutoff time dependent. Furrows on reasonably uniform soils and slopes are the most efficient method of irrigation if proper management uses a small advance ratio, turns water off on time, and utilizes a return flow system. Low efficiencies are not the fault of the method, but of management (Merriam, 1977). Total water losses by deep percolation in irrigated fields can account for 20% or more of the total amount of water applied and the losses may be held to minimum by adequate planning, proper design and efficient operation of irrigation system and adequate land preparation (Micheal, 1978). Soil variability, furrow slope, furrow flow rate, advance times, compaction differences and varying antecedent soil water content make each irrigation unique (Yoder and Duke, 1990).

2.13 Surge flow irrigation:

The concept of surge flow irrigation was introduced in Bulgaria as a method for improving the uniformity of moisture distribution along the furrow (Varlev, 1971). Stringham and Keller (1979) presented surge flow as a new approach for automating surface irrigation systems in which problems with slow advance and excessive surface runoff occur. Surge flow irrigation is a surface irrigation method that can be used to improve the efficiency of water applied by furrows. It is the intermittent application of water to
furrows or borders in a series of relatively short on- and off-time periods, which usually vary from about 5 minutes to several hours. The inflow cycling allows a large outlet discharge from individual constant flow valves to be reduced with respect to a field discharge by creating a time average flow in the furrow or border that can be varied during and between irrigations (Coolidge et al., 1982). By reducing the volume of water required to complete an advance the surge irrigation technique gives the potential to increase the distribution uniformity and, hence, increase the effective use of water in furrow irrigation (Coolidge et al., 1982; Walker, 1987; Mostafazadeh and Mousavi, 1989 and Izadi, 1990). With this technique water is applied intermittently and not continuously as in conventional surface irrigation. The main objective of surge flow irrigation is to improve the efficiency by reducing deep percolation and runoff losses and to obtain a uniform wetting of the root zone, with minor differences in the infiltration depth at the beginning and the end of a furrow (Ismail and Depeweg, 2002). There are two characteristics of surge flow that save irrigation water. When water is admitted to the furrow for a given period of time, and then shut off to allow the furrow to de-water, the intake rate of the furrow is reduced. Thus, when the second surge of water is admitted, less water infiltrates into the soil than would otherwise occur, hence more water is available in the dry parts of the furrow, and the advance is more rapid. The combined effects of reduced infiltration during the advance phase plus a more rapid advance lead to a more uniform distribution of water along the furrow. In some soils, the same quantity of water normally required to get the water to the end of one furrow can be spread out over two furrows with surge flow. Thus, the uniformity of application is significantly improved. In some tests, uniformity of more than 90% has been achieved. Crop yields are improved by the
improved uniformity of application. Over-watering at the head of the field and under-watering at the end are almost eliminated under surge flow irrigation. The crop is much more uniform through the length of the field (Miller et al., 1991). Surge flow irrigation has the potential to improve the performance, versatility, and efficiency of surface irrigation systems when the conditions favor its use (Humpherys, 1989). It is accomplished by alternating furrows with rest periods of zero inflow. The duration of time between successive inflow periods, called the cycle time, is chosen so that several on-off cycles are required to complete the advance phase of the irrigation. During the advance phase the duration of rest periods is normally long enough for most, if not all, water to infiltrate before the next inflow period begins. The ratio of on to off times is the cycle ratio. Although the cycle time varies during the irrigation, the cycle ratio must remain constant, i.e., the on time equals to the off time (James, 1988). Each surge is characterized by a cycle time and cycle ratio. The cycle times ranges from one minute to as much as several hours. Cycle ratios typically range from 0.25 to 0.70. By regulation these two parameters, surge flow can improve irrigation efficiency and uniformity (Walker, 1987). More rapid advance improves the uniformity of the irrigation and allows higher application efficiency to be achieved. Proper management is required to reduce deep percolation and runoff losses and to achieve higher application efficiencies. In many situations surging increases the rate of advance during inflow periods because of reduced surface roughness and lower infiltration rates in the previously wetted portion of the field (James, 1989). Mostafazadeh and Mousavi (1989) stated that cumulative infiltration and the basic intake rate of the furrow under surge flow were less than continuous flow. Walker (1987) showed that intermittent application reduces infiltration rates and/or
substantially reduces the time necessary for the infiltration rates to approach the final or basic rate. Uniform water distribution over the furrow length was obtained by overlapping surges. Deep percolation losses decreased from 12-15% to 6-8%, while runoff losses were reduced from 25-30 to 12% when using surge irrigation. Surge irrigation required 20-25% less water than continuous irrigation. Many irrigators found it impossible to complete the advance phase of an irrigation following a major cultivation because of the high intake rate. Today, surge flow management practice can be applied to many surface irrigated conditions. It can be either to “cut back” the inflow at the completion of advance and minimize tail water, and/or to accelerate the advance on problematic soils (Varlev et al., 1995). When comparing surge and continuous irrigation surge irrigation reduced advance inflow times an average of 20%. Cut-back and surge flow simulation resulted in 5-7% savings in applied volume of water when compared to continuous flow simulation respectively (Izadi et al., 1992). Izadi et al., (1990) stated that 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 pulses.
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 versus pressure head relationship.
4- Air entry and entrapment occurring between pulses.
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 pulses.

Among the six causes, categories two through six are related to the reduction of infiltration rate of the subsequent surges. The reduced advance times are due to reduced infiltration rate which is a consequence of interrupting the flow and is highly variable (Trout, 1990).

The surge flow has two significant practical advantages:

1. The time average variation of stream size allows the design of a system that will cut back flow after advance is completed, approximating the intake rate and decreasing runoff.

2. The surge flow method causes the same volume of water to advance farther along the furrow than a continuous flow.

2.14 Irrigation scheduling:

The purpose of irrigation scheduling is to maintain a good soil moisture status in the root zone reservoir and thereby provide near optimum environmental conditions for crop growth. Traditionally, irrigation scheduling is considered as a decision-making process used by irrigators to decide when to irrigate their crops and determine the appropriate quantity of water to apply. This concept has proved to be adequate for pressurized irrigation systems in general (spray and drip) but inadequate for surface irrigation where the amount of irrigation is far less controllable. The traditional irrigation scheduling concept addresses only two variables:

(a) Timing of irrigation.

(b) Amount of irrigation.

One purpose of irrigation scheduling is to determine when to irrigate. Irrigations should occur at intervals such that crop yield is not adversely affected by insufficient soil moisture. For furrow, flood, and sprinkler
irrigation methods, the irrigation interval depends on potential evapotranspiration, soil type, and allowable depletions. A second purpose of irrigation scheduling is determining the amount of water to be applied. The amount of water applied is determined by using a criterion to determine irrigation need and a strategy to prescribe how much water to apply in any situation. Irrigation criteria are the indicators used to determine the need for irrigation. The most common irrigation criteria are soil moisture content and soil moisture tension. Less common types are irrigation scheduling to maximize yield and irrigation scheduling to maximize net return. A critical element is accurate measurement of the water to apply or the depth of application. A farmer cannot manage water to maximum efficiency without knowing how much was applied. Also, uniform water distribution across the field is important to derive the maximum benefits from irrigation scheduling and management. Accurate water application prevents over- or under-irrigation. Over-irrigation wastes water, energy and labor, leaching expensive nutrients below the root zone of the plants; and reduces soil aeration, and thus crop yields. Under-irrigation stresses the plant and causes yield reduction.
CHAPTER THREE  
MATERIALS AND METHODS

3.1 Experimental Site:

In order to evaluate the effect of cycle ratios on surge irrigation efficiencies using a hydroflume and compare advance and recession times for cycle ratios, an experiment was conducted at the Top Farm of the University of Khartoum at Shambat. The Farm lies at latitude 15° 40' N and longitude 32° 32' E. The climate can be described as tropical arid. The experiment was conducted during 2004-2005. The furrow length was 80m and the furrow spacing was 0.7m. The furrow had a blocked end. The discharge used was 1 lit/sec for all outlets. The cycle time was 28 minutes. Nine stakes were established along the furrow with a spacing of 10m. Advance time and beginning of recession phase were recorded. The total area was 1920m². The cycle ratios were $\frac{1}{4}$, $\frac{1}{2}$, $\frac{3}{4}$ and 1 of 28 minutes.

3.2 Land Preparation:

The experimental area was prepared to maintain a suitable seed bed, and land preparation included:

(I) Disc ploughing to a depth of about 0.25m with a standard integral disc plough.
(ii) Disc harrowing was performed with an offset disc harrow to break the clods and firm the top soil.
(iii) Land surveying was conducted with a grid spacing of 5m. A rectangular field has been staked on 20 by 20m grid spacing. The first stake, located at the upper left-hand corner, was placed one-half spacing from both sides of the field to start the staking. The evaluations of the grid points were determined with an engineer level and rod to measure at each stake. The
field was to be furrow irrigated.

(iv) Leveling was done with a long span blade leveler to obtain uniform surface.

(v) Ridging was done with a three bottom ridger, which was mounted on a tool bar to give a standard ridge spacing of 0.7m. The head ditch was excavated at the upper part of the field in order to facilitate the control and measurement of the inflow rate of irrigation water.

3.3 Soil Physical Properties:

Soil physical properties determined were soil textural class, bulk density and field capacity. Soil samples were taken from random stations in the field at three depths. From each depth three samples were taken using an auger at depths of 0.2, 0.4 and 0.6 m below the soil surface. The mean for each depth was taken to represent the soil class.

3.3.1 Soil Textural Class:

Soil mechanical analysis was conducted at the Soil Science Laboratory of the Faculty of Agriculture, University of Khartoum. Soil textural class was determined using the hydrometer method proposed and improved by Bouyoucus (1957).

3.3.2 Bulk Density:

Soil bulk density was determined using the Paraffin (clod) method. An area of one meter square was dug to a depth of 0.6m. Four clods, each approximately 5cm in diameter were taken at increments of 0.2m from the surface to 0.6m depth. The bulk density of the soil at each depth was determined in gm/cm³. This was done at three randomly selected furrows in each furrow three such pits were dug.
3.3.3 Field Capacity:

Field capacity of the soil of the experimental site was determined by making a basin (1m×1m) well leveled, filled with water and covered with a plastic sheet to prevent evaporation. Soil samples were collected from the basin three days after water application at 0.2m increments from the surface to a depth of 0.6m. Soil moisture was measured each 24 hours until the change in its value was small, a point at which the soil moisture content of the samples represented the moisture content at field capacity.

3.3.4 Infiltration:

The infiltration of the soil was determined by using the double ring infiltrometer (plate 3:1) as described by Michael (1978). The infiltrometer consisted of two concentric cylinders and a measuring device. The inner cylinder, where infiltration measurements were taken, was 0.3m in diameter, while the outer one (0.6m in diameter) is regarded as a guard cylinder or buffer area around the inner cylinder. Both cylinders were 0.25m in height. The double ring infiltrometer was placed at three randomly selected locations over the field. The cylinders were carefully driven into the ground to a depth of about 0.1m with an ordinary hammer and using a short wooden plank to prevent damage to the edges of the metal cylinder. Care is taken to keep the installation depth of the cylinders the same in all trials. This was accomplished by marking the outside of the cylinders at 0.1m level and driving the cylinders down to the mark. A plastic sheet was used to cover the soil surface in the inner cylinder before filling with water in order to minimize soil disturbance and puddling. The depth of water in the cylinder was maintained by refilling to a fixed level. A graduated scale was used to measure the drop in water level. Readings were taken at 5 minutes intervals until they became constant. The data was tabulated. The average infiltration
rate in mm/h and the cumulative infiltration (mm) were determined. Typical curves of infiltration rate and cumulative infiltration were plotted with time plotted in the X-axis.

3.4 System Design and Operation:

A brick basin with the following dimensions: 0.7m width 1.5m length and 1.25m height was built at the South West corner of the experimental area. An outflow pipe was fixed at the bottom of the basin. The plastic gated pipe (Hydroflume) used to supply water to the furrows was clamped to the outflow pipe. A two inch centrifugal pump was used to drew water from a near by irrigation ditch into the basin. The system was operated when the water level in the basin reached 0.9m. The gated pipe (Hydroflume) had the following components (plate 3:2).
3-5 Surge Irrigation:

Four surge irrigation cycles were tested in this experiment. The first cycle ratio was 1:1 this was 28 minutes on and 28 minutes off. This was chosen because the advance time or the time taken by the advancing front from the head of the farm to reach the end of the furrow was 28 minutes. The other three surge times were 21, 14, and 7 minutes. For each treatment the on time was equal to the off time. For all treatments the advance times and beginning of recession were recorded. For each treatment the required amount of water was applied.

3-6 Soil Moisture Determination:

Soil moisture was determined gravimetrically. Soil samples were augured from successive stations along the furrows. The soil samples were taken at 0.2m increments from the soil surface to a depth of 0.6m before and three days after each irrigation. Soil samples were oven dried at 105°C-110°C for 24 hours, then weighted to determine moisture content as percentage on dry mass basis as shown below:

\[ \theta_{m \%} = \left( \frac{M_w - M_d}{M_d} \right) \times 100 \] ……………….. (3-1)

Where:

- m\% = Moisture content on mass basis as percent.
- Mw = Mass of wet sample (gm).
- Md = Mass of oven dry sample (gm).

To convert moisture content on dry mass basis as percentage to moisture content on volume basis as percentage and depth basis (cm/m depth) the corresponding bulk density was multiplied by moisture content on mass basis:

\[ \theta_{V \%} = \theta_{m \%} \times pb \] ………………..(3-2)
\[ \theta V\% = \theta d \text{cm/m depth} \] \hspace{1cm} (3-3)

Where:

\[ \theta V\% = \text{Moisture content on volume basis as percent.} \]

\[ Pb = \text{Bulk density (gm/cm}^3\text{).} \]

\[ \theta d = \text{Moisture content cm per m depth of soil.} \]

The weighted average change in water content has been computed in three steps first, the water content before the irrigation and after 24 hours has been measured as a volume percent at three points and along a vertical line namely at 0.0—0.2, 0.2—0.4 and 0.4—0.6m at 10m, 40 and 70m from the upper end of the furrow. The measured water content for these points was weighted by multiplying the water content for each point by its measuring depth. Second, the weighted average change in water content at locations was found by summation of the change in water content in each point along a vertical divided by the total measured depth.

**3-7 Surface irrigation process:**

To evaluate the irrigation efficiencies in surface irrigation, the experimental procedure was based on the following steps:

1. Three uniform furrows with 0.7m spacing and 80m long were chosen.
2. 8 stakes were set at 10m spacing along the furrows.
3. A stream size of a mean value of 1 lit/sec was turned into each furrow using three outlets of the hydroflume.
4. Using a stopwatch the time when water reached station zero in the tested furrow was recorded.
5. The time when the advancing front of water reached any station was recorded. Also the times when the water was cut were recorded and the time when water was depleted was recorded.
3-7-1 Measurement of the irrigation stream:

The outlets were calibrated in situ to estimate their discharge per unit time and to select the suitable irrigation stream size. Using the selected irrigation stream size water was applied to each furrow.

3.7.2 Calibration of hydroflume:

The hydroflume was located on a leveled area (plate3:3). The calibration was made as follows:
Holes were dug adjacent to the outlets and a bucket of known volume was installed at each hole separately. The rim of the bucket was kept with the soil surface. The outlets were primed and directed into the buckets where they discharged water. Using a stopwatch the time required to fill the bucket was recorded. The discharge of the outlets in lit/sec was calculated using the following equation:

$$Q = \frac{V}{t} \quad \text{......................... (2.4)}$$

Where:

- $Q =$ discharge (lit/sec).
- $V =$ volume of water (lit).
- $t =$ time required to fill the bucket (sec).

For each outlet three readings were made and their mean was taken to represent the discharge per unit time for that outlet.
3-7-3 Irrigation stream:

A head of 0.9m was maintained for the hydroflume in the riser. With this head of water the discharge of 1 lit/sec was obtained as a furrow stream to apply water to the furrow. The depth of irrigation water applied was calculated using the following equation:

\[
d = \frac{Qxtx60x1000}{WxLx100x1000} \text{ cm } \ldots \ldots \ldots (3-5)
\]

Where:

- \(d\) = depth of water applied in irrigation (cm depth).
- \(Q\) = stream size (lit/sec).
- \(t\) = irrigation period (advance time)(min).
- \(W\) = furrow width (m).
- \(L\) = furrow length (m).

3-7-4 Run-off measurement:

A Parshall flume was set at the end of the furrow so as to measure the run-off (plate 3:4). To determined the discharge, the readings of the two scales, \((H_a)\) at the upstream end of the flume and \((H_b)\) at the downstream end of the flume were taken. When the ratio of \(H_b/H_a\) is equal to or less than 0.5 the flow through the flume is free and a calibration curve of \(H_a\) versus flow was used to obtain the flow in lit/sec. This represented the run-off at the end of the open furrow.
3-8 Irrigation efficiencies:

3-8-1 Application efficiency:

Application efficiency was determined from the depth of water stored in the root-zone as a percent of that applied during irrigation. Application efficiency was calculated as shown in the equation below:

\[
E_a\% = \frac{W_s}{W_f} \times 100 \quad \ldots \quad (3-6)
\]

Where:
- \( E_a\% \) = water application efficiency in percentage.
- \( W_s \) = the average depth of water stored in the root zone prior to irrigation.
- \( W_f \) = the average depth of water diverted to the field during irrigation.

Water stored in the root zone was determined using the following equation:

\[
Z_1 = \frac{Q_{xt1}}{L_1} - A_1 \times a \quad \ldots \quad (3-7)
\]
\[
Z_2 = \frac{Q_{xt2}}{L_2} - A_2 \times a \quad \ldots \quad (3-8)
\]

Where:
- \( A \) = furrow surface. \ a = 0.75 of \( A \)
- \( Q \) = discharge in l/sec.
- \( L \) = length of furrow in (m).
- \( Z \) = depth of water stored in the root-zone (cm).

3-8-2 Storage efficiency

Storage efficiency was determined using the following equation:

\[
E_s\% = \frac{W_s}{W_n} \times 100 \quad \ldots \quad (3-9)
\]

Where:
- \( E_s\% \) = water storage efficiency in percentage.
Ws = water stored in the root zone during the irrigation.
Wn = water need in the root zone during the irrigation.

3-8-3 Distribution efficiency:

The weighted average change in water content has been computed in three steps first, the water content before the irrigation and after 24 hours has been measured as a volume percent at three points and along a vertical line namely at 0.0—0.2, 0.2—0.4 and 0.4—0.6m incremental depths at 10m, 40 and 70m distance from the upper end of the furrow. The measured water content for these points was weighted by multiplying the water content for each point by its measuring depth. Second, the weighted average change in water content at any location was calculated by the summation of the change in water content in each point divided by the total measured depth. Third, the distribution efficiency was calculated by the mean at 10m, 40m and 70m from the upper end of the furrow using the following equation:

$$\text{Ed}^\% = \frac{(1-y)}{d} \times 100 \quad \ldots \ldots \ldots \ldots (3-10)$$

Where:

\text{Ed}^\% = \text{water distribution efficiency in percentage.}

\(d\) = Average depth of water stored along the run during the irrigation.

\(y\) = Average numerical deviation from \((d)\).

The water stored in the soil was obtained gravimetrically. The gain in soil moisture (mm) in 0.6m depth was obtained at three locations along the run. The average depth of water stored along the run was calculated by summing up the depths in the three stations and then divided by three. The average numerical deviation of water depth from the mean at each station was determined.
CHAPTER FOUR

RESULTS AND DISCUSSION

4:1 Introduction:
Results of determination of land elevations (slope), soil physical characteristics, moisture content down the profile and along the furrow run, advance and recession time, infiltration and effect of cycle ratio on surge irrigation efficiencies were presented, analyzed and discussed in this chapter with Sas method.

4:2 Lands Surveying:
Table 4.1 and Fig 4.1 show the reduced level of the experimental area at the Top Farm of the University of Khartoum, Shambat from the field surveying conducted after land preparation. The land slope from south to north was found to be 0.075 percent. This can be considered as a gentle slope and suitable for furrow irrigation as mentioned by Micheal (1978).

4:3 Soil Textural Class:
Table 4.2 shows the percentage particle size distribution for increments of 0.2 m down the soil profile to 0.8m depth. According to the USDA soil textural classification chart, the soil of the experimental area can be classified as a clay soil. There were no significant differences between the four incremental depths for the clay, silt and sand percentages. These results were similar to the findings of Abdeen (1999) and El Sheikh (2002) who worked in the same area.
Table 4.1 The reduced levels (m) of the experimental area

|-------|-------|-------|-------|-------|-------|

Fig. 4.1 General layout of the experimental area
Table 4.2 Soil particle size distribution of the experimental area

<table>
<thead>
<tr>
<th>Depth(m)</th>
<th>Clay (%)</th>
<th>Silt (%)</th>
<th>Sand (%)</th>
<th>Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0-0.2</td>
<td>48</td>
<td>23.58</td>
<td>24.42</td>
<td>Clay</td>
</tr>
<tr>
<td>0.2-0.4</td>
<td>51</td>
<td>21.86</td>
<td>25.14</td>
<td>Clay</td>
</tr>
<tr>
<td>0.4-0.6</td>
<td>49</td>
<td>22.39</td>
<td>24.61</td>
<td>Clay</td>
</tr>
<tr>
<td>0.6-0.8</td>
<td>53</td>
<td>21.59</td>
<td>25.41</td>
<td>Clay</td>
</tr>
</tbody>
</table>

Soil class

4.4 Bulk density:

Table 4.3 shows the results of the bulk density values in (gm/cm³) for each 0.2m increment from the soil surface to 0.8m depth down the profile for the experimental area. Bulk density was found to increase with depth. The average bulk density value obtained was 1.33 gm/cm³ after tillage. Abdeen (1999) who worked in the area obtained similar results.

4.5 Field Capacity:

Table 4.4 shows the results of the field capacity (cm/m depth) for each 0.2m increment from the soil surface to 0.8 depths. Field capacity was found to decrease with depth. This might be due to the increase in bulk density down the soil profile. Saeed (1984) and Abdeen (1999) attributed this to the decrease in pore space down the soil profile.
Table 4.3 Bulk Density of the Experimental area (g/cm³)

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Bulk density (gm/cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0-0.2</td>
<td>1.31</td>
</tr>
<tr>
<td>0.2-0.4</td>
<td>1.32</td>
</tr>
<tr>
<td>0.4-0.6</td>
<td>1.35</td>
</tr>
<tr>
<td>0.6-0.8</td>
<td>1.36</td>
</tr>
<tr>
<td>mean</td>
<td>1.33</td>
</tr>
</tbody>
</table>

Table 4.4 Field Capacity of the Experimental area (cm/m depth)

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Field capacity (cm/m depth)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0-0.2</td>
<td>46.02</td>
</tr>
<tr>
<td>0.2-0.4</td>
<td>45.24</td>
</tr>
<tr>
<td>0.4-0.6</td>
<td>43.11</td>
</tr>
<tr>
<td>0.6-0.8</td>
<td>41.05</td>
</tr>
<tr>
<td>mean</td>
<td>43.9</td>
</tr>
</tbody>
</table>

4.6 Infiltration:

Fig 4.2 and Table 4.5 show the average infiltration rate (mm/h) and the average cumulative infiltration values (mm) for the experimental area. Fig 4.2 shows the best fitted curves for the mean values of infiltration rate which were selected on the basis of the procedure of Bautista (1984) who indicated that, the mean values best represent the soil infiltration in the evaluation of furrow irrigation using double ring infiltrometer.

The high initial infiltration rate was mainly due to the heavy cracking of the soil when dry and the low rates were the results of swelling of the clay
soil particles on wetting as mentioned by Micheal (1978). From Table 4.5 and Fig 4.2 it is clear that the soil of the experimental area had a high initial infiltration rate of 278 mm/h, during the first five minutes of elapsed time and a low final infiltration rate of 60mm/h after 50 minutes elapsed time. Abdeen (1999) obtained similar results for the same site using double-ring infiltrometer.

Abdeen (1999) obtained 160 and 276 mm/h infiltration rates after five minutes at two sites of clay soil. Abdel Nour (1984) found a high infiltration rate after five minutes of 147 mm/h. Also Elramlawi (1992) reported infiltration of 109 mm/h after five minutes in an experiment conducted at Rahad Scheme using double-ring infiltrometer.

<table>
<thead>
<tr>
<th>Elapse time(min)</th>
<th>Infiltration rate (mm/h)</th>
<th>Cumulative infiltration(mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>278</td>
<td>23.2</td>
</tr>
<tr>
<td>10</td>
<td>135</td>
<td>34.4</td>
</tr>
<tr>
<td>15</td>
<td>97</td>
<td>41.2</td>
</tr>
<tr>
<td>20</td>
<td>74</td>
<td>46.1</td>
</tr>
<tr>
<td>25</td>
<td>74</td>
<td>52.1</td>
</tr>
<tr>
<td>30</td>
<td>68</td>
<td>59</td>
</tr>
<tr>
<td>40</td>
<td>61</td>
<td>64</td>
</tr>
<tr>
<td>50</td>
<td>61</td>
<td>74</td>
</tr>
</tbody>
</table>
Fig. 4.2  Infiltration rate (mm/h) and cumulative infiltration (mm) vs time (min)

Data points:
- Infiltration rate (mm/h)
- Cumulative infiltration (mm)
4.7 Water Flow Measurement:

The flow of each outlet of the gated pipe in this experiment was adjusted at 1l/s for all irrigation cycles as a procedure. This flow was chosen to suitable the length of the furrow and to maintain a head not less than 90cm at the riser. This arrangement was maintained throughout the experiment.

4.8 Advance and recession characteristics:

Advance and recession times for the different cycle ratios and four irrigations were shown in Table 4.6 which shows the flow velocity down the furrow in m/min. It can be seen that except for the first irrigation, the flow velocity values incremental during the following irrigations. Also it was observed that the velocity of flow during the first irrigation was relatively low compared with those of the subsequent irrigations. This can be attributed to the even distribution of water along the furrow. Throughout the experiment the cycle's time was 28 minutes and cycle ratios were ¾, ½ and ¼ of the cycle time. The results showed that surge flow irrigation leads to a decrease in advance time compared to continuous flow (Table 4.6). The reduction in advance time is more pronounced for the cycle ratio ½ followed by cycle ratio ¾ and cycle ratio 1. For the cycle ratios 1, ¾ and ½ the advance time was less compared to continuous flow, but the cycle ratio ¼ led to an increase in the advance time. It can be said that the reduction was due to the effect of off-time. When the off-time is long enough to allow the water to infiltrate before the second surge starts, the mechanism of surge flow works effectively. The fastest advance time to reach the end of the furrow was observed for the treatment of ½ cycle ratio. As the soil bulk density increases, the hydraulic conductivity decreases and consequently, the infiltration rate decreases (Samani et al., 1985). Also Jalali-Farahani et al., (1993) stated that the rate of advance along a furrow has been increased in surge flow irrigation mainly due
to a reduction in intake leading to increased irrigation uniformity. Similar results were obtained by Ismail (2002). Recession curves showed that all cycle ratios tested were in a descending manner. This can be attributed to the even distribution of water along the furrow. James (1988) reported that in many situations surge increases the rate of advance during inflow periods because of reduced surface roughness and lower infiltration rates in the prevailing wetted portion of the field. It was also noted that the recession rate varied during the first irrigation but in later cycles became slower. This was a result of the higher soil moisture content as reported by Farbrother (1967) who carried out experiments on heavy clay soils in Gezira to test their behavior.

4.9 The Advance Rate of Surge and Continuous Flows:

The advance rate of surge and continuous flows were shown in (Table 4.6) and the comparison of cumulative surges and continuous flows advance along the furrows with constant discharge rate of 1l/s was considered. The results indicated that less time is required to complete the advance phase under surge flow compared with continuous flow. This finding is in accordance with that reported by Bishop et al., (1981), who found three to four times faster advance rate in surge flow compared to continuous flow in furrows. Similarly, the results were supported by the findings reported by Stringham and Keller (1979), Allen (1980), Poole (1981), Cooledge et al., (1982), Mahmood et al., (1993) and Mahamood et al., (1995).
Table 4.6 Advance Time (min) for Continuous and Surge Flow

<table>
<thead>
<tr>
<th>Distance from inlet (m)</th>
<th>Continuous flow</th>
<th>Surge flow 1</th>
<th>Surge flow ¾</th>
<th>Surge flow ½</th>
<th>Surge flow ¼</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>3.5</td>
<td>3.5</td>
<td>3.4</td>
<td>3.3</td>
<td>3.4</td>
</tr>
<tr>
<td>20</td>
<td>7.1</td>
<td>6.8</td>
<td>6.6</td>
<td>6.5</td>
<td>6.7</td>
</tr>
<tr>
<td>30</td>
<td>10.6</td>
<td>10.3</td>
<td>10.4</td>
<td>10.1</td>
<td>13.9</td>
</tr>
<tr>
<td>40</td>
<td>14.2</td>
<td>13.8</td>
<td>13.6</td>
<td>13.2</td>
<td>19.7</td>
</tr>
<tr>
<td>50</td>
<td>17.7</td>
<td>17.2</td>
<td>17.3</td>
<td>16.7</td>
<td>25.5</td>
</tr>
<tr>
<td>60</td>
<td>21.3</td>
<td>20.7</td>
<td>20.5</td>
<td>19.4</td>
<td>28.1</td>
</tr>
<tr>
<td>70</td>
<td>24.9</td>
<td>24.1</td>
<td>23.8</td>
<td>22.4</td>
<td>31.3</td>
</tr>
<tr>
<td>80</td>
<td>28.8</td>
<td>26.7</td>
<td>25.5</td>
<td>24.8</td>
<td></td>
</tr>
</tbody>
</table>

4.10 Effect of Different Cycle Ratios and Distance from the Upper End of the Furrow on Soil Moisture Content:

Table 4.7, shows the results of soil moisture content as affected by cycle ratios and distance from the upper end of the furrow. Soil water measurements at three points in the furrow showed that the soil moisture levels were generally higher at the upper head of the furrow than at the tail end, the moisture content at the same locations for different cycle ratios gave similar results. These results can be attributed to the high control of water;
same discharge for all cycles; the time of the soil to infiltrate the water was similar to the time of cycles and a long contact time with the soil.

Different locations along the furrow gave different soil moisture contents as shown in Table 4.7. At 10m from the upper end of the furrow the moisture content was higher than the moisture content at location 40m and this followed by location 70m. This may be attributed to the high number of surges used to complete the advance phase.
Table 4.7 The Effect of Different Cycle Ratios and Distance From the Upper End on Soil Moisture Content on volume basis

<table>
<thead>
<tr>
<th>Location (m)</th>
<th>Irrigation 3</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th>Irrigation 2</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th>Irrigation 1</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>F</td>
<td>Q</td>
<td>H</td>
<td>T</td>
<td>F</td>
<td>Q</td>
<td>H</td>
<td>T</td>
<td>F</td>
<td>Q</td>
<td>H</td>
<td>T</td>
<td>F</td>
<td>Q</td>
<td>H</td>
</tr>
<tr>
<td>2.3</td>
<td>31.8</td>
<td>31.8</td>
<td>32.6</td>
<td>32.2</td>
<td>32.2</td>
<td>32.8</td>
<td>32.6</td>
<td>32.3</td>
<td>32.3</td>
<td>31.4</td>
<td>32.6</td>
<td>32.4</td>
<td>32.8</td>
<td>32.8</td>
<td>10</td>
</tr>
<tr>
<td>29.7</td>
<td>29.3</td>
<td>29.9</td>
<td>30.9</td>
<td>30.4</td>
<td>29.7</td>
<td>30.1</td>
<td>31.3</td>
<td>27.9</td>
<td>29.4</td>
<td>30.2</td>
<td>30.8</td>
<td>30.6</td>
<td>40</td>
<td>30.6</td>
<td>40</td>
</tr>
<tr>
<td>27.9</td>
<td>27.4</td>
<td>27.9</td>
<td>27.9</td>
<td>28</td>
<td>28.4</td>
<td>28.5</td>
<td>28.2</td>
<td>28.6</td>
<td>27.7</td>
<td>28.8</td>
<td>28.5</td>
<td>29.2</td>
<td>70</td>
<td>29.2</td>
<td>70</td>
</tr>
</tbody>
</table>
4.11 Irrigation efficiencies:

4.11.1 Distribution efficiencies (Ed %):

Table 4.8 shows the results of the distribution efficiencies for the different cycle ratios. The table shows that the distribution efficiencies for all cycle ratios were similar. The distribution uniformity had a similar trend. The high distribution efficiencies obtained may be due to the acceleration of the advance of the surge flow. Similar results were obtained by Elsheikh (2002) and Mostafazadeh (1990) who reported that higher advance rates reduced the differences in intake opportunity time between the head of the furrow and the lower end; this gives more uniform water distribution along the furrow. It was observed that the distribution efficiencies obtained under all cycle ratios tested were almost the same and relatively high. This may be due to the relatively short furrow length and period of off-time allowed for water to distribute along the furrow. These results showed that surge furrow irrigation tends to reduce the infiltration capacity and leads to a faster water advance, which distributed the water more uniformly along the furrow. Similar results were found by El-dine and Hosney (2000) and Tabuada et al., (1995). This similarity of distribution efficiencies may be attributed to the similarity of moisture content at all locations along the furrows. There were no significant differences in distribution efficiency due to the cycle ratios in all irrigations.

4.11.2 Application efficiency (Ea %):

Results of application efficiencies as affected by the cycle ratios are shown in Table 4.8. It was noted that throughout the experiment the application efficiencies values obtained during the first irrigation were relatively low and increased with subsequent irrigations. Similar results were obtained by Abdeen (1999), Elramlawi (1992), and Elsheikh (2002) who attributed this to the dryness of the soil, the percolation through the cracks and
deep percolation of irrigation water below the root zone in the first irrigation. Abdeen (1999) stated that application efficiency decreased as the furrow length increased. The highest application efficiency of 98% was recorded in the second irrigation with cycle ratio \( \frac{3}{4} \) and this might be due to the fact that with this cycle ratio the opportunity time is greater for water intake in the soil as stated by Evans (1995). The lowest application efficiency of 63% was recorded with cycle ratio \( \frac{1}{4} \) and this might be due to the numbers of surges to complete the advance phase. Similar results were obtained by Evans (1995) who reported that the surge flow was superior in furrow irrigation for maintaining acceptable application uniformities. Surge irrigation improves the application efficiencies and this might be attributed to the reduction of run-off and deep percolation losses under surge irrigation. This finding is supported by many investigators e.g. Evans (1995), Criddle et al., (1956), Bos (1974) and Abdeen (1999) who reported that surge flow was found to be the most suitable technique to improve furrow irrigation performance because it maintained the highest irrigation efficiencies and the highest opportunity time compared to the other techniques studied. In this study the suitable cycle ratio to increase the application efficiency was cycle ratio \( \frac{3}{4} \) while cycle ratio \( \frac{1}{4} \) led to more advance time and this led to decrease application efficiencies. In application efficiencies there were significant differences between cycle ratios.
Table 4.8. Application, distribution and storage efficiencies for the different cycle ratio

<table>
<thead>
<tr>
<th>Irrigations</th>
<th>1st</th>
<th>2nd</th>
<th>3rd</th>
<th>4th</th>
</tr>
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<tr>
<td>EA</td>
<td>ED1</td>
<td>ES1</td>
<td>ED2</td>
<td>ES2</td>
</tr>
<tr>
<td>F</td>
<td>77b</td>
<td>84a</td>
<td>71a</td>
<td>80c</td>
</tr>
<tr>
<td>T</td>
<td>87a</td>
<td>83a</td>
<td>67a</td>
<td>95a</td>
</tr>
<tr>
<td>H</td>
<td>85a</td>
<td>85a</td>
<td>68a</td>
<td>88b</td>
</tr>
<tr>
<td>Q</td>
<td>56c</td>
<td>81a</td>
<td>67a</td>
<td>58d</td>
</tr>
</tbody>
</table>

* F = full time of irrigation period. = 28 minutes.
* T = three quarter of full time of irrigation period. = 21 minutes.
* H = half of full time of irrigation period. = 14 minutes.
* Q = quarter of full time of irrigation period. = 7 minutes.
* EA = application efficiency.
* ED = distribution efficiency.
* ES = storage efficiency.
* Means followed with similar letters is not significantly different from each other at 0.05 level of probability according to SAS.
4.11.3 Storage efficiency (Es %):

Results of storage efficiencies obtained under each cycle ratio were shown in Table 4.8. The highest storage efficiency of 78% was obtained under cycle ratio ½. Whereas the lowest storage efficiency of 71% was recorded by cycle ratio ¼. These results might be due to the fact that in cycle ratio ½ the duration of the rest period was long enough for the water to infiltrate into the soil before the next cycle begins and this had resulted in higher storage efficiency compared to the other cycle ratios. Similar results were obtained by James (1988), Mostafazadeh and Mousavi (1989). In addition to that surge irrigation technique resulted in a longer contact time which increased the water infiltrated into the soil. This finding is supported by the work of Lal and Pandya (1977) and Abdeen (1999) who reported that in surge irrigation technique the intermittent water flow resulted in a long opportunity time as a result of the fast advance front.
CHAPTER FIVE
CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions:
The following conclusions can be drawn from the results of this work:-

1. The gated pipe irrigation technique resulted in higher application efficiencies and the system is movable and convenient to operate which is very important for the system acceptance.
2. Surge irrigation with gated pipe in this experiment was found to maintain high irrigation efficiencies especially application and conveyance and provides more uniform water distribution.
3. Hydroflume has high control on the water flow through the outlets and all the quota of water diverted from the source reached the field.
4. Flow velocity and efficiencies values increased as irrigation proceeded.
5. Throughout the experiment there were cycles resulted in higher efficiencies compared to the other one.
6. In the surge irrigation technique the intermittent water flow resulted in a large opportunity time as a result of fast advancing front and slow recession front compared to the continuous flow.
7. Under surge irrigation technique the furrow length can be increased because there was a similarity in distribution efficiencies along the furrow.
5.2 Recommendations:

From the results and conclusions of this study the following recommendations can be made:-

1- The four cycle ratios used in this study should be tested under different soil types, different cycle times, different furrow lengths and different inflow rates.

2- Comparative study using different cycle times, different cycle ratios, different inflow rates on different soil types should be carried out.

3- The material of hydroflume used was very sensitive and easy to damage, so a more dependable material should be used.

4- A study concerning possibility of automation of surge technique using hydroflume should be conducted.
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