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SUSTAINABLE MANAGEMENT OF MANGO NUTRITION FOR BETTER YIELD AND QUALITY

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ABSTRACT. Optimum supply of macro and micronutrients is of critical importance in improving the yield and quality of horticultural crops. Alike, the quality and yield of mango plants significantly increase by balanced application and uptake of macro and micronutrients. However, soil type and characteristics are important factors that directly influence the bio-availability of these nutrients to the plants. In addition, variability in climate has an impact on mango yield in the current scenario. Many scientists have found that mango cultivation in saline soils is a major obstacle to achieving the desired yield and improving quality. Overdose of fertilization is the major factor for the development of saline soils, furthermore, rise in climate temperatures is also a major factor. Therefore, to overcome this problem, nutrient management and the use of balanced fertilizer are the important factors to be controlled. Thus, this review focuses on the performance and importance of essential macro and micronutrients to improve the yield and quality of mango fruits. To understand the effective use of macro and micronutrients, the positive and negative impacts of the nutrients are explained. It is suggested that analyzing the soil, mango fruits, and mango plant leaves for their nutrient status can be useful to formulate fertilization strategies for higher fruit production and quality. Research and development, along with agricultural extension, should focus more on introducing genetically effective mango varieties to improve nutrient and water utilization efficiency.

Keywords: nutrient management; fruit quality; mango production; yield.

INTRODUCTION

Mango (*Mangifera indica* L.), most cultivated fruit in tropical region, and it is categorized in the plant family named as "Anacardiaceae" and it is found to be of South East Asia

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origin (Douthett, 2000). Mango is the second major fruit after citrus in Pakistan and is widely known as 'king of fruits' (Usman *et al.,* 2003). To determine the quality of mango fruit, the size, total sugar contents, acidity and β-carotene, total soluble solids (TSS), ascorbic acid, sugar-acid ratio and golden yellow color must be observed.

Owed to disease, insufficient nutrients and improper management of fertilizer, mango fruits produce low yields and quality that are unsatisfactory for export or to be sold locally (Gurjar *et al.,* 2015). Further, higher physical damages and deteriorated quality have been observed in mango farms. Imbalanced fertilization, including micronutrients, improper cultural practices and inadequate handling of trees result in reduced quality farms. In accordance with horticultural experts, it is necessary to use basic nutrients along with micronutrients to get the best quality of mango fruit. The micronutrients are often used as foliar application to reduce nutritional deficiencies and to improve the quality of mangoes (Sankar *et al.,* 2013). Although, owing to the type of soil and climate, Pakistan is considered suitable for good quality and production of mango fruit; however, yet, the country is far behind achieving the potential yield. There are many factors which influence the sustainability of mango farms and affect the quality and production of mangoes, such as soil characteristics, climate circumstances and fertilization stratagems, which are being discussed in this review.

Soil type

Soil characteristics directly influence the mango cultivation. Plants use soil as inert medium for growth. Nutrients availability is regulated in soil through root growth and soil effects the functional activities of the plants. Several types of soil, as of low fertility and low-growing soils to well-fertile deeper soils (Red Cross Nosium), can be used for mango growth (Dirou, 2004). Though, cultivation and growth of mango is influenced by the physical and chemical characteristics of the soil. Soil of less fertility, light and of good drainage properties are deliberated as good soils for mango production because mango fruit cannot produce good fruit color in highly fertile soils (Madonsela, 2019) and such soils can also have nutritional problems (Paul and Duarte, 2011). The soil which are sandy clay, flat and deep, with sufficient organic matter, is considered suitable for mango plantation (Magalhaes and Borges, 2000). In addition, sandy loam, sandy, lateritic and alluvial soils are appropriate for the cultivation of mango trees. Moreover, soils with a considerable depth of 2-2.5 m, having a pH range from neutral to alkaline, with specific value point as 5.5-7.5 (Bally, 2006), are ideal for growing and cultivating good amounts of organic manganese (Chowdhury and Mehta, 2010). It was reported that cultivation of mango trees on sandy loam and loam soils advantages to improve the skin color of mango fruit during the period of ripening and reduces the rate of mass thawing of the fruit, cf. soft nose or jelly seeds (Bitange *et al.,* 2020). In addition, mango trees have also been reported to be sensitive to sodic and saline conditions (Madonsela, 2019). The hardpan of the soil under the subsoil surface layer or sometimes known as plow layer should be broken as it reduces the mango tree root infiltration into the soil (Paull and Duarte, 2011). Therefore, for the high yield and quality of mango fruit, the selection of suitable soil is a main factor to consider.

Soil pH

Trees of mango can withstand a pH range from 5.5 to 7.5 because they can tolerate alkaline conditions (Bally, 2006). It has been reported that at high pH, the growth and quality of mango reduces because of the unavailability of trace elements, which adversely affects the quality of the mango fruit. Low soil pH reduces the availability of nutrients for trees. When this happens, it is not advantageous to apply more fertilizer to the trees, because it often leads to leaching and fixation of the nutrients. To reduce this problem, it is necessary to add lime to the soil of fruit plants to lower the pH of the soil. Therefore, soil sample for the analysis of basic parameters including soil pH in the laboratory is important. So that we may know the requirement for the establishment of garden. Regular cultivation and production of mango has been reported by Madonsela (2019), in calcareous soil type (> 38% $CaCO_3$), according to pH 9 in Israel. According to Usman *et al.* (2003), pH ranges from 5.5 to 8.7 has been reported for mango production in Pakistan. Soil having characteristics of stickiness, waterlogging conditions and hardpan below subsurface should be avoided to obtain higher mango production. Likewise, the pH of the soil helps in selecting criteria for establishing mango plantation.

Soil salinity

Owing to the moderate tolerance of mango plants against saline conditions, soil salinity is the major concern for reduced mango fruit production (Elsheery *et al.,* 2020). Leaves tip and edge burning and leave curling of mango plants occur in severe saline conditions, subsequently leading to plant death. The effect of salinity in growth and development cycle of mango trees is the same and their symptoms are same as appear in plants other than mango trees (Elsheery *et al.,* 2020). The rate of transpiration in mango trees dropped sharply when the salinity period increases maximum (Schmutz and Ludders, 1993). Photo assimilation process in mango plants has been found to susceptible for higher salinity levels (Schmutz, 2000). However, the extent of salinity tolerance in mango rootstock and fruit production has not been studied well (Maas and Grattan, 1999). Therefore, a diversity in the mango varieties should be induced to develop salt tolerant rootstock (Dinesh, 2003). Nevertheless, a calculated data is required containing critical values of salinity in soil and water, for obtaining the required quality and production of mango fruit.

Climatic conditions

Temperature and available water are considering as important factors that influence the mango production by affecting the vegetative growth, initial flowering and occurrence of disease in the mangoes (Madonsela, 2109; Davenport, 2006). Ideal temperature range, which is required during growth season is 24-30^{o}C, with 890 to 1015 mm rainfall and maximum humidity. The areas receiving inadequate (254 mm) to heavy rainfall (2540 mm) are also recognized appropriate for mango plantation. During flowering, rainfall is dangerous owing to reduced pollinating activities (Choudhary and Mehta, 2010).

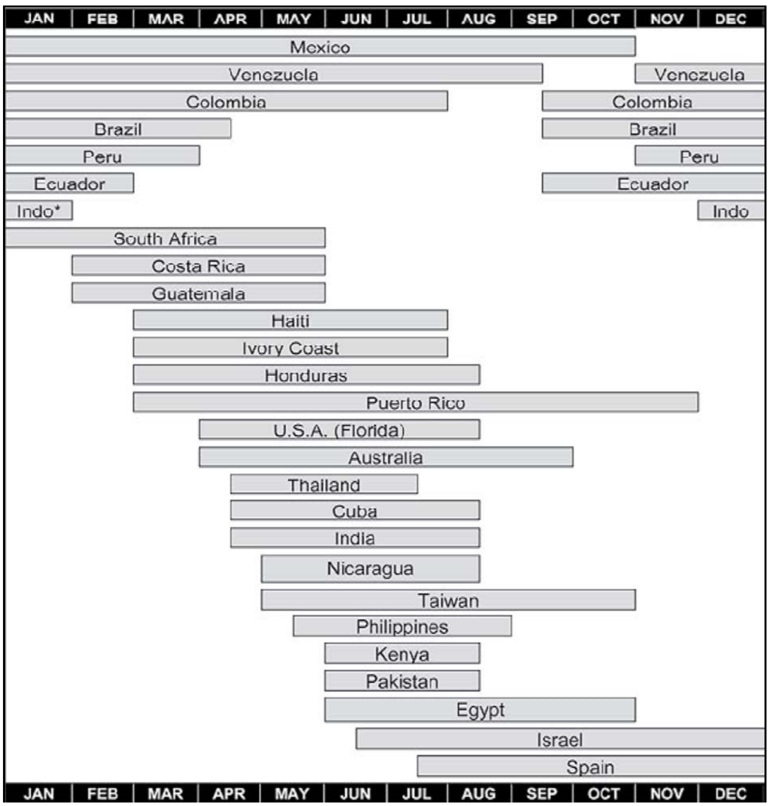

Figure 1 - Data of several countries with different seasons (Information source: Saúco, 2004; Siddiq *et al.*, 2017)

Mango trees have the capability to withstand flooding conditions. Nonetheless, rain is needed for the initiation of flowering and fruits but it is not possible to initiate flowering without dry span. Internal osmotic pressure of the plant helps to keep the leaves and lactiferous cells turgid (Fisher *et al.,* 2012). Due to the deep root system, by which plants absorbs nutrients and water from deep into the soil, makes the mango trees drought tolerant (Paul and Duarte, 2011). Dry periods are necessary to increase flowering in the mango plant (Paul and Duarte, 2011). The climatic condition in different countries varies due to different time zone; the *Fig. 1* justifies the mango plantation.

Fertilization of mango plants

Young trees

A pit size of 60 × 60 × 60 cm is recommended for the mango plantation. Fertilizer dosage recommendation for the aforementioned pits varies from area to area. The fertilizers dose required in these pits depends upon the qualitative analysis of the soil and the volume of soil existing in the pits. Mango plants can grow in the soil of low fertility, but a sufficient amount of fertilizer added to the soil and uptake nutrients helps the better plant growth and mango fruit. To maintain the plant health and proper growth of plant canopy, the fertilizer is applied in the initial stages of plant growth. The first application of fertilizer is generally applied according to the soil analysis. *Table 1* shows that a small dose of fertilizer is applied to young mango plants. The nitrogen (N), phosphorus (P) and potassium (K) are applied twice a year. However, P and K are used only if they are insufficient. The recommended dosage of these fertilizers should incorporate into the soil or it should be applied to the plant rows through broad casting method of fertilizer application (Andrade, 2004; Sousa *et al.,* 2004). The fertilization with macronutrients should be proceeded to the plants at plantation stage or should be applied on various growth stages depending on the analyses of the soil and mango leaves.

The fertilizer impacts on the plants varies with many factors, including method and time of application, source of fertilizer, climatic conditions, variety of cultivar, moisture conditions of soil and growth rate and linear condition of tree. Stassen *et al.* (1999) stated that a plant of 6 years of age contains 29.6% of P in the dry matter of plant leaves. Similarly, 16.6% of P was found in new branches, 14.9% P was investigated in fruit, 11.7% P in wood, 9.3% P inside the bark and 17.9% P was inside the roots. It was discovered that a large portion of P was found within leaves of the plants, while 70.4% of P was found in the rest of the vegetative plant parts. In the South Pacific areas, young mango plants were supplied with NPK dosage of 0.4-0.2-0.2 kg^{-1} $tree^{-1}$ $year^{-1}$ during the age of 1st to 5th years, whereas, 0.7-0.7-0.7 kg^{-1} $tree^{-1}$ $year^{-1}$ was applied later on. The recommended NPK dosage for plants of 1-4 years' age was 0.4-0.2-0.2 kg^{-1} $tree^{-1}$ $year^{-1}$ and for 5-10 years' age was 1.3-0.55-0.85 kg^{-1} $tree^{-1}$ $year^{-1}$ in the North Pacific region. In Taiwan, the amount of fertilizer is applied in two equal splits, *i.e.,* in marble and after harvest. The fertilizers are applied though broadcasting, side coating, banding and hole application. The dose of N, P, and K fertilizers increases with increasing age of the plants.

Table 1 - Fertilization of nitrogen (N), phosphorus (P) and potassium (K) to young mango trees in various countries

Country	Tree age (year)	Amounts of nutrients (g plant^{-1} year^{-1})			Reference
		N	P	K	
Brazil	2-3	210	160	120	Silva *et al.* (1996)
China	7-9	400	125	320	Xiuchong et al. (2001)
India	7-9	700	500	700	Choudhary and Mehta (2010)
Queensland, Australia	2	400	500	360	Sanewski (1991)
Mexico	1-4	200	100	100	Crane *et al.* (2009)
Southern Pacific region	1-5	400	200	200	Crane *et al.* (2009)
Northern Pacific region	1-4	400	200	200	Crane *et al.* (2009)
Taiwan	1-2	150	20	120	Crane *et al.* (2009)

Bearing trees

Mango fertilizer is essential for the suitable health of trees, the initiation of flowers, the onset and avoidance of alternative effects. Excessive use of fertilizers can lead to continuous vegetative growth of bearing mango trees and can cause reduction in flowers and lower fruit production and also the incidence of physical damages in mango fruit may be increased (Nguyen *et al.,* 2004).

Similarly, improper application of fertilizers in mango plants can induce deficiencies and toxicities of nutrient and can result in stunted growth. Thus, fertilization strategies must be managed according to the need of the plants in order to obtain higher production of mango fruits (Crane *et al.,* 2009).

Less than 30% of the mango farms in the Central Pacific regions are supplied with fertilizers. Crane *et al.* (2009) reported that 86% mango farms are fertilized in South Pacific regions, whereas, 56.7% are supplied once a year, and 39.5% are supplied with fertilizers twice a year. The mango orchards, where fertilizers are used regularly, there has been a noteworthy difference in time, content, quantity and source of fertilizers. In Central Pacific regions, an NPK dose of 1.1-0.4-0.9 kg^{-1} tree^{-1} year^{-1} is applied to the Tommy Atkins and Haden verieties. Whereas, an NPK doses of 0.4-0.2 - 0.2.2 kg^{-1} tree^{-1} year^{-1} are recommended for plants aged from 10 - 15 years of age in North Pacific regions (Chávez-Contreras *et al.,* 2001).

Table 2 shows the fertilizers dosage recommendation for bearing mango trees in various parts of the world where mangoes grow.

Table 2 - Fertilization of nitrogen (N), phosphorus (P) and potassium (K) to fruit bearing trees in various countries

Country	Tree age (years)	Amounts of nutrients (g plant^{-1} year^{-1})			Reference
		N	P	K	
Pakistan	20-25	1000	750	750	Anees *et al.* (2011)
Northern Pacific region	10-15	2800	900	1800	Crane *et al.* (2009)
India	>10	1000	500	1000	Negi (2000)
Mexico	>20	1000	500	1000	Crane *et al.* (2009)
Queensland, Australia	10	1750	880	1650	Sanewski (1991)
Taiwan	>11	360	240	540	Crane *et al.* (2009)
Brazil	-	1200	1500	2500	Crane *et al.* (2009)

Soil and mango leaf analyses

Soil chemical analysis of mango farm and mango leaves analysis is a useful step in determining and handling the nutrients status of the mango garden. Analysis of soil samples provides information of the necessary minerals and nutrients essential for the mango plant growth and development plants within appropriate limits (Anonymous, 2007). Soil chemical analysis helps to determine the phyisochemical properties of soil, including soil pH, electrical conductivity, organic matter content, and clay content. Cell tissue analysis of mango plant, with chemical analysis of soil from a mango orchard, is a helpful tool for measuring the variations in soil mineral properties and can influence fertilization use (Bally, 2009).

Samples from depths and locations should be collected to examine the nutrients status of soil before the establishment of mango orchard. Whereas, the sampling depth and sampling points will be different depending upon soil type and age of the tree, form the already established mango garden. In the soil with sandy texture and deep sampling is recommended (1-1.5 m) because nutrient may leach down, and deep sampling is required to analysis the accommodated nutrients and to prevent the over fertilization (Bally, 2009).

The leaf of mango plant should be analyzed in order to monitor and manage the nutrient requirements of the plants. Nutrient deficiency and abundance can be determined by visual leaves symptoms. The nutrient index status is often displayed by the leaves at different time for different minerals. When the mango plants have reached the full phenolic stage (the nutrient level of the leaves is very stable), the leaves sampling should be proceeded. The leaves from the plants of age of 6-8 months be plucked from different sides and canopy to avoid the variations in the analysis of results (Bally, 2009). The leaf samples should be collected from different cultivars, soil types and cultural practices individually. Further, the mango trees receiving nutrients and fungicides, such as follicle application, are prevented should be avoided from leaf sample collection. It is also suggested to wash the leaf samples with water to get rid of spray residues (Bally, 2009).

Young and Koo (1969) examined the nutritional status of the leaf samples of mango grown on calcareous and sandy soils. Significant differences in mineral content were found due to sampling of the presence or absence of fruit, soil type, cultivator and fruit. Leaf analysis shows that *Table 3* reveals the sufficiency and deficiency of various mineral-related nutrients. In Brazil, mango orchards are often deficient boron (B) and zinc (Zn). Zinc sulfate and borax are used to treat deficiencies; however, leaf analysis decides the rate of fertilizers application (Silva *et al.,* 2002). Pakistan's soils are basically alkaline, with repeated use of phosphatic source of fertilizers, which eventually enhances the phosphorus levels of the soil. These kinds of circumstances can alter the solubility and movement of micronutrients within the soil system and decreases the uptake of these nutrients by plants (Iorio *et al.,* 1996) and can lead to deficiencies of micronutrient in Pakistani soil (Anees *et al.,* 2011). Basal and foliar methods of fertilizer applications are used to apply the micronutrients to plants; however, in comparison to soil application, the foliar application is considered to be 6-20 times more effective, as micronutrients are quickly available to the plants via leaves (Silberbush, 2002).

Yield and nutrient contents

Studies have been performed between nutrient concentrations and yields for several crops (Cotrim *et al.,* 2019); nevertheless, the nutritional status of mango trees and its statistical relationship to the soil is complicated to determine owing to the higher buildup of minerals in trees and due to dispersal of minerals in the soil (Lobo *et al.,* 2019). A system describing the diagnosis the leaf mineral analysis called Diagnosis and Recommendation Integrated System (DRIS) is used for this purpose. In DRIS, a ratio is needed for mineral concentrations, in spite of the full mineral contents to recognize the deficient mineral concentration. However, the DRIS has been used in mango orchards with a varying degree of success.

Raghupathi *et al.* (2004) suggested that the deficiencies of nutrients could not be identified by DRIS in separation, whereas, some of the researchers efficiency utilized this system. Wadt *et al.* (2007) and Raj and Rao (2006) used the DRIS system to identify the minerals which result in reduced yields of mango fruits in Brazil and India, respectively.

Xiuchong *et al.* (2001) examined the relationship between fruit production and nutrients status in leaf tissues of mango tree. They performed two studies at different locations in China, *i.e.,* Shenzhen and Sunshui. They reported that with the appropriate application of N, P, K, S, and Mg, the nutrient contents in the leaves of mango plants were in order of: N> Ca> K> P>S>Mg. After using 300 and 400 g N plant^{-1} in mango orchard, no significant difference was found in N concentrations in leaf tissues. The contents of P in soil reached to 4.8 - 19.4 mg kg^{-1} with the application of 0 and 125 g P_2O_5 plant^{-1} of P, whereas there was no significant difference in leaf P concentrations. Likewise, application of 320 g K_2O plant^{-1} resulted in an increase of 0.166 - 0.18% K in plant leaf then control. Akin, 40 g Mg plant^{-1} and 80 g S plant^{-1} increased the contents of Mg and S by 0.04% - 0.09% and 0.03% - 0.04%, respectively, as compared to control. They concluded that increasing the application of nutrients directly increases the mango production, as a result of improved nutrient use efficiency. Further, Oosthuyse (1997) suggested that the application of N, K, phosphorus P, Zn and Mg in mango orchards improves the size and fruits retaining ability of mango plants.

Nutrients removal

It has been established that the concentration of mobile nutrients (N, P, K and Mg) decreases, whereas the concentration of immobile nutrients (calcium (Ca), boron (B), manganese (Mn) and sulfur (S)) increase with the age of mango leaf (Medeiros *et al.,* 2004). Mango leaf taken from fruiting branches of tree generally contain the higher concentration nutrients, such as N, K, Fe, Mn, Zn, Ca, and Cu, whereas the content of aforementioned elements decreases as the fruit grows till ripening. The contents of nutrients significantly change at fruit terminals with exception of P and Mg (Oosthuyse, 2000). Moreover, it was suggested that the preference of nutrient removal by mango tree was: $K_2O > N > P_2O_5 > Ca > Mg > S$ (Xiuchong *et al.,* 2001). Moreover, it was reported that the nutrient removal capability of the mango tree varies with the obtained yield.

Impact of various fertilizers on production and quality of mango fruit

Role of nitrogen

Nitrogen is one of the most critical yield-reducing nutrients of all the plant's essential nutrients. Nitrogen is the basic constituent of amino acid, which are considered as building blocks of proteins and are used in formation of protoplasms (Uchida, 2000). N is required by the plants to accomplished various functions in plant growth, as stated below: 1. Enzymes are very important for the growth and development of plant. Enzymes are comprising of proteins, which in turn are made up of amino acids. N is the building blocks for amino acid production; 2. Much of chlorophyll consists of N. Therefore, the process of photosynthesis in plants cannot be accomplished without N; 3. N is an important constituent for the quantity and quality of dry matter production in plant; 4. Different vitamins within plants are composed of N; 5. N is necessary for the mineralization of carbohydrates;

6. N plays a dynamic role in the development and functioning of roots; 7. N plays a significant role in uptake of other essential plant nutrients.

Mango plants require an adequate supply of N fertilizer to accomplish various growth stages. The N from soil solution is absorbed by mango plant through roots in two ionic forms, *i.e.,* ammonium (NH_4^+) and nitrate (NO_3^-). The effects of the N supply are more obvious at plant stage, the growth of floral buds, and the formation of fruit. A constant supply of N results in the development of shoots regularly, that effectively starts producing fruit at maturity stage (Silva, 1997). It has been reported that the application of 960 g N plant^{-1} increased the yield of mango fruits by 86% (Nasreen *et al.,* 2014). In another study, Sarker and Rahim (2012) used urea and cow manure (1125 g and 37.5 kg, respectively) together and achieved almost 6-fold higher fruit production than the control. Abbas *et al.* (2002) observed that N fertilization resulted in higher amounts of soluble solids, whereas reduced the acidity in mango fruits than that of the fruits obtained from non-fertilized orchards. The impacts of N fertilizer on mango fruit quality are given in *Table 4.*

Adequate amount, time and method of N fertilization are of critical importance in acquiring the higher plant and fruit production, as well as improving the fruit quality. In general, reduced growth, chlorosis on older leaves, lack of flowers, and early maturity are the indications for N deficiency in mango plants (Uchida, 2000). The deficiency of N in mango plants in turn results in stunted growth, subsequently resulting in decline the quality and mango fruit production (Reshmi *et al.,* 2018). On contrary, the sufficiency of N in mango trees can lead to excessive vegetative growth, inappropriate flower differentiation, and reduced fruit yield with lower quality. Furthermore, N sufficiency in mango plants develops lush green leaves, subsequently attracting pests and increasing the risk of disease development. Magwaza and Kruger (2005) concluded that the unnecessary N fertilization may damage the canopy of mango tree in the post-harvest period. Njuguna (2017) stated that >1.2% N in mango leaf results in the development of greenish spots on mango fruits. Hence, the balanced utilization of N fertilizer is of significant importance for achieving higher fruit production with improved quality.

Role of phosphorus

Phosphorus possesses a much greater effect on the natural and agroecosystem than the other plant minerals (Brady and Wile, 2002). It has been estimated that the application of P in crop production has resulted in 30-50% increment in global food production, as compared to the food production in 1950 (Higgs, 2000). P is considered an integral part of several plant molecules, which are responsible for photosynthesis and respiration, cell division, and growth.

Table 3 - Dry weight contents of various nutrients in mango leaves

Country	Mango varieties	Leaf nutrient concentration												Reference
		N %	P %	K %	Ca %	Mg %	S %	Cu mg kg^{-1}	Fe mg kg^{-1}	Mn mg kg^{-1}	Zn mg kg^{-1}	B mg kg^{-1}	Mo mg kg^{-1}	
Florida	Tommy Atkins, Keitt, Kent, Haden and Sensation	1.0-1.2	0.1-0.2	0.8-1.2	2.0-3.3	0.2-0.3	0.1-0.2	9-18	120-190	170-450	30-75	40-80	0.3-0.6	Oosthuyse (1997)
Mexico	Haden	1.20	0.09	0.59	3.40	0.16	0.17	5.43	101.3	328.1	16.6	-	-	Guzmán-Estrada (2001, 2004, 2006).
	Keitt	1.28	0.15	0.56	2.87	0.19	0.20	11.70	99.4	191.1	21.4	-	-	
	Kent	1.16	0.08	0.57	3.23	0.19	0.15	6.70	96.6	243.8	13.6	-	-	
	Tommy Atkins	1.28	0.13	0.62	2.77	0.15	0.17	6.96	96.2	219.3	16.4	-	-	
Brazil	-	1.2-1.4	0.08-0.16	0.5-1.6	2.0-3.5	0.25-0.5	-	10-50	50-200	50-100	20-40	50-100	-	Santos *et al.* (2002)
Taiwan	-	1.4-1.7	0.1-0.15	0.9-1.2	1.0-1.8	0.2-0.35	-	5-20	60-120	30-200	20-100	-	-	Job (1989)
USA	-	1.0-1.5	0.09-0.18	0.5-1.0	3.0-5.0	0.15-0.47	-	28-35	38-120	92-182	101-119	24-54	-	Young and Koo (1969)
China (Shenzhen)	Zihuaman	1.62	0.16	0.98	1.39	0.14	0.14	-	-	-	-	-	-	Xiuchong *et al.* (2001)

Moreover, the functioning of phospholipids, nucleotides, as well as other metabolic molecules need the presence of P (Salisbury and Ross, 1992). An important role of P application has been identified in fruit maturing, leaf elongation, and root development (Bally, 2009). Two ionic forms of P, *i.e.,* primary orthophosphate ion ($H_2OP_4^-$) and secondary orthophosphate (HPO_4^{2-}), are available in the soil solution for plant uptake. The speciation of P ionic forms in the soil solution is largely dependent on soil pH. It has been established that the level of pH above 7 favor the occurrence of HPO_4^{2-}, whereas the soil pH below 7 favor the presence of $H_2OP_4^-$. The extremely higher as well as lower soil pH levels are usually considered undesired, as they result in result in reduce P availability to the plants.

Table 4 - Variations in quality of mango fruits under the application of nitrogen fertilizer

Sr. no.	Parameters	Reported positive effect	Reported negative effect	No effect
1	Total soluble solids	-	-	Nguyen *et al.* (2004)
2	Titratable acidity	-	-	Nguyen *et al.* (2004)
3	Anthracnose incidence	Nguyen *et al.* (2004)	-	-
4	Internal disorders	-	Assis *et al.* (2004)	-
5	Lenticel damage	Magwaza and Kruger (2005)	-	-
6	Mango fruit color		Young *et al.* (1962)	

At higher soil pH levels, P may combine with Ca and produce calcium phosphate, whereas at lower soil pH levels, P may bound with Al, Mn and Fe, consequently making P unavailable to plants. Therefore, an optimum P availability occurs at pH of 6-7. Generally, the P bounded onto clay dissolved into the water, where plants roots can absorb it. In addition, HPO_4^{2-} is more easily absorbed by the plant roots than $H_2OP_4^-$. The P is translocated from roots to other parts of plants in form of organic phosphate. It has been reported that phosphate ions are mobile can easily be translocated from older tissues to growth points in mango trees (Bally, 2009). That is the reason that the deficiency symptoms of P are seen on old leaves. Singh and Saxena (1994) suggested that these symptoms include browning of the leaves accompanied with mild necrosis, tip necrosis and stem death. However, P deficiency is uncommon in mango plants. Moreover, bark and roots of mango plants contain more P than its leaves (Vuuren and Stassen, 1997). Medeiros *et al.* (2004) observed higher P contents in plants during vegetative stage, than that of fruiting stage. Stassen *et al.* (1999) reported that inadequate supply of P to mango plants may results in shorter roots, reduced growth and lower fruit production. In general, P is positively correlated with the other macronutrients, such as N, K, and Mg (Fageria, 2009). Therefore, an integrated application of fertilizers may result in higher plant growth and fruit production.

Role of potassium

Potassium it plays a major role in enzyme activation, photosynthesis, respiration and starch formation (Marshner, 1995). The K is required for cell growth and epidermal cell walls thickness, which enabling them to resist against insects/pests and pathogens attack. K regulates the water levels inside the plants *via* controlling stomatal activities (Salisbury and Ross, 1992). It has been estimated that about 90-98% of K is present in the form of insoluble crystalline minerals, and is not available to plants. The ionic form of K which is K^+ occurs in soil solution and becomes available to plants (Gourley, 1999). However, due to competition with other cations, the availability of K varies with soil conditions. For instance, Madonsela (2019) stated that higher amounts of Ca and Mg in soil resulted in reduced K^+ availability to plants, owing to higher competition for the exchange sites. Besides, various other factors are also responsible for the availability of K to plants. K is transported through diffusion process from soil to the roots; however, the diffusion process is influenced by various aspects, such as moisture content, temperature, path tortuosity, and K^+ diffusion coefficient. It has been reported that K^+ is usually translocated towards younger leaves from old leaves and, therefore, roots, bark, leaves, and fruits of mango plants contain higher amounts of K (Vuuren and Stassen, 1997). Moreover, K usually remains higher mango plants during vegetative flushing time, as compared to time of flowering and fruiting (Medeiros *et al.,* 2004). However, the higher concentration of K by the mango plants may interfere with the other nutrients, resulting in lower fruit production (Gourley, 1999).

The most commonly used K fertilizers for optimum mango production include muriate of potassium nitrate (KNO_3), potash (MOP), and potassium sulfate (K_2SO_4). Among these fertilizers, K_2SO_4 is the widely accepted K fertilizer due to neutral pH effect, as mango plants are very susceptible to higher chloride (Bally, 2009). Owing to the mobile nature of K^+ ions, symptoms of its deficiency are obvious in older leaves. It has been reported that the application of KNO_3 at flowering stage improves flowering, as well as fruit setting and retention (Shinde *et al.,* 2006; Saleh and El-Monem, 2003). There are fewer studies for exploring the effects of K fertilization on fruit quality (Marschner, 1995). Shinde *et al.* (2006) observed higher contents of fruit weight and ascorbic acid (5.15% and 26.99%, respectively), as well as color, taste and durability, whereas a reduction in spongy tissues and weight loss with K fertilization. K has also been reported for disease control in mango plants. For instance, Reuveni *et al.* (1998) and Oosthuyse (2000a) observed positive effects of K application for controlling.

Role of calcium

Calcium is abundantly found in alkaline and neutral soils as divalent cation (Fageria, 2009). Despite of its category of secondary nutrients, Ca is thought to be very crucial for proper plant growth (Fageria and Gheyi, 1999). Ca can be found in soil as exchangeable, soluble and non-exchangeable forms. About 65-85% of the exchange capacity of a soil is composed of loosely bounded exchangeable Ca (Mengel and Kirkby, 1987). Moreover, amphiboles, feldspar, carbonates, and phosphates minerals are bounded to the Ca within the soil, making it non-exchangeable. Generally, the contents of Ca are 10-folder higher than that of Mg^{2+} and K^{+} ions.

Lower Ca fertilization, reduced uptake by plants, as well as decline translocation results in the development of Ca deficiency. The mango fruit setting is influences more with Ca deficiency as it has been observed that growing points of plants require higher amounts of Ca (Mengel and Kirkby, 1987; Marschner, 1995). Mass flow and root pressure are the means of transportation for the Ca from soil to roots. Nevertheless, the mechanism of root pressure to transport Ca in mango is not studied well (Bally, 2009). Moreover, indole acetic acid, that is produced in root apex, helps in Ca translocation within the plant (Ho and Adams, 1989; Banuelos *et al.,* 1987).

Calcium deficiency is manifested in young and growing leaves first owing to its mobile nature within the plants. Therefore, the symptoms of Ca deficiency are obvious as membrane degeneration associated with fruit ripening (Fallahi *et al.,* 1977; Bangerth, 1979). Further, the deficiency of Ca in plants directly results in cell-wall deterioration, and cell disruption (Van Eeden, 1992). The durability of mango fruits and resistance against diseases in mango plant is directly associated with Ca availability to plants. Various researchers have reported an improved quality of mango fruits, when Ca was applied through foliar spray (Hojo *et al.,* 2009; Wahdan *et al.,* 2011). However, the excessive amount of Ca contents in soil may replace the other nutrients in soil owing to competitive effects. Therefore, an integrated application of all the essential nutrients to mango plant would result in enhanced production and quality of mango fruits.

The Ca accumulation within the leaves of mango plants increases with the age of the plant (Reuter and Robinson, 1997). There is always ambiguousness in estimating the content of Ca in the leaves and the fruits of mango plants, as it varies from one fruit to another (Bally, 2007). This could be due to variations in the location of vascular tissues and translocation of Ca in the tissues (Shorter and Joyce, 1998). For instance, Bally (2007) concluded that the Ca concentrations varied within the mango fruits from fruit developmental stage to ripening. The variations in mango fruit quality with Ca applications are demonstrated in *Table 5*.

Table 5 - The variations in mango fruit quality with calcium applications

Sr. no.	Parameters	Reported positive effects	Reported negative effect	No effect
1	Total soluble solids	Hojo *et al.* (2009); Rani and Brahmachari (2003)	-	-
2	Fruit colour	-	-	-
3	Titratable acidity	Wahdan *et al.* (2011); Assis *et al.* (2004)	-	-
4	Fruit mass	Wahdan *et al.* (2011); Hojo *et al.* (2009)	-	-
5	Fruit firmness	Wahdan *et al.* (2011); Rani and Brahmachari (2003); Evangelista *et al.* (2000, 2002); Hojo *et al.* (2009)	-	Silva and Menezes (2001); Sampaio *et al.* (1999)
6	External appearance of the fruit	Freire-Junior and Chitarra (1999)	-	-
7	Internal disorders	Assis *et al.* (2004)	Van Eeden (1992)	Hojo *et al.* (2009); Silva and Menezes (2001); Freire-Junior and Chitarra (1999); Sampaio *et al.* (1999)

Role of magnesium

Magnesium is the second most dominant cation in the soil and is an essential macronutrient for a successful growth of plant. Mg^{2+} is an important component of enzymes involved in transport of P, it activates various enzymes, produces green color, and is involved in carbohydrate metabolism (Yan and Ho, 2018). Mango plants require adequate supply of Mg for higher fruit production. Similar to the Ca deficiency, the deficiency of Mg is generally seen in acidic soils (Fageria and Souza, 1991). The contents of Mg^{2+} in the soil varies greatly according to weathering of the soil and the parent material. The Mg^{2+} requirements for optimum growth are lower than Ca and varies with varieties, species, type of soil, and crop type (Fageria *et al.,* 1997). Various factors are responsible for affecting the Mg^{2+} availability to mango plants such as, concentration of Mg^{2+}, the Mg^{2+} saturation, soil physiochemical properties, soil texture and type, and mango variety. Furthermore, the concentrations of Na and K ions in the soil reduces the availability of Mg^{2+} ions to mango plants owing to competitive effect (Aitken and Scott, 1999). Alike, higher amounts of other ions such as NH_4^+, Mn^{2+}, Ca^{2+} and Al_3^+ in the soil, compete with Mg^{2+} as well (Yan and Ho, 2018). Various studies have demonstrated that the application of Mg^{2+} to mango plants resulted in enhanced plant growth, fruit yield, and quality (Xiuchong *et al.,* 2001). The impacts of Mg^{2+} fertilization for improving mango fruit quality is presented in *Table 6.*

It has been seen that Mg^{2+} is a mobile nutrient and it is translocated within the plant body in the form of Mg^{2+} ion. Hence, the deficiency of Mg^{2+} appears in older leaves initially. The symptoms of Mg^{2+} deficiency can be recognized as yellowish leaves and necrosis in leaf lamina. The yellow leaves round and color, while the leaf veins remain green. The deficiency Mg^{2+} has widely been seen in sandy soils, where leaching is more. Further, the soil with lower cation exchange capacities, and higher K fertilization are prone to Mg^{2+} deficiency (Stassen *et al.,* 1999). Therefore, appropriate use of integrated fertilization schemes including Mg^{2+} along with weed, diseases and pest control measures could result in enhances mango fruit production with enhanced quality.

Table 6 - The impacts of magnesium fertilization for improving mango fruit quality

Sr. no.	Parameters	Reported positive effect	Reported negative effect	No effect
1	Total soluble solids	-	-	-
2	Titratable acidity	-	-	-
3	Fruit mass	Xiuchong *et al.* (2001)	-	-
4	Internal disorders	-	Assis *et al.* (2004)	-

Role of boron

Boron (B) is among the essential micronutrients for plant development and growth. However, the excessive B supply could develop toxicity. The function of B in plant physiology is not studies well, nonetheless, its role in cell wall formation is well established (Zia *et al.,* 2006; Hu and Brown, 1994). The formation of pollen, retention of flowers, protein synthesis, as well as transport of sugar in mango plants is controlled by B (Hansch and Mendel, 2009; Gupta *et al.,* 1985). Hence, a continuous supply of B is essential for successful fruit setting in mango plants (Raja *et al.,* 2005). If not supplied in appropriate amount, inner and outer cork of mango plants may hinder and mango fruit may get cracks due to inadequate supply of B (Zia *et al.,* 2006). According to an estimate, the soils of more than 80 countries, including Pakistan, Thailand, India, Brazil, Africa, South and Central America, and Australia are suffering from B deficiency (Singh *et al.,* 2005; Naik and Bhatt, 2017; Zia *et al.,* 2006; Fageria *et al.,* 2002; Oldoni *et al.,* 2018). Zia *et al.* (2006) reported the deficiency of B soil of Pakistan, whereas Xu *et al.* (2001) reported 33 million hectares of arable land in China are B deficient. The main reason for widespread B deficiency could be to the insoluble mineral source of B (tourmaline) (Gupta *et al.,* 1985). The overall effects of B application to mango fruit quality are presented in *Table 7.*

The preferable forms of B for plants uptake are identified as boric acid (H_3BO_3 or $B(OH)_3$ (Marshner, 1995). It has been reported that B moves within soil *via* mass flow; however, the involvement of active and passive method of B transportation in soil has not been studied well (Mattiello *et al.,* 2009.). Soil physicochemical characteristics (pH), B concentration is soil, type and texture of soil, specie, and soil moistures contents significantly affect the B availability to mango plants (Welch *et al.,* 1991). In addition, B retention in coarse soil is lower due to higher leaching. It is worth mentioning that, unlike other nutrients, the B uptake from soil to mango plants increases with rise in temperature.

The application of B to mango orchard has been seen to improve the fruit production and quality for various cultivars of mango (Galli *et al.,* 2013). Likewise, Anees *et al.* (2011), Barbosa *et al.* (2016), Baiea *et al.* (2015) and Ali *et al.* (2017) observed an enhanced quality and production of mango under B fertilization. Moreover, Raja *et al.* (2005) suggested that application of B with foliar spray was more effective than soil application. Thus, integrated application of foliar B in the form of H_3BO_3, $FeSO_4$ and $ZnSO_4$ could significantly improve the mango yield and production with enhanced fruit quality (Anees *et al.,* 2011; Bhatt *et al.,* 2012).

The deficiency of B in mango plants can be recognized by less flowering, less pollination and fewer fruit setting. This could be due to irregular cell division resulting in curved leaves, fruit pitting, as well as bent margins and lumina (Siddiq *et al.,* 2017; Crane *et al.,* 2009). As a result, the stems start to black losing apical dominance, consequently resulting in stunted growth. Moreover, the higher levels of N and Ca contents in soil result in B deficiency as well (Raja *et al.,* 2005; Ram *et al.,* 1989). Marshner (1995) stated that here is a marginal difference between B deficiency and toxicity. Excessive application of B fertilizer may develop a B toxicity in soils. Black spots on the edges of the leaves and necrosis on the margins of leaves are the indications of B toxicity (Crane *et al.,* 2009). Therefore, in case of the appearance of B toxicity symptoms, the surplus B must be leached down from root zone for persistent mango plant growth. Alike, a deficiency of B can also be compensated with appropriate application of B fertilizer in order to achieve optimum mango fruit production and quality (Saran and Ratan, 2011; Sharma and Singh 2009).

Table 7 - The effects of boron fertilization on production and quality of mango fruit

Sr. no.	Parameters	Reported positive effect	Reported a negative effect	No effect
1	Total soluble solids	Oldoni *et al.* (2018); Anees *et al.* (2011); Bhatt *et al.* (2012)	-	-
2	Titratable acidity	Oldoni *et al.* (2018); Anees *et al.* (2011); Bhatt *et al.* (2012)	-	-
3	Fruit mass	Bhatt *et al.* (2012); Raja and Kumar (2003); Oldoni *et al.* (2018)	-	-
4	Internal disorders	Saran and Ratan (2011); Sharma and Singh (2009)	-	-
5	Total sugar	Bhatt *et al.* (2012)	-	-
6	Ascorbic acid	Baiea *et al.* (2015); Anees *et al.* (2011); Oldoni *et al.* (2018)	-	-

Role of zinc

Zinc is an essential micronutrient for the successful growth and production of the plant owing to its significant contribution in the synthesis of chlorophyll, proteins, hormones and in conducting the process of photosynthesis (Weir and Chresswell, 1995). Plants absorb Zn from the soil solution in in ionic form (Zn^{2+}), and then translocate it to other parts of the plant. However, the translocated Zn does not become available easily to other tissues of the plant. In addition, due to deep rooting system of mango, it is harder to apply Zn in root zone. However, the chelating agents produced from roots of mango plants may help in Zn translocation (Stevenson, 1986). Therefore, foliar application of Zn because it is considered as more efficient, as plant can absorb Zn through leaves as well. Further, foliar Zn application is preferred as Zn is immobile in soil (Tisdale *et al.,* 1985). Exogenous Zn application to mango plants improves the quality and production of mango fruits (*Table 8*).

The deficiency of Zn in various soils have been reported globally. The development of leaflets and shortening of internode spacing on mango plants could be a sign of Zn deficiency (Dilly *et al.,* 1997; Agarwala *et al.,* 1988; Marshner, 1995). The Zn availability to plants is directly linked with pH of the soil. Further, the higher calcite ($CaCO_3$) contents in soil reduces the availability of Zn to plants owing to higher pH levels (Trehan and Sekhon, 1977). Similar, it was reported that Zn availability to plants is significantly influenced by the soil pH (Anderson and Christensen, 1988). Therefore, widespread Zn deficiency is reported in the soils of Pakistan and India owing to alkaline soils with higher calcite contents (Naik and Bhatt, 2017; Zia *et al.,* 2006). Besides, the availability of Zn to plant is also influenced by the contents of clay, organic matter, calcite contents, iron oxide, and aluminum oxide. Moreover, higher concentrations of P in the soil may also reduce the availability of Zn to the soil (Robson and Pitman, 1983). Fageria and Gheyi (1999) observed Zn deficiency in soil exhibiting P toxicity and *vice versa*. The improved fruit production and quality has been seen with the application of Zn by various researchers. For instance, Singh and Rajput (1977) reported that the application of $ZnSO_4$ application resulted in higher ascorbic, fruit sugar, and production of mango fruit. Likewise, an improvement in fruit quality and setting was reported by Daulta *et al.* (1981) with foliar application of Zn fertilization.

Table 8 - Exogenous zinc application on fruit quality and production of mango fruits

Sr. no.	Parameters	Reported positive effect	Reported negative effect	No effect
1	Total soluble solids	Panwar *et al.* (2007); Singh and Rajput (1977); Inees *et al.* (2011); Bhatt *et al.* (2012)	-	-
2	Titratable acidity	Inees *et al.* (2011); Singh and Rajput (1977); Bhatt *et al.* (2012)	-	-
3	Fruit mass	Raja and Kumar (2003); Singh and Rajput (1977); Bhatt *et al.* (2012); Inees *et al.* (2011)	-	-
4	Total sugar	Panwar *et al.* (2007)	-	-

In another study, it has been observed that 1% foliar application of $ZnSO_4$ resulted in enhanced vitamin A and sugars with lower acidity (Kumar and Kumar, 1989). Likewise, it was reported that 1% foliar spray of $ZnSO_4$ was sufficient to prevent optimum plant growth (Littlemore *et al.,* 1991).

Role of other micronutrients

Beside afore mentioned micronutrient, Fe, Cu and Mn are also essential for optimum plant growth. Therefore, appropriate application of all these nutrients is necessary for higher mango fruit production and deficiency of either one or more than one micronutrient would lead to reduced plant growth and fruit production (Schaefer *et al.,* 1988).

The reduction of sulfates and nitrates, process of photosynthesis and assimilation of N_2 is linked with Fe; therefore, Fe management in mango plants is of critical importance. However, Fe deficiency in soils is widespread globally in mango orchards, despite of its abundance in most of the soils (Zia *et al.,* 2006; Schmidt, 1999). It is due to the fact that Fe availability is directly influenced by the soil pH. One unit increment in soil pH results in 1000 times reduction in Fe solubility (Lindsay, 1979). Hence, proper Fe fertilizer management is complicated in calcareous soils. Due to higher pH of calcareous soils (7.5-8.5), only a small proportion of the applied Fe becomes available to the plants (Lindsay, 1991). Plants can absorb Fe either in the form of Fe^{2+} and/or Fe^{3+}; nevertheless, Fe^{2+} has been shown to be more soluble than Fe^{3+}. Moreover, in aerobic condition, Fe^{2+} can be oxidized to produce Fe^{3+}, which is not accessible to plants, whereas, through reduction process Fe^{3+}, can be transformed to Fe^{2+} enhancing the availability of Fe to plants (Salisbury and Ross, 1992). However, the process of reducing Fe^{3+} to $Fe^{2+}$is controlled by the soil pH. Ligands obtained from plants can be develop chelates Fe^{3+} making them available for plants. Furthermore, the efficiency of Fe can be enhanced substantially through foliar application of Fe than that of soil application (Bhatt *et al.,* 2012; Anees *et al.,* 2011).

The crucial role of Mn in the redox reaction, enzyme activation, decarboxylation and hydrolytic and reactions has been established (Bally, 2009). Additionally, the photosynthetic process, as well as formation of lipids, proteins and carbohydrates is linked with adequate levels of Mn in plants (Marchner, 1995). Plants can uptake Mn in the form of Mn^{2+}, which is generally bounded to the organic matter and soil colloids (Bally, 2009). The MnO_2 is transformed to Mn^{2+} through reduction in aerobic conditions, under lower pH, while the microbial oxidation may occur in higher pH. Therefore, both oxidation and reduction processes take place simultaneously in the soil system controlling the availability of Mn to the plants (Peverill *et al.,* 1999). The deficiency of Mn in mango plants can be evidenced through the development of necrosis at leaf tips (Mohamed, 2017). The possible impacts of Mn application on the mango fruits quality have not been investigated well (Bally, 2009). Therefore, appropriate quantities of micronutrients must be applied on right time using right application method to achieve the optimum mango fruit production with improved quality and nutrition.

Future directions

In order to understand the factors responsible for reducing the quality, growth and production of mangoes, it is necessary to constantly research and examine different factors in several different ecological zones. Modern and smart technologies can recognize the factors that decrease the mango production, including mineral nutrients, specifically micronutrients, which are not only responsible to reduce the quality of mango fruit, but also to reduce productivity. Steps are needed to be taken to make better mango production and quality of fruits through the integrated and balanced nutrient management. Mango producers, scientists, horticulture specialist and extension workforces should work in joint ventures to share the knowledge. To predict and diagnose phenological needs at different ecological regions and times, there is a need to combine biotic and abiotic factors to increase productivity. Increasing research and horticulture requires the incorporation of new models, software and friendly programs into the light production and plant growth phases. The importance of supporting organic farming techniques in conjunction with nature and science cannot be deprived. Finally, there is an urgent need to sustain and build a resilient bridge between mango producers, technologists and researchers in order to increase mango production and ensure quality production.

CONCLUSIONS

Due to nutritional values with a nice aroma, taste, flavor and health, mango is recognized as “king of fruits” in South Asia. Although, mango trees can be cultivated on a vast range of soil characteristics nonetheless, tree mineral status should be measured by repeating leaf and soil chemical analysis. True understanding was gained from the nutritional effects of the explanations rather than from the results on the qualitative parameters of the mango fruit. The yield and quality of the mango fruit can be improved to a great extent in result of the applied mineral nutrients by describing their role in phenology. Continuous monitoring of the mango tree helps to plan a nutritional program for mangoes. It is essential to monitor the mineral status at different growth stages. The growth and development of the mango industry requires the development and commitment of a fast, economical, easily accessible and ecological mineral nutrition program.

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