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EFFICIENT USE OF WATER AND FERTILIZERS IN IRRIGATED AGRICULTURE: DRIP IRRIGATION AND FERTIGATION

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Increasing food demand and decreasing water resources have composed a kind of pressure to find new technologies for efficient use of water and fertilizers in agriculture. Drip irrigation can be able to save irrigation water from 30% up to 50% in case it is properly designed, installed and operated compared to surface irrigation, and it can also enable increasing crop yields and crop quality. In order to get the highest benefits using drip irrigation, some soil data (infiltration rate, soil texture and soil structure), crop characteristics (row space, plant density, canopy cover, root system, crop species, crop variety) and water resources properties (water quality, surface or well water) must be considered in drip system design, management and operation. Fertigation is basically an agricultural technique and application together with water and fertilizer to soil and/or plants. It increases both yield and fertilizer use efficiency; therefore, leaching of nutrients is prevented. In order to utilize fertigation successfully, the four main factors must be considered: (i) the consumption rate of water and nutrients throughout the growth season that result in optimal yields, (ii) response in uptake of different crops to nutrient concentration in the soil and soil solutions, (iii) monitoring for total soil water potential, nutrients concentration in soil solution and % elements in plants as a function of time and (iv) root mass and distribution in the soil for given irrigation regimes and soil types.

Keywords: nutrient use efficiency, water use efficiency, water saving, sustainability

Water is essential to grow crops, to provide food and to decrease drought risks. Irrigated agriculture globally uses more than 70% of water (Khokhar, 2017; Anonymous, 2019a). Thus, it places increasing pressure on freshwater resources, especially in developing countries. Considering demand of industrial and domestic water, the ways of efficient water use must be practiced in irrigated agriculture. Use of surface irrigation methods in the world, especially in developing countries, is still preponderant. In general, these conventional irrigation methods use water excessively. This situation is mainly dependent on the nature of these methods and farmers' conditions.

In semiarid and arid climatic conditions, increasing agricultural production is mainly dependent on irrigation. As known, the conventional irrigation methods (surface irrigation) use much more water compared to the pressurized irrigation systems such as sprinkler and drip irrigation. Increasing food demand and decreasing water resources have composed a kind of pressure to find new technologies for efficient use of water and fertilizer for agriculture. In addition, protection of soil and water resources and environmental sustainability are other crucial factors to be considered. Thus, efficient and less water and fertilizer use is significantly important in terms of environmental protection (Hagin et al., 2003).

A considerable amount of water is lost as leakage and/or evaporation during storage and transport to the fields where the crops are grown in irrigated agriculture. The runoff is also an important loss considering surface irrigation (Wallace, 2000). Thus, the most important issue on use of water resources is to minimize the amount of water used in irrigated agriculture.

In order to increase water use efficiency and to shift to a more sustainable use of water in agriculture, improvement in water use efficiency is required (Barua, Kumar and Singh, 2018). This aim can be reached by: use of water efficient irrigation systems, appropriate irrigation scheduling, watershed management development, growing drought-tolerant crops, dry farming, rotational grazing, use of mulch and compost, cover crops, conservation tillage, and organic agriculture. One of the most important ways is to shift to the pressurized irrigation systems such as drip and sprinkler irrigation. The plant root zone receives water directly into the root zone by means of these systems. However, reducing the evaporation that happens with sprinkler irrigation systems is another important issue. Therefore, the adoption of drip irrigation, low-pressure sprinkler systems, and other water saving technologies and practices, has been becoming more widespread (Üzen, Çetın and Karaer, 2013; OECD, 2010).

The aim of this review paper is to give some basic benefits, gains and rules of drip irrigation and fertigation in case those are used in irrigated agriculture.

Increasing water use efficiency in irrigated agriculture: Use of drip irrigation

Drip irrigation is a method/kind of pressurized irrigation in which water is in form of portions slowly delivered to the plant root zone using less amount of water. Studies in many countries have shown that drip irrigation can save

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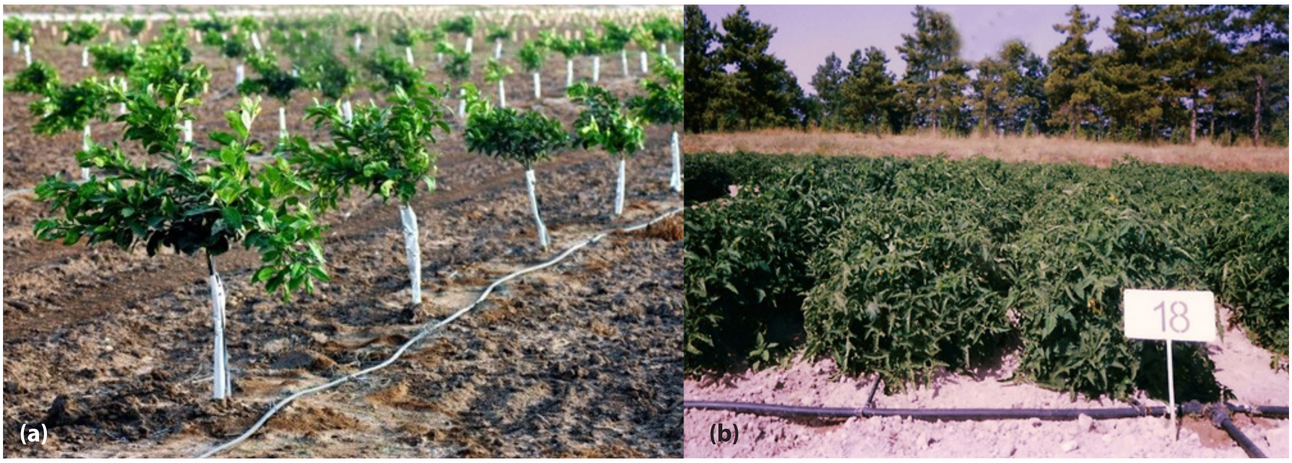

Figure 1 Use of drip irrigation for different horticultural crops. Young orange trees (a), field tomatoes (b)
Source: (a) – anonymous, 2019b; (b) – Çetın and Uygan, 2008

water use by 30% to 70% and raises crop yields by 20% to 90% depending on soil, climatic and crop characteristics, and farmers practices if it is properly designed, installed and operated (Postel et al., 2001; Çetın and Bilgel, 2002). In addition, considering water savings and higher yields by drip irrigation, water use efficiency also increases at least by 50% (Chartzoulakis and Bertaki, 2015).

At first, drip irrigation was mainly started to be used for horticultural (Fig. 1) and ornamental plants (Fig. 2). Then, it has been used for all kind of crops including field crops (Fig. 3), landscape and forest plants. (Stein, 2019). Drip irrigation enables a way of making sure each plant gets exactly the amount of water it needs, because it uses flexible tubing and/or pipes such as PE connected to individual drippers, or emitters. The drippers are placed at the root zone of each plant and apply a specific or certain amount of water in every irrigation cycle.

Table 1 shows how much irrigation water could be saved compared to the surface irrigation. The resulting efficiency, of course, depends on climatic, soil and crop characteristics and farmer practices. Thus, water saving ratio can vary depending on these conditions.

The advantages of drip irrigation could be specified as water saving (30–50%), higher crop yield, maximum utilization of available water, no water being available for weeds, high efficiency in the use of fertilizers, less weed growth, lower labour, no soil erosion, possible sophisticated automatic control, no runoff, no leaching of fertilizers into ground water, and less evaporation losses compared to surface irrigation. However, drip irrigation has some limitations such as clogging, salinity hazards at the top of soil profile for arid and semi-arid regions, higher investment costs compared to surface irrigation, higher skills and

Table 1 Efficiency of drip irrigation when compared to surface irrigation

Crop	Yield (kg.ha^{-1})			Irrigation		
	surface	drip	increase (%)	surface	drip	saving (%)
Beet root	570	880	54	86	18	79
Bitter gourd	3,200	4,300	34	76	33	57
Potato	17,200	29,100	69	60	28	54
Cucumber	4,230	6,090	44	109	42	62
Broccoli	14,000	19,500	39	70	60	14
Chili	17,100	27,400	60	27	18	33
Pomegranate	3,400	6,700	97	21	16	24
Okra	15,500	22,500	45	54	24	56
Onion	28,400	34,200	20	52	26	50
Tomato	6,180	8,870	44	50	11	79
Sweet potato	4,240	5,890	39	63	25	60
Banana	57,500	87,500	52	176	97	45
Watermelon	8,210	50,400	514	72	25	65
Grapes	26,400	32,500	23	53	28	47

Source: Shah, 2011

Figure 2 Use of drip irrigation for ornamental plants
Source: Anonymous, 2019c

Figure 3 Use of subsurface (a) and surface drip (b) drip irrigation on field crops such as cotton
Source: Çetın et al., 2018

experiences required for its design, install, operation and management.

In order to get the highest benefits using drip irrigation, some soil data (infiltration rate, soil texture and soil structure), crop characteristics (row space, plant density, canopy cover, root system, crop species, crop variety) and water resources properties (water quality, surface or well water) must be considered for drip system design, management and operation. Among others, the lateral design, dripper discharge, dripper space and requirement of energy are the most important components of drip irrigation system design.

The main problems in the use of drip irrigation systems are physical (sand and suspended solids) biological (bacteria, fungi and algae, slime) and chemical causes (mineral precipitation,- lime content of water) of emitter clogging. The common elements are calcium, magnesium, iron and manganese that may clog drip emitters by precipitation and sedimentation.

The most important irrigation water parameters in use of drip irrigation systems are content of suspended solids, dissolved solids, iron, manganese and bacteria (total plant count/ml), pH, hardness (as $CaCO_3$).

Use of fertilizers together with irrigation: Fertigation

Fertigation is basically defined as an application of fertilizers in irrigation water by means of irrigation systems. Fertigation has become a common practice in modern irrigated agriculture. Localized irrigation systems such as drip irrigation enable higher efficiency of water and fertilizer use. Considering the conventional fertilizing, this technique has got many advantages and is a kind of modern technology. Thus, the combined irrigation and fertilization has been widely used for the cultivation of crops and fruit orchards all over the world (Yan, Dai and Jia, 2018). Drip irrigation is more appropriate for applying fertigation. Thus, the soluble fertilizers at any concentrations needed by crops can be applied through irrigation systems to wetted zones of soil (Chartzoulakis and Bertaki, 2015).

Fertigation can be practiced for any irrigation system. However, fertilizers applied by surface irrigation and open canals might be inappropriate for nutrient distribution in the field. Fertigation can be applied as an integral part of plant nutrient management and specifically under micro-irrigation, because such systems provide a concentrated and space-limited root system within the wetted soil volume and fertigation can ensure the optimum plant nutrition. On the other hand, soluble N fertilizers such as urea, ammonium sulphate, ammonium nitrate, and liquid urea are easily injected and applied through drip and microsprinkler systems and are commonly used for fertigation in vine and tree fruit crops (Schwankl, Hanson and Prichard, 1998; Bar-Yosef, 1999; Kafkafi and Tarchitsky, 2011).

The advantages of fertigation could be mentioned such as healthier plants, quick delivery of nutrients to plant roots, nutrient requirements can be adjusted with immediate effects, uniform distribution and precision application for nutrients, less labour, less water use, reduced runoff, increasing fertilizer use efficiency and nutrient availability, saving about 20–40% of fertilizer without affecting growth and yield of crops, saving labour and energy in application of fertilizer, reducing environmental contamination and leaching of nutrients. Additionally, fertigation prevents losses of nitrogen due to the fact that there is no leaching, because nutrients are directly supplied to root zone in available forms in the form of portions. Thus, nutrient concentration in soil solution can be controlled and application cost decreased.

Possible disadvantages and/or limitations of fertigation are higher initial investment cost, some inappropriate chemical reactions in the equipment of drip irrigation and fertigation, corrosion and precipitation of fertilizer and clogging of emitters. In addition, some other limitations can occur such as non-uniform fertilizers/nutrients distribution, the over-fertilization in case that irrigation is not based on actual crop requirements and the excessive use of soluble fertilizers (Chartzoulakis and Bertaki, 2015).

Fertigation is associated and/or considered together with irrigation engineering, soil science, plant nutrition, fertilization (soil physics, soil chemistry, soil biology, plant nutrition, soil fertility and fertilizer) and plant physiology. Thus, affecting factors of fertigation can be specified such as soil texture, plant root system, dripper discharge and dripper space, irrigation time, wetting area, fertigation injection rate, water quality, crop canopy cover and crop yield. In the case that all these conditions are taken into consideration, an appropriate and/or desirable quality and benefits could be provided by fertigation.

In addition, in order to utilize fertigation successfully, the four main factors must be considered:

a) the consumption rate of water and nutrients throughout the growth season that results in optimal yields;
b) response in uptake of different crops to nutrient concentration in the soil and soil solutions;
c) monitoring of total soil water potential, N concentration in soil solution and amount of elements in plants as a function of time;
d) root mass and distribution in the soil for given irrigation regimes and soil types.

Application methods and devices of fertigation

The application of fertilizers in fertigation can occur:

a) with gradual decrease;
b) constantly during the entire irrigation;
c) during a part of irrigation;
d) with intermitted chemical concentration (Manor et al., 1983).

Thus, different injection equipment can be used such as by-pass (closed tank) system, venturi (suction) and a hydraulic or external pump to apply different fertigation application methods. Fig. 4 shows the trend of fertilizer concentration in irrigation water during irrigation according to the application methods of fertigation.

The application devices of fertigation have got some different advantages and disadvantages. The advantages in use of the by-pass (closed tank) system are:

a) very simple operation;

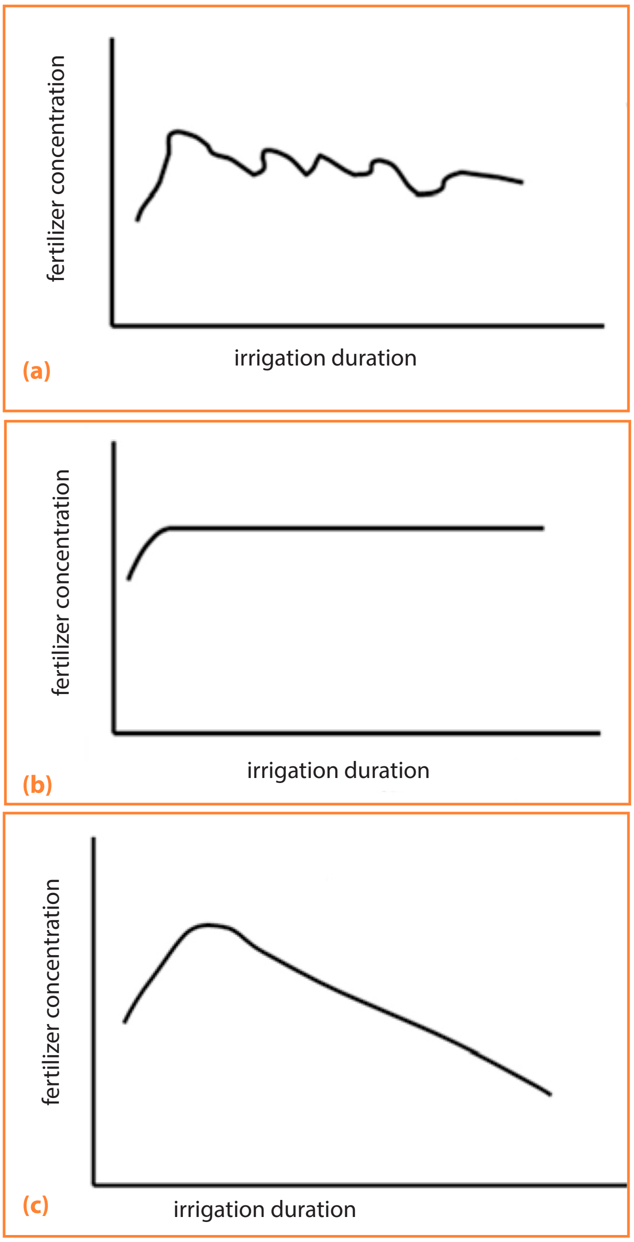

Figure 4 Distribution of fertilizer concentration in irrigation water during irrigation according to the application devices of fertigation
(a) venturi (suction) (b) external pumps and (c) pressure differential injection (closed tank, by-pass)

b) the stock solution does not need to be pre-mixed;
c) easy to install and not much maintenance needed;
d) it is not difficult to change fertilizers;
e) suitable for dry formulations;
f) no need of another energy source such as electricity or fuel.

The limitations in use of by-pass tank system are:
a) decreasing fertilizer concentration as fertilizer dissolves;
b) accuracy of application is not high.

There is some pressure loss in main irrigation line, proportional fertigation and equal concentration maintenance during irrigation is not possible, it is not suitable for automation. This system has been used commonly because of some advantages given above. The system was used successfully in different field crops such as silage corn and cotton (Yolcu and Çetın, 2015; Üzen and Çetın, 2016). Venturi (suction) device does not need an external energy (pressure) source to operate, its cost is relatively lower compared to other fertigation devices and it is easily connected to computer systems. However, its limitations include pressure loss in main irrigation line and the difficulty of quantitative fertigation and automation. The external pumps provide very accurate and proportional fertigation. There is no pressure loss in irrigation line and it is very suitable for automation. Disadvantages of this device are complicated design, it is expensive and requires more skills and experiences.

Basic rules for fertigation

Some basic rules for fertigation could be specified as below (Burt, 1998):

- Fill the mixing tank (container) with about 50–75% of the required amount of water to be used in the mix for dry and soluble fertilizers.
- Add the liquid fertilizers to the water in the mixing container before adding dry and soluble fertilizers. The additional fluid will create some heat in case the dry fertilizers have the characteristic of making solutions cold.
- Add the dry materials slowly with dispersion or shaking to prevent the formation of large, insoluble or slowly soluble lumps.
- Do not put water into acid, put acid into water.
- When chlorinating water with chlorine gas, chlorine is added into water.
- An acid or acidified fertilizer with chlorine is never mixed, whether the chlorine is in the gas form or the liquid form such as sodium hypochlorite. A toxic chlorine gas will form. Never store acids and chlorine together in the same room.
- Do not attempt to mix either anhydrous ammonia or aqua ammonia directly with any kind of acid. The reaction is violent and immediate.
- Do not attempt to mix concentrated fertilizer solutions directly with other concentrated fertilizer solutions.
- Do not mix a compound containing sulfate with another compound containing calcium. The result will be a mixture of insoluble gypsum.
- Always check with the chemical supplier for information about insolubility and incompatibility.
- Be extremely cautious about mixing urea sulfuric fertilizers with most other compounds. Urea sulfuric is incompatible with many compounds.
- Many incompatibility problems tend to disappear if chemicals are spoon-fed.
- Do not mix phosphorus containing fertilizers with another fertilizer containing calcium without first performing the jar test.
- Extremely hard water (containing relatively large amounts of calcium and magnesium) will combine with phosphate, neutral polyphosphate or sulfate compounds to form insoluble substances.

Conclusion

It can be assumed that because of its advantages, mainly drip irrigation systems should be used for conservation and sustainability management of soil and water resources. Drip irrigation provides more crops per drop and it saves about 30–50% of water. Thus, a major increase in water use efficiency and reduction in land and water degradation is essential. All researches, studies and approaches showed that increasing water use efficiency in irrigated agriculture is inevitable considering climatic change, drought conditions and decreasing water resources. This could be achieved mainly by use of drip irrigation. However, drip irrigation systems must be designed and installed considering soil and crop characteristic, and if operated appropriately, higher water use efficiency and higher benefits can be obtained. In addition, fertilizers and chemicals can be applied in safe and desired concentrations. Taking into account fertigation and drip irrigation, both of them could markedly improve availability and absorption of water and nutrients in soil, resulting in substantial increase of crop production and quality. Design, management, operation and maintenance of drip irrigation and fertigation need much more data on soil and crops, and higher skills and experiences. If all these conditions are taken into consideration, the maximum benefit can be obtained by use of drip irrigation and fertigation.

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