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Nutrient Management in High Density Apple Orchards – A Review

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Authors' contributions

This work was carried out in collaboration between all authors. Author Shabnam Ahad designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors MMM and Shahida Ashraf managed the analyses of the study. Authors SM and MH managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

All plants require a sufficient supply of essential nutrients to reach their potential, and deficiency of any single nutrient is enough to limit yield. Supply of adequate quantities of nutrients is essential for sustainable high yield and good quality fruits over a long period. The nutritional requirements are different during the vegetative and reproductive growth stages, thus these requirements must be met as per their needs. Nutritional requirements are ascertained through soil chemical analysis, leaf analysis and loss of nutrients through crop production. Due to the effective role of macro and micronutrients in orchard productivity, nutrient management has become as important as other cultural practices in high density orchards. Nutrient management is simply based on 4R's concept i.e right source, right rate, right time and right method. The phenological period and frequency of uptake determine the application time and the quantity of nutrient to be applied. Different methods of fertilization are used in fruit production, including fertilization with mineral fertilizers (conventional type), fertigation, foliar nutrition and a range of other methods. Due to various reasons, in high density orchards priority is given to fertigation and foliar nutrition. The high effectiveness of fertigation results from the possibility of applying optimal concentrations of fertilizing solutions and a

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higher root density in the wetted soil volume. Plant nutrient availability and their uptake rely upon various factors like soil texture, pH, temperature and moisture, maintaining all these factors is an important goal of orchard nutrient management programme. A better understanding of nutrient interactions is essential in understanding the importance of balanced supply of nutrients. Nutrient use efficiency in orchards can be improved by making the use of controlled release fertilizers (CRF's), biofertilizers and enhancing the use of organic matter.

Keywords: Nutrients; fertilizers; fruits; fertigation; management.

1. INTRODUCTION

Apple (*Malus* x *domestica* Borkh) a crop of global horticulture importance and is the most critical temperate fruit of the North-Western Himalayan region. It belongs to family Rosaceae and sub-family Pomoidae and has originated in the temperate region between Black Sea and Caspian Sea. Although apple is grown over several regions with temperate climates throughout the world, commercial production activities are common over the areas or countries with strong competitive power [1]. Cultivation of apple is widespread in the areas within cold temperate climates between latitudes 30° and 50° in the North and South of the Equator [2]. In India, the area under apple is 314 thousand hectares with a production of 2872 thousand metric tons and productivity of 6.98 M.T/ha [3]. The important apple producing states in India are Himachal Pradesh, Jammu and Kashmir and Uttarakhand which cover 95% of total area under apple and 86% of the total apple production. Achieving the goal of feeding the global human population entails increasing the quantity and quality of crop production inputs such as water, seed, pesticide, and nutrients [4]. The supply and absorption of chemical compounds needed for growth and metabolism may be defined as nutrition and the chemical compounds required by an organism are termed as nutrients. Thus plant nutrients are the chemical elements that are essential to the nourishment of plant health. Based on the criteria proposed by Arnon and Stout, there are 20 elements known to be essential for higher plants. Based on the quantity required, nutrients have been classified into two categories viz. macronutrients and micronutrients. The nutrients which are required by plants in larger quantities are called as macro or major nutrients which include nitrogen, phosphorous, potassium, calcium, magnesium, sulphur, carbon, hydrogen and oxygen. Micronutrients also called as minor or trace elements are those which are required by plants in small quantities and include manganese, iron, zinc, copper, boron, molybdenum, chlorine, nickel and cobalt [5]. Both macro and micronutrients are equally essential for the proper growth of plants. Each nutrient performs unique functions in tree growth and development, and good tree growth, cropping and fruit quality not only depends upon the adequate supply of each nutrient but also the proper balance between them [6] and [7]. Although fruit trees represent about 1% of the global agricultural land, they are of a significant economic importance in many provinces as well as in world trade [8]. Fruit crops by the feature of their perennial nature of woody framework (nutrients locked therein), extended physiological stages of growth, differential root distribution pattern (root volume distribution), growth stages from the point of view of nutrient requirement and preferential requirement of some nutrients by specific fruit crop, collectively make them nutritionally more competent than the annual or yearly crops [9,10]. At least 60 percent of the world's arable land endures mineral deficit or elemental toxicity problems [11,12,13]. There will be increasing importance of nutrient efficient cultivars that are highly productive. Nutrient efficient plants are defined as those plants, which produce higher yields per unit of nutrient, applied or absorbed than other plants (standards) under similar agro-ecological conditions [14,15,16]. Nutrient supply and balance also have a significant impact on the sensitivity of fruit trees to various diseases, as it affects the metabolism of the tree, leading to fluctuations in cell wall composition and strength, concentrations of defense compounds, and the abundance of sugars and amino acids. Excessive nutrient availability compared to plant requirements convey negative results such as excessive plant vigor, decreased yield and fruit skin color, abortion of flowers [17,18], as well as increased prevalence of fungal diseases on leaves and fruit [19]. An increase in concentration of a nutrient up to the optimal level promoted absorption of other nutrients (synergism), while an excess level inhibited the accumulation of nutrients (antagonism). Productivity of the plant depends substantially on the nutrient balance and the biological activity.

Consequently, the highest biomass production and nutrient aggregation was associated with an optimal supply of both macro and micronutrients [20].

Nutrient management is the process of managing the amount, source, timing and method of nutrient application with the aim of optimizing productivity whereas minimizing nutrient losses that could create environmental problems [21]. It includes developing nutrient budgets, determining the amount of nutrients required by the crop, accounting for all the probable sources of nutrients and then applying manures, compost or inorganic fertilizers to meet the nutrient demand of the crop. As a crucial input in modern agriculture, fertilizers make an important contribution to the attainment of high crop yields. Soil quality is also a significant part of nutrient management because it influences nutrient retention and water movement through the soil. Evaluating what nutrients you need for an expected crop production yield and accounting for nutrients provided by the soil, manures, composts or legumes can reduce the supplementary amount of inorganic fertilizer needed. Thus in addition to the environmental benefits, there are economic benefits to nutrient management. Appropriate applications of water and nutrients allow the temporal adjustment of fertigation requirements according to the phenological stages, age and health of the plants, as well as providing an efficient use of water and the diminution of pollution [22]. There is an increasing concern with fertilizing specific organs, in addition to optimizing the overall nutrition of the tree [23]. The goal should be to promote flowering and fruit set, thus assuring standard yield. Orchard nutrition management for the high density plantations of spur type cultivars based on farmer's friendly integrated nutrient combinations will be very much profitable. Integrated application of organic manures and inorganic fertilizers amplifies overall behavior of apple trees in terms of plant growth, yield and fruit quality [24] and organic mulches also facilitates better availability of nutrients like N, P, K, Ca, Mg and B for enhancing fruit yield and quality without any adverse effect [25]. Biostimulants are incorporated in the practice of fruit production due to their ability to enhance nutrient uptake, stimulate plant development and minimize the use of fertilizers [26]. In commercial orchards, some soils with high organic matter provide a substantial amount of N (NH_4, NO_3) during the summer [27]. Heavy N fertilization late in the spring with natural release of N from the soil during the summer can elevate tree N status to excess levels, leading to vigorous vegetative growth, poor fruit color development, storage quality problems, and increased disease susceptibility. At the other extreme, lack of N supply from soils with low organic matter can result in poor fruit set, small fruit size, low yield, and alternate bearing. Because nitrogen has differential effects of fruit set and size, fruit color, flesh firmness, storage quality, and disease susceptibility [28,29], nitrogen management has to be optimized to balance these several effects with the ultimate goal of producing a high yield of quality fruits [30]. With global commodity and fertilizer prices sure to continue rising as world food and fiber demand grow, the 4Rs will without question continue to grow in importance among farmers. Thus orchard nutrition is the pre-harvest and post harvest practice that affects productivity and fruit quality, and has to be executed very carefully [31]. In simple terms, nutrients such as nitrogen, phosphorous, potassium and calcium need to be managed in such a way that they are present in the soil in the right quantity for good plant growth and better fruit quality. Thus nutrient management has become as important as other cultural practices in high density fruit orchards as it plays a more critical role in ensuring good tree growth, cropping and fruit quality for apple trees on dwarfing rootstocks in high-density plantings than for those on vigorous rootstocks as dwarf apple trees crop earlier and have higher yield and smaller root systems. Also, good nutrient management is an integral part of sustainable farming system.

2. NUTRIENT AVAILABILITY AND UPTAKE

Nutrient availability is a function of the presence of nutrients in soil solution, their diffusion rates through soil and their interactions with soil minerals. It is interrelated with soil productivity and is evaluated by observations and tests which are used to predict the response of plants and management of nutrients. The nutrient uptake is the mechanism by which plants capture all those elements that are essential for their growth and nutrient uptake in soil is achieved by cation exchange. Compared with cereal crops, the apple farming system could be more sustainable due to the relatively low nutrient removal in the yield, high nutrient recycling (e.g., through decomposition of fallen leaves) and retention in the system (e.g., through nutrient storage in woody part of the tree) [32]. The nutrient uptake and removal by apple trees (through harvest and pruning) is relatively low in contrast to other types of farmlands. As lately indicated by Zanotelli et al. [33] maximum uptake of nitrogen occurs from 37 to 81 days after full bloom and then starts to decrease. For a typical high-density apple orchard, a total amount of 25–60 kg ha^{-1} N is removed annually (by fruits harvest, falling leaves and pruning) for different tree varieties [22]. It can be assumed that the nutrient removal will be much lower in low density and low productivity orchard. Due to the comparatively lower rooting densities (particularly those with dwarf rootstocks such as M.9), fruit trees are inefficient in their use of N fertilizer [22]. The typical N recovery efficiency of applied fertilizer N on apple trees is approximately 20 percent [34] which is remarkably low compared to that on croplands (55%) and grasslands (70%) [35]. Apple fruit, in fact, is a strong sink for K and it usually contains considerable quantities of K, with concentration ranging from 0.55 to 0.8 kg K Mg^{-1} fruit d.w. [36]. Therefore annual K uptake strongly depends on fruit yields and can vary from 80 to 100 kg K ha^{-1} with yields ranging from 40 to 60 Mg fruit (f.w) ha^{-1}. Due to its high phloem mobility, K allocation to fruit remains quietly steady from fruit set to fruit maturity [36]. Scandellari et al. [37] anticipated that 74 kg Ca ha^{-1} are taken up annually by 'Gala' trees, then allocated as follows: 11% in the tree framework, 4% in fruits, 60% in leaves and 25% in pruned wood. Nutrient availability and their uptake depends upon the following essential factors:

a. Texture
b. Structure
c. Moisture
d. Temperature
e. pH

a) **Texture:** It is defined as the proportion of sand, silt and clay in the soil. High clay content increases CEC and thus the ability to hold nutrients, while high sand content decreases the CEC and nutrient holding capacity. Sandy soils also have large pore spaces, thus resulting in more leaching of nutrients. Soil texture has influenced the ripening and cooking character of fruits grown in South Africa and North America [38].
b) **Structure:** It is defined as the arrangement of soil particles into aggregates. Suitable structure is essential for water and nutrient movement, penetration, and retention. Large spaces between aggregates allow soil water and the nutrients therein to move more freely, resulting in losses through leaching. Small or no spaces between aggregates, primarily due to compaction, prevents water from moving through the soil profile, resulting in runoff. Soil structure directly influences the growth of root system and ultimately the crop productivity level [39].
c) **Moisture:** It is important for root growth as well as nutrient uptake. Adequate moisture will improve absorption of nutrients by diffusion and root interaction and will increase organic matter decomposition. Low moisture can result in the formation of insoluble nutrient-containing compounds. In the perennial tree crops outcome of the long-lasting trails generally tend to show that the less available water a tree has its disposal, the less it will nurture vegetatively [40].
d) **PH:** It affects nutrient availability by changing the nutrient form. For instance, different forms of N (affected by pH) have different leaching capabilities; other nutrients may become adsorbed or desorbed, precipitated, mineralized or immobilized at different pH values. Many nutrients are more available in slightly acidic soils; P is most available at neutral pH (about 6.5); Mb is available at high pH and can be toxic to plants. In Italy, lower pH levels may result in the unavailability of some nutrients to apple trees [41] and deficiencies of Mn and Cu have been detected in trees growing in soils at pH below 5.0 [42]. In general, a soil pH 6.0-7.5 is acceptable for most of the crops as most of the nutrients become obtainable at this pH range. In general, a soil pH 6.0-7.5 is acceptable for most of the crops as most of the nutrients become available at this pH range.
e) **Temperature:** It affects plants ability to grow, and thus affects nutrient uptake. Ideal temperatures vary by plant species and cultivar. Ketcheson [43] observed greater P uptake at 20°c than at 13°c due to increased rate of diffusion at higher temperature. The soil temperature also influences microbial activity which is an important part of organic decomposition.

3. DESIRED LEVEL OF NUTRIENTS IN LEAVES

As leaf analysis is an accurate guide for determining the nutritional status of fruit trees.

Plant nutritionists across the globe are on their toes to find ways and means to recognize the nutrient constraints as early in standing crop season as possible while dealing with perennial crops. Exciting progress has been made over the years, and accordingly, the basis of nutrient management strategy has experienced many paradigm shifts [44]. While doing so, it is increasingly felt to have some diagnostic tool to identify nutrient restrictions as and when it originates by capturing the signals released at subcellular level. But despite so much of genuine attempts worldwide, no one of these alone provides complete information, except the pooled use of leaf and soil analysis, which are used on a comparatively broader scale [45]. Leaves are mostly sink for N compounds and there is a close relationship between the nitrogen content of leaves and yield, size of fruit and coloring [46]. The most suitable leaf position and sampling time are those which gave rise to least variation in its mineral concentration, the nutrient accumulation curves of apple trees are good indicators of nutrient requirement in each plant development stage [47]. The knowledge of seasonal variation in leaf nutrient concentrations is essential to accurate the prescription of subsequent fertilizer additions and will play theoretical and fundamental task in practical steps for production [48]. With the development of leaf nutrient analysis and its wide adoption for diagnosis of tree nutrient status [49,50,51], fertilization practices in orchards are now routinely adjusted by comparing leaf analysis results against the optimal range of leaf nutrient concentrations. However, effective nutrient management in high density orchards still requires a good understanding of their nutrient demand in terms of amount and timing because optimal leaf nutrient concentrations do not reflect the actual amount and timing of tree nutrient requirements.

Desired level of nutrients in apple leaves

Nutrient	Concentration
Nitrogen	2.2-2.6%
Phosphorous	0.13-0.33%
Potassium	1.35-1.85%
Calcium	1.3-2%
Magnesium	0.35-0.5%
Sulfur	0.18-0.25%
Boron	25-50 ppm
Zinc	25-50 ppm
Copper	7-12 ppm
Magnesium	50-150 ppm
Iron	50+ ppm

- Young nonbearing apples should have leaf nitrogen levels of 2.4 to 2.6 percent.
- Young bearing trees need nitrogen levels of 2.2 to 2.4 percent.
- Mature soft apple varieties need nitrogen levels of 1.8 to 2.2 percent. (Soft varieties include Cortland, Empress, Golden Delicious, Honey crisp, Jerseymac, Jonagold, Jonamac, Jonathan, Macoun, McIntosh, Mutsu, Paula red, Spartan, Tydeman Red, and other early ripening varieties).
- Mature hard apple varieties and processing apples need 2.0 to 2.4 percent nitrogen in the leaf tissues (Hard varieties include Red Delicious, Empire, Gala, Idared, Liberty, Melrose, Rhode Island Greening, Rome, Stayman, and York Imperial).
- As a rule of thumb, every 10 percent increase in nitrogen fertilizer application results in an increase of 0.1 percent leaf nitrogen. “If nitrogen is provided via fertigation, nitrogen needed is less, as nitrogen uptake efficiency is higher in fertigation than in usual soil application”.

4. NUTRIENT NEEDS BY APPLE TREE

Plants require nutrients for completing their growth and metabolism and managing the nutrient requirement is essential to enable the manipulation of vegetative and reproductive development as well as fruit quality in deciduous fruit trees. It is essential to know the tree's mineral requirement and the phenological stage at which a certain element is taken up to supply nutrients at the right time to the soil so that nutrients can benefit the physiological processes taking place in the trees. The fertilizer requirement of perennial fruit crops is determined by a choice of ways, including surveys, experience of growers, following the fertilization program of high yielding orchards, replacing the amount of nutrients removed by fruits, deficiency symptoms, applying results from sand or soil culture and field experiments and leaf/soil analysis, with each one of these having distinct benefits and limitations [52]. Three approaches to fertilizer recommendations that are used to a wide extent: the deficiency correction philosophy (originates from nutrient constraints based crop response through nutrient additions to the point of maximum economic yield), maintenance concept (aims to maintain soil fertility level faintly greater than the point of highest economic yield), and nutrient removal or balanced philosophy (put emphasis on the return to the soil what is removed by the crop to maintain productivity, but often over recommends nutrient need since it does not take into account for the soil's ability to provide available nutrients to the plants over time) [53]. Like in many deciduous tree crops, the growth and yields of apple trees are reliant on nutrient accumulation in the trees over a number of seasons [54]. The annual retention of N in the woody part of the tree is just about 50% of the total N taken up by the trees [55]. The nutrient uptake by apple trees to attain a high yield of 9t ha^{-1} was estimated at 120 kg N, 46 kg P_2O_5 and 241 kg K_2O $ha^{-1}yr^{-1}$ in 14-yr-old "Golden Delicious" apple orchard with tree density of 500 trees ha^{-1} [51]. While developing fertilization programmes in apple orchards, soil nutrient availability and tree nutrient status must be taken into consideration along with tree nutrient requirements.

Ecologically sound fertilizer application recommendations can be developed based on the amount of annual removal of nutrients from apple orchards [34,56,35]. In this way, the annual N requirements for a high density (3 300 trees ha–1) "Gala/M.9" apple orchard was estimated at 20, 34.4 and 40 kg N $ha^{-1,}$ respectively, the second, third and sixth established year to attain an apple yield of 4.9 (2 yr), 18.8 (3 yr) and 43 t ha–1 (4 yr) [22]. The total amount of each nutrient contained in the fruit at harvest is also proportional to fruit yield. Since the amounts of nutrients contained in the fruit are permanently removed at harvest from the orchard where the fruit are grown. The nutrient removal on the basis of pounds per acre through fruits in relation to yield (bushels/acre) and subsequently their requirement to apple trees is shown below. It is clear from the below shown data that the requirement of each nutrient increases as the yield increases.

Fruit nutrient removal (pounds/acre) at harvest in relation to yield						
Yield (bushels/acre)	**N**	**P**	**K**	**Ca**	**Mg**	**S**
500	8.6	2.2	27.7	1.8	1.4	0.7
750	12.9	3.3	41.5	2.6	2.1	1.0
1000	17.2	4.4	55.3	3.5	2.8	1.3
1250	21.5	5.5	69.1	4.4	3.5	1.6
1500	25.7	6.6	83.0	5.3	4.2	2.0
1750	30.1	7.7	96.8	6.1	4.9	2.3

Tree nutrient requirements (pounds/acre) in relation to yield						
Yield (bushels/acre)	**N**	**P**	**K**	**Ca**	**Mg**	**S**
500	22.1	3.7	40.2	15.9	4.9	1.8
750	33.2	5.5	60.2	23.9	7.3	2.7
1000	44.3	7.4	80.3	31.8	9.8	3.6
1250	55.4	9.2	100.4	39.8	12.2	4.5
1500	66.4	11.1	120.5	47.7	14.7	5.4
1750	77.5	12.9	140.6	55.7	17.1	6.3

4.1 Suggested Rates of Nitrogen for High Density Apple Orchards

Age (yrs)	**Recommended rate of N(g/tree)/urea**
1^{st}	15/32.6
2^{nd}	30/65
3^{rd}	45/97.65
4^{th}	60/ 130.2
5^{th}	75/162.75

4.2 Suggested Rates of Phosphorous for High Density Apple Orchards

Soil test (ppm)	**Phosphates required(P_2o_5) Kg/ha)**
0-3	80
4-5	60
6-7	50
8-9	40
10-12	20
13-15	0

4.3 Suggested Rates of Potassium for High Density Apple Orchards

Trunk diameter	Rate of K to be applied
2.5 cm	80 g MOP per tree
5.0 cm	160 g MOP per tree
7.5 cm	240 g MOP per tree
10.0 cm	320 g MOP per tree

5. METHODS OF NUTRIENT APPLICATION

1. Application of solid fertilizers	2.Application of liquid fertilizers
a. Broadcasting	a. Starter solutions
b. Placement	b. Foliar application
c. Band Placement	c. Fertigation
d. Pellet application	d. Aerial application

Broadcasting: It refers to the even and uniform spreading of fertilizers or manures either manually or mechanically over the entire surface of field. Depending upon the time of fertilizer application, it can be either basal application or top dressing.

Placement: It refers to the placement of fertilizers in soil at a specific place. It is normally recommended when the small quantity of fertilizer is to be applied and when the development of the root system is poor. The most common methods of placement are localized placement and deep placement.

Band placement: It refers to placement of fertilizers in bands and includes hill placement and row placement. In orchards mostly hill placement is practiced for application of fertilizers.

Pellet application: It refers to the placement of fertilizer in the form of pellets. Mostly nitrogenous fertilizers are applied by this method.

Starter solutions: It refers to the application of nutrient solutions like N, P_2O_5 and K_2O in the ratio of 1:2:1 and 1:1:2 to the young plants. Starter solution helps in rapid establishment and quick growth of seedlings.

Foliar application: It refers to the spraying of fertilizer solutions containing more than one nutrient on the foliage of growing plants. The spray solution concentration has to be controlled, otherwise serious damage may result due to scorching of leaves. It is also effective for the application of minor nutrients like iron, boron, zinc etc. Iron foliar fertilization is a cheaper and more environmentally-friendly alternative to soil treatments with synthetic Fe(III) chelates for the control of Fe chlorosis in trees [57]. Urea is mostly used and cheapest foliar N fertilizer due to its swift absorption and high efficiency (90%) [58,59].

Fertigation: It refers to the application of water soluble fertilizers through irrigation system by the use of “T” tape, drippers, micro-jets, sprinklers, etc. The nutrients are thus carried to soil in solution. In high density orchards with tall spindle system and highly feathered trees, lateral growth is not required. In these orchards fertigation for the first two years is essential both for water to avoid stress and nutrients which are rapidly moved towards root zone where they become readily available to plants. It results in higher N use efficiency in apples [60].

Aerial application: The fertilizer solutions are applied by aircraft particularly in hilly areas or in the areas where ground application is not practicable. It is generally practiced in developed countries.

High-density trees grown with micro-irrigation and more so with drip irrigation have a relatively restricted root zone both in depth and lateral spread. Micro-sprinklers tend to have shallow roots but more lateral spread. Trees may be very productive especially in the early years of fruiting with drip and there is heavy use of nutrients in the zone occupied by the roots. In addition, due to relatively small wood and trunk volumes even in mature trees on dwarfing rootstocks, less nutrients are stored, and are thus not available to the tree during periods of stress. These types of trees will have to be supplied with necessary nutrients to obtain consistent cropping. Fertigation offers increased flexibility in managing orchard nutrition programs because of the potential for more closely synchronizing nutrient application with plant demand [61] and thus makes it possible to reduce the quantity of nutrients applied and thus reducing environmental impact [22]. Due to various reasons, in high density orchards priority is given to fertigation and foliar nutrition as these methods assist in increasing efficiency of applied fertilizers [62]. Fertigation allows to lessen nitrogen doses by half [63].

Fertigation rates of NPK for Apple Trees

Age (yrs)	crop load (bins)	N required g/ tree/season
1-4	25	12
5	30	16
6	40	20
7	50	26
above 7	60	32

Age (years)	P2O5 required g/tree/ season
Planting year	58
Second year and older	36

Age (years)	crop load (bins)	K_2O required g/tree/season
1-4	25	20
5	30	24
6	40	32
7	50	40

These grams per tree are based on 1500 trees per acre. The amounts specified should be reduced or increased per tree for numbers greater than 1500 trees/acre and less than 1500 trees/acre respectively. The amount of N should be applied to start at rapid shoot growth, and divided up over a 4 to ten week period, ending no later than mid-July. The P rates should be supplemented with a strong post-harvest and pre-bloom foliar nutrient program, including urea, and boron. Apply these amounts preferably in three separate doses or divide into daily doses and fertigate for one to two weeks. Fertigating with a soluble form of P like ammonium polyphosphate (10-34-0) allows the phosphorus to be available as the root growth occurs. Soluble forms of potassium are moved relatively easily with irrigation water and leached as well but not as quick as nitrogen. Potassium requirements increase after the June drop, the amounts increase according to the crop load.

According to Neilsen et al. [64], Application of P in this manner, timed to coincide with a period of high shoot, fruit, and root growth around bloom, is highly efficient as specified by its mobility in applied water throughout the rooting zone and its capability to raise leaf P concentration throughout the growing season and fruit P concentration at harvest. Furthermore, the cumulative yield of these trees was increased by 20% for all tested apple cultivars throughout the first five growing seasons.

6. NUTRIENT INTERACTIONS

Interaction among nutrients in crop plants occurs when the supply of one nutrient affects the absorption and utilization of other nutrients. This type of interaction is most common when one nutrient is in excess concentration in the growth medium [65]. Specific nutrient interactions are classified as soil, rhizosphere and plant processes [66]. Rhizosphere processes are classified as cation-cation, cation-anion or anion-anion [67]. The second form of interaction is between ions whose chemical properties are almost similar that they compete for their site of adsorption, absorption, transport and function on plant root surfaces or within plant tissues. Such interactions are more common between the nutrients having analogous charge, size, electronic configuration and geometry of coordination [68].e.g. Ca^{2+}, $Mg^{2+,}$ K^+ and Na^+.

Nutrient interaction could be positive or negative and also possible to have no interactions. The interaction is said to be positive when nutrients in combination result in a growth response that is greater than the sum of their individual effects and if the combined effect is less, the interaction is negative. In the former case the nutrients are synergistic, whereas in the latter they are antagonistic. If there is no deviation from two nutrient's additive response when applied separately, absence of interaction [69,70]. Numerous studies have shown that there is a positive interaction between nitrogen and phosphorous resulting in yield improvement [71,72]. Nutrient interaction is influenced

Table 1. Effect of fertigation of ammonium polyphosphate (20 g) immediately after bloom on P content, fruit number and yield of apple cultivars (Ambriosa, Cameo, Fuji, Silken and Gala) /M9

Treatment	------------------------------------1999-2003-------------------------			
	Leaf P (mg/g DW)	Fruit P (g/kg FW)	Fruit number (n/tree)	Fruit yield (kg/tree)
+P	2.4	128	239	47.2
-P	1.8	101	203	39.3

Source- Neilsen et al. 2008 [64]

by factors such as concentration of nutrient, temperature, light intensity, soil aeration, soil moisture, soil pH, architecture of root and growth rate. As the interactions occur, changes are initiated at the sub cellular level which may ultimately be manifested through changes in photosynthesis, cell division, cell expansion, utilization and translocation of carbohydrates and organic acids. The net influence of these interactions and processes produces the final yield of a crop. Better understanding of these nutrient interactions in fruit crops can led to more efficient fruit production particularly in high density orchards.

7. FERTILIZER USE EFFICIENCY (%)

According to Tamil Nadu Agriculture University AGRITECH Portal 2016 [73], fertigation results in increase in fertilizer use efficiency (FUE) percentage.

Nutrient	Soil application (%)	Drip fertigation (%)
Nitrogen	30-50	95
Phosphorous	20	45
Potassium	50	80

7.1 Nutrient Use Efficiency

Nutrient use efficiency may be defined as yield per unit input. In horticulture, this is related to the input of fertilizer, whereas in scientific literature the nutrient use efficiency is often expressed as fresh weight or product yield per content of nutrient. The present yield trends are not enough to meet forecasted food demands [74]. One of the causes of the current stagnating yield levels is the deficiency and imbalance of nutrients which suggests the need for a great potential to increase the nutrient use efficiency [75]. Nutrient use efficiency not only depends on the ability to efficiently take up the nutrient from soil, but also on the transport, storage, mobilization, usage within the plant, and even on the environment. Nutrient use efficiency can be improved by-

- **a)** Use of controlled release fertilizers(CRF’s)
- **b)** Use of biofertilizers
- **c)** Use of organic matter
- **d)** Foliar fertilization

a) Controlled release fertilizers

The Association of American Plant Food Control Officials defines CRFs as fertilizers that contain a plant nutrient in a form the plant cannot absorb instantly. Uptake is delayed after application, so that controlled release fertilizers provide the plant with nutrients for a longer time in comparison to quick release fertilizers, such as urea. Controlled-release fertilizers are typically coated or encapsulated with inorganic or organic materials that manage the rate, pattern, and duration of plant nutrient release. Polymer-coated urea exemplifies controlled release fertilizers [76,77]. These fertilizers control the release of nutrients with semi-permeable coatings, occlusion, protein materials, or other chemical forms, by slow hydrolysis of water-soluble, low-molecular-weight compounds, or by other unknown means [78]. Most importantly, the release rate of a controlled release fertilizer is designed in a pattern synchronized to meet changing crop nutrient requirements.

b) Biofertilizers

According to Subba Rao [79] biofertilizers also called as microbial inoculants are the carrier based preparation containing beneficial microorganisms designed to improve the soil fertility and help the plant growth by their more number and biological activity in the rhizosphere. Biofertilizer is a cost effective renewable energy source and plays a crucial role in reducing the inorganic fertilizer application and at the same time increasing the crop yield besides maintaining soil fertility. In other words, biofertilizers are based on renewable energy sources and are ecofriendly compared to commercial fertilizers [80]. Biofertilizer is a recent concept in horticultural crops. Generally, fruit crops have now received more attention than vegetables and ornamental crops. Glomusfasciculatum, Glomusmosseae, Azospirillum, Azotobacter and Phosphorous solubilizing bacteria are found useful for different horticultural crops. Narender and Bhardwaj [81] reported that in apple, the height and stem girth of the plants were improved along with the leaf area and chlorophyll content by inoculation of Glomus spp. In association with VAM fungi, the absorption of mobile nutrients like nitrogen also increases [82]. Liu et al. [83] stated that reasonable application of microbial fertilizer improved yield, sugar and vitamin C contents as well as ratio of sugar to acid and enhanced fruit quality of 8 year old Dangshan crisp pear and the optimum amount of microbial fertilizer applied was 1.0 kg per tree. Sharma et al. [84] studied the correlations between endomycorrhizal and Azotobacter population with soil nutrient status of apple orchards. They observed that the fraction and intensity of mycorrhizal colonization were negatively allied with soil P and Zn, while higher status of N and organic C showed positive affiliation with microbial population.

c) Organic matter

Incorporation of organic fertilizers is a common practice to improve the yield of many fruit crops. It also limits chemical intervention and finally minimizes the negative impact on the wider environment [85] and [86]. Due to the high cost of chemical fertilizers and poor purchasing capacity, organic manures have been used for their eco friendly and beneficial effect on environment and fruit crops. Good quality farmyard manure, vermicompost, and green manures are the most valuable organic matter applied to the soil. Farmyard manure consists of decayed mixture of cattle dung and remnants of straw and plant stalks fed to the cattle. In vermicompost, some of the secretions of worms and the allied microbes act as growth promoters along with other nutrients. Green manuring is a practice of ploughing or turning into the soil undecomposed green plant tissues for the purpose of improving physical structure as well as fertility of the soil [87]. Rathi and Bist reported that 10 kg poultry manure + 300:150:250 g NPK per tree had a momentous enhancement in fruit quality in terms of fruit weight, volume, TSS, total sugar, reducing sugar, non reducing sugar etc. in low chilled pear cv. PANT PEAR –18. In addition to the environmental conditions, the rate of decomposition of organic matter depends on the quantity and composition of material.

d) Foliar fertilization

Foliar sprays have been also used as an important tool to meet tree nutrient demand. This fertilization method is more target-oriented and environmental friendly since the nutrients are applied in controlled quantities [88]. Taking into account the limitations of nutrients addition through soil, foliar sprays are an effective way to meet the plant nutrients requirements [89]. The most common macronutrients applied as foliar fertilizers are N (as urea, ammonium nitrate and ammonium sulfate), P [as H_3PO_4,KH_2PO_4, $NH_4H_2PO_4$, $Ca(H_2PO_4)_2$ and phosphites], K (as K_2SO_4, KCl, KNO_3, K_2CO_3, KH_2PO_4), Mg(as$MgSO_4$,$MgCl_2$,$Mg(NO_3)$]$_2$, and Ca(as$CaCl_2$, Ca-propionate, Ca- acetate). Also, to the most commonly foliar applied micronutrients belong the B [as boric acid (B(OH)3], borax (Na2B4O7), Na-octoborate ($Na_2B_8O_{13}$), B-polyols, Fe [as $FeSO_4$, Fe(III)-chelates, Fe-complexes], Mn [as $MnSO_4$, Mn (II)chelates], and Zn [as $ZnSO_4$, Zn(II)-chelates, ZnO, Zn-organic ‘complexes] [90]. In addition to this, it has become apparent that foliar nutrients can regulate flowering, fruit yield and fruit quality. For example, several studies revealed that foliar sprays of B increase pollen-tube germination and fruit set in a number of fruit tree species [91].

Proper Timing of Foliar Applications:

1. Proper Growth Stage: This is one of the most critical aspects of a foliar feeding program. Foliar applications should be timed to provide needed nutrients during the yield potential determining time frame of plant development, which will in turn favorably influence the post reproductive development stages. Careful crop growth stage monitoring on a weekly, and sometimes a daily basis, is essential.

2. Proper Meteorological Conditions: Environmental influences such as time of day, temperature, humidity and wind speed influence the physical and biological aspects of foliar applications. Plant tissue permeability is an important factor in absorption of nutrients into the plant: warm, moist and calm conditions favor highest tissue permeability, conditions found most often in the late evening hours, and occasionally in the early morning hours. Below shown table summarizes meteorological conditions favoring foliar applications [92].

Table 2. Meteorological conditions favoring foliar applications

Time of Day	Late evening; after 6:00 pm early morning; before 9:00 am
Temperature	18-21°C
Humidity	greater than 70% relative humidity
Wind speed	Less than 5 mph

7.2 Advantages of Foliar Fertilization over Soil Application

Foliar feeding is a reliable method of feeding plants when soil feeding is inefficient [93], therefore foliar feeding is considered among the major techniques used for plant nutrition, supplementing the ground application. The merit of foliar application of the nutrients over the soil applications is as under:

Table 3. Effect of boron on fruit set, yield and quality of apple

Treatment	Fruit set (%) DAF			Yield (kg/tree)	Mean fruit wt (g)	TSS (%)	Acidity (%)
	14	28	42				
Soil boron application	36.2a	15.3a	7.2a	4.3b	226b	13.6b	0.72b
Foliar boron application	40.2a	25.3b	15.2b	6.8c	191a	12.5a	0.65a
Control	39.4a	11.4a	6.9a	3.1a	188a	12.4a	0.63a

Source- Wojcik et al. 2008 [94]

1) To overcome soil fertilization limitations.
2) To overcome root problems.
3) Foliar spraying focuses the nutrient application on the target plants.
4) Fast and linear nutrient delivery.
5) Periods of drought or high humidity.
6) When plant demand cannot be satisfied due to: Field conditions, application costs or growth stages that prevent the use of soil applications.
7) To minimize the potential risks of unpredictable nutrient deficiencies.
8) When a quick growth response is desired.
9) Foliar fertilizers may have compatibility with pesticides.
10) Low environmental impact.
11) It stimulates photon pump priming effect mechanism.
12) To give a crop a nutritional boost at a critical growth stage.

Wojcik et al. [94] observed that pre-bloom foliar application of boron to apple trees increases fruit set as well as yield (Table 2). Moreover, soil application of boron also increases yield but to a lesser extent. The authors also explained the increase in yield of apple to increase in fruit size and fruit number through soil application and foliar spray of boron respectively and also reported an increase in total soluble solids as well as total acidity due to soil boron application. This can be attributed to transportation of higher amount of assimilates into fruit tissues.

8. CONCLUSION

In deciduous fruit orchards, accurate nutrient management is necessary if reproductive and vegetative development and fruit quality are to be manipulated effectively. The primary objective in managing nutrition should be to avoid either deficiency or toxicity situations that might interfere in the normal plant functioning. Nutrient management is the process of managing the amount, source, timing and method of nutrient application with the goal of optimizing productivity and minimizing nutrient losses. It includes; Nutrient requirements, Nutrient supply sources, Tree nutrient status and Management strategies. Good management of nutrients requires that supply should match the demand, in terms of amount, timing and retention in the root zone. Fertigation allows such flexibility in the timing and precision of nutrient supply. It gives greater P and K mobility than broadcasting. Improving nutrient use efficiency is very essential both from economic as well as environmental point of view. Building up of soil organic matter should be enhanced as it supports diverse microbial community and reduces nutrient leaching. Incorporation of organic fertilizers is a common practice to improve the yield of many fruit crops. It also limits chemical intervention and finally minimizes the negative impact on the wider environment.

In spite of many cutting edge technologies, addressing a range of core issues on role of soil type based nutrient management in raising the productivity of perennial fruits is the main research and developmental issue. The various nutrient management based issues and strategies would find their worth only when backed up with sound methodologies of nutrient constraints diagnosis. The presently existing leaf nutrient standards for different fruit crops have certain distinct restrictions in terms of: i. Sampling index plant part(s) leaving very short time for remediation of identified constraints, ii. Application of various interpretation tools bring out varying limits of nutrient concentration and iii. Do we need to apply some correction factor when such nutrient standards are applied in fruits under fertigation. A better rationale of nutrient constraints diagnosis as early as possible in a standing crop would surely pave the way for precision based nutrient response accruing in elevated productivity. Delineation of production management zones allied with variable rate fertilizer application as per the crop Phenology is expected to tailor the fertilizer requirement without altering the fertilizer requirement of a crop soil fertility based spatial variogram would further act as a decision support tool for exact fertilizer recommendation. Evaluating nutrient response at a cellular, subcellular, tissue level and plant part level instead of whole plant basis, would lay a solid foundation of nutrient management strategy in fruit crops. Eventually, such attempts warrant for developing Nutrient Experts based on 4R Stewardship Concept advocated by International Plant Nutrition Institute, Gurgaon which have displayed some definite yield advantages in cereal crops, but such serious efforts are direly required in fruit crops, if nutrient management is to be associated with nutrient use efficiency.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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