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Nutrient management for avocado (*Persea americana* miller)

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ABSTRACT
Achieving full yield potential of avocado plantations is of great challenge. Among the causes of poor crop yield, inadequate nutrient management is majorly considered apart from climate, cultivar, etc. The objective of the manuscript was to analyze the nutrient requirement of avocado under different growth stages and appropriate nutrient management practices for avocado. The nutrient requirement of the avocado may vary according to its seasonal growth pattern, soil conditions, cultivar type, and yield potential, etc. Therefore, synchronizing fertilizer nutrient supply on the basis of crop demand can improve fruit yield and quality, and enhance nutrient uptake, thereby reduction of nutrient losses could sustain the production system from the environmental degradation. The nutrient requirement of an avocado cultivar at different growth stages can be formulated based on periodic soil analysis, monitoring leaf nutrient concentration at different growth stages, and total nutrient removal by harvested fruits, and yield potential. Standardization of the best nutrient management practices will be useful in improving yield and quality of avocado and farm income.

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Avocado nutritional value and quality; fertilization; mineral nutrient deficiency/toxicity; nutrient removal and partitioning; sustainable crop yield

Introduction

Avocado (*Persea americana* Miller) is a native fruit tree of Mexico and Central America (tropical America) and was mostly distributed in western hemisphere before 15th century. Due to its nutritional quality and economic value, it has been introduced almost across the world. The avocado production in 2016 was 5.57 million metric tonnes (MMTs) and Mexico alone had contributed 1.89 MMT (34% total avocado production). Domnican Republic, Indonesia, Peru, and Colombia are other significant contributors and collectively accounted about 1.67 MMTs (30% of world production) (FAOSTAT 2017). In the last century, it has been introduced to tropical and subtropical countries such as Asian countries and Sub-Saharan Africa. Despite long history since introduction the avocado production in Asia is limited but some of the countries like China, Vietnam, and Korea. Avocados are considered as good preventer of soil erosion and are majorly grown in high altitude hilly areas. Particularly avocados are popular in Sikkim the northern Himalayan State of India and are planted on the hill slopes between 800 and 1600 m above mean sea levels. In addition, avocados are grown on the Western Ghats of India in scattered mainly in Karnataka, Kerala, Tamil Nadu, and Maharashtra (Figure 1). Avocado is planted mainly in coffee-based cropping systems as one of the mixed crops (Tripathi and Karunakaran 2013; Tripathi et al. 2016). As coffee, a shade-tolerance crop, needs shade trees for its higher production,

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Figure 1. Avocado plantations at Research Farm of ICAR-IIHR-CHES, Chettalli in Coorg District, Karnataka, India.

producers consider avocado as one of the important shade trees while also benefiting a lot from the sale of the avocado fruits.

The avocado cultivation has gained an overwhelming popularity from the last one decade due to its nutritional properties and high market demand. Generally, avocado is grown sporadically in backyards or home gardens or as an integral component of coffee-based mixed system. The limitations of avocado cultivation are unavailability of improved grafted plants and subsequently lacking of information on suitable horticultural practices like water, fertilizer, and other intercultural operations. Further fruit setting is another issue due to poor pollination, on the other hand, high fruit setting lead to reduction in fruit size. Therefore, optimum fruit set to be achieved through introduction of pollinators in the avocado orchards. Most of the avocado orchard in India is raised with seedlings that germinated from seeds, due to its poly-embryonic nature, genetic makeup of each plant and their nutrient and water requirements and yield potentials may vary. In this regard identification and release of promising lines through vegetative propagation with known yield potential can be beneficial. Further its water, nutrient and other intercultural requirement could be optimized to achieve maximum yield potential. Though information on the above aspects is plenty in abroad but is meager in India. So generation of scientific information on fertilizer requirement of the avocados based on their yield potential and nutrient removal across the agro-climatic regions will be very useful to growers to adopt the recommended management practices for enhancing crop productivity, quality as well as farm income. In this connection, it is reviewed in the manuscript on nutrients requirements of avocado. The yield potential of crop may be affected due to different factors such as cultivars, climatic conditions, nutrient management, etc. The crop phenology may totally different in different region. Consideration of seasonal or crop growth stage wise nutrient requirements of crops is essential to develop the effective fertilizer management practices. Nutrient absorption of avocado trees vary accordingly to its seasonal growth patterns, thus synchronizing fertilizer nutrient supply accordingly to meet the crop requirement can improve fruit yield and quality, and enhance nutrient uptake, thereby reduction of nutrient losses. Therefore, it is inevitable to standardize nutrient requirement of identified avocado cultivars under different regions for higher productivity and sustainability.

Nutritional value of avocado fruits

Among the fruits, Avocado is rich of nutrients and can play a major role and contribute to the Modern World human diet. The avocado pulp is rich in fat (30%) and proteins (4%), but the carbohydrates content is low. Avocados have the highest energy value of any fruit and contain good

Table 1. Chemical Composition of Avocado Fruit (per 100 g of edible portion).

I. General composition	g or cal	III. Minerals	mg
Energy value	245	Calcium	10.0
Protein	1.72	Chlorine	11.0
Fat	26.4	Copper	0.45
Total carbohydrates	5.13	Iron	0.60
Crude fiber	1.81	Magnesium	35.0
II. Vitamins	mg	Manganese	4.21
Vitamin A as carotene	0.17	Phosphorus	38.0
Ascorbic acid	16.0	Sodium	368
Niacin	1.10	Sulfur	28.5
Riboflavin	0.13		
Thiamine	0.06		

Source: USDA (2011).

amount of several vitamins and minerals (Table 1). There is a little variation in the nutritional compositions among the cultivars. For example, about 68 g Hass avocado servings consist of 4.6 g dietary fiber, 0.2 g total sugar, 345 mg K, 5.5 mg Na, 19.5 mg Mg, 43 µg vitamin A, 6.0 mg vitamin C, 1.3 mg vitamin E, 14 µg vitamin K1, 60 mg folate, 0.2 mg vitamin B6, 1.3 mg niacin, 1.0 mg pantothenic acid, 0.1 mg riboflavin, 10 mg choline, 185 µg lutein/zeaxanthin, 57 mg phytosterols, 6.7 g high-monounsaturated fatty acids, and 114 kcal energy (Dreher and Davenport 2013). The avocado fruit fat is largely used in cosmetics industry and is of almost as similar to olive oil in composition. The avocado oil consists of monounsaturated fatty acids (71%), polyunsaturated fatty acids (13%), and saturated fatty acids (16%). The unsaturated fatty acids help to promote healthy blood lipid profiles. Moreover, they enhance the bioavailability of fat soluble vitamins and phytochemicals from the avocado and/or other fruits and vegetables, naturally low in fat, which are consumed along with avocados. Avocado is consumed as fresh fruit or used in sandwich fillings or in salads. Avocado pulp can be preserved in freezer and used in ice creams and milk shakes. Peel extracts of immature fruits particularly of Green cultivar is having antifungal properties. Avocado consumption generally preferred for cardiovascular health, weight management, and healthy aging.

Avocado cultivation across world and in india

Avocado has been widely cultivated in more than 50 countries across the world. Avocado is largely cultivated in Mexico with an area of 1.68 lakh hectares and production of 1.47 million tonnes. Other major producing countries are Chile, Dominican Republic, Peru, Colombia, US (California [about 59,000 acres] and Florida), Kenya, Brazil, Rwanda, China, and Indonesia (Table 2). Other minor producing countries (<1 lakh tonnes) include Guatemala, Spain, Venezuela, Israel, South Africa, Congo, Cameroon, Haiti, Australia, New Zealand, etc.

In India, the avocado was introduced in 1920s (the early part of the 20th century) from Sri Lanka. The avocado is not a common commercial fruit crop in India and is grown in a very small scale and in a scattered manner in Karnataka, Kerala, Tamil Nadu, and Maharashtra in the south-central India and in Sikkim, the eastern Himalayan state (Ghosh 2000). The hot dry winds and frosts of northern India is not favorable for cultivation of this crop. Generally, it is grown in tropical or semitropical areas and subtropical areas that experience some rainfall in summer and/or in humid. Mainly avocados are grown in hill slopes to control the erosions. As the plant is shallow rooted with most of the feeder roots are distributed in top 6 inches, the soil should be fully aerated. Soil should be neutral or slightly acidic in reaction, alkaline condition are not suitable for the crop, however, by supplying sufficient organic matter soil pH can be reduced before planting.

Table 2. Avocado production – 2016.

Country	Production (million tonnes)
Mexico	1.89
Dominican Republic	0.60
Peru	0.46
Colombia	0.31
Indonesia	0.30
World	5.57

Source: FAOSTAT (2017).

Nutritional disorders in avocado

Due to its high yield potential, avocado requires a large amount of nutrients. Low soil fertility status and inadequate supply of nutrients affect the growth and development of the crop and reduce the crop yield. There are many nutrients disorders reported in avocado (Figure 2).

N deficiency: The N deficiency mainly affects the older leaves. The affected leaves are become small, narrow and pale green because of insufficient N to the tree. The leaves rolled slightly upwards. The plants are also smaller.

K deficiency: Due to insufficient availability of K caused by imbalance of Ca, Mg, and K. The symptoms are yellowing of margin to veins and browning of affected portions.

Mg deficiency: Insufficient available Mg to tree due to imbalance of Ca, Mg, and K and very common in acid sandy soils. The Mg deficiency symptoms appear in older leaves by progressive yellowing from tips and margins to main vein. A dark green band along the main veins is noticed.

Zn deficiency: Mainly due to alkaline soil pH and excessive phosphorus in soil. Uneven blotchy yellowing between the veins are the main symptoms. With a very mild deficiency, the distance between the leaves is reduced and look like feather duster, but minimal leaf distortion and size reduction. Leaf distortion and size reduction is prominent in severe deficiency. Under very severe deficiency incidence of yellowing, small and distorted young leaves and also affect fruits.

Mn deficiency: The Mn deficiency in avocado causes color loss of leaves generally between the veins and become pale green. The deficiency occurs mainly due to much use of liming material and in coarse textured sandy soils.

Fe deficiency: This is major problem in high sodic soils (pH > 7.5), with elevated soil Mn levels, also result of excessive use of liming materials and/or phosphorus fertilizer. The affected upper leaves become completely yellow or white color with the green veins. The similar symptoms also appear in lower young leaves of summer flush, whereas the leaves of spring flush remain green.

B deficiency: Affected trees are yellow and stunted. The affected leaves are becoming distorted and holes also appear in leaves and leaf holes symptoms are more prevalent in the spring leaf flush. B deficiency also affects main stem and branches, flowers and fruits (Whiley et al. 1996). It also causes sickle-shaped fruit with navel-like lesions. Adequate foliar B concentrations in avocado tree leaves ranged from 40 to 80 mg kg^{-1}, respectively. The misshapen of fruit is associated with low mean foliar B concentrations 20 mg kg^{-1} which was recorded at less than 10 avocado farms in Kona area during Fall 1989, It seemed to be much below the adequate B levels of 40 mg kg^{-1} (Whiley et al. 1996). Further B toxicity in avocado occurs when leaf B concentration reach beyond 180 mg kg^{-1} levels.

Salt injury: It causes fairly even burning of margins and extends to the veins mainly due to application of salty irrigation water and fertilizers containing high Cl.

Mn toxicity: Due to excess uptake of Mn caused when soil available Mn level is higher than 40 ppm and soil pH lesser than 6. Under water logged condition and continuous application of ammonium fertilizers. In between the leaf veins, irregular yellowing with small dark spots and sometimes burning of tip particularly in summer leaf growth was reported.

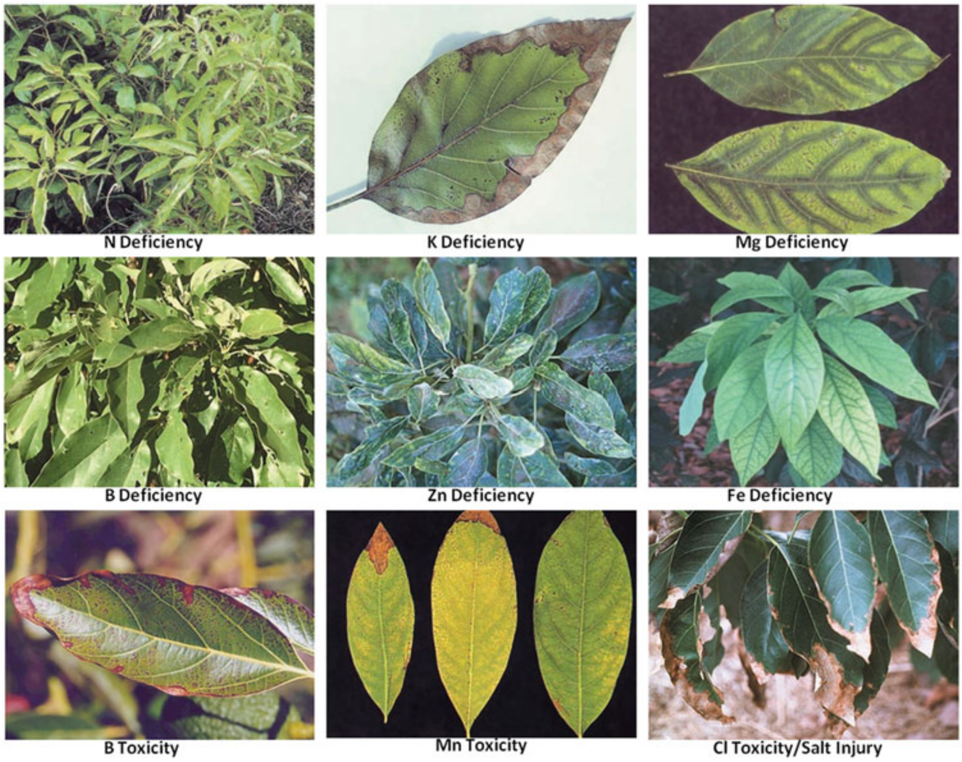

Figure 2. Mineral nutrient deficiency and toxicity symptoms in avocado.

B toxicity: Higher uptake of B and mainly because of excess and uneven application of B. the b toxicity symptoms are leaf margin burning with defined edges, pale yellowing areas of burnt portion with innumerable tiny dark spots and leaf fall in case of acute B toxicity.

Nutrient removal of avocado

Economic gain of avocado production is estimated taking into account of total fruit yield per tree, size and fruit quality. To achieve these, information on nutrient removal along with proper fertilizer management is required. The nutrient removal or requirement may vary among the cultivars due to its yield potential. Further soil nutrient status can also play a major role in fulfilling the nutrient requirement of crops. Cultivar specific balanced fertilizer programs are critical for augmenting fruit yield and quality. But information on agro-production techniques of avocado cultivation in India is not available. Moreover, the better estimate of fertilizer requirement is achieved through analysis of fruit nutrient content in correlation with soil and leaf nutrient content.

The nutrient removal of avocado cultivars (100 kg fruit) ranged from 150–300 g N, 50–110 g P_2O_5 and 300–500 g K_2O, 7–10 g Ca, 15–30 g Mg; 20–35 g S, 0.2–0.5 g Zn and B, 0.2 g Cu, 0.5–1.0 g Fe (Garciana and Ferrat 2001) (Table 3). Gentile et al. (2016) studied the nutrient removal of avocado fruit in Central Highlands of Kenya and based on that they had calculated the organic manure required to fulfill the crop demand. Mere supplying of the amount of nutrients removed by harvested produce is not sufficient to sustain the production system and adequate nutrients also supplied to maintain basic soil fertility.

Leaf analysis is considered as important procedure to understand the nutrient status and requirement of plants instead of soil analysis. Therefore, it is very important to follow proper

Table 3. Nutrients removed by an avocado crop based on a 10 t ha^{-1} yield.

Nutrient	Value (kg ha^{-1})	Nutrient	Value (g ha^{-1})
N	11 to 41	B	401
P	2 to 10	Fe	47 to 212
K	20 to 61	Zn	45 to 156
S	4 to 8	Mn	9 to 47
Ca	2 to 7	Cu	10 to 58
Mg	4 to 8		

Source: Rosecrance, Faber, and Lovatt (2012).

sampling technique to harvest required information from leaf analysis. The samples should be collected during August–October period and 5–7 months old fully matured leaves from non-bearing branches. Generally, 35–45 leaves from a single tree covering all the directions and separate samples have to be collected from blocks with different soils, cultivars, and yield levels. The optimum nutrient concentration in leaf tissues is 2.0–2.5% N, 0.1–0.25% P, 1–2.0% K, 1.5–2% Ca, 0.5–0.7% Mg, >50 ppm Fe, >80 ppm Mn, >30 ppm Zn, >7 ppm Cu, >20 ppm B, and Na and Cl should be lesser concentration.

Other studies reported nutrient accumulation and distribution pattern in the 'Hass' avocado fruit for a period of 2 years cycle and found that dry matter and nutrient accumulation followed a double sigmoid curve in California and growth was ceased during winter season (December–March) and might have differ from tropical areas. In tropical areas only a single sigmoid growth curve was recorded. Accumulation patter differed for the individual nutrients. In case of N, P, Mg, and S, 50% total fruit nutrient accumulation happened in the first year and another 50% in the second year. On the other hand, 30% of B and K accumulated in the first season and 70% in the subsequent growing season. Whereas, fruit Ca content, totally contrast from other nutrients, followed a single sigmoid pattern. First five months fruit Ca content has increased, and then remained constant throughout the crop growth period until harvest in the next year (Rosecrance, Faber, and Lovatt 2012). Henceforth meeting total nutrient removal by harvested portion only is not sufficient, rather standardizing nutrient scheduling accordingly to match nutrient accumulation pattern at different growth stage is inevitable to achieve higher crop yield and quality.

Nutrient management in avocado

In order to develop appropriate fertilizer management strategies for any crop, it is inevitable to understand seasonal nutrient requirements of a crop. The phenological growth stages and their nutrient requirements are very important for nutrient scheduling. In Table 4, the length of growth phases with nutrient and irrigation scheduling for Hass cultivars had been recommended in Chile. Matching fertilizer application based on crop demand can benefit the farmers via improving fruit size, yield and quality. Furthermore, it encourages higher nutrient absorption and accumulation in plants, thus lessen the potential for nutrient loss to the environment. The amount and frequency of fertilizer nutrients applications of different farms and even within a farm vary widely due to cultivar type, age of plant, soil nutrient status, etc. For instances, the nutrients applied to matured avocado plantations ranged from 16–131 kg N, 1–33 kg P and 16–131 kg K per acre, respectively with 2–6 times applications in an annum. Furthermore, it was recommended that nitrogen, phosphorus, sulfur, magnesium, zinc, and iron had to be supplied every year in spring season after full bloom; K and B during the later stages (second season) of fruit development, and Ca during early stage of fruit development (Rosecrance, Faber, and Lovatt 2012).

Under rainfed tropical situations, site-specific fertilization in Nayarit region of Mexico had benefited the "Hass" avocado growers through enhanced yield and fruit size (Garciana and Ferrat

Table 4. The length and season of phenological stages of the Hass variety viz-a-viz management schedule.

Phenological phase	Length (days)	Fertilizer and irrigation
Floral bud break	60	Yes
Flowering to fruit set	60	Only irrigation
Fruit set to small fruit	90	Yes
Small fruit to final caliber	120	Limited
Harvest	30	Yes

Source: http://sqmspn.com/en-US/productos/nutricionvegetaldeespecialidad/cultivos/palta.aspx.

Table 5. Fertilizer Schedule for Avocado in Sikkim.

		Age of plants (in year)						
Manure/Fertilizer (kg tree^{-1})	Time of application	1st	2nd	3rd	4th	5th	6th	7th & above
FYM	February/March	–	10	20	30	40	50	60
Urea	March/April	0.10	0.15	0.20	0.25	0.30	0.35	0.40–0.60
	September/October	0.10	0.15	0.20	0.25	0.30	0.35	0.40–0.60
KCl	March/April	0.10	0.20	0.30	0.40	0.50	0.60	0.70–0.80
Bone-meal	March/April	0.30	0.40	0.50	0.60	0.70	0.80	1.00–1.50

Source: Upadhyay and Srivastava (1996).

2003). Upadhyay and Srivastava (1996) had recommended a tentative fertilizer schedule for Sikkim with 60 kg FYM and about 500 g N (two equal split during March/April and September/October) 250 g P_2O_5 and 450 g K_2O per tree (Table 5). However, these recommendations were not based on the systematic periodic observations or a result of scientific fertilizer experimentations. Furthermore, information on phenological growth stage wise nutrient requirement and time, amount and proportion of nutrients to be supplied at each stage is still lacking. Therefore, the fertilizer recommendation of avocado has to be refined or modified accordingly to meet the crop requirement. In addition, impact of integrated nutrient management or organic cultivation of avocado has to be focused.

Apart from major nutrients, micronutrients were also equally crucial for plant growth and development. Application of micronutrient at right time, right method and right quantity is very important to harvest its beneficial effect. Foliar application of boron at flowering period of avocado could have some benefits. The B absorption was mostly happened through flower structures rather than leaves, so time of application should be given due consideration. Further application of urea and B alone and their combinations to 'Hass' avocado was noticed via four bloom studies under glasshouse and field conditions and results revealed that the efficacy was more when they are applied in initial stages flowering i.e. earlier than full panicle development and anthesis. The pre-bloom urea spray improved ovule viability, but not in case with B treated flowers. However, the number of pollen tubes was more in B treated flowers. But combine application of urea and B yielded negative results even urea was applied 8 days after B application (Jayanath and Lovatt 1995). In contrast, when leaf N and B were below the critical levels (1.71% and 23 ppm, respectively), foliar application of multi-nutrients including N and B at first flower starting to open improved fruit yield and size in 'Hass' trees and not effective when applied during pre-bloom and fruit (Mans 1996). Therefore, spraying at right stage of flowering is very important. At the same time, the key advantage of foliar spray is enhancement of boron concentrations in specific targeted organs. Under severe chronic deficient conditions, it was insufficient to supply B through leaves to remedy the affected trees. Whiley et al. (1996) evidenced that foliar application of B during flowering did not show significant effect on fruit yield regardless of an increase in fruit set. The deficient trees might have required B for its root growth and foliar applications would not supply/translocate sufficient nutrient to roots. On the other end, soil applications had dramatically improved the health of boron deficient trees. Similarly, Fe chlorosis in avocado orchards could be overcome through soil application of different Fe compound or chelates and on a commercial scale foliar spray of Fe in avocado is not successful (Kadman and Lahav 1972). Gregoriou, Papademetriou, and Christofides (1983) had demonstrated that soil application of Sequestrene 138 Fe-EDDHA was the fast, efficient and successful practice to manage trees with iron chlorosis on calcareous soils.

Moreover, avocado trees found to be less efficient in absorbing mineral elements through their foliage (Kadman and Cohen 1977). Yet foliar application of micronutrient elements in deficient avocado orchards was common practice across the avocado growing areas of the world. For example, In Israel, avocado growers generally spray micronutrients for their orchards; however, there was no significant improvement noticed in leaf and fruit nutrient concentration or fruit yield and the same has also proven through experimental studies. Because penetration or entry of zinc through leaves was very meager and thus supplying Zn to avocado through foliar means is practically irrelevant. Similarly, using Zn-65 isotope for foliar application studies of avocado in Queensland orchards, Whiley and Pegg (1990) revealed that spraying zinc to avocado foliage was highly unsuccessful. Further they found very poor response of leaf absorption (less than 1% of applied Zn) due to foliar application of Zn in greenhouse avocado seedlings. The translocation of Zn from applied spot to adjacent leaf spots or into other leaves was very meager. Price (1990) reported that the amount of absorbed Zn from foliage could not meet plants requirement specifically in avocado. Because of above mentioned issues of foliar zinc application, soil application of Zn or through fertigation might be trustworthy practice to correct zinc deficiency in avocado on calcareous soils (Crowley et al. (1996). For instances, two years experiments with 'Hass' cultivar on a calcareous soil (pH 7.8) in California, Crowley et al. (1996) found that soil application or fertigation of $ZnSO_4$ (@3.2 kg tree^{-1}) was very effective among the various treatments such as soil application, fertigation, foliar application and trunk injection. The soil and fertigation Zn application methods had improved the zinc content of leaf to the extent of 75 and 90 mg kg^{-1}, respectively. Among these treatments, while new growing points of roots and shoots must require Zn for its growth and development, it is essential to supply Zn to soil to enhance the uptake through the roots.

Conclusion and future line of research work

Avocado is a perennial fruit tree species and the growing pattern of the avocados may vary from other fruit trees. The phenological growth stages and their length, nutrient requirement and yield potential can vary among cultivars. Adoption of phenological crop management and proper leaf sampling techniques can improve the plant nutrient management. Optimum leaf nutrient levels should be known for better fertilizer management. Bringing perfection to irrigation and fertilizer management practices could greatly reduce the ground water pollution by reducing leaching of nutrients. Nutrient removal and accumulation pattern of different cultivars should be widely studied across the agro-ecological regions. In addition, periodic monitoring of leaf and soil nutrient status of the avocado orchards could result in better understanding of nutrient requirement. These understandings will be very useful in development of nutrient management scheduling of avocado orchards for optimizing crop yield, quality, and nutrient use efficiency and in fetching higher farm income. The future thrust areas are as follow:

- The major constraint in avocado cultivation is difficulty of obtaining high quality seedlings. Therefore, research work is needed on development of good quality and high yielding avocado seedlings. The advanced breeding techniques such as tissue culturing and mutation breeding may be employed.
- Biotic and abiotic stress tolerant avocado rootstocks can also be identified for sustaining productivity under unfavorable conditions and its wide spread cultivation in disadvantageous areas.

- Crop phenology and growth pattern may vary under different climatic conditions and can be focused under various agro-climatic conditions as well as the responses of the crop to climatic change need to be studied.
- Fruit setting is considered as a major issue in avocado, effect of introduction of pollinators on fruit setting, fruit size, yield and quality should be given more attention. Optimum fruit setting for higher yield and quality may be worked out.
- Developing or refining leaf nutrient standards/norms needs to be focused for understanding the nutrient uptake, transportation and re-deposition in edible portion. Henceforth periodic monitoring of leaf and soil samples to be done to establish correct standards for achieving higher yields.
- Irrigation research should focus on identifying advanced practical and cost-effective soil moisture monitoring equipment and developing evapo-transpiration or crop factors for irrigation scheduling.
- Improper cultural practices and higher production costs are the critical issues. Standard fertilizer and irrigation scheduling at different growth stages need to be worked out.
- Cultivar specific and site specific nutrient scheduling and region wise tailor made customized fertilizer should be developed.
- Organic cultivation of avocado should be given due attention and improvement of fruit quality and overall orchard health under organic management needs to be focused.
- Dynamics of bio-ecology of avocado orchards under different agro-climatic condition might be studied to understand the ecological changes for sustaining the production system.

Disclosure statement

No potential conflict of interest was reported by the authors.

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