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NRM Interventions for Enhanced Mango Productivity and Quality

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Abstract

Despite a rich legacy and unparalleled lead in global mango production, India lags behind other major mango producing countries in mango productivity and quality. Preponderance of unproductive orchards, widely spaced plantations, poor orchard management and the losses caused by different biotic and abiotic stresses are the major causes of low fruit yield and quality. Nearly 10% of the total produce goes waste indicating weak marketing linkages between the farm gate and consumers. Mango growers continue to bear the brunt of problems like alternate bearing, malformation and spongy tissue. Low returns to the growers, inefficient use of natural resources, higher prices for the domestic consumers and reduced share in global mango exports are some of the repercussions of low productivity and inferior fruit quality. Consequently, despite a lion's share in total production (≈42%), India lacks truly deserved preeminence in global mango trade. Taking a cue from the astonishing success of mango industry in different countries, where commercial mango cultivation is of relatively recent origins, this article analyzes the ills plaguing Indian mango industry. Recent innovations in soil and water management for sustainable mango production are discussed.

Key words: High density planting, intercropping, fruit quality, productivity, soil organic carbon, sustainable.

Introduction

Mango (*Mangifera indica* L.; family Anacardiaceae) is widely grown in tropical and sub-tropical regions of the world making it the fifth largest tropical fruit industry. Although mango crop is produced in about 100 countries transcending continental boundaries, Asia accounts for a bulk of the global production. India continues to be the world's largest mango producer contributing ≈42% to the global production; total mango area and production in India exceed those of other nine major producers combined. However, current average mango productivity in India is below other mango growing countries except Nigeria (Table 1; MAFW 2016; UNCTAD 2016). World mango production increased by ≈2.5 times over 1990-91 to 2012-13 period. Although India continues to occupy the lead position, its share in total world mango production consistently declined during this period. In contrast, countries like China, Bangladesh and Indonesia registered nearly twofold increase in total mango production during this period. While much growth in production did not occur in Pakistan and Thailand, they continue to maintain the total output level albeit with yearly fluctuations (Balyan *et al*. 2015).

In comparison to India where average mango productivity stands at ≈7 t ha^{-1}, average yields are considerably higher (≈10 t ha^{-1}) in other major mango producing countries. Several mango growing countries, where commercial mango cultivation is of relatively recent origins, have achieved exceptionally higher mango yields. For example, in Israel, where mangoes are grown over a very small area (≈2,000 ha),

Table 1. Mango area, production and productivity in leading mango producing countries of the world.

Country	Area (m ha)	Share (%)	Production (m t)	Share (%)	Productivity (t ha^{-1})
India	2.50	46.0	18.00	41.6	7.20
China	0.48	8.8	4.62	10.7	9.60
Thailand	0.38	7.0	3.14	7.3	8.27
Indonesia	0.20	3.7	2.06	4.8	10.50
Mexico	0.20	3.7	1.90	4.4	9.56
Pakistan	0.17	3.1	1.66	3.8	9.68
Brazil	0.07	1.3	1.16	2.7	16.53
Bangladesh	0.12	2.2	0.95	2.2	7.66
Nigeria	0.13	2.4	0.85	2.0	6.54
Egypt	0.09	1.7	0.83	1.9	9.09
Others	1.10	20.2	8.12	18.8	7.41
World	5.44	----	43.30	----	7.96

Source: MAFW 2016

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yields below 30 t ha^{-1} are considered poor. Over the years, concerted efforts made for developing high yielding cultivars, efficient irrigation and fertilizer management, eco-friendly pest management and utmost care to meet export standards have enabled Israel to capture a significant share (20 %) of European mango market. Availability of cultivars having different maturity periods has allowed a staggered fruit picking season spread over 6 months: June-August (Haden, Tommy Atkins and Maya), August (Omer, Noa and Shelli), August-September (Kent) and September-October (Keitt) (Israel Agri 2015). Efforts are underway to further improve the fruit yield in export cultivars (Omer and Maya) by moderating microclimatic conditions through provision of shade nets, mild pruning, additional irrigation and early harvesting (Schneider *et al*. 2015). This is a notable achievement in face of constraints such as low winter temperatures and unstable spring weather unfavorable for mango production, and widespread salinity problem.

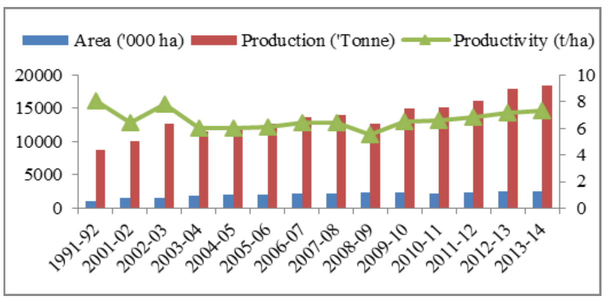

Fig. 1. Trends in area, production and productivity of mango crop in India over 1991-2013 period (Source: MAFW 2016).

In India, mango is grown in almost all agro-climatic regions except extremely arid and temperate areas. Trends in area, production and productivity over 1991-2013 period (Fig. 1) reveal two temporally distinct phases of growth in Indian mango industry. During the first phase (1991-2001), total area and production increased by 1.5- and 1.2-times, respectively. During the second phase (2002-2013), area expanded at a similar pace but growth in production was relatively greater. Notwithstanding the steady surge in area and production, mango productivity consistently decreased during most of this period. Although green shoots of recovery are visible since 2011-12, productivity still remains below the base period of 1991-92 as well as the present global average. These observations necessitate a thorough examination of the ills plaguing Indian mango industry to draw a robust action plan for sustainable mango production. Poor orchard yields not only diminish the growers' profits, but also result in inefficient land and water use, reduced availability of nutritional fruits and higher market prices for the consumers. Because mango is grown in virtually every part of India having different agro-climatic conditions, a detailed understanding of region-specific constraints hampering mango crop is necessary to develop appropriate remedial measures. While many problems affecting mango crop are common throughout the country, there are several region-specific limitations that can be addressed by location-specific measures.

Table 2. Mango area, production and productivity in different states of India

State	Area ('000 ha)	Production (t)	Productivity (t ha^{-1})	Major growing districts
Uttar Pradesh	262.2	4300.9	16.4	Lucknow, Sharanpur, Unnao, Bulandshahar, J. P. Nagar
Andhra Pradesh	304.1	2737.0	9.0	Chittoor, Krishna, Vizianagaram
Karnataka	180.5	1755.6	9.7	Kolar, Ramnagara, Tumkur, Dharwad, Chikkaballapura
Telangana	190.9	1717.9	9.0	Khammam, Warangal
Bihar	149.0	1367.6	9.2	Darbhanga, Samastipur, Muzaffarpur, East Champaran,Vaishali
Gujarat	142.7	1125.6	7.9	Valsad, Navsari, Junagadh, Surat, Kutch, Amreli
Maharashtra	485.0	1212.5	2.5	Ratnagiri, Sindhudurg, Ahmdnagar, Pune
Tamil Nadu	161.6	785.5	4.9	Dharmapuri, Krishnagiri, Vellore, Dindigul, Thiruvallur, Theni
West Bengal	93.5	430.7	4.6	Malda, Murshidabad, North-24 Parganas, Hoogly, Midnapore (E)
Odisha	197.5	751.0	3.8	Dhenkanal, Rayagada, Koraput, Kalahandi

Source: MAFW 2016; with modifications

Reasons for Low Mango Productivity and Quality in India

Mango, aptly referred to as the 'King of Fruits', is widely grown in tropical and sub-tropical regions of India. India boasts a very rich genetic diversity of mango: over 1,000 recognized varieties/improved cultivars and innumerable landraces suited to varied commercial and traditional household needs are grown in different states. A very long history of mango cultivation in India has led to identification of superior cultivars, development of propagation techniques and successive refinements in cultivation practices. Available evidence suggests that Indian people had accumulated rich traditional knowledge on mango culture by 16th century AD or even earlier. In a nutshell, mango tree and its different parts remain deeply embedded in Indian art and tradition from time immemorial (Singh *et al*. 2015). All said and done, the fact remains that despite a rich legacy and a preeminent position in global mango production, India remains an insignificant player in global mango trade. Currently, Mexico is the leading mango exporting country accounting for ≈20% of the total global mango export. Although India has ≈16% share in the global mango exports, only ≈1% of the total mango produced is exported (Balyan *et al*. 2015). An estimated 10% of the total produce goes waste due to improper harvesting, handling and storage (Jha *et al*. 2015). These observations suggest that we should not remain too obsessed with our rich legacy in mango cultivation, but must be ready to address diverse challenges to transform Indian mango industry into a globally competitive profit making venture.

***Preponderance of senile orchards*:** Predominance of senile orchards is a major cause of poor mango productivity in India. Under Lucknow conditions, fruit yield starts declining after the trees have attained age of 40-45 years (Lal and Mishra 2008). In Alphonso growing areas of Maharashtra, tree vigor and productivity diminish in ≈30 y old trees. Canopy shading in older plantations (≥ 60 y) reduces light penetration and results in very low yields (≈2.5 t ha^{-1}). Tall and crowded trees also pose difficulties in orchard management and harvesting (Burondkar *et al*. 2000). In rainfed red loam soil areas of Karnataka, widely spaced Alphonso orchards become less productive ≈25 y after establishment (Reddy and Kurian 2011). In West Bengal, Himsagar orchards above 40 y age display very low productivity (Ray *et al*. 2009). In many conventional mango producing regions, *e.g*., in Chittoor (Gajanana *et al*. 2016) and Lucknow (Rajan *et al*. 2016), low yielding multivarietal orchards still exist. Despite low fruit yields, mango growers in these areas continue to maintain heritage trees for traditional household uses and for improving pollination services. Fruits borne on ageing trees may also be poor in bioactive compounds. For example, fruits from 30-y old Amrapali trees had less total phenols, ascorbic acid and antioxidants due to higher fruit respiration rate and the activities of polygalacturonase and pectin methylesterase enzymes. In comparison, fruit from middle-aged trees (18-y) were nutritionally superior and better suited to consumer and industrial needs (Meena and Asrey 2018).

***Yield declines in high density orchards*:** Release of high yielding, regular bearing mango hybrids Mallika (Neelum x Dashehari; semi-vigorous) and Amrapali (Dashehari x Neelum; dwarf) in 1970s gradually paved the way for high density orcharding in mango. After an incubation period of about three decades, these cultivars finally became the premium choices of mango growers. Amrapali in the Eastern states of Odisha, West Bengal, Jharkhand and Tripura, and Mallika in Karnataka and Maharashtra (Anon. 2011). In majority of situations, high density orchards of Amrapali show progressive decline in yield after ≈15 years in absence of annual pruning. In such dense orchards, poor light penetration results in reduced availability of photo-assimilates adversely affecting vegetative growth, flowering and fruit set (Sharma and Singh 2006a). Similarly, ≈25 y old high density orchards of Mallika and Dashehari also exhibit marked reductions in productivity (Singh *et al*. 2010). In Sirmour district of Himachal Pradesh, high density orchards (3 x 3 m) of Mallika, Dashehari and Amarpali became unproductive within a few years of first bearing. Dense canopies, virtually impenetrable to sunlight, altered orchard microclimate in such a way that trees could not withstand a few spells of severe frost and declined (Chauhan *et al*. 2013). High density Amrapali orchards (5-6 x 5-6 m) in many areas of Jharkhand state exhibit marked reductions in fruit yield after 20 years in absence of regular canopy management (Das and Jana 2012).

***Low yields in rainfed areas*:** Grown up mango trees can withstand soil moisture deficits albeit with appreciable reductions in fruit yield; water stress reduces the fruit size and accelerates the fruit drop. Mango is widely grown in many rainfed areas of India where one or another soil constraint(s) often compound drought-induced yield losses. In rainfed subtropical foothill zones of the north-western Himalayas, mango growing soils are gravelly (≈70% gravels and boulders) with low water holding capacity (WHC) (Rathore *et al*. 2013).

In Dharmapuri, Tamil Nadu (Budhar and Palaniappan 1993) and Chittoor, Andhra Pradesh (Gajanana *et al*. 2016) mangoes grown in rainfed red soil areas meet their water requirement mostly from residual moisture except in some cases where crop is irrigated at critical stages. In the Eastern Ghats Highland zone of Odisha, endowed with favourable climatic conditions for mango, undulating topography, low soil organic matter (SOM) and poor WHC make upland soils to remain dry for extended periods (Swain *et al*. 2012). Similarly, insufficient soil moisture availability is one of the major limitations to sustainable mango production in rainfed red and lateritic soil zones of West Bengal (Sharma *et al*. 2017), lateritic coastal soils of Deccan plateau (Rao and Rao 2007, Reddy and Kurian 2011) and black clay loam soils of Madhya Pradesh (Tiwari and Baghel 2015). Ironically, many of these areas receive high annual rainfall but ≈80% of the precipitation occurring during June-September is lost as run-off.

***Soil related constraints*:** Although mango can be grown on a wide range of soils, it does well on relatively deeper (watertable ≥ 2 m), well drained fertile lands having slightly acidic to slightly alkaline reaction (pH 6.5-7.5). It is, however, pertinent to mention that such ideal soil conditions seldom exist compelling the growers to raise mango plantations in marginal lands. Even some pockets of Malihabad mango belt in Lucknow having deep alluvial soils considered optimum for mango production suffer from mild to moderate alkalinity and calcareousness (Rajan *et al*. 2016) that can adversely affect root growth and nutrient absorption. In Alphonso growing Ratnagiri district and adjoining areas of Maharashtra, lateritic soils developed from basalt have poor fertility and low nutrient retention capacity. Heavy rainfall and undulating terrain further reduce nutrient availability by hastening the nutrient leaching. As a result, soils and mango trees exhibit deficiencies of many important nutrients. Improper nutrient management by the growers has also increased the severity of problem (Joshi *et al*. 2016). Mango growing acid soils of Jharkhand suffer from low water holding capacity, soil crusting, excessive nutrient leaching, deficiencies of P, Ca and Mg and phytotoxic levels of soluble Mn and Al. Application of lime to raise the soil pH and precipitate exchangeable Al as insoluble hydroxy aluminium is necessary for optimum mango yields in these soils (Naik 2014).

***Nutritional deficiencies*:** Low soil fertility is a major yield limiting factor in many mango growing areas. In India, mango growing soils are either inherently nutrient deficient or nutritional constraints have slowly cropped up due to poor management. In the last few decades, commercial mango cultivation has gathered momentum in several non-conventional areas where certain topographic and edaphic factors seem to be responsible for poor soil fertility. For example, soils in rainfed mango growing areas of Uttarakhand (Rathore *et al*. 2013) and Jharkhand (Naik 2014) are acidic, low in soil organic carbon (SOC) and deficient in major (NPK) and some micronutrients. Furthermore, high rainfall in these areas also increases nutrient leaching to the lower depths. Nearly 80% of the mango growing soils of Odisha are acidic and deficient in B and Zn resulting in low mango productivity (≈4 t ha^{-1}) (Samant *et al*. 2018). Quite the contrary, mango growing soils in traditional zones seem to have gone less productive due to unbalanced use of chemical NPK fertilizers. Mango orchard soils of central Indo-Gangetic Plains (IGP) were found to be deficient in SOC and N. Available Zn, Cu and Mn were deficient in 48, 14 and 8% of the sampled orchards, respectively. B deficiency was recorded in all soil and leaf samples. Nearly two thirds of the orchards showed fruit yields below the national average. Specifically, Zn and B were adjudged to be the yield limiting nutrients in this region (Kumar *et al*. 2012). Similarly, Mn, Cu and Zn were deficient in 92, 46 and 23% of the mango orchard soils in north-central Uttar Pradesh. Foliar nutrient analyses also indicated widespread deficiencies of K, Cu and Zn. SOC in majority of the orchards was below the critical limit of 0.58% apparently due to rapid SOM decomposition under high temperature conditions of the region restricting SOC build up. Moreover, virtually no application of organic manures by the farmers was also responsible for poor soil fertility (Kumar *et al*. 2015). P, Zn and B were found deficient in Alphonso orchards of Konkan, Maharashtra (Mahajan 2001). B deficiency in ≈60% of the orchard soils was ascribed to low B adsorption capacity, excessive leaf N and high free Al in soils that impaired B absorption by roots. High humidity, high temperature and long sunshine hours appeared to further aggravate B deficiency. Foliar application of B partially alleviated B deficiency symptoms (Raja *et al*. (2005). Mango orchard soils in Rajapuri, Gujarat were low in N, Mg, Mn and Zn. Surprisingly, trees did not show nutrient deficiency symptoms (*i.e*., hidden hunger) suggesting that continued exhaustion may cause sudden orchard decline. Over half of the orchards sampled were economically non-viable (Pimplaskar and Bhargava 2003). Despite several reports on soil and leaf nutrient status in mango, a lack of correlation between nutrient availability and fruit yield data in many studies makes it difficult to draw meaningful conclusions. Indiscriminate application of NPK fertilizers not only diminishes tree vigor and fruit yield but also leads to the depletion of secondary and micronutrients in mango orchards. Adequate supply of secondary and micronutrients is particularly necessary in areas prone to physiological disorders like soft nose, jelly seed and spongy tissue that cause internal flesh breakdown and may render 35-55% of the fruits unfit for human consumption.

Major production problems

Alternate bearing**:** Most of the commercial Indian mango varieties exhibit alternate cycles of heavy yield in 'on-year' followed by reduced or no fruiting in the 'off-year'. Though essentially a cultivar-specific trait, alternate bearing is also modulated by environmental factors and cultural practices. While some cultivars like Langra and Dashehari are distinctly irregular bearers, others like Alphonso exhibit inconsistent yields in on- and off-years. Despite continued efforts to understand the physiological and genetic bases of the problem, its underlying cause(s) still remain elusive (Kulkarni 2004). Cool-dry conditions are a major environmental trigger for floral initiation (FI) in mango, especially in tropical areas where relatively higher temperature and humid conditions suppress FI. In such situations, application of gibberellin-biosynthesis inhibitor paclobutrazol has been found promising (Hegele *et al*. 2006). Application of time series yield data can provide a precise quantification of alternate bearing intensity in mango and may help develop yield-prediction models in distinctly irregular bearer cultivars like Langra to empower the growers for optimizing input management for sustained yields (Singh *et al*. 2014).

Mango malformation**:** Malformation of vegetative and floral organs is a serious problem in north Indian mango varieties. Mango orchards in south and western India are seldom affected by this problem (Singh *et al*. 2012). Severe malformation incidence can trim fruit yields by 50-80% in susceptible cultivars (Singh 2006). Factors like excessive soil moisture, mite infestation, fungal and viral pathogens and herbicides seem to aggravate malformation incidence but the exact cause remains unclear. Recent studies have shown that fungus *Fusarium moniliforme* var. *subglutinans* could be the probable cause: it secretes different toxins called '*toxic principles*' linked to the malformation symptoms. Affected tissues produce metabolites like phenols and steroids, collectively called '*malformation inducing principles*', that cause different morphological and biochemical changes in the malformed plants. Different malformation symptoms- leaf epinasty, altered orientation of shoots and panicles, loss of apical dominance, hypertrophy of lenticels and increased gummosis- are an indication of increased ethylene accumulation caused by the aforementioned putative causal agents. Based on floral malformation intensity, Singh *et al*. (2012) categorized 44 diverse mango cultivars into four groups: resistant (no incidence; *e.g*., Bhadauran and Ellaichi); tolerant (1-10% intensity; Rataul and Safeda Malihabadi), susceptible (20.1-40% intensity; Chausa and Langra) and highly susceptible (>40% intensity; Amrapali and Mallika). A GIS-based spatial interpolation technique revealed regional differences in malformation incidence. Mango orchards in Delhi, Uttar Pradesh and Haryana were highly susceptible, those in Gujarat, Punjab and Jharkhand moderately susceptible and in southern states least susceptible to malformation (Nagaraja *et al*. 2012).

Physiological disorders: Mango crop is affected by many physiological disorders. Gaseous emissions from brick-kilns cause the development of '*black tip*' at the distal end of fruit. Small etiolated area gradually enlarges, turns black and checks the fruit growth. '*Internal necrosis*' of fruits starts with the development of water-soaked grayish spots on the lower side of the fruit. Enlargement of spots into dark brown necrotic area eventually leads to tissue disintegration, oozing of yellow droplets and fruit drop. '*Fruit clustering*', characterized by the formation of several dark green fruit lets at the panicle tip, results due to pollination deficits. Development of '*woody stem galls*' of varying diameter on limbs and branches adversely affects cultivars like Langra and Neelam. '*Red nose*' problem affects late maturing cultivars like Mallika. Development of pea to marble sized '*tumors*' on stylar end imparts an ugly look to the fruits. '*Jelly seed*' disorder, though seen in several cultivars, causes substantial damage in Dashehari fruits. Pulp near the stone becomes jelly-like and disintegrates while the outer pulp remains unaffected. '*Spongy tissue*' continues to be a serious bottleneck in the export of Alphonso fruits. Most of these problems can be contained by practices like mulching, provision of bee hives for pollination, balanced nutrition and early harvesting (NHM 2012, Shivashankar 2014).

Insect-pests and diseases: Numerous insect-pests and diseases are observed on mango trees. At least 18 insects and 14 fungal/bacterial pathogens cause appreciable economic losses in different growing regions. In addition, post-harvest infections like anthracnose often spoil the stored fruits. Nutritional deficiencies, especially those of K, Zn, Fe, Cu and B in marginal soils, and unfavorable climatic conditions weaken the trees making them more susceptible to pest-diseases infestations (NHM, 2012). Recently, an expert system called 'AMRAPALIKA' has been developed for diagnosing the most common mango diseases in Indian cultivars. It is a computer-based support to help the farmers identify a particular pathogen on the basis of symptoms so that corrective measures can be implemented timely (Prasad *et al*. 2006).

Post-harvest losses: Based on a survey conducted in 8 agro-climatic zones covering all major mango producing areas of India, Jha *et al*. (2015) found that overall total post-harvest loss at national level was 9.16% (INR 7186 Crore in monetary terms). They separated total loss into losses at the farm (6.92%) and in storage chain (2.24%). Among regions, overall total loss was only 4.91% in western plateau and hills region (including Alphonso growing regions of Maharashtra) but relatively higher (10%) in IGP region. In all other regions surveyed, post-harvest losses were invariably >8.5% reflecting poor handling and storage operations. Relatively less post-harvest losses in Western India can be ascribed to the adoption of improved harvesting and handling practices; especially in Alphonso growing areas.

Table 3. Improvements in selected soil properties after implementation of conservation practices for 5-y in a mango orchard on an Alfisol.

Soil properties	Intensively managed	Conservation Horticulture
Organic C, g kg^{-1}	4.16	6.32
Active C(AC), mg kg^{-1}	18.06	37.7
Soil microbial biomass C, mg kg^{-1}	128	199
C mineralization, mg kg^{-1} soil day^{-1}	10.68	18.71
pH	5.84	6.18
CEC, cmol (p^+) kg^{-1}	7.7	8.6
Soil bulk density, Mg m^{-3} (0-5 cm)	1.32	1.03
Bacteria	6.2	13.6
Fungus	4.6	18.7
Dehydrogenase, µg $TPFg^{-1}$ soil h^{-1}	117	414.04
Urease, µg Urea g^{-1} soil hr^{-1}	379	602
Phosphatase, µg pnp g^{-1} soil h^{-1}	8.43	9.94
Arylsulphatase, µg pnp g^{-1} soil h^{-1}	6.18	8.66
Earthworms, numbers	0	7

Source:ICAR-IIHR, Bengaluru; with modifications

Technological interventions for improving productivity

Different improved horticultural practices have been developed for reviving the productivity of ailing mango orchards in traditional belts and to obtain sustainable yields in non-traditional areas. It is, however, pertinent to mention that a single technique may not always be a panacea for varied problems suggesting the need to choose '*a la carte*' package to achieve the desired results. It seems that in spite of being aware of potential benefits of improved technologies, mango growers' often find it difficult to adopt them. Advantages of such techniques and factors stalling their adoption are briefly reviewed in the succeeding paragraphs:

Sustainable soil management practices

Foregoing discussion makes it evident that adverse soil conditions are a major hindrance to sustainable mango production in many mango growing areas of India. In certain cases, lands available are often completely unsuitable for mango cultivation. Yet, concerted R & D efforts coupled with farmers' wisdom have made it possible to raise commercial mango orchards in such areas.

Lateritic Oxisols: Development of mango plantations on Oxisols (laterites) of Konkan region is perhaps the best example of how wastelands can be utilized for sustainable horticultural production. In several pockets of Konkan region, unabated deforestation for decades caused denudation of hill slopes exposing the hard lateritic rock surfaces to the erosive impact of high intensity rains. Over time, these lateritic barren surfaces became degraded to the extent that their restoration seemed virtually impossible. Thanks to the creativity of local farmers, however, these lands now produce Alphonso mango fruits for the export and domestic markets. In this indigenous method, existing native trees are uprooted followed by blasting of below ground hard surfaces (locally called *jambha dagad*) to create bowl-shaped pits that are filled with non-native soils to overcome the nutritional constraints in the local acidic soils. Using this technology, over 130,000 ha hard lateritic lands in Ratnagiri, Sindhudurg and Raigad districts have been put under Alphonso cultivation. After planting, due care is necessary for soil placement around saplings for the proper development of feeder roots. On windward south-western side, a small semi-circular stone wall

Table 4. Intercrops recommended/adopted in different mango growing regions of India.

Region	Agro-climatic conditions	Orchard characteristics	Intercrops recommended/adopted
North-western Himalayas[1]	Humid subtropical; sandy loam soils (pH 6.5-7.0)	CV. Mallika, 8 × 8 m	Cowpea-toria and okra-toria rotations in pre-bearing phase Turmeric and colocasia in bearing orchards
North-eastern Himalayas[2]	Humid subtropical; sandy loam acidic soils (pH 5.3-5.8)	CV. Kalcho, 8 x 8 m	Cowpea, roselle, French bean, pineapple and turmeric in bearing orchards
Indo-Gangetic plains[3,4]	Humid subtropical; sandy loam slightly alkaline soils	CV. Dashehari	Brinjal and bottle gourd in pre-bearing orchards
	Humid subtropical	CV. Dashehari	Wheat, brinjal and potato + pumpkin
Central India (Mandsaur)[5]	Rainfed, black clay loam soils	CV. Dashehari, 7 × 7 m	Companion intercropping of pigeon pea + soybean; sequential intercropping of cowpea-chickpea
Deccan plateau[6,7]	Rainfed lateritic coastal soils	3-y old trees	Green chilli and palak in pre-bearing phase
	Semi-arid red soils	Pre-bearing orchard	Brinjal-onion rotation
Eastern Ghat Highland Zone[8]	Rainfed uplands; sandy clay loam soils (pH 6.3)	CV. Totapori; 10 × 10 m	Guava as filler tree and cowpea/French bean as intercrops
Western India[9,10]	Rainfed light soils	5-6 y old trees; 10 x 10 m	Soybean-mustard sequence
	Rainfed plains zone of western Maharashtra	CV. Kesar	Minor millets and pulses up to 5-y

Source: [1]Rathore *et al*. (2013), [2]Sahoo (2016), [3]Singh *et al*. (2015), [4]Singh *et al*. (2008), [5]Tiwari and Baghel (2015), [6]Rao and Rao, (2007), [7]Sarkar *et al*. (2004), [8]Swain *et al*. (2014), [9]Pawar and Sarwade (2006), [10]Bhosale *et al*. (2016)

(locally called *gadaga*) is created to prevent uprooting of the trees by strong winds as tree roots remain confined to the upper soil layers. Trees on bare rocks (locally called *katals*) are dwarf and bushy- a desirable horticultural trait for orchard management and harvesting. After about three years, when roots are properly developed, watering is not required though manuring is done to support tree growth (http://devgadmango.com).

Acidic soils: Mango is widely grown in acidic soils of Tripura, Wes Bengal, Jharkhand, Odisha and Maharashtra where nutritional deficiencies and toxicities often take a heavy toll on fruit yield and quality. Mangoes grown in sandy acidic soils display K deficiency symptoms like small fruits and low sugar levels necessitating K applications to improve fruit size and quality; albeit with caution because excessive K may reduce Mg uptake. Although conclusive evidence is lacking, Ca deficiency in mango growing soils of Konkan is said to predispose fruits to spongy tissue development. Boron deficiency usually occurs on acid soils that have been limed particularly when trees suffer from extended periods of water stress. Though Mo deficiency is not a major issue, prolonged hidden hunger of Mo can be detrimental to mango productivity. Aluminum toxicity in Alphonso orchards in Oxisols of Konkan region is manifested as P deficiency, reduced growth and very low yields. While terminal shoot and root growth are suppressed, lateral branches continue to grow. Severe Al toxicity suppresses root growth to the extent that strong winds would uproot the trees. Mango orchards on Alfisols in Odisha and West Bengal also exhibit this problem; especially when soil pH drops below 5.5. Symptoms of Mn toxicity like development of red spots and withering of leaves are also noted on highly acidic sandy soils in coastal areas or in flood prone areas. Most of these problems can be overcome by liming to raise the soil pH. Exact quantity of lime to be applied depends on factors such as desired change in soil pH, buffering capacity of the soil, type of liming material and the texture of liming material. To circumvent Al and Mn toxicities, soils with pH below should be limed. In general, fine textured soils

Box 1. Commercial mango cultivation turns the fortunes of tribal farmers in Odisha

Realizing the huge commercial importance of mango, Government of Odisha has initiated many programmes to develop a climate resilient mango industry with special focus on creating Farmer Producer Organizations, farmers' training, improving transport and storage infrastructure and contingency planning. Efforts in this direction since early 2000s have paid rich dividends: mango area has steadily increased in rainfed tribal dominated Dhenkanal, Rayagada, Koraput and Kalahandi districts. Increased availability of quality planting material, technological interventions by local research institutions (*e.g.*, IIHR CHES, Bhubaneswar), establishment of growers' associations (*e.g.*, 'HARPAL- Horticulture and Agriculture Related Panchayats Association for Livelihood) and marketing companies (*e.g.*, Dhenkanal Fruits and Vegetables Marketing Company Limited) have propelled the growth in mango production. Varieties like Amrapali and Mallika are increasingly being planted in new areas. In Kalahandi district alone, having 12,000 ha under mango, crop area is increasing by 500 ha annually. Tribal households fetch remunerative returns (₹ 75,000-100,000 ha^{-1} $season^{-1}$) by high density orcharding (5 x 5 m) in lands otherwise considered to be less productive. Despite multifarious benefits to the tribal farm families in terms of higher incomes, employment opportunities and nutritional security, mango production continues to be beset by poor marketing linkages, lack of crop insurance cover and climate change impacts often compelling the growers' for distress sales at throwaway prices (Source: Business Standard 2013b, Mustaquim 2015, OrissaPost 2015, New Indian Express 2017).

have greater buffering capacity than coarse soils and need more lime to achieve the same results. Additions of organic residues, FYM, vermin composts, green manures and animal wastes to acid soils can reduce the total concentration of Al in soil solution and/or the concentration of monomeric Al in solution and thus reduced Al phytotoxicity. Gypsum may also be used to correct Al toxicity problems in the subsurface soil. However, it is to be remembered that in contrast to lime that raises the soil pH gypsum alleviates Al toxicity by providing soluble Ca that reducee Al saturation on soil exchange complex (Ganeshamurthy *et al*. 2016).

Salt-affected soils: In many areas, sodicity/salinity and related problems like high soil pH often hamper mango growth and fruit yield. Singh *et al*. (2008) studied the effects of pit and auger-hole methods of planting on establishment and growth of mango plants in a sodic soil (pH_2: 10, ESP: 70-80) in central IGP. Planting was done in pits (90 cm^3) or in auger-holes (120 cm deep, 45 cm diameter at surface and 20 cm at base) at 5 x 4 m spacing. Auger-holes were filled with the mixture of original soil, 7.5 kg gypsum, 4 kg usar tor khad (UTK), 10 kg FYM and 20 kg silt while pits were filled with a mixture of original soil, 15 kg gypsum, 8 kg UTK, 20 kg FYM and 40 kg silt. After 10 years of planting, tree survival was 55% in pit method and 25% in auger-hole method. Soil pH and salinity also marginally declined due to amendment application and litter fall. Notwithstanding relatively high tree mortality, pit method of planting with gypsum application can still prove superior over other methods of planting under similar conditions. Use of polyembryonic sodicity tolerant rootstocks (GPL-1 and ML-2) in grafting can further enhance the acceptability of this practice. Available evidence also defies the logic that mango should not be planted on saline soils, particularly those underlain with saline groundwater. Reports from Mediterranean countries like Spain (Zuazo *et al*. 2004) and Israel, where salinity in soil and groundwater often hampers crop production, suggest that an ensemble of improved techniques *viz*., salt tolerant rootstocks (Gomera-1, Gomera-2, 13-1), drip irrigation and mulching can make it possible to grow mangoes in saline soils. Studies conducted at ICAR-CSSRI Nain Experimental Farm, Panipat have shown that planting on raised beds (~2 feet above ground level) and saline water coupled with basin irrigation with marginally saline water (EC_{iw} 3-4 dS m^{-1}) resulted in profuse growth in grafted guava (cv. Allahabad Safeda) and bael (cv. NB-5) plants in lands otherwise considered to be unsuitable even for field crops. Successful establishment and growth of these crops was ascribed to the absence of direct contact between plant roots and saline water as well as leaching of salts to the lower depths. These observations suggest that even mango can be raised in moderately saline soils; especially when good quality water is available for irrigation at critical crop growth stages.

Mango farming in wastelands in tribal areas: Under Wasteland Agriculture Development Initiative (WADI), NABARD has been promoting orchard establishment in tribal dominated areas of different states. Wadi, literally 'small orchard' of 1 acre area, constitutes the core of the WADI program around which other development interventions are built and strengthened. Depending on prevailing socio-economic milieu and agro-climatic conditions, two or more fruit crops are planted to minimize the climatic and marketing risks. Tribal families having < 2 ha of land are selected for holistic land development plans including soil and water conservation measures on watershed basis, capacity development, provision of credit and crop inputs, drudgery reduction measures and women empowerment. Promotion of mango farming under WADI has led to manifold increase in farm incomes in many tribal areas of country with simultaneous improvements in soil quality transforming the uncultivated wastelands into viable economic assets. WADI model of tribal empowerment has gained global applaud and is increasingly being seen as a reproducible, sustainable model for poverty alleviation in different parts of the world (www.nabard.org).

Conservation agriculture in mango orchards: Conservation horticultural practices are gaining momentum to achieve interrelated goals of high productivity and sustainable natural resource management. Successful demonstration of conservation practices in mango cultivation at ICAR-IIHR, Bengaluru has encouraged many farmers to adopt this system for sustainable profits. Conservation practices, *inter alia*, minimal soil disturbance, improved orchard floor management and prevention of uncontrolled grazing lead to SOM accumulation, reduced nutrient loss, weed control, carbon sequestration, nutrient recycling and improved soil structure while curtailing the production costs and enhancing the fruit yield. Importantly, there was concurrent improvement in the diversity of beneficial orchard fauna in orchards where conservation measures were implemented (Table 3).

Mango-based agro-forestry systems for efficient utilization of interspaces

In India, mango plants usually start bearing 4-5 years after planting and attain full bearing capacity usually after 10 years. Widely spaced orchards (10 x 10 m) provide ample scope for growing short duration crops for harnessing the productivity of interspaces; especially during the pre-bearing phase. Factors such as crop duration, compatibility with mango trees and market demands influence farmers' decision making in intercrop selection. Ideally, short duration, locally adapted leguminous crops providing higher net returns should be taken as subsidiary crops. Mango-based cropping systems can maintain year-round cash flow improving the standard of living of farm families. Intercropping can particularly sustain incomes of small and marginal farmers during pre-bearing phase and off-years of production. Suitable intercrops for mango orchards have either been recommended by the research institutions or, in some cases, have been spontaneously adopted by the growers themselves in different parts of the country (Table 4).

Intercrops not only provide additional returns to the growers, but also lead to tangible improvements in fruit yield and soil quality. In north-eastern India, average mango fruit weight was the maximum in mango + roselle + French bean system followed by mango + cowpea system. Average mango yields and land equivalent ratio were invariably higher with intercrops than in sole mango crop. Intercropping also improved the soil health by enhancing available NPK (Sahoo 2016). In gravelly soils of humid subtropical north-western Himalayas having high infiltration rate (26 mm h^{-1}), cowpea, okra and toria can be profitably intercropped with mango up to 4-y of tree age. Subsequently, canopy spread interrupts light interception resulting in reduced intercrop yields. In grown up trees (≥ 11 y), shade tolerant turmeric and colocasia should be intercropped for additional returns. Compared to initial values, mango + cowpea-toria system improved SOC, total NPK and reduced pH by 49.0, 56.3, 48.6, 58.5 and 11.6 %, respectively whereas mango + turmeric system increased SOC, NPK and reduced pH by 51.0, 45.0, 29.7, 29.0 and 3.4 %, respectively, within 0-30 cm soil depth (Rathore *et al*. 2013). Intercrops gradually improved the physicochemical properties of mango orchard soils in rainfed uplands of Odisha. Mango + guava + cowpea system resulted in the maximum improvements in bulk density, EC, WHC, SOC and pH within 0-30 cm depth. This system also displayed the highest available N and K contents (Swain *et al*. 2012). Pigeon pea and black gram intercrops not only increased the fruit yield but also improved SOC and available NPK while decreased soil pH at Jhargram, West Bengal (Dhara and Sharma 2015). Under Lucknow conditions, intercropping of brinjal enhanced mango yield by ≈9% compared to control. Monetary return (₹ 160,300 ha^{-1}) was over threefold higher in mango + brinjal system than ₹ 49920 ha^{-1} in sole mango crop (Singh *et al*. 2015). A 5-y study revealed that co-planting of N-fixer *Leucaena leucocephala* enhanced mango growth in tropical Alfisols of southern India (Swaminathan *et al*. 1998).

Paclobutrazol use for flower induction

Inconsistent response of chemical treatments and cultural practices in overcoming alternate bearing enhanced the interest in plant growth retardants for bearing regulation in mango. Although many such growth retardants were found effective, anti-gibberellin growth retardant paclobutrazol (PBZ) finally emerged farmers' choice due to low prices and ease in application. Initial experiments conducted at Vengurla (Burondkar and Gunjate 1993) and Bengaluru (Kurian and Iyer 1993) revealed that soil drenching (2.5, 5 or 10 g tree^{-1}) of PBZ could induce regular cropping in distinctly alternate bearing Alphonso cultivar by suppressing the September-October vegetative flushes and annual shoot growth. PBZ treated trees displayed early and profuse flowering resulting in over threefold increase in fruit yield without any adverse effects on quality. At Bengaluru, however, application of 10 g PBZ tree^{-1} reduced the fruit size and quality, and delayed the fruit ripening. Foliar sprays of PBZ were also equally effective but significantly lower costs and convenience in application made soil drenching more appealing to the farmers. A subsequent study by Burondkar *et al*. (2000) revealed that severe pruning and soil applied PBZ (7.5 or 10 g tree^{-1}) could even restore the productivity of declining Alphonso trees. PBZ treated trees produced nearly twelvefold higher yields than control. These findings eventually led to commercial adoption of PBZ in different mango growing areas of India. In Alphonso growing areas alone, ~20,000 l of PBZ is used every year in July-August over an area of ~10,000 ha for flower induction (Burondkar *et al*. 2013). Investigations carried out at Dapoli centre of AICRP on Water Management showed that maximum fruit yield in Alphonso (3.8 t ha^{-1}) was recorded when PBZ (@ 3 ml per metre of canopy diameter) was applied along with the recommended dose of fertilizers (RDF) through drip irrigation. Mean fruit yield was only ~ 2 t ha^{-1} and ~1.5 t ha^{-1} in RDF without PBZ and 50% RDF + PBZ treatments, respectively. Similar results have been reported from Parbhani where PBZ application @ 2 ml significantly improved fruit yield in drip irrigated high density orchards of Mallika, Neelam, Totapari and Fazali cultivars.

Alphonso trees flower during December-February and fruit harvesting extends from the third week of March till May end. Fruit arrival on markets peaks in the second fortnight of May resulting in market glut. While early (February-March) harvested fruits fetch premium price (~₹ 800 dozen^{-1}), prices drop by one-fourth during the peak season (April-May). This has led to increased interest in inducing early flowering to maximize the returns to the Alphonso producers. Alphonso orchards along the west coast in south Konkan covering ~30,000 ha area often exhibit off-season flowering during August-September every 2nd or 3rd year that is believed to be caused by water stress, mechanical leaf shaking and deposition of sea-borne salts. Nonetheless, this is a rare phenomenon and fruits borne on off-season panicles are also spoiled by anthracnose and blossom blight pathogens. PBZ application has also been found effective in advancing Alphonso flowering. When applied into soil on 15th May, PBZ can advance the flowering by 82 days without impairing fruit weight and TSS. Nonetheless, suitable technology is still needed for inducing vegetative shoots required for early flowering (Burondkar *et al*. 2013).

Studies have shown that PBZ does not persist in soils, leaves and fruits; thereby allaying the consumer fears over possible health problems with PBZ intake. Regardless of the total amount of PBZ applied under varying orchard situations, Sharma *et al*. (2008) did not found PBZ residues above quantifiable levels (0.01 ppm) in 80% of the whole mango fruit and in 100% of the mango pulp samples from Konkan region. Again, no PBZ residues were detected in tree basin soils where PBZ had been applied continuously for 5 or more years in the past. Similarly, Bhattacherjee and Singh (2015) found that PBZ residues dissipated in soil from initial values of 3.51/7.04 to 0.01/0.03 mg kg^{-1} after 300 days of application of normal (0.8 g)/higher (1.6 g a.i. tree^{-1}) doses in Dashehari trees. Residues in leaves gradually increased after 240 days of PBZ application but then declined with time. Premature fruits harvested between 40-70 days after fruit set contained PBZ below permissible limit (0.5 mg kg^{-1}), but no residues were found in fully mature fruits harvested after 85 days of fruit set. In areas where PBZ is used, certain changes in irrigation and fertilizer management may be necessary. For example, Kotur (2012) observed that PBZ application reduced root activity and caused roots to move closer to the trunk and soil surface during seasons of higher soil moisture regime. In such trees, fertilizer should be placed close to the trunk (between 90-160 cm radial distances) compared to farther placements at 160-230 cm and 230-300 cm in non-treated trees to achieve high fertilizer use efficiency. Currently, PBZ is available as two commercial formulations, *viz*., Cultar and Austar that seem to be equally effective in flower induction. However, Austar comes at nearly 40% less market price than Cultar (Kumbhar *et al*. 2009).

High density planting

In India, mango varieties are usually planted at 10-12 m spacing accommodating 70-100 trees ha^{-1}. Low yields

(≈5-7 t ha^{-1}) in such orchards not only curtail growers' profits but also result in inefficient use of land and water resources. In contrast, HDP can maximize the resource use efficiency resulting in at least 2-3 times higher fruit yields than widely spaced orchards. In India, mango HDP area has consistently increased. In many non-traditional areas like Odisha and Jharkhand, new mango orchards are being established at reduced spacing of 4-6 m. Studies conducted at a multivarietal HDP site in Jamnagar, Gujarat (188 ha area; 102,000 trees) showed that doable practices such as planting of pollinizer cultivars (in every 10th row), biofencing with casuarina, fertigation and application of PBZ can result in very high productivity even in extreme arid areas considered to be unsuitable for mango. While pollinizer partners improved the fruit set, biofence insulated trees from the scorching high velocity winds. Improved management practices virtually eliminated pest-disease infestations and resulted in exceptionally high fruit yields of ≈15 t ha^{-1} in only 7-y old Tomy Atkins, Maya, Kesar, Totapuri and Mallika cultivars (Gunjate *et al*. 2009). Such improved practices have also been successfully used for establishing a hi-tech mango plantation (60 ha area) in Jalgaon, Maharashtra- a non-traditional mango area- afflicted by the problems of salinity and fresh water scarcity (Krishna *et al*. 2009). The practical utility of mango HDP in enhancing farm incomes is perhaps best illustrated by the booming mango business in tribal areas of Odisha state (Box 1).

Farmers' interest in ultra high density planting (UHDP) has also increased in many areas. For example, Banganpalli mango growers in coastal Andhra Pradesh are gradually switching over to UHDP (3×2 m; over 1600 trees ha^{-1}) to grow off-season Punasa (Royal Special) variety. In UHDP, trees are pruned in December to delay the flowering and avoid the production glut. Profuse flowering in April produces a bumper crop in August-September when the market prices peak coinciding with the Onam festival in Kerala and growers fetch nearly double the price than during the main season. Even during the main season, Punasa growers realize almost three times higher profits than Banganapalli producers (Murali 2017). These developments have even prompted private players to launch specific projects to promote HDP/UHDP in mango. Jain Irrigation Systems Limited and Hindustan Coca-Cola Beverages Pvt. Ltd. have jointly launched 'Project Unnati' to promote UHDP in mango. This initiative aims to increase UHDP area to 10,000 ha in the next few years in Tamil Nadu, Andhra Pradesh and Karnataka. UHDP accommodates ≈1750 trees ha^{-1}. Orchards attain full bearing potential in 3-4 years and display 2-3 times higher productivity. The project aims at creating an ecosystem that delivers higher growth and income for farmers by demonstrating innovative methods of cultivation which lead to higher productivity, lower operating cost and increased utilization of inputs including water and nutrients (http://www.jainfarmfresh.com/unnati/; Varadharajan, 2015).

Water saving technologies

***Rainwater harvesting*:** Rainwater harvesting for irrigation can substantially enhance the productivity of drylands. Rainwater harvested using structures of different sizes and shapes can be used for supplemental irrigation and/or groundwater recharge. In Chittoor (Andhra Pradesh), farm pond water is profitably used for supplemental irrigation in mango and vegetables (Kumar *et al*. 2016). Half-moon shaped micro-catchments should be constructed across mango trees to capture surface runoff in hot semi-arid areas of Karnataka. Vetiver grass should be planted on catchment bunds to control soil erosion. Mango trees in the half-moon system show ≈22% higher fruit yield than control (Ali *et al*. 2017). Cup-and-plate system of rainwater harvesting and mulching with paddy straw or black polythene led to the maximum increase in fruit yield in 'Arka Neelachal Kesri' HDP (5m x 5m) at Bhubaneswar, Odisha (Samant *et al*. 2015). A rainwater harvesting structure called '*Jalkund*' (8.0 m long, 6.0 m wide and 1.5 m high) can store ≈72,000 l water for irrigating ≈0.2 ha crop area through drip. A drainage channel is constructed across the slope on upper side of the *Jalkund* for draining the excess water. All sides and bottom of *Jalkund* should be lined with 250 GSM thickness silpaulin polyfilm to arrest the seepage. This intervention, originally developed for the rainfed areas of Goa, can be adopted in other regions with some modifications (Verma *et al*. 2013).

Mulching: Mulching with farm wastes or black polythene improves soil moisture availability, moderates soil temperature, reduces the erosive impact of rainfall, suppresses weed growth and improves SOM after decomposition. Mulching with paddy straw or grass (each at 1 kg m^{-2}) enhanced soil moisture availability and rhizome yield of turmeric intercropped with Gulabkhas trees in an acidic (pH: 5.2) red lateritic soils of Odisha (Kumar *et al*. 2008a). Organic mulching and deficit irrigation (30 l water $tree^{-1}$ at 10 days interval) increased Amrapali fruit yield by 2.5-times over control at Mohanpur, West Bengal (Singh *et al*. 2014). Black polythene mulch (100 µm) stimulated lateral root growth in fertile upper soil layers. Mulched Chausa and Langra trees had more tubular hairs with prominent conductive tissues and showed profuse flowering and very less fruit drop resulting in higher fruit yields presumably (Singh *et al*. 2009). Mulching and pre-harvest sprays together can extend the quality and storability of mango fruits. Borax (1.0%) spray and polythene mulch improved yield and quality (TSS and total sugars) of Dashehari fruits. Substitution of borax with $CaCl_2$ (2.0%), however, was better in extending the fruit shelf-life by arresting the physiological loss in weight (PLW) (Singh *et al*. 2012). Mulching with dried leaves and sprays of *Pseudomonas fluorescens* FP7 (0.2%) and chitin (0.5%), and 1% $CaCl_2$ delayed the ripening, reduced PLW and anthracnose infection and extended the fruit shelf-life (Suresh *et al*. 2016). Mulching with black polythene and borax (1.0%) application 30 days before harvest improved fruit quality while $CaCl_2$ (2.0%) application reduced PLW in Amrapali fruits (Bhusan and Panda 2015).

Pitcher irrigation: In this highly efficient traditional method of irrigation, unglazed porous earthen pots containing water are buried under the soil to provide controlled irrigation to plants. Water slowly moves out through the wall of buried pot to meet the plant's water requirement. In certain cases, pitcher irrigation results in even higher WUE than drip irrigation. This method can also permit sustained use of saline water in irrigation. Pitcher irrigation and mulching with coconut husk and crop residues has emerged as a popular practice for raising mango plantations in parts of rainfed Alfisols region in southern India (Palaniappan *et al*. 2010). A study conducted at Rahuri, Maharashtra revealed that provision of 2 pitchers of 4 l capacity and 2-days irrigation interval was superior over other treatments with regard to *in situ* establishment of mango rootstocks. Plants in surface irrigation treatment (at 75 mm CPE) and those receiving 1 l water day^{-1} could hardly survive and did not attain graftable size (Devbhat 1995). Provision of pitcher irrigation along with integrated nutrient management and introduction of intercrops (pigeon pea, paddy, beans and vegetables) played a critical role in the adoption of mango farming in wastelands of Navsari, Gujarat (Tandel *et al*. 2014). Pitcher irrigation ensured 96% survival in mango saplings of cv. Kesar under south Gujarat. Provision of one pitcher of 10 l capacity filled weekly could save as much as 50% irrigation water while resulting in better plant establishment (Shrivastava *et al*. 2010).

***Drip irrigation*:** Daily total water requirement (WR) of mango varies with climate, tree age, season and ground cover. Singh *et al*. (2007) estimated the reference ET for drip irrigation (DI) in mango at Dehradun (per-humid) and Pantnagar (moist sub-humid) in Uttarakhand, India using FAO Penman-Monteith model. Average daily WR of 1-y old plants in Dehradun region ranged from 2.1-16.2 l day^{-1} $plant^{-1}$. WR increased with age and became constant in fully developed 35-y old trees. Peak WR of matured trees was estimated to be 139 and 129 l day^{-1} $plant^{-1}$ with and without ground cover, respectively. WR was very high from April-June and then progressively declined. At Pantnagar, average WR of 1 to 40 years old trees varied from 2.45-183 l day^{-1} $plant^{-1}$ and from 3.85-197 l day^{-1} $plant^{-1}$, with and without ground cover, respectively. Numerous studies have shown the usefulness of DI for reducing the water consumption and improving the fruit yield and quality. Application of 100% recommended dose of fertilizers (RDF; 120-75-100 g NPK $tree^{-1}$ $year^{-1}$) along with irrigation water (24 L day^{-1} $plant^{-1}$) resulted in the highest fruit yield and quality in an Alphonso UHDP (Prakash *et al*. 2015). Fruit yield was much higher (5.44 t ha^{-1}) in fertigation treatment compared to 3.58 t ha^{-1} when NPK were applied in tree basins under Lucknow conditions (Adak *et al*. 2014a). DI at 80% WR and black plastic mulch resulted in the highest fruit yield (15.8 t ha^{-1}) in an Amrapali HDP (5 x 5 m) in clay loam soils of Odisha. Although DI at 60% WR led to the maximum water use efficiency (WUE), the highest B: C ratio was observed in 80% WR treatment (Pradhan *et al*. 2010). Black plastic mulch (100 μm) and DI conserved soil moisture, checked weed growth and improved fruit yield and quality in 15-y old Dashehari orchard in clay loam soils of Raipur, Chhattisgarh. Maximum fruit yield, 122% higher than in basin irrigation, was recorded in DI at 60% WR. WUE was 0.98 and 3.2 q ha^{-1}-cm in DI and control treatments, respectively (Panigrahi *et al.* 2010). Dry grass mulch and DI at different pan evaporation replenishment (PER) rates (25, 50 and 75%) significantly improved canopy volume and fruit yield in mango cv. Lat Sundari planted in an acidic red lateritic soil of Odisha. Total soil moisture content in the top 30 cm soil was nearly two- and three-fold higher in DI at 75% PER compared to mulched rainfed and rainfed trees, respectively. Improved availability of soil moisture ensured higher nutrient translocation to sink tissues for optimum fruit growth (Kumar *et al*. 2008b). DI at 75% WR coupled with the application of 100% NPK (100 g each) and 75 kg FYM $tree^{-1}$ led to the highest net income in a Kesar HDP (6 x 5 m) in semi-arid Alfisols of Andhra Pradesh (Sujatha *et al*. 2006). In hot, humid areas of Odisha, Amrapali trees should be mulched (10 cm thick layer of paddy straw or 100 μ UV stabilized black polythene) and drip irrigated at 50 or 75% PER during fruit setting to fruit maturity period (February-May) to get the optimum fruit yield and quality (Samant 2018). Sub-surface drip has been found superior over surface drip in terms of fruit yield, quality and WUE under south Gujarat conditions. Highest mango yield (19 t ha^{-1}), WUE (32.3 kg ha^{-1} mm) and net profit (INR 253,100 ha^{-1}) was recorded when irrigation water was applied through drip pipes buried at 50 cm depth in 9-y old Kesar trees. The corresponding values of yield, WUE and net profit in surface drip treatment were 14 t ha^{-1}, 23.6 kg ha^{-1} mm and INR 179,000 ha^{-1}, respectively.

Deficit irrigation: Recently, some studies have shown that irrigation water volumes in mango orchards can further be reduced by adopting deficit irrigation (DFI) and partial root zone drying (PRD) techniques. DFI seems to be quite useful in semi-arid and humid areas where rainfall can meet crop WR at critical stages and also leach the salts accumulated during the irrigation season. Less utility of DFI in arid climates emanates from the fact that salinity may develop even with the prolonged use of fresh water. Two variants of DFI are regulated deficit irrigation (RDI) and sustained deficit irrigation (SDI). In PRD, only half of the root-system is irrigated while the rest half is kept dry. Compared to control trees receiving water at 100% of ET_c, PRD and RDI methods of irrigation (50% of ET_c in each case) led to much higher WUE in 14-y old ‘Chok Anan’ trees grafted on ‘Talap Nak’ rootstocks (4 m 4 m) in Regosols (high stone content, low WHC) of Thailand. Average fruit yields in control, RDI, PRD and no-irrigation treatments were 83.35 kg, 80.16 kg, 80.85 kg and 66.1 kg $tree^{-1}$ over a 3-y experiment period. Due to marginal yield reduction, trees in deficit irrigation treatments showed considerably higher WUE reflecting water saving of 30-50% (Spreer et al. 2009). In semi-arid Bahia region of Brazil (≈650 mm annual rainfall), RDI (50% ET_c) in 9-y old Tommy Atkins trees (8.0 x 8.0 m; sandy loam eutrophic Fluvic NeoSol) did not affect fruit productivity and quality. Although differences for WUE were non-significant among treatments, there can still be appreciable water saving by switching over to RDI (Cotrim *et al*. 2011). SDI treatment providing 50% of ET_c is recommended for the highest mango yield (18.4 t ha^{-1}) and WUE (7.14 kg m^{-3}) in costal Mediterranean areas of Spain (Zuazo *et al*. 2011).

Nutrient Management

Nutritional requirement of mango trees is governed by factors such as climate, tree age, bearing habit and potential yields. In countries like India where mango is grown under highly varied conditions, it may not be possible to develop a universal orchard nutrition schedule applicable to all the growing areas. This problem can partly be overcome by developing regional-scale models to assess the nutritional needs of mango orchards. Stassen *et al*. (2000) standardized a model for nutrient uptake and distribution in mango using 2-y old bearing ‘Sensation’ trees. They found that nutritional requirements can be expressed in terms of fruit yield. If yield information is unreliable then it should be based on the stem circumference (cm) of representative trees in the orchard. Leaf and soil analyses can also be used to adjust these guidelines. This model was also successfully tested in 6- and 18-year-old trees under field conditions. A 10-y study revealed that N at 50 and 100 g $tree^{-1}$ $year^{-1}$ of age resulted in optimum canopy development and maximum fruit yield, respectively, in Totapuri trees in rainfed soils of Karnataka. P application was economic only at higher rates while K application did not have any beneficial effect on young trees (Raddy *et al*. 2000). Another long term (15-y) study showed that 100 g N and 100 g K_2O $tree^{-1}$ $year^{-1}$ of tree age from 3rd and 10th orchard years and continuation of the 10th year dose thereafter led to the maximum returns in 'Alphonso' mango under rainfed conditions (Reddy *et al*. 1998).

Assessment of plant’s nutritional needs on the basis of visual observations is grossly impractical. By the time plants exhibit nutritional deficiencies, irreparable metabolic damages could have occurred; particularly in the perennial trees. Conventionally, tissue analysis is considered to be a promising tool to assess nutritional requirements of fruit trees. Nonetheless, this approach suffers from some limitations and may not provide valid results. Of late, mango researchers are increasingly using Diagnosis and Recommendation Integrated System (DRIS) for optimum nutrient management in mango (Raghupathi *et al*. 2005, Raj and Rao 2006). DRIS enables the simultaneous identification of nutrient imbalances, deficiencies and excesses that is fairly independent of leaf age and other effects. It is based on the comparison of crop nutrient ratios with optimum values from a high yielding group. DRIS indices more precisely detect yield limiting nutrients compared to the conventional critical nutrient concentrations (range) method and are found to be sensitive to both long- and short-term fertilizer management practices.

Available evidence suggests that integrated use of organic and inorganic inputs can partly reduce the dependence on costly chemical fertilizers while improving soil quality and fruit yields. Authors are unanimous with regard to tangible improvements in fruit yield and, in certain cases, fruit quality with the conjunctive applications of fertilizers and organic inputs (Gautam *et al*. 2012, Hasan *et al*. 2013, Saha *et al*. 2010, Singh *et al*. 2015, Yadav *et al*. 2011). NPK fertilizers and FYM are the common components of integrated nutrient management (INM) plans in mango; main difference lies in the selection of microbial inoculants(s) suggesting that a single product may not be effective under varying situations. Again, in many situations, a consortia of microbes and not a single product gives better results. It is pertinent to mention that such INM studies often do not include micronutrients in the treatment plans. It appears that organic manure/biofertilizer additions, though not a significant source of micronutrients, can slowly improve SOM and microbial activities resulting in enhanced availability of micronutrients for vegetative growth and fruiting. Use of organic (FYM, vermicompost, *Azotobacter* and *Trichoderma*) and inorganic (NPK) sources of nutrients for four consecutive years significantly increased soil and leaf nutrients concentrations compared to control in mango orchard soils of Lucknow. Tree basins receiving organic inputs, in particular, showed significant increases in SOC content, available nutrients, dehydrogenase activity and leaf nutrient concentrations (Adak *et al*. 2014b). Long-term (10-15 y) INM studies may provide more useful results. After a particular INM recommendation has been found effective, local farmers must be sensitized for its large-scale adoption. Subsequently, impact evaluation studies should be conducted to understand the changes, *inter alia*, in yields, income and soil fertility so that desirable modifications/improvements can be made for maximizing the benefits.

ICAR-IIHR, Bengaluru has developed a foliar nutrition formulation called '*Arka Mango Special*' to overcome micronutrient deficiencies in mango. It contains different secondary (Mg and S) and micronutrients (Zn, B, Fe, Cu, Mo) effective in enhancing mango fruit yield and quality in Zn and B deficient alfisols of peninsular India. Three foliar sprays at flower bud differentiation, flower initiation and marble stage of fruit growth significantly improve fruit retention, yield and fruit quality (TSS, TSS/acid ratio) in acidic soils of Odisha (Samant *et al*. 2018). Application of KH_2PO_4 @ 1% + KNO_3 @ 1% before bud break has been found effective for improving fruit set and yield in most of the growing areas. Foliar spray of boric acid (0.02 %) + sorbitol (2%) at flowering onset improves fruit quality under Uttarakhand conditions. At Paria and Periyakulam, however, these chemicals should be sprayed at 50% flowering stage for better results (https://aicrp.icar.gov.in/fruits/achievements/production-technology/).

Canopy management

Tree size control is a prerequisite to realizing high mango productivity in humid tropics and subtropics where trees produce frequent flushes and often become unmanageable and unproductive if left unpruned. Factors such as tree age, planting density and climatic conditions govern the intensity of pruning to achieve the desired results. Removal of shoot tips accelerates flushing and branching, promotes synchronous flowering and ensures precocious bearing in the newly planted young trees. In bearing orchards, annual formation pruning controls the tree size and improves light penetration for higher productivity. Severe pruning is recommended for restoring the productivity of senile orchards (Davenport 2006). In India, conventional low density mango orchards are seldom pruned, and unrestricted canopy spread eventually leads to the intermingling of branches. In overcrowded orchards, decreased light penetration and temperature coupled with increased relative humidity adversely affect tree physiology. Unpruned trees also exhibit higher sex ratio (male: hermaphrodite flowers) and more incidence of floral malformation (Sharma and Singh 2006b).

Low density orchards: Senile mango trees can be rejuvenated by removing the overgrown and superfluous branches. Heading back at 6-7 m height in the first fortnight of March followed by paclobutrazol application (5-7 g $tree^{-1}$) in July result in over tenfold increase in fruit yield in unproductive Alphonso orchards of Maharashtra (Burondkar *et al*. 2000). Removal of third order branches nearly doubles the fruit yield in ageing Alphonso trees in rainfed red loam areas of Karnataka (Reddy and Kurian 2011). Cutting of third and fourth order branches is suggested for restoring the productivity of old Dashehari orchards in IGP (Lal and Mishra 2008). Mango rejuvenation technology developed by ICAR-CISH, Lucknow consists of heading-back of 3-4 branches at 2.5-3.0 m height from ground and thinning of the remaining branches during December. Pruned branches sprout during April-May; thinning is done to retain only 6-8 healthy shoots per branch. Fruit bearing in the rejuvenated trees starts in 3^{rd} year and increases by 2.5-times after five years of rejuvenation. This technology is being adopted in different mango growing regions of the country. Care in nutrition and irrigation, shoot thinning and shoot borer management is necessary to achieve the desired results. Growers' can compensate yield losses by selling the pruned wood and growing short duration intercrops during the initial 3-4 years. Mango growers' perception on orchard rejuvenation is shaped by factors like family income and risk orientation. Lack of skilled man-power, unavailability of suitable pruning instruments, additional costs and the fears of yield loss hamper the adoption of recommended pruning practices (Kadam 2006, Singh *et al*. 2016).

***High density orchards*:** In high density plantings (HDP), canopy shading leads to progressive decline in fruit yield after about 15 years. Depending on the extent of overcrowding and other factors, various pruning treatments have been found effective in IGP. Sharma and Singh (2006a) reported that removal of 10-15 cm shoot from the apex enhanced fruit yield in Amrapali HDP. However, Asrey *et al*. (2013) observed that removal of 50 cm of shoot apex in September resulted in significantly higher fruit weight, fruit firmness, total carotenoids, antioxidant capacity and total phenolic content under similar conditions. Singh *et al*. (2010) recommended the removal of shoot tips up to 30 cm from the apex (light pruning), up to 60 cm (moderate) and up to 90 cm (severe) for restoring the productivity of ≈25-y old HDP of Amrapali, Mallika and Dashehari cultivars, respectively, under Delhi conditions. Topping of trees at 1 m above ground and shortening of primary shoots gave the best results in low yielding Amrapali HDP (5 x 5 m) in Jharkhand (Das and Jana 2012). Tip pruning could rejuvenate frost affected Mallika, Dashehari and Amrapali HDP in Sirmour, Himachal Pradesh (Chauhan *et al*. 2013). Shoot tip pruning leads to synchronized and uniform vegetative and floral flushes by removing growth- and flower-inhibiting factors accumulated in stems during previous season's flowering (Ramírez *et al*. 2010). Vigorous, alternate bearer Dashehari cultivar is also amenable to HDP without use of dwarfing rootstock. Dashehari HDP (1333 trees ha^{-1}) produced 238 t ha^{-1} fruits compared to 24 t ha^{-1} in conventional low density orchard (69 trees ha^{-1}) during 20 years orchard life. Tree size was controlled by pruning after harvest. Soil application of paclobutrazol 60-75 days after pruning also decreased floral malformation to only 0.2% (Ram *et al*. 1997).

Top-working in seedling trees: Seedling trees of little commercial value can be top worked with scions of improved cultivars by grafting. In north India, relatively young trees (< 20 y) are beheaded in early spring and new spring shoots are veneer grafted during the rainy season. In older trees, simultaneous heading back of branches should be avoided as it can cause splitting of the main trunk (Singh 1996). Wedge grafting of Kesar scions on beheaded trees (2 m from ground level) is recommended for the rejuvenation of seedling orchards in Maharashtra. Tree beheading in November and grafting in February give the best results. Beheading in other months leads to severe infestation of stem borer (Jadhav *et al*. 2015). A study conducted in Kolar, Karnataka showed that mango producers often partially replace (≈20%) less remunerative non-table varieties with table varieties in the existing orchards. Rejuvenated trees (> 30-y) give B: C ratio of about 2.9 compared to 2.2 in seedling trees (Shree 2015).

Organic mango cultivation

Global demand for organic fruits has consistently increased due to growing demand for organic food. During 2008-2013, global area under organic temperate fruits, citrus and tropical/sub-tropical fruits increased by 109%, 42%, and 53%, respectively, compared to much lower growth in non-organic area in these crops. Globally, hardly 1-2% of total crop in different fruits is organically produced except avocado where organic produce constitutes ≈8% of the total production. Currently, Mexico, Italy, China, Poland and the United States are the top producers of organic tree fruits (Granatstein *et al*. 2016). Available evidence suggests that organic mangoes are rich in bioactive compounds like ascorbic acid, β-carotene, phenols and antioxidants. Higher phenolics and antioxidants in organically produced fruits may be due to increase in endogenous phenolics and antioxidant molecules involved in plant defense as plant protection chemicals are not applied. Notwithstanding higher antioxidant and phenolic levels, possible microbiological risks to consumers from organically produced fruits need greater attention (Mditshwa *et al*. 2017).

Perennial fruit crops like mango seem to be amenable to organic farming. Large tree canopies store considerable amounts of dry matter such that grown up trees can derive a bulk of their nutritional needs by mobilizing nutrient reserves even when chemical or organic sources of nutrients are not applied. Availability of bio-control methods for pest and diseases management, and chemical-free postharvest treatments further increase the scope of organic mango farming; especially in marginal areas where little or no agro-chemicals are applied (Iyer 2004). During 2012-2013, India exported 165,262 million tons of organic products across 135 commodities valued at $312 million. Domestic market for organic commodities is also growing at an annual growth rate of 15-20%. A wide variety of horticultural crops including mango are being organically grown. The United Kingdom, Netherlands and Germany have a high demand for organic mangoes (Mitra and Devi 2016). Small scale organic mango farming has recently taken-off in some mango growing areas of India. Several farmers in Surat, Navsari and Valsad districts of Gujarat have switched over to organic mango production to lessen the production costs and fetch premium prices in export markets. Out of total 57,000 ha mango area, ≈2,800 ha is currently under organic management (Mehtal 2014). In the last few years, ≈ 300-400 tonnes of mangoes are being organically produced in Krishnagiri district of Tamil Nadu. Conversion from chemical to organic farming causes 30-50% yield reduction during the first few years of changeover (Ramesh 2017). For the existing mango orchards, a minimum of three years is required as conversion period for organic cultivation. In case of new orchards, the first yield itself can be considered as organic, since mango has a pre-bearing period of four years. Varieties selected for organic production must be well adapted to local conditions. Cultivars with in-built tolerance to biotic and abiotic stresses are desirable. In organic production systems, particularly in marginal lands, certain practices including residue management, green manuring and compost application can enhance SOM, improve soil structure and soil biological activity for sustaining soil fertility and fruit yield. Mango leaf litter should be used for *ex situ* composting because *in situ* decomposition of thick leaves often takes longer time due to their high lignin content and unfavorable orchard conditions. Annual leaf litter production in conventional mango orchards (100 trees ha^{-1}) ranges from 2-5 t ha^{-1} in 10-15 y old and 25-40 year old plantations, respectively. Bee keeping can also be taken up to further enhance the profits provided a large organic/wild mango area is available to meet the nutritional needs of the bees (Iyer 2004).

Improving the availability of quality planting material

Inadequate availability of quality planting material (QPM) is a major limitation to the expansion of mango area through improved cultivars. Although precise data are not available for mango, existing government nurseries can supply ≈40% of the total annual demand in different fruit crops. Despite institutional efforts and an enabling policy environment, non-availability of QPM often compels the prospective growers to procure spurious material from other sources (GOI 2007). Orchard establishment entails high initial costs and recurring expenses suggesting that initial flaws in cultivar selection and planting can substantially trim the profits. Owing to cross-pollinated and monoembryonic nature, Indian mango clones of commercial importance are not propagated through seeds as it results in non-uniform progenies having prolonged juvenile phase. This has led to standardization of vegetative propagation techniques such as veneer and epicotyls (stone) grafting. Yet, the shortage of QPM continues. Unlike pineapple, banana and strawberry, micropropagation does not give desired results in mango due to problems such as latent microbial infection, excessive polyphenol exudation and early explant necrosis. Recently, two state-of-the-art centres *viz*., Indo-Israel Centre of Excellence for Sub-Tropical Fruits at Kurukshetra, Haryana (Business Standard 2013a) and Centre of Excellence for Mango at Gir Somnath, Gujarat (Kateshiya 2018) have been established to utilize Israeli expertise areas such as propagation on salt tolerant rootstocks, establishment of model nurseries, revival of unproductive orchards and hi-tech orcharding for area expansion under mango crop.

Prospects of carbon sequestration

Soil organic matter (SOM) has beneficial effects on soil physical, chemical and biological properties, which in turn improve the soil productivity. Soil organic carbon (SOC) is the main constituent of SOM (55-60% by mass). While a high SOM content ensures adequate availability of nutrients and water to plants, SOC improves soil structural stability by promoting aggregate formation. Depending on physical and chemical stability, SOC is divided into 'fast' (labile or active pool), 'intermediate' (microbially processed, partially stabilized) and 'slow' (refractory or stable pool) pools having different residence time (1-2 years, 10-100 years and 100-1000 years, respectively) in soil (FAO 2017). Pervasive land use is likely to remain the second largest source of carbon emissions in the coming decades. Tree-based land use systems are seen as a simple means to reduce carbon emissions, sequester atmospheric carbon and maintain soil productivity. A study conducted in four different climate zones of southern India found that conversion of forests into agricultural systems resulted in the heavy loss in original SOC stock (50-61 %) in the top one meter soil. Establishment of homegardens and coffee plantations on agricultural lands caused SOC stocks to rebound to near forest levels, while in mango- and coconut-based systems SOC stock was only slightly above that of agricultural lands that was due to removal of leaves and other residues for use as fodder or fuel (Hombegowda *et al*. 2016). In Poanta valley of Himachal Pradesh, total SOC pool was the highest in forest land (1373.7 t ha^{-1}) followed by horti-silvipastoral (mango + poplar + grasses; 719.6 t ha^{-1}) and the least in silvi-pastoral system (*Dalbergia sissoo* + grasses; 599.10 t ha^{-1}) (Khaki *et al*. 2016). Based on selected soil carbon fractions, microbial biomass carbon, basal soil respiration and certain biochemical parameters, organically managed pulse crops (LTFE), mango and *Dalbergia* systems were found to be the most sustainable land use systems in ecologically fragile Mollisols of Uttarakhand. Mango orchard soils had the highest total carbon (23.25 g kg^{-1}) and total organic carbon (23.21 g kg^{-1}) (Bhattacharjya *et al*. 2017). In normal soils of Central Himalayan Tarai region of India, total carbon sequestration in mango (15 y; 100 trees ha^{-1}) was 21.4 t ha^{-1} compared to only ≈6.5 t ha^{-1} in both litchi (7 y; 100 trees ha^{-1}) and plum (5 y; 400 trees ha^{-1}) which seemed to be due to their low carbon sequestration rates (0.94 and 1.28 t ha^{-1} y^{-1}, respectively) than 1.43 t ha^{-1} y^{-1} in mango (Kanime *et al*. 2013). The highest total organic carbon was recorded in teak soils (0.69-1.11 %) followed by mango (0.64-0.85 %), sapota (0.36-1.07 %) and coconut (0.57-0.81 %) at 0-20 cm soil depth in 20-y old trees in Dindigul, Tamil Nadu. In mango plantations (220 trees ha^{-1}), carbon stock and equivalent CO_2 were assessed at 28.3 t ha^{-1} and 103.9 t ha^{-1}, respectively (Selvaraj *et al*. 2016). Total above ground biomass carbon stocks (kg ha^{-1}) in 6-y old plantations were 33.1 in *Emblica officinalis*, 30.6 in mango, 36.9 in *Tamarindus indica*, 12.9 in *Achras sapota*, 83.1 in *Annona retiaculata* and 73.5 in *Annona squamosa* in Aurangabad, Maharashtra (Chavan and Rasal 2011). In 6-y old litchi, mango and guava orchards (5 × 5 m), the maximum total SOC in 0-60 cm depth was noted in mango (62.47 Mg ha^{-1}) that was 17.2 % higher over control. The higher total SOC in mango orchards may be attributed to the higher amount and quality of mango litter. Mango orchard registered highest significant increases of 20.7, 13.5 and 17.4 % in very labile, labile and non-labile carbon fractions, respectively, over control (Naik *et al*. 2017).

Conclusions and suggestions: Preceding deliberations make it amply clear that adoption of improved orchard management practices can lead to manifold increase in mango productivity and quality while sustaining the natural resource base. Sustainable intensification of mango cultivation seems to be achievable by large-scale dissemination of innovative soil and water management techniques. In changing circumstances, a paradigm shift from business-as-usual approach is absolutely essential to realize the goal of enhanced net returns to the growers instead of exclusive focus on raising productivity. Mango orchards should not merely be viewed as means of income generation but as viable ecological entities for multifarious benefits in terms of soil conservation, biodiversity maintenance and carbon sequestration. Some of the specific recommendations for future R & D in mango are:

1. Geospatial techniques need to be applied to delineate degraded lands in different parts of the country where an ensemble of easy-to-do practices can help expand the mango growing area.
2. GIS-based geospatial tools can also be helpful in demarking old and senile mango orchards on a regional-scale so that recommended rejuvenation techniques can be implemented to enhance orchard productivity and fruit quality.
3. As with field crops, mango growers need to be provided Soil Health Cards that should be periodically updated to reflect the changes in soil quality subsequent to the adoption/discontinuation of a particular technology.
4. Socio-economic factors hindering the adoption of proven technologies like drip irrigation and integrated nutrient management need to be studied to remove bottlenecks in their adoption.
5. Increased collaboration with other mango producing countries like Israel can lead to area expansion in salt- and water-stressed regions.
6. Public-private partnerships need to be harnessed specifically for promoting high density orcharding and creating state-of-the-art processing and value addition facilities.

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