ISSN: 0974-5823 Vol. 7 No. 2 February, 2022

International Journal of Mechanical Engineering

Management of Fertigation and Its Effects on Irrigation Systems Performance and Crop Yield

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1. Introduction

According to the population projections of the World Bank, the world's population will increase from 6 billion people in 1999 to 7 billion people in 2020. Countries in Africa or South Asia have the highest growth rates or a high absolute increase in the number of people. Consequently, the world demand on food will increase by the global population growing. World food production can be increased by: (a) intensifying food crop production on land already under cultivation and (b) expanding the planted to food crops, e.g. through more continuous use of the very large area of poor soils which are now usually employed only for "shifting cultivation". The success of both methods will depend on judicious use of fertilizers (FAO 1981; 2000).

Fertigation is application of plant nutrients through irrigation water. It is a modern agro-technique provides an excellent opportunity to maximize yield and minimize environmental pollution (Hagin et al., 2002) by increasing fertilizer use efficiency, minimizing fertilizer application and increasing return on the fertilizer invested. It can improve fertilizer timing and reduce non-beneficial losses in deep percolation and surface runoff. Although this is possible with other methods of irrigation, it is a common and easily achieved practice with micro-irrigation systems. Being applied with irrigation, the fertilizer is easy to apply, with little extra labour and no extra machinery. Provided the hydraulic design of irrigation system is adequate, the fertilizer is applied uniformly to each plant, targeted at the root zone. Fertilizer can be applied at frequent intervals and at any required concentration, to suit plant requirements (Wichelns, 2007; Kafkafi and Tarchitzky, 2011).

The factors that govern the fertigation are soil types, crops, methods of irrigation used, water quality, types of fertilizers available, economic feasibility, equipment etc. Water and nutrient are the main factors of production in irrigated agriculture and the major inputs contributing to higher productivity. In intensive agriculture, both fertilizer and irrigation management have contributed immensely in increasing the yield and quality of crops. The method of fertilizer and irrigation application affects the efficiency of these inputs in arid and semi-arid regions (Biswas, 2010, Mansour et al., 2019a-e, Hu et al., 2019, Abdalla et al, 2019, Jiandong, et al, 2019, Abd-Elmabod et al, 2019a-b, Tayel et al 2019a-c, Hellal et al, 2019, Mansour and Pibars 2019, Attia et al., 2019, Pibars and Mansour, 2019, Hellal et al., 2021, Gaballah, et al, 2020, Pibars et al, 2020, Mansour et al, 2020a-d; Mansour and Aljughaiman 2020).

Various types of injection equipment are used to deliver fertilizer concentrate into the irrigation mainline. The most common used injectors are pressure differential tank, venturi suction device, and positive displacement (diaphragm or piston) injection pump. Both pressure differential tank and venturi are driven by pressure differentiation, where the positive displacement is driven electrically or hydraulically .The latter is the most expensive one, but gives greatest control over fertilizer application and therefore more accurate and flexible management. Other factors in the choice of system include suitability to automation, effect on pressure in the mainline, resistance to corrosion, maintenance requirements, and whether fertilizer is to be injected in proportion to water flow through the main on a continuous basis, or in separate, defined doses (so that injection rate is independent of irrigation rate) (Southorn, 1997).

Gains in net income due to fertigation can help justify the initial investment and the variable costs of operating and maintaining micro irrigation systems. Those gains are more likely to be achieved on high-valued crops, such as fruits as vegetables (Wichelns, 2007). Fares and Abbas, (2009) reported that savings about 29–78% in application costs may result due to the improved efficiency of fertilizer application, low fertilizer leaching, precise nutrient application, and right-amount and right-time fertilizer application. Although no significant increases in crop yield have been reported (Alva et al. 2005), uptake of major plant nutrients, i.e., nitrogen, phosphorous, and potassium, is higher with fertigation than with conventional methods (Papadopoulos 1988).

The article will review the management Techniques of fetigation to maximize both water and fertilizer use efficiency under suitable irrigation methods. This targeted improving crop yield productivity with an economical costs and taking into consideration human and environmental protection aspects are the main target of the article.

2. Fertigation

2.1. Definitions

Fertigation is the application of water soluble solid fertilizer or liquid fertilizers through drip irrigation water (Biswas, 2010). The use of fertigation is gaining popularity because of its efficiencies in nutrient management, time and labour and potentially a greater control over crop performance (Treeby et al. 2011). It is an efficient and economical mean of applying inputs necessary for crop, turf, nursery, greenhouse, and landscape management among others (The Irrigation Association 2000 and Sabreen et al., 2018).

2.2. Advantages

Fertigation offers a numerous benefits by applying though different irrigation methods (Evans and Waller, 2007; Biswas, 2010). These include:

- Fertilizer application is synchronized with plant need which variesrom plant to plant in drip fertigation, the amount and form of nutrient supply is regulated as per the need of the critical stages of plant growth.
- Optimization of nutrient balance in soils by supplying the nutrients directly to the effective root zones as per the requirement.
- Reduction in labour and energy cost by making use of water distribution systems for nutrient application.
- Timely application of small but precise amounts of fertilizers directly to the roots zone. This improves fertilizer use efficiency and reduces nutrient leaching below the root zone.
- Ensures a uniform flow of water and nutrients.
- Improves availability of nutrients and their uptake by crop.
- Safety application method, as it eliminates the danger affecting roots due to higher dose.
- Lower energy requirements for applying agrochemicals.
- Minimal percolation of water transporting chemicals and minerals below the root zone.
- Improves productivity through better control of the root environment relative to water and nutrient availability throughout the growing season.
- Reduces soil compaction due to much lower vehicular traffic.
- Reduces foliar crop damage.
- Improves and timely application of micronutrients (e.g., chelated iron, manganese, zinc and other micronutrients) fertilizers.
- Reduced wind drift of agrochemicals
- Improves incorporation of agrochemicals into the soil matrix.
- Reduces application cost.
- Decreases worker exposure to agrochemicals hazards.

2.3. Disadvantages

There are also disadvantages to fertigation which include (Evans and Waller, 2007):

- High management requirements. Careful management and supervision is required for accurate and safe applications, calibration, handling, maintenance and use of safety equipment.
- Uniformity of fertigation will depend upon a well-designed and operated maintained irrigation system.
- High initial equipment costs. Injectors, safety equipment, emergency showers, and containment areas are needed, but are usually less costly than for ground application equipment. Restricted storage and containment facilities for large volumes of dilute liquids may be required. Portability of injection equipment is usually limited unless mounted on trailers.
- Complexity of chemical interactions. Various fertilizers may have to be injected at separated points to limit reactions with fertilizers and/or biocides that are applied simultaneously.
- Chemical corrosion may reduce the life of irrigation system components.
- Environmental risk of system mismanagement or improper design. The possibility of water source contamination is increased if appropriate equipment is not correctly installed, operated, and maintained.
- Irrigation/fertigation scheduling difficulties. Timing, amount, and label requirements for fertigation may influence irrigation scheduling and depth of water applications.
- Fertilizers might be required when irrigations are not necessary, this increases the potential for leaching.
- Placement problems. Limited wetted area could limit access to nutrients in the dry soil volumes resulting in temporal crop nutrient stresses. Excessive applications of some nutrients may induce micronutrient deficiencies that are difficult to correct.
- Enhanced biological clogging hazards. Bacterial growth may be enhanced in the irrigation system components by nutrients addition.
- Disposal of back flush and rinse water. Back flush water from filter cleaning activities as well as rinse water from cleaning injection equipment may require special disposal measures due to the presence of various fertilizers.

3. Suitability of fertilizers for fertigation

Tayel, (2010) generalized the following considerations of the used fertilizers used in fertigaion:

- High solubility in irrigation water at normal temperature.
- Available in local market with suitable price.
- Contains the needed nutrients for plant in available compounds.
- Reaction may not occur between fertilizers each other or/and metal parts in the irrigation system which result in precipitates.
- Low level of vaporized loss of some forms of nitrogen fertilizers.
- Movement of fertilizer through soil profile has no restrictions comparing with water movement.
- Safe in field use.
- Improve both the quantity and quality of planted crop.
- Supplied from trusted commercial sources.

4. Fertigation system components:

Chemical injection into irrigation systems (Fig.1) requires three basic components (Evans and Waller, 2007):

a) Chemical supply tank;

b) Injection system; and,
c) Safety and anti-pollution devices to prevent any potential contamination of the water source.

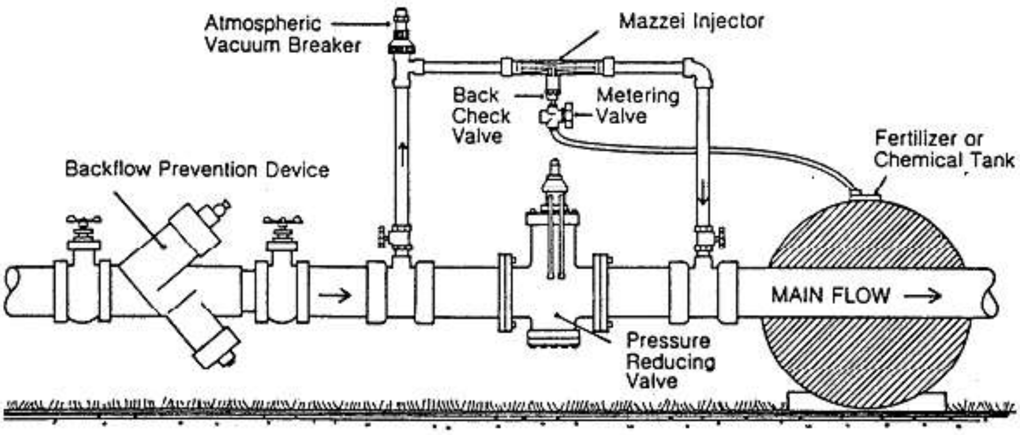

Fig.1: Fertigation system components connected to the irrigation system main line.

4.1. Fertilizer tank

Fertilizer tank is usually made of polyethylene or fiberglass.

Appropriate size chemical tanks equipped for agitation and a calibration tube are important to successful chemigation (The Irrigation Association 2000). Tank size is an important consideration for a fertigation system. Tank size should be large enough to contain the chemicals sufficient for at least one fertigation operation .To avoid overflow and to accommodate dead storage, it is always recommended to have a 10% extra tank volume. The size of the tank can be doubled, tripled, or increased to any size depending upon the number of fertigation planned between tank refilling (Fares and Abbas, 2009).As metal tanks may corrode plastic containers are preferred for the stock solution (Papadopoulos , 2001 and Mansour, et al., 2015).A sensor can be placed within the fertilizer tank. The sensor shuts the injection system off after the required volume of chemical is injected. It is a good practice to place a solenoid valve on the fertilizer injection tank discharge line. The solenoid valve (normally closed) should be interlocked with the irrigation pump so that the chemical tank is isolated from the irrigation pipeline in case of malfunction. The solenoid valve can also be connected to pressure switches and flow sensors to provide extra protection (Evans and Waller, 2007).

Proper selection of a chemical solution tank must include consideration of the following (The Irrigation Association 2000):

- Type of irrigation system.
- Crop grown.
- Irrigation system flow rate.
- Injection rate.
- Irrigation system operating pressure.
- Determination of whether a fixed volume ratio of chemical to water is needed.
- Duration of operation.
- Expansion requirements**.**

4.2. Injection devices

There are many types of injectors available, all with their own advantages and disadvantages. Some types of injection systems are not recommended due to the safety hazards that are inherent with those systems. According to The Irrigation Association, (2000) the choice of method and equipment will depend on the following:

- Type of chemical to be injected.
- Safety consideration.
- Source of power.
- Portability versus permanent installation.

4.2.1. Pressure differential tank

This system utilizes an air tight pressure metal tank with anti-acid internal wall protection in which a pressure differential is created by a throttle valve that diverts part of the irrigation water into the tank. This is the only fertigation system that enables the use of both solid and liquid fertilizers. The entire fertilizer amount in the tank is delivered to the irrigation area. The concentration at the water emitter end is kept constant as long as a solid fertilizer is present in the tank and solubility of the fertilizer is quickly achieved. Once the solid fraction is completely dissolved the fertilizer concentration is reduced at an exponential rate. In practice, when four tank volumes have passed through it, only a negligible amount of fertilizer is left in the tank. This equipment was used in the early stages of fertigation development. A limited area can be irrigated at a time according to the tank volume. The use of solid fertilizers must be handled with care (Kafkafi and Tarchitzky, 2011).

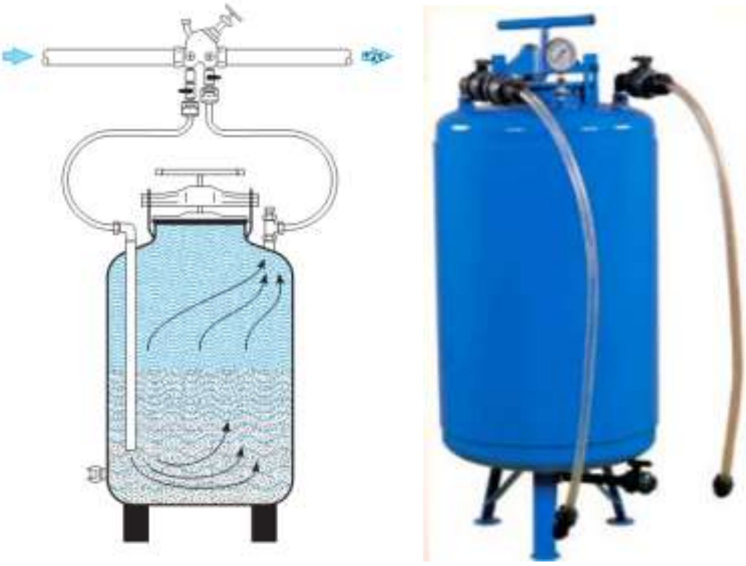

Fig.2: Pressure differential tank.

Advantages (Imas, 1999):

- Very simple to operate, the stock solution does have not to be pre- mixed.
- Easy to install and requires very little maintenance.
- Easy to change fertilizers.
- Ideal for dry formulations.
- No electricity or fuel is needed.

Disadvantages:

- Concentration of solution decreases as fertilizer dissolve.
- Accuracy of application is limited.
- Requires pressure loss in main irrigation line or a booster pump.
- Proportional fertigation is not possible.
- Limited capacity.
- Not adapted for automation.

4.2.2. Venturi suction device

This is a unit that makes use of the Venturi suction principle by using the pressure induced by the flowing water to suck the fertilizer solution from the fertilizer tank into the irrigation line. A conical constriction in the pipe induces an increase in the water flow velocity and a pressure decrease to an extremely low value which causes fertilizer suction (through the filter screens) from the supply tank through a tube into the irrigation system. A valve can be adjusted to control the difference between the water velocities across the valves (Kafkafi and Tarchitzky, 2011).

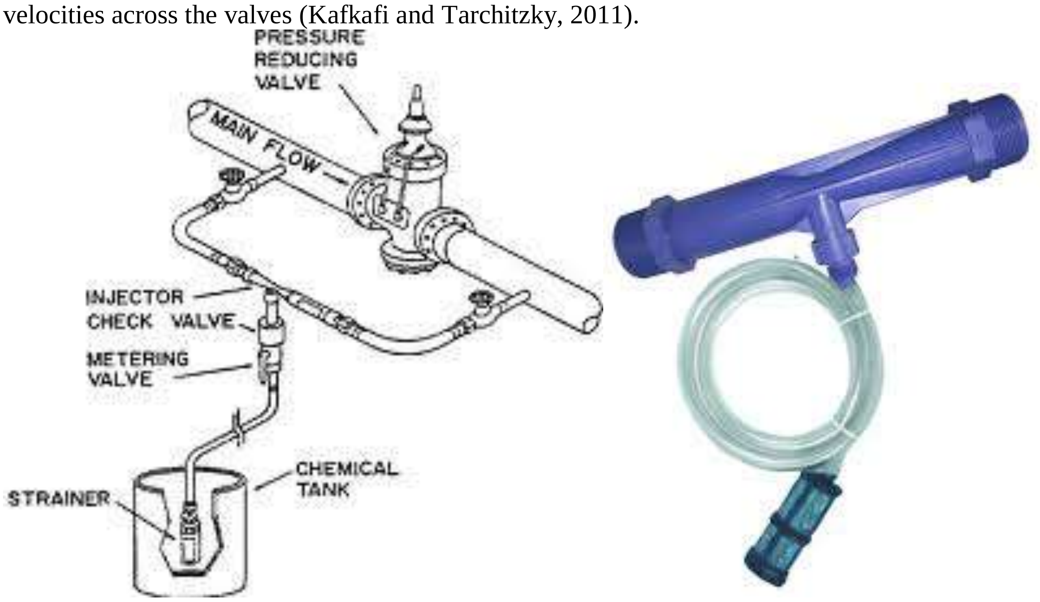

Fig.3: **Venturi suction device.**

Advantages (Imas, 1999):

- Very simple to operate , no moving parts.
- Easy to install and to maintain.
- Suitable for very low injection rates.
- Injection can be controlled with a metering valve.
- Suitable for both Proportional and quantitative fertilization.

Disadvantages:

- Requires pressure loss in main irrigation line or a booster pump.
- Quantitative fertigation is difficult.
- Automation is difficult.

4.2.3. Positive displacement

Positive-displacement pumps are able to raise the pressure of the liquid fertilizer from a stock solution tank at a predetermined ratio between fertilizer solution volumes to irrigation water volume, hence achieving a proportional distribution of nutrient in the irrigation water.

Positive-displacement pumps are recommended where precise control of injection flow rate of chemicals is required. Flow rate of positive displacement pumps remain constant over a range of irrigation pipeline pressures and chemical viscosities. Positive displacement pumps can typically control injection flow rates with a range of error of ±1% to

2%.Two types of injectors are commonly used in fertigation: piston pumps and diaphragm pumps. (Evans and Waller, 2007; Kafkafi and Tarchitzky, 2011) mentioned that the most common power sources for fertigation pumps are:

- Hydraulic energy: The device uses the hydraulic pressure of the irrigation water to inject nutrient solution while the water used to propel it (approximately three times the volume of solution injected) is discharged. These pumps are suitable for fertigation in areas devoid from any source of energy.
- Electric dosing pumps: The device activates the fertilizer pump. These are common in glasshouses and in areas where electricity is available and reliable.

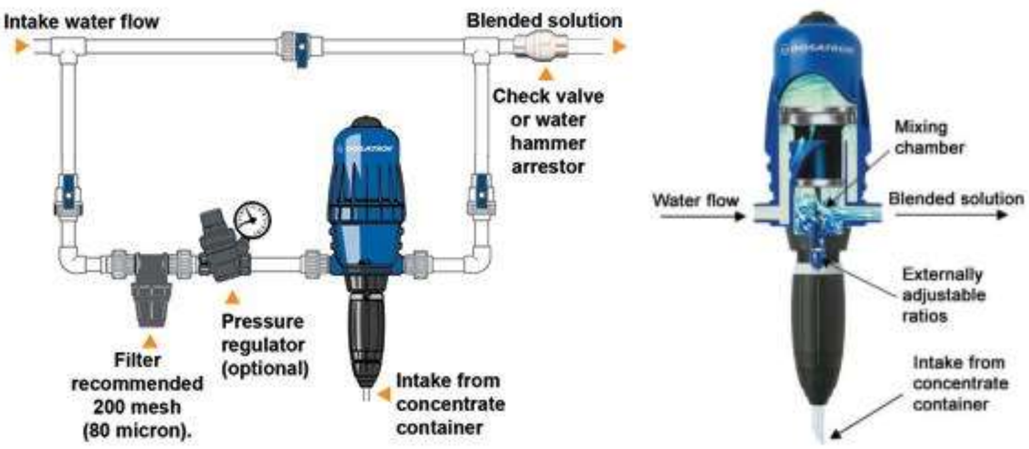

Fig.4: Positive displacement**.**

Advantages (Imas, 1999):

- Very accurate, for Proportional fertigation.
- No pressure loss in the line.
- Easily adapted for automation.

Disadvantages:

- Expensive.
- Complicated design, including a number of moving parts, so wear and breakdown are more likely.

3.3. Safety components

Adequate backflow prevention is required to protect groundwater and drinking water supplies from chemical contamination. Many types of backflow prevention are available in the market. In addition, many governmental agencies in same countries specify that the location of the chemigation system must be at a minimum distance, such as 30 m, from a water well, stream, drainage way, or other water source to reduce the pollution potential.

Chemigation has three main ways of potentially polluting irrigation water sources if safety devices are not functioning correctly (Evans and Waller, 2007):

- The chemical in the supply tank and in the irrigation pipeline could flow or be siphoned back into the water source when the irrigation system shuts down because of mechanical or power failures.
- The chemigation system could continue to inject chemical into the irrigation pipeline when the irrigation system shuts down causing the chemical solution to flow back into the water source or spill onto the ground. Continued injection of concentrated chemicals into a non-flowing irrigation line can also result in toxic solutions to be applied in a small areas of the field when the irrigation system is restarted creating a potential for runoff into surface water supplies as well as crop damage.
- The chemigation system could shut down while the irrigation system continues to operate and force water back into the chemical supply tank causing it to overflow and spill concentrated chemicals onto the ground.

3.3.1. Backflow prevention device:

A safety device is used to prevent water pollution or contamination by preventing flow of a mixture of water and/or chemicals in the opposite direction of that intended (ASAE, 1998).

Fig.5: Backflow prevention device**.**

3.3.2. Check valve:

A device to provide positive closure which effectively prohibits the flow of material in the opposite direction of normal flow when operation of the irrigation system pumping plant or injection unit fails or is shut down (ASAE, 1998).

Fig.6: Check valve.

3.3.3. Interlock devices:

Safety equipment used to insure that if the irrigation pumping plant stops, the chemical injection process will also stop .Devices may also be used to shut down the irrigation system if the injection system fails (ASAE, 1998 and Imam et al., 2019).

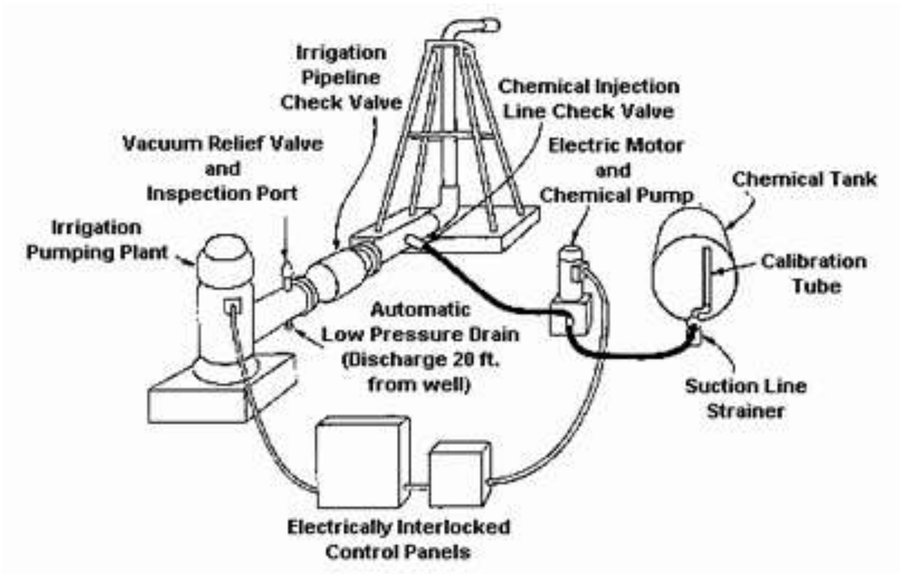

Fig.7: Interlock devices.

4. Effects of fertigation on irrigation system components

4.1. Chemical effects on irrigation system components

Field experience has indicated that the commonly used materials such as 28-32 percent UAN solutions, APP and UP solutions and most approved herbicides, insecticides and fungicides generally do not adversely affect system components. Recommended concentrations of fertilizer materials, although salty, will not damage galvanized surfaces, although painted surfaces are more susceptible to fertilizer corrosiveness. Caution should be used in adding solutions that they will not cause reduce water pH to 6.5 or lower, to prevent some irrigation system component damage may occur due to increasing reactivity/corrosivity of some solutions, clean out injection pumps and solution tanks with clean water (Curley et al. 1994; Kafkafi and Tarchitzky, 2011).

4.2. Clogging

Fares and Abbas (2009) had reviewed clogging caused by both alkalinity and acidity of fertilizer compounds in fertigation system. They cited that, since alkaline water forms insoluble compounds, it is not considered favorable for use in fertigation operations. Alkalinity of the water is especially crucial when P is used in fertigation, as the added P forms insoluble tri-basic calcium phosphate that can clog some irrigation equipment (Rauschkolb et al. 1976). This necessitates the continuous monitoring of pH of the P-carrying solutions flowing in the irrigation equipment (Koo 1980). Because MAP and DAP are excellent sources of P and N, these compounds are commonly used to enhance crop yield. There is a high possibility of precipitation of soluble P if MAP or DAP is mixed with irrigation water high in Ca^{++} or Mg^{++}. The precipitates formed in the irrigation equipment during fertigation can be dissolved and cleared with the use of acidic fertilizers (Bucks et al. 1979).

Although acidic fertilizers are corrosive to metallic components of the irrigation system and can potentially damage cement and asbestos pipes, they dissolve the precipitates and help to unclog the system's emitters or drippers. Periodic injection of phosphoric, nitric, sulfuric, or hydrochloric acid into the fertigation system can remove bacteria, algae, and slime trapped in the system.

Clogging is particularly crucial for drip irrigation systems because of their small orifices of the emitters (Koo 1980 and Tayel et al., 2013). Chemical solutions or low-quality, brackish water can also cause emitter clogging (Bucks et al. 1982). Very few reports on clogging of sprinklers during or after fertigation operations have been reported. Koo (1980) did not experience emitter clogging while using solution fertilizer in overhead sprinkler systems. However, Koo reported very little difference in the incidence of clogging between pre- and post-fertigation. The use of acidic fertilizers temporarily unclogs the system emitters. The irrigation and chemical injection systems should be thoroughly washed and flushed with fresh water, especially after the injection of acids into the system.

4.2.1. Reduction of clogging in fertigation systems

- **Filter irrigation water**

Good-quality water is crucial to reduce clogging problems in fertigation systems. If the irrigation water has visible debris and/or algae, irrigation water filters should be used to improve the quality of irrigation water and remove debris, clay particles, and algae before they enter the fertigation part of the system (Liu and McAvoy, 2012).

- **Acidify irrigation water**

Alkaline and hard irrigation waters are difficult to manage due to its high contents of bicarbonate, Ca and Mg which easily create insoluble compounds causing clogging of the irrigation system (Patricia and Ariana, 2009). There are different acids, such as hydrochloric, sulfuric, citric, and phosphoric. Acidic fertilizers can also acidify irrigation water. For example, urea-sulfuric nitrogen fertilizers can provide acid, fertilizer, and lower water pH. Urea-sulfuric fertilizers are not compatible with many compounds. Growers should never combine urea-sulfuric fertilizers with other fertilizers or compounds when acidifying irrigation water (Liu and McAvoy, 2012).

As a rule, never inject any chemical into micro irrigation systems that could raise the pH of the water without pre-acidification to counteract the effect. However, irrigation water pH generally should not be lower than 6.5 because of potential for system corrosion and excessive soil acidification (Evans and Waller, 2007).

- **Chlorinate irrigation water**

To effectively prevent bacterial growth in irrigation water, chlorine may be injected continuously at low levels. Either liquid or gas chlorine can be used. Sodium hypochlorite (NaOCl) solution (household bleach) is also readily available. At a concentration of 5 ppm or lower, active chlorine, and not chloride, can effectively kill bacteria in irrigation water. After chlorine application, the free chlorine concentration should be measured at the hose ends toward the completion of an irrigation set. For irrigation water with high bacteria populations, a continuous application may be needed, and 0.5–1.0 ppm free available chlorine should persist at the ends of lines. For irrigation water with relatively low bacterial populations, intermittent application of chlorine may be used. For occasional application, a concentration of approximately 5 ppm should be measured at the ends of lines. Regarding the bacterial count in the irrigation water, surface water has the potential to have greater bacterial population than deep well water (Liu and McAvoy, 2012).

- **Ensure that injected nutrients are compatible**

A recommended method used to pre-test for chemical precipitation is to appropriately mix the chemical or mixture of chemicals in a transparent glass jar or other clear, inert container of irrigation water at slightly higher concentrations than field application. The jar is shaken and observed for 24 h or more to see whether precipitation has occurred. The presence of precipitates mandates that the mixture must be modified to avoid clogging problems. If cloudiness occurs it is highly likely that the injected mixture will also cause some clogging and that remedial measures are needed. These “jar tests” should be conducted at the same pH, temperature, and other similar conditions that the chemicals will be applied. Safety glasses and protective clothing should always be worn when conducting jar tests (Evans and Waller, 2007).

5. Modern Techniques of fertigtion management

5.1. Fertigation system design software

Irrigation combined with fertigation has produced unquestionable results for the last few decades. It is arather complicated process as many factors must be controlled in order to produce good and environmentally safe fertigation practices. The efficiency and uniformity of irrigation, as well as the balance of the nutritive solution used to irrigate are highly ruled by the complex and diverse information (weather, soil,water, and crop data)(Barradas and Dolezal, 2012 ; Mansouret al., 2014 and Mehannaet al., 2015).For optimum plant performance under fertigation, all fertilization-irrigation-input factors must be balanced so that none impose a significant limit. Implementing a fertigation program the actual water and nutrient requirements of the crops, together with a uniform distribution of both water and nutrients, are very important parameters.

Many software were devloped to design a fertigation system. Inputs and outputs of ideal software for fertigation system design can be summarized as follows(Papadopoulos et al. 2003; Patel and Rajput, 2004 ; Sabreen and Mansour 2018):

Table (1): Inputs and outputs of fertigation system design software.

Inputs	Outputs
• Soil type, • Nutrient and water requirements of the crop. • Irrigated area in one application. • Fertilizer application rate. • Fertilizer requirement (kg/ha). • Solubility of fertilizer. • Frequency of irrigation. • Concentration of the liquid fertilizer. • Desired quantity of nutrients to be applied during the irrigation. • Ratio of fertilizer application time to the duration of irrigation.	• Irrigation water requirement. • Irrigation System capacity. • The maximum possible fertigation duration. • Capacity of fertilizer tanks. • The fertilizer injection rate. • Discharge through the fertilizer injector. • Requirement of Nitrogen, Potassium and Phosphorous nutrients of the crop. • Nutrient concentration in irrigation water.

5.2. Automation of fertigation system

Continuous cultivation within efficient management of fertilizers inputs has affected the consumed nutrients, environmental concerns and decrease in yields-qualitative and quantitative (Kaur and Kumar, 2013and Mansour et al., 2015).Controllers are available which allow complete automation and monitoring of the chemigation operation. For instance, several are capable of initiating injections, monitoring their activity, and deactivating injections according to external sensors such as flow and pressure switches, EC and pH monitors, and weather data (Curley et al. 1994 and Mehanna et al ., 2015).

5.2.1. Benefits of fertigation automation

The use of electronics in fertigation /chemigation process brings many benefits due to its accuracy, powerful calculation software and automation. Iacomi et al. (2014) summarized these benefits as follows:

- Optimize water/ nutrients/ pesticides inputs and protects natural resources (water, soil and soil nutrients),
- Use the correct rates of nutrients and water for plants, being essential not only for the improvement of irrigation system but also for reducing inputs costs and increasing crop yield.

- The proportion of fertilizer & water proportion is set as per software.
- Reduce the cost especially for those who are involved in agriculture.
- There are no skills required.
- The system set as automated and it will reduce the human error.

5.2.2. Components of fertigation automatic system

Kaur and Kumar, (2013) developed nutrients composition control system that can automatically monitor EC and pH level of fertigation solution with respect to the parameters of soil. The system measure these parameters (pH and EC)with the help of electrical sensor and maintained their level using required amount of fertilizers .The fertilizer quantity is limited according to the crop requirement.
General description of system components is:

- **Keypad:** Keypad is a part of Human Machine Interface which is used to enter or select the pH and EC values.
- **Microcontroller:** The system is based on PIC16F877A programmable controller used to measure and maintained the pH and EC according to the required values entered through keypad. The PIC controller has inbuilt ADC to measure the analog signal received from pH and EC sensor.
- **Relay:** Relay switch is electrically operated and used to operate the solenoid flow valve. The current flowing through the coil of the relay creates a magnetic field which attracts a lever and changes the switch contacts.
- **Relay Driver:** For relay's interfacing with microcontrollers or other low current digital ICs, a power or current amplifier circuit is required known as relay driver circuits. Diodes and opt couplers are used to operate relay using micro controller.
- **Solenoid valve:** A solenoid valve is an electromechanically operated valve which is most frequently used to control fluids flow. The irrigation tasks are to shut off, release, dose, distribute or mix liquid form solutions.
- **Mixing Tank:** A mixing tank contains the fertilizer solution mixed with water dropped through solenoid valves from other fertilizers tanks.
- **Nutrient Tanks:** Fertilizer tanks contain the different types of fertilizer to make solution acidic or alkaline.
- **Buzzer:** A buzzer is an audio signal producing output device. In this system buzzer is used for the indication of completed process.
- **Liquid Crystal Display (LCD):** The LCD is used to display the computing results. The main features of Hitachi 44780 LCD are: 16 X 2 displays used for alphanumeric characters & based on ASCII codes.

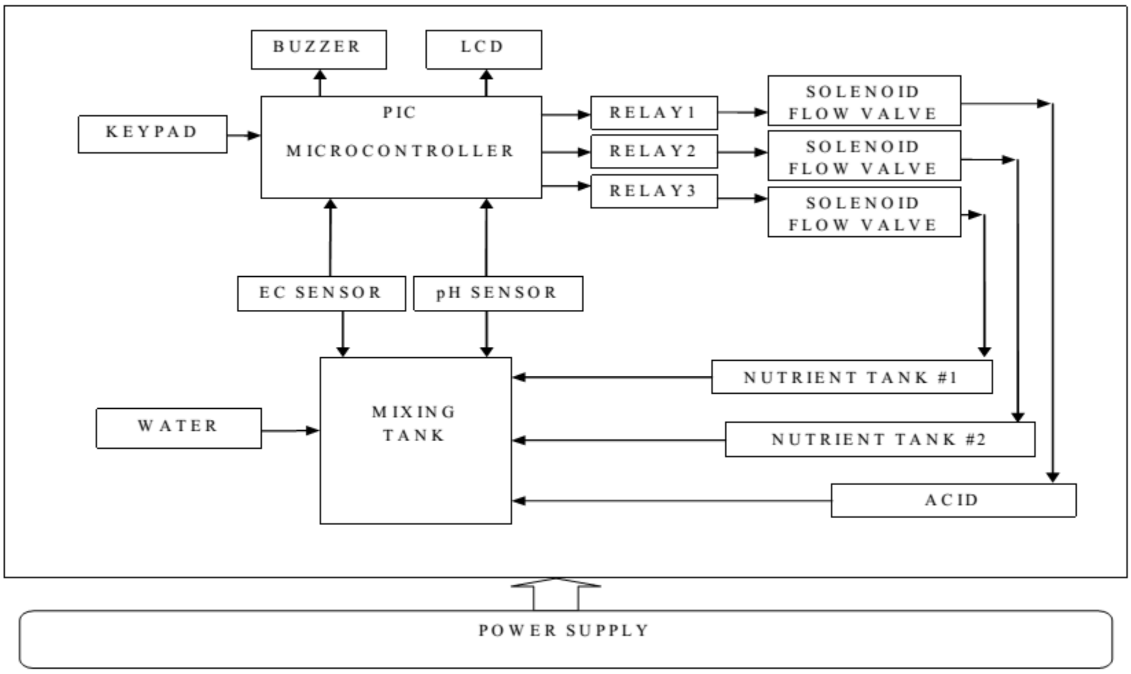

Fig.8: Components of automatic fertigation system.
Salih et al. (2012) developed a project to provide low cost solution for precise control of fertilizer mixing and irrigation to local farmers. The developed systems was powered totally by solar power system and were tested on its effectiveness to control the nutrient mixing process and injecting nutrient solutions according to plants growth rate and in the same time monitor all keys parameter in fertigation process.
They found that, by being fully operated with solar energy the system can be installed at rural and remote locations to achieve reductions in costs and produce better yield for rock melon or other crops cultivated using fertigation systems.

6. Effect of fertigation on crop yield

(BarYosef and Sagiv 1982 ; Sabreen et al., 2015) observed that the dry matter content of tomato was increased when the soil water potential decreased, whereas the optimum average N concentration in the irrigation solution was determined to be 130 ppm N. In drip irrigation system, water and nutrients can be applied directly to crop at the root level, having positive effects on yield and water savings and increasing the irrigation performance (Phene and Howell, 1984 ; Imam and Sabreen 2019) reported that the highest brinjal yield of 822g plant-1 was observed in drip fertigation at 180 kg N ha^{-1}compared to surface irrigation with 360 kg N ha-1 (202 g plant-1). Singh et al. 1998; Tayel and Sabreen, 2011; Hussien, and Sabreen, 2012 revealed that, when N and K fertilizers were applied through drip irrigation, higher tomato yield was obtained with 75 percent of recommended level compared to 100 percent and 50 percent of recommended levels of fertigation through drip.

According to Intrigiliolo et al. 1994 ; Tayel and Sabreen, 2011 the water consumption by orange trees was 21 percent lower in drip system than normal irrigation and also there was improved water, nutritional and physiological plant status in fertigation compared with the manual application of fertilizers. Parikh et al. (1996) studied the response of vegetables, sugarcane and fruit crops to micro irrigation system and fertigation and reported that the water saving ranged from 10 to 56 percent in various crops with improved yield of 13 to 60 percent. Fertigation studies in selected crops showed that about 40 percent of nitrogenous fertilizers can be saved without detrimental effect on yield and quality. The water use efficiency and fertilizer use efficiency were almost doubled due to fertigation. Malik and Kumar1996 and Ebtisam et al., 2012. observed that the drip irrigation level of 75 percent pan evaporation with 25 kg N ha^{-1}fertigation was the optimum combination for maximizing the water use efficiency and yields of peas grown on a sandy loam soil in Himachal Pradesh.

Dalvi et al.(1999) evaluated the effect of irrigation level, fertigation and frequency of micro irrigation on the yield of tomato. The study revealed that drip irrigation scheduled at every second day with irrigation at 79 percent of ET and fertigation 96 percent of recommended dose resulted in higher yield of tomato.

Muralidhar et al. (1999) reported that the drip fertigation at 80 percent of recommended N and K level with water soluble fertilizers registered higher tomato yield (22.3 t $ha\text{-}^{1}$) compared to 100 percent and 60 percent of recommended levels in drip irrigation .Jeyabal et al. (2000) reported that the drip fertigation at 75 percent of recommended N and K level recorded 12.3 percent higher yield of tomato than drip fertigation at 100 percent and 50 percent of recommended N and K levels. Decreasing the fertilizer level by 20 percent than the recommended level especially under fertigated conditions may not affect the yield level in chilli because of improved fertilizer use efficiency. Between furrow and drip methods of irrigation, drip irrigation method resulted significantly higher dry chilli yield with 42 percent higher water use efficiency over furrow method even with the same level and method of normal fertilizer application (Veeranna et al. 2000) observed the highest onion bulb yield of 18 t ha^{-1}in drip fertigation at 100 percent of recommended NPK level compared to 75 and 50 percent of recommended NPK levels. El-Gendy (1988) observed that fertigation with various amount of N; P and K fertilizers increased the yield of tomato, induced early flowering, and significantly improved the crop quality and water use efficiency. Baskar (2010) recorded the highest yield of banana with maximum water use efficiency of 2.18 kg m^{-3}in drip fertigation at 75 percent of recommended NPK level compared to drip fertigation at 100 and 50 percent of recommended NPK levels. Patel and Rajput 2002 and Ebtisam et al., 2015 reported that the fertigation at 100 percent of recommended level recorded an increased yield of 25.21percent (28.8tha-^{1}) compared to conventional method of fertilizer application in bhang.

Summary

The world demand on food is increasing by the global population growing. World food production can be increased by intensifying food crop production on land already under cultivation and expanding the planted to food crops. The success of both methods will depend on judicious use of fertilizers.

Fertigation is application of plant nutrients through irrigation water. It is a modern agro-technique provides an excellent opportunity to maximize yield and minimize environmental pollution by increasing fertilizer use efficiency, minimizing fertilizer application and increasing return on the fertilizer invested.

Basic components of fertigation system are chemical supply tank; injection system (pressure differential tank, venturi suction device, and positive displacement injection pump); and, safety and anti-pollution devices to prevent any potential contamination of the water source.

The irrigation system could be affected due to unsuitable management of fertigation system. Use of fertilizers changes the injected solution pH. Some irrigation system components may be damaged due to increase of reactivity /corrosivity by lowering of solution pH to 6.5 or lower. Clogging of lines and emitters may become a problem if not managed appropriately. Since fertigation is a combination of irrigation and fertilization, clogging problems can be traced back to either the water supply or injected fertilizers.

Modern technology gives powerful tools for both designing and managing fertigation systems. Many computer programs had developed to facilitate the design of a fertigation system .Controllers are available which allow complete automation and monitoring of the chemigation operation. For instance, several are capable of initiating injections, monitoring their activity, and deactivating injections according to external sensors such as flow and pressure switches, EC and pH monitors, and weather data.

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