Agric. Rev., **26** (1) : 1 - 13, 2005

FERTIGATION IN HIGH VALUE CROPS - A REVIEW

A. Solaimalai*, M. Baskar, A. Sadasakthi and K. Subburamu

Krishi Vigyan Kendra,
Tamil Nadu Agricultural University, Vridhachalam - 606 001, India

ABSTRACT

Drip irrigation has the greatest potential for the efficient use of water and fertilizers. The limited area of wetting under trickle irrigation reduces the active root zone and also the foraging area of plants to draw water and nutrients from the soil. For minimizing the cost of irrigation and fertilizers, adoption of drip irrigation with fertigation is essential which will maximize the nutrient uptake while using minimum amount of water and fertilizer. Fertigation gives advantages such as higher use efficiency of water and fertilizer, minimum losses of N due to leaching, supplying nutrients directly to root zone in available forms, control of nutrient concentration in soil solution and saving in application cost. Thus, fertigation becomes prerogative for increasing the yield of most of the crops under drip irrigation. In this paper, the literatures pertaining to the different aspects of fertigation are reviewed.

India has the largest irrigation network in the world, its irrigation efficiency has not been more than 40 %. Bringing more area under irrigation will largely depend upon efficient use of water. In this context, micro-irrigation has most significant role to achieve not only higher productivity and water use efficiency but also to have sustainability with economic use and productivity. It is the process wherein fertilizer is applied through an efficient irrigation system like drip. In fertigation, nutrient use efficiency could be as high as 90 % compared to 40 - 60 % in conventional methods. The amount of fertilizer lost through leaching can be as low as 10 % in fertigation whereas it is 50 % in the traditional system. Adoption of micro-irrigation systems may help to increase the irrigated area, productivity of crops and water use efficiency (Sivanappan, 1985). Drip irrigation has proved its superiority over other methods owing to direct application of water in the root zone. Indiscriminate use of water through conventional irrigation system with only 60 % application efficiency is causing serious threat to available ground water resources. Drip irrigation can play a vital role in maximizing water use efficiency. Low nitrogen use efficiency in conventional method of irrigation is also a major reason for low productivity of crops. Drip irrigation is at present economically feasible in high value crops. The use efficiency of these key inputs is currently very low in India leading to a lot of problems such as low crop productivity, degradation of soil health and increased environmental pollution apart from the wastage of substantial quantity of these costly and scarce inputs, increasing the efficiency of water and fertilizer can itself go a long way in realizing the growing demand for food and other plant products consequent to rapidly escalating population (Koo, 1981). The shrinking land: man and water: man ratios, increasing fertilizer prices, haunting energy crisis, wide spread pollution and fast degradation of natural resource further emphasise the need for improved water and fertilizer use efficiency (Dass, 1985). Drip fertigation optimize the use of water and fertilizer enabling to harness high crop yield, simultaneously ensuring a healthy soil and environment. The drip fertigation technology encompasses the application of solid or liquid mineral fertilizers through drip irrigation systems thus supplying a nutrient containing irrigation water to crops. Crop growth and yields under drip irrigation can be lower than those achieved under conventional irrigation methods if fertilizer placement is not modified to meet the needs of drip irrigated crops (Miller

* Present address: Agricultural Research Station, Virinjipuram (Vellor) - 632 104, India.

et al., 1976). Fertigation can be effected by using single or multiple nutrient fertilizers in their solid or liquid form. Some of the desirable characteristics of the fertilizer material for use in fertigation are full solubility, quick dissolution in water, fine grained product, high nutrient content in the saturated solution, compatibility with other fertilizers, absence of chemical interaction with irrigation water and minimum content of conditioning agents. Fertilizer applied to the soil have to be close the water source (emitter) in order to be used effectively by the crops. This implies the use of banded fertilizer application or the addition of fertilizer nutrient to the irrigation water. As high as 50% of N requirement of brinjal was reduced under drip irrigation over furrow irrigation (Jaime *et al.*, 1987).

Scope

Fertigation permits application of a nutrient directly at the site of a high concentration of active roots and as needed by the crop. Scheduling fertilizer applications on the basis of need offers the possibility of reducing nutrient element losses associated with conventional application methods that depend on the soil as a reservoir of nutrients thereby increasing nutrient use efficiency. Fertilizer savings through fertigation can be to the tune of 25 - 50 % (Haynes, 1985). Under drip irrigation only a portion of the soil volume around each plant is wetted and thus traditional methods of fertilizer application is ineffective. The limited root zone and the reduced amount of mineralisation are the main reasons for the reduced nutrient availability to the plants with normal method of fertilizer application under drip irrigation (Magen, 1995). Fertigation is application of water soluble solids/liquid fertilizers through the drip irrigation on weekly/ monthly basis so as to reach each and every plant regularly and uniformly. It is the most effective and convenient means of maintaining optimum fertility level and water supply according to the specific requirement (Shirgure *et al.*, 2000). Fertilizers and pesticides applied through a drip irrigation system can improve efficiency, save labour and increase flexibility in scheduling of applications to fit crop needs (Rolston *et al.*, 1979). However, all chemicals must meet the following criteria for the successful maintenance of the drip irrigation system (Bucks and Nakayama, 1980). They must avoid corrosion or clogging of any component of the system, be safe for field use, not decrease crop yield, be soluble in water and not react with salt or other chemicals in the irrigation waters. A correct rate and concentration of fertilizer is desired in fertigation system to avoid over fertilization and achieve the best results. It is to be specifically worked out for different cropping situations. Needs of most crop can be met with a concentration of 100 mg/litre in irrigation water.

Osmotic potential of soil solutions

Optimization of levels of nutrient application through drip irrigation is closely related to osmotic potential usually expressed as electrical conductivity (EC) generated by the salts in the root medium solution. Increasing osmotic potential has a negative effect on plant growth and yield. Among the several N fertilizers given through irrigation water, only urea did not increase appreciably the EC of the soil solution. A nutrient concentration in irrigation water generated an EC of 1.8 dSm^{-1} after fruit set (Hagin *et al.*, 1990).

Frequency of fertigation

Fertigation of nutrients with very great dilution in each irrigation increased the fertilizer use efficiency far beyond the previously possible level (Menzel and Obe, 1990). The time of K application had less effect on tomato yield than the time of N application when both were applied through drip irrigation (Dangler and Locascio, 1990). However, since a higher N supply is known to encourage vegetative growth but stimulate the production of poor quality fruit, the N concentration in the fertilizer solution can be increased at vegetative stages of growth and restricted during the period of ripening (Levin *et al.*, 1980). No difference in yield of straw barries was recorded when N and K were applied either daily or at weekly intervals with the drip irrigation (Locascio *et al.*, 1977). Multiple application of N fertilizers through drip irrigation did not improve the efficiency of fertilizer uptake by tomatoes over a single injection (Miller *et al.*, 1981).

Fertigation of nitrogen

Nitrogen is the most commonly deficient and often applied through drip irrigation. Generally all the nitrogen fertilizers are suitable for drip fertigation since they cause little clogging and precipitation problems except NH_4SO_4 which may cause precipitation of $CaSO_4$ in hard calcium rich water. N source selection should be based on its possible reactions with the irrigation water and the soil. Prolonged use of NH_4 containing fertilizers through drip system can have detrimental effects on soil fertility in the wetted soil volume. This is because nitrification of the applied NH_4 causes soil acidification. Injection of anhydrous ammonia or aqua ammonia will cause the pH of the irrigation water to rise with the possibility those insoluble salts of Ca and Mg would precipitate. Urea is well suited for injection through drip irrigation since it is highly soluble and dissolves in non-ionic form and does not react with the substances in the water. Nitrate salts are characteristically soluble and are well suited for use in drip irrigation (Haynes, 1985). The optimum concentration of N for tomato to be applied through trickle irrigation was found to be 240 mg/litre on a coarse textured soil (Yosef *et al.*, 1980) and 180 mg/litre on a sandy loam soil (Papadopoulous, 1987).

The initial distribution of N added to the soil from trickle emitters is likely to differ markedly depending upon the source of N applied. Nitrification is generally rather rapid in most agricultural soils. However, if the soil is kept relatively wet below the emitter, nitrification process requires oxygen. During irrigation, NH_4 concentration rose from 7.1 to 13.5 ppm in the surface 6 cm depth of soil extending upto a distance varying from 30 to 65 cm from the outlet. Ammonium concentration decreased rapidly as the soil dried out and 8 hours after the irrigation, it had fallen from 13.5 to 8.5 ppm. As there was no change in the NO_3 concentration in this region during the 8 hour period, the NH_4 was being immobilized rather than nitrified (Bacon and Davey, 1982). During a fertigation cycle, applied NH_4 was concentrated in the surface 10 cm of soil immediately below the emitter and little lateral movement occurred. Urea is relatively mobile in soils and it is not strongly absorbed by soil colloids. It tends to be more evenly distributed within the wetted profile than does applied. Fertigated urea and nitrate were more evenly distributed down the soil profile below the emitter and had moved laterally in the profile to 15 cm radius from the emitter (Haynes, 1990). Indeed, with 80 kg N/ha by drip fertigation, total or fertilizer N recovered, growth pattern and sugar cane yields were similar to those obtained with the standard practice of burying 120 kg N/ha along the cane rows (Kwong *et al.*, 1999). In sugarcane, nitrogen use efficiency was increased by approximately two fold when the fertilizer N was injected into the drip irrigation net work. The improved efficiency of the fertilizer N was however not accompanied by a concomitant increase in yield of Sugarcane (Kwong and Devile, 1994). The highly mobile NO_3 ion moves with the wetting front of the irrigation application and tends to accumulate at the periphery of the wetted soil volume and at the soil surface midway between emitter. The bulk of any form of N applied to the soil is likely to eventually be transformed to NO_3-N (Haynes, 1985). Soil N content was influenced

Table 1. Solubility of different fertilizers

Fertilizers	Solubility (g/litres)
Urea	1100
Ammonium nitrate	1190
Ammonium sulphate	710
Potassium nitrate	130 - 320
Potassium chloride	280 - 340
Potassium sulphate	70 - 110
Phosphate	580 - 690
Urea phosphate	350 - 500
Magnesium sulphate	710

(Gnanamurthy and Manickasundaram, 2001).

by quantity of water applied through drip irrigation but nitrogen levels showed significant influence on soil available nitrogen (Salvadore and Allen, 1996). Drip irrigation levels did not influence availability of soluble nutrients at the later stage of application of fertilizer as soluble nutrients are easily leached out by drip irrigation. Soil N changes with the frequency of irrigation and water application rate (Goldberg *et al.*, 1971).

Fertigation of phosphorus

It has not been generally recommended for application in drip irrigation system because of its tendency to cause clogging and its limited movement in the soil. If irrigation water is high in Ca and Mg, precipitates of insoluble calcium and magnesium phosphates may result from the application of inorganic phosphates (Bucks *et al.*, 1982). But the addition of H_3PO_4 to the irrigation water maintained a low pH and prevented the precipitation of insoluble salts, thus allowing the introduction of P through drip irrigation systems. The recommended P concentration in irrigation water of glass house grown tomato was 1.0 m mol P/litre (Sonneveld and Wees, 1988). The resulting P concentration in the root environment was 0.5m mol/litre indicating considerable precipitation of phosphates. The P_2O_5 concentration in the standard nutrient solution for tomatoes should be raised from 1.0 to 1.25 mm with intended concentration in the root environment should be raised from 0.5 to 0.7 mm (Voogt and Sonneveld, 1989).

The extent of movement of P in the soil from the emitter depends upon the P adsorption capacity of the soil. However, the distance of P movement was found to be proportional to the application rate since movement resulted from saturation of adsorpiton sites on the soil near the point of application and subsequently mass flow with the soil water. P was delivered to greater soil volume when applied as H_3PO_4 acid through a drip irrigation system than triple super phosphate applied as a soil amendment beneath each emitter (Neill *et al.*, 1979). Drip irrigation caused both horizontal and vertical movement of native soil P near the outlet and P fertilizer applied 50 - 80 cm away from the outlet, remained near the soil surface and above the root zone (Bacon and Davey, 1982). Phosphors when applied as urea phosphate moved in a calcareous loam soil to a depth of 30 cm. In tomato, considerable movement of P throughout the soil profile was possibly because of slower precipitation of calcium phosphate due to the lower pH of the irrigation water, possible presence of Mg and HCO_3 in solution and predominant move of fertilizer solutions through soil macropores. Placement of small quantities of super phosphate near the trickle outlet is a satisfactory alternative to broadcasting (Bacon and Davey, 1989).

Fertigation of potassium

Application of potassium fertilizers do not cause any precipitation as salts except in the case of K_2SO_4 with irrigation water containing high amount of calcium. Common K sources such as potassium sulphate, potassium chloride and potassium nitrate are readily soluble in water. These fertilizers move freely into the soil and some of the K ions are exchanged on the clay complex and are not readily leached away. Recommendations on rates of K application through drip irrigation for tomato go up to 350 mg K/litre (Sonneveld and Wees, 1988). Fertigation of K did not increase fruit production of peaches when initial soil K level was high (Bussi *et al.*, 1991).

Potassium is less mobile than nitrate but distribution in the wetted volume may be more uniform due to interaction with binding sites (Kafkafi and Yosef, 1980). There was some movement observed after the K ions became concentrated in the soil near the emitter (Uriu *et al.*, 1977). Like NH_4, the K ion is adsorbed on the cation exchange sites on soil colloids so that the extent of movement is dependent upon the CEC of the soil and the rate at which K is applied. Most workers have detected considerable lateral and downward movement of trickle applied K (Goode *et al.*, 1978: Keng *et al.*, 1979; Kafkafi and Yosef, 1980). Lesser movement of K was attributed after fertigation due to large plant uptake of K (Goyal *et al.*. 1989).

Micronutrients

Micronutrients such as iron, manganese, zinc and copper can be applied through irrigation water as chelated form (Fe EDTA) without causing any precipitation problem.

Yield of crops

Successful cropping of tomato was obtained with drip irrigation using fertigation on a highly calcareous desert soil where control of nutrient level was more difficult than sand dunes (Kafkafi and Yosef, 1980). A linear relationship existed between total N uptake by tomato and fertigation of N up to 300 kg/ha (Stark *et al.*, 1983). When NPK were applied through drip irrigation, higher tomato yield was obtained with 75 % of the recommended dose (Singh *et al.*, 1989). Marketable yield of tomato was higher when 50 % N was fertigated than fertigation of N at 75 to 100 % level (Dangler and Locascio, 1990). Application of N through fertigation performed better than soil application alone. When N was fetigated N saving to the tune of 20 % was observed compared to soil application alone in tomato (Haroon, 1991). Drip irrigation with 100 % N and K applications gave higher fruit yield of tomato (Salvodar *et al.*, 1997). Highest yields of high quality fruits of tomato were obtained with 50 % trickle applied N + K grown on polyethylene mulched beds (James *et al.*, 1990). In tomato, fertigation 1/2 N and K and black poly mulch was found to be good with respect to yield and growth parameters like yield of 121.3 t/ha, fruit weight (64.5 g), number of fruits/plant (62), yield/plant (4 kg), number of branches/plant (7.7) and number of clusters/plant (12.3). The fruit dry matter content (41.2 %) was highest in the treatment 1/2 N and K fertigation through multi K + black ploy mulch (Prabhakar *et al.*, 2001). Drip fertigation of 80 % recommended dose with water soluble fertilizer registered 22.3 and 31.0 % higher dry fruit yield over drip and furrow irrigation methods even with same level and method of normal fertilizer application (Muralidhar *et al.*, 1999). In tomato, there was considerable saving of fertilizers and water through fertigation using water soluble fertilizers (Jeyabal *et al.*, 2000). Application of 50 % N and full dose of P and K as basal and remaining 50 % N through fertigation at 15 days interval throughout the crop period significantly improved the yield and quality of tomato grown on coirpith mixed potting media (Baskar, 1996). Compared to fertilization, fertilizer saving under fertigation was found to the extent of 50 % with yield increase in tomato (Goyal *et al.*, 1985). Similarly utilization of N by tomato was more when applied through the drip irrigation system than when banded either in furrow irrigation or drip irrigation (Miller *et al.*, 1976; Miller *et al.*, 1981).

Yield of sweet pepper was higher when N and K were fertigated through drip irrigation (Keng *et al.*, 1979). Compared to fertilization, fertilizer saving under fertigation was found to the extent of 50 % with yield increase in pepper (Haynes, 1988) and sweet pepper (Ruiz *et al.*, 1988). In capsicum, 25 and 18 % higher green fruit yield was recorded with fertigation and drip irrigation over furrow method (Gnanamurthy and Manickasundram, 2001). In chilli, fertigation using water soluble fertilizers gave higher yield than soil application by about 15 % and saved water by 40 % (Jeyabal *et al.*, 2000). Fertigation with water soluble fertilizers in french beans saved 25 % of fertilizers and recorded an yield increase of 28 % over soil application of fertilizers (Jeyabal *et al.*, 2000). But the fruit yield of cucumber was maximum when N alone was fertigated through drip irrigation than fertigation of N along with K, NPK and control (Rubeiz, 1990). In gherkins, fertigation with 100 % NPK through poly feed and urea registered higher yield but considering the economics, 75 % NPK through multi - K, monoammonium phosphate and urea was found to be the best (Jeyabal *et al.*, 2000).

Fertigation at 300 kg N/ha provided the highest tuber yield (38.3 q/ha) (Table 2). Drip fertigation at 180 kg N/ha recorded tuber yield (30.6 q/ha) at par with furrow irrigation fertilized at 300 kg N/ha (30.5 q/ha) which indicate 40 % nitrogen saving in potato (Patel and Patel 2001). Potato crop fertilized by high frequency irrigation of fertigation techniques absorbed more N than those conventionally fertilized (Phene *et al.*, 1979). In potato, four split nitrogen fertigation under drip irrigation resulted in higher WUE over furrow irrigation method (Keshvaiah and Kumaraswamy, 1993). High frequency application of N with drip irrigation improved the efficiency of fertilizer use by potato more than two fold over conventional fertilizer application method (Rolston *et al.*, 1979).

Fertigation improved the yield of banana (Cv. robusta) and water economy (Mahalakshmi, 2000). Surface irrigation scheduled at 1.00 IW/CPE ratio to 5 cm depth was comparable with drip irrigation applied at 2 days interval @ 24, 32 and 40 litres/tree. In all the drip irrigation treatments, application of N as fertigation @ 80 and 110 g/tree produced comparable yields of banana. In surface irrigation, significant variation was observed between 80 and 100 g/plant applied as band placement. Thus fertigation saved 37.5 % of N compared with that of traditional band placement. Higher yields was obtained in robusta banana due to N fertigation (Hegde, 1998). Increased yield and quality of neypoovam and robusta banana respectively were obtained under drip fertigation. The fertilizer savings through fertigation are presumably because fertilizer and water are applied to soil where active roots are concentrated (Srinivas, 1998; Mahalakshmi *et al.*, 2000). The increasing level of fertigation gave significant increase in height of the plant of banana Cv. Nendran. Maximum bunch weight 9.82 kg was recorded in conventional crop geometry + 100 % irrigation requirement + 100 % N fertigation. Minimum of 7.5 kg bunch weight was recorded under normal planting + 80 % irrigation requirement + 75 % N fertigation (Pandey *et al.*, 2001). Fertigation was effective in increasing the vigour of the plants as measured by the plant girth, number of leaves and phyllochron. Crop

Table 2. Effect of method of irrigation and nitrogen levels on potato

Treatment		Plant height (cm)	Tubers/ plant	Tuber yield/ plant (g)	Tuber yield (q/ha)	WUE (kg/ha mm)
Furrow irrigation						
180 kg N/ha		24.9	3.0	244	23.88	3411
220 kg N/ha		26.0	3.1	300	26.50	37.86
260 kg N/ha		28.0	3.6	344	28.51	40.81
300 kg N/ha		27.6	3.8	362	30.57	43.67
Mean		26.6	3.3	312	27.36	39.08
Drip irrigation						
180 kg N/ha		29.7	3.1	325	30.59	72.93
220 kg N/ha		33.5	3.3	389	35.21	83.83
260 kg N/ha		38.2	3.7	417	27.23	88.64
300 kg N/ha		34.7	3.9	456	38.36	91.33
Mean		34.0	3.5	397	35.35	87.17
CD(0.05)	I	1.69	NS	NS	1.81	-
	N	2.39	0.55	54	2.56	-

(Patel and Patel, 2001).

duration was significantly less in fertigation than the control plants. The fertigation with 25 litres/day/plant and 100% NK/plant registered the maximum bunch weight of 44.5 kg with corresponding highest number of hands (10.52) and fingers (203.7). Fertigation has proved to economize water and fertilizer with a corresponding lower expenditure in cost of production and labour towards weeding, fertilization and water application (Mahalakshmi *et al.*, 2001). The improved growth and yield components with nitrogen and potassium fertigation could be due to timely application of nutrients directly to the rooting zone of the plant thus improving the fertilizer use efficiency (Nakayama and Bucks 1986). Increase in level of nitrogen and potassium fertigation improved the growth parameters of plants. However, differences beyond 100 g were not significant. Further, both levels and ratios of nitrogen and potassium fertigation influenced yield and yield attributes of banana robusta (Chandrakumar *et al.*, 2001). General reduction in fruit quality was observed when irrigation was given in higher amounts at frequent intervals. TSS increased with increasing levels of fertilizer irrespective of water levels (Hegde and Srinivas, 1990). Crop duration was reduced by fertigation with 40 litres/day/pit + 75 % of recommended N and K/pit in banana (robusta). Fertigation resulted in heavy bunches weighing 36.5 kg with maximum number of hands (11) and number of fingers/bunch (188.4) (Mahalakshmi *et al.*, 2001a). In banana, the same yield level obtained through conventional irrigation and fertilization practice can be achieved with half the fertilizer dose when applied through drip fertigation. Likewise, the WUE of 470 kg/ha mm in conventional irrigation was increased to 570 kg/ha mm in subsurface drip fertigation system (Jose Mathew, 2003).

Application of 75 % recommended dose through fertigation with 20 % wetted area gave the maximum yield (19.35 kg/plant) without affecting fruit quality of pomegranate (Colapietra, 1987; Idate *et al.*, 2001). In a three year old plantation of guava, fertigation at 75 % rcommended NK level with urea and multi - K gave 12.3 % higher yield than soil application at 100 % NK level indicating a saving of 25 % NK in addition to improvement in productivity (Jeyabal *et al.*, 2000). Fertigation has been proved successful in a wide range of horticultural crop particularly in fruit crops like citrus (Boman, 1996;

Shrigure *et al.*, 2000; Swietlik, 1992), grapes (Spayd *et al.*, 1994) and date palm (Reuveni *et al.*, 1991). Application of 10 litres of water/ day + 13.5 g urea and 10.5 g of murate of potash/week through fertigation and soil application of super phosphate 278 g/plant in bimonthly intervals improved growth, yield and quality characteristics in papaya. This might be due to the better physiological efficiency of the plant owing to supply of nutrients and water in splits through fertigation (Jeyakumar *et al.*, 2001). In sapota, drip irrigation with fertigation (80 % water soluble fertilizer) increased fruit yield (5800 kg/ha) whereas basin irrigation with recommended fertilizer application gave only 4300 kg/ha (Gnanamurthy and Manickasundram, 2001). Fertigation of N with balanced amount of K in early stage of citrus prevented sappy soft growth. At flowering, lowering the N levels with increased levels of P led to heavier and more even fruit set. Fertigation with higher levels of K during the period of fruit enlargement gave good flavour, texture and shelf life. After harvest, fertigation with higher levels of N assisted the citrus crop in the following year (Menzel and Obe, 1990). Fertigation with navel oranges and shemouti oranges resulted in increased yield and quality of the fruits (Bielorai *et al.*, 1984; Fouche and Bester, 1987). In mandarin orange, the highest canopy volume, fruit weight, TSS, juice content and yield were recorded with 20 % depletion of available water content and the fertigation treatment consisting of 500: 140: 70 g NPK/ tree (Shirgure et al., 2001). In grapes, fruit yield with 80 % water soluble fertilizer as fertigation gave 5770 kg/ha as against 2635 kg/ha with 100 % fertilizer under basin irrigation (Gnanamurthy and Manickasundram, 2001). In strawberries, yields were significantly higher when 50 or 100 % N and K were injected through the drip irrigation system. The inferiority of soil incorporated fertilizers was attributed to the leaching of fertiliser nutrient out of the root zone below the drip emitters during the growing season (Locascio *et al.*, 1977). Compared to fertilization, fertilizer saving under fertigation was found to the extent of 50 % with yield increase in peaches (Bussi *et al.*, 1991). Fertigation which combines irrigation with fertilizers is well recognized as the most effective and convenient means as maintaining optimum fertility level and water supply according to the specific requirement of each crop and resulting in higher yields and better quality of fruits (Smith *et al.*, 1979; Syvertsen and Smith, 1996). The nitrogen fertigation increased the yield of various fruit crops like apple (Nielson *et al.*, 1993), peach (Richard *et al.*, 1996), pepper (Haynes, 1988). shamouti sweet orage (Bielori *et al.*, 1984). valencia orange (Koo and Smjstrala, 1984), naval orange (Louse, 1990) and sunburst mandarin (Ferguson *et al.*, 1990). Fertigation with 80 % of recommended dose of N gave higher TSS (7.68^0 brix), juice (49.08 %), acidity (4.10) and fruit / tree (1493) than other levels of N fertigation to acid lime (Shirgure *et al.*, 1999).

Scheduling irrigation through drip once in 2 days at 100 % of surface method of irrigation registered highest tuber yield of 58.7 t/ha which was significantly superior over surface irrigation scheduled at 0.6 IW/CPE ratio. However, fertigation of N at different levels failed to reveal marked variation on tuber yield of tapioca. The three levels of N tried produced comparable yields both under surface and drip irrigations. Higher rhizome yield was recorded under drip irrigation at 80 % of surface irrigation, however the yield was comparable with 60 and 40 % of surface irrigation through drip which were significantly higher than 0.9 IW/CPE ratio. The three levels of N (100, 75 and 50 % of recommended level) @ 125, 93.75 and 62.5 kg/ha produced comparable yields which indicated saving of 50 % N over recommended level when applied as fertigation in turmeric. In coconut, fertigation with water soluble fertilizer at 80 % recommended fertilizer improved trunk girth (6 %), number of fronds (18 %), fruit bunches (21.5 %), nut yield and economized 20 % fertilizer over control. In oil palm, fertigation with water soluble fertilizer (80 %) improved the trunk girth (18 %), number of fronds (22 %) and yield (83 %) with a saving in fertilizer and water by 20 and 33 % over control (Gnanamurthy and Manickasundram, 2001). In paprika, fertigation with urea and multi - K at 100 % recommended NK level gave higher dry fruit yield of 63.8 q/ha which was 31.5 % higher over yield obtained with soil application of 100 % NK and surface irrigation (48.5 q/ ha) (Jeyabal *et al.*, 2000).

Nutrient uptake

The highest uptake of N was observed with more frequent drip irrigation in tomato (Yosef, 1977). In tomato, N uptake increases with increase in N application rate up to the optimum level (Yosef and Sagive, 1982). Significantly higher total N uptake by different parts of tomato plant was recorded under drip irrigation over conventional irrigation (Balfna et *al.*, 1993). The N application rate was having linear relationship with N uptake in drip irrigation system. Nitrogen uptake was markedly influenced by frequency as well as time of irrigation (Stark *et al.*, 1983). In trickle irrigated tomato, P uptake was not influenced by quantity of water applied (Yosef, 1977). The highest P uptake was recorded in most drip irrigation with more quantum of water (Yosef *et al.*, 1980). A significantly higher P content was measured in trickle irrigated tomato over surface irrigation method (Rauchkolb *et al.*, 1978). Goyal *et al.* (1984) found significant influence of trickle irrigation on K uptake in tomato. On contrary no significant difference was observed in K uptake with the water application rate through trickle irrigation in tomato(Kafkafi and Yosef, 1980). Drip fertigation of 80 % recommended dose with water soluble fertilizer registered 29.2, 27.2 and 27.0 % higher N, P_2O_5 and K_2O uptake over soil application of fertilizer with drip irrigation and 40.8, 44.8 and 43.7 % higher N, P_2O_5 and K_2O uptake respectively over furrow irrigation (Haynes, 1988).

Soil properties

High concentrations of mineral nutrients applied by drip irrigation may lead to localized salinity problems or changes in soil pH in the wetted zone. Changes in pH might not only affect root uptake but could significantly influence the solubility of mineral elements within the irrigated soil volume possibly leading to deficiencies or toxic levels of certain elements. Fertigation with ammonium nitrate @ 33 kg ha^{-1} on 11 occasions over a 2 year period caused a decrease in soil pH from 6.2 to 3.7 in the zone wetted by emitters (Edwards *et al.*, 1982). Decrease in soil pH was greater in fertigation of N as urea than broadcast application whereas level of soluble salts below the trickle emitters was increased due to the fertigation of N as compared to broadcast application but within non-injurious level to plants (Haynes, 1988). Generally, increased level of N through fertigation resulted in increased soluble salt concentration in soil below the drip emitters (Papadopoulous, 1987). Fertigation with both ammonium sulphate and urea caused acidification in the wetted soil volume. Acidification was confined to the surface 20 cm of soil in the ammonium sulphate while it was up to a depth of 40 cm in urea due to its greater mobility. Increasing the drip discharge rates reduced the downward movement of urea and encouraged its lateral spread in the wetted soil. As a consequence, acidification was confined to the surface 20 cm soil (Haynes, 1990).

Soil moisture availability

Slow and frequent watering eliminated

wide fluctuation of soil moisture under drip irrigation resulting in better growth and yield (Sivanappan, 1998). The soil water content in a portion of plant root zone remains fairly constant because irrigation water can be applied slowly and frequently at a predetermined rate (Bucks *et al.*, 1984). Water content in drip irrigation is always nearer to field capacity in root zone but unsaturated hence gravitational force is minimum (Black, 1976). Water retention curve was constant which showed constant water retention in soil under drip irrigation (Yosef and Sheikhoslami, 1976). According to Hendrick and Wierenga, (1990) variability in soil water tension was related to the method of irrigation (trickle and flood).

Water use efficiency

The highest WUE of 362 l/kg/ha cm under drip irrigation whereas it was 118.8 kg/ha cm in furrow irrigation in brinjal (Sivanappan and Padmakumari, 1980). In okra, Kadam *et al.* (1993) also recorded higher WUE (374 kg/ha cm) under drip irrigation than furrow irrigation (214 kg/ha cm). Decreasing the fertilizer level by 20 % than the recommended level especially under fertigation conditions may not affect the yield level in chilli because of improved fertilizer use efficiency. Between furrow and drip irrigations, drip irrigation produced significantly higher dry chilli yield with 42 % higher water use efficiency over furrow method (Veeranna *et al.*, 2001).

Non-uniform nutrient distribution

The effect of uneven nutrient distribution under drip fertigation viz., accumulation of P close to the emitter (Goldberg *et al.*, 1971) and rapid movement of NO_3 to the periphery of wetted volume is not great as plant can adopt to this spatial variability of nutrients through the rate of nutrient uptake per unit weight or length of roots in the nutrient enriched area (Dasberg *et al.*, 1981). Localized root proliferation can occur in the zones of soil high in nutrients (Haynes, 1985). Under arid soil conditions, the whole root system may develop in the trickle irrigated zone since there is little water available beyond the soil volume (Yosef, 1977; Levin *et al.*, 1979; Levin *et al.*, 1980).

Economics

Drip irrigation to brinjal not only offers water economy, but also provides a high yields of the produce which in turn gives higher net return than traditional furrow irrigation (Chauvan and Shukla, 1990). The B:C (benefit : cost) ratio of drip irrigation system for tomato crop was found to be 5.15 while it was 2.96 for conventional method (Gutal *et al.*, 1989). The B:C ratio was much higher in tomato under drip irrigation when the water so saved was assumed to be utilized to cover additional area of the same crop than conventional irrigation (Hugar, 1996). Higher discounted B:C ratio of 9.89 was obtained in tomato due to drip irrigation than surface irrigation (5.44). Fertigation under high density planting reduced the cost of production per kg of banana to as low as Rs.0.83 with a possibility of economizing water and fertilizer with increase in productivity (Mahalakshmi *et al.*, 2001a). The higher profit/rupee invested was realized with 150 g of N and K fertigation in 1:2 ratio (Chandrakumar *et al.*, 2001).

CONCLUSION

It is quite clear from the foregoing literature that fertigation had many advantages like higher WUE and FUE, minimum losses of N, optimization of the nutrient balance by supplies nutrients directly to root zone, control of nutrient concentration in soil solution and saves application cost. It increases the yield and economics of most of the high value crops under drip irrigation. High initial investment and comparatively low technical skill of average Indian farmers are some of the major constraints limiting the large scale adoption as drip fertigation technology in the country.

However, increasing water scarcity and escalating fertilizer prices may lead to greater adoption of the technology especially in high value crops and green houses to ensure higher efficiency of the two most critical inputs in crop production.

REFERENCES

Asokaraja, N. (1998). *In:* Proc. Workshop on Microirrigation and Sprinkler Irrigation Systems, April 28 - 30., New Delhi., P: 49-53.

Bacon, P.E. and Davey, B.G. (1982). *Soil Sci. Soc. Am. J.*, **46**: 987-993.

Bacon, P.E. and Davey, B.G. (1989). *Fert. Res.*, **19**: 156-167.

Bafna, A.M. *et al.* (1993). *J. Water Magmt.*, **1**: 1-5.

Baskar, M. (1996). M.Sc.(Agri.) Thesis, Tamil Nadu Agricultural University, Coimbatore.

Bielorai, H. *et al.* (1984). *In:* Proc. Int. Soc. Citriculture, Vol. I, pp 118-120.

Black, J.D.F. (1976). *Hort. Abst.*, **46**: 69-74.

Boman, B.J. (1996). *Fertigation Res.*, **44**: 123-128.

Bucks, D.A. and Nakayama, F.S. (1980). *In :* Proc. Agri-Turf. Irrig. Conf., California, pp 166-180.

Bucks, D.A. *et al.* (1982). *Adv. Irrig.*, **1**: 219-298.

Bucks, D.A. *et al.* (1984). *Irrig. Rev.*, **1**: 219-295.

Bussi, C. *et al.* (1991). *J. Hort. Sci.*, **66**: 487-493.

Chandrakumar, S.S. *et al.* (2001). *South Indian Hort.*, **49**: 92-94.

Chauvan, H.S. and Shukla, K.N. (1990). *In:* Proc XI International Congress on Use of Plastics in Agriculture, February 26 - March 02. New Delhi, pp 57.

Colapietra, M. (1987). *Rikvista dividticolturae di Enologia*, **40**: 223-239.

Dangler, J.M. and Locasscio, S.J. (1990). *J. Am. Soc. Hort. Sci.*, **115**: 585-589.

Dasberg, S. *et al.* (1981). *Acta Hort.*, **119**: 103-108.

Dass, H.C. (1989). In: proc. Citrus Shows Cum – Seminar, R.F. Research station, Abhor, January 6-7, pp 12-16.

Edwards, J.H. *et al.* (1982). *J. Am. Soc. Hort. Sci.*, **107**: 1142-1148.

Ferguson, J.J. *et al.* (1990). *Hort. Sci.*, **103**: 8-9.

Fouche, P.S. and Bester, D.H. (1987). *Citrus and Subtropical Fruit J.*, **62**: 8-12.

Gnanamurthy, P. and Manickasundram, P. (2001). *In:* Advances in Integrated Nutrient Management System for Sustainable Crop Productivity and Soil Fertility, October 4-24, 2001, Tamil Nadu Agricultural University, Coimbatore, pp 110-116.

Goldberg, D. *et al.* (1971). *J. Am. Soc. Hort. Sci.*, **96**: 645-648.

Goode, J.E. *et al.* (1978). *J. Hort. Sci.*, **53**: 307-316.

Goyal, M.R. *et al.* (1984). *J. Agric. Univ. P.R.*, **67**: 486-493.

Goyal, M.R. *et al.*(1985). *In:* Proc. 3rd International Congress on Drip Irrigation, November 18-21, Fresh No., California, USA.

Goyal, M.R. *et al.* (1989). *In:* Proc. 1st Congress on Irrigation in Puerto Rico, Ponce, March 8, pp 11-114.

Gutal, G.B. *et al.* (1989). *In:* Cost Economics of Drip Irrigation System for Tomato Crop. Oxford & IBH Publishing Co. Pvt. Ltd., New Delhi, pp 171-176.

Hagin, J. *et al.* (1990). *Fert. Res.*, **26**: 53-60.

Haroon, M.A.R. (1991). Ph.D. Thesis, Tamil Nadu Agricultural Univeristy, Coimbatore.

Haynes, R.J. (1985). *Fert. Res.*, **6**: 235-255.

Haynes, R.J. (1988) *Scientia Hort.*, **35**: 189-198.

Haynes, R.J. (1990). *Fert. Res.*, **23**: 105-112.

Hegde, D.M. (1998). *Scientia Hort.*, **37**: 144-155.

Hegde, D.M. and Srinivas, K. (1990). *Indian J. Agron.*, **35**: 106-112.

Hendrick, J.M.H. and Wierenga, P.J. (1990). *Irri. Sci.*, **11**: 23-30.

Hugar, L.B. (1996). *In:* Proc. All India Seminar on Modern Irrigation Techniques, Bangalore, June 26-27, pp 293-297.

Idate, G.M. *et al.* (2001). *South Indian Hort.*, **49**: 69-70.

Itulya, F.M. and Aguyoh, J.N. (1998). *Expl. Agric.*, **34**: 171-176.

Jaime, S. *et al.* (1987). *Anales de Edapologn Agrobiologin*, **46**: 1375-1383.

James, M. *et al.* (1990). *J. Am. Soc. Hort. Sci.*, **115**: 547-549.

Jeyabal, A. *et al.* (2000). *Agro India*, **4**: 34-37.

Jeyakumar, P. *et al.* (2001). *South Indian Hort.*, **49**: 71-73.

Jose Mathew (2003). *Kisan world*, **30**: 50-51

Kadam, R. *et al.* (1993). *J. Water Magmt.*, **1**: 53-54.
Kafkafi, U. and Yosef, B.B. (1980). *Agron. J.*, **72**: 893-897.
Kafkafi, U. and Yosef, B.B. (1980). *Agron. J.*, **72**: 893-897.
Keng, J.C.W. *et al.* (1979). *Agron., J.*, **71**: 971-980.
Keshavaiah, K.V. and Kumaraswamy, A.S. (1993). *J. Indian Potato Assoc.*, **20**: 240-244.
Kolo, M.G.M. (1995). *Trop. Agric.*, **72**: 102-104.
Koo, R.C.J. (1981). *Hort. Sci.*, **93**: 33-36.
Kwong, N.K. *et al.* (1999). *Expl. Agric.*, **35**: 31-37.
Kwong, N.K. and Deville, J. (1994). *Fert. Res.*, **239**: 223-228.
Levin, I. *et al.* (1979). *Pl. Soil*, **52**: 31-40.
Levin, I., *et al.* (1980). *Acta Hort.*, **92**: 255-264.
Locascio, S.J. *et al.* (1977). *J. Am. Soc. Hort. Sci.*, **102**: 456-468
Louse, F. (1990). Nitrogen Fertigation of Citrus Summery of Citrus Research. Citrus Res. Centre and Agricultural Station, University of California, Riverside, pp 20-22.
Magen, H. (1995). *Fertil. News*, **40**: 97-98.
Mahalakshmi, M. (2000). Ph.D. Thesis, Tamil Nadu Agricultural University, Coimbatore.
Mahalakshmi, M. *et al.* (2000). *In:* Proc. National Seminar on Hi-tech Horticulture, June 26-28, IIHR, Bangalore, pp 37.
Mahalakshmi, M. *et al.* (2001). *South Indian Hort.*, **49**: 80-85.
Mahalakshmi, M. *et al.* (2001a). *South Indian Hort.*, **49**: 86-91.
Menzel, S.W.O. and Obe, A.O. (1990). *In:* Proc. XI International Congress on Use of Plastics in Agriculture, New Delhi, pp B 3-11.
Miller, R.J. *et al.* (1976). *Calif. Agric.*, **30**: 16-18.
Miller, R.J. *et al.* (1981). *Agron. J.*, **73**: 265-270.
Muralidhar, A.P. *et al.* (199). *In:* Proc. of National Seminar on Problems and Prospects of Microirrigation -A Critical Appraisal, November 19-20, Bangalore, pp 74-78.
Nakayama and Bucks (1986). Management Principles and Fertilization in Trickle Irrigation,Elsevier Applied Science Publishers, Amsterdam, pp 317.
Neill, M.K. *et al.* (1979). *Soil Sci. Soc. Am. J.*, **43**: 283-286.
Nielsen, G.H. *et al.* (1993). *J. Am.Soc. Hort. Sci.*, **188**: 50-53.
Pandey, S.D. *et al.* (2001). *South Indian Hort.*, **49**: 76-77.
Papadopoulous, I. (1987). *Common. Soil., Sci. Plant Anal.*, **18**: 897-907.
Patel, J.C and Patel, B.K. (2001). *J. Indian Potato Assoc.*, **28**: 296-295.
Phene, C.J. *et al.* (1979). *Am. Potato J.*, **56**: 51-59.
Prabhakar, M. *et al.* (2001). *South Indian Hort.*, **46**: 98-100.
Rauchkolb, R.S. *et al.* (1978). *Soil Sci. Soc. Am. J.*, **40**. 68-72.
Reuveni, O. *et al.* (1991). Israel Ministry of Agriculutre. Special publications No., 250:50.
Richard, E.C. *et al.* (1996). *Hort. Sci.*, **31**: 370-375.
Rolston, D.E. *et al.* (1979). *Univ. Calif. Bull.*, **1893**: 1-14.
Rubeiz, I.G. (1990). *J. Plant Nutrition*, **13**: 269-273.
Ruiz, M.C. *et al.* (1991). *J. Agric. Univ. P.R.*, **72**: 575-584.
Salvadore, J.L. and Allen, G.S. (1996) *J. Am. Soc. Hort. Sci.*, **21**: 63-68.
Salvoder, J. *et al.* (1997). *Hort. Sci.*, **32**: 230-235.
Shirgure, P.S. *et al.* (1999). *Indian J. Soil Cons.*, **27**: 45-49.
Shirgure, P.S. *et al.* (2000). *In:* Proc. of National Seminar on Hi-tech Horticulture, IIHR, Bangalore, June 26-28, pp 73.
Shirgure, P.S. *et al.* (2001). *South Indian Hort.*, **49**: 95-97.
Singh, S.D. *et al.* (1989). *Can. J. Plant Sci.*, **69**: 991-999.
Sivanappan, R.K. (1985). *In:* Drip irrigation in Action, vol. II, ASAE, Michigan, pp 736-740.
Sivanappan, R.K. (1998). *In:* Proc. Workshop on Microirrigation and Sprinkler Irrigation Systems, April 28-30, New Delhi, pp 11-17.
Sivanappan, R.K. and Padmakumari, O. (1980). Drip irrigation. Tamil Nadu Agricultural University, Coimbatore, pp 70.
Smith, M.W. *et al.* (1979). *J. Am.. Soc. Hort. Sci.*, **104**: 311-313.
Sonneveld, C. and Wees, A.V. (1988). Proefstation voor Tuinbours onder Glas Te Naaldwijk, **42**: 31.
Spayd, S.C. *et al.* (1994). *Am. J. Ecol. Vitic.*, **45**: 34-42.
Srinivas, K. (1998). *Trop. Agric.*, **74**: 260-264.
Stark, J.C. *et al.* (1983). *Agron. J.*, **75**: 672-676.
Swietlik, D. (1992). *J. Am. Soc. Hort. Sci.*, **117**: 22-27.

Syvertsen, J.P. and Smth, M.L. (1996). *J. Am. Soc. Hort. Sci.*, **121**: 57-62.
Uriu, K. *et al.* (1977). In: Proc 7th International. Congress on Use of Plastics in Agriculture, New Delhi, pp 211-214.
Veeranna, H.K. *et al.* (2001). *South Indian Hort.*, **49**: 101-103.
Voogt, W. and Sonneveld, C. (1989). *Groenten in Fruit*, **45**: 37.
Yosef, B.B. (1977). *Agron. J.*, **69**: 486-491.
Yosef, B.B. and Sagive, B.B. (1982). *Agron. J.*, **74**: 633-638.
Yosef, B.B. and Sheikhoslami, M.R. (1976). *Soil Soc. Am. J.*, **40**: 575-582.
Yosef, B.B. *et al.* (1980). *Agron. J.*, **72**: 815-852.