"Development of farm irrigation"

Development of irrigation systems by adding fertilizer with irrigation water

By

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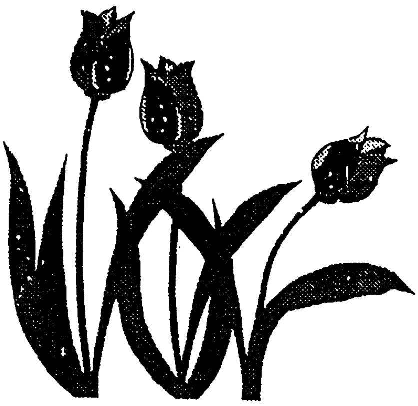
بسم الله الرحمن الرحيم

DEDICATION

to

my parents,

my brother and my sister



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1 - INTRODUCTION

Chemigation, as this practice is commonly called, can be defined as the application of a chemical, bacterium,.. etc., via an irrigation system by injecting the chemical into the water flowing through the system. The use of modern irrigation methods became very important for water and chemicals saving, as well as to optimize water fertilizer use efficiency.

The term of chemigation began to be used in the 1970' S **(Abdel-Aziz, 1998).** Fertilizers were the first chemicals to be injected into modern irrigation systems **(Goldberg and Shamueli, 1970).**

Chemigations currently used on a very limited basis and only for applying fertilizers in Egypt. The first reported application of fertilizer through a trickle irrigation system was in **1982** by **Hegazi** then **El-Kobia et al. 1986.** While the first reported injection of herbicides and fertilizers through both drip and sprinkler irrigation systems by **El-Gindy, 1988.**

A variety of agricultural chemicals can be applied via the micro-irrigation system, including pesticides, herbicides, fertilizers and growth regulators. However, care must be taken that these chemicals don't react with naturally occurring dissolved solids such as calcium, or with each other, in such away as to result in precipitation or deposition. Precipitation of dissolved solids will cause clogging of emitters or orifices, and in some instances the addition of chemicals to adjust the pH or to otherwise prevent precipitation may be necessary.

Agricultural chemicals are frequently injected into pressurized irrigation systems. Injection methods include the following:

(a) Positive displacement pumps; and

(b) Pressure differential injectors, such as the venturi, some hydraulic pumps, and the by- pass tank. The application of the by-pass tank injector has been limited due to high energy requirements, difficulty in controlling injection rates .By-pass injection can be improved by using a bend to provide a simple and economical way to inject chemicals into pressurized water line when the power source is neither available or out of use. Often times, at least two injection devices are used, one with low and one with a moderate injection rate for chemigation.

Maize is considered the important crop for human, animal and industry. In egypt, maize occupied 1.5-2.0 million feddan **(Khalil, 2001)**

The objectives of this study were to:

1- Manufacture a bend to use it with by-bass tank as a new fertigation unit and evaluate this unit under different irrigation systems.

2- Comparing between different fertigation methods under different operating pressures.

3- Improving water and fertilizer application efficiency to increase corn production.

2 - REVIEW OF LITERATURE

2.1. Irrigation systems:

2.1.1. Definitions of irrigation systems:

2.1.1.1. Furrow irrigation:

Michael et al., (1972) reported that, furrow method of irrigation is used to irrigate the row crops with furrows developed between the rows in the planting and cultivating processes. Water is applied by running small streams in furrows between the crop rows. Water infiltrates into the soil and spreads laterally to irrigate the areas between the furrows depends on the amount of water required to replenish the root zone and the infiltration rae of the soil.

Hansen et al., (1979) stated that using furrows for irrigation necessitates the wetting of only a part of the surface (from one- half to one fifth) thus reducing evaporation losses, lessening the puddling of heavy soil, and making it possible to cultivate the soil sooner after irrigation.

Punmia (1981) said that a furrow consists of a narrow ditch between rows of plants, where one- half to one- fifth of the surface is wetted. The length of furrows varies from 3 m or less for gardens to as much as 500 m for field crops, the common length being 100 to 200 m. if the furrows are of excessive length depreciation losses and soil erosion near the upper end of the field may result. The general slopes provided for furrows may vary from 0.2 to 5%.

Birdie (1988) stated that in furrow irrigation method the fields are divided into ridges and furrows as shown in crops are sown on the ridges and watering is done in the furrows. Depth of furrows varies from 20- 30 cm. When the furrows have small size, they are known as corrugations that used for growing grain crops.

James (1988) mentioned that furrow irrigation is accomplished by running water in small channels (furrows) that are constructed with or across the slope of a field. Water laterally and downward to wet the soil and to move soluble salts, fertilizers and herbicides carried with the water. Water is diverted into furrows from open ditches or pipes. He added that furrows can be classified as level, contour, or graded furrows.

Lenka (1991) showed that in furrow irrigation method small furrows are used to convey the water to soil surface in small individual parallel streams. Water infiltrates through the sides bottom of the furrow.

Water moves laterally vertically downward. Careful land grading for uniform slopes is essential in this method.

Garg (1995) defined furrows as a narrow field ditches, excavated between rows of plants and carry irrigation water through them. Spacing of furrows determined by the proper spacing of the plant. Furrows vary from 8 to 30 cm deep, and in too much percolation near the upper end and too little water near the down- slope end. Deep furrows are widely used for particularly suitable for relatively irregular topography and close growing crops, such as meadows and small grains.

2.1.1.2. Drip irrigation:

There are many definitions of drip irrigation, however there are no much differences between them.

Bucks et al. (1980) stated that drip irrigation is the frequent application of small quantities of water directly on or below the soil surface usually as discrete drops, continuous drops, tiny streams, or miniature sprays, through emitters placed along plastic pipelines.

Phene et al. (1986) defined another kind of drip irrigation which is the uniform application of small quantities of water at frequent intervals below the soil surface from discrete emission points or line sources.

El-Gindy (1989) stated that drip irrigation is a method for applying water to the soil under low- pressure head. Drippers are distributed along a pipe constructed near the plants.

2.1.2. Advantages and disadvantages of irrigation systems:

2.1.2.1. Furrow irrigation:

Michael et al., (1972) reported that furrow irrigation is the most suitable method of surface irrigation when the crops are sensitive to the pounded surface water or susceptible to fungal root rot, root injury.. etc. furrows are most commonly rundown the slope, but they can also be run nearly on the contours when the land slope exceed the safe limits of soil erosion. He added that the furrows can be used to dispose- off run off from rainfall rapidly if surface drainage is necessary.

Punmia (1981) and Punmia and Lal (1990) summarized the advantage of furrow irrigation as follows:

1- Water contacts only $^1/_5$ to $^1/_2$ of the land surface, thereby reducing puddling and crusting of the soil.

2- Earlier cultivation is possible in heavy soils and may be adapted to use, without erosion on a wide range of natural slope by carrying furrows across a sloping field rather than down the slope.

3- It is specially suitable for some crops (like maize ... etc.) that are injured by contact with

4- There is no wastage of land in field ditches.

James (1988) said that furrow irrigation is suitable for irrigating crops that are subject to injury if water covers the crown or stems of the plants. He added that the labor required is generally greater for furrows than for other surface irrigation methods and need experience to divide water in the supply ditch into a number of furrow streams and to maintain correct rates of flow until irrigation is complete.

Lenka (1991) summarized advantages of furrow irrigation as follows:

1- Economic use of water and increased use efficiency due to lateral and downward flow of water into the root- zone.

2- Evaporation loss is reduced for lesser contact zone in the furrow.

3- Reduces pudding and crusting of the ridge since zone of wetting is only 1/3- 1/5 of the total furrow depth.

4- Cultural operations become easy.

5- The furrows can be used as drainage channels.

6- During water scarcity alternate furrows can be irrigated to save water. The salinity hazard to crops can be reduced.

2.1.2.2. Drip irrigation:

Bucks et al. (1981) summarized the potential advantages of trickle irrigation as follows:

1- Increased beneficial use of available wate,

2- Enhanced plant growth and yield,

3- Improved fertilizer and chemical applications,

4- Reduced salinity hazard to plants,

5- Limited weed growth and

6- Improved cultural practices.

They added that the potential disadvantages of drip irrigation are as follows:

1- Persistent maintenance requirements,

2- Salt accumulation near plant,

3- Restricted soil water distribution and plant root development, and

4- Economic technical limitations.

James (1988) reported that trickle irrigation has many desirable features, high yield, improved crop quality, and reduced water in addition energy use have all been attributed to trickle irrigation. One the other hand, there are several problems associated with trickle irrigation. The most several problems is clogging of system components by particulate, chemical, and biological materials. He added that costs of the system generally comparable to solid set sprinkler and surface irrigation systems. Except when extensive land leveling are higher, also limited root zone development and salt accumulation problem can occur.

Habib (1992) concluded disadvantages of drip irrigation as follows:

1- Emitter cloggin,

2- Rates can spoil laterals,

3- Unsuitable for dense crops,

4- Salinity hazards and

5- High costs in comparison with some of the other irrigation system.

Strelkoff et al. (1999) reported that modern surface irrigation methods and practices can achieve significantly higher performance levels than existing methods and practices.

2.2. Definition of chemigation/ fertigation:

Threadgill (1981) defined chemigation as the application of a chemical (fertilizers, herbicides, insecticides, fungicides, nematicides, etc.) via an irrigation system by injecting chemicals into water and distributing it with the irrigation water.

Gascho and Mashail (1991) mentioned that fertigation (ferti-irrigation) is the frequent application of appropriate amounts of fertilizers in irrigation water or through irrigation systems at a time when the crop needs it. This definition includes surface irrigation methods and pressurized systems.

Threadgill (1991a and b) stated that terms heribigation, insectigation, fungigation, nemagation and mycroherbigation have been coined to describe various type of chemigation now in use. He also added that, it considered the shift from conventional practices in irrigation and agrochemical application to fertigation and chemigation has been remarkable in developed countries during the last two decades.

Hoffman et al. (1992) defined chemigation as application of a chemical, bacterium, etc, via an irrigation system by injecting the chemical into the water flowing through the system. They added that new terms such as fertigation, heribigation, fungigation, insectigation and nemagation have been coined to describe the various types of chemigation, thus, chemigation now encompasses both soil- and foliar- applied chemicals.

2.3. Advantages of chemigation:

Harrison and Skinner (1981) reported that, the advantages of chemigation can be summarized as follows:

1- It provides excellent uniformity of chemicals application,

2- It allows easy and effective chemical incorporation and activation,

3- It reduces soil compaction, mechanical damage to the crop and operator hazards,

4- It may reduce chemical requirement and environmental contamination,

5- Chemigation of both soil and applied chemicals can be effective and economical.

Hoffman et al. (1992) decided that the chemigation offers many advantages compared with aircraft, tractor,.or hand sprayer modes of chemical application methods. The advantages of chemigation include the following:

1- Prescription application of chemicals. Chemigation can be performed at any time of irrigation, therefore, chemigation does not usually depend on the weather or the time of day,

2- Easy chemical incorporation and activation. Any chemical requiring incorporation and water for activation can be applied with an appropriate amount of water to incorporate the chemical to the desired depth and to activate it immediately,

3- Reduction of soil compaction and mechanical damage to the crop. With chemigation, it is not necessary to drive tractors through the field, thus eliminating traffic that may cause soil compaction and mechanical damage in many crops,

4- Reduction of operator hazards. Potential for exposure of the chemical applicator to the chemical being applied is reduced.

5- Potential reduction of chemical requirement. Multiple applications of small amounts of plant nutrients that are subject to leaching, particularly nitrogen, can reduce the amount lost through leaching and thus allow reduction of the total quantity applied to the crop. There is also some evidence that the application rate of certain herbicides and insecticides may be reduced when chemigation is used.

6- Potential reduction of environmental contamination. Drift of chemicals applied through irrigation systems would certainly not occur, and it is evident from several years of chemigation with center pivots that drift is likely less than that experienced with aircraft or tractor chemical applications under the same environmental conditions.

Arnaout (1999) stated that the applied fertilizers through the three selected irrigation methods (surface drip, subsurface drip, and sprinkler) are more efficient than broadcasting fertilizer. It resulted in a highly significant increase in stem length, brenches, number of leaves/plant, Lima beans seed yield and both water and fertilizer efficiency are obtained by fertigated plants. He also found that the fertigation through surface and subsurface drip and sprinkler reduced the cost of production unit by 38%, 40% and 33.75%, respectively, than broadcasting fertilizer.

Bar- Yosef (1999) reported a number of potential agronomic advantages of fertigation with subsurface drip irrigation (SDI) over surface drip irrigation. These include nutrients being supplied to the center of the root system, drier soil surfaces that help reduce weed germination, deeper root growth that buffers the plant against water and nutrient stresses, prevention or reduction of soil crusting in sodic soils or when saline water is used, and utilization of secondary municipal effluents for edible crops.

Sayed et al. (1999) showed that the chemigation has several inherent advantages over conventional dry-blend fertilization for crop production on coarse textured soil such as lower fertilizer inputs, reduced nutrient leaching, flexibility in scheduling to meet crop demands and lowering the variable costs. They also stated that the irrigation method becomes a multifunction unit able to supply crops with necessary water and nutrients needed.

Lamm et al. (2001) stated that microirrigation can potentially "spoon feed" nutrients to a crop. Accurately suppling the crop's nitrogen (N) needs throughout the season enhance crop yields and reduce the potential for groundwater contamination from nitrates.

2.4. Disadvantages of chemigation:

Threadgill (1991a,b) reported that the disadvantages of chemigation include the following:

1- Over fertilization in case that, irrigation is based on actual water requirements.

2- Unequal chemical distribution when irrigation system design or operation is faulty.

3- Calibration to achieve the proper chemical injection rate is required for each chemigation system and for each irrigation system with which it is used.

4- Potential offset or non- target chemical application.

5- Leaching if rainfall occurs at the time of fertilizer application.

6- Chemical reaction in the irrigation system lead to corrosion, precipition of chemical materials and clogging.

Hoffman et al. (1992) said that, chemigation has some possible disadvantages which can be summarized as:

1- Potential chemical back flow into water supply. The back flow of a chemical into the water supply when being applied via chemigation is a well-recognized potential environmental hazard. This hazard exists regardless of source of water ground water, reservoir, or stream and regardless of the type of irrigation system.

2- Capital outlay. The capital outlay for chemigation consists of two components: the chemical injection system and associated chemical tanks. If an irrigator uses a portable chemigation unit that serves two or more irrigation systems, the capital outlay per system is dramatically reduced.

3- Potential non-uniform chemical distribution.

4- Calibration. Proper calibration of chemical injection rate is required for each irrigation system. The calibration injection rate may need to be changed during the application period (e. g., corner center- pivot system, center- pivot gun turning on off).

5- Potential non- target chemical application. Non- target chemical application can occur as a result of drift, malfunctioning equipment such as end gun shutoffs, and runoff.

6- Potential excessive over or under application of chemical. Safety equipment malfunction during chemigation with continuous move irrigation systems (i. e., center pivot and linear move) may result in excessive over or under application of the chemical on a concentrated area (e. g., when the chemical injection system continues to operate after the irrigation water pump has shut down).

7- Management requirements. While some consider chemigation to be a quick and easy technique for applying chemicals, a chemigator must recognize that safe and effective chemigation requires careful and attentive management.

2.5. Chemigation methods:

Bennett et al. (1987) said that chemicals are frequently injected into pressurized irrigation systems by many injection methods which: (a) positive displacement pumps driven by either electric, gasoline, hydraulic, or PTO power; and (b) pressure differential injectors, such as the venturi; some hydraulic pumps, and the by-pass tank.

Aboukhaled (1991) mentioned that in addition to direct use of irrigation pumps, three other major categories of chemigation equipment are in use in countries of the Near East namely: venturi type devices, differential pressure tanks and positive displacement pumps.

2.5.1. Differential pressure tank:

Beth (1981) stated that the application of the by-pass tank injection has limited due to high energy requirements (reported as exceeding 30 kpa operating pressure), difficulty in controlling injection rates because, the concentration of chemicals in the tank decreases gradually until it reaches the level of irrigation water, and the expense of large pressurized tank. He added that by- pass tank has many advantages such as, it is simple construction and operation and of low cost and also, it does not need an external power supply and is not very sensitive to change in pressure or flow rate.

Nakayama and Bucks (1986) reported that pressure differences can be developed by valves, venturi, elbows, or pipe friction, most pressure difference systems use closed tanks so that the tanks must withstand the pressure of the irrigation system. They added that the main advantage of the pressure differences is the absence of moving parts, which are simple in operation and require no electric, gasoline, or water- powered pumps. Also, they can operate whenever water is flowing and where a pressure drop is present. The primary disadvantage of the pressure difference units is that the rate of application is not constant; thus, a uniform concentration of a nutrient cannot be maintained.

Aboukhaled, (1991) reported that the dry fertilizer may be placed into differential pressure tank. When the irrigation systems being operating, water will flow into the tank through the heigher pressure inlet port, filling the tank with water and dissolving some of the dry fertilizers. Once the tank has been filled, water will flow out through the outlet port, carrying some of the dissolved fertilizers with it.

Papadopoulos (1991) mentioned that a modification of the pressure differential system is a tank that contains collapsible plastic bag into which dry fertilizer may be added. Water is admitted to the area between the tank and the bag, which forces the fertilizers compound the bag into the system. He also added that the disadvantages of the pressure differential system are: the varient concentration of nutrients causes the bulk of the chemical to be applied at the beginning of the irrigation cycle leading to some fertilizer losses, particularly

N; and the tank has to be refilled with solution at each irrigation and not suitable for automatic or serial irrigation.

Abdel- Aziz (1998) found that increasing the pressure differential between inlet and outlet of the pressurized tank lead to increasing fertilizer injection rate for different operating pressures. He also reported that fertilizer concentration in the irrigation water increased rapidaly at starting time, then it decreased with increasing the injection time.

Metwally (2001) reported that differential pressure tank method employs a tank into which the dry or liquid chemical are placed. Two types of pressure tanks are used Fig. 1 A and B. The tank is connected to the main irrigation line by pass by two small pipes so that some of the pumped irrigation water is flows throw the tank and dilute the chemical solution.

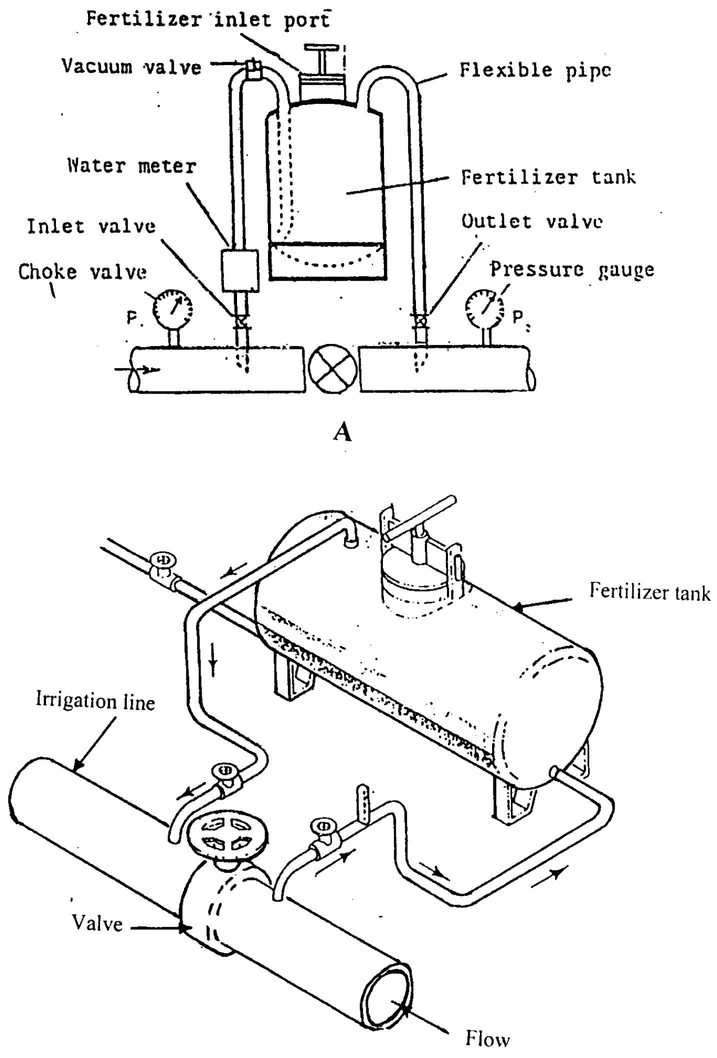
There are cheke valves are fitted between the connecting points in the water line. These valves are used to create a small pressure drop (1-2 m) which is sufficient to cause some of the flow to be diverted through the tank. The entry pipe reaches to the bottom of the tank, thus mixing the solution and expelling it into the water line.

2.5.2. Venturi suction devices:

Alkeng and Schmidt (1985) showed that constricting a venturi tube in the main water flow pipe causes a differential pressure (vacuum) which is sufficient to suck chemical solution from an open reservoir into the water flow as shown in Fig. 2A and B. The rate of flow can be regulated by means of valves. They added that, venturi device is simple and inexpensive method of chemigation injection. On the other hand venturi has some disadvantages as. The pressure loss across a venturi tube is high and precise regulation of flow is difficult.

Nakayama and Bucks (1986) said that some venturi injection systems allow fertilizer to be added directly into the system from open tanks without being diluted. A portion of the irrigation water is bypassed through a venturi, which functions as an aspirator to pull the solution into the system. The larger venturies may require booster pumps because of high pressure losses. Solution injection rates are regulating by flow meters and valves.

Abou Khaled (1991) mentioned that the venturi method has many advantages as: the operation mechanism is very simple, it has no movable parts, fertilizer dilution is constant under stable operating conditions, many sizes and models are available, and lower cost compared with alternative devices. There are some disadvantages for venturi as follows: large loss in pumping pressure (about 1/3 of the operating pressure), it must be installed only where the pressure is high enough to ensure adequate operating pressure



B

Fig. 1: Differential pressure tank. **(Metwally, 2001)**.

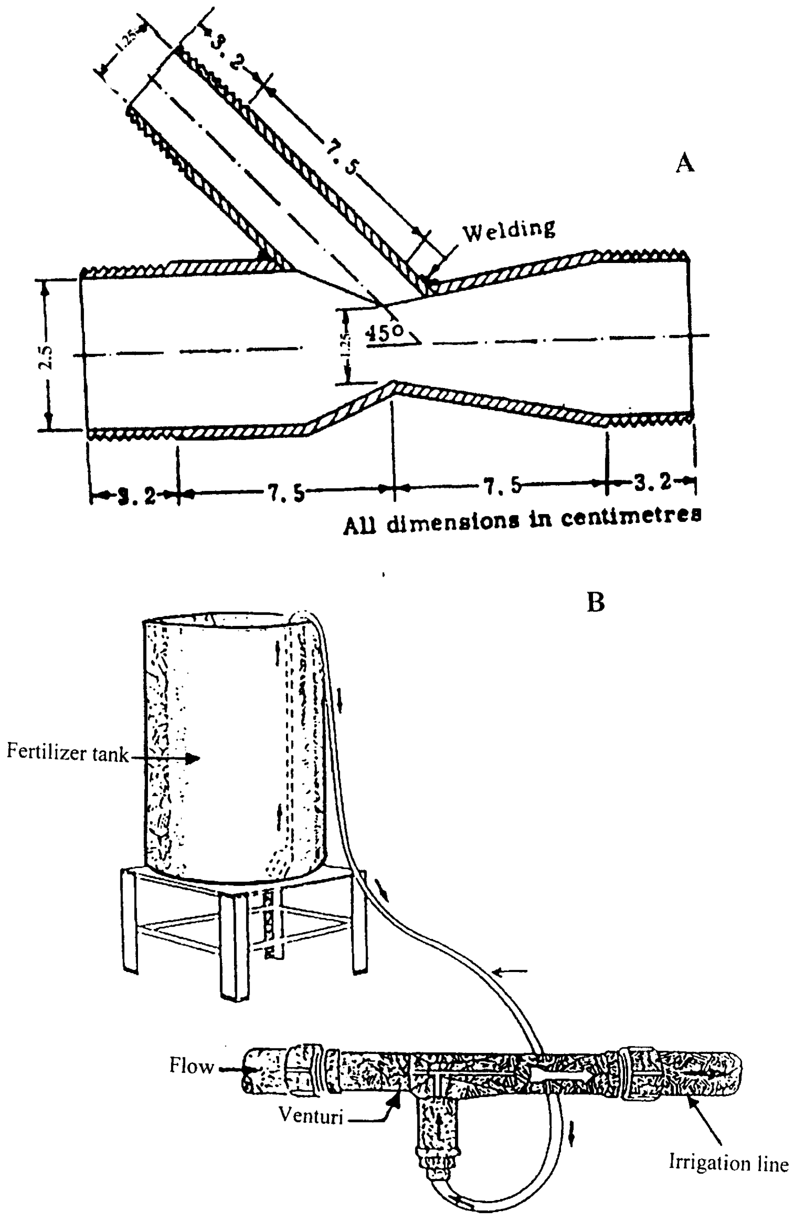


Fig. 2: Venturi suction device. **(Alkeng and Schmidt, 1985).**

after the pressure drop and also where the flow and pressure are constant and stable, and fluctuation in operating conditions may cause a large change in the mixing ratio of solution.

Hoffman et al. (1992) showed that chemigation injection devices based upon the venturi principle utilize a differential pressure generated across a venturi device that creates a vacuum, thereby sucking the chemical into the irrigation system. The rate of injection depends upon and varies with the differential pressure. This can create difficulty in obtaining accurate and consistent rates of chemical injection.

Abdel-Aziz (1998) indicated that by increasing the percentage of pressure difference between the inlet and outlet of the injector the fertilizer suction rate increased for all different operating pressures. This is due to certain of inside the injector vaccume. He added that fertilizer concentration in the irrigation water changes during the injection period, but this changing is small, there for, no prefer using a venturi for pesticide injecting.

2.5.3. Positive displacement pumps:

Threadgill (1985) used a positive displacement pump to inject chemical solution from an open tank into the irrigation line as shown in Fig. 3. It is more costly but more accurate than the previous systems. At each stroke of the pump a certain predetermined volume of solution is injected, and the number of strokes per unit time can be adjusted. Pumps may be classified on the basis of their power sources namely electricity, internal combustion engine, tractor power take off, or water pressure form the irrigation system itself (hydraulic pumps). This device requires a minimal pressure (1.5 to 2.0 atm.) to operate.

Nakayama and Bucks (1986) sated that pumping is the most common method of injecting fertilizer into a trickle irrigation system. The positive injection pumps include the single or multiple piston pumps, diaphragm pumps, gear pumps, and roller pumps. Where two or more different types of fertilizers are required, multiple pump units can be used to avoid or reduce precipitation problems.

Papadouplos (1991) postulated that the general advantages of the injection system are: the high degree of control of dosage and timing of chemical application, centralized and sophisticated control, portability, no serious head loss in the system, labor saving and relatively cheap in operation. On the other side, the installation is complex and costly compared to other techniques and outside power sources may be need.

Hoffman et al. (1992) stated that piston- type injection devices have been used extensively and successfully for chemigation. However, due to the

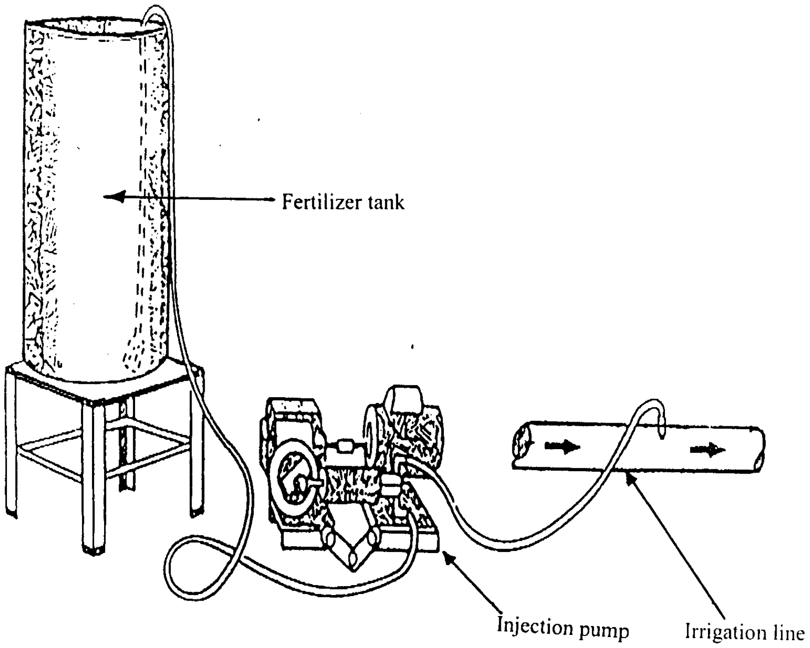


Fig. 3: Positive displacement pump. **(Threadgill, 1985).**

inherent design characteristics of piston pumps, they have two disadvantages for chemigation. First, they have a relatively large internal area exposed to the chemical being pumped, this factor has led to accelerated corrosion and wear of this unit. The second disadvantage is the inherent difficulty of setting the pump stroke length to obtain the desired injection rate. They also added that diaphragm- type pumps are widely used in chemigation due to their inherent advantages. One major advantage is the small number of moving components and the limited area exposed to the chemical being injected This greatly reduces the potential for corrosion wear and leakage. The second major advantage is that it lends itself to design for easy adjustment of injection rate while the pump continues to operate.

Abdel-Aziz (1998) reported that the fertilizer injection rate increased continuously by increasing the piston stroke length, He also noticed that the concentration increased at the beginning of injection, then it becomes a constant during the injection period and there is no difference in the fertilizer injection rate for fertilizer types.

2.5.4. Bend as a fertigation method:

Bennett et al. (1987) designed and tested a low energy by- pass system for injection of chemicals into irrigation systems as shown in Fig. 4. The components of a system include a chemical storage tank, inlet and outlet hoses with fittings to connect the tank to the irrigation system, and valves to isolate the by-pass when recharging the tank with a chemical. They reported that by-pass injection across a bend requires low pressure differential to operate (less than 1 kPa) and eliminating the need for additional system pressure, fittings, and valves. They also added that the by-pass system is a low-cost method for injecting chemicals when the amount of chemical is important, but the chemical concentration is not a consideration.

Mohammed and Nishiyama (1996) showed that by pass injectors operating on the basis of the pressure differential generated between the inner and outer wall at the midpoint of a bend. It may be the only way to chemical injection when the power source is either not available or out of use and also when flow rates are too low to operate a venturi. They added that since the by pass and main flow discharge relationship is almost linear, across 90^0 PVC pipe elbows Fig. 5, the ratio of by pass discharge for a given elbow is constant; this means that a constant dilution rate could be achived when using a chemical tank operating across an elbow.

Larhrafi and Nishiyama (1996) explained operating idea of the bend as, presence of a curve in a piping system generates a centrifugal force that acts at right angles to the main flow direction as shown in Fig. 6 , this effect distorts the flow filed from that in a straight pipe, and generates a transverse

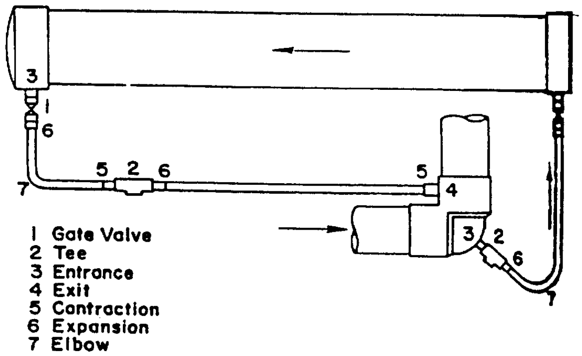


Fig. 4: By-pass tank injector system for an elbow pressure source.**(Bennett et al, 1987)**.

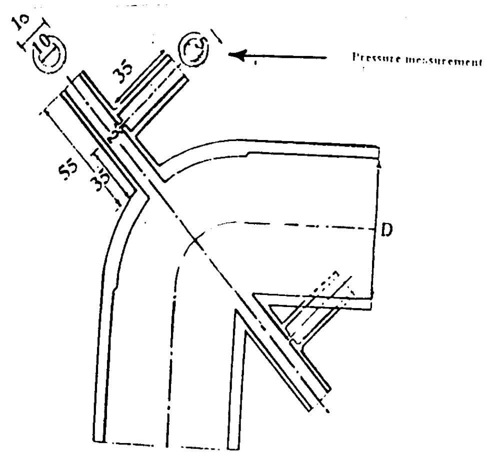


Fig. 5: 90° PVC pipe elbow, (Dim. In mm.). **(Mohammed and Nishiyama, 1996)**.

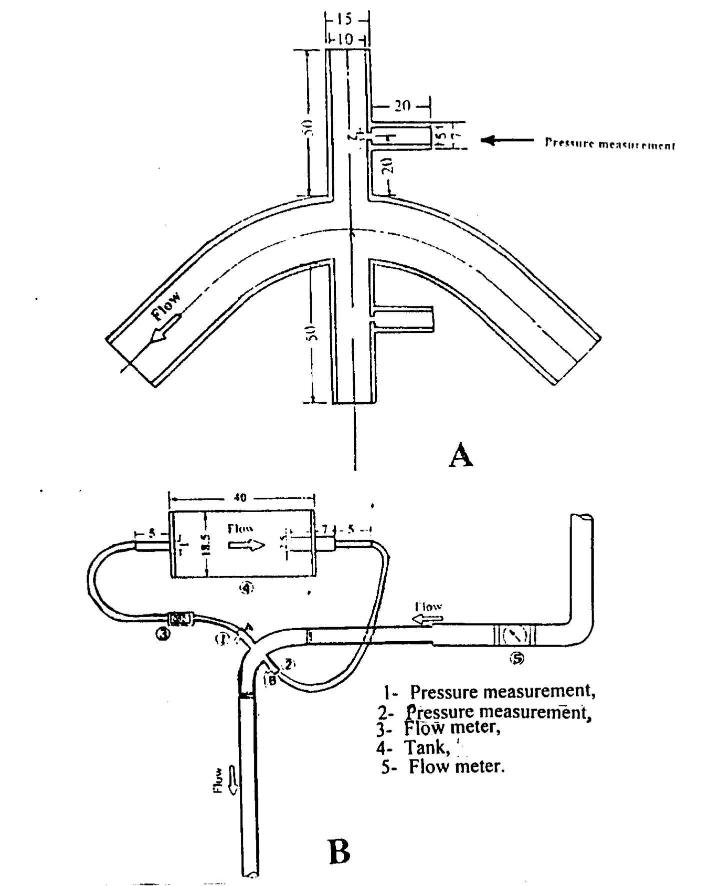


Fig. 6: Schematic of the bend design. **(Larhafi and anishiyama, 1996)**.

motion on the primary axial flow, known as secondary flow. The water in the central region of the pipe moves away from the center of curvature, giving rise to a pressure differential between the inner and outer wall of the pipe. They added that by pass injection using a bend provides a simple and economical way to inject chemicals into pressurized waterline.

2.6. Chemigation management:

Keller and Karameli (1974) reported that the effect of most important design criteria on the efficiency of irrigation and chemigation systems, are: filtration efficiency, permitted variations of pressure head allowed, base operating pressure used, degree of flow or pressure control used, relationship between discharge and pressure at the pump, use of secondary safety screening and allowance for reserve system capacity or pressure to compensate for reduced flow due to clogging.

Miller et al. (1976) indicated that nitrogen is used more efficiently when it is applied through the trickle system than the banded with furrow irrigation or banded with trickle irrigation. When fertilizer is banded beside the plant row, furrow irrigation is the better irrigation method, because the applied water moves the nitrogen toward the plants.

Nakayama, et al. (1979) reported that the emitters line materials and other equipment must be resistant to chemicals that may be injected into irrigation system, such as fertilizers, bactericides, insecticides, herbicides and fungicides.

Bucks and Nakayama (1980) reported that all chemicals applied through irrigation systems must meet the following criteria:

(1) avoid corrosion, softening of plastic pipe and tubing or clogging of any component of the system,

(2) be safe for field use,

(3) increase or at least not decrease crop yield,

(4) be soluble or emulsifiable in water, and

(5) not react adversely with salts or other chemicals in the irrigation water.

In addition, the chemicals or fertilizers must be distributed uniformly through the field. They added that, achieving such uniformity of distribution requires efficient mixing, uniform water application, and knowledge of the flow characteristics of water and fertilizers in the distribution lines.

Ogg, et al. (1983) mentioned that system should be completely flushed after installation to remove foreign particles from the pipelines. If possible should be flushed once before the emitters are putting on the lines. Also, the installation of sediment traps or on auxiliary line screen after sand and screen filters is recommended to protect a possible failure of sand or screen filter.

Nakayama and Bucks (1986) claimed that fertilizer injection should not begin until all lines are filled with water and the emitters are running. For many systems, it is preferable for chemical injection to begin one hour after the system has been operating and for injection to cease one hour before the system is to be turned off. Applying chemicals into a partially filled system will result in poor fertilizer distribution. Also they added that, surface application of fertilizer is a practical alternative to applying fertilizer through the trickle system. The material may be weighed or measured for each plant and may also be divided to give equal portions to each of several emitters of a plant. This is a good method of applying slowly soluble materials that may cause excessive wear on pumps or that may produce a precipitate and plug the materials.

Keller and Ron (1990) indicated that the rate at any chemical must be injected into the irrigation water should be calculated carefully. It depends on the concentration of the liquid fertilizer and desired quantity of nutrients to be applied during the irrigation. It can be computed as follow:

$$q = \frac{F.A}{C.t.T} \quad \text{..........} 2.1$$

Where:

q = Rate of injection of fertilizer solution into the system, l/h.,

F = Fertilizer application rate per irrigation cycle, kg/ha,

A = Irrigated area , in ha,

T = Irrigation application time, hr.

C = Concentration of actual nutrients in the liquid fertilizer, kg/l and

t = Ratio between fertilizing time and irrigation application time.

Gasho and Mashali (1991) reported that there are three qualities are necessary for a good source of fertilizer for fertigation:

1- It must be contain the needed nutrient elements in a form available to plants or in a form that is readily converted to available (i.e. urea is converted to available NH_4 and No_3-N forms in good soil conditions),

2- The chemistry of the application must be such that plants are not burned or stunted and irrigation lines, emitters, or orifices are not restricted or plugged, and

3- It must be uniformity distributed either uniformity broadcast for sprinkler, furrow, or flood or uniformity distributed among emitters for drip irrigation systems.

Hoffman et al. (1992) sated the process for chemigation calibration for surface irrigation systems is very essential, it is basically a matter of determining the land area irrigated per set and knowing the amount of time required to irrigate that set. In most cases the chemical will be applied during the entire irrigation set this is especially true if the reuse system is available to collect the run off at the end of the filed. If the system is not equipped with a reuse system, then it is not advisable to chemigate. For adequate distribution of the chemical under this condition, it is probably desirable to delay injection of any chemical until the water has advanced approximately one- half way across the field, the chemical can then be injected during the last half of the advance phase. Also they recommended that, when chemigating with surface irrigation then tailwater recovery systems must be used.

Threadgill et al. (1995) found that using completely soluble fertilizers increased cotton yield comparing with using conventional fertilizers. On the other hand cotton crop yield was more when using liquid fertilizers in every 2nd irrigation than when added each irrigation or 3rd irrigation. There results indicated that chemigation method tended to increase cotton yield by about 30 % comparing with band method.

Larhrafi and Nishiyama (1996) stated that bypass flow rate depends on the curvature ratio, discharge and the ratio of bybass flow orifice to the bend diameter as follows:

$$q = 0.6\left(\frac{r}{a}\right)^{-0.64}\left(\frac{e}{D}\right)^{2.22} Q^{1.09} \quad \text{......................................2.2}$$

Where:

q = By pass flow rate through the tank (l/s),

r/a = Curvature ratio, where “r” is the radius of curvature and “a”is the bend radius,

e = By pass orifice size, m,

D = Bend inside diameter, m and

Q = Main discharge (l/s).

Knowledge of the various factors which influence the velocity and pressure distribution in a bend will help improve the performance of bend injection system.

Abdel-Aziz (1998) reported that the amount of fertilizer remaining in the tank after injection ends is a big when using the fertilizers slowly soluble, therefore, fertilizers highly soluble must be used. Using perforated tube with pressure differential tank making as agitation lead to increase the fertilizer solubility, and consequently, increasing the injector efficiency. He added that fertilizer injection rate by using a venturi effecting to the distance of the venturi from the suction level and also, the fertilizer tank position relation to the injector.

El-Sayed and El-Araby (1998) concluded that fertigation through surface drip is more efficient than fertigation through sprinkler. This may be due to limited wetted area affected by drip compared to sprinkler and the fertilizer reaches only where the irrigation water is applied.

El-Marsafy (1999) investigated four-fertilizer application time through drip irrigation system First fertilizer application timing was during the total irrigation time. Second was with first one half of irrigation time. Third was with second third of irrigation time, and fourth was for second and third quarter time of irrigation. His results indicated that, the third and fourth treatments decreased residual nitrates after harvesting more than the first and second treatments. He recommended that, the ideal timing for fertilizer application was during the second third or second and third quarter of irrigation time, because they gave a highest yield, water use efficiency and nitrogen use efficiency.

Lamm et al. (2001) found that nitrate- N concentrations increased by increasing rates of N injected by drip irrigation systems in both of surface and sub surface and migrated deeper into the soil profile. This losses in nitrogen occur if over irrigation was increased.

Sultan (2001) studied the effect of different irrigation systems (surface drip, sub- surface drip and porous tube) and two fertilizer programs (daily and weekly fertigation) on vegetable production. His results revealed that, daily fertigation with different irrigation systems was more efficient than weekly fertigation. Also the most suitable irrigation systems to mange chemigation for vegetable production in sandy soil were surface and subsurface drip (10 cm depth, 50 cm distance between drippers, and 8 l/h m tube).

2.7. Fertigation efficiency:

Hubbard et al. (1984) suggested that when nitrogen was applied to the root zone of growing corn with a center pivot irrigation system, it did not leach from the root zone during the growing season. Leaching occurred only following plant senescence (or harvesting) during rainy periods in the early fall, winter and early spring. They suggested that nitrogen can be managed during the growing season by adjusting the nitrogen rates to the yield goal so that no nitrogen would remain in the soil at the end of the growing season.

Chase (1985) reported that subsurface trickle system can be used to distribute fertilizer within the root zone of crops. Sub-optimal levels of phosphorus applied in this manner are immobilized near the emitter at elevated concentrations and can provide significantly more phosphorus to the first crop than if the same amount is broadcast applied.

Nakayama and Bucks (1986) reported that nitrogen availability is usually limited in the soil compared with other plant nutrients because its various forms can be leached, volatilized, denitrified, or fixed in the organic fraction of the soil. One of the favored forms of nitrogen for use in fertigation is urea, because it is a highly soluble nitrogen fertilizer that does not react with water to form ions unless the enzyme, urease is present. Nitrogen in the ammonium (cation) form and at low fertilizer application rates will adsorb onto the soil (clay) colloids, thus moving only a minimal distance from the source of application.

Also they added that a trickle irrigation system is convenient and efficient to operate and provides a low- cost approach for correcting potassium deficiency by allowing low rates and frequent applications, thus avoiding excess use and buildup of salts while maintaining high nutrient availability. Potassium concentration in the leaves can be almost twice as high when potassium is added with the trickle irrigation water.

Elwali and Gascho (1988) presented a comparison of preplant nutrient application by supplying a minimal quantity of a complete fertilizer and analyzed plant leaf to determine the quantity of supplemental nitrogen (N), sulfur (S), zinc (Zn), and calcium (Ca) to fertigate of corn crop . They recommended that preplant applications be made of the non- leaching nutrients, followed by split applications of nitrogen and other mobile nutrients, particularly for sandy soils, where leaching is more likely to occur or where early season rains occur that may promote leaching. Nitrate nitrogen (N) is a very mobile nutrient, which is used extensively in crop production.

Keller and Ron (1990) indicated that potassium is easily applied by fertigation. Potassium oxide is the most common soluble form, that the fertilizer moves freely into the soil. However potassium molecules become exchanged on the soil complex and are not readily leached away. Potassium can be applied as potassium sulfate, potassium chloride and potassium nitrate. These potassium sources are soluble and have few precipitation problems. Also they added that, there are several kinds of ammonium phosphates are available on the market and are commonly used for both nitrogen and phosphorus in fertilizer, these include ammonium phosphate sulfate (16- 2- 0), monoammonium phosphate (11- 48- 0), and diammonium phosphate (16- 46- 0). As all these forms of phosphorus are very soluble in water, they may be adaptable to fertigation. The quality of the irrigation water must be considered before deciding to inject phosphorus fertilizers into the system. If the water contains appreciable amounts of calcium, any form of phosphorus will precipitate as dicalcium phosphate in the pipe line and emitters, consequently the flow of water restricted and emitters plugged.

Taufiq and Sudargono (1992) found that use of different kinds of nitrogen sources did not give a significant effect on the grain yield of maize in upland soils compared to urea fertilizer. This is due to efficiency of the nitrogen fertilizer in Alluvial soil was higher than in Regional soils .It is caused by, (1) sandy soil texture leaching of nitrogen from fertilizer, (2) the maize roots can absorb natural nitrogen from the lower soil to support their need.

Koszanski et al. (1995) reported that high nitrogen doses and supplemental irrigation increased the filed water consumption. On the other hand the amount of water needed for production of one unit of dry matter on irrigation plots was 70 % as compared to not watered ones. Neither watering nor nitrogen had any effect on the chemical properties of soil, the only exception being higher levels of nitrate and ammonia found on plots fertilized with high doses of nitrogen.

Nonaka et al. (1996) summarized the nitrate movement through soil profile as follow:

1- The chemical form of leached nitrogen was mostly as nitrate the nitrate concentration in groundwater was increased by more than 100 mm, accumulated water per month, but was decreased by below 100 mm, accumulated water per month.

2- In the case of more than 100 mm accumulated water per month, the maximum peak of nitrate leaching appears at 3 weeks after basal application during autumn radish cropping. But, in the drought summer season of 1994, the nitrate leaching was depressed during summer tobacco in the drought summer season of 1994, the nitrate leaching was depressed during summer tobacco cropping.

Sexton et al. (1996) found that turkey manure produced equal or greater crop yields as that from urea application ،however, nitrate leaching was equal or less than urea, at equivalent nitrogen rates. Also they found that, the maximum crop yield is suggested to substantially reduce nitrate leaching past the root zone. Using this guideline nitrates leaching would reducing by 35 % compared with nitrate leaching at the maximum yield.

Waddell et al. (1999) evaluated the impact of alternative irrigation (sprinkler and drip) and nitrogen management practices (urea, turkey manure and sulfur- coated urea) on nitrogen uptake for potato. The results showed that. the sulfur coated urea and buried drip irrigation with fertigation treatments had the lowest tuber nitrogen uptake. Vine nitrogen uptake in the sulfur coated urea treatment was not significantly different from vine nitrogen uptake for the control (0 kg nitrogen), while the manure treatments had the highest vine nitrogen uptake. They concluded that the use of unconventional nitrogen sources such as turkey manure and sulfur-coated urea are viable alternatives for potato production, provided they are managed properly.

Guertal (2000) studied the effectiveness of preplant sulfur-coated urea (SCU) and polyolefin resin-coated urea (PCU) nitrogen fertilizer compared to split applications of soluble fertilizer on green bell pepper yield and quality. The results showed that nitrogen from PCU treatments may have been releasing more rapidly than SCU, producing more nitrogen for plant uptake, there were few consistent differences in pepper yield or quality due to nitrogen source. He added that given cost considerations of drip application and nitrogen sources, slow- release nitrogen materials may be available option for small- scale growers not using drip application systems.

Sultan (2001) concluded that the relation between moisture content and (nitrogen, phosphorus and potassium) distribution were the same in all direction. Also the most suitable irrigation systems for vegetable production in sandy soil were surface and subsurface drip (10 cm depth) at 50 cm distance between water outlet and 8 l/h m tube. The movement of potassium was lower than nitrogen and phosphorus. Nitrogen, phosphorus and potassium were concentrated near the water outlet surrounding to the manure layers. The difference in nitrogen, phosphorus, and potassium distribution due to, the difference in nutrients mobility, the solubility of nutrients and unequal uptake (nitrogen, phosphorus and potassium).

2.8. Irrigation systems effect on soil moisture and salt distribution:

2.8.1. Soil moisture distribution:

Badr (1980) found that soil moisture around the watermelon plant stems in the surface layer depth of 0-15 cm, after 24 h from irrigation was higher in the drip than in both sprinkler and furrow irrigated plots.

El-Kobia et al. (1986) compared between furrow and drip irrigation methods and their effect on the soil moisture distribution in the root zone.

Their results indicated that the highest mean value of soil moisture content was found directly under the emitters; however it decreased away form them. Under furrow method, there was a gradual decrease in soil moisture from bottom to top of line.

Kim and Lee (1989) concluded that the value of wetted distance in the vertical direction of sandy loam soil irrigated by subsurface drip irrigation systems decreases, when irrigation rates increased, while the value of wetted distance in the horizontal direction changes to opposite direction.

Mohamed (1995) stated shat soil moisture content, decreased by increasing soil depth under both furrow and trip irrigation methods. He also found that the soil moisture content was higher under drip irrigation method than furrow one. This may be due to the high efficiency of drip irrigation comparing to the furrow one.

Helmy et al. (2000) reported that increasing the applied water volume tends to increase soil moisture content in both direction of vertical and horizontal under drip irrigation system and in vertical direction only under furrow irrigation system. Also they stated that the soil moisture content was higher under drip irrigation system than furrow irrigation because the irrigation was used daily under drip irrigation system.

Mehawed (2002) found that subsurface drip irrigation system gives the best moisture pattern after irrigation comparing with surface drip irrigation, meanwhile there was no significant difference in moisture distribution pattern before irrigation in the different treatments. Also results indicated that subsurface drip irrigation system gives the best results for soil moisture distribution pattern specially in the second layer of the soil profile (15-30 cm) below point source.

2.8.2. Salt distribution patterns:

Badr (1980) reported that the salt concentration increased by decreasing moisture content. Furrow irrigation gave in general a low salt content with all over the soil layers at the different intervals of sampling. At the end of the experiment the treatments of drip irrigation succeeded in leaching salt downwards till 30- 35 cm depth, while accumulation of salts tock place at the end of the season for drip treatment at 35-40 cm depth.

El-Kobia et al. (1986) stated that the electrical conductivity increased with the radial distance from the emitter forming an isolated pocked with the accumulated salts through the wetted zone. The salt distribution is uniform near the middle and bottom of furrow side. However the pattern of electrical conductivity increased toward the top of furrow.

Hamdy (1992) mentioned that the analysis of salt accumulation through the soil profile at different distances from sources showed that movement of salt further from the water sources under both drip and furrow irrigation methods. Under drip method, the variations between different points of soil profile were more pronounced as compared to the furrow one.

Helmy et al. (2000) stated that the soil salinity increased by increasing soil depth after irrigation but before the next irrigation, the soil salinity decreased by increasing depth under furrow irrigation system. Under drip irrigation system the soil salinity increased by increasing the distance from emitter in both vertical and horizontal direction.

Metwally (2001) claimed that under surface and subsurface drip irrigation systems salt concentration increased with depth and with distance far from point source (emitter), also salt concentration in the soil profile was less under irrigation at 80% of available soil water treatment than irrigation at 60 % of available soil water treatment.

Mehawed (2002) concluded that the highest values of salt accumulation occurred when applying 50% of crop evapotranspiration for both surface and subsurface drip irrigation systems, comparing with 75 % and 100 % of crop evapotranspiration. Also added that less salt concentration when using lower rate of fertilization and more water application, however yield response was related to medium or high rates of fertilizer application.

2.9. Irrigation systems effect on yield and water use efficiency:

Baker and Shakshook (1977) concluded that the drip irrigation system had better vegetative growth of tomato plants than both sprinkler and the furrow irrigated ones. It might be due to relatively high amount of water in the root zone, more water penetration, less evaporation losses, less salinity and better aeration. Tomato yield was increased by 15 % through drip irrigation method over that the other two methods.

El-Gindy (1984) compared the effect of furrow and drip irrigation system on water use efficiency for sweet paper. Average yields of both furrow and drip irrigation was 2.35 and 2.75 Mg/fed of the experimental plot, respectively. The water use efficiencies were 3.21 and 5.8 kg/m^3 under both furrow and drip irrigation, respectively.

El-Berry et al. (1989) found that water use efficiency was the highest in case of subsurface drip method (5.93 kg/m^3) which was approximately twice and seven times of sprinkler and basin methods, respectively, in case of alfalfa production under desert conditions.

Abdel-Maksoud et al. (1992) studied the effect of drip, sprinkler and furrow irrigation systems on tomato yield under new land conditions. The results indicated that yield under drip irrigation systems (20 Mg/fed.) increased by 19.36% than that under sprinkler irrigation system (16.8 Mg/fed.) and by about 13.6% than that under furrow irrigation system (17.6 Mg/fed.). Meanwhile, water use efficiency was increased by about 19.34 and 14.4 % than the sprinkler and furrow irrigation systems respectively.

Mohamed (1995) noticed that the use of drip irrigation for cucumber plant highly increased water use efficiency as compared to furrow method. He concluded that drip irrigation is considered as the very suitable method for water management to obtain the highest yield and to save more water.

Kassem (2000) found in a comparative study for the effect of subsurface drip, surface drip and furrow irrigation on the growth of sunflower crop. The resulted revealed that the maximum crop yield was 1.23 Mg/fed. for subsurface drip laid at 30 cm depth ،while the minimum value was 0.98 Mg/fed. for subsurface drip laid at 40 cm depth.

El-Nemr (2002) concluded that increasing operating pressure head at drip irrigation system increased corn crop yield and water use efficiency. The highest crop yield and water use efficiency values were 10.08 Mg/fed and 0.00545 Mg/m^3 respectively under long path emitter at 12 m operating pressure and two days intervals, while the some values for surface irrigation were 7.883 Mg/fed. and 0.000292 Mg/m^3 respectively.

2.10. Fertigation effect on yield and water and fertilizer use efficiency:

Bakker et al. (1984) showed that the yield of lettuce was significantly higher when nitrogen was applied by fertigation comparing with broadcast fertilization at the same level of nitrogen. Moreover, nitrogen fertigation increased both the uptake of nitrogen by lettuce plants and nitrate content of the crop.

Bravdo and Hepmer (1987) reported that availability of nitrogen and potassium fertilizers were increased by fertigation and this was reflected in improved yields of graps compared with broadcasting.

El-Gindy (1988) found that fertigation of N fertilizer increased the yield of tomato by 16.1 %, 23.8 % and 35.1 % under furrow, sprinkler and drip irrigation methods respectively comparing with traditional method of fertilizer application.

Gascho (1991) reported that drip fertigation require less phosphorus than other application methods to achieve comparable tissue phosphorus concentration and yields, concentration effected by the placement of phosphorus in the rooting zone of tomatoes.

Hamdy (1991) concluded that fertigation at each irrigation resulted in a notable increase in tomato production which is nearly 70 % greater than that obtained with conventional methods of N applications.

Threadgill et al. (1995) compared the onion production under different irrigation systems, surface drip irrigation- GR, pivot, solid set sprinkler, and furrow irrigation. The results indicated that fertigation with completely soluble fertilizers increased crop yield by about 17 % more than the case of using conventional fertilizers using the some irrigation systems.

Abdel-Aziz (1998) reported that generally completely soluble fertilizers produced higher yield comparing with traditional fertilizers under different modern chemigation systems, whereas fertigation via drip irrigation increased onion by 20.1 %. Also find that in injection the fertilizers through irrigation water produced 23.4 % more in yield than that when using the conventional methods of fertilization under both GR and Bi- wall drip irrigation systems. Water and fertilizer use efficiencies increased by 26.1, 30.4 and 37.7 % at venturi, diaphragm and electrical injection pumps comparing with fertilizer tank respectively.

El-Sayed and El-Araby (1998) found that pea steam length under the fertigation (76.04 cm) was longer than that under the broadcasting (65.14 cm) by 17 %, also pods and branches per plant increased. Yields of peas under fertigation increased by 28.3 % comparing with broadcasting. Fertigation increased nitrogen and water use efficiency by 29.4 % and 28 % respectively comparing with broadcasting.

Guertal (2000) found that using ammonium nitrate by fertigation increased bell pepper yield by 20.7 % comparing with broadcasting sulfur-coated urea, also bell pepper yield increased by 72 % comparing with control treatment (zero nitrogen).

Metwally (2001) studied effect of fertigation on squash under surface and subsurface drip irrigation. He found that fertigation increased fruit diameter and number of fruit per plant by 13.7 %, 33.25 %, 12.75 % and 20.3 % for surface and subsurface drip irrigation respectively comparing with broadcasting. Also fertigation increased crop yield by 18.4 % and 21.2 % for surface and subsurface drip respectively. Water and fertilizer use efficiency for fertigation methods increased by 16.4%, 20.7%, 27.1% and 27.5% for surface and subsurface drip comparing with broadcasting.

Lamm et al. (2001) stated that corn yields were affected significantly by different factors (irrigation regime, injected- nitrogen rate, and preplant-applied nitrogen rate). The interaction between injected nitrogen and preplant-applied nitrogen had statistically significant effects on yields. On the other hand they reported that, there was no statistically significant increase in yields attributable to the fertilization method (injected- nitrogen with the subsurface drip irrigation or surface applied preplant nitrogen banded in the furrow.

Mohamed (2001) reported that application of fungicide (Topsin-M WP70) with drip irrigation system increased seed yield of sunflower by 9 % in sandy comparing with the general mean production by the Ministry of Agriculture. Also water use efficiency increased reached 0.331 kg/m^3 at the same conditions.

Sultan (2001) concluded that acidification of irrigation water caused a marked increased in some growth parameters, total yield and water use efficiency for pea crop, while solid sources of fertilizers caused a marked decrease in both yield and irrigation system efficiency.

3. MATERIALS AND METHODS

The field experiments were carried out at the research farm of Rice Mechanization Center (RMC), Meet, El-Deeba, Kafr El-Sheikh Governorate during the sowing cultivation season of 2003. The aim of the present work was to improve and increase the efficiency of fertigation methods under different irrigation systems. Soil samples from the experimental field were collected from different soil depths, 15cm each down to 60 cm and mechanical analysis was carried out in laboratory of soil, water and environment laboratory, Kafr El-Sheikh governorate, to obtain the soil texture. The soil texture was clayey as shown in Table 1.

Table 1: Some physical analysis of experimental site:

Soil depth, cm	Particle size distribution, %			Texture	Bulk density, g/cm^3	Field capacity, %	Wilting point, %
	Sand	Silt	Clay				
0-15	20.6	24.3	54.8	Clay	1.10	40.2	18.5
15-30	23.4	19.2	55.15	Clay	1.21	38.3	17.6
30-45	22.09	21.0	55.0	Clay	1.28	37.1	16.0
45-60	20.25	20.73	56.25	Clay	1.30	36.6	15.4
Average	22.09	21.3	55.3	Clay	1.22	38.05	16.9

3. 1. Experimental layout:

Maize TWC 310 variety was used in the present study. The field was ploughed by a seven mounted shares chisel plough which mounted on Naser tractor 48.49 kw (65 hp), the average value of ploughing depth was 20 cm, traditional leveling was used. All agricultural practices were the same as recommended for the area except fertilization and irrigation treatments under study. The furrow was designed to be 0.7 m spacing and 20 m length. The maize was planted manually in June 10, 2003 with one plant per hill, and 30 cm spacing between hills within the row. 100 P_2O_5 units (Calcium super phosphate 16 % P_2O_5) per fed. were added before planting. 120 N units (Urea 46.5% N) per fed. were used as a fertilizer by fertigation methods under study. Hoeing, thinning and weed control were practiced manually before the first irrigation (21 days after planting irrigation).

3.2. Treatments:

The experiments was arranged in split- split plot design as shown in Fig. 7. The main plots were assigned to three irrigation systems, while the sub plots were three fertigation methods and sub sub plots were four operating pressures.

3.2.1. Main treatments:

The main treatments included three irrigation systems as follows:

(a) Surface drip irrigation **(SD),**

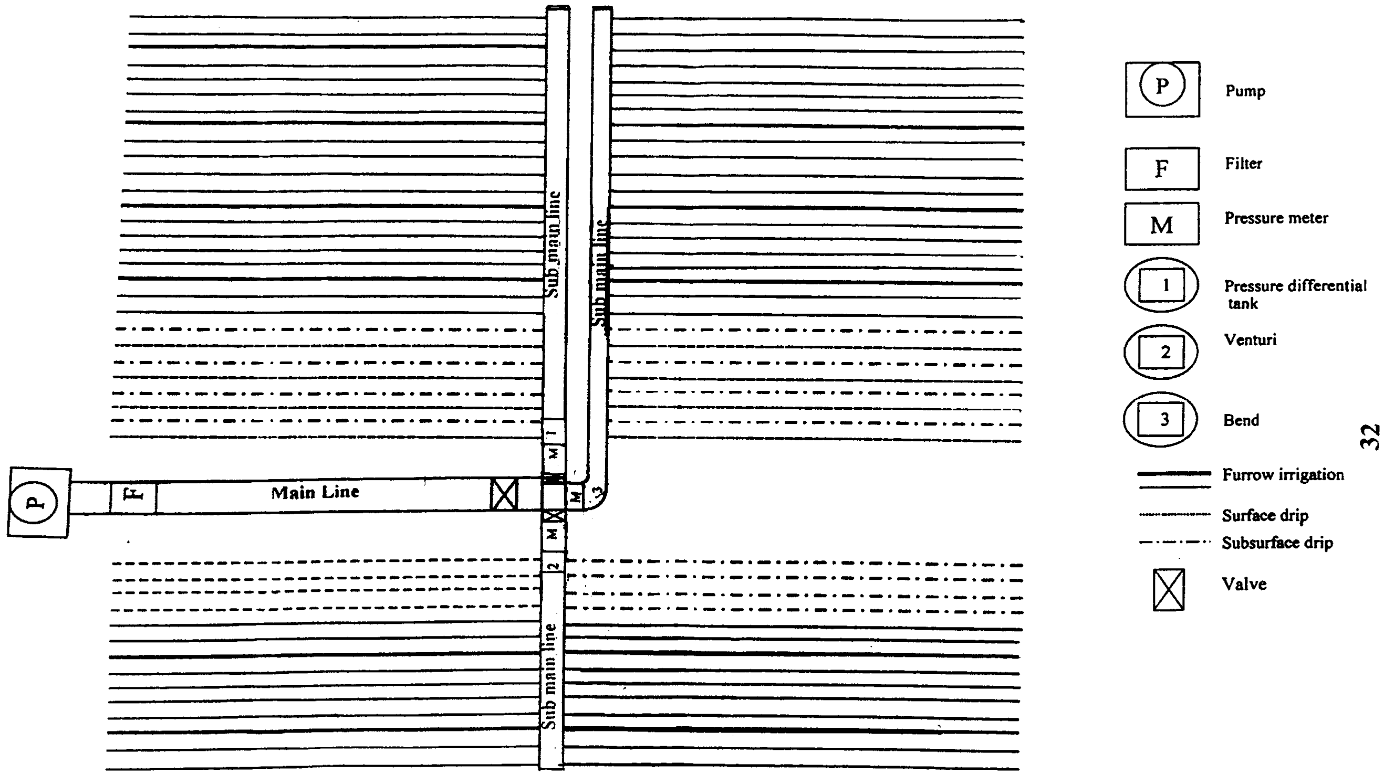


Fig 7: Schematic diagram showing experiment layout

(b) Sub-surface drip irrigation **(SSD)**, and

(c) Furrow irrigation with perforated pipes **(FI)**.

3.2.2. Sub treatments:

The sub treatments included three of fertigation methods as follows:

(a) Pressure differential tank **(PD)**,

(b) Venturi **(V)**, and

(c) Bend **(B)**.

3.2.3. Sub-sub treatments:

It had four different operating pressure heads, 2, 6, 10 and 14 m of water head respectively.

3.3. Irrigation system and its components:

The irrigation system consisted of the following components:

A) The pump:

A centrifugal pump with 3.8 kw (5 hp) gasoline engine was used to provide a sufficient discharge (900 l/min) and 26 m pressure head at 3600 r. p. m.

B) The control unit:

It consists of the following

- Screen filter 250 mesh,
- Valves to control pressure head and water flow,
- Pressure gauges 0.5 m head accuracy.

C) Fertigation unit:

It consists of three different fertigation units as follows,

- Pressure differential tank:

Fig. 8 indicates the fertigation unit of pressure differential tank. It consists of plastic tank one liter capacity and connected to the irrigation line by using hose 12.5 mm diameter through two control valves (one at inlet and the other at outlet).

- Venturi:

Fig. 9 indicates the fertigation unit of venturi. It consists of a cylindrical entrance section 25 mm diameter, cylindrical throat section 12.5 mm diameter and diffuser section 25 mm diameter. Plastic tank one liter capacity connected to the venturi using hose 12.5 mm diameter through control valve at absorption line. Venturi unit connected to the irrigation line by using 25 mm through two control valves (one at inlet and the other at outlet).

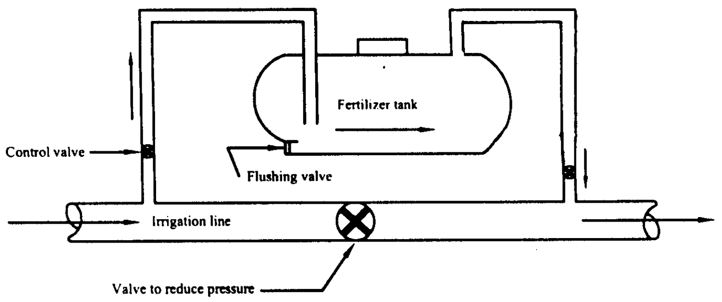


Fig. 8: Schematic diagram showing pressure differential tank.

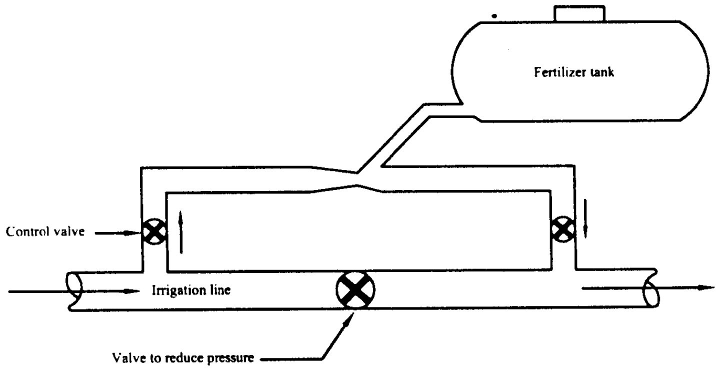


Fig. 9: Schematic diagram showing venturi injection device.

- **Bend:**

Fig. 10 indicates the fertigation unit of bend. It consists of an iron curvatured pipe 38 mm diameter, 30 cm radius of curvature, two 12.5 mm by-pass orifice sizes (one for inlet and other for outlet) and double crests 12 mm length emerged on both inner and outer walls of a bend. Plastic tank one liter capacity connected to the bend by using hose 12.5 mm diameter through two control valves (one at inlet and the other at outlet).

D) Pipe lines:

1- Main line:

Polyethylene pipe 76 mm diameter was used and provided by 76 mm control valve to control of operating pressure.

2- Sub main line:

Polyethylene pipe 38 mm diameter was used and provided by 38 mm control valve to control of operating pressure.

3- Lateral line:

Poly ethylene lateral 16mm diameter and 20 m length was used. Fig. 11 indicates emitter G.R. type having 4 l/h theoretical flow rate at 13 m operating pressure head located at 30 cm spacing along the lateral line. Sub surface drip laterals were the same as surface drip and buried at 0.2 m depth from soil surface as recommended by **Hassan and Bakeer 1994**.

Each lateral line was connected to the sub main line through a ball valve.

E) Furrow irrigation:

Every treatment consists of five furrows with 70 cm spacing, 20 m length and 0.1 % slope. The water was delivered to every furrow across opening of 2.5 mm diameter on perforate tube 37.5 mm diameter.

3.4. Irrigation requirements

Potential evapotranspiration for corn crop was calculated using CROPWAT computer program that was depending on penman equation. Climatic data were collected from Sakha weather station during period from June to September for the years 2001 and 2002. Table 2 summarized the obtained data from CROPWAT program.

Gross irrigation requirements were calculated as follows.

- **Crop evapotranspiration (ETcrop):**

It was calculated by using the following equation **(James, 1988).**

$$ET_{crop} = K_c * ET_o \qquad \text{..........3.1}$$

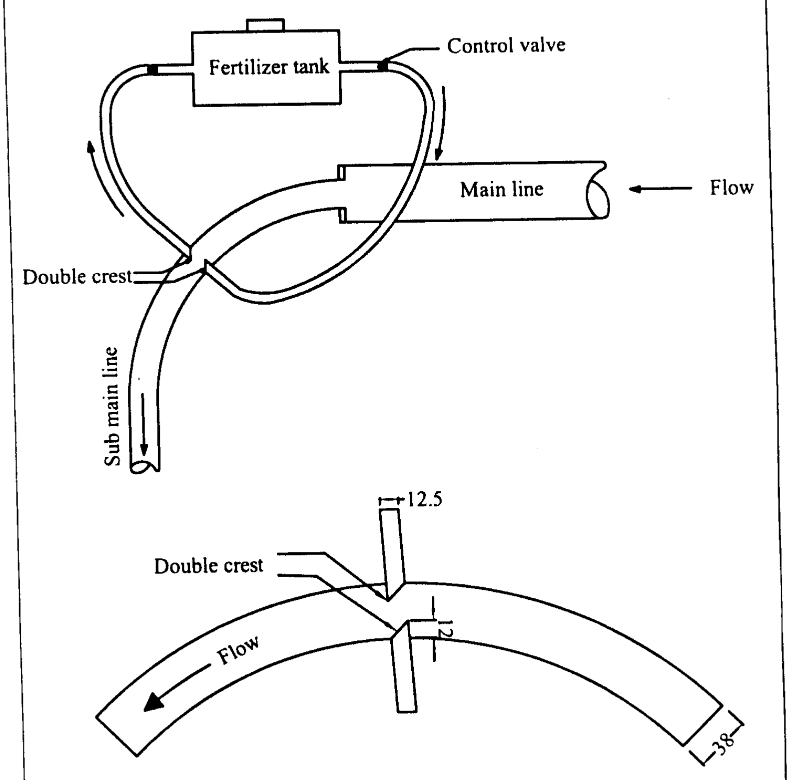


Fig. 10: Schematic diagram showing bend injection device. (Dim. in mm)

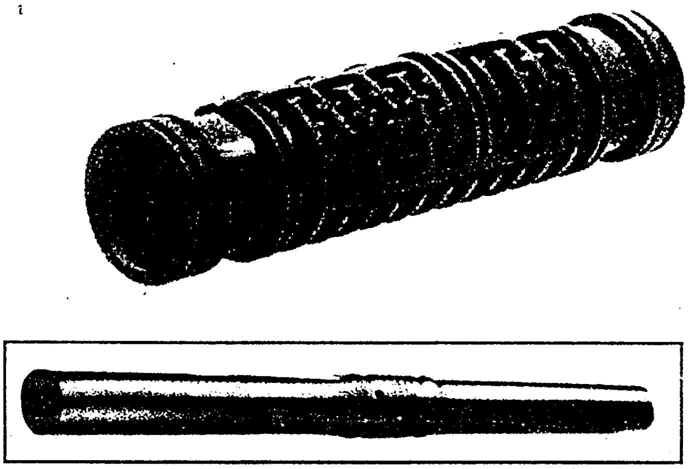


Fig. 11: G. R. emitter type.

Where:

K_c = Crop factor (0.55- 1.05) for corn according to the months withing growing season, and

ET_o= Potential evapotranspiration (mm/day) which was calculated depending on climatic data

Table 2: Climatic data and potential evapotranspiration.

Month	Air temperature, ˚C		Relative Humid, %	Wind speed, km/h	Solar Rad. $MJ/m^2/day$	Pot. Evap (ET_o) mm/day
	Max.	Min.				
June	32.3	18.4	63.3	68	24	5.6
July	34.4	21.0	67.6	51.2	20.8	5.4
August	33.6	20.3	65.3	52.1	19.4	5.0
September	34.0	19.8	61.4	52.1	17.6	4.0
Mean	33.6	19.9	64.4	55.9	20.5	5.0

- Net irrigation requirement (IRn):

It was calculated by using the following equation **(FAO, 1976).**

$$IR_n = ET_{crop} + L_r \qquad \text{.......3.2}$$

Where:

L_r = Leaching requirements, mm/day. It was calculated as follows **(FAO, 1976)** and **(James, 1988).**

$$L_r = \frac{EC_i}{EC_d} \qquad \text{.......3.3}$$

Where:

EC_i = Electric conductivity for irrigation water, mmhos/cm, and

EC_d = Electric conductivity for drainage water, m mhos/cm

- Grass irrigation requirements (IRg):

It was calculated by using the following equation **(FAO, 1980).**

$$IR_g = \frac{IR_n}{E_a} \qquad \text{.......3.4}$$

Where:

E_a = Irrigation system efficiency, assumed 80 % for drip irrigation as recommended by **(Habib, 1992).**

Experimental irrigation started after 21 days of planting, July 1, 2003. Drip irrigation treatments were irrigated twice weekly as recommended by

(**El-Nemr, 2002**), for furrow irrigation the intervals were 15 days, irrigation stopped in September 30, 2003 for different irrigation systems.

For drip irrigation, the relationship between emitter flow rate and pressure head for G.R. emitter type is calculated by **El- Nemr (2002)** according to **Keller and Karameli equation (1974)** as follows.

$$q = 0.66h^{0.70} \qquad \text{.......3-5}$$

Where:

q = Emitter flow. l/h. and

h = Pressure head, m.

For furrow irrigation, flow rate was calculated by calibration method, where a constant volume of water received from the perforation (liter), and the time required for receiving this volume was calculated by using stop watch (sec), this calibration was repeated many times for every operating pressure head during irrigation process.

- Fertilizer application:

120 kg N/fed. (Urea 46.5% N) was divided into 6 doses and added with irrigation water at concentration of 780 g/l as recommended by **(Threadgill et al., 1990)** by using the previous mentioned fertigation methods as follows: in drip irrigation one does every 2 week and every irrigation time with furrow irrigation started from Jule 1, 2003.

3. 5. Statistical analysis:

Split- split plot design was as statistical analysis with independent variables root volume, corn crop yield, water use efficiency and nitrogen use efficiency. The main plot was irrigation system, sub plot was fertigation method and sub-sub plot was operating pressure head. Split plot design was used as statistical analysis with independent variable water distribution uniformity, fertilizer distribution uniformity and pressure difference. The main plot was irrigation system and sub main plot was operating pressure head, while for fertilizer distribution uniformity and pressure difference the main plot was fertigation method and sub main plot was operating pressure head. The mean values were compared by L. S. D. test.

3.6. The previous factors affected the following:

3.6.1. Soil moisture distribution:

Soil samples were taken to determine soil moisture content. For drip irrigation, the soil samples were taken in two direction with the soil depth. The first direction was along the lateral line at 0, 5, 10 and 15 cm from emitter. The second was perpendicular the laterals at 0, 5, 10, 15 and 25 cm from the emitter. The soil samples were taken at the different soil depths as follows: 0, 15, 30, 45 and 60 cm.

For furrow irrigation, soil samples were taken at depths of 0, 15, 30, 45 and 60 cm from three different locations of the furrow 5, 10 and 15 m from water inlet. Soil samples were weighted by an electronic balance, dried in oven at 105°C for 24 h and weighted after drying again. Moisture content was measured gravimetrically on a dry basis.

3. 6. 2. Salt distribution:

Soil samples were taken to determine soil salinity. For drip irrigation, the soil samples were taken in two directions with the soil depth. The first direction was along the lateral line at 0, 5, 10 and 15 cm from emitter. The second was perpendicular the laterals at 0, 5, 10, 15 and 25 cm from the emitter. The soil samples were taken at the different soil depths as follows: 0, 15, 30, 45 and 60 cm.

For furrow irrigation, soil samples were taken at depths of 0, 15, 30, 45 and 60 cm from three different locations of the furrow 5, 10 and 15 m from water inlet. Distilled water was added to 200g. of air- dry soil and stir the mixture with a spatula until a condition of saturation is reached. After allowing the saturated soil paste to stand 4 or more hours, it transferred to filter funnel fitted with low-ash, highly retentive filter paper, then 0.1 % sodium hexametaphosphate solution for each 25 ml. of extract was added.

Total soluble salt were determined in the collected samples using the electrical conductivity meter (EC- meter).

3.6.3. Water distribution uniformity:

Distribution uniformity of irrigation water for different irrigation systems was evaluated by using the Christiansen uniformity coefficient **(Cu)** **(James, 1988)**:

$$Cu = 100\ (1.00 - \frac{\sum |d|}{n\bar{X}}) \quad \text{......3.6}$$

$d = x_i - \bar{x}$

Where:

x_i = Depth/ caught volume / infiltrated at observation point i,

$\grave{x}$ = Average depth/volume amount caught/ infiltrated and

n = Number of observations.

3.6.4. Fertilizer distribution uniformity:

Laboratory experiment was carried out in water Management Research Institute, Kafr El-Sheikh Governorate to determine the relationship between fertilizer concentration (g/l) and electrical conductivity (mmhos/cm). The following equation was obtained to describe this relationship.

$$EC = 0.4398\, e^{-0.0007X} \quad \text{..........3.7}$$

Where:

EC = Electrical conductivity, mmhos/cm, and

X = Fertilizer concentration, g/l.

Statistical uniformity of fertilizer under drip line was evaluated by using the following equation **(Bralts et al., 1987)**:

$$U_s = 100\left(1 - \frac{Sq}{\grave{q}}\right) \quad \text{..........3-8}$$

Where:

U_s = The statistical uniformity coefficient, %

Sq = The sum of absolute deviation of each sample from the mean (g/l), and

$\grave{q}$ = The mean of solution concentration ,g/l.

3.6.5 Pressure difference (ΔP):

Pressure difference in sub main line which caused across fertigation unit has been used to describe the loss in operating pressure which caused by fertigation unit, this loss led to decrease in discharge. Pressure difference was measured by installing pressure gauge (kg/cm^2) before fertigation unit and other after it. Pressure difference percentage was calculated using the following equation:

$$\Delta P = (A - B)/A \quad \text{..........3.9}$$

Where:

ΔP = Pressure diffeence, %;

A = Pressure head before fertigation unit, m and

B = Pressure head after fertigation unit, m. (Pressure head, m = 10^{-1} kg/cm^2).

3.6.6. Fertilizer concentration change:

Fertilizer concentration change during irrigation time has used to describe fertilizer behaviour along irrigation time, where uniformity of fertilizer concentration show relability of fertigation unit to use and obtainment maximum benifit of fertilizer. Irrigation water samples were taken every five minutes (for accuracy in results) during fertigation process to measure fertilizer concentration. E.C. meter was used to measure electrical conductivity, and equation 3.7 was used to calculate fertilizer concentration.

3.6.7 Corn crop yield and its components:

3.6.7.1. Root volume:

Root volume indicates the limit of the plant's activity, in taking up nutrients and moisture. Root volume determined by excavation method according to **(Schuurman and Goedewaagen, 1971)**. Rectangular iron frames were used, these frames had a length of 30 cm, width of 70 cm and a hight of 60 cm. The bottom edge was sharpened, the frame was pushed vertically into the soil, then excavated and washed. Root volume determined from the volume of water displaced by immerising the root sample in the graduated cylindrical beaker filled with tap water.

3.6.7. 2. Corn crop yield:

Ten plants from each treatment were chosen to determine the corn yield per plant (Mg). The average corn yield per feddan was obtained by multiplied the corn yield per plant by number of plants per feddan.

3.6.7.3. Water use efficiency (WUE):

Water use efficiency has been used to describe the relationship between corn crop production and the total amount of water used. It was determined according to **James, 1988** by using the following equation:

$$WUE = \frac{Y}{W_a} \qquad \text{..... ....} 3.10$$

Where:

WUE = Water use efficiency, kg/m^3,

Y = Total yield, kg/fed; and

W_a = Total applied water, m^3/fed.

3.6.7.4. Nitrogen use efficiency (NUE):

Nitrogen use efficiency has been used to describe the relationship between corn crop production and the total amount of nitrogen used. It was calculated according to the following equation:

$$NUE = \frac{Y}{N_a} \qquad \text{......3.11}$$

NUE = Nitrogen use efficiency, Kg. y/kg N,

Y = Total yield, kg/fed, and

N_a = Total applied nitrogen fertilizer, kg N/fed. (120 N unit/fed.).

4. RESULTS AND DISCUSSION

4. 1. Applied irrigation water:

The number of irrigations during the whole season were seven undr furrow irrigation and twinty six under drip irrigation in addition to sowing irrigation. Daily gross irrigation requirement (liter) for drip irrigation during period from July 1, 2003 to September 30, 2003 and total water applied, m^3/fed were summarized in table 3.

Table 3: Gross irrigation requirement, l/day/plant.

Month	July	August	September
Daily requirement l/day/plant	1.1	1.33	0.98
Total water applied m^3/fed	2037		

Under furrow irrigation the relationship between operating pressure head, flow rate and advance time every month during experiment period were summarized in table 4.

Table 4: Flow rate l/Sec., advance time (min) and total water applied (m^3/fed) under furrow irrigation

Operating pressure head, m	Flow rate l/Sec.	Month	Distance from water inlet, m					Applied water, m^3/fed
			4	8	12	16	20	
			Average of advance time, min					
2	2.2	July	2.5	5.0	7.6	9.8	12.5	980
		August	2.0	4.3	6.7	8.8	10.8	860
		September	2.0	4.0	6.5	8.3	9.5	760
Total water applied, m^3/fed			**2600**					
6	3.8	July	1.5	3.2	4.8	6.1	7.3	988
		August	1.3	2.6	3.8	4.8	6.3	870
		September	1.2	2.2	3.4	4.1	5.6	767
Total water applied, m^3/fed			**2625**					
10	5.1	July	1.2	2.5	3.2	4.0	5.75	1050
		August	1.0	2.0	3.2	4.0	5.0	912
		September	0.75	1.5	2.3	3.0	4.0	728
Total water applied, m^3/fed			**2690**					
14	6.0	July	1	2	3.1	4.1	5.2	1120
		August	0.75	1.5	2.5	3.5	4.4	955
		September	0.5	1.25	2.0	2.75	3.3	716
Total water applied, m^3			**2791**					
Average of Total water applied, m^3			**2676**					

The results showed that drip irrigation saved about 639 m^3/fed. (23.9 %) comparing with furrow irrigation method , where the amount of applied irrigation water under drip irrigation was 2037 m^3/fed., these results are in agreement with **El-Gindy (1988)**.

Under furrow irrigation, increasing operating pressure head tended to increasing the total irrigation water because run off and drainage losses increased by increasing operating pressure head where discharge increased.

The analysis of variance table 9 and 10 in appendix indicated that, the irrigation method and operating pressure head in addition their interaction had a highly significant effect on the amount og irrigation wate per feddan.

4. 2. Soil moisture distribution:

Figures 12, 13, 14, 15 and 16 showed the soil moisture distribution through the soil profile under different irrigation systems and different operating pressures.

The results indicated that in case of drip irrigation method (surface and subsurface) moisture content decreased at increasing the distance from drippers in both horizontal and vertical directions for the across and along laterals. Increasing operating pressure head tended to increase dripper discharge and increase soil moisture content in the horizontal direction more than the vertical direction because low infiltration rate in clayey soil, these results are in agreement with **Hassan (1987)**. The highest moisture content for surface drip was obtained in the surface layer (0) cm at 14m operating pressure head, while the highest value under subsurface drip was obtained in second and third layer (15 and 30) cm at the same operating pressure head (14 m). This is due to the depth of lateral line (20 cm). Soil moisture content under subsurface drip was higher than that of, the surface drip at different layers except the surface layer (0 cm), consequently the results indicated that, subsurface drip improved soil moisture and its distribution in clayey soil comparing with surface drip. these results are in agreement with **Metwally (2001)**.

For furrow irrigation method, the results revealed that, increasing operating pressure head tended to increase soil moisture content for its different layers, whereas irrigation water applied increased. The highest value of soil moisture content was obtained at 14 m operating pressure.

In general, soil moisture content before irrigation was higher for drip irrigation comparing with furrow irrigation, because of decreasing the irrigation intervals under drip irrigation which was 3 days but it was 14 days in case of furrow irrigation, as shown in Table 1, 2, 3, 4 and 5 in the appendix fore different irrigation methods and operating pressure head.

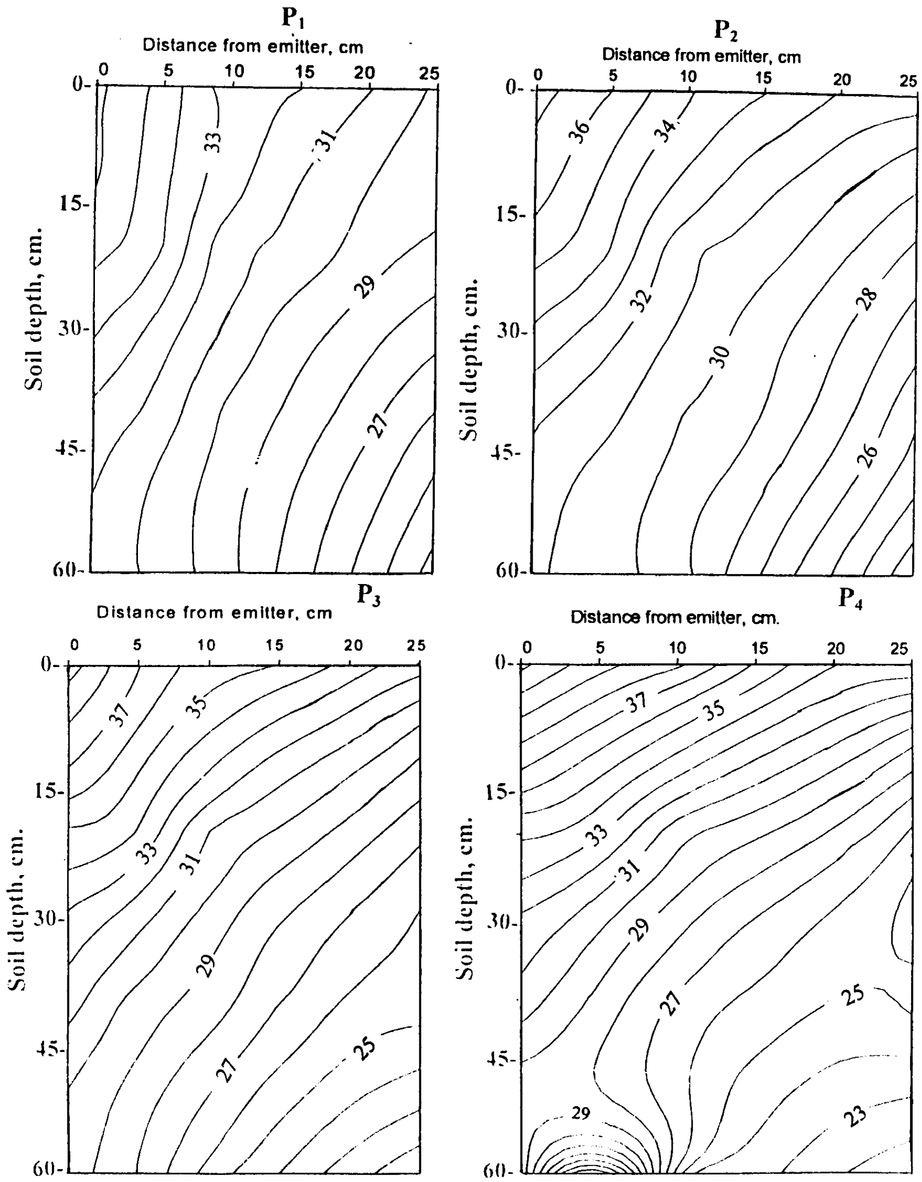


Fig.12: Soil moisture content (%) after irrigation across laterals for surface drip irrigation at different operating pressure head ($P_1 = 2$ m, $P_2 = 6$ m, $P_3 = 10$ m and $P_4 = 14$ m.)

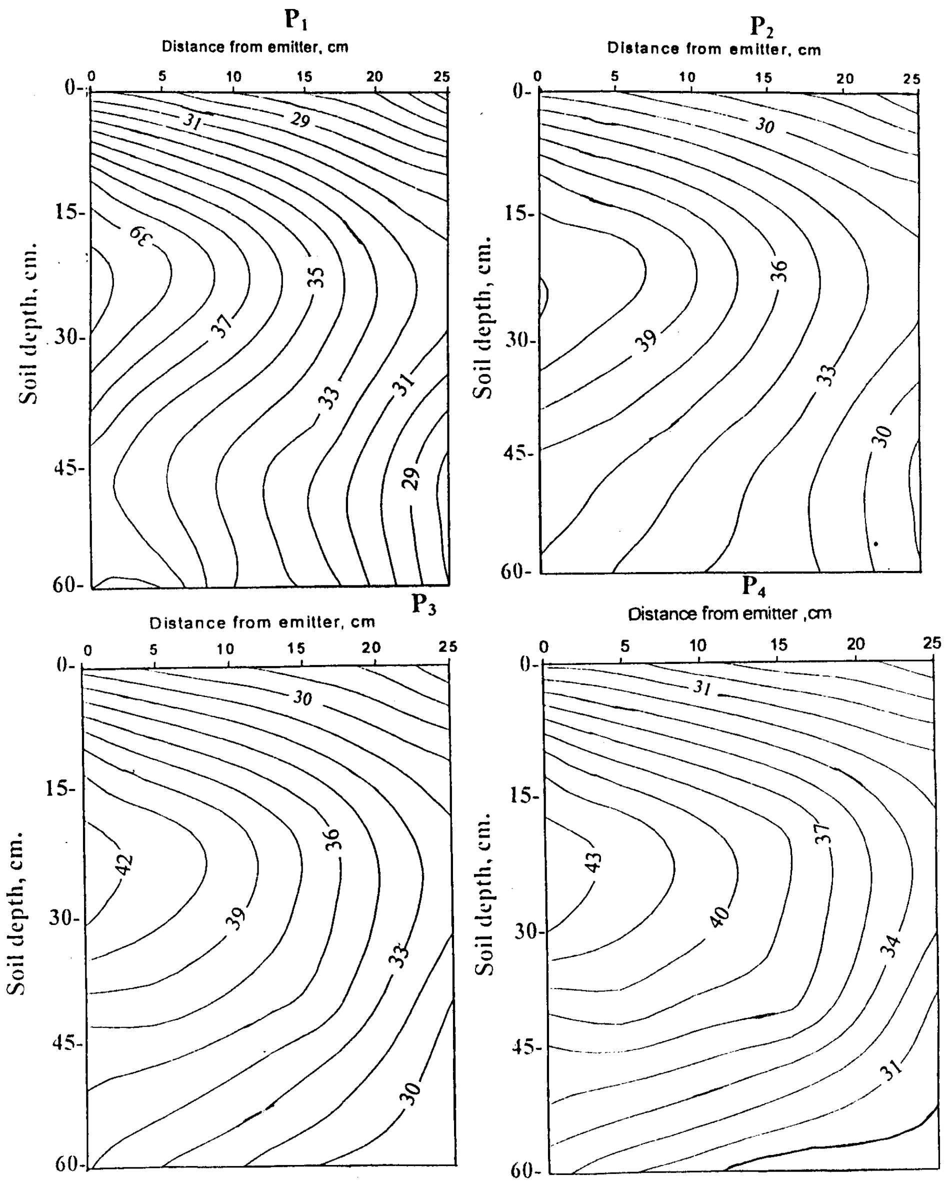


Fig.13: Soil moisture content (%) after irrigation across laterals for subsurface drip irrigation at different operating pressure head ($P_1 = 2$ m, $P_2 = 6$ m, $P_3 = 10$ m and $P_4 = 14$ m.).

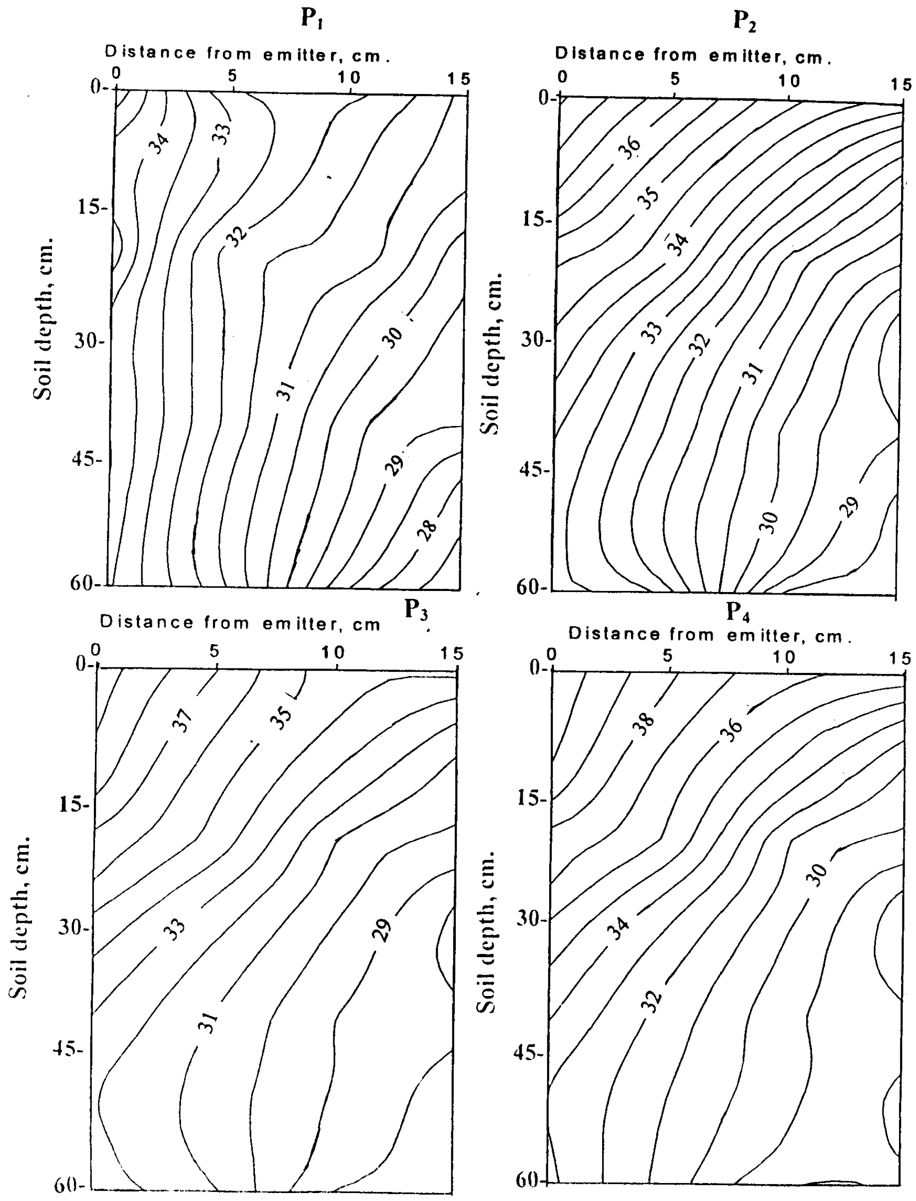


Fig.14: Soil moisture content (%) after irrigation along laterals for surface drip irrigation at different operating pressure head (P_1 = 2 m, P_2 = 6 m, P_3 = 10 m and P_4 = 14 m.).

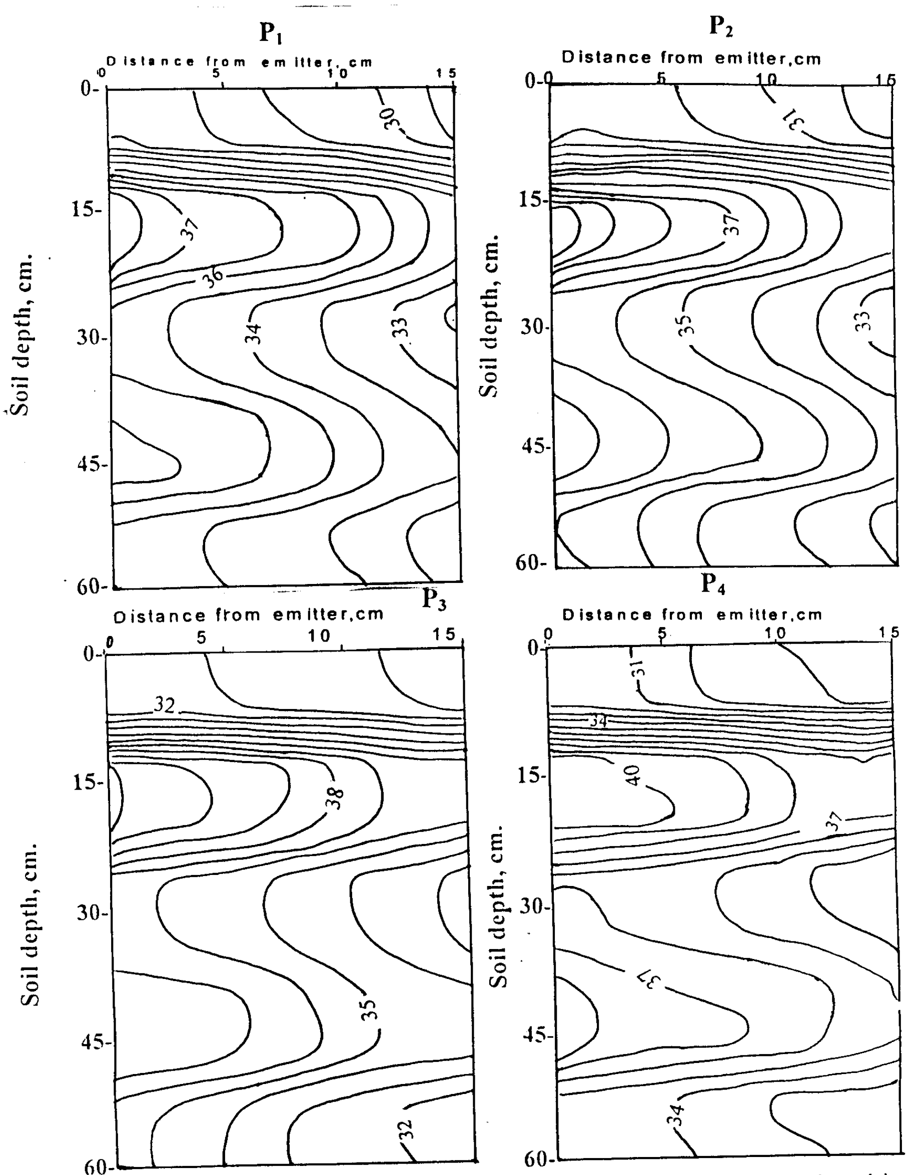


Fig.15: Soil moisture content (%) after irrigation along laterals for subsurface drip irrigation at different operating pressure head (P_1 = 2 m, P_2 = 6 m, P_3 = 10 m and P_4 = 14 m.).

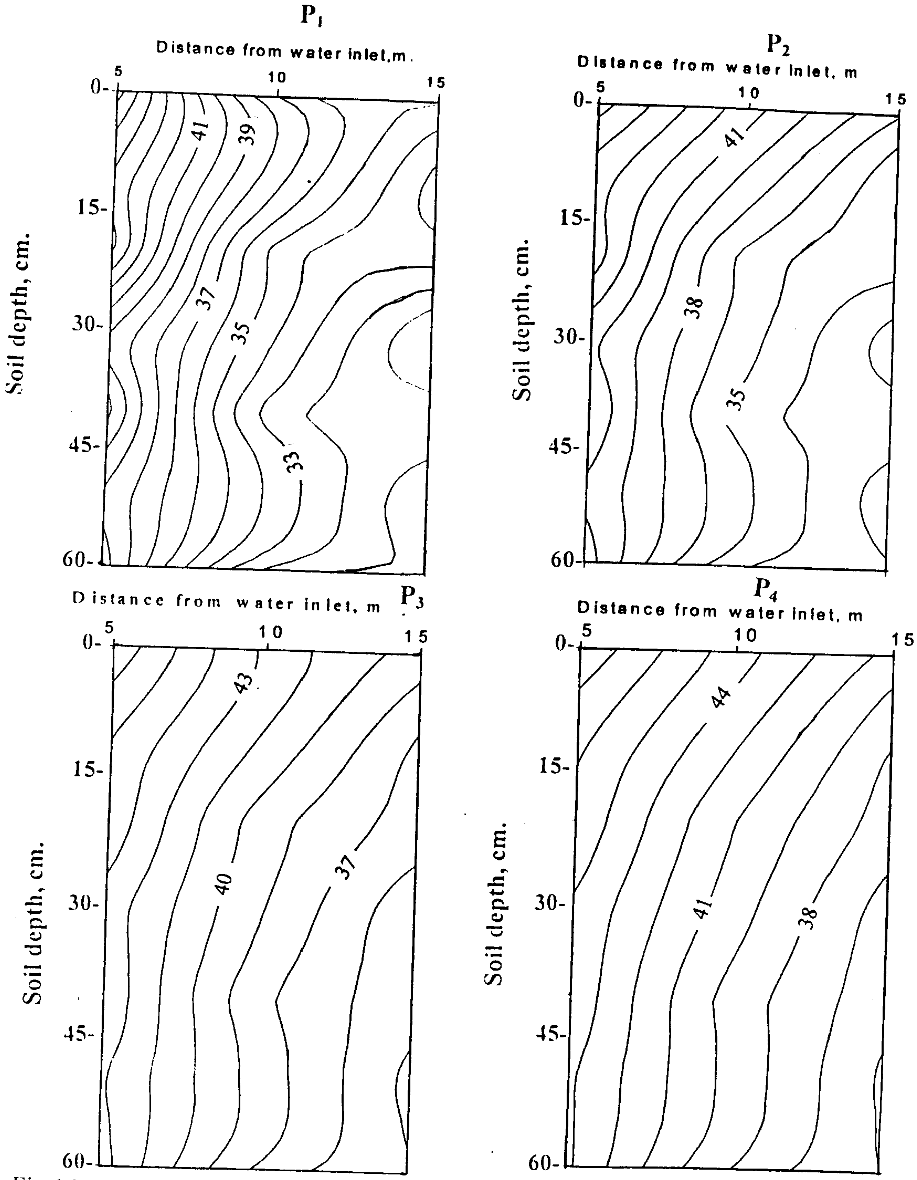


Fig.16: Soil moisture content (%) after irrigation for furrow irrigation at different operating pressure head ($P_1 = 2$ m, $P_2 = 6$ m, $P_3 = 10$ m and $P_4 = 14$ m.).

4. 3. Salt distribution pattern:

Figures 17, 18, 19, 20 and 21 indicate the salt distribution pattern under different irrigation methods at along and across laterals.

In case of drip irrigation methods salt concentration increased by increasing the horizontal distance from emitter at along and across laterals, while it decreased by increasing the vertical distance. Increasing operating pressure head tended to increase dripper discharge and decrease salt concentration. The lowest concentration of salt distribution was obtained with sub surface drip at 14 m operating pressure head and depths (15 and 30) cm where the lateral line was buried at 20 cm depth. While, the highest values were obtained with subsurface drip at 2 m operating pressure head at surface layer where low moisture content values. The salt concentration decreased with sub surface drip irrigation for all depths comparing with surface drip irrigation except surface layer this may be due to decrease soil moisture content for this layer. Salt concentration decreased by increasing operating pressure under surface drip.

For furrow irrigation method salt concentration decreased when operating pressure head is increased where, irrigation water applied increased. The maximum concentration was 4.4 mmhos/cm for surface layer at 2 m operating pressure head, while the minimum concentration was 2 mmhos/cm at 60 cm depth and 14 m operating pressure head. Salt concentration decreased with depth where evaporation decreased.

In general furrow irrigation method decreased salt concentration comparing with drip irrigation methods where total water applied increased. Also, the results revealed that the fertigation systems did not had an observed effect on the salt concentration and distribution, this is may be due to the type and quantity of fertilizer used and application period along the season, Table 6, 7 and 8 in appendix revealed the effect of different irrigation methods and operating pressure head on salt distribution.

4. 4. Water distribution uniformity:

Data presented in Table 5 and Fig. 22 showed that, the surface drip irrigation method has developed the water distribution efficiency compared with subsurface drip and furrow irrigation methods. These results are in good agreement with **Arnaout (1995 and 1997).**

The uniformity coefficient for surface drip irrigation increased by 1.16 and 18.8 % compared with subsurface drip and furrow irrigation respectively, where the average value of uniformity coefficient for surface drip was 90.52 %. The highest value of uniformity coefficient was 92.4 % for surface drip and 6m

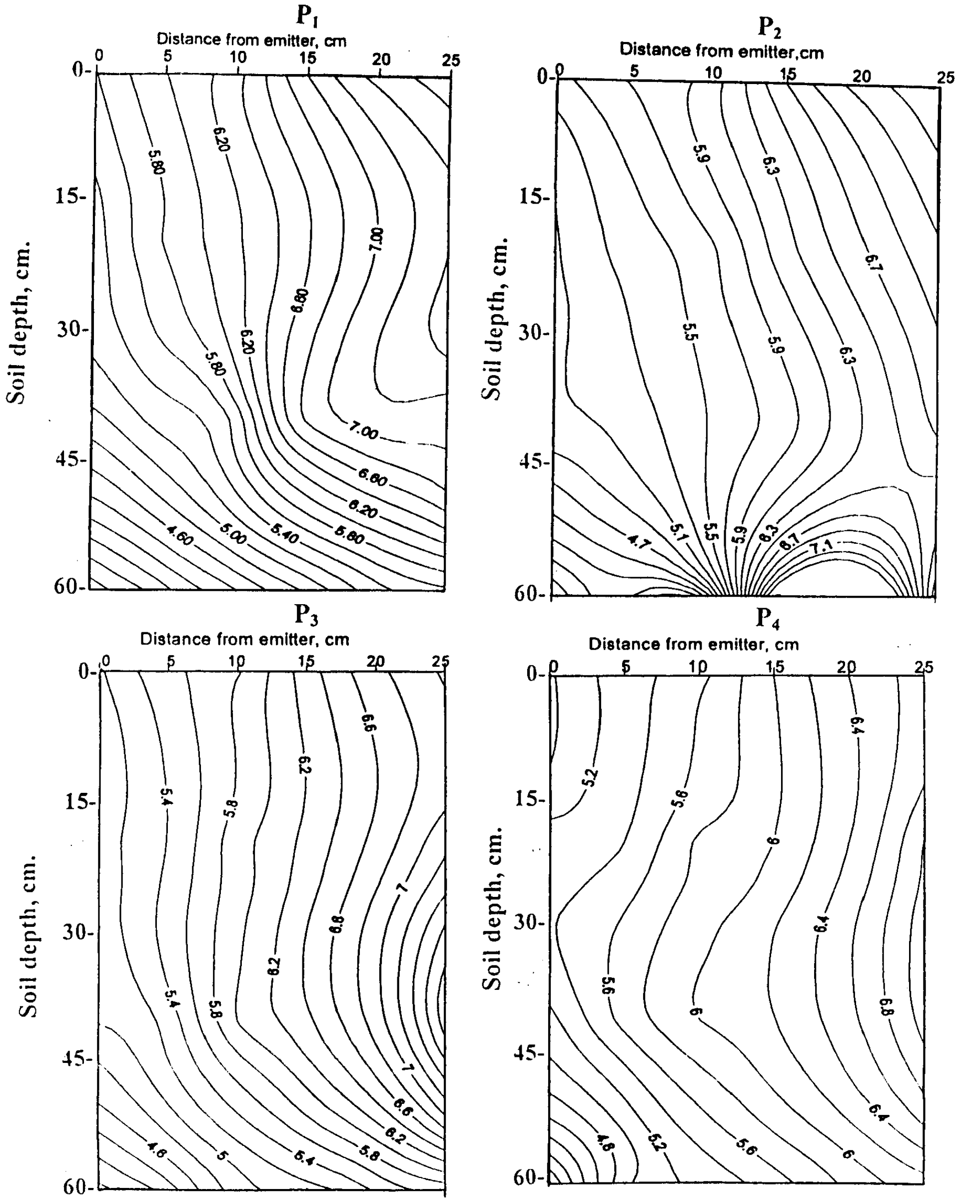


Fig. 17: Salt distribution (mmhos/cm) across laterals for surface drip irrigation at different operating pressure head (P_1= 2 m, P_2 = 6 m, P_3 = 10 m and P_4 = 14 m.).

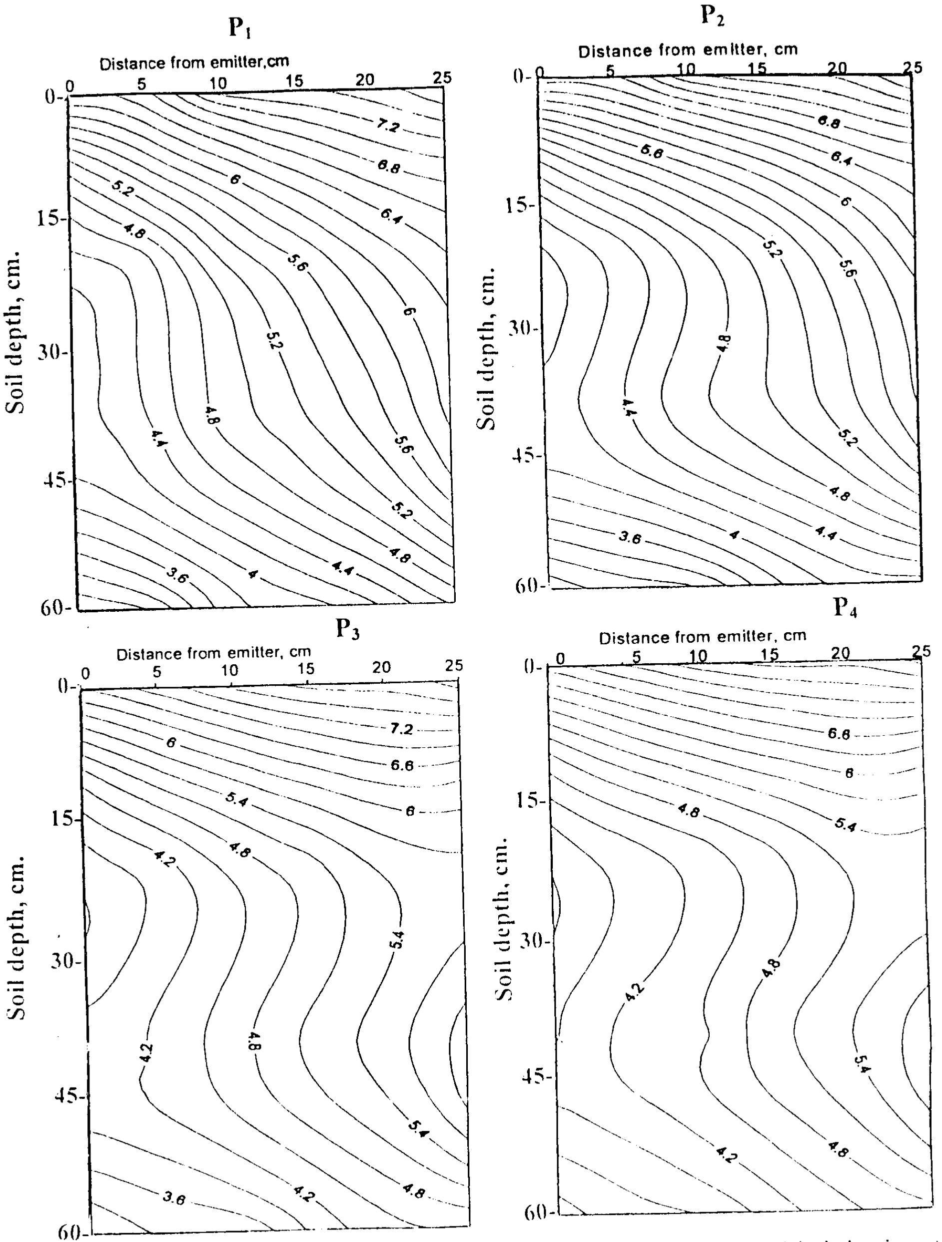


Fig. 18: Salt distribution (mmhos/cm) across laterals for subsurface drip irrigation at different operating pressure head (P_1 = 2 m, P_2 = 6 m, P_3 = 10 m and P_4 = 14 m.).

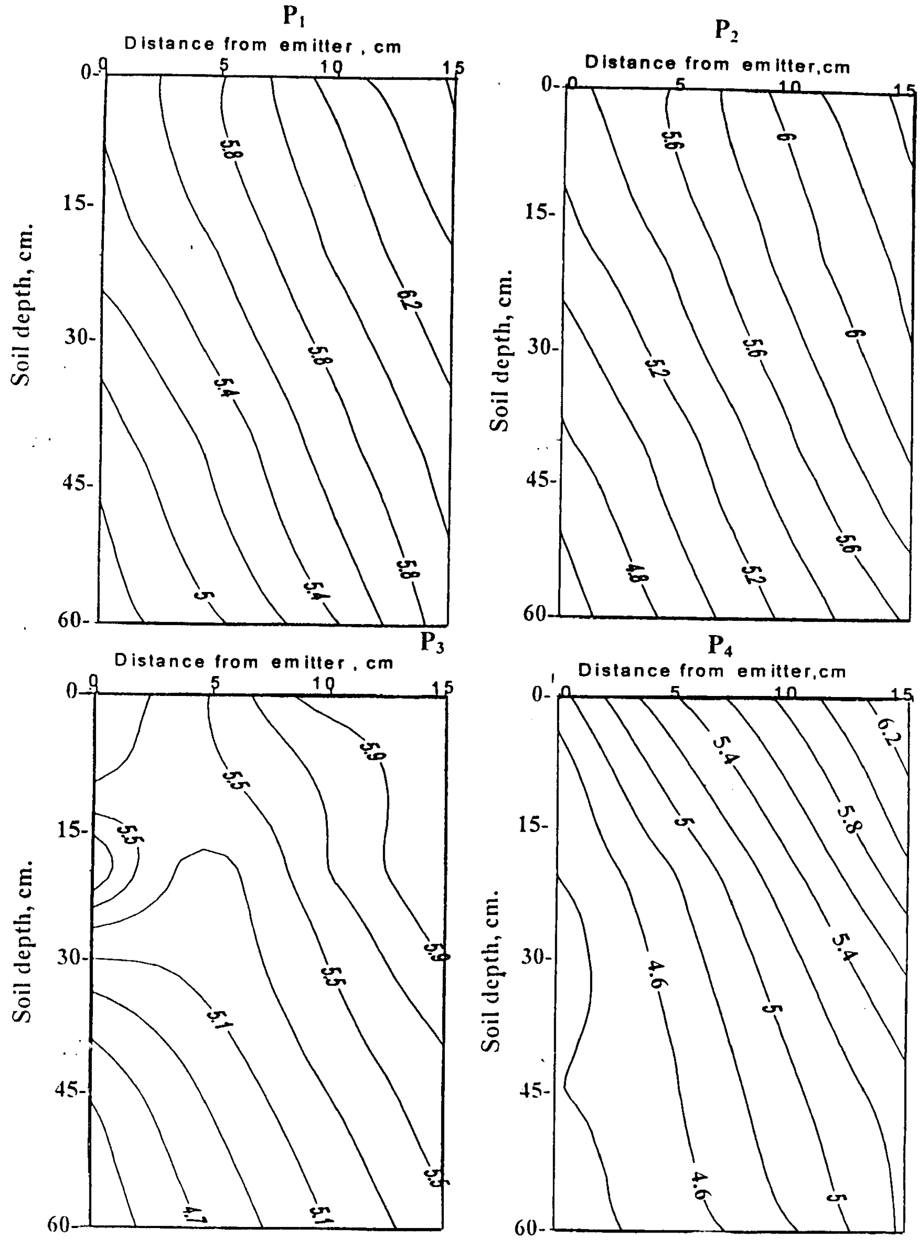


Fig. 19: Salt distribution (mmhos/cm) along laterals for surface drip irrigation at different operating pressure head (P_1 2 m, P_2 = 6 m, P_3 = 10 m and P_4 = 14 m.).

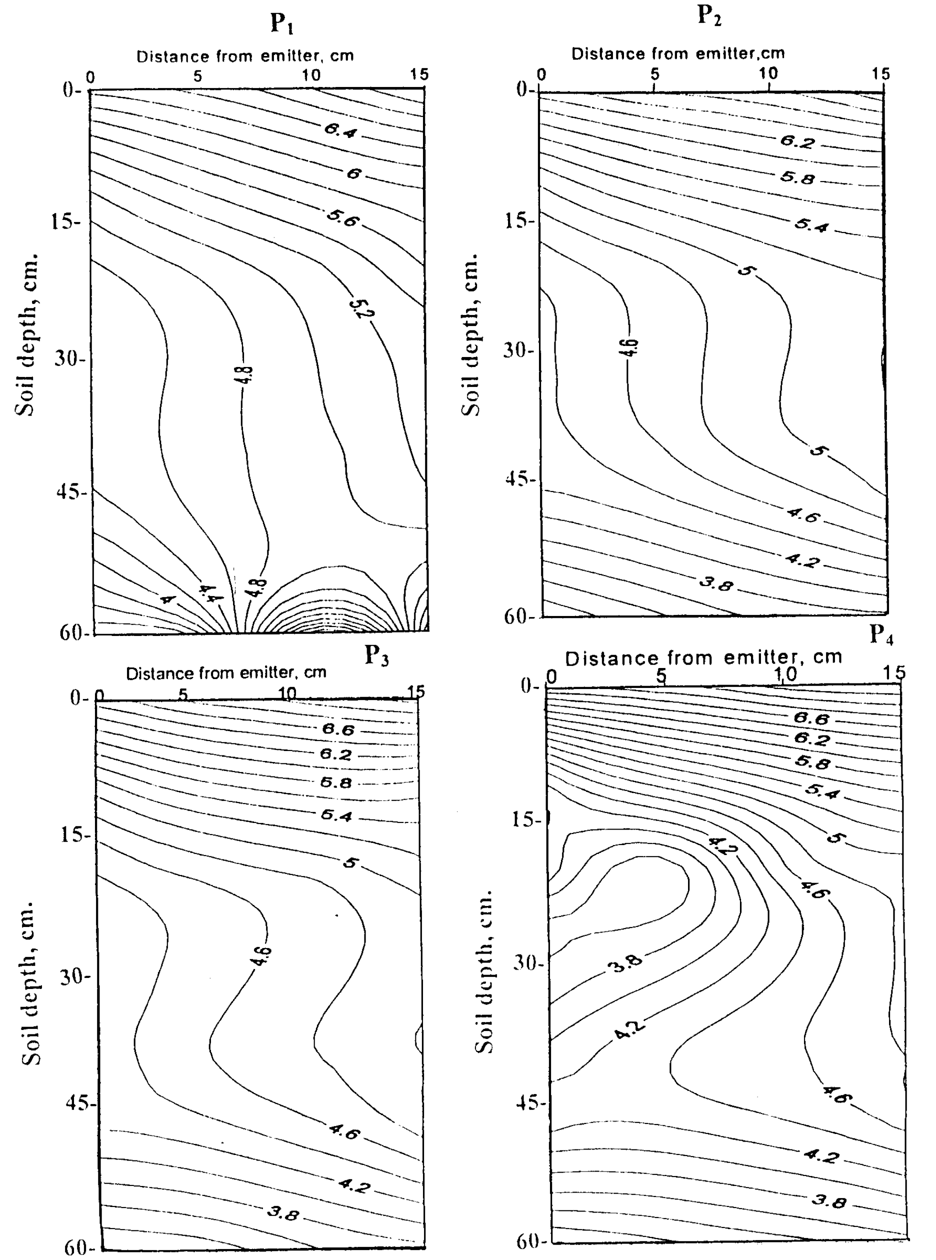


Fig. 20: Salt distribution (mmhos/cm) along laterals for subsurface drip irrigation different operating pressure head (P_1 = 2 m, P_2 = 6 m, P_3 = 10 m and P_1 = 14 m.).

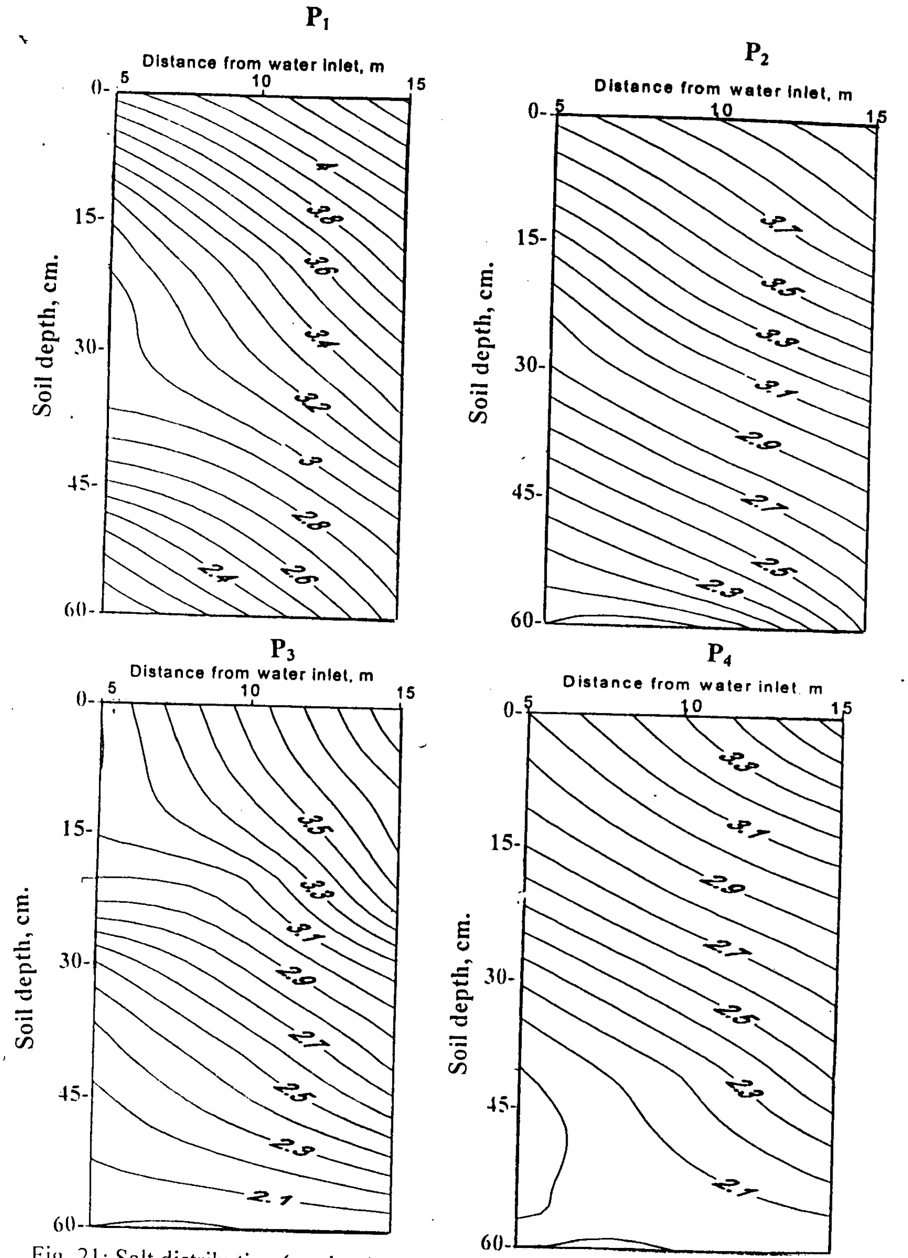


Fig. 21: Salt distribution (mmhos/cm) for furrow irrigation at different operating pressure head ($P_1 = 2$ m, $P_2 = 6$ m, $P_3 = 10$ m and $P_4 = 14$ m.).

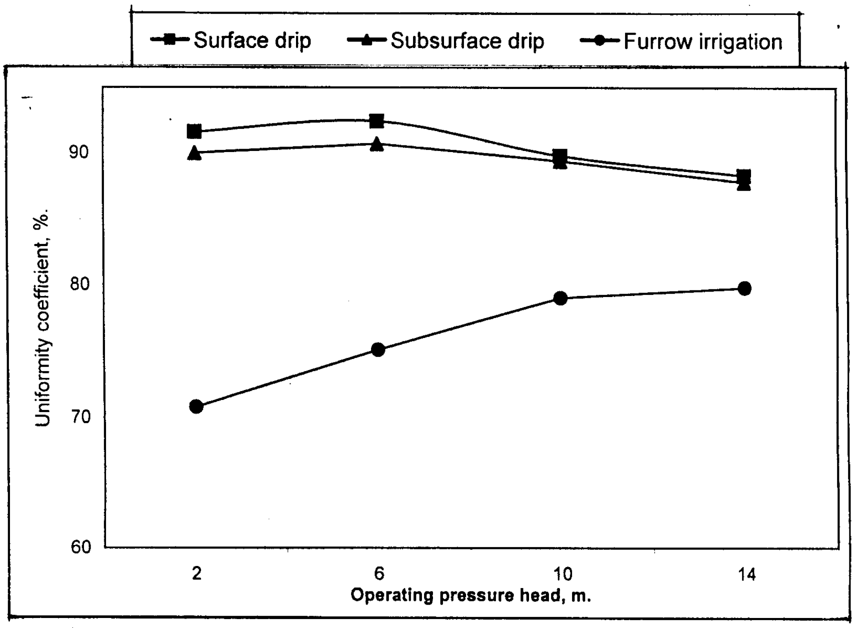


Fig. 22: Effect of irrigation methods and operating pressure head on the uniformity coefficient, % .

operating pressure head, while the minimum value was 70.8 % for furrow irrigation and 2 m operating pressure head.

Table 5: Effect of irrigation methods, and operating pressure head on uniformity coefficient, %.

Operating pressure head, m	Surface drip	Subsurface drip	Furrow irrigation
2	91.6	90.0	70.8
6	92.4	90.7	75.1
10	89.8	89.4	79.0
14	88.3	87.8	79.8
Mean values	90.52	89.48	76.18

The results indicated that, in case of drip irrigation methods (surface and subsurface), the uniformity coefficient increased with increasing operating pressure head from 2 to 6 m after that uniformity coefficient decreased by increasing operating pressure head over than 6 m because different head losses increased asshowed by **Bournival et al. (1987).**

For furrow irrigation method, uniformity coefficient increased by increasing operating pressure because the stored water decreased along the furrow where advance time decreased.

Analysis of variance using split plot design showed that, irrigation method had no significant effect on water distribution, also operating pressure head and interaction between irrigation method and operating pressure head had no significant effect on water distribution as shown in Tables 11 and 12 in appendix for different irrigation methods and operating pressure head.

4. 5. Fertilizer distribution uniformity:

Uniformity coefficient was used to describe fertilizer distribution along lateral line under surface drip irrigation, electrical conductivity for water samples was used to evaluate uniformity coefficient.

Data presented in Table 6 and illustrated in Fig. 23 showed that, the bend injection method has improved the fertilizer distribution along lateral under surface drip irrigation method comparing with pressure differential and venturi injection methods.

The fertilizer uniformity coefficient for bend injection method increased by 21.55 % and 1.54 % comparing with pressure differential tank and venturi

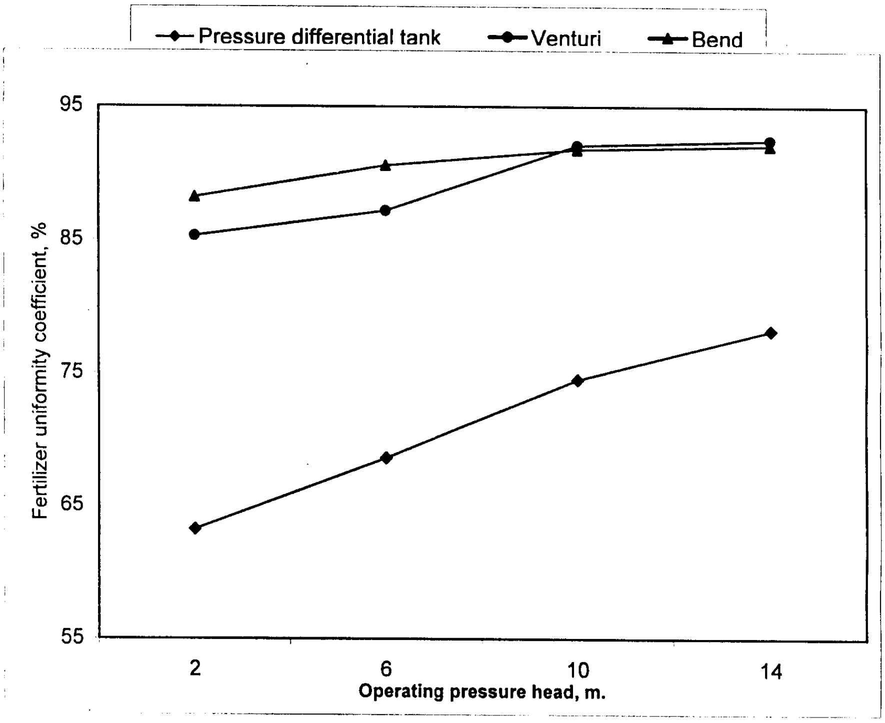


Fig 23: Effect of fertigation methods and operating pressure head on fertilizer uniformity coefficient along drip line , %.

injection methods respectively, where the average value of fertilizer uniformity coefficient for the bend injection method was 90.68 %.

The highest value of fertilizer uniformity coefficient was 92.5 % for the venturi injection method at 14 m operating pressure head. While, the lowest value was 63.2 % for pressure differential tank at 2 m operating pressure head.

Table 6: Effect of fertigation methods and operating pressure head on fertilizer distribution along drip line, %.

Operating pressure head, m	Pressure differential tank	Venturi	Bend
2	63.2	85.3	88.2
6	68.6	87.2	90.6
10	74.5	92.1	91.8
14	78.2	92.5	92.1
Mean values	71.13	89.28	90.68

Increasing operating pressure head tended to increase fertilizer uniformity coefficient under different fertigation methods, this may be due to increase injection rate by increasing operating pressure head.

Analysis of variance using split plot design showed that, fertigation method and operating pressure and their interaction had a highly significant effect on fertilizer uniformity coefficient as showen in Tables 13 and 14 in appendix for different fertigation methods and operating pressure head under surface drip irrigation method.

4. 6. Pressure difference:

Pressure difference across fertigation units was measured at different operating pressures head. Data presented in Table 7 and illustrated in Fig. 24 showed that, pressure differential tank introduced the lowest value of pressure difference compared with venturi and bend injection methods, while venturi injection method showed the highest value of pressure difference.

The pressure difference for venturi injection method increased by 70.11 and 60.1 % comparing with pressure differential tank and bend injection methods respectively, where the average value of pressure difference for venturi injection method was 12.75 %.

The maximum value of pressure difference was 19.62 % for venturi method at 14 m operating pressure head, while the minimum value was 1.32 % for pressure differential tank at 2 m operating pressure head.

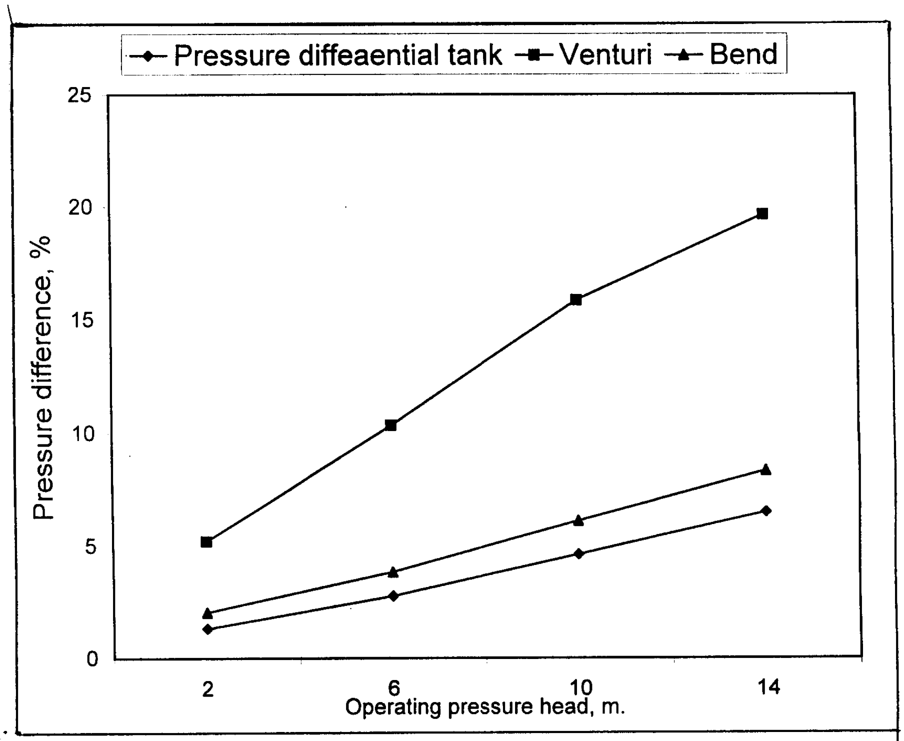


Fig 24: Effect of fertigation methods and operating pressure head on pressure difference ,%.

Table 7: Effect of fertigation methods, and operating pressure head on pressure difference, %.

Operating pressure head, m	Pressure differential tank	Venturi	Bend
2	1.32	5.21	2.05
6	2.77	10.34	3.84
10	4.62	15.84	6.12
14	6.52	19.62	8.35
Mean values	3.81	12.75	5.09

The results indicated that pressure difference increased by increasing operating pressure head for different fertigation methods, this may be due to increase different losses by increasing operating pressure head.

Analysis of variance using split plot design showed that, the fertigation methods and operating pressures had a highly significant effect on pressure head difference, while their interaction had no significant effect as showen in Tables 15 and 16 in appendix for different fertigation methods and operating pressure head.

4. 7. Fertilizer concentration change:

Fertilizer concentration in irrigation water was measured many times during irrigation time, this shows the change of fertilizer concentration along fertigation time. Fertilizer concentration at different operating pressure head presented in Table 8 and showed in Fig. 25.

The results indicated that, venturi and bend injection methods had developed fertilizer distribution along irrigation time comparing with pressure differential tank. The highest concentration was 300 mg/l under pressure differential tank with 14 m operating pressure head at 20 % of irrigation time, while the highest concentration for bend and venturi injection methods was 158 and 160 mg/l at 14 m operating pressure head at 40 and 20 % of irrigation time respectively.

Also, the results showed that fertilizer concentration reached to minimum value faster in case of, pressure differential tank (50 % of irrigation time) comparing with venturi and bend injection methods (80 % of irrigation time).

Increasing operating pressure head tended to increase maximum concentration and decrease injection time under different fertigation methods where increasing operating pressure head tend to increase injection rate, these

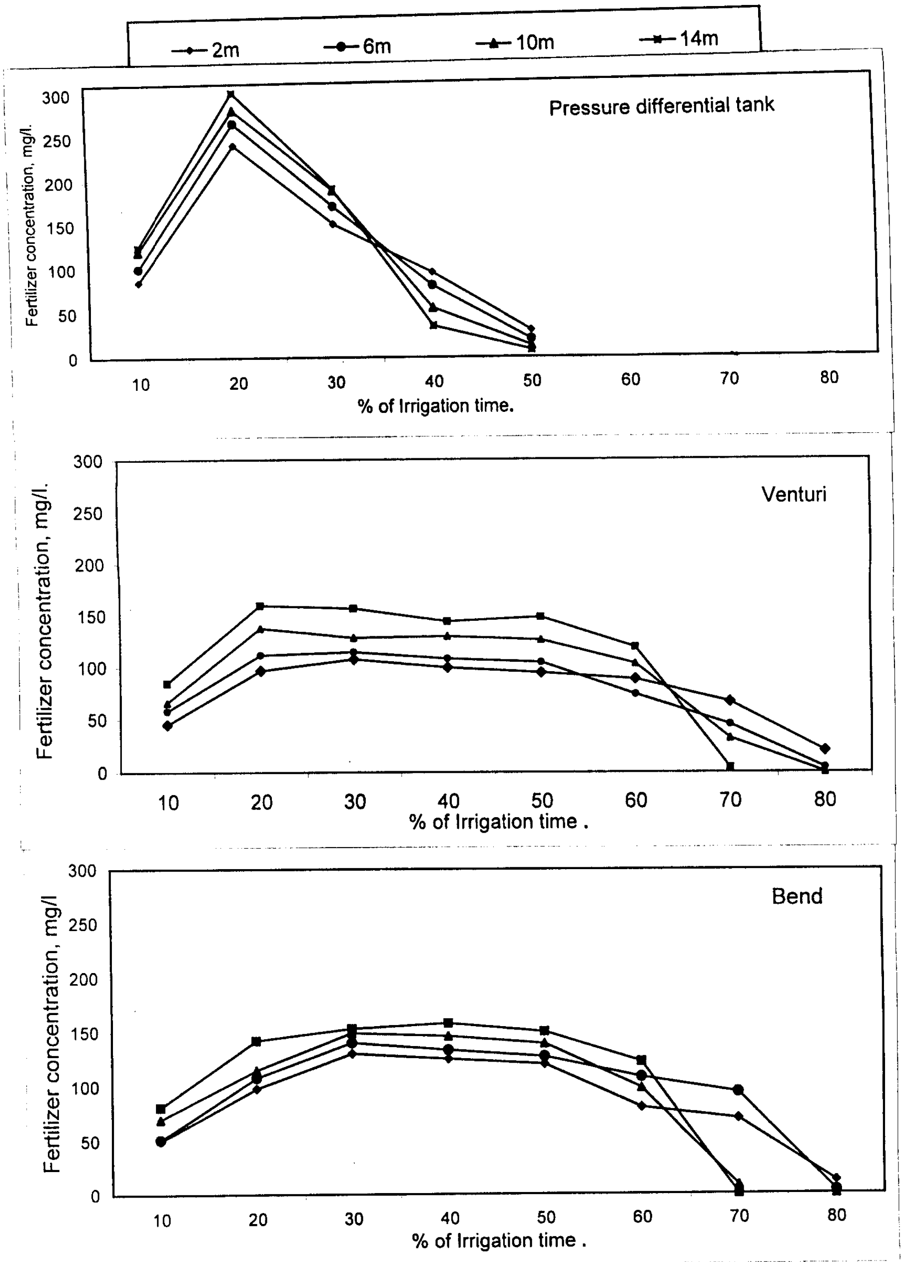


Fig. 25: Effect of fertigation methods and operating pressure head on fertilizer concentration change along irrigation time.

results are in good agreement with **Abd el-Aziz (1998) and Larhrafi and Nishiyama (1996).**

Table 8: Effect of fertigation methods and operating pressure head on fertilizer concentration change along irrigation time, mg/l.

fertigation method	Operating pressure head, m	Percent of irrigation time						
		10	20	30	40	50	60	70
Pressure differential tank	2	85	240	150	95	30	-	-
	6	100	265	170	80	20	-	-
	10	120	280	188	55	13	-	-
	14	125	300	190	35	8	-	-
Venturi	2	45	97	108	100	95	89	67
	6	58	112	115	108	105	74	45
	10	66	138	129	130	127	104	32
	14	85	160	157	144.9	149	120	4
Bend	2	50	98	130	125	120	80	70
	6	51	108	140	133	127	108	94
	10	70	115	149	146	139	98	8
	14	81	142	153	158	150	122	-

4. 8. Crop yield and its components:

4. 8. 1. Root volume:

Corn root volume for different treatments are presented in Table 9 and illustrated in Fig. 26.

The results indicated that, bend and venturi injection methods had improved root volume comparing with pressure diffferential tank. Bend and venturi injection methods increased root volume by 3.33 and 3.0 % respectively, comparing with pressure differential tank, where root volume for pressure differential tank was 398.2 cm^3.

The highest value of root volume was 441 cm^3 for venturi injection method with subsurface drip irrigation and 14 m operating pressure head, while, the lowest value was 357cm^3 for pressure differential tank, surface drip irrigation method and 2m operating pressure head.

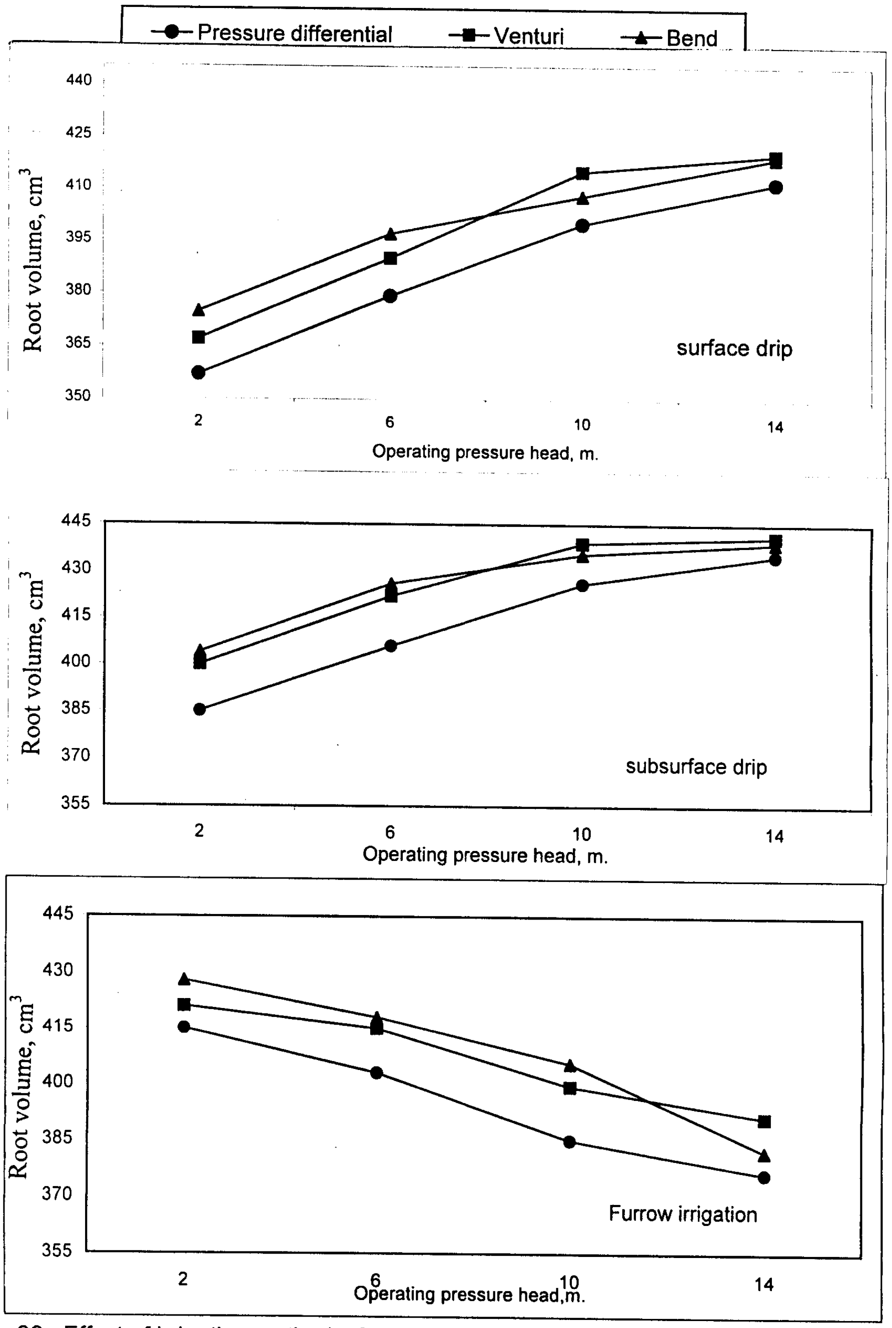


Fig 26: Effect of irrigation methods, fertigation methods and operating pressure head on root volume, cm^3

The results showed that subsurface drip irrigation method increased root volume by 6.4 and 4.4 % as compared with surface drip and furrow irrigation methods respectively, where the root volume for subsurface drip was 421.7 cm^3, because the water and fertilizer were applied into root zone (20 cm depth).

Table 9: Effect of irrigation methods, fertigation methods and operating pressure head on root volume cm^3.

Fertigation method	Irrigation method	Operating pressure head, m			
		2	**6**	**10**	**14**
Pressure differential tank	Surface drip	357	379	400	412
	Subsurface drip	385	406	426	435
	Furrow irrigation	415	403	385	376
Venturi	Surface drip	367	390	415	420
	Subsurface drip	400	422	439	441
	Furrow irrigation	421	415	400	391
Bend	Surface drip	374	397	408	419
	Subsurface drip	404	426	435	439
	Furrow irrigation	428	418	405	382

Increasing operating pressure head tended to increase root volume for surface and subsurface drip irrigation methods, this may be due to increase water distribution area by increasing operating pressure head. For furrow irrigation method, the results revealed that, increasing operating pressure head tended to decrease root volume whereas irrigation water applied increased.

Analysis of variance using split split plot design showed that, fertigation method and operating pressure head had a highly significant effect on the root volume also interaction between different parameters had a highly significant effect on root volume as showen in Tables 17, 18, 19, 20 and 21 in appendix for different irrigation methods, fertigation methods and operating, pressure head.

4. 8. 2. Corn crop yield:

Data presented in Table 10 and illustrated in Fig 27 showed that, the bend injection method increased corn crop yield by 2.6 and 9.93 % as compared with venturi and pressure differential tank respectively, where the corn crop yield for the bend was 7.35 Mg/fed.

High production of corn under bend injection method attributed to the improvement of fertilizer distribution and maintenance of nutrients. The

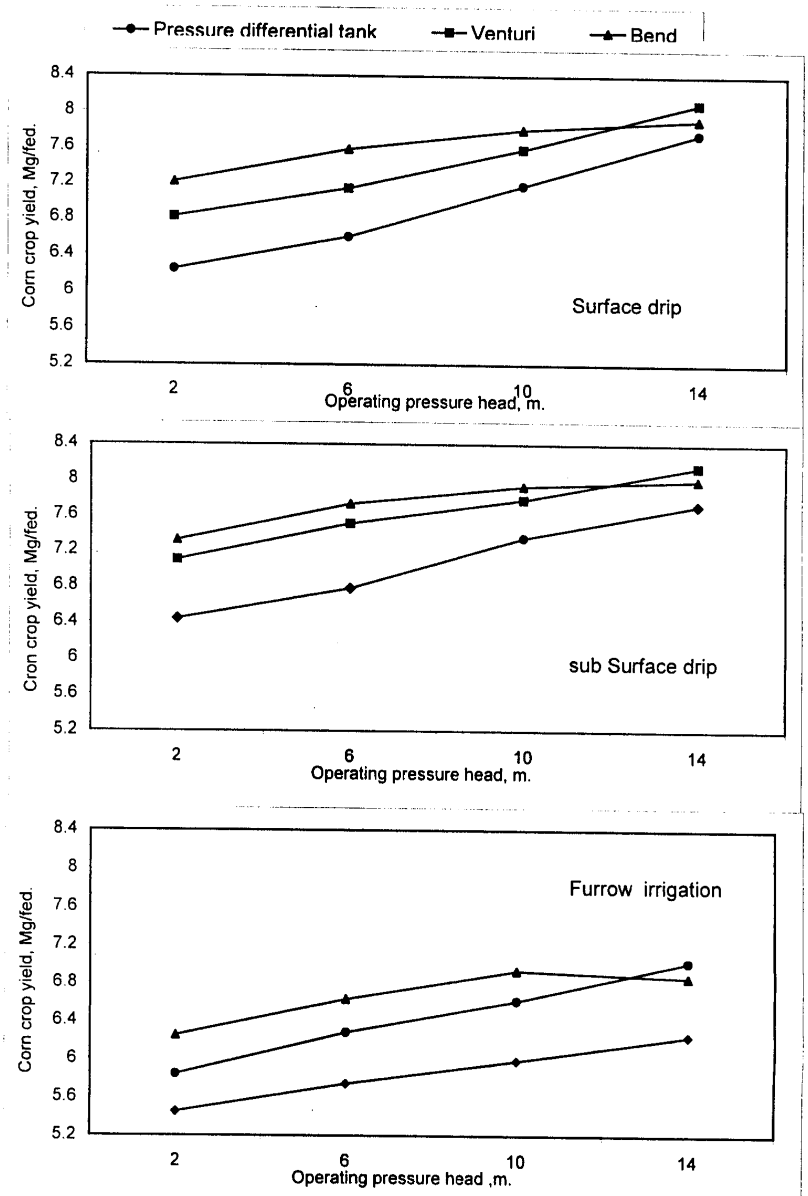


Fig. 27: Effect of irrigation methods, fertigation methods and operating pressure head on corn crop yield, Mg/fed.

maximum corn crop yield was 8.15 Mg/fed for venturi injection method under subsurface drip irrigation at 14 m operating pressure head. While, the minimum value was 5.45 Mg/fed for pressure differential tank under furrow irrigation method at 2 m operating pressure head.

The results indicated that sub surface drip irrigation produced the highest corn crop production followed by surface drip, while furrow irrigation produced the lowest production, where corn crop production was 7.48, 7.32 and 6.32 Mg/fed under three irrigation methods respectively. This is attributed to improve water and fertilizer distribution and reduce fertilizer leaching along irrigation line under drip irrigation comparing with furrow irrigation, this results are in agreement with **Arnaout (1995) and El-Gindy et al (2001).**

Table 10: Effect of irrigation methods, fertigation methods and operating pressure head on corn crop yield, Mg/fed.

Fertigation method	Irrigation method	Operating pressure head, m			
		2	6	10	14
Pressure differential tank	Surface drip	6.24	6.6	7.17	7.75
	Subsurface drip	6.44	6.78	7.35	7.72
	Furrow irrigation	5.45	5.74	5.98	6.24
Venturi	Surface drip	6.82	7.14	7.58	8.09
	Subsurface drip	7.1	7.51	7.78	8.15
	Furrow irrigation	5.84	6.28	6.61	7.02
Bend	Surface drip	7.21	7.58	7.80	7.91
	Subsurface drip	7.32	7.73	7.93	8.00
	Furrow irrigation	6.25	6.63	6.93	6.86

Increasing operating pressure head tended to increase crop production under different irrigation methods, whereas fertilizer distribution along drip line and total water applied under furrow irrigation increased.

Analysis of variance using split split plot design showed that, operating pressure head and fertilizer methods had a highly significant effect on corn crop yield.

Interaction between irrigation method and operating pressure head in addition to the interaction between irrigation method, operating pressure head and fertigation methods had significant effect on corn crop yield, while interaction between operating pressure head and fertigation method, and between irrigation method and fertigation method had no significant effect on the corn crop yield, as showen in Tables 22, 23, 24, 25 and 26 in appendix for different irrigation methods, fertigation methods and operating pressure head.

4. 8. 3. Water use efficiency (WUE):

Water use efficiency is one of the most important criteria, where it is of greater practical importance. The highest value of water use efficiency means that less amount of irrigation water and highly crop yield.

Data presented in Table 11 and illustrated in Fig 28 showed that the bend injection method followed by venturi injection method recorded highly water use efficiency as compared with pressure differential tank.

Table 11: Effect of irrigation methods, fertigation methods and operating pressure head on water use efficiency, kg/m^3.

Fertigation method	Irrigation methods	Operating pressure head, m			
		2	6	10	14
Pressure differential tank	Surface drip	3.06	3.24	3.52	3.80
	Subsurface drip	3.60	3.33	3.60	3.79
	Furrow irrigation	2.10	2.19	2.22	2.23
Venturi	Surface drip	3.34	3.51	3.72	3.97
	Subsurface drip	3.48	3.63	3.82	4.00
	Furrow irrigation	2.25	2.40	2.46	2.52
Bend	Surface drip	3.54	3.72	3.83	3.88
	Subsurface drip	3.60	3.79	3.90	3.93
	Furrow irrigation	2.40	2.53	2.58	2.46

Water use efficiency increased by 10.45 and 7.26 % for bend and venturi injection methods respectively, comparing with pressure differential tank, where water use efficiency was 3.03 kg/m^3 for pressure differential, tank.

The results showed that the highest value of water use efficiency was 4 kg/m^3 at venturi injection method, subsurface drip irrigation method and 14 m operating pressure head. The worst value was 2.1 kg/m^3 under pressure differential tank, furrow irrigation method and 2 m operating pressure head.

Drip irrigation improved water use efficiency comparing with furrow irrigation, because crop yield increase and total water applied decrease for drip irrigation, water use efficiency was 2.37, 3.59 and 3.67 kg/m^3 for furrow, surface drip and sub surface drip irrigation methods respectively.

Increasing operating pressure tended to increase water use efficiency for surface and subsurface drip irrigation methods, because crop yield increased.

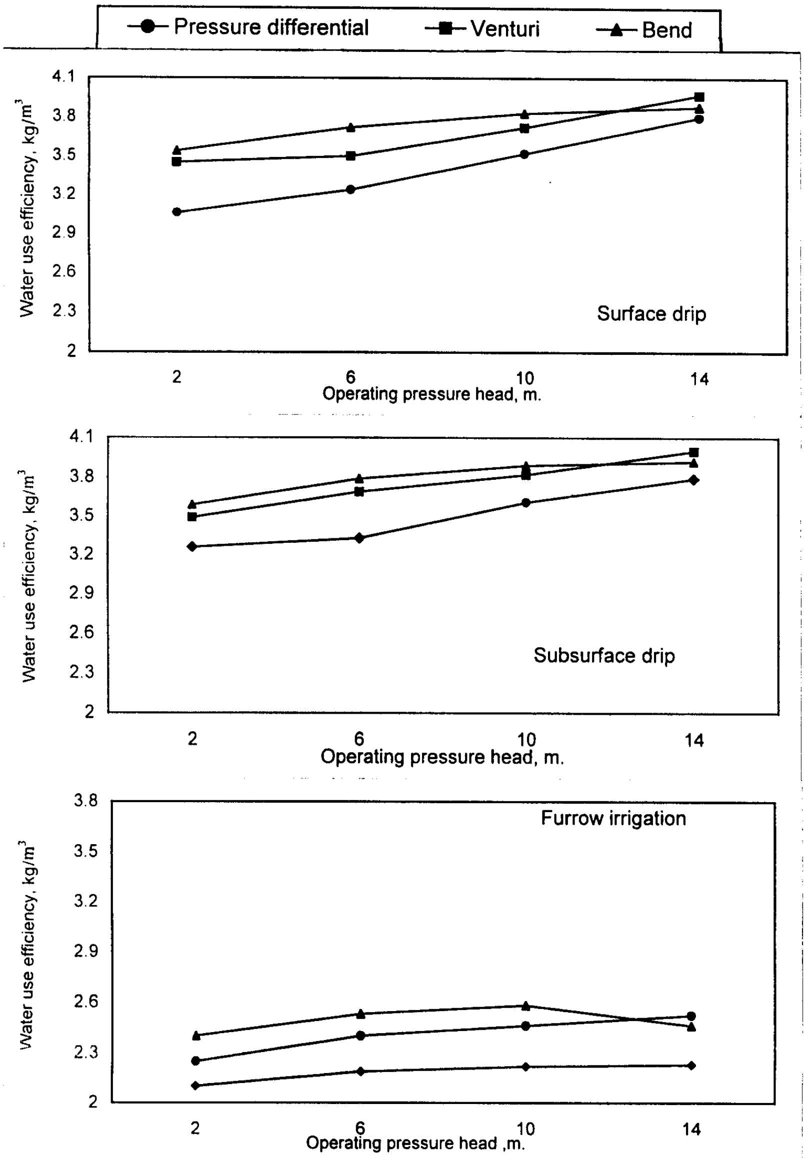


Fig.28: Effect ofirrigation methods, fertigation methods and operating pressure head on water use efficiency, kg/m^3.

Increasing operating pressure head tended to increase water use efficiency under furrow irrigation at 2.6 and 10 m operating pressure head, but at 14 m operating pressure head water use efficiency decreased, because total water applied increased highly.

Analysis of variance using split split plot design showed that, fertigation method and operating pressure head in addition to interactions between irrigation method and operating pressure had a highly significant effect on the water use efficiency, while interaction between operating pressure head and fertigation method had significant effect on water use efficiency. On the other hand the interaction between irrigation method and fertigation method and between irrigation method, fertigation method and operating pressure head had no significant effect on water use efficiency as shown in Tables 27, 28, 29, 30 and 31 in appendix for different irrigation methods, fertigation methods and operating pressure head.

4. 8. 4. Nitrogen use efficiency (NUE):

Data presented in Table 12 and illustrated in Fig. 29 showed that bend injection method recorded highly nitrogen use efficiency comparing with venturi and pressure differential tank, because the bend improves fertilizer distribution along irrigation time with high concentration and reduce fertilizer losses more than venturi and pressure differential tank. Nitrogen use efficiency increased by 2.53 and 9.87% for bend injection method as compared with venturi and pressure differential tank respectively, where nitrogen use efficiency was 61.22 kg-yield/Kg-N for bend.

Table 12: Effect of irrigation methods, fertigation methods and operating pressure head on nitrogen use efficiency, kg-y/kg-N.

Fertigation method	Irrigation method	Operating pressure head, m			
		2	6	10	14
Pressure differential tank	Surface drip	52.0	55.0	59.75	64.60
	Subsurface drip	53.7	56.5	61.25	64.33
	Furrow irrigation	45.42	47.83	49.83	52.0
Venturi	Surface drip	56.83	59.5	63.17	67.42
	Subsurface drip	59.17	62.58	64.83	67.92
	Furrow irrigation	48.67	52.33	55.10	58.50
Bend	Surface drip	60.08	63.17	65.0	65.92
	Subsurface drip	61.0	64.42	66.10	66.67
	Furrow irrigation	52.10	55.25	57.75	57.17

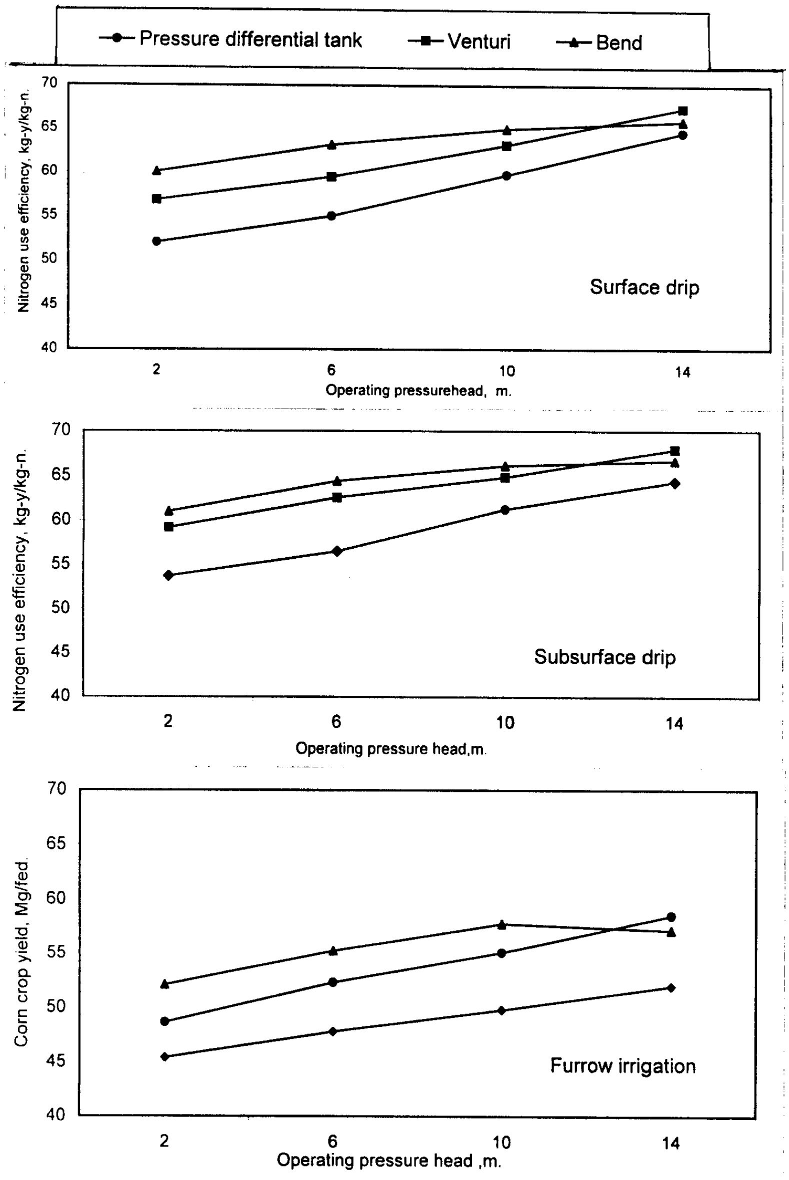


Fig.29: Effect of irrigation methods, fertigation methods and operating pressure head on nitrogen use efficiency, kg-y/kg-n.

The results indicated that the highest value of nitrogen use efficiency was 67.92 kg-yield/kg-N under venturi injection method, subsurface drip irrigation and 14 m operating pressure head, while the lowest value was 45.42 kg-yield/kg-N under pressure differential tank, furrow irrigation method and 2 m operating pressure head.

Surface and subsurface drip irrigation methods improved nitrogen use efficiency comparing with furrow irrigation method, because drip irrigation reduces leaching nutrients also sub surface drip recieves nutrients into root zone consequently protect it from evaporation. Nitrogen use efficiencies were 61.03, 62.38 and 52.66 kg-yield/kg-N for surface and subsurface drip and furrow irrigation methods respectively.

Increasing operating pressure head tended to increase nitrogen use efficiency for all treatments, because crop yield increased by increasing operating pressure head and fertilizer distribution improve.

Analysis of variance using split split plot design showed that, irrigation method, fertigation method and operating pressure head and their interactions had a highly significant effect on nitrogen use efficiency as shown in Tables 32, 33, 34, 35 and 36 in appendix for different irrigation methods, fertigation methods and operating pressure head.

5. Summary and Conclusion

Field experiments were carried out during the growing season of 2002/ 2003 at Rice Mechanization Center (RMC), Meet El-Deeba, Kafr El-Sheikh Governorate, Egypt. Three irrigation Methods (surface drip, subsurface drip and furrow irrigation), three fertigation methods (pressure differential tank, venturi injection device and bend injection device) and four operating pressure head (2, 6, 10 and 14 m) were the factors for achieving the following objectives:

1. Manufacture a bend to use it with by-bass tank as a new fertigation unit and evaluate this unit under different irrigation systems.
2. Comparing between different fertigation methods under different operating pressures.
3. Improving water and fertilizer application efficiency to increase corn production.

The irrigation intervals were 4 and 15 days for drip and furrow irrigation respectively. The laterals in case of subsurface drip were buried at a depth of 20 cm. Drip irrigation saved about of 639 m^3/fed (23.9 %) comparing with furrow irrigation, where the amount of applied irrigation water under furrow irrigation was 2676 m^3/fed per season. Increasing operating pressure head tended to increase the total of applied irrigation water with furrow irrigation, because the run off and drainage losses increased.

120 nitrogen units per fed. (Urea 46.5 % N) were used, devided to 6 doses (one dose every 2 weeks).

The main results of this study can be summarized as follows:

1. Soil moisture distribution:

Soil moisture content decreased by increasing the distance from dripper in both horizontal and vertical directions for both across and along laterals under drip irrigation.

Increasing operating pressure head tended to increase moisture content in horizontal direction more than vertical.

Under furrow irrigation, increasing operating pressure head tended to increase soil moisture content for different layers. The highest soil moisture content after irrigation under surface drip and furrow irrigation methods was obtained in surface layer at 14 m operating pressure head while the highest moisture content under subsurface drip was obtained at soil depth 15 and 30 cm at the same operating pressure head where lateral line buried.

2. Salt distribution:

Total soluble were determined in the collected samples using the electrical conductivity meter.

Salt concentration increased by increasing the horizontal distance between emitters at along and across laterals, while decreased by increasing the vertical distance with drip irrigation .

The lowest salt concentration obtained by subsurface drip irrigation at 14 m operating pressure head and soil depths 15 and 30 cm, while the highest values obtained in case of subsurface drip at 2 m operating pressure head at surface layer.

Salt concentration tended to decrease by using furrow irrigation comparing with drip irrigation, the highest concentration was 4.4 mmhos/cm at soil surface and 2 m operating pressure head, while the minimum concentration was 2 mmhos/cm at 60 cm depth and 14 m operating pressure head.

3. Water distribution uniformity

Water distribution efficiency had improved by surface drip irrigation comparing with subsurface drip and furrow irrigation methods.

The uniformity coefficient for surface drip irrigation increased by about of 1.16 and 15.8 % comparing with subsurface drip and furrow irrigation methods respectively, where uniformity coefficient for surface drip was 90.52%.

Uniformity coefficient increased by increasing operating pressure head from 2 to 6 m under drip irrigation (surface and subsurface), after that uniformity coefficient decreased by increasing operating pressure where losses cross drip line increased.

Under furrow irrigation method, uniformity coefficient increased by increasing operating pressure head because the difference in water stored along the furrow decreased.

4. Fertilizer distribution uniformity:

Adding fertilizer with irrigation water by using bend injection method in case of surface and subsurface drip irrigation methods had improved the fertilizer distribution along the lateral.

Fertilizer uniformity coefficient for bend injection method increased by about 21.55 and 1.54 % comparing with pressure differential and venturi method respectively, where the average value of fertilizer uniformity coefficient for bend injection method was 90.68%.

Increasing operating pressure head tended to increase fertilizer uniformity coefficient under different fertigation methods.

The highest value of fertilizer uniformity coefficient was 92.5% for the venturi injection method at 14 m operating pressure head , while the worst value was 63.2% for pressure differential tank method at 2 m operating pressure head .

Increasing operating pressure head tended to increase fertilizer concentration with irrigation water and decrease injection time along irrigation time under different fertigation methods.

The highest value of fertilizer concentration was 300 mg/l using pressure differential tank method and 14 m operating pressure head at 20 % of irrigation time.

The maximum concentrations of fertilizer for bend and venturi injection methods were 158 and 160 mg/l at 14 m operating pressure head at 40 and 20 % of irrigation time respectively.

5. Pressure difference:

Pressure difference in sub main line which caused across fertigation unit had been used to describe the losses in operating pressure head which caused by fertigation unit, this losses led to decrease in discharge.

The pressure difference for venturi increased by 70.11 and 60.1 % comparing with pressure differential tank and bend injection methods respectively, the average value of pressure difference for venturi injection method was 12.75 %.

Pressure difference increased by increasing operating pressure head for different fertigation methods.

The highest value of pressure difference was 19.62 % for injecting fertilizer by venturi injection method at 14 m operating pressure head , while the lowest value was 1.32 % for injecting fertilizer by pressure differention tank at 2 m operating pressure head.

6. Root volume:

Root volume increased by about 3.17 and 2.83 % when fertilizer injected by Bend and venturi injected methods respectively comparing with injecting fertilizer by pressure differential tank, where root volume for pressure differential tank method was 398.2 cm^3.

Subsurface drip increased root volume by 6.4 and 4.4% comparing with surface drip and furrow irrigation methods respectively, where the root volume for subsurface drip irrigation was 421.7 cm^3.

Increasing operating pressure head tended to increase root volume for surface and subsurface drip irrigation method, while root volume decreased by increasing operating pressure under furrow irrigation.

The highest root volume was 441 cm^3 for injecting fertilizer by venturi injection method during subsurface drip irrigation and 14 m operating pressure head, while the lowest root volume was 357 cm^3 for pressure differential tank method surface drip irrigation method and 2 m operating pressure head.

7. Corn crop yield:

Adding fertilizer by bend injection method increased corn crop yield by 2.6 and 9.93 % comparing with venturi and pressure differential tank methods respectively, where corn crop yield for the bend injection method was 7.35 Mg/fed.

Subsurface drip irrigation method produced the maximum corn crop production followed by surface drip irrigation, while furrow irrigation method gave the lowest production, where corn crop yield were 7.48, 7.32 and 6.32 Mg/fed under three irrigation methods respectively.

The highest corn crop yield was 8.15 Mg/fed under venturi injection method, subsurface drip irrigation method and 14 m operating pressure head, while the lowest corn crop yield was 5.45 Mg/fed under pressure differential tank method , furrow irrigation method and 2 m operating pressure head.

Increasing operating pressure head tended to increase crop production under different irrigation methods.

8. Water use efficiency:

Adding fertilizer by bend and venturi injection methods improved water use efficiency comparing with adding fertilizer by pressure differential tank.

Bend and venturi injection methods increased water use efficiency by 9.28 and 7.33 % respectively comparing with injecting fertilizer by pressure differential tank, where water use efficiency was 3.03 kg/m^3 for injecting fertilizer by pressure differential tank.

Drip irrigation improved water use efficiency comparing with furrow irrigation, where water use efficiency was 2.37, 3.63 and 3.68 kg/m^3 for furrow, surface and subsurface drip irrigation methods respectively.

Increasing operating pressure head tended to increase water use efficiency for surface and subsurface drip irrigation, while under furrow irrigation water use efficiency increased by increasing operating pressure head from 2 to 10 m and decreased at 14 m operating pressure head where total water applied increased.

The highest value of water use efficiency was 4 kg/m^3 under subsurface drip irrigation method and venturi injection method at 14 m operating pressure head, while the lowest value was 2.1 kg/m^3 under furrow irrigation method and pressure differential tank at 2 m operating pressure head.

9. Nitrogen use efficiency:

Adding fertilizer by bend injection method recorded highly nitrogen use efficiency comparing with venturi and pressure differential tank injection methods.

Nitrogen use efficiency increased by 2.53 and 9.87 % for injecting fertilizer by bend injection method comparing with venturi and pressure differential tank injection methods respectively, where nitrogen use efficiency for bend injection method was 61.22 kg-y/ kg-N.

Drip irrigation system improved nitrogen use efficiency comparing with furrow irrigation, where nitrogen use efficiency were 61.03, 62.38 and 52.66 kg yield/kg-N for surface and subsurface drip and furrow irrigation methods respectively.

The highest value of nitrogen use efficiency was 67.92kg-yield/kg-N under subsurface drip irrigation and venturi injection method at 14 m operating pressure head, while the worst value was 45.42 Kg-yield/Kg-N under furrow irrigation and pressure differential tank method at 2 m operating pressure head. Increasing operating pressure head tended to increase nitrogen use efficiency

Recommendation:

Bend injection device is consider very suitable fertigation unit under local condition especially under low operating pressure head. Also subsurface drip irrigation is suitable irrigation method for irrigation and injecting fertilizer.

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Table A-1: Effect of operating pressure head on moisture content before and after irrigation across laterals under surface drip irrigation , %.

Operating pressure head, m	Depth , cm	Distance from dripper, cm									
		Before irrigation					After irrigation				
		0	5	10	15	25	0	5	10	15	25
2	0	20.2	19.8	19	18.2	16.2	36.2	34.6	32.5	32	29.8
	15	25.6	24.2	23	22.2	17.3	35.3	34.1	31.3	30.6	28.8
	30	25.8	25	24	22.8	17.8	32.8	31.6	29.8	28.7	26.0
	45	26	25.6	24.0	32.0	18.3	32.0	31.0	29.8	29.5	25.0
	60	27.4	26.8	24.5	32.0	19.0	31.6	30.7	29.3	27.5	32.6
6	0	24.5	23.5	22.3	21.5	17.5	37.3	35.8	33.9	32.8	31.4
	15	27.0	25.7	24.2	23.0	18.2	35.1	33.8	31.0	30.2	27.5
	30	26.6	25.8	25.0	24.0	19.1	32.0	31.0	29.8	28.8	25.0
	45	27.2	26.3	25.8	24.0	19.4	30.5	30.0	29.5	28.8	24.0
	60	28.4	27.1	26.6	24.5	19.8	31.0	30.2	29.0	26.8	22.0
10	0	25.0	24.0	23.1	22.2	18.3	39.1	36.6	35.2	34.5	32.0
	15	26.6	25.7	24.7	23.2	18.9	34.4	33.5	30.5	29.4	26.8
	30	26.5	25.4	23.5	23.0	20.0	31.0	29.2	28.1	26.6	25.0
	45	26.8	25.6	24.2	23.0	20.0	29.6	28.3	26.7	24.9	23.4
	60	27.1	26.0	25.0	23.0	20.6	29.2	27.6	25.2	23.6	20.7
14	0	26.8	24.5	24.0	23.1	19.0	41.6	38.0	35.6	33.6	33.0
	15	25.4	25.1	24.4	23.5	19.3	34.0	33.0	30.2	29.0	25.6
	30	25.9	25.2	24.7	23.9	20.8	30.3	28.3	26.6	25.6	25.0
	45	26.0	25.6	25.2	24.0	21.3	29.4	26.7	25.6	25.0	24.4
	60	26.3	25.8	25.0	24.0	22.0	28.0	25.6	25.0	23.0	21.0

Table A-2: Effect of operating pressure head on moisture content before and after irrigation across laterals under subsurface drip irrigation, %.

Operating pressure head, m	Depth, cm	Distance from dripper, cm									
		Before irrigation					After irrigation				
		0	5	10	15	25	0	5	10	15	25
2	0	20.2	20.0	19.2	18.6	16.3	30.1	29.2	27.8	27.0	23.4
	15	29.6	28.1	26.7	25.2	22.4	40.2	39.1	37.4	35.1	31.3
	30	26.8	25.4	24.6	24.0	21.3	37.7	35.6	34.3	33.2	28.6
	45	27.0	25.8	25.0	25.0	21.8	37.0	35.3	33.3	32.6	28.2
	60	27.3	26.0	25.6	25.2	2.3	37.0	35.5	33.3	32.0	28.0
6	0	21.0	20.2	19.0	18.3	17.2	31.0	20.0	28.5	27.2	24.0
	15	29.5	28.6	27.1	26.0	32.6	41.5	40.0	39.0	36.1	31.8
	30	27.4	26.1	25.2	23.8	21.8	38.8	37.5	35.8	34.0	29.0
	45	27.5	26.6	25.8	24.8	22.0	37.2	35.8	34.6	33.1	29.0
	60	27.8	27.0	26.3	24.6	22.7	35.8	34.4	33.0	32.6	28.6
10	0	21.1	20.8	19.4	19.2	17.0	31.3	20.0	28.8	28.0	24.6
	15	30.6	29.4	28.8	27.1	23.0	42.3	41.3	39.5	37.5	32.0
	30	28.8	27.1	25.0	24.2	21.7	38.8	38.5	37.4	36.1	30.3
	45	28.4	27.5	25.8	24.8	22.0	37.1	35.8	35.0	32.3	29.2
	60	28.2	27.6	26.0	25.0	22.5	35.0	33.4	32.1	30.6	29.0
14	0	22.5	21.1	20.0	19.5	17.8	31.0	30.4	28.6	27.5	25.6
	15	32.3	30.8	29.0	27.6	23.2	43.2	40.0	40.0	37.9	33.3
	30	30.2	28.4	27.1	24.0	21.6	39.2	39.6	38.3	37.8	31.1
	45	30.5	28.8	27.3	25.0	22.2	35.8	37.8	36.5	31.4	30.8
	60	30.6	29.1	27.8	25.4	23.0	23.5	31.2	30.4	29.5	28.8

Table A-3: Effect of operating pressure head on moisture content before and after irrigation along laterals under surface drip irrigation, % .

Operating pressure head, m	Depth, cm	Distance from dripper, cm							
		Before irrigation				After irrigation			
		0	5	10	15	0	5	10	15
2	0	20.5	19.2	18.8	18.0	35.8	33.0	32.6	31.2
	15	24.8	23.2	21.6	20.7	35.2	32.2	31.8	30.0
	30	26.0	24.9	22.5	22.0	34.4	32.3	30.2	29.4
	45	26.8	25.1	23.4	23.0	34.0	32.0	29.6	29.0
	60	27.6	26.3	25.1	24.3	34.0	32.0	29.0	28.5
6	0	22.4	21.2	20.6	20.0	38.4	36.8	35.2	34.6
	15	24.1	22.8	21.2	20.2	35.6	34.4	31.5	30.0
	30	26.4	24.6	23.2	22.4	34.0	32.2	30.0	29.0
	45	27.9	25.0	24.3	23.4	33.2	32.6	29.4	28.1
	60	27.2	25.8	25.0	24.4	32.0	32.6	28.3	27.2
10	0	24.4	23.2	21.6	21.0	40.1	37.6	35.0	34.6
	15	25.8	25.0	23.8	21.8	37.2	35.1	31.4	30.2
	30	27.1	26.4	25.0	23.3	33.5	31.5	29.6	28.7
	45	28.0	26.8	25.7	23.8	33.0	31.6	28.0	28.0
	60	28.6	27.1	26.0	23.8	23.0	31.7	28.5	28.0
14	0	2.37	23.0	22.2	21.4	40.6	38.0	36.2	35.0
	15	25.1	24.4	23.0	21.9	37.4	35.6	30.8	29.5
	30	27.5	27.0	25.3	23.0	34.0	31.5	29.2	28.0
	45	27.9	27.0	25.5	24.2	23.8	21.0	28.4	28.0
	60	28.1	27.8	26.0	25.0	33.1	30.5	28.0	28.0

Table A-4: Effect of operating pressure head on moisture content before and after irrigation along laterals under subsurface drip irrigation, %.

Operating pressure head, m	Depth, cm	Distance from dripper, cm							
		Before irrigation				After irrigation			
		0	5	10	15	0	5	10	15
2	0	19.3	18.7	17.6	17.1	31.8	31.0	30.2	28.7
	15	28.0	26.8	24.0	23.7	38.4	36.6	35.8	34.7
	30	22.5	22.0	20.6	20.0	36.2	35.8	34.4	33.2
	45	23.4	23.0	21.2	20.4	34.7	34.0	33.0	32.2
	60	24.8	23.6	21.9	21.0	34.1	33.8	33.0	32.4
6	0	20.5	19.6	18.0	17.0	31.6	31.2	30.2	29.0
	15	28.2	27.1	24.0	23.8	37.8	37.7	36.1	35.1
	30	23.2	21.8	20.1	16.4	37.2	36.0	35.0	33.6
	45	23.6	22.5	21.0	20.6	36.4	35.4	34.0	33.2
	60	24.6	23.3	21.9	21.2	35.8	34.2	32.6	32.2
10	0	19.7	19.3	17.8	17.5	31.2	30.6	29.9	29.0
	15	28.8	27.6	26.1	24.2	41.0	38.2	37.6	36.0
	30	21.6	21.0	19.4	18.5	37.4	36.9	35.0	34.0
	45	22.5	21.8	20.2	19.3	36.3	34.6	33.8	32.4
	60	23.2	23.0	21.6	20.8	35.4	33.8	32.2	31.4
14	0	19.6	19.2	18.1	17.0	31.4	30.5	29.0	28.1
	15	28.5	27.4	26.8	25.0	41.1	40.1	38.4	35.3
	30	22.6	20.4	20.0	19.3	37.5	36.0	35.6	33.8
	45	23.0	21.8	20.6	20.0	35.5	34.0	33.4	32.2
	60	23.0	22.4	21.5	20.5	33.6	32.0	30.0	28.4

Table A-5: Effect of operating pressure head on moisture content before and after irrigation under furrow irrigation, % .

Operating pressure head, m	Depth, cm	Distance from water inlet ,m					
		Before irrigation			After irrigation		
		5	10	15	5	10	15
2	0	19.8	19.0	18.2	45.5	37.3	35.1
	15	23.5	21.8	21.2	44.2	34.8	34.0
	30	27.4	27.0	26.3	41.3	33.7	31.3
	45	28.4	27.9	27.5	40.1	32.5	31.0
	60	29.4	28.6	28.0	39.5	32.0	31.0
6	0	21.1	20.0	19.5	46.5	39.4	36.5
	15	24.6	22.4	21.8	44.6	36.0	33.7
	30	28.6	26.6	25.1	42.3	34.2	32.0
	45	29.4	28.1	26.8	41.9	34.0	32.1
	60	30.7	29.7	28.8	41.6	33.7	32.0
10	0	22.8	21.8	21.0	46.2	43.2	39.2
	15	25.5	24.0	23.4	44.2	39.4	36.1
	30	29.2	28.1	27.4	44.1	37.8	34.9
	45	30.3	29.8	28.1	42.8	37.0	35.5
	60	31.8	30.2	29.6	43.5	36.5	36.0
14	0	24.5	23.1	22.6	46.8	43.6	40.5
	15	27.0	25.0	24.6	46.7	41.6	37.3
	30	30.6	29.3	27.8	45.2	39.1	35.6
	45	31.2	30.5	28.4	44.8	38.7	35.5
	60	32.2	31.1	30.3	44.3	38.2	35.6

Table A-6: Effect of operating pressure head on salt distribution across laterals under surface and subsurface drip irrigation, mmhos/cm.

Operating pressure head, m	Depth, cm	Distance from dripper, cm									
		Surface drip					Subsurface drip				
		0	5	10	15	25	0	5	10	15	25
2	0	5.59	6.0	6.35	7.00	7.71	6.41	6.55	7.26	7.40	7.81
	15	5.29	5.8	6.15	6.56	7.38	4.34	4.53	5.21	5.60	6.38
	30	4.94	5.31	5.67	6.81	7.05	4.11	4.34	4.83	5.11	6.00
	45	4.5	5.0	5.6	6.4	6.9	4.0	4.22	4.63	4.95	5.8
	60	3.47	5.91	4.37	4.82	5.56	2.83	3.04	3.71	3.91	4.64
6	0	5.43	5.74	6.01	6.70	7.48	6.54	6.58	7.16	7.35	7.84
	15	5.07	5.40	5.64	6.21	7.05	4.00	4.33	4.78	5.18	6.19
	30	5.04	5.20	5.50	5.82	6.73	4.10	4.34	4.73	4.97	5.78
	45	4.8	5.2	5.6	6.0	6.6	4.1	4.25	4.58	4.8	5.61
	60	3.72	4.20	4.40	5.07	5.95	2.85	3.10	3.22	3.74	4.12
10	0	5.17	5.55	5.78	6.30	7.03	6.62	7.05	7.58	7.90	8.26
	15	5.14	5.40	5.91	6.25	7.14	3.72	4.04	4.61	5.00	5.64
	30	5.02	5.28	6.02	6.35	7.90	4.10	4.28	4.72	5.20	6.16
	45	4.8	5.2	5.7	6.1	7.5	3.52	4.0	4.3	4.8	5.5
	60	3.95	4.30	4.90	5.13	5.66	3.00	3.35	6.36	4.00	4.52
14	0	4.97	5.31	5.54	6.00	6.70	6.74	7.22	7.67	7.92	8.23
	15	5.3	5.40	5.83	6.00	7.00	3.70	4.10	4.42	4.83	5.30
	30	5.15	5.67	6.00	6.20	7.08	3.90	4.30	4.50	5.05	5.90
	45	5.0	5.4	5.8	6.1	6.9	4.1	4.2	4.7	5.0	5.9
	60	3.79	4.90	5.23	5.52	6.10	3.15	3.50	3.64	4.10	4.73

Table A-7: Effect of operating pressure head on salt distribution along laterals under surface and subsurface drip irrigation, mmhos/cm.

Operating pressure head, m	Depth, cm	Distance from dripper, cm							
		Surface drip				Subsurface drip			
		0	5	10	15	0	5	10	15
2	0	5.46	5.78	6.31	6.62	6.26	6.47	6.81	7.23
	15	5.29	5.60	6.03	6.38	4.55	4.85	5.15	5.60
	30	4.91	5.26	5.72	6.10	4.44	4.72	4.93	5.26
	45	4.8	5.0	5.52	6.1	4.05	4.33	4.62	5.0
	60	4.72	4.97	5.37	5.91	3.25	3.57	3.75	4.04
6	0	5.34	5.64	6.13	6.47	6.28	6.62	6.77	7.16
	15	5.10	5.44	5.90	6.26	4.47	4.76	5.07	5.24
	30	4.77	5.12	5.60	6.04	4.31	4.60	4.95	5.10
	45	4.7	4.92	5.4	5.84	3.92	4.22	4.51	4.83
	60	4.50	4.86	5.26	5.63	3.00	3.36	3.65	3.78
10	0	5.14	5.5	6.04	6.00	6.49	6.88	7.11	7.32
	15	5.90	5.25	5.71	6.09	4.35	4.60	4.78	5.08
	30	4.66	5.00	5.38	5.69	4.27	4.58	4.8	5.00
	45	4.55	4.84	5.0	5.62	3.63	4.21	4.55	4.84
	60	4.35	4.72	5.10	5.43	3.18	3.29	3.60	3.78
14	0	4.79	5.28	5.66	6.04	6.76	6.94	7.29	7.41
	15	4.55	4.84	5.27	5.71	4.11	4.35	4.62	4.90
	30	4.54	4.70	5.0	5.31	4.08	4.42	4.58	4.82
	45	4.5	4.6	4.82	5.0	3.62	3.88	4.24	4.51
	60	4.50	4.63	4.82	5.18	3.00	3.18	3.35	3.56

Table A-8: Effect of operating pressure head on salt distribution under furrow irrigation, mmhos/cm.

Operating pressure head, m	Depth, cm	Distance from water inlet, m		
		5	10	15
2	0	3.85	4.14	4.52
	15	3.00	3.39	3.84
	30	2.80	2.95	3.30
	45	2.43	2.66	2.94
	60	2.00	2.3	2.75
6	0	3.64	3.90	4.12
	15	3.00	3.37	3.63
	30	2.52	2.78	3.00
	45	2.31	2.55	2.73
	60	2.00	2.00	2.51
10	0	3.11	3.55	4.00
	15	3.00	3.10	3.62
	30	2.25	2.50	2.84
	45	2.0	2.2	2.53
	60	2.00	2.00	2.00
14	0	3.00	3.30	3.66
	15	2.55	2.81	3.00
	30	2.00	2.20	2.51
	45	2.0	2.0	2.25
	60	2.00	2.00	2.00

Table A-9: Analysis of variance for total water aplied.

SV	DF	SS	MS	F
REP (R)	2	0.077	0.039	<1
IRRIGATION METHOD (I)	1	3029721	3029721	23039706 **
ERROR (a)	2	0.263	0.1315	
PRESSURE HEAD (P)	3	32723.09	10907.7	385431**
P x S	3	32697.27	10899.1	385127.2**
ERROR (b)	12	0.34	0.0283	
TOTAL	23	3095142.5		

** = significant At 1% level.

Table A-10 : Interaction between operating pressure head and irrigation methods for total water aplied

PRESSURE HEAD (P)	IRRIGATION METHOD (I)		
	I_1	I_2	I-Mean
P_1	1965.6a	2600d	2282.9
P_2	1966a	2625c	2295.5
P_3	1966a	2960c	2328.2
p_4	1966a	2791a	2378.3
P - MEAN	1965	2676.6	2321.3

	LSD (5%)	LSD (1%)
P means at each I	0.40	0.60
I means at each P	0.39	0.56

Table A-11: Analysis of variance for uniformity coefficient.

SV	DF	SS	MS	F
REP (R)	2	214.8	107.4	---
IRRIGATION METHOD (I)	2	3060.8	1530.4	---
ERROR (a)	4	428.4	107.1	
PRESSURE HEAD (P)	3	515.4	171.8	1.12 n
P x S	6	644.7	107.5	<1
ERROR (b)	18	2772.2	154.0	
TOTAL	35	7636.33		

ns = not significant; --- = insufficient error df

Table A-12 : Interaction between operating pressure head and irrigation methods for uniformity coefficient.

PRESSURE HEAD (P)	IRRIGATION METHOD (I)			I-MEAN
	I_1	I_2	I_3	
P_1	92.4 a	90.7 a	70.3 ab	84.45 a
P_2	91.6 a	90.23 a	74.6 ab	85.5 a
P_3	89.8 a	89.4 a	81.7 a	86.9 a
p_4	88.3 a	87.8 a	55.3 b	77.1 a
P - MEAN	90.51	89.52	70.47	83.5

	LSD (5%)	LSD (1%)
P means at each I	21.29	29.17

Table A-13: Analysis of variance for fertilizer distribution.

SV	DF	SS	MS	F
REP (R)	2	0.00005	0.000025	<1
FERTIGATION METHOD (F)	2	2820.6	1410.312	18556737 **
ERROR (a)	4	0.00031	0.000076	
PRESSURE HEAD (P)	3	423.3	141.1	2313114.8 **
F x P	6	109.03	18.17	297868.9 **
ERROR (b)	18	0.001111	0.000061	
TOTAL	35	3352.94		

** = significant at 1% level

Table A-14: Interaction between operating pressure head and fertigation methods for fertilizer distribution.

PRESSURE HEAD (P)	FERTIGATION METHOD (F)			F- MEAN
	F_1	F_2	F_3	
P_1	63.2 d	85.3 d	88.2 d	78.9
P_2	68.6 c	87.2 c	90.6 c	82.13
P_3	74.5 b	90.5 b	91.1 b	85.36
p_4	78.2 a	93.1 a	92.8 a	88.03
P - MEAN	71.13	89.02	90.7	83.61

	LSD (5%)	LSD (1%)
F means at each P	0.0144	0.0199
P means at each F	0.0143	0.0203

Table A-15: Analysis of variance for pressure difference.

SV	DF	SS	MS	F
REP (R)	2	10.9	5.43	<1
FERTIGATION METHOD (F)	2	417.52	208.76	25.61**
ERROR (a)	4	32.62	8.156	
PRESSURE HEAD (P)	3	352.44	117.5	24.3 **
P x F	6	81.64	13.61	2.8 n
ERROR (b)	18	86.98	4.833	
TOTAL	35	982.1		

** = significant at 1% level ; n = not significant

Table A-16: Interaction between operating pressure head and fertigation methods for pressure difference.

PRESSURE HEAD (P)	FERTIGATION METHOD (F)			F- MEAN
	F_1	F_2	F_3	
P_1	1.32 b	5.21 c	2.05 b	2.9 c
P_2	2.77 ab	10.34 b	3.84 b	5.65 b
P_3	4.62 ab	11.17 b	6.12 ab	7.31 b
P_4	6.5 a	19.62 a	8.35 a	11.5 a
P - MEAN	3.81	11.59	5.09	6.83

	LSD (5%)	LSD (1%)
F means at each P	4.036	5.56
P means at each F	4.24	6.06
P means	2.7	4.07
F means	2.02	2.78

Table A-17: Analysis of variance for root volume .

SV	DF	SS	MS	F
REP (R)	2	0.00661	0.0033	--
IRRIGATION METHOD (I)	2	14593.7	7296.85	--
ERROR (a)	4	0.023	0.0057	
FERTIGATION METHOD (F)	2	2329.03	1164.52	119143.4 **
I X F	4	60.8	15.18	1554.04 **
ERROR (b)	12	0.117	0.0098	
PRESSURE HEAD (P)	3	6841.9	2280.6	367406.57 **
I X P	6	25196.9	4199.5	676528.1 **
P X F	6	453.7	75.61	12180.9 **
I X P X F	12	999.7	83.31	13420.3 **
ERROR (c)	54	0.335	0.00621	
TOTAL	107	5047.15		

** = significant at 1% level ; -- = insufficient error df

Table A-18: Interaction between irrigation methods, operating pressure head and fertigation methods for root volume.

PRESSURE HEAD (P)	FERTIGATION METHOD (F) F_1	F_2	F_3	F- MEAN
I= I_1				
P_1	357 d	383.9 d	362 d	360.97
P_2	387 c	390.13 c	397 c	391.38
P_3	405 a	415 b	408 b	409.33
P_4	400 b	420 a	418.9 a	412.98
I = I_2				
P_1	385 d	404 d	400 d	396.34
P_2	406 c	426 c	422.01 c	418
P_3	435 a	438.9 b	431.01 b	434.97
P_4	432.1 b	440.9 a	439 a	437.32
I = I_3				
P_1	415 a	421 a	427.93 a	421.31
P_2	403 b	414.9 b	418 b	411.98
P_3	385 d	402 c	391 c	392.7
P_4	387 c	391 d	381.9 d	386.63
P- MEAN	399.8	410.65	408.07	406.16

	LSD (5%)	LSD (1%)
P means at each I * F	0.149	0.193
F means at each I * P	0.129	0.172

Table A-19: Interaction between operating pressures and fertigation methods for root volume .

PRESSURE HEAD (P)	FERTIGATION METHOD (F)			F- MEAN
	F_1	F_2	F_3	
P_1	385.7	396.3	396.64	392.8
P_2	398.7	410.36	407.12	407.12
P_3	408.4	418.63	412.33	412.33
P_4	406.4	417.3	412.3	412.31
P - MEAN	399.76	410.65	408.07	406.16

Table A-20: Interaction between operating pressure head and irrigation method for root volume .

PRESSURE HEAD (P)	IRRIGATION METHOD (I)			I- MEAN
	I_1	I_2	I_3	
P_1	360.97	396.34	421.31	392.87
P_2	391.38	418.0	411.98	407.12
P_3	409.33	434.97	392.69	412.33
P_4	412.98	437.32	386.63	412.311
P - MEAN	393.66	421.66	403.15	406.16

Table A-21: Interaction between fertigation method and irrigation method for root volume .

FERTIGATION METHOD (F)	IRRIGATION METHOD			I- MEAN
	I_1	I_2	I_3	
F_1	387.25	414.52	397.52	399.76
F_2	397.26	427.45	407.23	410.65
F_3	396.48	423.01	404.71	408.07
F - MEAN	393.66	421.66	403.15	406.16

Table A-22: Analysis of variance for yield .

SV	DF	SS	MS	F
REP (R)	2	0.031	0.015	--
IRRIGATION METHOD (I)	2	39.7	19.83	--
ERROR (a)	4	0.48	0.12	
FERTIGATION METHOD (F)	2	1.64	0.81	19.69 **
I X F	4	0.261	0.65	1.57 n
ERROR (b)	12	0.49	0.42	
PRESSURE HEAD (P)	3	10.43	3.48	61.99 **
I X P	6	0.889	0.15	2.64 *
P X F	6	0.578	0.096	1.72 n
I X P X F	12	1.44	0.12	2.14*
ERROR (c)	54	3.03	0.056	
TOTAL	107	58.94		

** = significant at 1% level ; -- = insuficient error df

Table A-23: Interaction between irrigation method, operating pressure head and fertigation methods for yield.

PRESSURE HEAD (P)	FERTIGATION METHOD (F) F_1	F_2	F_3	F- MEAN
$I=I_1$				
P_1	7.75 c	7.82 c	8.21 c	7.93
P_2	8.12 b	8.26 b	8.37 bc	8.28
P_3	8.61	8.72 a	8.74 ab	8.69
P_4	8..75	8.91 a	8.91 a	8.86
$I=I_2$				
P_1	7.8 c	8.094c	8.211 c	8.04
P_2	8.48 b	8.81 b	8.59 bc	8.53
P_3	8.211 b	8.78 ab	8.81 ab	8.6
P_4	8.88 a	9.08 a	9.0 a	8.99
$I=I_3$				
P_1	6.42 d	6.8 b	7.12 b	6.78
P_2	6.85 c	7.04 ab	7.74 a	7.21
P_3	7.72 a	7.31 ab	7.39 ab	7.47
P_4	7.24 b	7.48 ab	7.45 ab	7.36
P- MEAN	7.91	8.06	8.212	8.06

	LSD (5%)	LSD (1%)
P means at each I * F	0.381	0.514
F means at each I * P	0.388	0.516

Table A-24: Interaction between operating pressure head and fertigation method for yield .

PRESSURE HEAD (P)	FERTIGATION METHOD (F)			F- MEAN
	F_1	F_2	F_3	
P_1	7.33	7.58	7.84	7.58
P_2	7.84	7.94	8.24	8.00
P_3	8.18	8.27	8.31	8.26
P4	8.29	8.46	8.45	8.40
P - MEAN	7.91	8.06	8.21	8.06

Table A-25: Interaction between operating pressure head and irrigation method for yield .

PRESSURE HEAD (P)	IRRIGATION METHOD (I)			I- MEAN
	I_1	I_2	I_3	
P_1	7.93	8.04	6.78	7.58
P_2	8.28	8.53	7.21	8.01
P_3	8.69	8.60	7.47	8.26
P4	8.56	8.99	7.36	8.41
P - MEAN	8.43	8.54	7.21	8.06

Table A-26: Interaction between fertigation method and irrigation method for yield .

FERTIGATION METHOD (F)	IRRIGATION METHOD (I)			I- MEAN
	I_1	I_2	I_3	
F_1	8.33	8.34	7.06	7.91
F_2	8.43	8.62	7.14	8.06
F_3	8.56	8.65	7.43	8.21
F - MEAN	8.44	8.54	7.21	8.06

Table A-27: Analysis of variance for water use efficiency .

SV	DF	SS	MS	F
REP (R)	2	0.019	0.0092	--
IRRIGATION METHOD (I)	2	67.76	33.88	--
ERROR (a)	4	0.037	0.0093	
FERTIGATION METHOD (F)	2	.4122		22.26 **
I X F	4	0.063	0.21	1.71 n
ERROR (b)	12	0.111	0.016	
PRESSURE HEAD (P)	3	1.747	0.0092	692.9 **
I X P	6	0.61	0.58	10.97 **
P X F	6	0.16	0.026	2.85 *
I X P X F	12	0.10	0.0082	<1
ERROR (c)	54	0.50	0.0092	
TOTAL	107	71.512		

-- = insuficient error df, * = significant at 5% level ; ** = significant at 1% level.

Table A-28: Interaction between irrigation method, operating pressure head and fertigation method for water use efficiency.

PRESSURE HEAD (P)	FERTIGATION METHOD (F)			F- MEAN
	F_1	F_2	F_3	
$I=I_1$				
P_1	3.94 c	3.98 c	4.18b	4.033
P_2	4.18 b	4.2 b	4.59 a	4.32
P_3	4.35 a	4.44 a	4.45 a	4.41
P_4	4.45 a	4.53 a	4.53 a	4.5
$I=I_2$				
P_1	3.97 c	4.12 c	4.18 c	4.09
P_2	4.32 b	4.33 b	4.37 b	4.34
P_3	4.43 ab	4.47 ab	4.48 ab	4.46
P_4	4.52 a	4.62 a	4.58 a	4.57
$I=I_3$				
P_1	2.47 b	2.59 a	2.74 a	2.6
P_2	2.61 ab	2.68 a	2.8 a	2.69
P_3	2.68 a	2.72 a	2.75 a	2.71
P_4	2.59 ab	2.65 a	2.67 a	2.64
P- MEAN	3.71	3.78	3.86	3.78

	LSD (5%)	LSD (1%)
P means at each I * F	0.161	0.217
F means at each I * P	0.158	0.210

Table A-29: Interaction between operating pressure head and fertigation method for water use efficiency .

PRESSURE HEAD (P)	FERTIGATION METHOD (F)			F- MEAN
	F_1	F_2	F_3	
P_1	3.46	3.56	3.7	3.57
P_2	3.703	3.74	3.92	3.79
P_3	3.82	3.88	3.89	3.86
p_4	3.85	3.93	3.93	3.9
P - MEAN	3.71	3.78	3.86	3.78

Table A-30: Interaction between irrigation method and operating pressure head for water use efficiency .

PRESSURE HEAD (P)	IRRIGATION METHOD (I)			I- MEAN
	I_1	I_2	I_3	
P_1	4.033	4.09	2.6	3.57
P_2	4.32	4.34	2.7	3.79
P_3	4.41	4.46	2.72	3.86
p_4	4.50	4.57	2.64	3.9
P - MEAN	4.32	4.37	2.67	3.78

Table A-31: Interaction between irrigation method and fertigation method for water use efficiency .

FERTIGATION METHOD (F)	IRRIGATION METHOD (I)			I - MEAN
	I_1	I_2	I_3	
F_1	4.23	4.31	2.59	3.71
F_2	4.29	4.39	2.66	3.78
F_3	4.44	4.40	2.74	3.86
F - MEAN	4.32	4.37	2.66	3.78

Table A-32: Analysis of variance for nitrogen use efficiency .

SV	DF	SS	MS	F
REP (R)	2	0.074	0.04	--
IRRIGATION METHOD (I)	2	2864.8	1432.43	--
ERROR (a)	4	0.15	0.037	
FERTIGATION METHOD (F)	2	105.08	52.54	1418.6 **
I X F	4	31.82	7.96	214.82 **
ERROR (b)	12	0.444	0.037	
PRESSURE HEAD (P)	3	528.9	176.3	4760 **
I X P	6	132.14	22.02	594.6 **
P X F	6	62.75	10.46	282.4 **
I X P X F	12	95.93	7.99	215.84 **
ERROR (c)	54	2.00	0.037	
TOTAL	107	3824.15		

** = significant at 1% level ; -- = insuficient error df

Table A-33: Interaction between irrigation method, operating pressure head and fertigation method for nitrogen use efficiency.

PRESSURE HEAD (P)	FERTIGATION METHOD (F)			F- MEAN
	F_1	F_2	F_3	
$I=I_1$				
P_1	64.59 d	65.19 d	68.41d	66.06
P_2	68.43 c	68.68 c	69.78 c	69.02
P_3	71.28 b	72.71 b	72.83 b	72.27
P_4	72.9 a	74.27 a	74.22 a	73.79
$I=I_2$				
P_1	65.3 d	67.45 d	68.43 d	66.97
P_2	70.71 c	70.88 c	71.58 c	71.05
P_3	72.60 b	73.20 b	73.42 b	73.07
P_4	73.99 a	75.70 a	75.0 a	74.89
$I=I_3$				
P_1	53.50 c	65.13 a	59.40 d	59.34
P_2	57.08 b	58.68 d	61.17 b	58.97
P_3	60.08 a	60.95 c	61.60 a	60.87
P_4	60.34 a	61.55 b	60.74 c	60.87
P- MEAN	65.87	67.88	68.04	67.26

	LSD (5%)	LSD (1%)
P means at each I * F	0.322	0.435
F means at each I * P	0.315	0.42

Table A-34: Interaction between operating pressure head and fertigation method for nitrogen use efficiency .

PRESSURE HEAD (P)	FERTIGATION METHOD (F)			F- MEAN
	F_1	F_2	F_3	
P_1	61.04	65.92	65.41	64.13
P_2	65.41	66.14	67.51	66.35
P_3	67.99	68.95	69.28	68.74
p_4	69.08	70.51	69.99	69.86
P - MEAN	65.88	67.88	68.05	67.27

Table A-35: Interaction between irrigation method and operating pressure head for nitrogen use efficiency .

PRESSURE HEAD (P)	IRRIGATION METHOD (I)			I- MEAN
	I_1	I_2	I_3	
P_1	66.06	66.97	59.34	64.13
P_2	69.02	71.06	58.98	66.35
P_3	72.27	73.90	60.88	68.74
p_4	73.80	74.90	60.88	69.86
P - MEAN	70.29	71.50	60.02	67.27

Table A-36: Interaction between irrigation method and fertigation method for nitrogen use efficiency .

FERTIGATION METHOD (F)	IRRIGATION METHOD (I)			I - MEAN
	I_1	I_2	I_3	
F_1	69.30	70.58	57.75	65.88
F_2	70.26	71.81	61.58	67.88
F_3	71.31	72.11	60.73	68.05
F - MEAN	70.29	71.50	60.02	67.27

ARABIC SUMMARY

الملخص العربي

إضافة الأسمدة مع مياة الرى عبر شبكة الرى ذات أهمية كبيرة لما تحدثه من زيادة فى الانتاج وتحسين الاستفادة من السماد لأقصى درجة نظراً لانخفاض نسبة الفقد فى السماد المضاف سواء بالتطاير أو مع ماء الصرف مما يعمل على تقليل كمية السماد المستخدمة والحصول على أقصى انتاجية فى نفس الوقت وبالتالى زيادة كفاءة أستخدام السماد، كما أنة يمكن أضافة السماد مع مياة الرى خلال أى مرحلة عمرية للنبات مما يعمل على تحقيق أستفادة أفضل من السماد.

نظراً للأهمية الاقتصادية لمحصول الذرة فأنه تم إجراء هذه التجربة على محصول الذرة (هجين ثلاثى ٣١٠) فى المزرعة البحثية بمركز ميكنة الأرز بميت الديبة- محافظة كفر الشيخ خلال الموسم الزراعى٢٠٠٢ / ٢٠٠٣ وكان الهدف من الدراسة الأتى :-

١-تصنيع الانحناء واستخدامه مع خزان السماد كوحدة جديدة للتسميد مع نظم الرى وتقييم هذة الوحدة الجديدة تحت نظم رى مختلفة.

٢-المقارنة بين طرق التسميد المختلفة تحت ضواغط تشغيل مختلفة.

٣-تحسين كفاءة إضافة الماء والسماد وذلك لزيادة أنتاجية محصول الذرة.

وقد اشتملت الدراسة على العوامل الآتية :

أ – نظم الرى :

تم أستخدام ثلاثة نظم للرى كما يلى:-

١ – الرى بالتنقيط السطحى.

٢ – الرى بالتنقيط تحت السطحى (على عمق ٢٠سم).

٣ – الرى بالخطوط بأستخدام الأنابيب المثقبة.

ب – طرق إضافة السماد :

أستخدم فى الدراسة ثلاث طرق لأضافة السماد وهى كالأتى

١ – الانحناء (الكوع)

القطر الداخلى ٣,٨سم، نصف قطر الانحناء ٣٠سم، فتحتى دخول وخروج المحلول (السماد مع مياة الرى) بقطر ١,٢٥سم، زائدة مزدوجة داخل الأنحناء عند فتحتى دخول وخروج السماد على شكل مثلث بارتفاع ١,٢٥سم.

٢ – الاختناق (الفنشورى)

قطر داخلى ٢,٥سم وقطر الاختناق ١,٢٥سم.

٣ – خزان فرق الضغط

فتحتى دخول وخروج بقطر ١,٢٥سم.

جـ- ضاغط التشغيل :

تم استخدام أربعة ضواغط تشغيل هى ٢، ٦، ١٠، ١٤ متر.

كان الرى يتم كل ١٥يوم فى نظام الرى بالخطوط وأربعة أيام فى نظام الرى للتنقيط السطحى وتحت السطحى. كمية مياة الرى للتنقيط (سطحى – تحت سطحى)كانت ٢٠٣٧م^{٣}/فدان بينما متوسط كمية المياة المضافة مع نظام الرى بالخطوط كانت ٢٦٧٦ م^{٣}/فدان. تم التسميد باستخدام ١٢٠ وحدة آزوت (يوريا ٤٦,٥٪ آزوت) والتى تم تقسيمها على ٦ جرعات من بعد رية الزراعة (جرعة كل اسبوعين).

ويمكن تلخيص النتائج التى تم التوصل إليها فيما يلى :

1- توزيع الرطوبة الأرضية :

تقل الرطوبة الأرضية بزيادة المسافة (الرأسية والأفقية) عن النقاط وذلك على طول وعبر خط التنقيط وذلك مع نظام الرى بالتنقيط .

زيادة ضاغط التشغيل أدى إلى زيادة المحتوى الرطوبى فى الاتجاه الأفقى عن الاتجاه الرأسى.

فى نظام الرى بالخطوط زيادة ضاغط التشغيل أدى إلى زيادة المحتوى الرطوبى للأعماق المختلفة حيث تزداد كمية الماء المضافة.

أعلى قيمة للمحتوى الرطوبى تم الحصول عليها فى الطبقة السطحية عند ضاغط تشغيل ١٤ م فى كل من نظام الرى بالتقيط السطحى والرى بالخطوط بينما فى نظام الرى بالتنقيط تحت السطحى كانت أعلى قيمة للمحتوى الرطوبى عند اعماق ١٥، ٣٠سم عند ضاغط تشغيل ١٤متر.

٢ – توزيع الأمـــلاح :

يزداد تركيز الأملاح بزيادة المسافة الأفقية عن النقاط سواء على طول أو عبر خط التنقيط، بينما يقل تركيز الأملاح بزيادة العمق.

زيادة ضاغط التشغيل أدى الى أنخفاض تركيز الأملاح فى نظام الرى بالتنقيط السطحى والرى بالخطوط وخاصة فى الطبقة السطحية.

الرى بالخطوط قلل تركيز الأملاح فى قطاع التربة مقارنة بالرى بالتنقيط (سطحى وتحت السطحى) نظرا لزيادة كمية المياة المضافة.

أقل تركيز للأملاح للرى بالتنقيط كان مع التنقيط تحت السطحى عند أعماق ١٥، ٣٠سم وضاغط تشغيل ١٤متر، بينما أعلى تركيز للرى بالتنقيط كان مع التنقيط تحت السطحى عند الطبقة السطحية وضاغط تشغيل ٢متر.

مع الرى بالخطوط كان أعلى تركيز للأملاح عند الطبقة السطحية وضاغط تشغيل ٢متر بينما أقل تركيز كان على عمق ٦٠سم وضاغط تشغيل ١٤متر.

٣ – انتظام توزيع الماء :

زاد انتظام توزيع الماء على طول الخط الحقلى فى نظام الرى بالتنقيط مقارنة بالرى السطحى.

معامل الانتظام زاد بنسبة ١,١٦٪، ١٥,٨٪ فى نظام الرى بالتنقيط السطحى مقارنة بالتنقيط تحت السطحى والرى بالخطوط على التوالى حيث كان متوسط معامل الانتظام للتنقيط السطحى ٩٠,٥٢٪.

معامل الانتظام مع نظام الرى بالتنقيط السطحى وتحت السطحى زاد بزيادة ضاغط التشغيل من ٢متر إلى ٦متر، بعد ذلك قل معامل الانتظام بزيادة ضاغط التشغيل أكثر من ٦متر نظراً لزيادة الفواقد عبر خط التنقيط.

زيادة ضاغط التشغيل أدى الى زيادة انتظام توزيع الماء للرى بالخطوط حيث يقل التباين فى الماء المخزن على طول الخط.

٤ – انتظام توزيع السماد :

أظهرت النتائج زيادة معامل انتظام توزيع السماد لطريقة الحقن بالانحناء بنسبة ٢١,٥٥٪، ١,٥٤٪ مقارنة بالحقن بخزان الضغط والاختناق على التوالى، حيث كان معامل الانتظام بالانحناء ٩٠,٦٨٪.

زيادة ضاغط التشغيل أدت الى زيادة معامل انتظام توزيع السماد لطرق الإضافة المختلفة.

أعلى قيمة لمعامل انتظام توزيع السماد كانت ٩٢,٥٪ للحقن بالاختناق مع ضاغط تشغيل ١٤متر، بينما كانت أقل قيمة ٦٣,٢٪ عند الحقن بخزان الضغط التفاضلى مع ضاغط تشغيل ٢متر.

يتم قياس التغير فى تركيز السماد بأخذ عينات من مياة الرى على مدار زمن التسميد ثم يتم تقدير تركيز السماد بها وبالتالى يمكن تحديد مدى أنتظام توزيع السماد على مدار زمن التسميد مما له أثر فى تحقيق توزيع أفضل للسماد فى قطاع التربة وبالتالى تحقيق أستفادة أفضل من السماد.

أظهرت طرق الحقن بالانحناء والاختناق توزيع أكثر انتظامية للسماد مقارنة بخزان الضغط.
زيادة ضاغط التشغيل أدى إلى رفع تركيز السماد مع مياة الرى نتيجة زيادة معدل الحقن بزيادة ضاغط التشغيل.

أظهرت النتائج أن تركيز السماد فى مياة الرى كان ٣٠٠ مج/لتر عند ضاغط تشغيل ١٤ م وذلك عند أستعمال خزان الضغط كطريقة أضافة السماد مع مياة الرى ، وقد تم أضافة السماد بهذا

التركيز خلال ٢٠ ٪ من زمن الرى وبعد ذلك أنخفض التركيز ولذلك يسمى خزان الضغط بخزان الدفعة الواحدة.

أعلى تركيز للسماد مع مياة الرى عند الحقن بالانحناء والاختناق كان ١٥٨، ١٦٠ مج/لتر عند ضاغط تشغيل ١٤متر وقد تم الوصول لهذا التركيز فى حوالى ٤٠٪، ٢٠٪ من زمن الرى على التوالى.

٥- الانخفاض فى الضغط :

تم قياس التغير فى الضغط الناتج من وضع وحدات التسميد على الخط تحت الرئيسى، أوضحت النتائج الأتى:-

أعطى الاختناق أعلى انخفاض فى الضغط حيث زاد الانخفاض فى الضغط بنسبة ٧٠,١١٪، ٦٠,١٪ مقارنة بخزان الضغط والانحناء على التوالى، حيث كان متوسط الانخفاض فى الضغط للاختناق ١٢,٧٥٪.

زيادة ضاغط التشغيل أدى إلى زيادة التغير فى الضغط مع طرق التسميد المختلفة. أعلى قيمة للتغير فى الضغط كانت ١٩,٦٢٪ مع الاختناق وعند ضاغط تشغيل ١٤متر، بينما كانت أقل قيمة ١,٣٢٪ مع خزان الضغط وعند ضاغط تشغيل ٢متر.

٦ - حجم الجذر :

زاد حجم الجذر بنسبة ٣,١٧٪، ٢,٨٣٪ عند أستخدام الانحناء والاختناق كوسيلة لأضافة السماد على التوالى مقارنة بخزان الضغط التفاضلى، حيث كان حجم الجذر فى حالة أستخدام خزان الضغط ٣٩٨,٢ سم٣.

الرى بالتنقيط تحت السطحى رفع حجم الجذر بنسبة ٦,٤٪ و٤,٤٪ مقارنة بالتنقيط السطحى والرى بالخطوط على التوالى، حيث كان حجم الجذور للرى بالتنقيط تحت السطحى ٤٢١,٧سم٣.

زيادة ضاغط التشغيل أدت إلى زيادة حجم الجذر للرى بالتنقيط، بينما يقل حجم الجذر بزيادة ضاغط التشغيل عند الرى بالخطوط.

أعلى قيمة لحجم الجذر كانت ٤٤١سم٣ مع الرى بالتنقيط تحت السطحى وأضافة السماد بالاختناق وضاغط تشغيل ١٤متر، بينما أقل قيمة كانت ٣٥٧سم٣ مع الرى بالتنقيط السطحى وأضافة السماد بواسطة خزان الضغط التفاضلى وضاغط تشغيل ٢متر.

٧- محصول الحبوب :

محصول الحبوب من الذرة زاد بنسبة ٢,٦٪ و٩,٩٣٪ وذلك فى حالة أستخدام طريقة أضافة السماد بالانحناء مقارنة بأضافة السماد بالاختناق وخزان الضغط على التوالى، حيث كان محصول الحبوب ٧.٣٥ميجا جرام/ فدان فى حالة أضافة السماد بطريقة الأنحناء.

أعطى الرى بالتنقيط تحت السطحى أعلى انتاج للمحصول يليه التنقيط السطحى بينما أعطى الرى بالخطوط أقل انتاج حيث كان ناتج محصول الحبوب للنظم الثلاث ٧.٤٨، ٧,٣٢، ٦,٣٢ميجا جرام/ فدان على التوالى. أعلى ناتج حبوب كان ٨,١٥ ميجا جرام/ فدان مع الرى بالتنقيط تحت السطحى وأضافة السماد بطريقة الاختناق وضاغط تشغيل ١٤متر، بينما كانت أقل قيمة للمحصول حبوب كان ٥,٤٥ ميجا جرام/ فدان مع الرى بالخطوط وأضافة السماد بطريقة خزان الضغط التفاضلى وضاغط تشغيل ٢متر. زيادة ضاغط التشغيل أدت إلى زيادة المحصول وذلك لنظم الرى المختلفة.

٨ – **كفاءة استخدام المياه :**

كفاءة استخدام المياه زادت بنسبة ٩.٢٨٪، ٧.٣٣٪ وذلك فى حالة أضافة السماد بطريقة الانحناء والاختناق على التوالى مقارنة بأضافة السماد بطريقة خزان الضغط، حيث كانت كفاءة استخدام الماء ٣,٠٣ كجم/م٣ فى حالة الحقن بخزان الضغط التفاضلى.

أعطى الرى بالتنقيط تحت السطحى أعلى قيمة لكفاءة استخدام المياه يليه الرى بالتنقيط السطحى بينما أعطى الرى بالخطوط أقل قيمة حيث كانت كفاءة استخدام المياه للنظم الثلاث ٣.٦٨، ٣.٦٣، ٢,٣٧ كجم/م٣ على التوالى.

زيادة ضاغط التشغيل أدت إلى زيادة كفاءة استخدام المياه للرى بالتنقيط السطحى وتحت السطحى، بينما تزداد كفاءة استخدام المياه بزيادة ضاغط التشغيل من ٢ إلى ١٠م للرى بالخطوط ثم تقل القيمة عند زيادة ضاغط التشغيل عن ١٠متر.

أعلى قيمة لكفاءة استخدام المياه كانت ٤ كجم/م٣ مع الرى بالتنقيط تحت السطحى وأضافة السماد بطريقة الاختناق مع ضاغط تشغيل ١٤متر، بينما أقل قيمة كانت ٢,١ كجم/م٣ مع الرى بالخطوط وأضافة السماد بطريقة خزان فرق الضغط مع ضاغط تشغيل ٢ متر.

٩– **كفاءة استخدام النيتروجين :**

تمثل كفاءة أستخدام النيتروجين العلاقة بين محصول الحبوب وكمية السماد المضافة وتعبر عن مدى أستجابة محصول الحبوب لنظم الرى ووحدات التسميد المستخدمة.

كفاءة استخدام النيتروجين زادت بنسبة ٢,٥٣٪، ٩,٨٧٪ وذلك فى حالةأضافة السماد بطريقة بالانحناء مقارنة بأضافة السماد بطريقة الاختناق وخزان فرق الضغط على التوالى، حيث كانت كفاءة استخدام النيتروجين ٦١,٢٢ كجم محصول/ كجم نيتروجين لأضافة السماد بطريقة بالانحناء.

كفاءة استخدام النيتروجين للرى بالتنقيط زادت مقارنة بالرى بالخطوط حيث كانت كفاءة استخدام النيتروجين ٦١,٠٣، ٦٢,٣٨، ٥٢,٦٦ كجم محصول/ كجم نيتروجين للرى بالتنقيط السطحى وتحت السطحى ورى الخطوط على التوالى.

أعلى قيمة لكفاءة استخدام النيتروجين كانت ٦٧,٩٢ كجم محصول/ كجم نيتروجين مع الـرى بالتنقيط تحت السطحى وأضافة السماد بالاختناق وضاغط تشغيل ١٤متر، بينما أقـــل قيمـــة كـــانت ٤٥,٤٢ كجم محصول/ كجم نيتروجين مع الرى بالخطوط وأضافة السماد بطريقة خزان فرق الضغـط وضاغط تشغيل ٢متر.

زيادة ضاغط التشغيل أدت إلى زيادة كفاءة استخدام النيتروجين تحت نظم الـــرى ووحـــدات التسميد المختلفةز

التوصية النهائية:-

أستخدام الأنحناء الملحق على خزان السماد يعتبر طريقة ناجحة وفعالة فى اضافة السماد مع نظم الرى المختلفة لما يحدثة من استخدام امثل للسماد وتقليل نسبة الفقد بقدر كبير، كمـــا ان الرى بالتنقيط تحت السطحى يعتبر طريقة الرى مثلى لحقن السماد حيث التوفير فى مياة الـــرى والسماد المستخدم.

بسم الله الرحمن الرحيم

﴿ ٱللَّهُ ٱلَّذِى خَلَقَ ٱلسَّمَٰوَٰتِ وَٱلْأَرْضَ وَأَنزَلَ مِنَ ٱلسَّمَآءِ مَآءً فَأَخْرَجَ بِهِۦ
مِنَ ٱلثَّمَرَٰتِ رِزْقًا لَّكُمْ ۖ وَسَخَّرَ لَكُمُ ٱلْفُلْكَ لِتَجْرِىَ فِى ٱلْبَحْرِ بِأَمْرِهِۦ ۖ
وَسَخَّرَ لَكُمُ ٱلْأَنْهَٰرَ ﴿٣٢﴾ ﴾

صدق الله العظيم

لجــنة الأشــراف

د / السعيد محمد أحمد خليفة

أستاذ الهندسة الزراعية المساعد،

قسم الميكنة الزراعية،

كلية الزراعة بكفر الشيخ ،

جامعة طنطا

د / زكريا محمد أسماعيل عمارة

باحث أول بمعهد بحوث الهندسة الزراعية ،

مركز البحوث الزراعية ، الدقى– القاهرة،

جمهورية مصر العربية

" تطويـــر الـــري الحقلـــي"

تطويـــر نـظـم الــري بإضافــة السمـاد مع مـياه الــري

رسالة مقدمة من

طـارق محمـود عطافـــى مـــرســـى

للحصول على درجة دكتوراه الفلسفة
في العلوم الزراعية (الميكنة الزراعية)

لجنة المناقشة والحكم على الرسالة:

أ. د./ زكريا يونس عبداللطيف ....
أستـــاذ الهـنـدســـة الـزراعيـــة
قســـم الهـنـدســـة الـزراعيـــة
كليـــة الـزراعـــة – جـــامعـة الأزهر.

د./ سمير محمود جمعة ....
أستـــاذ الهـنـدســـة الـزراعيـــة المســـاعد
قســـم المـيكنـــة الـــزراعيـــة
كليـــة الزراعة بكفر الشيخ – جامعة طنطا.

د./ السعيد محمد أحمد خليفة ....
أستـــاذ الهـنـدســـة الـزراعيـــة المســـاعد
قســـم المـيكنـــة الـــزراعيـــة
كليـــة الزراعة بكفر الشيخ – جامعة طنطا.

د./ زكريا محمد إسماعيل عمارة..............................
باحث أول – معهد بحوث الهندسة الزراعية
مركز البحوث الزراعيـة، الدقـى، القـاهرة،
مصـــر.

التاريخ ٧/ ٢ / ٢٠٠٥

"تصوير الرى الحقلى"

تطوير نظم الرى بأضافة السماد مع مياة الرى

رسالة مقدمة من

طارق محمود عطافى مرسى

بكالوريوس فى العلوم الزراعية (الميكنة الزراعية) ١٩٩٦ قسم الميخنة الزراعية ـ كلية الزراعة بكفر الشيخ ـ جامعة طنطا

مابستير فى العلوم الزراعية (الميكنة انزراعية) ٢٠٠١ قسم الميكنة الزراعية ـ خلية انزراعة بكفر الشيخ ـ جامعة طنطا

استيفاء لمتطلبات الحصول على درجة دكتوراة الفلسفة

فى

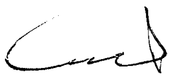
العلوم الزراعية

(الميكنة الزراعية)

جامعة طنطا

كلية الزراعة بكفر الشيخ

قسم الميكنة الزراعية



٢٠٠٥.