Indian Journal of Agricultural Sciences **86** (10): 1245–56, October 2016/Review Article

Water soluble fertilizers in horticultural crops— An appraisal

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Received: 27 July 2016; Accepted: 30 August 2016

ABSTRACT

Horticultural crops have now attained a status, parallel to not only field crops, but stake strong claim of offering nutritional security, thereby, cutting the unnecessary load on consumption of cereals. However, raising productivity of horticultural crops is still a constraint. One of the prime reasons is the abysmal use of fertilizers, hardly 10% of total fertilizer use is diverted towards the share of horticultural crops. Of different fertilizers, liquid fertilizers are again a special class of fertilizers, hold very strong promise in protected cultivation, hydroponic/aeroponic or even open field hydroponic for perennial fruit crops. The liquid fertilizers, as special class of fertilizers provide an enormous possibility of tailoring nutrient use across critical growth stages, a pre-requisite for better nutrient-use-efficiency. Customized fertilization/fertigation is another potential reality, besides its suitability in site specific nutrient managements. In this background, these issues have been addressed in this review.

Key words: Customized fertigation, Fertigation, Horticultural crops, Hydroponics, Liquid fertilizers, Nutrient-use-efficiency, Protected cultivation

Sustainable growth in agricultural productivity and production is essential for national, social and economic development in the context of increasing world population and assured access to food and nutritional security. Intensification in agriculture including horticulture is one of the basic strategies to accomplish this objective. Additional food required for the increasing population must accrue from those lands already under cultivation coupled with intensified efforts for balanced use of nutrient like inputs. Horticultural crops form a significant part of total agricultural production and contribute alternatively in food security as well as nutritional security (Srivastava and Shirgure 2015). But one of the main factors contributing towards low productivity is our failures in understanding the behavior of soil-plant relationship as a nutrient and water supply chain. Fertilizer feeds the world through feeding the soils and in turn plants, and if world is not to go hungry, fertilizers will continue to play a pivotal role in foodgrain production (Steward *et al*. 2005, Anonymous 2012). Worldwide mineral fertilizer nutrient use is expected to increase from 175 million tonnes in 2015 to 199 million tonnes in 2030 (FAO 2000).

Nutrient imbalance, consumption and fertilizers requirement

The mining of nutrients by increased production over the years have far exceeded the amount of nutrients replenished through fertilizers. Due to intensive cultivation and imbalance of nutrients use in last four decades the deficiency of secondary and micronutrients have developed in addition to N, P and K (Muralidharudu *et al*. 2011). Soil analysis data has shown that at the country level, and out of 500 districts surveyed, the soils of 93, 91 and 51% districts were low in available N, P and K, respectively. Incidences of micronutrients deficiencies are also increasing. Among the secondary and micronutrients, 41% of soils have been found deficient in S, 44% in Zn, 15% in Fe, 8% in Cu, 6% in Mn, 33% in B and 13% in Mo (Shukhla 2012).

Fertilizer is a critical input for the optimum growth and production of fruit and vegetable crops. Very little or no fertilizer is applied in some of the crops like mango and guava. Whereas, some crops like banana and grapes are so heavily fertilized through excess doses of N, P and K are reported. Their excessive and imbalance use in horticultural crops has resulted in several problems. Heavy application of nitrogenous fertilizers has resulted in high levels of nitrates in ground water leading to its pollution in some states like Punjab, Maharashtra and Karnataka (Bhargava and Raghupati 1993). Fertilizer consumption growth rate has increased many folds before green revolution era and after that consumption of fertilizers has increased about 18 times from 1.54 million tonnes in 1967-68 to 28.12 million tonnes in 2010-11. The bulk of fertilizer is used for food grain crops (69%), followed by oilseeds (10%), and sugarcane/ cotton (6%) with another 6% for fruits and vegetables. This

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is purely an abysmal quantity of fertilizer usage considering the fact that the horticulture production has surpassed the total food grain production. In horticultural crops, banana, grapes, potatoes are high fertilizer consuming crops. Despite these disappointing statistics, the average fertilizer application rates in fruits and vegetables in India (219 kg/ha) is not distinctly so low compared to world average (259 kg/ha) according to Chanda (2014).

Horticultural crops vary a great deal in their capacity of nutrient removal pattern depending upon targeted yield. Quantum of K removal was observed to be 3-4 times higher in fruit crops than N and P compared to annual vegetable crops. Hence, nutrient removal patterns uphold two cardinal points, one in many crops, magnitude of removal of K is higher than N or P and two that highlight towards necessity of tailoring fertilizer requirement as per crop. In a study made in India, considering the nutrient removal rate projections, in the year of 2016-17, the fertilizer requirement for fruits and vegetable will be 7.56 million tonnes (Malhotra and Srivastava 2015). For most horticultural crops (fruits, vegetables and ornamental plants), the economic concern is so much of fertilizer cost in addition to market value of crop yield and quality. Therefore, growers are most concerned about ways and means to improve fertilizer use efficiency ensuring maximum yield and quality. Use of fertigation in fruit crops was reported to save 30-50% of fertilizer doses as well as irrigation (Shirgure and Srivastava 2014, Shirgure *et al*. 2003a). Therefore, it is imperative to achieve the high nutrient use efficiency and reducing the requirement of bulk fertilizers to 25%.

Commercial fertilizers

The ancient farmer observed the influence of organic farm and animal waste on the growth of plants and made a practice of utilization as fertilizer for getting good yield of crops. Collings (1955) described the history of commercial fertilizers and mentioned the use of chemical fertilizers probably dates from 1665, when Sir Kenelm Digby wrote that he had increased the yield of crops by the application of saltpeter. In the year 1804, Nicholas Theodore de Saussure, of Switzerland, first established the fact which was later verified by Boussingault at his farm in Alsace in the year 1830 that the ash ingredients of plants were taken from the soil is essential for plant growth. In 1855 or 1856, Justus von Liebig, a German chemist described the importance of phosphorus and potassium which was based on his famous mineral theory in 1840. The necessity for supplying plants with nitrogen was also recognized in 1857 by British scientists Lawes, Gilbert and Pugh (Collings 1955). In the early 19th century saltpetre and guano where shipped from Chile and Peru to the United Kingdom and Western Europe for use as explosives were also used as fertilizers in agriculture. Single super phosphate (SSP) named as first artificial fertilizer was produced in 1843 in the United Kingdom followed by Europe for industrial production. In 1860, production of potash fertilizers started in Germany and N fertilizers from ammonia in 1890. A significant advance in the production technology of N fertilizers came with the production of synthetic ammonia by the Haber-Bosch process in Germany in 1913. Production and use of urea as a fertilizer started from 1921. Since then, a large variety of solid and liquid fertilizers containing one, two or several plant nutrients have been produced and used. The fertilizer scene is dominated by products containing N, P and K in many chemical and physical forms and their combinations in order to meet the need for their application under different conditions throughout the world (Roy *et al*. 2006, Melililo 2012). Nutrient management based on “Four R’s” of fertilizer use: apply the right nutrient, at the right rate, at the right time, and in the right place for the selected crop have been documented in the IPNI 4R Plant Nutrition Manual (2012). Fertilizer management technologies have been developed for different fruit and vegetable crops in the different countries and provinces based on scientific principles (Srivastava and Malhotra 2014, Liu *et al.* 2012, Meena *et al.* 2006, Aishwath and Malhotra 2013). Optimum requirement of fertilizers for different fruits and vegetable crops have been worked out by different workers and described in the review (Malhotra and Srivastava 2015). Inorganic and organic fertilizer can be found in different types of products like compound, straight, controlled released, blended, granulated, water soluble and liquid fertilizer (Srivastava *et al*. 2014, 2015). The proposed review highlights the liquid and water soluble fertigation for achieving high nutrient use efficiency.

Formulations and applications of liquid fertilizers

Liquid fertilizers come in a variety of different formulations, including complete and incomplete. Liquid fertilizers are water-soluble powders or liquid concentrates that mix with water to make a fertilizer solution. All are made to be diluted with water; some are concentrated liquids themselves, while others are powder or pellets. The advantage of liquid fertilizers is that they are quickly absorbed, so plants get their benefits soon after you apply them. Liquid fertilizers are great in delivering nutrients to the plants since it seeps right into the root zone where can be taken by plants immediately. However, the effect of a liquid fertilizer is also a short term and need to fertilize plants again. Liquid fertilizers may also be applied to plant foliage where the nutrients are absorbed directly through the leaf surface. These fertilizers are in solution form containing one or more than one nutrient. Generally bulk fertilizers are used as raw material for the production of these fertilizers like ammonium nitrate, ammonium sulphate, urea, ammonium phosphate, phosphoric acid, potassium sulphate, potassium nitrate, potassium chloride, etc.

Aqueous ammonia (NH_3+H_2O) is a liquid fertilizer which may be used in fertigation. It is low pressure ammonia solution which contains both gaseous ammonia and ammonium hydroxide. But due to limited safety hazards, handling of this fertilizer is little difficult. Therefore, storage tanks are used to hold such kind of pressurized liquids. Another type of solution (UAN) which is based on urea and ammonium nitrate in water is used as a fertilizer. The combination of urea and ammonium nitrate has an extremely low critical relative humidity (18% at 30°C) and can therefore only be used in liquid fertilizers. The most commonly used grade of these fertilizer solutions is UAN 32.0.0 (32%N) also known as UN32 or UN-32, which consists of 45% ammonium nitrate, 35% urea and only 20% water. Other grades are UAN 28, UAN 30 and UAN 18. The solutions are quite corrosive towards mild steel (up to 500 mill inches per year on C1010 steel) and are therefore generally equipped with a corrosion inhibitor to protect tanks, pipelines, nozzles, etc. Urea–ammonium nitrate solutions should not be combined with calcium ammonium nitrate (CAN-17) or other solutions prepared from calcium nitrate. Triazones are also slow release liquid N- fertilizer. These products combine the advantages of using a liquid with the benefits of a slow release source of N. However, like all liquid applications they require appropriate equipment and the ability to store and handle liquids. Phosphoric acid is used in fertigation in many countries. It contains high concentration of P that varies between 51 and 54% expressed as P_2O_5. The disadvantage of this is the proper care for handling because of acid as the major constituent.

Water-soluble fertilizers

Water soluble fertilizers are used as chemical fertilizer in sprinkler or drip irrigation systems and for foliar spray to augment to increase yield and to improve quality of fruits and vegetable crops. Water soluble fertilizers are generally considered 100% soluble in water having low salt index to reduce the potential for burning of plant tissue and suitable for foliar application or fertigation. These are mostly combination of nitrogen, phosphorus, potassium, calcium, magnesium, sulphur and micronutrients with different ratios. These are high analysis fertilizers developed to suit the matrix of status of soil fertility, type of crop, quality of water to be used and climatic conditions. In water soluble fertilizers it is easy to make the precise amount of nutrient solution for plants. Water-soluble fertilizers should meet certain criteria such as 100% soluble and no inert matter, high purity, driven by R&D, nutrients in readily available form, free from sodium and chloride, low salt index, (EC=0.9-1.2), pH acidic (5.5 to 6.5), suitable for fertigation and foliar application, improve crop yields and quality of produce and ultimately higher nutrient use efficiency.

Use of liquid or water soluble fertilizers in India is meager in comparison to developed countries. In USA during 2009 the consumption of water soluble fertilizers was 17% of the total fertilizers used in all crops (Patel 2011). Adoption of drip irrigation system has led to apply nutrients through fertigation. Generally 100% water soluble or liquid fertilizers are imported; some of Indian companies have started the import of water soluble or liquid fertilizers. But some Indian manufacturers have also started the production of these fertilizers. A number of water soluble fertilizers have been developed and included by GOI in Fertilizers Control Order, 1985 (FAI 2013). Various water soluble grade fertilizers can be used at different growth stages of crops either alone or in combination to improve the crop productivity. The NPK combination are starter grades (19:19:19; 20:20:20; 18:18:18), nitrogen-potash rich grade (13:5:26) for growth in middle stage and mono-potassium phosphate (0:52:34); mono-ammonium phosphate (12:61:0); potassium nitrate (13:0:45) for sugar conversion and disease resistance. So far sixteen grades of 100% water soluble fertilizers has been notified in FCO -1985 (Table 1).

Table 1 FCO approved nutrient composition of 100% water-soluble fertilizers

Name of product (Grade)	Nutrient composition (%)						
	N	P_2O_5	K_2O	S	Ca	MgO	Zn
Potassium nitrate (13-0-45)	13	0	45				
Mono potassium phosphate (0-52-34)	0	52	34				
Calcium nitrate	15.5				18.8		
NPK (13-40-13)	13	40	13				
NPK (18-18-18)	18	18	18				
NPK (13-5-26)	13	5	26				
NPK (6-12-36)	6	12	36				
NPK (20-20-20)	20	20	20				
NPK (19-19-19)	19	19	19				
Potassium magnesium sulphate			22	20		18	
Mono ammonium phosphate (12-61-0)	12	61	0				
Urea phosphate (17-44-0)	17	44	0				
NPK (12-30-15)	12	30	15				
NPK (12-32-14)	12	32	14				
Urea phosphate with SOP (18-18-18)	18	18	18	6.1			
NPK Zn (7.6-23.5-7.6-3.5)	7.6	23.5	7.6				3.5

Source: Fertilizer (control) order 1985 (FAI 2013).

Consumption of water soluble fertilizers

In India, the production and use of conventional fertilizers started in 1906. However, the use of liquid or water soluble fertilizers is new and their use started with growth of microirrigation system 20 years back. Initially growth was slow and confined to Maharashtra. The country has witnessed good growth in last 20 years as their usage started in modest quantities from 1200 MTs in 1995 to 130000 MTs in 2013-14 (Patel 2011 and Chander 2014). Out of which fertigation segments has major share of about 84% and balance by foliar segments. The growth in consumption increased over the years. Total consumption of water soluble fertilizers is still lower than the other countries which are less than 0.25% in comparison to the global average is 5-6%. The India's share of conventional fertilizers is 14% at world level, whereas it is about 1% of water soluble. So there is more scope for the growth of use of liquid or water soluble fertilizers to increase the production of horticultural crops.

Maharashtra state was the first to start the use of water soluble fertilizers in 1992, however now their use has spread in other states also (Chander 2014). Maharashtra, Karnataka, Andhra Pradesh, Tamil Nadu, Kerala and Gujarat are the major consumers and account for 75% of total consumption of water soluble fertilizers in India.

Some of water or liquid fertilizers are manufactured in the country for creating niche of NPK fertilizers. But largely country is dependent on import and about 90% of requirement is imported either as finished product or raw material. Main suppliers of water soluble fertilizers to India are Russia, UAE, Malaysia, Belgium, Israel and China. Manufacturing and use of liquid fertilizers can save considerable energy spent on solidifying the fertilizer in the factory. National Fertilisers Ltd, Nangal had developed a liquid fertilizer 'Ankur' which was found to be as good as urea and calcium ammonium nitrate for wheat (Singh and Prasad 1985). Urea plants are recycling a part of their effluents at a fairly high cost and even then have to strip off some urea before allowing it to flow in the plant water stream. A 1 000 tonnes/day (TPD) plant discharges about 20-25 m^3/hr effluent containing 0.8 to 1.5% urea (by weight) and 4-5% ammonia (by weight). With some more effort, this effluent can be developed into a liquid fertilizer. Urea plant effluent can also be used for developing a slow release nitrogen fertilizer by co-precipitating it with neem oil. This technology was developed at the Indian Agricultural Research Institute, New Delhi and the product was named as Pusa Neem Gold Urea. It is a coral shaped golden yellow adduct (35% N as urea and 12% neem oil) and in a field trial at IARI gave 36% higher grain yield of rice at 120 kg N/ha (Prasad *et al.* 1998).

Conversion of liquid fertilizer into dry fertilizer in fertigation

Both dry and liquid fertilizers are widely used in crop production. These days, more and more liquid fertilizers were used in vegetable and fruit crops (Shirgure *et al.* 2003b). Thus, conversion either from a dry fertilizer basis to a liquid fertilizer basis, or from a liquid fertilizer source to the recommended nutrient rate is often required for correct application rate. Thus, here the purpose is to help growers understand the conversion method from liquid to dry fertilizer (Liu *et al.* 2012).

Dry fertilizer and its active ingredients are both *gravimetric*—in other words, expressed as a *weight/unit area*. For this type of fertilizer, the calculations are fairly straight forward. For example, 100 kg a 10-10-10 fertilizer-grade material contains 10 kg each of active ingredients nitrogen (N), phosphorus (P_2O_5), and potassium (K_2O), equaling 30 kg total of active ingredients, while the remaining 70 kg consist of inactive materials. Similarly a 32-10-10 dry fertilizer bag label fertilizer-grade material contains 50-kg fertilizer has 16 kg of N and 5 kg each of P_2O_5 and K_2O active ingredients. Namely, it has 26 kg of active ingredients and 24 kg of inactive ingredients.

Liquid fertilizer and its active ingredients are expressed on a volumetric basis. The density of the liquid fertilizer is a key detail because it is impossible to know the weight of a liquid fertilizer before the density is known. Typically, the net volume and net weight are available on the liquid fertilizer label. The liquid density can be calculated based on these values. For example, on the label, its net volume is 0.946 liters (1 US quart), and its net weight is 1.2 kg. Therefore, its density is 1.26 kg/l. This source is a 3-3-3 liquid fertilizer. A quart of this liquid fertilizer contains 36 g each of N, P_2O_5, and K_2O (108 g of N, P_2O_5, and K_2O in total) and 1 089 g of water or other inactive ingredients. Likewise 1 quart of 4-3-3 liquid fertilizer label has 41 g of nitrogen (N) and 31 g each of phosphorus (P_2O_5) and potassium (K_2O). Namely, it has 103 g of active ingredients and 917 g of water or other inactive ingredients. Liquid fertilizers differ in density (Liu *et al.* 2012). These are related in terms of active ingredients, but the density is not always proportional to the active ingredients. The key point for the conversion from liquid to dry fertilizer is the density of the liquid fertilizer. The greater the density of a liquid fertilizer, the more active ingredient volume. To avoid any errors, the conversion calculation from liquid to dry fertilizer must include the liquid fertilizer's density and active ingredient content.

Conversion of nutrient analysis to composition

In most countries, the effectiveness and safe use of substances to be registered as fertilizers is ensured by law. The nutrient concentration of fertilizers is traditionally expressed in terms of N, P_2O_5, K_2O, etc. For example, an NPK fertilizer 15–15–15 contains 15% each of N, P_2O_5 and K_2O, or 45% total nutrients. The percentage composition of a fertilizer refers mostly to the total concentration of a nutrient, but sometimes only to its available portion. For solid fertilizers, the percentage generally refers to the weight basis, e.g. 20% N means 20 kg of N in 100 kg of product. For liquid fertilizers, both weight and volume percentages are used, e.g. 20% by weight of N of a solution with the specific weight of 1.3 corresponds to 26% by volume (260 g N/l) (Roy *et al.* 2006). In scientific literature, the nutrients are expressed mostly in elemental form whereas the industry, trade and extension services continue to express P and K in their oxide forms. The fact is that neither N nor P exists in soils, plants or fertilizers in elemental form. In any case, owing to the mismatch between the forms in which plant nutrients are expressed in research, extension and trade literature, care is needed when converting research data into practical values. Where the optimal application rate is reported as 26 kg P/ha in a research document, this translates into 60 kg P_2O_5/ha (Roy *et al.* 2006). Such conversion, we need to keep in mind, while working out the amount of nutrient, exactly required.

Application of water soluble fertilizers

In horticultural crops, the fertilizer input is very expensive and for its economic return there is need to increase the fertilizer use efficiency (FUE). We must keep in mind while applying fertilizers to high value crops for getting better FUE, i.e. 4R: apply the right product at the right rate at the right time in the right place. The FUE depends upon the method and time of application of fertilizer. For increasing the fertilizer use efficiency, fertilizers applied must be distributed uniformly in the field and available to the plants. There are different methods to apply fertilizers, depending on its formulation and the crop needs as broadcasting, banding, topdressing, foliar feeding and fertigation. In horticultural crops in the field as well as protected cultivation foliar application and fertigation are the most suitable and economical methods for the application of plant nutrients.

Foliar feeding

Application of fertilizers directly to leaves is called foliar feeding or foliar spray. The method is almost invariably used to apply water-soluble straight fertilizers and used especially for high value crops such as fruits (Heinrich Dittmar *et al*. 2009). Foliar feeding is used when insufficient fertilizer was used before planting, when a quick growth response is wanted, when micronutrients (such as Fe or Zn) are locked into the soil, or when the soil is too cold for the plants to extract or use the fertilizer applied to the soil. Foliar-applied nutrients are rapidly absorbed and used by the plant. Absorption begins within minutes after application and, with most nutrients; it is completed within 1 to 2 days. Foliar fertilizer applications are a alternative to provide nutrients to plants when soil conditions may limit the root uptake or during fast growth periods when needs may exceed root supply (Toscano *et al*. 2002). Foliar application can be a supplement to soil fertilization at a critical time for the plant, but not a substitute since greater amounts of plant nutrients are needed than what can be absorbed through the plant leaf at any given time. At transplanting time, an application of phosphorus spray will help in the establishment of the young plant in cold soils. For perennial plants, early spring growth is usually limited by cold soil, even when the air is warm. Under such conditions, soil microorganisms are not active enough to convert nutrients into forms available for roots to absorb; even if the nutrients were available, the plants could utilize them. A nutrient spray to the foliage will provide the needed nutrients immediately, allowing the plants to begin growth. Under certain conditions, foliar application is considered better than conventional soil application (Fernandez and Ebert 2005 and Srivastava and Singh 2003b) like; acute shortage of nutrient supply, nutrient imbalances, nutrient either absent or immobilized and nutrient imbalances. Foliar fertilizers are applied directly to leaves and this method is invariably used to apply water-soluble straight nitrogen fertilizers and used especially for high value crops such as fruits (Heinrich Dittmar *et al*. 2009). Foliar application of fertilizers in many crops has been reported effective with respect to growth, yield, quality and shelf life. These are: Urea-double superphosphate-K_2SO_4 at 0.5% each in citrus (Govind and Singh 2003), 0.6% Ca (NO_3) – 0.8% KH_2PO_4 in tomato (Peyvasi *et al*. 2009) and 0.5% B (foliar spray) – 5 kg/ha borax (soil application) in litchi (Dutta *et al*. 2000). If a foliar feeding is desired, follow directions carefully. Apply the spray volume needed to wet the foliage without dripping or running the liquid off the leaves. Using too much fertilizer, especially the synthetic forms, can quickly burn the foliage. Foliar feed should not be applied in bright sunlight because the foliage may be scorched.

Fertigation

Fertigation is used extensively in commercial agriculture and horticultural crops. Fertilizer (solid/liquid mineral, single or multiple) application through the drip irrigation/micro irrigation system is the fertigation (Srinivas 2004). It is the most advanced and efficient practice of fertilization. Fertigation combines the application of water and nutrient required for plant growth and development. Fertigation allows an accurate and uniform application of nutrients to the wetted area in the root zone, where the active roots are concentrated. Therefore, it is possible to adequate the nutrients quantity and concentration to their demand through the growing season of the crop. To produce high yield and quality fruits and vegetables the right combination of water and nutrients is the key. Consequently, recommendations were developed for the most suitable fertilizer formulation (including the basic nutrients NPK and microelements) according to the type of soil, physiological stage, climate and other factors. Special attention should be given to the pH and NO_3/NH_4 ratio, nutrient mobility in soil and salinity conditions. Planning the irrigation system and nutrient supply to the crops according to their physiological stage of development, and consideration of the soil and climate characteristics, result in high yields and high quality crops with minimum pollution. Fertigation is the most efficient method of fertilizers application, as it ensures application of the fertilizers directly to the plant roots (Rajput and Patel 2002). The efficiency of conventional fertilizers application is very low. Fertigation has an edge with regard to nutrient use efficiency (NUE) in comparison to conventional application. (Thomson *et al*. 2003) observed the NUE of 90 and 81% with 250 and 350 kg N/ha in broccoli. Fertigation can save fertilizers by 50% and may increase the crop yield by 20-30%. Drip in microirrigation have a characteristic not shared by other methods of fertilizer application. Fertigation is not optional, but is actually necessary for horticultural crops. It provides only good way to apply fertilizers physically to the root zone. In high value drip irrigated crops such as lettuce, tomato and peppers the level of fertigation management for achieving high yields and crop qualities exceeds to what is found with other irrigation systems and crops.

Selection of fertilizers for fertigation and suitability criteria

For effective fertigation farmer should have knowledge of plant growth behavior including nutrient requirements and rooting patterns, soil chemistry such as solubility and mobility of the nutrients, fertilizers chemistry (mixing compatibility, precipitation, clogging and corrosion) and quality of irrigation water like pH, salt and sodium hazards, and toxic ions. The fertilizer requirements will depend on soil and leaf analysis. The choice of fertilizers will also depend on availability of product, price and the quality of the irrigation water. The fertilizer products which can be used are limited to those that are readily soluble. Many of these formulations are prepared for specific crops, or combinations can be used depending on the crop cycle. These are stable and highly soluble, dissolving rapidly and providing a balance of nutrients. Generally liquid or 100% water soluble fertilizers are more expensive per unit of nutrient when compared to standard fertilizers. While selecting a fertilizer for fertigation one should have criteria of solubility, compatibility with other fertilizers, convenience and cost (Rajput and Patel 2002). Some of common fertilizers used in fertigation are given in Table 2.

Fertilizers solubility

The amount of fertilizer which can be dissolved in unit quantity of water is called the solubility. Solubility of any fertilizer is an important and critical factor when preparing the solution for ferrtigation, particularly from granular fertilizers. Pre-requisite for the solid fertilizer use in fertigation is its 100% solubility in the irrigation water. Examples of highly soluble fertilizers suitable for the use in fertigation are: ammonium nitrate, potassium chloride, potassium nitrate, urea, ammonium monophosphate and potassium mono-phosphate. The solubility indicates the quantity of fertilizer that can be dissolved in unit quantity of water. The solubility of fertilizers depends on the temperature (Wolf *et al*. 1985). Normally the solubility values are taken for 20^o C. The fertilizer solutions stored during the summer form precipitates and it is recommended to dilute the solutions stored at the end of the summer. Fertilizer solutions of smaller degree specially formulated

Table 3 Solubility of water soluble special fertilizer and conventional fertilizer

Fertilizer	Grade	Solubility (g/l) at 20^0 C	pH (1 g/l at 20^{o}C)
Water soluble special fertilizers			
Mono ammonium phosphate (MAP)	12-61.0	282	4.9
Poly feed (PF)*	19-19-19		
Mono potassium phosphate (MKP)	0-52-34	230	5.5
Potassium nitrate (multi-K)	13-0-46	316	7.0
Sulphate of potash	0-0-50		
Othophosphoric acid	0-52-0	457	5.5
Conventional fertiliser			
Urea	46-0-0	1100	5.8
Ammonium nitrate	34-0-0	1920	5.7
Calcium nitrate	16-0-0	1290	5.8
Potassium chloride (Red)	0-0-60	347	7.0
Potassium sulphate (White)	0-0-50	110	3.7
Ammonium sulphate	21-0-0	760	5.5

Source: Rajput and Patel (2002) and NCPAH (2012). (*All poly feed fertiliser contain micronutrients, viz. Fe, Mn, Zn, Cu, Bo, Mo).

Table 2 Common fertilizers suitable for fertigation in their soild and saturated liquid form

Nutrient	Compound	Nutrient content in solid fertilizer ($N-P_2O_5-K_2O$)	Nutrient content in saturated liquid fertilizer ($N-P_2O_5-K_2O$) at 25^{o}C
Nitrogen	Urea	46-0-0	21-0-0
	Ammonium nitrate	33-0-0	21-0-0
	Ammonium sulphate	21-0-0	10-0-0
Phosphorous	Phosphoric acid	-	0-61-0
	Mono-ammonium phosphate	12-61-0	4-18-0
	Di-ammonium phosphate	18-46-0	7-25-0
Potassium	Potassium chloride	0-0-62	0-0-15
	Potassium nitrate	13-0-46	4-0-12
	Potassium sulphate	0-0-50	0-0-6
	Mono-potassium phosphate	0-52-34	0-10-7

Source: Magen (1995).

by the manufacturers are used during the winter. The specifications of some water soluble and conventional fertilizers pertain to solubility and pH (Table 3).

Interaction between the fertilizers and irrigation water

Sources of fertilizers have different effects on the pH of irrigation water. The pH of irrigation water should be near to neutral. Higher pH values (>7.5) of irrigation waters are undesirable. Any water source having Ca, Mg and bicarbonates can have interaction with fertilizers and can cause diverse problems, as formation of precipitation in fertilizer tank and clogging of drip system. In water having high Ca and carbonates may cause the precipitation of $CaSO_4$ if sulphate fertilizer is used, urea may precipitate as $CaCO_3$ because urea increase pH. In case of high concentration of Ca and Mg and high pH value may lead the precipitation of Ca and Mg phosphate. When Ca and Mg is high in irrigation water the Phosphoric acid or Mono-ammonium phosphate fertilizer is used for P. If the pH values (<5) of irrigation water can have detrimental effect on plant roots. The ideal pH of irrigation used for fertigation should be between 5-7.5.

Effect on soil reaction

The fertilizers can be classified into three groups depending upon their effect on the soil pH, i.e. acidic, basic and neutral. The constant use of anhydrous ammonia and ammonia compounds will eventually have an acidifying effect on the soil. This soil acidifying action tends to bring into solution some minor elements such as iron, manganese, copper, zinc and molybdenum. This does not mean that the entire soil becomes acidic but the area around each fertilizer particle becomes acidic. This acidifying effect persists only for short duration. Phosphatic fertilizers keep the soil pH near neutral but potassic fertilizers increase the soil pH and make the soil basic.

Fertilizers compatibility

Some fertilizers should not be mixed together, when preparing the fertigation solution. Mixing the solution of two or more water soluble or liquid fertilizers can sometimes create the problem of precipitation means these are not compatible to each other. For example, the mixture of $(NH_4)_2SO_4$ and KCl in the tank considerably reduce the solubility of the mixture due to the K_2SO_4 formation. Other forbidden mixtures are:

Calcium nitrate with any phosphates or sulphates

(a) Calcium nitrate with any sulphate = formation of $CaSO_4$ precipitate (gypsum):
$Ca(NO_3)_2 + (NH_4)_2SO_4 = CaSO_4 +$ ——

(b) Calcium nitrate with any phosphate = formation of Ca phosphate precipitate
$Ca(NO_3) + NH_4H_2PO_4 = CaHPO_4 +$ —
Magnesium nitrate with di- or mono- ammonium phosphate

(c) Magnesium nitrate with mono-ammonium phosphate = formation of Mg Phosphate precipitate
$Mg(NO_3)_2 + NH_4H_2PO_4 = MgHPO_4 +$ —
Ammonium sulphate with KCl or KNO_3 = formation of K_2SO_4 precipitate

(d) $SO_4(NH_4)_2$ + KCl or $KNO_3 = K_2SO_4 +$ ——
Phosphoric acid with iron, zinc, copper and manganese sulphates

(e) Formation of iron phosphate etc

Antagonistic or synergetic effect may be observed when two or more ions are present in the medium. There is a competitive antagonism effect between NO_3 and Cl anions; the presence of Cl reduces the absorption of NO_3 and vice versa (Imas 1991). Thus under saline conditions the effect of salinity can be reduced by the use of NO_3 fertilizer. Here more NO_3 ion will be absorbed and replace Cl ions.

Cooling effect dissolution

Some fertilizers during dissolution cool down the temperature of water resulting in reduced solubility of the fertilizer. This will influence the desired fertilizer ratio in the solution. The fertilizers which lower the temperature of water during dissolution are urea, ammonium nitrate, calcium nitrate and potassium nitrate.

Schedule for fertigation

To decide fertigation schedule for any crop, basically soil analysis and leaf analysis is necessary. The application rate of fertilizer depends upon the type of soil and type of crop to be grown and the stage of growth. If plant gets balanced nutrition at all stages of growth, it will grow fast and gives more yield. The availability of nutrients to plant will depend upon the quality of medium to supply nutrients to the plant and method of irrigation. For deciding fertigation schedule following points must be keep in mind: (i) Nutrient requirement of crop to get target yield. (ii) Nutrient supplied in the form of organic manure/green manure. (iii) Nutrient requirement at different growth stages.

The scheduling of fertigation for crops will benefit the farmers to increase the yield and improve the quality of produce through efficient use of water and fertilizers. The schedule for nutrients to be applied through fertigation for vegetable crops suggested by Bar-Yosef (1991). Fertigation allows the amount of the applied fertilizers to meet the actual nutritional requirement of the crop throughout the growing period. In order to make a planning of the nutrients supply to the crop according to physiological stage, one must know the optimum daily nutrient consumption during the growing cycle which results maximum yield and better quality of produce. These functions are specific for each crop and climate and should be determined accordingly. Scaife and Bar-Yosef (1995) in Israel developed some functions for tomatoes, eggplant, broccoli and melon.

Nutrient use efficiency of liquid/ water soluble fertilizers under fertigation

Though the liquid and water soluble fertilizers are costly compared to conventional fertilizers, but their use is growing over the years. This is because the benefit from these fertilizers in terms of increase in yield, quality and nutrient use efficiency far exceeds their higher cost. Fertigation is the most efficient method of fertilizers application, as it ensures application of the water and fertilizers directly to the plant roots leading to greater efficiency of application (Rajput and Patel 2002). Fertigation can save fertilizers by 50% and may increase the crop yield by 20-30%. Fertigation has been substantiated for many crops throughout world. It has been reported that efficiency of nitrogenous fertilizers is 95% under drip-fertigation compared to 30-50% under soil application.

Research on various fruits and vegetable crops have indicated that using different combinations of water soluble fertilizers for increasing the productivity (Table 4). Several other studies have also indicated the much better NUE with liquid and water soluble fertilizers applied through fertigation like banana (Reddy *et al*. 2002, Pawar and Dingre 2013), apple (Banyal and Sharma 2011), kiwifruit (Chauhan and Chandel 2008), sweet cherry (Ahmed *et al*. 2010), litchi (Dey *et al*. 2010), mango (Singh *et al*. 2009), citrus (Srivastava *et al*. 2003, Shirgure *et al* 2003b), grapevine (Reynolds *et al*. 2005), squash (Du Plessis and Koen 1996 and Mohammad *et al*. 2004), garlic (Castellanos *et al*. 2001,

Table 4 Effect of fertigation on crop yield and fertilizer savings

Crop	Treatment	Reference
	Vegetables	
Onion (*kharif*)	More than 50 % fertilizers of RDF (160 kg/ha N, 115 kg/ha P_2O_5 and 95 kg/ha K_2O) with 33 % savings in irrigation water.	Patel and Rajput (2013)
Onion (*rabi*), tomato, broccoli and okra	Fertigation saved fertilizers to the tune of 40%.	Patel and Rajput (2003)
Broccoli	NUE was 90% and 81% of N when applied @ 250 and 350 kg N/ha respectively (80% ET + 80% recommended fertilizer)	Thomson *et al.* (2003) Gupta *et al.* (2009)
Tomato	Drip fertigation of 80% RDF with water soluble fertilizer registered 22.3 and 31.0 % higher fruit yield over drip and furrow irrigation methods.	Muralidhar *et al.* (1999) Prabhakar *et al.* (2001) Singandhupe *et al.* (2003) Bradr and Abou El-yazied (2007)
Potato	180 kg N/ha through drip irrigation produced tuber yield of 30.6 q/ha with 40% nitrogen saving in potato.	Patel and Patel (2001)
Coriander	75% RDF with water soluble fertilizer through drip irrigation	Rajaraman *et al.* (2011)
Cauliflower	225 kg N/ha (2.0 L/h flow rate) at 100 kPa pressure.	Bozkurt *et al.* (2011)
Spinach	85 kg/ha through drip irrigation	Zhang *et al.* (2015)
Brinjal	80% RDF at IW/CPE ratio of 1.0 using drip irrigation	Ugade *et al.* (2014)
Onion seed crop	120:60:60 NPK kg/ha through drip irrigation at 100% ETC	Dingre *et al.* (2016)
	Fruits	
Papaya	100% recommended dose of N,P,K in bimonthly intervals resulted in maximum fruit yield.	Chaudhari *et al.* (2001) Jeyakumar *et al.* (2001)
Banana	Crop duration was reduced by fertigation with 40 litres/day/pit + 75 % of recommended N and K/pit in banana (cv. Robusta).	Mahalakshmi *et al.* (2001) Kavino *et al.* (2002)
Sapota	Drip irrigation with fertigation 80 % of RDF using drip irrigation.	Gnanamurthy and Manickasundram (2001)
Guava	Maximum B:C ratio (2.91) was obtained with 75% of water soluble fertilizers applied through drip	Ramniwas *et al.* (2012)
Mango variety:	75% doses of RDF	Panwar *et al.* (2007)
Dashehari	Estimated volume of water to be applied to the plant in litre/day/plant.	
Assam Lemon	80% RDF Drip irrigation thrice a week	Barua (2013)
Pomegranate	50% recommended dose of NPK Drip irrigation litre/day/plant	Shanmugasundaram (2015)
Watermelon	150 kg NPK/ha Irrigation twice in a week	Sabo *et al.* (2013)
	Plantation crops	
Cocoa	(125:50:175 g NPK/plant/year)20 litres/tree/day	Krishanamoorthy (2013)
Arecanut	75% NPK/ha at IW/CPE ratio of 1 with a 30mm depth of water through basin irrigation	Bhat *et al.* (2007)
Coconut	Fertigation at 80% recommended fertilizer economized 20% fertilizer over control.	Gnanamurthy and Manickasundram (2001)

Castellanos 2002), bell pepper (Silber *et al*. 2005) and okra (Rajput and Patel 2002), etc.

Physiological effects

Fertilizers will not burn or damage plants if they are applied correctly. Fertilizers are salts much like table salt, except that they contain various essential plant nutrients. When a fertilizer is applied to a soil, nearby water begins to move very gradually toward the area where the fertilizer has been applied. Fertilizer salts begin to diffuse, or move away from the place where they were applied. This dilutes the fertilizer and distributes it throughout a much larger area. If tender plant roots are close to the placement of a fertilizer, water is drawn from these roots, as well as from surrounding soil. The more salt or fertilizer applied, the more water is drawn from nearby roots. As water is drawn from the roots, plant cells begin to dehydrate and collapse and the plant roots burn or dehydrate to a point where they cannot recover. If soil moisture is limited, most of the water drawn toward the salt will come from the plant roots and the damage will be severe.

Foliar applications of fertilizer provide not only a means to apply nutrients at a particular growth stage but after diagnosing the deficiency of a nutrient it provide the remedy (Srivastava and Singh 2003a). Swietlik and Faust (1984) observed that foliar fertilization cause a plant to pump more sugars and other exudates from its roots into rhizosphere. Other beneficial microbes in the root zone are stimulated by the increased exudates in turn enhanced biological activity and in turn increased nutrients availability.

Fertigated papaya plants recorded higher nutritional status (N, P and K content), leaf N and K contents, physiological efficiency (especially total chlorophyll content), photochemical efficiency, stomatal conductance and net photosynthesis, water use efficiency and relative water content compared with plants not subjected to fertigation (Shirgure *et al.* 1999, 2001, 2004). In fertigated plants there was an increase in number of fruits per tree by 24%, average fruit weight by 30.6%, fruit length by 12.5% and TSS by 10.7% over plants which are not fertigated.

Future strategies

To maximize the productivity of horticultural crops and enhance the fertilizer use efficiency, there is vast scope to increase the consumption of liquid and water soluble fertilizers in the country. The involvement of research institute (ICAR and agricultural universities) is very little and any recommendation of water soluble fertilizers is not included in package of practices of horticulture crops. The prospects of use of liquid and water soluble fertilizers are bright as now farmers has started to shift on high value crops for more profits. The government is providing assistance for the installation of drip irrigation system bur no subsidy or financial assistance is provided for water soluble fertilizers, which is a matter of concern to the government. Following strategies need to be followed: (i) Optimum nutrient ratio of fertilizer (N-P-K) at different stages of growth for different crops required to be standardized. (ii) Tissue nutrient guidelines (based on critical growth stages as per crops) need to be developed for different fruits and vegetable crops to economize the fertilizer doses and proper time of application. (iii) Multiple micro-nutrient mixture to be developed (to customised fertilizers) for effective use to control micro-nutrients deficiencies. (iv) Way and means to be developed to fit such customised fertilizers suiting to a given soil type, crop and agro climate. (v) A sound basis of customising liquid fertilizers to be developed to add an additional dimension of nutrient-use-efficiency. (vi) More research is needed to establish fertigation schedules for different crops for achieving quality produce and higher fertilizer use efficiency. (vii) Comparative productivity of crops with speciality fertilizers and straight-fertilizers needs to be standardized. The B: C ratio of using specially fertilizer versus straight fertilizers needs to be worked out. (viii) Water soluble or liquid fertilizes need special attention as they are relatively not adopted so far by Indian farmers. In the coming time with more awareness consumption of these fertilizers is going to increase. So extensive evaluation of new products and their specific recommendation for different is necessary. (ix) Quality standards for liquid/ water soluble fertilizers should be established. Simultaneously, there is a strong necessity to develop robust system of labelling and certification of liquid fertilizers.

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