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EFFECT OF DRIP FERTIGATION ON FIELD CROPS - A REVIEW

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ABSTRACT

Water is the most important and critical input in man's life especially in agriculture. The pressure for the most efficient use of water for agriculture is intensifying with the increased competition for water resources among various sectors with mushrooming population. The need of the hour is therefore, maximising the production per unit drop of water. Hence in the present day context, lot of emphasis is being given in improving the irrigation practices to increase the crop production and to sustain the productivity levels. Micro-irrigation is introduced primarily to save water and increase the water use efficiency in agriculture. Reduction in water consumption due to drip method of irrigation over the surface method of irrigation varies from 30 to 70 per cent and productivity gain in the range of 20 to 90 per cent for different crops. By introducing drip irrigation, it is possible to increase the yield potential of crops by three fold with the same quantity of water. All these emphasize the need for water conservation and improvement in water-use efficiency to achieve "More Crop per Drop of water".

Key words : Drip irrigation, Fertigation, Water use efficiency.

To sustain the rapidly growing world population, agricultural production needs to be increased (Howell, 2001), yet the portion of fresh water currently available for agriculture (72%) is decreasing (Cai and Rosegrant, 2003). Hence, sustainable methods to increase crop water productivity are gaining importance in arid and semiarid regions (Debaeke and Aboudrare, 2004). Microirrigation has emerged as an appropriate water saving technique for row crops especially for wide spaced high value crops in water scarcity, undulated, sandy and hilly areas of India. However, the area under drip irrigation is only about 0.17 M ha which is very meagre compared to the total irrigated area in the country (Sivanappan, 1998).

Drip irrigation is one such hi-tech method receiving better acceptance and adoption, particularly in areas of water scarcity. Therefore, the efforts are now warranted to harness the available quantities of water and put them to efficient use to realize higher productivity per drop (Solaimalai *et al.*, 2005). Fertigation is a recent innovative cultural method, by which fertilizers are applied along with irrigation water through drip system to get higher fertilizer use efficiency besides increasing the crop yields.

In India, fertigation practice is only of recent interest, though this technology has been in use in many developed countries notably in Israel and USA. Although only limited research works have been done in India, the favourable results from these investigations have indicated immense potential for practicing this technology throughout the country in different crops.

The major factors limiting its large scale adoption are high initial cost, lack of information on various aspects such as crop water requirement, scheduling of irrigation and fertigation. So the literatures on different aspects of drip fertigation have been reviewed hereunder.

Need for micro irrigation

Agricultural sector is the largest consumer of water. The overall efficiency of the flood irrigation system ranged between 25 to 40 per cent. To meet the food security, income and nutritional needs of the projected population in 2020 the food production in India will have to be almost doubled. Adoption of micro irrigation may help in saving significant amounts of water and increase the quality and quantity of produce. All these emphasize the need for water conservation and improvement in water-use efficiency to achieve 'more crop per drop'. Micro-irrigation is just one of the many irrigation and water management technology tools, but it is a tool that has several advantages. Irrigation events can be fine-tuned to spoon feed water and nutrients just in time to avoid plant stress.

There are a number of potential advantages for micro irrigation. It includes increased beneficial use of water, enhanced plant growth and yield, reduced salinity hazard, enhanced efficiency of fertilizer and other chemicals, limited weed growth, decreased energy requirements and improved cultural practices. Maintaining available soil moisture at low water tension and almost constant during entire growth period through micro-irrigation with considerable water saving upto 50 per cent was possible with micro irrigation (Patel *et al.,* 2006). Microsprinkler fertigation once in 2 days with 75 per cent NPK dose through Mono Ammonium Phosphate (MAP) and Potassium Nitrate (Multi-K) could be a viable and economically feasible technology to achieve higher yield, income, water and fertilizer saving benefits over conventional practice of surface irrigation and soil application of normal fertilizers in radish (Shobana, 2002).

Drip irrigation

Drip irrigation is one of the latest innovations for applying water to row planted, widely spaced crops, especially in the water scarce areas. There can be considerable saving of water by adopting this method since water can be applied almost precisely and directly in the root zone without wetting the entire area. This technology not only uses each drop of water most efficiently but also results in good crop growth and yield advantage due to stable moisture content maintained always in the root zone of the crop by way of frequent irrigation at shorter intervals.

In drip irrigation system, only a fraction of the soil surface generally between 15 to 60 per cent is wetted. Earlier, drip irrigation was considered as an emerging technology with its application limited to some special crops. The benefits of drip irrigation may include better crop survival, minimal yield variability and improved crop quality. Several experiments have shown positive responses in most of the crops to high frequency drip irrigation (Segal *et al.*, 2000).

Drip irrigation has the potential for improving two of the most common contributing factors to N leaching *i.e.* over fertilization and over irrigation. Studies carried out on tomato using furrow, surface and sub surface drip irrigation showed that the yield is slightly better in sub surface drip system than those grown under surface drip irrigation. Drip irrigation has proved its superiority over other methods owing to direct application of water in the root zone. Drip irrigation can play a vital role in maximizing water use efficiency. A study conducted at Agricultural College, Madurai, revealed that the increase in seed cotton yield under drip irrigation was 24, 35, 45 and 53 per cent over-all furrow, skip furrow, alternate furrow and check basin method respectively (Sampathkumar *et al.,* 2006).

Effect of drip irrigation on growth, yield and quality

Abd El-Hafez *et al.* (2001) reported that drip irrigation method increased field and crop water use efficiency by 35 and 9.52 per cent respectively as compared to furrow irrigation in maize.

Yazar *et al.* (2002) conducted an experiment to study the effect of three different irrigation levels (100, 67 and 33 % cumulative pan evaporation), and two irrigation intervals (three and six-day) on yield of corn. Highest average corn yield (11920 kg ha^{-1}) was obtained from the full-irrigation treatment (100% CPE) with six-day interval. The results revealed that the trickle irrigation system could be used successfully for irrigating corn crop under the arid climatic condition. On-farm water savings of 20-25 per cent can be obtained with sub surface drip irrigation (SDI) for corn production on the deep silt loam soils of the semi-arid Great Plains (United States). The conjunctive use of SDI with appropriate nitrogen fertigation strategies resulted in optimization of corn yield, nitrogen uptake and water use efficiency at an irrigation level of approximately 75 per cent of normal (Lamm, 2005). Furrow (conventional) and drip irrigated corn yield were compared in Central Asian Uzbekistan. Under drip irrigation 371 to 428 mm of water was used and 547 to 629 mm of water used under furrow irrigation system (Nazirbay *et al.,* 2005). Growth, yield and water use efficiency of maize grown under different irrigation methods were measured in Sydney. Surface drip irrigation on permanent beds used 52 per cent less water than border check (Wentworth and Jacobs, 2006).

Effect of drip irrigation on water use efficiency and water saving

Micro irrigation system was found to result in 30 to 70 per cent water saving in various orchard crops and vegetables with 10 to 60 per cent increase in yield as compared to conventional method of irrigation (www.ikisan.com). Drip irrigation is often preferred over other irrigation methods because of its high water application efficiency on account of reduced losses, surface evaporation and deep percolation. Because of high frequency water application, concentrations of salts remain manageable in the rooting zone.

A well designed drip irrigation system benefits the environment by conserving water and fertilizer. A properly installed drip system can save as much as 80 per cent of the water normally used in other types of irrigation systems. Another advantage to drip irrigation is that there is less evaporation from the soil, especially when drip irrigation is used with plastic mulch. Water is applied more evenly throughout the field, thus eliminating the need to run the irrigation longer to wet the whole field (Anne Carter and John Howell, 2000). Field experiment conducted in North-western Botswana revealed that the highest mean marketable yield of broccoli (19.1 t ha^{-1}), carrot (58.9 t ha^{-1}), rape (61.8 t ha^{-1}) and cabbage (97.2 t ha^{-1}) was recorded at 80 per cent of pan evaporation replenishment. Also further increase in irrigation amount resulting from 100 per cent pan evaporation replenishment did not increase the marketable yield of crops but reduced the irrigation production efficiency significantly (Imtiyaz *et al.,* 2000).

Veeranna *et al.* (2000) compared the furrow and drip irrigations and reported that drip irrigation produced significantly higher dry chilli yield with 42 per cent higher water use efficiency over furrow method. Janat and Somi (2001a) conducted drip fertigation experiments at Syria in cotton and reported that water saving under drip fertigation was 35 per cent over surface irrigation. Drip irrigation at 0.8 E_{pan} with normal planting recorded higher water use efficiency (WUE) and green cob and fodder yield with a total water requirement of 330. 46 mm for sweet corn (Viswanathan *et al.,* 2002).

An experiment conducted at Punjab Agricultural University, Ludhiana, India, during summer 2002 concluded that in cotton the WUE increased by 26 per cent (22.1 from 17.6 kg $ha^{-1}cm^{-1}$) in drip irrigated system when same quantity of water and N fertilizer was applied as compared with check-basin (Aujla *et al.*, 2005). Crops were irrigated daily at 50, 75 and 100 per cent of estimated crop water use for each crop. There was no yield reduction in corn or peanut when irrigating at 75 per cent of the estimated water use compared with the 100 per cent irrigation level (Sorensen and Butts, 2005). Simsek *et al.* (2005) suggested that identification of the critical irrigation stage and scheduling of irrigation based on crop water status are the most effective way to improve water use efficiency.

Sampathkumar *et al.* (2006) reported that in cotton, increased WUE of 3.53 kg ha^{-1} mm^{-1} was obtained under drip irrigation and it was higher by 71.3, 68.8, 38.0, 34.2 and 18.0 per cent respectively when compared to check basin, border strip, all furrow, skip furrow and alternate furrow irrigation methods. Bandyopadhyay *et al.* (2009) reported that there was significant reduction in water use efficiency of cotton with the increase in the level of irrigation but there was an increase in water use efficiency due to N application over no nitrogen. The partial factor productivity of nitrogen decreased significantly with the increase in irrigation and N levels. Pandey *et al.* (2009) found that for bitter gourd highest water use efficiency of 50.7 kg $ha^{-1}mm^{-1}$ was obtained from 8 lph followed by 4 lph drip (46.8 kg $ha^{-1}mm^{-1}$) and micro sprinkler (29.7 kg $ha^{-1}mm^{-1}$). Field experiment was conducted at Ludhiana, to evaluate the performance of drip irrigation on different crop sequence consisting of only vegetable crop, only field crops and mixture of vegetable and field crops. The study revealed that cauliflower- hybrid vegetable crop sequence with drip at low level of irrigation (IW/ CPE -0.05) gave more yield and saved irrigation water as compared to other crop sequence. The crop sequences which comprised of vegetable and field crops shows non- significant increase in yield with drip irrigation as compared to furrow irrigation, but have substantial amount of water saving without affecting the crop yield (Ashok Kumar and Singh, 2006).

Fertigation

Application of water soluble / liquid fertilizer through irrigation water, also known as fertigation. By definition, fertigation is the precise application of water soluble fertilizer through sprinkler and drip irrigation. It is an efficient and agronomically sound method of providing soluble plant nutrients directly to the active plant root zone. The increasing acres of micro- irrigated crops provides an excellent opportunity to explore new methods of providing complete and balanced plant nutrient programs that have the potential to improve plant health and increase yields.

Fertigation permits improved efficiency of irrigation and nutrient use and reduces application costs. It improves plant growth and nutrient uptake and limits nutrient losses. Applying fertilizer through the irrigation system has several advantages:

- Nutrients can be applied at any time during the season and according to plant requirements.
- Placement of mobile nutrients such as nitrogen can be regulated in the soil profile by the amount of water applied.
- Applied nutrients are readily available for rapid plant uptake.
- Nutrients are applied uniformly over the field.
- Crop damage during fertilizer application is minimized (FAO, 2005).

With possible exception of foliar sprays, fertigation is one of the quickest ways to correct an existing nutrient deficiency, particularly for the macro nutrient which require in the largest amount. Plant foliage can be burnt if the macronutrients are applied at high rates in foliar sprays (Anonymous, 2004a).

Taha (1999) reported that fertigation enhanced the overall root activity; improved the mobility of nutritive elements and their uptake, as well as reducing the contamination of surface and ground water. Hebbar *et al.* (2004) suggested that for fertigation, use of 100 per cent water soluble fertilizer is recognized to safe guard the drip system in a long run.

Studies conducted at TNAU, Coimbatore during 2004-05 on the effect of shade and fertigation on tomato revealed that the application of 100 per cent water soluble fertilizer under shade improved the growth and yield parameters. The highest yield per hectare of 99.8, 109.5 and 106.7 tonnes during three seasons respectively were observed in the treatment with 100 per cent water soluble fertilizer under shade (Kavitha *et al.*, 2007).

Drip fertigation

A properly designed drip fertigation system delivers water and nutrient at a rate, duration and frequency, so as to maximize crop water and nutrient uptake, while minimizing leaching of nutrients and chemicals from the root of agricultural field (Gardenas *et al.,* 2005). Shinde *et al.* (2000) observed that in cotton, application of 50 per cent RDF as WSF through drip irrigation has produced almost identical seed cotton yield to that of 100 per cent recommended dose with surface method of irrigation and resulted in saving of 50 per cent fertilizer. Application of NPK from liquid fertilizer significantly increased the concentration and total uptake of N, P and K in tomato crop over solid fertilizer (Dhake *et al.,* 2009).

Drip fertigation in field crops

Janat and Somi (2001b) reported that seed cotton yield of the fertigated – cotton increased by more than 50 per cent compared with that of the surface-irrigated cotton. Aujla *et al.* (2005) conducted experiment at Punjab Agricultural University, Ludhiana during summer 2002 and concluded that when the same quantity of irrigation water and N was applied through drip irrigation system increases the seed cotton yield to 2144 from 1624 kg ha^{-1} (an increase of 32 %) under check basin method of irrigation. Rani (2006) suggested that drip irrigation at 80 per cent pan evaporation along with 50 per cent soil application (basal) and 50 per cent fertigation of recommended dose of N and K can be recommended as the best agronomic practice to boost the yield of baby corn. The hybrid, Cauvery coupled with 125 per cent drip fertigation was found to be the best treatment combination for maximizing the yield and economic benefits of tropical sugarbeet (Rajasekaran, 2007).

Lamm *et al.* (2000) in a four year experiment reported that nitrogen absorption rate, yield and water use efficiency by corn crop were improved as a result of nitrogen application by fertigation. Fertilizer use efficiency was always greater with fertigation while the higher rates of fertilizer application lowered the fertilizer use efficiencies (Malakouti, 2004). Thind *et al.* (2008) reported that when same quantity of water and nitrogen applied through drip to cotton, an average increase of 30 per cent in yield was achieved in normal sowing. Furthermore, 50 per cent of saving in irrigation water and cost of laterals can be realized under normal paired row sowing by sacrificing only 12 per cent seed cotton yield as compared with normal sowing.

Drip fertigation with water soluble fertilizer

Fertigation with soluble fertilizer can increase the yield and quality of gherkins and 25 per cent of the fertilizer can be saved without affecting the yield (Sundar Raman *et al.,* 2000). Jayabal *et al.* (2000) reported that fertigation with water soluble fertilizer in french beans saved 25 per cent of fertilizers and recorded a yield increase of 28 per cent over soil application of fertilizer. In gherkins, fertigation with100 per cent NPK through poly feed and urea registered higher yield but considering the economics, 75 per cent NPK through multi- K, mono-ammonium phosphate and urea was found to be the best (Jayabal *et al.,* 2000). Drip fertigation with 100 per cent water soluble fertilizer increased the fruit yield of tomato significantly (79.2 Mg ha^{-1}) over furrow-irrigated control at Bangalore. Fertigation resulted in lesser leaching of NO_3-N and K to deeper layer of soil (Hebbar *et al.,* 2004). Drip fertigation at 150 per cent RDF with P as water soluble fertilizer (urea phosphate) enhanced the productivity of maize and bhendi (Selva Rani, 2009).

Effect of drip fertigation on nutrient / fertilizer use efficiency

Veeranna *et al.,* (2000) reported that decreasing fertilizer level by 20 per cent than the recommended level especially under fertigation may not affect the yield level in chilli because of improved fertilizer use efficiency. Water and fertilizer saving to the extent of 30 and 70 per cent respectively with comparable yield levels were possible under the trickle fertigated crop as compared to the furrow irrigated crop of potatoes. Highest yield, 36.29 t ha^{-1} of fresh tubers was obtained under trickle irrigation as compared to 21.5 t ha^{-1} for the furrow irrigated crop (Chawla and Narda, 2001). Singandhupe *et al.* (2003) revealed that application of nitrogen through drip irrigation in ten equal splits at 8 days intervals saved 20- 40 per cent nitrogen in tomato as compared to the furrow irrigation where nitrogen was applied in two equal splits (at planting and one month thereafter). Solaimalai *et al.* (2005) reported that the amount of fertilizer lost through leaching can be as low as 10 per cent in fertigation whereas it is 50 per cent in the traditional system.

In tomato, the yield was increased linearly upto 50 kg P ha^{-1} application through broadcast. But fertigated treatment saved 25 kg P ha^{-1} i.e. 50 per cent of P was saved due to increased FUE (Carrijo and Hochmuth, 2000). Patel and Rajput (2000) observed that drip fertigation in onion resulted in 60 per cent saving of fertilizers for achieving the same level of production as compared to conventional method along with higher FUE of 5.28 kg N, P and K^{-1}. Ramas Lara *et al.* (2003) in a greenhouse experiment found that the highest yield (1.687kg $plant^{-1}$) and higher relative nitrogen recovery were obtained with 160 kg N ha^{-1} in tomato.

Application of 50 per cent recommended dose of fertilizer improved the fertilizer use efficiency of nitrogen, phosphorous and potassium. Reverse was the trend, when the fertilizer dose was increased to 100 per cent recommended dose (Singandhupe *et al.*, 2008). Anant (2006) reported that the highest yield of tomato was noticed when N (urea) was supplied in 8 or 10 split doses with 100 per cent ET_o through drip irrigation. Satyendra Kumar *et al.* (2009) observed that in potato crop fertilizer use efficiency was the highest (71 kg kg^{-1}) in micro-sprinkler followed by drip (67 kg kg^{-1}) and furrow irrigation (48 kg kg^{-1}).

Effect of drip fertigation on quality

Siviero *et al.* (2001) observed that fertigation with various amounts of N, P and K fertilizers increased the yield, induced early flowering and significantly improved the quality of tomato. Mineral contents of tomatoes grown with basal dressing alone were generally lower than those grown under drip fertigation (Akimasa Nakano *et al.,* 2003).

In a study conducted to investigate the effects of drip irrigation regimes on watermelon, an increase in IW/CPE (1.25) ratio and decreased total soluble solids (TSS), whereas it significantly increased the fruit weight, total vine length and total vine dry weight. In contrast, the highest TSS value was obtained from 0.75 IW/CPE and 0.5 IW/CPE treatments and supports the idea that increase in fruit water content causes a decrease in brix values (Simsek *et al.,* 2004). Studies conducted at TNAU, Coimbatore during 2004-05 on the effect of shade and fertigation on tomato revealed that the application of 100 per cent water soluble fertilizer under shade improved the fruit quality parameters *viz.*, fruit firmness, ascorbic acid, lycopene and carotene (Kavitha *et al.*, 2007). A field experiment conducted in sugarbeet at TNAU, Coimbatore revealed that in general brix reading and sucrose per cent were decreased with increasing fertilizer dose over the optimum level of 100 per cent RDF (Rajasekaran, 2007).

Fertigation scheduling

Tumbare and Bhoite (2002) concluded that weekly fertigation through drip irrigation in 14 equal splits starting from the first week of transplanting was beneficial for green chilli grown in a sandy clay loam soil. Ajmalkhan (2000) stated that fertigation of recommended dose of nitrogen as urea and K_2O as muriate of potash in 15 equal splits at eight days interval starting from 8 DAP to 120 DAP through drip system recorded higher tomato yield as compared to surface irrigation with conventional method of fertilizer application on sandy loam soil at Madurai (TNAU) in Tamil Nadu.

While appropriate frequency of fertigation at weekly or bi-weekly or monthly was the best to maximize the nutrient uptake by crop depending on the soil type (Hochmuth and Smajstrla, 2000); higher irrigation frequency might provide desirable condition for water movement in soil and for uptake by roots (Segal *et al.*, 2000). Fertigation scheduling allows for the greater degree of flexibility in effecting changes in quantity as well as frequency. Fertigation events can be scheduled as often as irrigation at an interval of a week, a fortnight or a month (Thompson *et al.*, 2003).

Effect of drip fertigation on moisture distribution pattern

In drip irrigation, water movement and its distribution in the soil depend upon many parameters such as the soil type, rate of infiltration, hydraulic conductivity, rate of emitter discharge, quantity of water applied, antecedent soil moisture content, depth of water table and certain climatic factors. The rate of applying water in drip irrigation is an important factor which governs moisture distribution in soil profile. A high rate may cause deep percolation loss whereas a very low rate may contribute to evaporation losses. Irrigation frequency and rate of water application in trickle system not only decide the size of the wetted soil surface, but also determine the geometry of the wetted zone. The former influence the extent of the evaporating surface and the latter determines the zone of root activities and the efficiency of the selected regime.

The soil water content (by volume) distribution in the profiles under all drip and fertigation treatments indicated that it was relatively higher near the emitter and decreased as the distance from the emitting point increased. Patil (1999) observed that frequent irrigations under drip irrigation has maintained most of the soil in the root zone in a well aerated condition and at a soil moisture content that does not fluctuate between wet and dry extremes. He also observed that the movement of water in the soil depends on the soil characteristics and the dripper discharge. Li *et al.* (2003) stated that higher application rate in faster wetting front movement in both the radial and the vertical directions. Increasing the applied volume significantly increased the wetted depth, but had little effect on the horizontal wetted area. This may be due to water entry saturated radius approaching a constant value after a certain time about 3.5 hrs. Increasing in water application rate allows more water to distribute in horizontal direction, while decreasing the rate allows more water to distribute in vertical direction for a given volume applied (Li *et al.,* 2004). Amin and Ekhmaj (2006) stated that soil type, the volume of water applied to the soil and emitter discharge rate are the major factors affecting the wetted zone geometry.

Visalakshi *et al.,* (2007) reported that the pattern of wetting of soil surface was circular and that of soil profile was elliptical under a single emitter. Under twin emitters the nature of wetting at the soil surface tended to become elliptical where as the moisture front advance in the profile changed from a three dimensional to almost two dimensional, after the moisture front of the two emitters touched each other. She stated that the pattern of soil moisture distribution under drip was bulb shaped. Suganya *et al.* (2007) stated that the soil moisture content was higher near the dripper (0-30 cm) and it decreased with the increase in lateral distance from the emitter. Similarly it was higher in the surface layer (0-15 cm) and followed a decreasing trend with the depth. This uniform soil water content represented soil water near the field capacity indicating optimum soil water availability conditions for the crop. It implies that the drip system could maintain an ideal moisture regime for optimum crop growth condition and thus ensures water saving or increasing the water use efficiency.

In drip irrigation with the increase in water application, the moisture content of soil increased horizontally and vertically. Horizontal spread of moisture content at 4 lit /h discharge rate of drip irrigation for 1hr and 2hr was 3 m and 0.6 m respectively on the soil surface. The depth attained by the outermost moisture profile in shallow soil was lowest as compared to deep and medium types of soil for 1hr and 2 hr operation. The moisture content was in the range of 71 to 100 per cent of field capacity under drip irrigation (Arulkar *et al.,* 2008).

Effect of drip fertigation on rooting pattern

In general, root development under drip irrigation is constrained to the soil volume wetted by the emitters, near the soil surface with root length density decreasing with depth. Roots are more concentrated near the water source for daily irrigated plots with 75 per cent of roots occurring within 50 cm of the emitter. In contrast, roots are more evenly distributed laterally in weekly irrigated plots with 63 per cent occurring within 50 cm of the emitter. Regarding the root length, in the daily irrigated plots roots are highly concentrated in the surface layers, with 64 per cent occurring in the upper 45 cm and the density markedly decreasing below 75 cm. Roots tend to accumulate in the margins of the wetted zone in trickle irrigated wheat and no root growth occurred beyond a distance of 35 cm, since the soil was wetted only until this lateral distance. Information about the structure and function of crop root systems is essential to match irrigation system design and management with crop requirement.

Rooting patterns have traditionally been analyzed by means of root weight density or root length density (RLD). The distribution of RLD is an important indicator of potential water uptake. However, studies have shown that actual water uptake patterns (root activity or effectiveness) reflect a complex interplay between RLD and other soil factors such as water, nutrient and aeration status of the root zone. A good understanding of crop root distributions and water uptake patterns has become increasingly important as we seek to develop modern and environmentally- friendly practices involving high frequency irrigation and fertigation.

Tomato rooting patterns were evaluated in a 2-year field trial where surface drip irrigation was compared with subsurface drip irrigation at 20 cm and 40 cm depths. For both surface and subsurface drip irrigation most of the root system was concentrated in the top 40 cm of the soil profile, where root length density ranged between 0.5 and 1.5 cm cm^{-3} (Machado *et al.,* 2003). Maximization of crop yield and quality and minimization of loss of nutrients by way of leaching below the rooting volume may be achieved by managing fertilizer concentrations in measured quantities of irrigation water, according to crop requirements.

Nutrient distribution under drip fertigation

Under drip irrigation, the highest reduction in soil NO_3 – N was observed in 30 to 60 cm depth, while the highest reduction in soil K was observed in 0 to 30 cm depth and the soil pH was not affected by drip irrigation. Bar- Yosef (1999) stated that drip fertigation with higher dose of nitrogen (74 kg ha^{-1}) resulted in higher EC, soluble P, K, and NO_3- N in soil compared to lower N doses (39 and 58 kg ha^{-1}). Bharambe *et al.* (2001) reported that higher amount of available P were confined at the top 0-15 cm layer just immediately below the emitter. The concentration of P decreased with increasing depth of soil profile irrespective of planting methods and depth of irrigation water. The available N content was confined to maximum at immediately below the emitter and moved laterally upto 15 cm and vertically up to 15-25 cm and thereafter dwindled. The mobility of P was observed to be the highest immediately below the emitter zone, moved laterally and vertically up to 5 cm and thereafter dwindled. AS regards to available K, it moved both laterally and vertically up to 15 cm and thereafter reduced (Bangar and Chaudhari 2004).

Nutrient management under fertigation

Fertigation events of longer duration distribute nitrate more uniformly throughout the root zone (Blaine Hanson *et al.,* 2004). Gardenas *et al.* (2005) studied the effects of fertigation strategy and soil type on nitrate leaching potential for different micro-irrigation systems. They found that fertigation at the beginning of the irrigation cycle tends to increase nitrate leaching. In contrast, fertigation events at the end of the irrigation cycle reduced the potential for nitrate leaching.

1. Nitrogen

Fink and Scharpf (2000) reported that the total uptake of nitrogen varied from 220 -411 kg ha^{-1} and the uptake by fruit was between 105-287 kg

ha^{-1}. Thomas *et al.* (2000) observed that more amount of residual N at 0-90 cm soil depth when supplied with higher N rates and irrigated at high soil moisture tension. But when irrigated at low soil moisture tension nitrogen was lost beyond root zone. Singandhupe *et al.* (2003) stated that total nitrogen uptake in drip irrigation was 8.11 per cent higher than that of furrow irrigation at the highest level of applied nitrogen (120 kg N ha^{-1}) in tomato. Janat (2004) conducted experiment in which drip fertigated cotton received five different nitrogen rates (0,60,120,180 and 240 kg N ha^{-1}), while only one rate (180 kg N ha^{-1}) was applied to the surface-irrigated cotton. Nitrogen recovery ranged between 48 and 55 per cent in drip- fertigated cotton and 43 per cent for the surface irrigated cotton. The overall average of total N uptake for cotton ranged between 145 for control and 417 kg N ha^{-1} for the highest N rate under drip fertigation. It is clear that increasing N rates under drip fertigation resulted in an increase of N uptake by the corresponding treatments. Hebbar *et al.* (2004) reported that fertigation treatment maintained high concentration of NO_3-N at shallow depth than deeper layer.

2. Phosphorus

Phosphorus is highly immobile in soils and is often a limiting nutrient. Phosphorus deficient plants suffer from reduced leaf expansion, reduced surface size and reduced number of leaves. Respiration and photosynthesis are both reduced in P-deficient plants. Stress from P deficiency at early growth stages has considerable negative influence on crop production (Grant *et al.,* 2001). Among all the elements required by a plant, phosphorus is one of the most important nutrients for crop production and emphasis is to be given on the efficient use of P fertilizer for sustainable crop production (Ryan, 2002). Iqbal *et al.*(2003) reported that application of DAP at the lower rate (33 kg P ha^{-1}) through fertigation resulted in almost the same wheat grain yield as obtained by the higher dose (44 kg P ha^{-1}) applied by broadcast method. An experiment with corn plants resulted in greater biomass production and higher plant tissue P content when water and nutrients were applied continuously as compared with a 2 days intermittent application regime. P content of corn leaves was 25 per cent greater for the continuous treatment as compared with the pulsed treatment (Ben – Gal and Dudley, 2003). Tumbare and Nikam (2004) stated that application of recommended dose of fertilizer at every irrigation (2 days interval) upto 105 days recorded significantly higher uptake of phosphorus (12.58 kg ha^{-1}) by chilli than surface irrigation (8.53 kg ha^{-1}).

3. Potassium

Anilkumar (2001) reported that potassium uptake was significantly higher (105.14 kg ha^{-1}) with 100 per cent water at 0.8 IW / CPE ratio than 75 per cent of water. Tumbare and Nikam (2004) stated that application of RDF at every irrigation (2 days interval) upto 105 days recorded significantly higher uptake of potassium (99.1 kg ha^{-1}) by chilli than surface irrigation (44.6 kg ha^{-1}). Higher concentration of potassium was found in the upper layers of the soil *i.e.* at 0 to 20 cm soil depth and lower concentration of potassium was found in the lower layers of the soil *i.e.* 20 to 40 cm soil depth under fertigation. Peak quantity of potassium under fertigation treatment was always found to be in the soil depth of 0- 10 cm at the emitter (Mishra *et al.,* 2006). Suganya *et al.* (2007) inferred that the available K content was more in the surface layer due to entrance of K ions on soil exchange complex resulting in very small movement to deeper layer.

Mmolawa (2008) reported that dynamics of potassium nitrate (KNo_3) around a dripper are influenced by presence of plants. In the presence of maize, the soil water content, soil electrical conductivity, soil water solution and mass of KNo_3 decreased substantially more than when there was no maize. And the difference in the dynamics of KNo_3 with and without maize is attributed to the uptake of KNo_3.

Economics of drip fertigation

Under drip fertigation system, 100 per cent recommended NPK registered the highest benefit cost ratio (2.17) in chilli (Tumbare and Bhoite, 2002). Singh *et al.* (2005) reported that drip irrigation in cauliflower – hybrid chilli sequence gave a net return of Rs. 52,685 ha^{-1} against Rs. 35,418 ha^{-1} in check basin method of irrigation. Drip irrigation at 100 per cent WRc with 100 per cent RDF registered the highest additional net income of Rs. 1,23,679 and BCR of 3.30 in chilli which was closely followed by drip irrigation at 80 per cent WRc with 100 per cent RDF registering an additional net income of Rs. 1,19,488 and BCR of 3.23 over surface irrigation (Selvakumar, 2006). Bangar and Chaudhari (2008) reported that net extra income occurred due to fertigation with WSF in sugarcane was 6.57 per cent higher (Rs. 59190 ha^{-1}) than fertigation with straight fertilizer (N as urea through fertigation, P and K as basal). Many scientists reported that additional benefit of WSF over normal fertilizer in fertigation was masked due to high cost of WSF in cotton (Shinde *et al.,* 2000); in rosemary (Vasundhara *et al.,* 2000); in sugarcane (Bhoi *et al.*, 2000).

From the foregoing review, it could be clearly seen that drip irrigation requires less irrigation water with increased irrigation efficiency and ensure uniform distribution of water and fertilizers as compared to conventional methods. Fertigation also increases the fertilizer use efficiency, which leads to increase in yield and income. The right combination of water and nutrients is the key factor for high yield and the quality of produce. Fertigation has the potential to ensure that the right combination of water and nutrients is available at the root zone, satisfying the plants total and temporal requirement of these two inputs.

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