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Fertigation in Horticulture : A Guarantee to Economized Quality Production

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Abstract

Doubling the farmers' income through maximising production per unit drop of water and sustaining soil health is the national goal. Horticulture sector is currently witnessing paradigm shift from 'yield maximisation' to 'enhancement of use efficiencies of irrigation water and nutrients'. Emphasis is on reducing excessive percolation of water along with precious nutrients beyond rhizosphere. Drip-fertigation system has been found to be very effective in achieving the judicious water and fertilizer use efficiency in horticultural crops. In the present day context, lot of emphasis is being given on improving the drip-fertigation practices for horticulture, where the crops are highly responsive to the need-based placement of water and nutrients. Adopting drip-fertigation has been found to increase the yields of horticultural crops by three-fold with the same quantities of water and nutrients. It has also been found to improve the quality of crop produce and help the growers in getting better price for their produce. Savings on irrigation water and fertilizer under drip-fertigation are 40-70% and 30-50%, respectively. Critical review of the research outcomes emanating from drip-fertigation strategy in horticultural crops is done in this paper.

Key words: Fertigation, horticulture, drip-irrigation, water productivity, nutrient use efficiency, fruits and vegetables.

Introduction

Water and fertilizer are the two major inputs for crops and interact with each other in influencing growth, yield and quality of crops. As most of the horticultural crops are water- and nutrient- exhaustive in nature, efficient management of these precious inputs is a must for achieving higher productivity but maintaining environmental quality. India is blessed with diverse agro-climatic conditions with distinct seasons, making it possible to grow wide array of horticultural crops. Besides, sustained higher yields with high yielding varieties depend entirely on the sustainable use of the limited water and energy resources, specifically in water-scarce arid and semi-arid regions. There is an urgent need to reduce the consumption of irrigation water by adopting effective water-saving technologies and methods. The increasing demands for irrigation water and fertilizers and their exorbitant costs call on adopting judicious, efficient and eco-friendly use of these inputs in horticultural crops. Every effort must be made to enhance water and fertilizer use efficiency by reducing their wastage. In recent years, drip fertigation has been used for applying water soluble fertilizers through drip irrigation. Drip irrigation achieves up to 90% per cent irrigation efficiency, generally increases the crop yields to the tune of 25 to 30%, and incurs 30% to 50% savings on irrigation water over conventional irrigation methods (Yadav et al., 1993). The fertigation allows application of right amounts of plant nutrients uniformly to the wetted root volume zone, where most of the active roots are concentrated and this helps in enhancing the nutrient use efficiency. It has been found to improve the productivity and quality of crop produce in addition to improving the resource use efficiency (Jat et al., 2011). Fertigation, a synergistic approach, saves up to 25% on fertilizers (Vaishnava et al., 1995). As the water-soluble fertilizers (WSFs) are very costly inputs, efforts have been made by various researchers to reduce the quantity of water-soluble fertilizers [nitrogen (N) and potassium (K)] in conjunction with straight fertilizer (single superphosphate, SSP) to enhance the yield potentials of crops and improve the fertilizer use efficiency. Key focus of this article is to discuss the importance and potential of drip fertigation technology for achieving higher productivity and maximizing the resource use efficiency in horticultural crops.

Fertigation

Fertigation is a technique of fertilizer application in which fertilizer is incorporated within the irrigation water by the drip system where timing, amounts and concentrations of fertilizers applied are easily controlled. Fertigation ensures saving in fertilizer (30-50%), due to "better fertilizer use efficiency" and "reduction in leaching" (Kumar and Singh, 2002). Drip

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irrigation is often preferred over other irrigation methods because it gives higher water application efficiency by reducing water losses through surface evaporation and deep percolation. Because of high frequency of water applications, concentrations of salts remain manageable in the rooting zone. In the present situation, water has become a scarce natural resource for agriculture due to competition caused by rapid industrialization, population growth, and urbanization. There is an urgent need to reduce the consumption of irrigation water by way of developing new irrigation-efficient technologies and methods that help in effective utilization of this precious input. As mentioned above, drip fertigation is a type of micro-irrigation that has the great potential to save on water and nutrients by allowing water to drip slowly to the roots of plant and minimize evaporation. Drip fertigation reduces the wastage of water and chemical fertilizers, and optimizes the nutrient use by applying them at critical stages and at proper effective root zone and time, which finally result in the increased water and nutrient use efficiencies. It is recognized as the most effective and profitable means of maintaining optimal nutrient level and water supply according to crop development stage, specific needs of crop and type of the soil.

Significance of Fertigation in Horticulture

In India, most of the horticultural crops are being cultivated on raised beds, with soil texture ranging from loamy clay to sandy loam, where downward percolation of water is rapid and often leads to leaching of nutrients beyond root zone under the conventional irrigation methods. Under such soil conditions, frequent occurrences of the deficiencies of macro and micro nutrients become a major production constraint exacerbated by the low moisture and nutrient holding capacities of these soils. Under conventional method of irrigation, rapid hydraulic conductivity, faster infiltration rate cause accelerated leaching of basic cations to the lower layers (below root zone). Net result is deterioration of soil fertility. This condition may load the ground water with pollutants like leached down fertiliser salts, other toxic pesticides, herbicides etc. Hence, the horticultural crops in such soils under conventional irrigation system require large quantities of nutrients to support its growth and yield for compensating the leaching losses of nutrients. Considering the soil and crop constraints, nutrient should be applied in synchrony with crop demand in smaller quantities during the growing season. The right combination of water and nutrients is a prerequisite for higher yield and good quality of produce. Method of fertilizer application is also important in improving the use efficiency of nutrients. Fertigation is the only irrigation strategy, which helps in adequate supplies of water and nutrients with precise timing and uniform distribution to meet the nutrient demand of horticultural crops. Besides, fertigation ensures substantial saving in fertilizer usage and reduces leaching losses (Mmolawa and Or, 2000).

Fertigation Scheduling

Factors that affect fertigation scheduling for horticultural crops are soil type, available nutrient status, organic carbon, soil pH, soil moisture at field capacity, available water capacity range, aggregate size distribution, crop type and duration and its physiological growth stages, and discharge variation and uniformity coefficient of installed drip irrigation system. The efficient fertigation schedule needs to take into account i) crop- and site- specific nutrient management, ii) timing and frequency of nutrient delivery to meet crop needs at critical growth stages, and iii) controlling irrigation to minimize leaching of soluble nutrients below the effective root zone.

In fertigation, nutrients can be injected daily or bimonthly depending upon system design, soil type, and farmers' preference. Frequent injection may be needed for sandy soils with poor water and nutrient holding capacity and for farmers who want to reduce injection pump size and cost. Fertilizer should be injected in a period such that it ensures enough time to permit complete flushing of the system without over-irrigation. The higher efficiency of water application reached in drip irrigation systems is ideal for the high efficiency of applied nutrients in fertigation. But, some of these potential benefits can become disadvantageous if and when the irrigation design or management is not correct as it may lead to non-uniform nutrient distribution, over-fertigation, excessive leaching, clogging etc.

Response to Fertigation in Different Horticultural Crops

Ferrtigation requirements and responses of important horticultural crops are summarized in **Table 1**. Major ones among these are discussed below category-wise:

A. *Fruit Crops*

1. *CITRUS*

Effect of Fertigation on Growth and Yield of Citrus

The influence of fertigation on growth, yields and fruit quality of citrus trees has been studied for more than 30 years. Results differ based on climate, soil type, root distribution and possibly tree age. Fertigation is an effective method of fertilizing plants in arid climates such as Israel. Fertilizer levels in the soil are

Table 1. Fertigation requirement and its response in major fruit, vegetable and plantation crops

S. No.	Crop	Fertigation requirement	Crop response	Reference
Fruit crops				
1.	Mango (*Mangifera indica* L.) Variety: Dashehari 10 m x 10 m spacing	75% RDF (380 g N-380 g P_2O_5-380 g K_2O per tree) + mulch + drip irrigation in V-area of basin in 16-year-old orchard	Increase in growth yield and quality, in addition to soil fertility	Panwar et al. (2007)
2.	Mango (*Mangifera indica* L.) Variety: Alphonso 2.5 m x 2.0 m spacing	100% RDF (120 g N- 100 g P_2O_5-100 g K_2O per tree) + 24 litres water per day in 3-year- old orchard	Increase in fruit yield and quality	Prakash et al. (2015)
3.	Mango (*Mangifera indica* L.) Variety: Dashehari 10 m x 10 m spacing	75% RDF (750 g N-375 g P_2O_5-750 g K_2O per tree) + 100% irrigation through drip based on 0.60W/CPE ratio in 30- year old orchard	Improvement in nutrition distribution, nutrient use efficiency coupled with better soil moisture distribution and yield	Adak et al. (2014)
4.	Guava (*Psidium guajava* L.) Variety: Shweta 2 m x 1 m spacing	75% RDF (30 g N-10 g P_2O_5-10 g K_2O per tree) + 75% irrigation requirement based on CPE in 3-year-old meadow orchard	Increase in flowering leaf nutrient status, growth, yield and quality	Ramniwas et al. (2013)
5.	Guava (*Psidium guajava* L.) Variety : Shweta 2 m x 1 m spacing	100 RDF + surface drip irrigation at 1.0 IW/CPE ratio	Increase in growth and fruit yield response	Sharma et al. (2013)
6.	Pomegranate (*Punica granatum* L.) Variety: Bhagwa 2 m x 2 m spacing	100% RDF (200 g N-200 g P_2O_5-500 g K_2O per tree using water soluble 19:19:19 fertilizer) + 100% irrigation at alternate day through drip irrigation in 4-year-old orchard	Better soil moisture distribution, fruit yield and quality	Haneef et al. (2014)
7.	Pomegranate (*Punica granatum* L.) Variety: Mridula 2 m x 2 m spacing	50% RDF using water soluble fertilizer + drip irrigation at 100% CPE in 2-year-old orchard	Improvement in flowering, soil available nutrients and fruit yield	Shanmugasundaram et al. (2013)
8.	Almond (*Prunus dulcis* L.) Variety: Waris	75% RDF (330 g N-45 g P_2O_5-455 g K_2O per plant through water soluble fertilizers) + drip irrigation based on pan evaporation in 8- year-old orchard	Increase in growth response and yield in addition to soil fertility	Dinesh Kumar and Almed (2014)
9.	Banana (*Musa paradisica* L.) Variety: Robusta	100% RDF (200 g N- 110 g P_2O_5 - 200 g K_2O plant^{-1} crop^{-1}) fertigation along with microbial consortium (*Azospirillum*, phosphate solubilizing bacteria and AM fungi mixed in equal proportions)	Increase in uptake of secondary nutrients and micro nutrients besides fruit yields	Senthilkumar et al. (2014)
10.	Banana (*Musa paradisica* L.) Variety: Robusta	100% RDF (13 g N-40 g P_2O_5-13 g K_2O per plant using urea, DAP and KNO_3 + drip irrigation at 1.0 IW/CPE	Improvement in growth, yield and quality	Mahendran et al. (2013)
11.	Apple (*Malus domestica* Borkh L.) Variety: Gala on M-26 rootstock 2 m x 4 m spacing	40 g N-17.5 g P_2O_5 using ammonium nitrate and ammonium pyrophosphate (10–15 – 0) in 5-year-old orchard	Improved root distribution and alleviated K-deficiency	Neilsen et al. (2000)
12.	Apple (*Malus pumilaalill* L.) Variety : Gala on M-9 rootstock 3.5 x 1.25 m spacing	60% RDF (30 g N, 4 g P, 37 g K, 6 g Mn and 4 g Ca per tree) + irrigation based on pan evaporation	Improved growth and yield initially with N-fertigation and later NPK fertigation proved better	Treder (2006)
13.	Strawberry (Fragaria x ananassa Duch.) Variety: Chandler 25 m x 50 m spacing	75% RDF (112 kg N-75 kg P_2O_5-90 kg K_2O per ha) + 100% ETC	Increase in growth yield and quality	Kachwaya and Chandel (2015)

Table 1. *Contd.*

S. No.	**Crop**	**Fertigation requirement**	**Crop response**	**Reference**
14.	Papaya Variety : Taiwan 2.5 m x 2.0 m spacing	100% RDF (250 g N-250 g P_2O_5-500 g K_2O per plant) + 50 mm CPE as 100% CPE	Improvement in growth, yield and quality	Deshmukh and Hardha (2014)
15.	Acid lime (*Citrus aurantifolia* Swimgle) Variety: Kagzi lime 6 m x 6 m spacing	75% RDF (450 g N-150 g P_2O_5-175 g K_2O per tree) + irrigation at 30% AWC depletion	Improvement in growth, yield, quality and leaf nutrient composition	Shirgure et al. (2014)
16.	Nagpur mandarin (*Citrus reticulata* Blanco) Variety: Nagpur mandarin 6 m x 6 m spacing	80% RDF (48 g N-160 g P_2O_5-240 g K_2O per tree) + irrigation at 20% AWC depletion	Increase in growth, yield, quality, leaf nutrient composition and soil fertility	Shirgure et al. (2016)
17.	Watermelon (*Citrullus lanatus* L.) 1.5 m spacing	RDF (20 g N-10 g P_2O_5-10 g K_2O) with irrigation twice in a week at 0, 100, 150 and 200 kg ha^{-1}	Improvement in plant height, number of leaves, fruit weight and increased yield.	Sabo et al. (2013)
Vegetable crops				
18.	Tomato (*Solanum lycopersicum* L.)	75% RDF (262.2 kg N- 40.4 kg P_2O_5 and 90.5 kg K_2O/per ha), using MAP, Multi K and urea in surface drip irrigation	Improved fruit yield, higher leaf area index. Root growth and NPK uptake was higher with fertigation.	Kalanjiyam and Manickam (2015)
19.	Potato (*Solanum tuberosum* L.)	100% RDF (50% nitrogen (N) mineral, 10 t/fed compost + humic substances, 10 t/fed compost + effective microorganism (EM) 4 L hr^{-1}	Highest tuber potato quality and quantity in sandy soil conditions	Mohamed et al. (2014)
20.	Cabbage (*Brassica oleracea* L.)	100% RDF (254.4 kg N, 19.1 kg P_2O_5 and 324 kg K_2O ha^{-1}) along with surface irrigation at IW/CPE ratio of 1.0	Increase in head diameter. TSS and ascorbic acid content was highest at 125% RDF but B:C ratio of 3.03 was recorded in daily fertigation with 100% RDF.	Vasu and Reddy (2013)
21.	Chilli (*Capsicum annuum* L.)	RDF: 100 kg N – 50 kg P_2O_5 – 50 kg K_2O per ha at irrigation of 1.0 PE (40.18 days)	Increase in number of leaves, plant height and yield response	Chaurasiya and Sahu (2016)
22.	Coriander (*Coriandrum sativum* L.)	75% RDF {N (50, 60 and 70 kg ha^{-1}), P_2O_5 (50 and 60 kg ha^{-1}) in combination with FYM (20 t ha^{-1}), K_2O (40 kg ha^{-1})} and foliar spray of soluble fertilizer (13: 0: 45) with water soluble fertilizer through drip irrigation	Improved quality and growth response	Rajaraman and Paramaguru (2011)
23.	Curry leaf (*Murraya koenigii* S.)	RDF: 150 g N : 25 g P_2O_5 : 50 g K_2O per plant per year with drip irrigation twice in a week	Significant effect on physiological parameters, improved plant growth, increased secondary branches and leaves	Sharon et al. (2012)
24.	Cauliflower (*Brassica oleracea* L.) transplanted at 0.60 m x 0.60 m	RDF: 225 kg N - 75 kg P_2O_5 - 75 kg K_2O per ha with irrigation @ 2.0 L hr^{-1} flow rate at 100 kPa pressure (KCP 0.75-1.25)	Improved yield and significant difference in curd weight and diameter, yield, AGB, number of leaves per crop and curd weight/AGB ratio.	Bozkurt et al. (2011)

Table 1. ***Contd.***

S. No.	Crop	Fertigation requirement	Crop response	Reference
25.	Spinach (*Spinach oleracea* L.)	RDF (170 kg N – 85 kg P_2O_5 – 85 kg K_2O ha^{-1}) drip irrigation twice a week	Leaf chlorophyll SPAD nitrogen balance index values, growth response, increase in nitrogen and WUE	Zhang et al. (2014)
26.	Brinjal (*Solanum melongena* L.) S_3 (175 cm- 50 cm x 50 cm) plant spacing	80% RDF (150 kg N: 50 kg P_2O_5: 50 kg K_2O ha^{-1}), IW/CPE ratio of 1.0, irrigation level – 0.6 PE.	Significantly higher value of total N, P and K uptake, maximum fertilizer-use-efficiency of NPK and yield	Ugade et al. (2013)
27.	Onion seed crop (*Allium cepa* L.)	Drip irrigation at 100% nutrients 240 kg ha^{-1} (120 kg N; 60 kg P_2O_5; and 60 kg K_2O) - F_3 ETC carried out the experiment in semi-arid climate.	Significantly increase in seeds per umbel, seeds yield per umbel per plant as well as soil nutrient uptake	Dingre et.al. (2016)
Plantation crops				
28.	Cocoa (*Theobroma cacao* L.)	125% RDF (125 g N+ 50 g P_2O_5 + 175 g K_2O per plant per year) with irrigation of 20 L per tree per day	A phenomenal increase in growth parameters such as trunk girth, canopy spread and weight of the pruned branches removed, leaf fresh weight and leaf dry weight as well as levels of NPK	Krishanamoorthy et al. (2013)
29.	Arecanut (*Areca catechu* L.)	75% NPK (RDF: 100 g N: 18 g P_2O_5 : 117 g K_2O per palm per /year) along with irrigation at IW/CPE ratio of 1 with a 30 mm depth of water through basin irrigation	Increase in leaf water potential, root biomass and organic carbon content in soil based on polynomial regression as well as significant increase in water use efficiency and agronomic nutrient use efficiency	Bhat et al. (2007)

maintained at constant levels of 35-60 mg kg^{-1} throughout the irrigation period. Studies suggest that optimum N rate for mature Shamouti orange trees is about 170 kg ha^{-1} yr^{-1}. Higher N rates increased the fruit yields but decreased the external fruit quality by delaying peel colour development and increasing peel thickness. However, juice quality, specifically total soluble solids (TSS), was not affected by N rate. The reduction in fresh fruit quality and increased costs for the additional N are probably not economically warranted. Similarly, research from Spain with navel oranges showed that daily fertigation significantly increased yields over application of dry fertilizer twice/year. Optimum N rate was 0.75 kg tree^{-1} yr^{-1}. High N rates increased fruit weight & number and peel thickness and decreased the juice content. In this instance, fertilizer was applied using 8 drippers per tree to ensure adequate root zone coverage which is an important factor in any fertigation programme. Fertigation does not always increase tree growth and yields over application of dry materials. Therefore, general recommendations concerning its effects cannot be made. Studies from South Africa found no difference in growth of young Valencia orange trees during the first 4 years after planting while using fertigation (6 times yr^{-1}) *vs.* dry application (4 times yr^{-1}) at the same N rates (Bester et al., 1977). Fertigation effects on tree performance are even less pronounced in humid subtropical areas such as Florida and Texas. Research related to the injection of fertilizers through drip irrigation system was started by Smith et al. (1979). Potential advantage of micro-irrigation systems and their usefulness was attributed to the fertigation. Bielorai et al. (1984) advocated use of fertigation technology in citrus as it resulted in higher production of good quality Shamouti oranges. These researchers compared N fertigation at 100, 170 and 310 kg ha^{-1} with broadcast application at 170 kg ha^{-1} through conventional irrigation system. Phosphatic and potash fertilizers were given at same rate by conventional methods in all the treatments. Average yields for 4 years were 62, 73 and 82 t ha^{-1} with 100, 170 and 310 kg kg ha^{-1}, respectively through fertigation.

Koo and Smajstrala (1984) supplied 15% and 30% of crop N and K requirements through fertigation and rest through conventional method to Valencia orange. Partial fertigation of N and K resulted in lower N contents of leaves. The TSS and acid concentration in juice was also reduced but yield was not affected. Haynes (1988) studied the comparison of fertigation with broadcast application of urea on levels of available soil nutrients and on growth and yield of trickle-irrigated peppers. He found that growth and yields were greatest at the low rate of N applied through fertigation or as a combination of broadcast plus fertigation. Fouche and Bester (1987) tried various fertilizer combinations through fertigation on 13-year-old Navel oranges. Fertigation was given with a soluble fertilizer 'Triosol' (3:1:5) + 350 g urea by broadcast, fertigation of N and K with broadcast of SSP and NPK through broadcast. Highest yield was obtained with fertigation of NPK through Triosol or by complete broadcasting of NPK fertilizers. No significant differences were observed on fruit size, acidity, percent juice content, and TSS among treatments. Ferguson et al. (1990) studied the effect of fertigation on growth of 'Sunburst' tangerine trees. Two-year-old *Citrus reticulata x C. paradisi* cv. Sunburst was fertilized with 0.66 or 1.32 lb N tree^{-1} during 1988-89 and it was 0.52 or 1.05 lb N tree^{-1} during 1990. Leaf analysis showed low to deficient concentrations of N, K, Mn and Zn under both of N treatments. Zekri and Koo (1994) tried micro-nutrients through fertigation with different sources at various rates. Inorganic forms (NO_3 and SO_4) were ineffective in influencing micronutrient levels in oranges. But chelated sources of Fe, Mn, Zn and Cu were very effective and their rates of application were comparable with rates added through foliar applications. Neilsen et al. (1993) reported that fertigation with calcium ammonium nitrate increased the vigor and leaf Ca concentration but decreased leaf Mg and Mn compared to trees fertigated with urea or ammonium nitrate (NH_4NO_3) in apple trees. Fertigation with P increased early tree vigor, leaf and fruit P concentration and decreased leaf Mn.

Syvertsen and Smith (1996) studied the nitrogen uptake efficiency and leaching losses from lysimeter-grown trees fertilized at three N rates. Based on the findings they concluded that the average N uptake efficiency decreased and overall canopy volume and leaf N concentration increased with increased N application rates, but there was no effect of N rates on fibrous root dry weight.

1.1. Increasing Efficiency of Fertigation through Optimum Scheduling and Suitable Nutrient Sources

Nitrogen application rates for fertigated mature, bearing trees range from 150 to 200 kg ha^{-1} yr^{-1} for most of the citrus-growing regions worldwide. Major sources of N include ammonium nitrate (AN), ammonium sulphate (AS), urea and potassium nitrate. Phosphorus (P) and potassium (K) rates vary across growing regions based on previous fertilization practices. These are based on leaf and soil analyses. Therefore, generalizations concerning P and K rates cannot be made. Major sources of phosphorus include phosphoric acid and polyphosphate; potassium sources include potassium nitrate and potassium chloride (MOP). Choice of fertilizer source depends on pH, calcium (Ca), magnesium (Mg) and TSS levels in the irrigation water. Increasing frequency of application from 5 to 30 times per year (weekly) had no effect on growth of citrus. Nevertheless, soil-nitrate nitrogen levels and the potential for nitrate pollution of groundwater were reduced significantly by frequent fertigation over less frequent dry fertilizer application. Research on mature orange and grapefruit trees in Florida also showed no yield increases for fertigated over non-fertigated (dry application) trees. However, fertigation decreased the juice acidity. In addition, ´Ruby Red´ grapefruit trees in Texas grew and yielded similarly for the first 4 years after planting irrespective of whether they received dry or liquid fertilizer (Swietlik, 1992). In contrast to the above, fertigation using reclaimed wastewater increased the yields over dry application for mature grapefruit trees on the east coast of Florida. In this instance, reclaimed wastewater containing less than 10 ppm nitrates was applied twice a week or more than 100 times a year. Increased yields may also have occurred due to improved water relations, although soil water content was maintained in the optimum range across all the treatments. The percentage increase in plant height, plant girth, and canopy volume was maximum with 100% N fertigation followed by with 80% N fertigation. The percentage increase in plant height, plant girth, and canopy volume was better in band placement treatment as compared to 60% N fertigation treatment. The percentage increase in leaf N content was more in case of 80% N fertigation (27.47%), followed by 100% N fertigation (24.32%), 60% N fertigation (20.23%), and band placement (7.5%). Study clearly indicated the advantage of N fertigation over the conventional method of fertilizer application (Shirgure et al., 2001). Various irrigation and fertilizer levels singly and in combination were evaluated through fertigation in terms of response on growth, yield, quality and leaf nutrient composition of Nagpur mandarin (*Citrus reticulata* Blanco) on rough lemon (*Citrus jambhiri* Lush.)

grown on alkaline calcareous Lithic Ustochrept under hot sub-humid tropical climate of Central India. Irrigation at 20% depletion of available water content and fertilizer treatment of 500 g N + 140 g P_2O_5 + 70 g K_2O per tree, individually were observed to be optimum irrigation and fertilizer treatments, respectively. Combined application of these two treatments produced significantly higher magnitude of fruit yield m^{-3} of canopy in addition to higher N, P, and K status, and other fruit quality indices (Srivastava et al., 2003).

Water quality is an important concern when fertigating citrus trees. Water with high pH, Mg and Ca levels may cause precipitation of P added through the fertilizer. Water high in salts may not be suitable for fertigation since some N source such as AN or K added through MOP increase total dissolved solids in the irrigation water and may cause damage to trees. Citrus trees, particularly those on trifoliate or trifoliate-hybrid rootstocks, are salt-sensitive. Therefore, water quality should be tested before using for fertigation and monitored after fertilizer is injected into the system. Liquid fertilizers also may crystallize leading to precipitate formation in the tank at temperatures below 15 °C. A partial solution to this problem is to use low analysis fertilizers that salt-out at lower temperatures. For example, a 10(N):0(P) :10(K) analysis fertilizer crystallizes at 15 °C; whereas, a 6(N):0(P):6(K) analysis material crystallizes at -3 °C. Use of potassium chloride in place of potassium nitrate in the fertilizer formulation also reduces salting-out at low temperatures.

A field experiment was conducted on Nagpur mandarin (*C. reticulata*) during 1998-2000 at NRC for Citrus, Nagpur. The treatments were 4 levels of irrigation (10%, 20%, 30% and 40% depletion of available water content) and 3 levels of fertigation (600, 200 and 100 g; 500, 140 and 70 g; and 400, 80 and 40 g of N, P and K per plant). The incremental plant height (0.46 m), girth (19.9 cm) and canopy volume (14.3 m^3) were more with irrigation scheduled at 20% depletion of available water and 500, 140 and 70 g N, P and K per plant fertigation. The fruit yield (26.1 kg per tree), fruit weight (135.1 g), total soluble solids in fruits and juice percentage (47.32%) were higher with irrigation scheduled at 20% and 500, 140 and 70 g N, P and K per plant fertigation (Shirgure et al., 2001a). The incremental height (0.40 - 0.60 m), stock girth (4.07 - 4.26 cm) and canopy volume (6.93 m^3) of the bearing acid lime were more in irrigation scheduled at 30% depletion of available water content with 500:140:70 fertigation. The combined effect of irrigation at 30% depletion of available water content and fertigation with 500:140:70 gave better growth and yield of acid lime. The average fruit yield was 15.83 kg $tree^{-1}$ under 30% depletion of available water content. The average fruit weight and total soluble solids was 30.1 g and 8.1% in irrigation scheduled at 30% depletion of available water content with 500:140:70 fertigation. The juice percent and acidity with irrigation scheduled at 30% depletion of available water content and 500:140:70 fertigation were more (42.5% and 7.0%) as compared to other treatments (Shirgure et al., 2001b).

Fertilization using drip irrigation has proved very effective in sustaining the fruit quality of Nagpur mandarin. For evaluation of the fertigation dose of through different K fertilizers applied through drip irrigation system, a field experiment was conducted on 11-14 years Nagpur mandarin during 2003-06. Treatments consisted of fertigation with 20 g K_2O $plant^{-1}$ $month^{-1}$, 30 g K_2O $plant^{-1}$ $month^{-1}$, 40 g K_2O $plant^{-1}$ $month^{-1}$ and 50 g K_2O $plant^{-1}$ $month^{-1}$. Nitrogen and P were given from October to January and all N, P and K as per the treatments were given during February to June. The leaf nutrient status was highest in fertigation with sulphate of potash (SOP) (40 g K_2O $plant^{-1}$) at 30 days interval from February to June. The fruit yield was highest (25.52 t ha^{-1}) with SOP fertigation followed by fertigation with 50 g K_2O $plant^{-1}$ at 30 days interval (23.67 t ha^{-1}). The fruit quality was influenced with different potassic fertilizers. Maximum juice TSS (9.63 °Brix) and fruit weight (163.3 g) was observed with K fertigation with 40 g K_2O $plant^{-1}$ at 30 days interval. The highest TSS/acidity ratio was observed with K fertigation with 40 g K_2O $plant^{-1}$ at 30 days interval (10.0). Fertigation with 40 g K_2O $plant^{-1}$ at 30 days interval using SOP fertilizer through micro-irrigation proved to be very effective for better fruit yield and quality of Nagpur mandarin. Treatments for evaluation of different potash fertilizers in K fertigation for Nagpur mandarin consisted of fertigation with potassium chloride (MOP), potassium nitrate (KN), sulphate of potash (SOP) and mono potassium phosphate (MKP) with dose as 150 g K_2O $plant^{-1}$. The fertigation was scheduled at 15 days interval and fruit yield and quality were measured at harvest. Nagpur mandarin yield was highest (31.13 t ha^{-1}) with MKP fertigation (150 g K_2O $plant^{-1}$) followed by fertigation with KN (150 g K_2O $plant^{-1}$) at 15-days interval (29.4 t ha^{-1}). Fruit quality was also affected by different K fertilizers. Highest fruit TSS (10.54 °Brix) and fruit weight (159.28 g) was observed under fertigation with KN (150 g K_2O $plant^{-1}$) at 15-days interval. The highest TSS / acidity ratio was observed under fertigation with MKP (13.7) followed by SOP (13.1). These results clearly indicate that the combined use of micro-irrigation and K fertigation technique is a sustainable solution for increasing the productivity as well as fruit quality of Nagpur mandarin orchards (Shirgure et al., 2004).

2. BANANA

In banana cultivation, fertigation system effects a saving of 35-52% on fertilizer and 40-60% on water compared to conventional cultivation (Ashokkumar et al., 2007). Fertilizer use efficiency was increased up to 67% over conventional fertilizer application. Fertigation with water soluble fertilizers in banana increased the yield by 60 to 70% as compared to soil application of conventional fertilizers. Forty per cent saving in fertilizer was achieved without any reduction in banana yield (Solia et al., 2010).

Banana, being a perennial crop, suits well to fertigation technology. In Hawaii, shifting to drip irrigation combined with fertigation in banana in a well-managed, conventional sprinkler irrigated plantation led to doubling the fruit yield (Young et al., 1985). Lahav and Kalmar (1995) opined that banana responded well to drip fertigation. More yield and significantly higher number of hands per bunch were obtained through fertigation (Smith, 1991, 1992; Guerrero and Gadbau, 1996). In India also, higher yields with improved quality through fertigation have been reported (Hegde and Srinivas, 1989; Srinivas, 1997; Srinivas et al., 2001; Mahalakshmi et al., 2001).

2.1. Effect of Fertigation on Crop Growth Parameters

Application of N, P and K through fertigation influenced vegetative growth, number of hands and fingers, bunch weight and fruit yield in banana (Hegde and Srinivas, 1989). Significantly higher plant height and girth was observed with application of N and K, each at the rate of 200 g plant^{-1} (Srinivas, 1997). Banana plants effectively utilized the accurately-placed fertilizer in solution form in the active root zone area, resulting in vigorous growth, early flowering and early bunch development. Similarly, leaf area index (which is a measure of source-size) was significantly higher with drip irrigation over the furrow-irrigated control. Bhalerao et al. (2009) studied the effect of different N sources on growth and yield in banana cv. Grand Naine under drip irrigation. Combined application of 25% N through AS + 25% N through calcium ammonium nitrate (CAN) was beneficial in terms of attaining maximum plant vigour, early flowering and lower crop duration.

2.2. Effect of Fertigation on Yield-attributing Characters

Post-shoot application of K (44th to 47th week after planting) favoured growth and development of bunches with better fruit-filling, resulting in increased finger weight, length and mid-circumference (Yadav et al., 1988). In cultivar Robusta, fertigation treatment (200:30:300 g NPK per plant) registered the maximum bunch weight, with corresponding highest number of hands and fingers (Mahalakshmi et al., 2000). Application of 240 g N plant^{-1} in four split doses at 2, 4, 6 and 8 MAP recorded significantly higher pseudo-stem height and girth, number of leaves plant^{-1}, number of fingers bunch^{-1}, yield, total sugar and sugar acid ratio in cultivar 'Jahajee'.

2.3. Effect of Fertigation on Yield

Banana crop under drip irrigation resulted in increased yield, higher number of hands with more length and girth of fruits. Weekly fertigation with proportionate quantities of 200:30:300 g NPK plant^{-1} yr^{-1} starting with 9th week after planting, effectively increased the yield of banana cultivar Robusta (Mahalakshmi et al., 2001). Similarly, increase in level of N and K fertigation improved growth and fruit yield which was significantly higher with more finger weight with 1:2 N and K fertilizers, compared to 1:1 ratio. Fertigation with 75% RDF through surface drip-irrigation increased fruit yield in both the main and ratoon crops of banana by 9.12% and 12.85%, respectively (Dinesh-Kumar and Pandey, 2008).

2.4. Effect of Fertigation on Fruit Quality Parameters

Drip irrigation significantly increased total sugars / reducing sugars and total soluble solids in banana fruits (Somogyi, 1952; Natesh Beena et al., 1993). In tissue-culture-raised banana cv. Dwarf Cavendish, application of 300 g N in 5 splits significantly increased the TSS (23.8 °Brix), reducing sugars (6.38%), total sugars (17.48%) and sugar acid ratio (Tirkey et al., 2003). Dinesh-Kumar and Pandey (2008) recorded statistically significant values of TSS, total sugars and reducing sugars with application of 75% RDF and the increased total sugars in banana due to higher N and P uptake by the plant. In general, it is observed that banana requires larger doses of K, moderate doses of N, and relatively lower doses of P for growth and yield. Higher requirement of N and K for banana was reported as early as in 1921 by Fawcett, and later confirmed by Norris and Ayyar (1942). Nalina (2002) justified that the application of 150% of recommended dose of NPK (165:5.5:495 g per plant) in four splits, *viz*., 2, 4, 6 and 8 months after planting, was essential to increase growth and development, and yield and quality of tissue-culture banana. Daniells and Armour (2010) observed that banana utilized about 50% of the applied fertilizers, while the remaining nutrients were held in the soil.

2.5. Strategies to Increase Efficiency of Fertigation

2.5.1. Fertigation scheduling

The real success of any fertigation programme mainly depends upon the systematic scheduling of fertigation as the frequency plays a critical role in fulfilling the requirement of the crop growth and development. In banana, it is expected that application should coincide with the climatic conditions, phenological stages (Shahar and Achilea, 1997) and the crop nutrient requirement at various stages. Frequency of fertigation also depends on the type of soil, rainfall pattern and weather conditions, and nature of nutrients, etc. Light soils with low fertility in high rainfall regions require frequent applications. Intensive leaching areas require immediate fertigation. Nitrogen and K fertilizers are applied at short intervals over long period of time (eight times) while P fertilizers should be applied once or twice manually due to its limited mobility in the soil (Robinson, 1996). Mahalakshmi et al. (2003) emphasized on the timing and regular frequency of fertigation. They were of the opinion that, high levels of N and K, particularly K, during the vegetative stage, floral initiation and differentiation increased the yield of Robusta cultivar of banana. They also recorded heaviest bunches (36.5 kg as compared to 20.5 kg in the control) with highest level of irrigation and fertigation at weekly intervals.

According to Sathya et al. (2008), frequent application of nutrients through drip system improves the uptake of nutrients through two main mechanisms: i) continuous replenishment of nutrients in the depletion zone at the vicinity of root interface; and ii) enhanced transport of dissolved nutrients by mass flow, due to the higher averaged water content in the medium. Lahav and Kalmar (1995) opined that there was a constant advantage in most of the parameters through weekly fertigation. For example, it increased bunch weight by 0.7 kg and the yield by 2.2 t ha^{-1} as compared to continuous application. Similarly, Bhalerao et al. (2009) observed that the application of fertilizers at weekly intervals with 75% RDF of N and K (44 splits up to 300 days) through fertigation and P by soil placement recorded higher yield in cultivar Grand Naine besides effecting a saving in N and K fertilizers of up to 25% over the conventional methods. Smith and Hoffman (1998) obtained higher mean bunch weight of 33.3 kg and 29.2 kg, respectively through monthly micro-spray and drip fertigation.

2.5.2. Fertigation in high density planting

Drip irrigation and fertigation have a significant role in achieving not only higher productivity and water use efficiency, but also in attaining sustainability with economic use and productivity. Fertigation could help in the long run efficient and uniform application of water and fertilizer with minimum manpower to improve productivity and quality of the produce. At Coimbatore, under the garden land system, highest bunch weight (26 kg) was recorded under conventional planting with 50% N and K fertigation and 3 suckers/hill with 100% (110:330 g plant^{-1}) N and K fertigation. Planting 2 suckers per hill at a spacing of 1.8 m x 1.8 m (6000 plants ha^{-1}) with 50% RDF as fertigation was found to be highly economical. It gave a maximum total yield (135.78 t ha^{-1}) with high cost–benefit ratio of 3.75. At Thrissur with Nendran (AAB), planting 2 suckers pit^{-1} (3086 plants ha^{-1}) with 75% of RDF recorded significantly higher bunch weight and total yield (31.90 t ha^{-1}) than the control (20.90 t ha^{-1}). At Jalgaon, Grand Naine (AAA) grown under conventional planting recorded earliest flowering (at 287.7 days). Maximum bunch weight (14.95 kg) was recorded in 3 suckers hill^{-1} with 75% N and K fertigation. Total yield of 82.8 t ha^{-1} was recorded in 2 plants hill^{-1} with 75% N and K fertigation. For export quality fruits (over 20 cm length and 12 cm girth), 3 suckers hill^{-1} under paired row system with 75% N and K fertigation was found to be superior. Irrigation of Robusta banana grown under the normal planting system on sandy loam soil of Coimbatore @ 25 L day^{-1} and fertigation with 100% RDF of 200:300 g N:K recorded the most vigorous plant growth, earliest flowering and harvest, and highest bunch weight (44.53 kg) and yield (111.33 t ha^{-1}). High density planting population of 5000 plants ha^{-1} + 40 L of water day^{-1} + 75% RDF fertigation (450 and 675 g of N and K plant^{-1}, respectively) recorded yield increase of 209.7% over conventional planting (Mahalakshmi et al., 2001).

3. GRAPES

Many factors, notably climate, soil, water and vineyard management, can influence the growth and yield components in the vineyards. These impact the grape and wine composition and quality. Irrigation strategies are being developed continuously for controlling excess vigour, reducing pest and disease pressure, and optimizing grape and wine quality. The application of fertilizers through irrigation water is a common strategy to meet the water and nutrient requirements of grapevines. Nutritional factors may have an impact on variables associated with varietal type; however, there is a very little work focusing on the impact of vine nutrition on yield and concentrations of aroma compounds in grapes.

Effect of Fertigation on Growth, Yield and Quality of Grapes

Shaymaa et al. (2019) conducted a field experiment to investigate the biological response of grape plants (*Vitis vinifera* L.) (var. Superior) to fertigation with the combination ratios of the three K fertilizers *i.e.*, KNO_3, K_2SO_4 and KCl. Based on the results, authors concluded that the grape plants showed a positive response to the fertigation with two treatments of the potassium fertilizers combination ratios namely, K-KCl/K-KNO_3/K-K_2SO_4 (50/50/0) and (50/0/50). Under these fertilizer treatments improved the nutrient content in grape plant tissues, grape plant's resistance to diseases, grape plant's growth, and the total and exportable clusters fresh yield. In general, N, K, P, Ca, Mg and Cl contents in the petioles and leaves of grape plants were slightly affected by fertigation with different potassium fertilizers. Vilanova et al. (2019) conducted a study during 2014–2015 to examine the effect of fertigation on chemical composition of Albarino. A control (rain-fed) and fertigation (60% and 100%) treatments were applied at same irrigation depth, where fertigation 100% is the complete nutrient requirement to Albarino trellis system in Rias Baixas AOC, NW Spain. Results showed that non-volatile compounds of Albarino musts were not affected by fertigation treatments. However, the effect of fertigation treatments on the volatile composition was observed. Terpenes and C_{13}-nor isoprenoids were the most affected families of volatile compounds by fertigation treatments, where 60% fertigation exhibited the highest concentration, thus improving the wine aroma quality. Application of principal component analysis (PCA) showed a good separation of Albarino grape according to fertigation treatments and vintages.

Philip Myburgh and Carolyn Howell (2012) compared three fertigation levels in a drip irrigated Dan-ben-Hannah/Ramsey vineyard near Paarl in the Berg River Valley region of South Africa during the 2002/03 and 2003/04 seasons. Fertilizers were applied either (i) three times per season, (ii) once a week from bud break to flowering, from fruit set to veraison and for six weeks after harvest, or (iii) in five to seven pulses per day. For each of the fertigation strategies, grapevines bore normal or high crop loads, *viz*. 26 or 36 bunches per grapevine, respectively. Daily irrigation pulses of 20 to 40 minutes each maintained soil water matric potential above -0.01 MPa in the wetted bulbs. Daily pulses accumulated to a seasonal total of ca. 490 mm irrigation compared to ca. 260 mm for weekly irrigation. The grapevines did not experience any detrimental water constraints throughout the season, irrespective of fertigation and irrigation frequencies or crop load. It became evident that grapevine water status not only depends on the size of the root structure, but also on the soil environment in which the roots function.

Reynolds et al. (2005) conducted fertigation trials with four levels in which 80 kg N ha^{-1} was applied as urea. in Concord and Niagara grapes in Ontario, Canada. With the help of modified FAO Penman-Monteith ET formula, they found small transpiration differences between control and irrigated or fertigated treatments, which was attributed to later season water stress induced by increase in canopy size caused by the early season irrigation. Irrigation and fertigation led to enhanced berry set, larger berry size, increased vine size, and small increases in yield. Slight yield increases (10% in Concord; 29% in Niagara) in irrigated and fertigated treatments were attributed to increased cluster numbers, cluster weights, and berry weights. In most of the seasons, yield increases were accompanied by small decreases in soluble solids (1.5 to 3.0 °Brix) and methyl anthranilate concentrations. Timing of fertilizer application did not play a major role in influencing any of these attributes. It was concluded that the use of Penman-Monteith formula for irrigation scheduling needs to be evaluated over several seasons and validated using both plant and soil moisture monitoring. Monterio et al. (2014) compared the effects of fertigation with monitoring by tensiometers, class A pan, nitrogen dose @ 40 kg, 98 kg, and 160 kg per ha. Evaluation was done for the parameters namely, mass of 10-berries (MB), level of chlorophyll per plant, length of bunch, width of bunch, length of berry, width of berry, total acidity and total soluble solids. There were no statistically significant differences between treatments in two harvests. However, plants under fertigation with 98 kg N ha^{-1} were better developed as compared to the rest.

B. *Vegetable Crops*

1. *CAULIFLOWER AND CABBAGE*

Fertigation of cauliflower with 100% recommended dose of N and K at every week up to 60 days after transplanting (DAT) and P as basal application registered significant increase in yield attributing characters over rest of the treatments. However, this treatment effect was at par with fertigation at 75% of recommended dose of N and K at every week up to 60 DAT and P as basal application in case of yield. At higher fertigation level, crop meets its nutritional requirements at respective growth stages which leads to luxurious growth, and resultant enhancement in the yield. Similar results were also reported by Chetan and Singh (2009), Imtiyaz et al. (2009) and Bozkurt et al. (2011). The yields of cauliflower were maximum at 100% of RDN through fertigation (Chetan and Singh, 2009). Kapoor et al. (2014) showed that increase in NPK fertigation level from 33% RDF to 100% RDF significantly increased the numbers of leaves, relative leaf water content, marketable yield of cauliflower, and benefit:cost ratio but decreased the fertilizer expense efficiency. Drip irrigation along with fertigation in general, had higher fruit yield but lower benefit:cost ratio in comparison to flood and conventional fertilizer application. Fertigation using water soluble fertilizers increased marketable yield of cauliflower by 21.3% over conventional application of fertilizers. Shinde et al. (2006) showed that fertigation with 125% of RD-NPK fertilizer resulted in higher weight of head cabbage over 150% and 100% recommended dose.

2. BROCCOLI

Singh et al. (2002) reported 115% and 17% increase in broccoli yield with fertigation over drip irrigation and check basin method, respectively. Selim et al. (2012) reported that application of humic substances through fertigation increased total marketable yield and head diameter of broccoli as well as quality parameters (*i.e.,* total soluble solids, protein and vitamin C). Higher nutrient concentrations were found in the broccoli heads and the contnets of plant available nutrients in soil after harvesting were also higher, indicating an improvement in soil fertility. Humic substances fertigation can be judged as an interesting option to improve soil water and nutrient status leading to better plant growth. Fertigation using water soluble fertilizers increased the marketable yield in broccoli by 21.4% as compared to conventional application of fertilizers. However, when 25% nutrients were applied as basal through conventional fertilizer and 75% nutrient through fertigation using water soluble fertilizers increase in marketable yield in broccoli was 12.3% as compared to conventional application of fertilizer.

3. RADISH

Shedeed et al. (2009) reported significant increase in growth parameters of radish (plant height, leaf area index, fruit dry weight, total dry weight), yield components (number of fruits plant^{-1}, mean fruit weight, fruit yield plant^{-1}) and total fruit yield with the application of 100% RDF through fertigation over furrow and drip irrigation and soil application of fertilizers. The increase in yield under fertigation might have accrued from better water utilization (Manfrinato, 1971), higher uptake of nutrients (Bafna et al., 1993), and excellent soil-water-air relationship with higher oxygen concentration in the root zone (Gornat et al., 1973). Manfrinato (1971) recorded the benefit:cost (B:C) ratio of 3.30 under 100% RDF applied through water soluble fertilizers in fertigation as against 2.78 in 100% RDF with conventional fertilizer application and surface irrigation.

4. BRINJAL

Papadopoulos and Ristimaki Leena (2000) reported that fertigation irrespective of the combination of fertilizers was superior to the soil application of fertilizers. With only 50% RDN through fertigation, higher yield of tomato and eggplant was obtained compared to application of full amount of N through conventional method, suggesting that N is more efficiently utilized when applied with the irrigation water. In brinjal, highest fruit yield of 42.33 t ha^{-1} was recorded in drip irrigation at 75% RD-N&K with maximum shoot length and number of branches per plant when compared to other levels of irrigation and fertigation (Vijayakumar et al., 2010). When different irrigation levels and nitrogen application levels were compared in brinjal, the highest yield (which was 23% higher) was obtained at 75% of surface irrigation and 120 kg N ha^{-1} with the saving of 25% water and 30 kg N ha^{-1} as compared to the maximum yield obtained in furrow irrigation (Aujla et al., 2007). When 25% of nutrients were applied as basal through conventional fertilizer and 75% of nutrients through fertigation using water soluble fertilizers, increase in marketable yield of brinjal was 15.4% as compared to the conventional application of fertilizer.

5. TOMATO

Tu et al. (2000) in a four year (1998-2001) investigation carried out in South-Western Ontario found that (a) drip irrigation and fertigation significantly increased tomato yield over the non-treated control, (b) percentage of tomato fruit with blossom-end rot was reduced significantly to the negligible level in the drip-irrigated and fertigated treatments, and (c) drip-fertigation provided significant yield advantage over drip-irrigation only in the year when rainfall was below normal during the periods of flowering, fruit set and fruit growth. Fruit yield of 45.7 t ha^{-1} was obtained for tomato with application of recommended dose of fertilizers using polyfeed (19:19:19), MAP (12:60:0) and urea through fertigation, which was 22-27% higher compared to the crop which was provided with ordinary fertilizers through soil application (Prabhakar and Hebbar, 1996). The highest tomato yield in drip is possible because water and fertilizers are applied in a gradual and uniform manner directly to the roots, in synchrony with the crop demand, without wetting the plants (Hartz and Bottoms, 2009; Shedeed et al., 2009; Marouelli et al., 2011). However, for better economic feasibility of the system, it is important to manage the entire production system properly, especially for irrigation and fertigation (Zhang *et al.*, 2010). Tomato plants properly drip-irrigated and fertigated by drip systems become more vigorous and productive, which facilitate greater extraction of soil nutrients (Hartz and Bottoms, 2009). However, as only part of the land is wet, a reduction in the volume of soil explored by the roots occurs (Marouelli et al., 2011). Thus, it is necessary to revaluate the pre-established fertilization practices to maintain adequate fertility in the root zone (Hartz and Bottoms, 2009). Shedeed et al. (2009) and Zhang et al. (2010) reported that the amount of nutrients required by a particular crop may be quite variable depending on its productivity potential and the climatic and soil conditions. Hebbar et al. (2004) showed that fertigation with 100% water soluble fertilizers increased the tomato fruit yield significantly over furrow-irrigated control and drip irrigation. The fertigation schedule was developed for protected conditions in tomato and a B:C ratio of 5.4 was obtained.

6. POTATO

Sasani et al. (2006) revealed that application of 80% of recommended dose of N and K_2O through drip fertigation was the most efficient in obtaining significantly higher total tuber yield of 42.0 t ha^{-1} as compared to application of recommended dose of N and K_2O coupled with furrow irrigation. It improved the fertilizer use efficiency and effected savings of 40% on water and labour. Ghiyal and Bhatia (2018) studied the effect of different N levels namely, 90 (N_1), 120 (N_2), 150 (N_3) and 180 (N_4) kg ha^{-1} and three fertigation frequencies, *i.e.* every 3rd day (F_1), every 6th day (F_2), and every 9th day (F_3). Plant emergence at 30 (96.33%) days after planting (DAP); plant height at 60 (49.63 cm) DAP; number of shoots per hill at 30 (4.43), 60 (4.68) and 90 (4.68) DAP; leaf area index at 30 (1.21), 60 (6.02) and 90 (5.24) DAP; and foliage weight (1.21 kg m^{-2}) were significantly higher with F_1 whereas values for plant emergence at 30 (96.89%) DAP, plant height at 60 (49.83 cm) and 90 (54.98 cm) DAP; number of shoots per hill at 60 (4.64) DAP; leaf area index at 30 (1.17) and 90 (5.14) DAP; foliage weight (1.17 kg m^{-2}) and total tuber yield were maximum under N_2.

7. CHILLI

Veeranna et al. (2001) reported that 80% water soluble fertilizer was effective in producing about 31.0% and 24.7% higher chilli fruit yield over soil application of normal fertilizers at 100% RDF in furrow and drip irrigation methods, respectively, with 20% of saving in fertilizers. Roy et al. (2011) showed that the length and width of fruit and number of fruits per plant in capsicum increased significantly with increasing N dose up to 100 kg N ha^{-1}. However, average weight of fruit increased significantly with increasing levels of N up to 150 kg ha^{-1}. Average weight of fruit and yield increased significantly with increasing levels of P up to 30 kg P ha^{-1}, whereas length of fruit and number of fruits per plant was increased significantly up to the 60 kg P ha^{-1}. Considering the combined effect of N and P, the maximum yield in under the treatment combination of 150 kg N and 30 kg P ha^{-1}. Fertigation using water soluble fertilizers increased marketable yield of capsicum by 15.1% over the conventional application of fertilizers. The fertigation schedule was developed for protected cultivation of capsicum in which 4.6 B:C ratio was obtained.

Chaurasiya and Sahu (2016) reported that irrigation at 100% PE (pan evaporation) + fertigation with 100% N and K and 50% PE + fertigation with 100% N and K being at par recorded 67.06 and 65.78%, respectively higher pod yield of chilli as compared to surface irrigation at 0.90 IW/CPE ratio + entire NPK as soil application. However, fertigation of 125% of N and K led to marginal decrease in chilli pod yield over fertigation of 100% of N and K. Fertigation of 75%, 100% and 125% N and K registered 50.6, 66.8 and 58.6% increase in pod yield, respectively over soil application of 100% N and K + surface irrigation. Hence, irrespective of the fertilizer dose, there was a marked increase in pod yield under fertigation. Similarly, Muralikrishnasamy et al. (2006) found B:C ratio of Rs. 1.87 Re^{-1} with drip irrigation at 75% PE + 100% N and K through fertigation over Rs. 1.77 Re^{-1} with surface irrigation at 0.90 IW/CPE ratio + entire NPK as soil application in chilli. The number of fruits per plant was higher in high fertility area compared to the low fertility area. The highest number of fruits obtained for low fertility area was (119.33) under site-specific drip fertigation providing daily drip irrigation, which was closer to that for site-specific drip fertigation and recommended dose of drip fertigation with daily drip irrigation (119.20 and 119.23, respectively) under high fertility area. Number of fruits per plant was increased with increase in drip irrigation levels and fertilizer levels, during both the experiments. In both the fields, alternate day drip irrigation treatments yielded less number of fruits compared to daily drip irrigation treatments. The lowest number of fruits was recorded in the treatment which had received alternate day drip irrigation along with manual fertilizer application (Abdul Hakkim, 2014).

8. ONION

Chopade et al. (1998) found that drip irrigation with the recommended rate of solid fertilizer in two applications gave the highest onion bulb yield while drip fertigation at 50% of the recommended rate gave the highest bulb quality. Rupel et al. (2004) obtained higher marketable onion yields when the 50 kg N ha^{-1} was applied through drip fertigation (41% increase) and highest after applying 150 kg N ha^{-1} through fertigation (79% increase) as compared to the control (without fertigation and irrigation). Dingre et al. (2012) showed that drip fertigation caused 12 to 74% increase in the productivity of onion seed as compared to conventional method. The total irrigation water applied through surface and drip system was 840 mm and 520 mm, indicating 39% of water saving whereas, field water use efficiency under drip fertigation was 2.5 times higher than that in control. Rajput and Patel (2006) recorded the highest onion yield in daily fertigation followed by alternate day fertigation; lowest yield was recorded under monthly fertigation frequency. Bhakare and Fatkal (2008) showed that the onion seed yield increased and yield contributing characters improved with fertigation levels with maximum increase observed in 125% RDF fertigation treatment which was at par with 100% RDF fertigation treatment. The treatment of 75% RDF through fertigation was significantly superior to application of 100% RDF through conventional fertilizer and as such, there could be a saving of 25% of the added fertilizer. They also stated that application of 125% recommended dose of water soluble fertilizer with fertigation gave the highest yield of onion seed and improved the yield contributing parameters such as plant height, number of umbels per plot, number of umbels per plant, diameter of umbel and reduced the time to 50% flowering, but the yield was at par with 100% recommended dose of water soluble fertilizers with fertigation.

9. GARLIC

Garlic crop grown under furrow irrigation required 64 kg P_2O_5 ha^{-1}, while under fertigation the crop needed 89 kg P_2O_5 ha^{-1} (Castellanos et al., 2001); the respective crop yields were 19.1 and 29 t ha^{-1}. Thus, higher yield potential of the crop under fertigation increased the P demand of plants by almost 50%. Highest yield of 36.29 t ha^{-1} of fresh tubers was obtained under trickle irrigation as compared to 21.5 t ha^{-1} got under the furrow-irrigated crop (Chawla and Narda, 2001).

10. CUCUMBER

Ibrikci and Buyuk (2002) obtained higher yield and leaf N, P and K content in drip-fertigated cucumber than furrow-irrigated plants. Beyaert et al. (2007) showed that drip irrigation coupled with fertigation showed significant advantages in terms of yield and economic returns of cucumber compared with overhead irrigation and conventional fertilization practices. The fertigation schedule developed for cucumber under protected conditions yielded a benefit:cost ratio of 3.3.

11. OKRA

Jadav et al. (1995) observed tallest plants, more leaves per plant, higher leaf area and dry matter production with the crop fertigated through subsurface drip with 75% RDN over band placement of 100% RDN with furrow irrigation.

Benefits of Fertigation

Use efficiency of applied nutrients in crops is greater under fertigation compared to that under conventional application of fertilizers to the soil. Intensification of agriculture led by use of irrigation water and indiscriminate use of fertilizers has led to the pollution of surface and ground waters by nutrients added through the chemicals fertilizers. Fertigation helps in i) lessening the pollution of water bodies by arresting the leaching or surface run-off of the nutrients such as N and K out of agricultural fields, and ii) saving of water, nutrients, energy, labour and time. It provides flexibility in field operations. For example, nutrients can be applied to the soil even under situations where crop or soil conditions would otherwise prohibit entry into the field with conventional equipment. Fertigation offers opportunity for efficient use of compound and ready-mix nutrient solutions containing small concentrations of micronutrients, which are otherwise very difficult to apply accurately to the soil when applied alone. When fertigation is applied through the drip irrigation system, crop foliage can be kept dry, thus avoiding leaf burn and delaying the development of plant pathogens. Fertigation helps to reduce weed menace, particularly between the crop rows. Use of plastic mulch along with fertigation through drip system allows effective weed control in widely spaced crops. The ability of micro irrigation system to irrigate undulating soils makes it possible to bring such lands under cultivation, which otherwise remain as wastelands or used as pasture lands. In micro irrigation system reduced need for surface traffic movement during irrigation and nutrient application helps in reducing the soil compaction.

Future Research

Perennial fruits of tropical nature (Citrus, banana, mango, papaya, guava) have emerged as an alternative source of nutrients to humans. These have potential to lessen the per capita consumption of cereals. Intensive growing of perennial fruit crops under high density and ultra-high density plant population has further put an additional pressure on soil fertility conservation. Concept of fertigation in perennial crops has given a definite edge over conventionally used basin method of irrigation coupled with basal or top dressing of fertilizers within the perimeter of trees (Shirgure et al., 2001; Srivastava and Singh, 2008). Reports are available on usefulness of this technology on fruit yield, quality indices, soil fertility improvements coupled water use efficiency (WUE) and fertilizer use efficiency (FUE) covering a variety of fruit crops (Srivastava and Singh, 2008; Srivastava et al., 2014). Fertigation has proved beyond doubt its utility in fruit culture (Srivastava et al., 2014; Shirgure et al., 2001).

Techniques and management of perennial fruits production are nowadays directed towards the need to conserve resources and energy and a commitment to reduce the environmental footprints. Fertigation has emerged as a valuable tool in recent years globally for managing scarce and costly water and fertilizer inputs in the major fruit belts. The million-dollar question strikes, why does fertigation out-perform conventional basin method of irrigation carrying fertilizers? A plant exposed to uniform regime of moisture and nutrient flow within rhizosphere zone has to spend much less energy than the one constantly changing growing conditions on time scale.

Fertigation is thus energy-efficient as well (Shirgure et al., 2001) leading to increase in both the fertilizer use efficiency (FUE) and water use efficiency (WUE). Fertigation will continue to replace traditional flood irrigation, so extensively adopted in water-surplus irrigated fruit growing areas (Srivastava et al., 2014).

Open hydroponics (OH), a concept synonymous to fertigation, is a management practice to address low fertility gravel base soils and saline water. The nutrient uptake is maximized if the ratio of ions in the solution matches with scion/stock requirements. In Spain, the performance of 'Nova', 'Marisol', and 'Dalite' mandarins at density of 1000 plants ha^{-1} under OH system was evaluated (Martinez-Valero and Fernandez, 2004). The average yield in sixth year was 60-75 t ha^{-1}, which is much higher than many conventionally managed orchards. In Israel, the response of 'Shamouti' orange under restricted root zone practices, a sprinkler *versus* drip irrigation treatment with three fertilizer rates, maintained at high moisture status (8-12 kPa) as a part of intensive OH programme was monitored. A significant increase in yield in the restricted root zone drip irrigation treatment was observed with the highest rate of fertilizer application *i.e.*, 400 kg N ha^{-1} (Kruger et al., 2000). Similar promising results were obtained in South Africa where OH system increased the yield of 'Valencia' orange and 'Clementine' orange by 19% and 25%, respectively using 16% less water and getting 25-31% higher returns compared to micro-irrigation with broadcast method of fertilizer application as standard control (Bravdo et al.,1992). More information on critical issues like capability to manipulate the soil solution as a restricted root zone *versus* conventional drip irrigation of root zone, buffering capacity of soil manipulating specific nutrient ratios at different physiological stages, evaluating orchard productivity-energy relationship through ionic balanced nutrient solution, planting density etc. is further required before OH system under citrus is recommended for adoption on a commercially large scale.

Principles of OH have some potential benefits in conventional production practices like intensive fertigation programmes (IFP). IFP is a fertigation programme that has principles similar to OH, but is less intensive than OH. Both use a nutrient solution containing various macro- and micro- nutrients (ionic balance is more important in IFP than OH), proportional injection of the nutrients into the water supply, pH adjustment of the irrigation water, and a high level of irrigation scheduling and monitoring. The most obvious difference is that IFP uses a larger conventional root zone volume and a refill point that is set lower than OH. The practical implication of using a conventional root zone is that the physical and chemical properties of the soil are more utilised. This can lower the application rates of some of the macro nutrients *e.g.*, Ca, Mg and K. The majority of growers using IFP would irrigate only once a day to maintain soil moisture at a good level (generally not exceeding 50% of readily available water), whilst OH would be focusing on maintaining soil moisture levels near field capacity. IFP is an intensive form of fertigation, whilst OH uses fertigation as part of a hydroponic management strategy. Nutrient application rates in majority of OH and IFP in citrus can be about 20% to 50% higher than the conventional practices due to higher productivity levels and a lower nutrient bank in the soil. Therefore, OH and IFP use a more intensive nutrition programme that may push the trees into a higher level of vigour and productivity, requiring higher nutrient application rates to maintain production (Srivastava et al., 2008).

Fertigation is considered synonymous to enhanced nutrient use efficiency which can further be fine-tuned with nitrification inhibitors (restrict the microbial conversion of ammonium to nitrate that it is mobile in soils) or plant growth-promoting bio-effectors (microorganisms and active natural compounds involved in plant growth). Thus, in addition to all these, precise soil sampling, whether to take samples from below drippers or in between drippers or mixing soil samples from both the sites and finally, drawing a representative soil samples, find a greater intervention while evaluating nutrient-water interaction in citrus (Shirgure et al., 2003). Another prominent concern is often raised with regard to threshold values of leaf nutrient diagnostics (Srivastava et al., 2003) on whether or not, optimum leaf nutrient values hold some application efficacy when compared with basin irrigation coupled with basal fertilizer application. Under two contrasting fertilizer application techniques, due to difference in fertilizer use efficiencies, optimum values could warrant minor adjustments, depending upon the mode of fertilizer application (Shirgure and Srivastava, 2013; Shirgure et al., 2004a).

Assessment of off-site movement of applied nutrients and their implications on temporal changes in ground water quality is still in a inconclusive stage and needs an elaborate study in the larger context of sustainability in quality production in addition to *in-situ* conservation of applied nutrients. Possibility of integrating liquid biofertilizers (broth using native isolates) as a starter with nutrients in order to further hasten the bio-availability of nutrients within plant rhizosphere needs to be looked afresh. Concept of rhizosphere hybridization triggering the nutrient dynamics across crop phenophases (Shirgure et al., 2004b) then finds its candid way into the curriculum of fertigation-oriented research. However, if the nutrient use efficiency has to be targeted then the net impact on soil solute fluctuations in both soluble and exchangeable phase of soil has to be studied besides keeping a focus on soil salinity build-up (Shirgure et al., 2014). While addressing these concerns, the major concern that emerges is how to enhance the orchard efficiency *vis-a-vis* FUE/WUE by adopting variable rate fertilizer application taking into consideration the spatial variability in soil properties in a time domain manner known as automated fertigation.

Conclusions

Fertigation system is an efficient method of applying fertilizers in which the irrigation system is used as the carrier and distributor of the crop nutrients. The combination of water and nutrient leads to an efficient use of both by the crop plants. The use of fully soluble fertilizers seems more economical in the first stages when fertigation is adopted, but the use of prepared clear liquid solutions is very convenient in other cases. Fertigation system is very suitable for commercial horticulture where maximization of profitability and yields is a target. Fertigation has been found to be one of the most successful ways of water and nutrient application, particularly N, K and micronutrients through drip system. Besides increasing the economic yields, fertigation helps in proper utilization of fertilizer nutrients, saves labour, and increases the productivity. Yield advantages have been reported across the wide range of crops under diverse agro-climatic situations. Fruit and vegetable crops have been found to be responsive to fertigation due to their wide spacing nature, continuous need of water and nutrients at optimal rate to give high yields with good quality, and high capital returns on the investments. Even though the initial cost of establishing the fertigation system is higher but on long-term basis it is economical compared to conventional methods of fertilization as it brings down the cost of cultivation. However, to get the desired results, it requires higher management skills at operator level like selection of fertilizers, timing and rate of fertilizer injection, watering schedule, as well as the maintenance of the system. Therefore, to make the horticulture sustainable and economically viable and to ensure food and nutritional security of the burgeoning population there is a need to promote the fertigation at large scale by all the concerned stakeholders.

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