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Response of nutrient management on growth, yield and quality of citrus crop: A review

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Abstract
Citrus is one of the widely grown fruit crops throughout the world and has important medicinal properties and used as an integral component of diet. Efficient nutrient management is prerequisite for quality higher production of citrus. Though chemical fertilizers are the sources of most of the nutrients, injudicious continuous use of chemical fertilizers may cause deleterious effect on soil health and environment. Application of organic manures can supply nutrients for sustainable growth, yield and quality of citrus but sole application of organic manure has some drawbacks like imbalanced nutrition, less fertilizer use efficiency, not cost effective and comparatively less production. Biofertilizers, the carrier of microbial inoculants, can be used to enhance citrus yield by maintaining soil fertility. Integrated nutrient management can play important role for sustainable growth, yield and quality of citrus by maintaining soil health. Keeping in view of proper nutrient management in citrus for enhanced growth, yield and quality, different nutrient management in citrus is reviewed.

Keywords: Citrus, vermicompost, biofertilizer, integrated nutrient management

Introduction
Citrus is one of the popular fruit crops, grown widely in the regions of tropical, subtropical and Mediterranean climate of the world in between approximately 40°N and 40°S latitude. In India, citrus occupies third position in fruit production in an estimated total area of 0.923 m ha with production of 8.60 m M tons (Anonymous, 2009) [10]. A wide genetic diversity of citrus, including cultivated and wild species are found in Northeast India (Malik *et al.*, 2013) [54]. Oranges, Mandarins, Tangerines, Limes, Grapefruits, Lemons and Citrons, and many hybrids and varieties are included as citrus (Waleed, 2019) [88]. Citrus fruit belongs to genus *Citrus*, family Rutaceae and subfamily Aurantioidae. Due to its distinct aroma, delicious taste and nutritious quality, citrus occupies an important position in the daily dietary food habit (Azman *et al*., 2019; Liu *et al.*, 2012) [12, 51]. Citrus is a rich source of vitamins, minerals, fiber and many secondary metabolites, like flavonoids, alkaloids, limonoids, coumarins, carotenoids, phenolic acids, essential oils, dietary fibres etc, (Ahmed and Azmat, 2019; Sidana *et al.*, 2013; Ghasemi *et al.*, 2012) [8, 80, 29]. Citrus has many important medicinal properties *viz.*, anti-oxidative, anti-inflammatory, anti-cancer, cardiovascular protective effects, neuroprotective effects *etc* Xinmiao *et al.*, 2015) [9, 90] and can protect against many chronic diseases (Amira *et al.*, 2012; Deena *et al.*, 2010) [20]. Citrus juice contains phytochemicals which help to boost up immune system of human (Seeram, 2008) [73]. Further, citrus occupies a significant importance in the fruit economy of the country and occupies 7.5% land under fruits and third largest fruit industry after mango and banana (Sidana *et al.*, 2013) [80]. Though citrus is a widely cultivated crop, its productivity is less due to nutrient constraints (Srivastava *et al.*, 2008) [83]. Pathak and Nedwell (2011) [66] reported that mineral deficiency or toxicity symptoms are common at least 60% of world's arable land and it can be rectified either by soil amelioration or by proper fertilization. The poor physical condition of soil and nutrient unavailability may lead to reduction in yield (Obreza *et al.*, 2010) [63] as well as deteriorate citrus orchards. Proper mineral nutrition plays an important role for enhancing plant growth and fruit yield (Sharma *et al.*, 2006; Talon *et al.*, 2020; White and Brown, 2010) [77, 85, 89]. Nutrient management through application of major nutrients, particularly nitrogen, phosphorus and potassium (Liu *et al.*, 2010) [49] and application of micro nutrients like zinc, boron and iron through foliar application (Obreza *et al.*, 2010) [63] helps to improve productivity of citrus. Though application of inorganic fertilizer is essential for growth, development, yield and quality enhance--ement of citrus, but continuous injudicious use of long-term inorganic fertilization may lead to many hazardous effects to human health as well as to environment and soil (Aref and Wander, 1998; Doran *et al.* 1996; Singh and Singh, 2009; Ye *et al.*, 2020) [11, 23, 81, 92].

Han *et al.* (2015) [33] reported that balanced supply of nutrients, including micronutrients, enhanced availability of nutrients and increased soil microbial activity by organic manure helps in soil fertility (Cui *et al.*, 2018) [19] enhancement. Along with enhancing soil fertility organic farming also improves enzymatic activity of fruit crops (Kumar *et al.*, 2018) [45]. But, due to lower fertilizer efficiency, imbalance of nutrients like nitrogen, phosphorus, potassium, organic manure decreases crop yield (Song *et al.*, 2017) [82]. Moreover, organic manures are slow in crop response (Mahmood *et al.*, 2017) [52], less available, expensive and cost may increase up to 30% (Hamlet, 2001) [32]. Therefore, application of only organic manure is not possible to increase economic quality fruit yield. Being the formulation of microbial strains (Riaz *et al.*, 2020) [71], biofertilizer helps in plant growth and production by providing direct or indirect benefits of phytostimulation, abiotic stress tolerance, biocontrol (Ferreria *et al.*, 2019; Liu *et al.*, 2020; Shirmohammadi *et al.*, 2020) [27, 50, 78], enhanced nitrogen fixation, phosphate solubilization, releasing hormones and vitamins (Bamboriya *et al.*, 2018) [15]. Therefore, rational integrated application of organic and inorganic nutrients along with biofertilizers help in enhancing soil fertility (Meena *et al.*, 2019) [57], growth, yield and fruit quality of citrus crop (Citrus, 2019) [18].

A. Influence of organic nutrients on growth, yield and quality of citrus:

Novara *et al.* (2019) [61] reported that long term organic cultivation of citrus crop improved soil organic carbon status of Meditrranean citrus systems. Scotton *et al.* (2018) [74] reported that four year period of time was sufficient as a transition period for minimum use or replacement of chemical fertilizers by organic means of nutrient management and encourages fungal flora and their activity. Organic acid concentration of organically grown citrus juice was found higher (Duarte *et al.*, 2010) [24]. With proper attention and dissemination of organic cultivation technology, there is ample scope of citrus cultivation in north-eastern states of India (Manesh, 2006) [55].

a) Effect of FYM (farm yard manure) on growth, yield and quality of citrus:

FYM is the most commonly used bulky organic manure which enhances fruit yield by improving physico-chemical properties of soil and release of macro and micro nutrients (Lakkineni and Abrol, 1994) [48]. Kumar *et al.* (2013) [42] reported that application of FYM or pig manure @ 80 kg per tree helped to replenish nutrient depletion in khasi mandarin growing soils of Arunachal Pradesh. Application of 60% nitrogen of RDF + 40% organic manure (FYM) gave highest tree height, annual shoot growth, fruit set, fruit yield, fruit weight, fruit size, fruit volume and fruit quality characteristics like TSS, reducing sugar, total sugar and non-reducing sugar in sweet orange cv. Mousambi. Haokip *et al.* (2021) [34] made an observation and found that 60% N from RDF + 40% N from FYM produced maximum yield attributing characteristics *viz.*, plant height increment (15.04%), highest percentage in canopy spread increment, North-South (22.17%) and East-West (20.35%), maximum fruit set percentage (37.78%), highest number of fruits (40.22) per plant and maximum yield (8.52 kg) per tree of Assam lemon. Orange plants receiving 60% of their required nutrients (as per soil test) from chemical fertilizers and 40% from cow dung gave maximum yield, fruit quality and highest marginal returns (Bhuyan *et al.*, 2016) [17].

b) Effect of compost on growth, yield and quality of citrus:

Application of compost can enhance soil fertility by adding nutrients to soil, improves physical, chemical and biological properties of soil, increases soil organic matter (Adugna, 2016) [6] and helps in growth and yield enhancement of many plants (Sarwar *et al.*, 2008) [72]. Abo-Ogiala and Khalafallah (2019) [4] made an experiment to study the effect of gypsum and compost on growth and yield of Washington Navel orange under saline-sodic soils and found that application of gypsum @ 10 tons/fed + compost @ 15 tons/fed is the best ameliorating material and enhanced growth, yield and quality of orange. Application of liquid organic fertilizers (both animal and plant based) in drip irrigated citrus could replace traditional mineral fertilizers (Martinez-Alcantara *et al.*, 2016) [56].

c) Effect of vermicompost on growth, yield and quality of citrus:

Vermicompost, a decomposed product of organic wastes (Devi *et al.*, 2015) [22] by earthworms and microorganisms (Benitez *et al.*, 1999) [16], is a rich source of nutrients, plant growth hormones and plant growth regulators (Kumar *et al.*, 2018) [45]. Vermicompost and vermiwash act as growth promoter and plant protector and enhances crop production (Adhikary, 2012) [5]. Makode (2015) [53] reported that application of 10 kg vermicompost per plant in the month of June significantly enhanced fruit number, fruit weight, fruit yield of orange and also improved soil physical condition and nutrient status of the soil. Combined application of nitrogen @ 350 g /plant + vermicompost 20 kg/plant resulted in best plant growth parameters *i.e.*, East-West plant spread (8.70) and North-South plant spread (8.30), plant height (20.93), canopy volume (34.58), shoot length (15.75), shoot diameter (8.36), relative water content (94.50) and number of leaves/shoot (32.95) in kinnow mandarin (Pareek *et al.*, 2017) [65]. Pawar *et al.* (2020) [67] made an experiment to study the effect of vermicompost and biofertilizer on growth, yield and quality of sweet orange and the results revealed that application of 75% vermicompost (on N-equivalent basis of RDF) + *Trichoderma harzianum* (30-40 ml/plant) + Azadirachtin (1% at 3-4 ml/lit as spray) + *Pseudomonas fluorescens* (30-40 ml/plant) in the month of January yielded maximum plant height (3.40 m), fruit weight (197.47 g), number of fruits (292.12 fruits/tree), yield (57.69 kg/tree and 15.97 t/ha), juice (48.05%), TSS (10.05^{o} Brix), ascorbic acid (55.32 mg/100 ml juice), reducing sugars (4.20%), non-reducing sugars (3.16%), total sugars (7.34%), B:C ratio (1.78) and minimum acidity (0.46%). Perungkotturselvi and Koilraj (2015) [68] found significantly better profit (54.75 no. of fruits/tree) in vermicompost treated plants than compost treated plants. Ghosh *et al.* (2014) [31] made an experiment to study the effect of organic manures on growth, yield and quality of sweet orange and found application of vermicompost and neemcake as the best treatment and yielded higher vegetative growth and higher quality fruit of sweet orange. Pachuau *et al.* (2019) [64] made an experiment to study the effect of organic manures on growth, yield and quality of Assam lemon and found that application of vermicompost (5 kg/tree) and mustard oil cake (1 kg/tree) before flowering resulted in highest number of fruits/plant (85.66), fruit set (30.02%), yield/plant (9.60 kg), juice content (47.46 ml/fruit), TSS (5.78^{0}B), total sugar (6.19%), reducing sugar (3.62%)

and ascorbic acid (52.63 mg/100 g). Thongney *et al.* (2018) [86] made an experiment to study the effect of different levels of vermicompost and FYM on quality of cucumber on citrus based agro forestry system and found that application of vermicompost @ 2 t/ha + FYM @ 15 t/ha as best treatment which increased TSS, vitamin C and % acidity of citrus. This treatment also improved the growth parameters and yield of crops (Thongney *et al.*, 2020) [87].

d) Effect of biofertilizer on growth, yield and quality of citrus:

Biofertilizers are microbial inoculants which can be used efficiently for sustainable production of crop with soil fertility maintenance and provide phytohormones to plants and enhance plant tolerance to pests (Abobatta, 2020) [2]. Nejad *et al.* (2020) [60] made an experiment to study the effect of mycorrhiza and vermicompost on drought tolerance of lime seedlings and found that inoculation of seedlings with biofertilizer *i.e.*, 100 g mycorrhiza/plant helped to reduce drought hazards to the seedlings and significantly increased leaf fresh weight (19.94%), leaf dry weight (17.31%), stem fresh weight (26.7%), stem dry weight (26.1%), root fresh weight (35.53%), root dry weight (14.82%), relative water content (76.19%), enzyme activity, chlorophyll content and carotenoid content. An experimental study made by Shamsiri *et al.* (2011) [75] on the growth and nutrient uptake response in kinnow to vesicular arbuscular mycorrhiza (VAM) resulted that AM application improved growth parameters like plant height, canopy volume, mean leaf area, number of new shoots per plant. In citrus orchard, application of a consortium of organic and biofetilizers with mineral fertilizers could provide positive response by improving fruit quality, tree productivity and soil fertility status (Abobatta and El-Azay, 2020) [3]. The interaction between soil fertilization and foliar application of biofertilizer (BF) @ 2g/L reveled superior result in the characteristics of plant height and soil fertilization with 1 g/L of BF and foliar application of 2 g/L of BF gave best diameter of rootstock of local lemon (Shukr and Shaheen, 2021) [79]. Mustafa *et al.* (2019) [59] reported that vermiwash along with natural extract (yeast and algal extract) in the same order, not only improved growth of the citrus lemon seedlings but increased soil microbial activity also. Jugnake *et al.* (2017) [38] made a study to evaluate the effect of biofertilizer and chemical fertilizers on growth and yield of sweet orange and found that application of RDF (800:400:400g NPK + 50 kg FYM) + 80 ml Azotobacter + 80 ml PSB resulted in maximum tree height (0.47 m), stem girth (4.16 cm), tree spread (E-W 0.37 m and N-S 0.50 m), maximum number of fruits (403.83), average yield (107.36 kg) and marketable fruit yield (105.46 kg). Inoculation of orange trees with biofertilizer (*Pseudomonas fluorescence* strain 843) significantly enhanced fruit quality, fruit yield, fruit weight, fruit length, TSS and would inhibit the growth of nematodes (Shamseldin *et al.*, 2010) [76].

e) Combined effect of organic manure and biofertilizer on growth, yield and quality of citrus:

Rana *et al.* (2020) [70] studied the effect of organic manure and biofertilizers on plant growth, yield and quality of sweet orange and results revealed that application of FYM (40 kg/plant) + VAM (100g/plant) + *Azotobacter* (10 g/plant) gave maximum increase in growth and yield parameters *viz.*, plant height, plant volume, trunk girth, leaf size, no. of flowers/plant, fruit setting, fruit yield/plant, fruit length and fruit diameter while application of FYM (40 kg/plant) + *Azotobacter* (10 g/plant) resulted maximum value of quality parameters like juice percentage, TSS, titratable acidity, ascorbic acid and total sugar. Application of biofertilizer *Bacillus circulans* with different levels of nitrogen in combination with 120 units of potassium could increase vegetative growth, yield and quality of Valencia orange (El-Khawaga and Maklad, 2013) [25]. Half recommended dose of chemical fertilizer (NPK), half amount compost with 150 or 200 ml biofertilizer (bio-enriched fluid of Baytuk company consists of *Bacillus circulance*, *Bacillus polymyxa*, *Candida* spp, *Trichoderma* spp. and *Bacillus megatherium*) (Ahmed *et al.*, 2018) [7].

B. Effect of Integrated Nutrient Management on growth, yield and quality of citrus:

Integrated application of organic manure and biofertilizers along with chemical fertilizers improves physicochemical properties of soil, soil organic carbon, available nitrogen, available phosphorus content of the soil and increases fruit yield of citrus like mandarin orange (Lalrinfela and Varte, 2021) [47]. Many biofertilizer species like *Azoltobacter*, *Beizerinkia*, *Clostridium*, *Klebsiella*, *Anabaena*, *Nostoc*, *Rhizobium*, *Frankia*, *Anabaena azollae*, *arbuscular mycorrhizae*, can be efficiently used as a part of integrated nutrient management system in citrus orchard (Abobatta, 2019) [1]. A study on the influence of FYM and biofertilizers with NPK fertilizers on soil fertility, growth, yield and fruit quality of Eureka lemon trees revealed that 50% NPK + 55 kg FYM + biofertilizers gave best result. FYM and biofertilizer applications can also compensate 50% reduction of chemical fertilizers with significant enhance of citrus yield (Ennab, 2016) [26]. Lal and Dayal (2014) [46] reported that integrated application of 50% RDF + 50% goat manure resulted in highest growth and yield (7.58 kg/tree) of fruits with highest fruit length (4.43 cm), fruit diameter (3.99 cm), fruit weight (35.71 g), maximum juice (43.37%), TSS (10.42%), ascorbic acid (86.33 mg/100 g juice) with minimum seed (1.15%) and acidity (6.06%). Kumar *et al.* (2017) [41] made an experiment and studied the effect of integrated nutrient management on growth, yield and quality of sweet orange and found that 60% nitrogen of recommended dose of fertilizer and 40% organic manure (FYM) produced highest tree height, annual shoot growth, fruit set, fruit weight, fruit yield, fruit size, fruit volume and fruit quality characteristics *viz.*, TSS, reducing sugar, total sugar and non-reducing sugar. Nurbhanej *et al.* (2016) [62] found that integrated application of 75% RDF + vermicompost 9 kg/tree + PGPR consortium 3.5 ml/tree significantly enhances fruit volume (53.87 cc), fruit weight (53.2 g), fruit diameter (4.52 cm), fruit yield/tree (46.92 kg/tree), total soluble solid (8.85^{o}Brix) and ascorbic acid content (29.63 mg/100 g juice) in acid lime *cv.*, kagzi. Integrated treatment of 50% NPK (210gN+140gP+210gK) + 15 kg vermicompost + 5 kg neemcake in lemon crop resulted in maximum number of fruits/tree, fruit weight (g), fruit diameter (cm), fruit yield (kg/tree), juice content (%), acidity (%) and ascorbic acid (%) (Kumar *et al.*, 2011) [44]. Prabhu *et al.* (2018) [69] made an experiment on effect of integrated nutrient management in acid lime and found that 100% RDF (600:200:300) g NPK/plant/year) + *Azospirillum* (100 g/plant) + phosphobacteria (100 g/plant) + Arbascular Mycorrhizal Fungi (500 g/plant) + *Trichoderma harzianum* (100 g/plant) gave highest yield, yield attributing components and quality attributes. Integrated treatment of 75% RDF (450:225:225 g NPK) + 50 kg FYM + 500 g AM/plant + 100 g PSB/plant +

200 g $ZnSO_4$/plant was found suitable for better growth and development of acid lime (Deshmukh *et al.,* 2018) [21]. Khehra and Bal (2016) [40] made an experiment and results proved that integrated application of FYM (2 times the standard dose *viz.* 150 Kg/tree) + inorganic fertilizer (1.5 times the standard dose viz. 525g/tree N) + Azotobacter (18g/tree) gave maximum fruit size in terms of length (5.47 cm) and breadth (4.98 cm), fruit weight (63.37 g), volume (67.65 cc), maximum moisture content of peel (76.32%) and pulp (85.83%), fruit quality like highest level of juice content (43.95%), highest level of ascorbic acid (48.42 mg/100g fresh weight), maximum TSS (7.43%) and acidity (5.65%). The same combination of different nutrients also enhanced average plant height up to 9.8% (Khehra and Bal, 2014) [39]. Ghosh *et al.* (2016) [30] reported that highest level of pruning with 75% RDF + vermicompost + *Azotobacter* + Vesicular Arbascular Mycorrhiza at 6^{th}, 12^{th} and 18^{th} month after pruning resulted in highest/best vegetative growth like trunk girth (33.04 cm) and its per cent increase (2.9%), canopy volume (103.7 m^3) and its per cent increase (67.37%), number of laterals per primary shoot (10.73) and its per cent increase (64.51%) and leaf chlorophyll content (1.98%) and per cent increase (106.61%). In an experiment, Kumar *et al.* (2019) [43] found that integrated application of inorganic fertilizers in combination with organic manure and biofertilizer significantly enhanced the biochemical properties of acid lime fruits and application of 50% RDF + 75% FYM + 75% vermicompost + Biofertilizers (*Azotobacter* + 25g PSB + 10g VAM) resulted in maximum TSS (7.99 Brix), acidity (6.09%), TSS: acidity (1.42), reducing sugar (1.08%), ascorbic acid content (35.41 mg/100 ml juice) and chlorophyll content (81.61). Garhwal *et al.* (2014) found that application of 60 kg FYM along with 500g N per plant enhanced yield and quality of Kinnow mandarin fruit in sandy soils of hot arid region. Hazarika and Aheibem (2019) [35] made an experiment to study the effect of integrated nutrient management on yield and quality of lemon 'cv' Assam lemon (*Citrus limon* Burm.) and found that application of 75% N through FYM + 25% through inorganic fertilizer + *Azotobacter* + phosphate solubilizing bacteria (PSB) + potash solubilizing bacteria (KSB) resulted in highest growth, yield and improved soil quality but superior quality characters of fruits were found when *Azospirillum* was applied instead of *Azotobacter* along with 75% N through FYM, 25% through inorganic fertilizer, PSB and KSB. Integrated application of 50% NPK + 55 kg FYM + biofertilizer resulted in best growth, yield, fruit quality, improved nutritional status of Eureka lemon and increased nutrient availability of soil (Citrus, A. H., 2019) [18]. Musmade *et al.* (2009) [58] found that application of 600:300:300 gm NPK + 15 kg FYM + 15 kg neem cake per plant (10-year-old acid lime plant) per year resulted in significantly higher yield (147.65 kg/plant), better quality fruits and improved soil fertility. Khehra and Bal (2014) [39] reported that integrated use of FYM (75 kg/tree) + inorganic nitrogen (350 g/tree) + *Azotobacter* (18 g/tree) minimizes fruit cracking and maximizes fruit quality of lemon. Bakshi *et al.* (2018) [14] made an experiment to study the effect of integrated nutrient management on growth, yield and quality of kinnow and found that maximum fruit length (5.84 cm), fruit width (6.53 cm), fruit weight (188.18 g), fruit volume (191.83 cc), number of fruits per plant (165.5), maximum yield per plant (31.14 kg) were recorded when 50% nitrogen was applied as poultry manure and 50% nitrogen as urea along with *Azotobacter*. Maximum leaf and fruit phosphorus (0.19 and 0.025%) were also observed in the combination (Bakshi *et al.,* 2017) [13]. Integrated nutrient management system (use of *Pseudomonas putida* with less amount of phosphorus fertilizer) was found better effect on morphological parameters and plant nutrient uptake of citrus seedlings (Jamshidi *et al.,* 2016) [37]. Yasmin *et al.* (2020) [91] made an experiment and found that integrated application of poultry manure 3 t/ha + IPNS based inorganic fertilizer resulted in highest average sweet orange yield (7.23 t/ha) highest soil fertility status *viz.*, soil organic carbon, total N, available P, K and S content of soil. Tarai and Ghosh (2016) [84] made an experiment to study the effect of integrated nutrient management on growth, yield and quality of sweet orange cv. Mosambi and maximum growth *viz.,* canopy height, basal girth, canopy volume, highest average fruit yield (9.0nkg/plant) and superior fruit quality *viz.*, total soluble solids, total sugar, TSS: acid ratio, vitamin C content of fruits, found when 200 g nitrogen, 75 g phosphorus and 150 g potassium along with 2.0 kg of neem cake were applied in integrated manner. This integrated application of nutrients also resulted with foliar concentration of 2.3% N, 0.12% P and 1.3% K, respectively. Huang *et al.* (2021) [36] reported that in acidic soil integrated nutrient management helped in root development and nutrient uptake in pomelo leading to maximize crop productivity.

Conclusion

Citrus, one of the important fruit crops in the world, requires proper nutrient management for increased quality yield. Efficient nutrient management is prerequisite for quality higher production of citrus. Injudicious application of chemical fertilizers for a long time may deteriorate both soil health as well as yield of crop. Though nutrients can be supplied through organic manures, sole application of organic manures have some limitations like imbalanced nutrition, less fertilizer use efficiency, not cost effective and comparatively less production. Biofertilizers, can play an important role in increasing citrus yield by maintaining soil fertility. Sustainable growth, yield and quality of citrus along with soil fertility maintenance can be achieved through integrated nutrient management approach.

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