International Journal of Innovative Horticulture. 6(1):7-24, 2017 **Review Article**

Status of arecanut production systems in India

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ABSTRACT

Arecanut (*Areca catechu* L.), which belongs to family *Palmae*, is a commercially and socially important non-food crop in south-east Asia. Sustainability issues are increasingly noticed in recent times in perennial crops as well due to climatic change, stagnant productivity trend and ecological imbalance. The sustainability issues are likely to increase in arecanut both in traditional and non-traditional areas due to impending problems like soil-plant nutrient imbalances, proliferation of pests and diseases, farmer's preference for monocropping, cultivation in contiguous areas and poor adaptability. Cropping/ farming systems approach is the prime requirement for development of sustainable arecanut production systems. There are reports of imbalanced and excess soil fertility status in arecanut growing regions resulting from wide spread adoption of organic farming practices, depletion of soil K, poor soil aeration and blanket recommendations. Need based input use is most important for sustaining the production and reducing the cost of production. Besides, integrated approaches are required for soil and plant health management in arecanut production system. The economic sustainability of arecanut can be ensured in future by adopting suitable adaptation strategies like cropping systems, drip-fertigation and organic matter recycling and by taking up various value addition options as microenterprises.

Keywords: Arecanut, cropping system, productivity, sustainability.

INTRODUCTION

Arecanut (*Areca catechu* L.), which belongs to family *Palmae*, is a commercially and socially important non-food crop in South-east Asia. It is popularly known as betel nut. Dry kernel is the main economic product, but all parts of the palm can be utilized efficiently through recycling and value addition (Sujatha *et al*., 2015). The pharmacological properties of nuts due to presence of alkaloids are widely reported (Amudhan *et al*., 2012; Rashid *et al*., 2015). It is essentially a crop of small and marginal land holders and the arecanut industry forms the economic backbone of nearly 30 million people in India and for many of them it is the sole means of livelihood. The dry kernel of arecanut forms a popular masticatory in India and West Asia and is chewed either alone or more commonly with betel leaf (*Piper betle*) and a dab of slaked lime. The nuts are used in many social and religious functions in India. It is estimated that one tenth of the world population has the habit of betel chewing. Despite favourable market prices during the last decade, increased cost of production has generated livelihood concerns for arecanut farmers.

Arecanut grows to a height of 10-15 m and the trunk formation starts by third year. The crown of the palm consists of 8-11 leaves and the longevity of each leaf is two years. The average leaf area of the palm is estimated at 25 m^2 and net photosynthesis ranges between 2.4-8.2 µmol CO_2 m^{-2} s^{-1} (Balasimha, 2004). Flowering initiates by 4th year and yield stabilizes by 8th year. During post monsoon period of December to March, maximum numbers of inflorescence are produced. Reproductive stage from flowering to maturity of kernel takes about 9-10 months. The root system in arecanut is shallow and fibrous with more than 70% of the roots occurring within the vicinity of 60 cm from the base of palm (Bhat and Sujatha, 2008). The root biomass production is quantified at 3.94 kg per palm in a 8-yr old palm (Bhat *et al*., 2007a). Majority of the fine/feeder roots of arecanut are concentrated within 30 cm depth and 60 cm distance from the trunk in drip irrigated palms.

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Arecanut can be grown up to an altitude of 1000 m above sea level, but the quality of the fruits deteriorates at higher altitudes. In India, it is grown within a wide range of temperatures, ranging from a minimum of 4°C in places like Mohitnagar in West Bengal to a maximum of about 40°C in coastal Karnataka and Kerala. However, the palm flourishes well within a temperature range of 14°C to 36°C. Extremes of temperatures and wide diurnal variations are not conducive for the growth of the palms. The palms are highly susceptible to sun scorching during October-January and need to be protected from direct exposure to sun by covering the palms with arecanut/coconut leaves or by raising shade crops like banana or by planting quick growing shade trees on South-west side of the plantation. Arecanut flourishes well in tracts of very heavy rainfall where annual rainfall goes above 4500 mm as well as in the low rainfall areas where the annual rainfall is about 750 mm. Due to the huge preference for this crop by the farmers, the area of arecanut is rapidly expanding by way of conversion of paddy fallows, slopy areas and forest lands that might put pressure on both crop and natural resources. Hence, it is important that new plantations are managed in a sustainable way to reduce the impact of production constraints.

An effort is made here to review the present status of perennial arecanut production systems and future strategies in view of the impending sustainability concerns based on the results of several long term trials. Such assessment is needed to adequately address the issue of sustainable management of arecanut as there are several instances of inappropriate interventions pursued by growers.

LONG TERM AREA AND PRODUCTION TRENDS IN THE WORLD AND INDIA

Despite few reports of health risks due to consumption of arecanut, the global arecanut area increased from 0.3 million ha in 1960-61, 0.6 million ha in 2000-01, 0.7 million ha in 2005-06 and 0.9 m ha in 2013-14. During 1970-2014, the global cultivated area under arecanut has more than tripled. The present production of arecanut in the world is about 1.22 million tonnes from an area of 0.91 million hectares. Production trend showed sharp increase from 0.214 m t in 1960-61 to 0.71 m t in 2000-01 and 0.85 m t in 2005-06. The productivity (kg ha^{-1}) is higher in countries like China (2885), Sri Lanka (2056) and Myanmar (1583) than in India (1268). Globally, arecanut is cultivated in East Africa, the Pacific Islands and South Asia and the major arecanut growing countries are India, Sri Lanka, Bangladesh, Malaysia, Indonesia and China. The annual arecanut crop is valued at around $ 300 million worldwide and Rs. 3000 crores in India.

The world's largest producer as well as consumer of arecanut is India. In India, it is cultivated in 0.45 m ha with a production of 0.73 m tonnes in humid tropics and plains of South India, North-eastern region, and Andaman & Nicobar Islands (GOI, 2015). The cultivation of arecanut is localized in Southern and North-eastern states of India, but it is widely utilized across the country. National statistics clearly indicate that area and production of arecanut exhibited an upward trend over time explaining 98 and 95% variability during 1956-2015, but the productivity showed 75% variability with stagnant trend during the last two decades (Fig. 1). The cultivated area of arecanut is

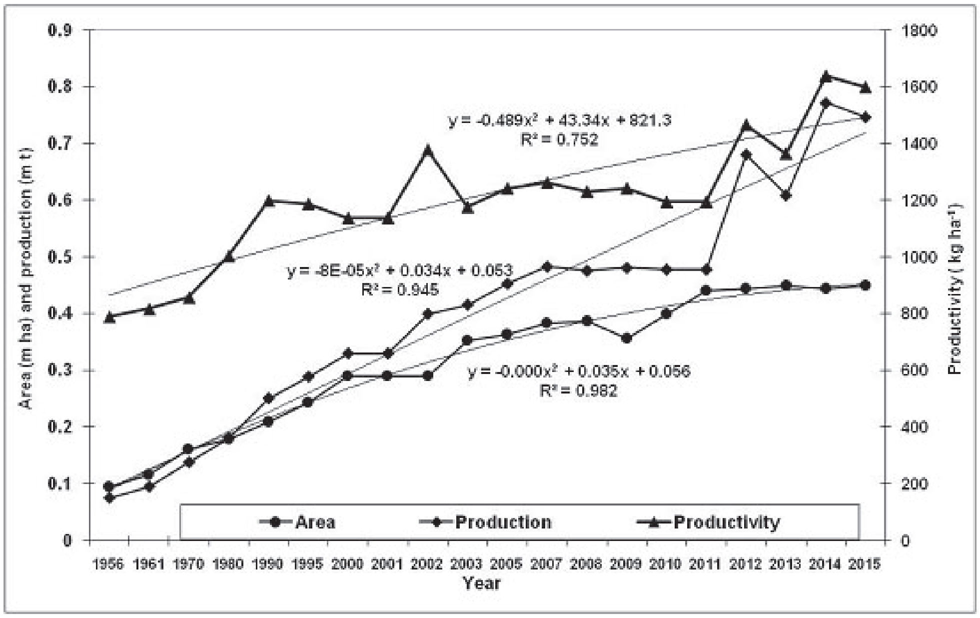


Fig. 1: Trends in growing area, production and productivity of arecanut

increasing at an alarming rate in the recent past due to lucrative price and huge regional preferences of farmers. Area expansion of arecanut is taking place in non-traditional tracts such as cleared forest lands, paddy fallows, sugarcane belt and canal irrigated areas in clay soil tract.

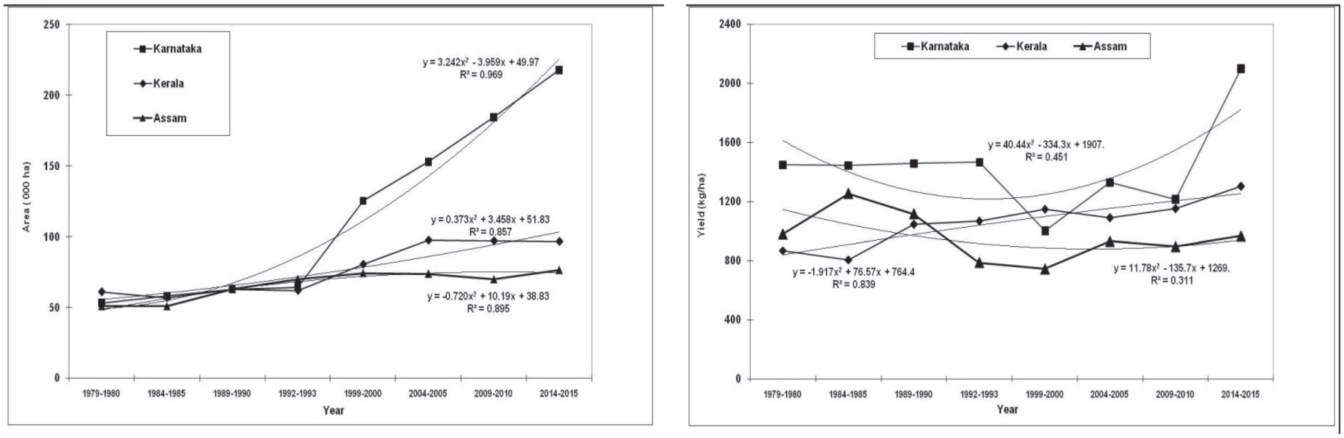
India became self-sufficient in its arecanut requirements in the mid 1970's itself. Since then, the area expansion of arecanut is discouraged as per government of India policy. Nevertheless, the area increased by 70% during the last two decades and the production increase was mainly due to area expansion. In India, the South and North-eastern states like Karnataka, Kerala, Assam and West Bengal are the major producers accounting for more than 70% of the area and production (Figure 2). The largest producer within India is the state of Karnataka, which contributes to 47% of India's annual output of arecanut. The productivity of arecanut (kg ha^{-1}) fluctuated from 400 in 1956 to 857 in 1970, 1379 in 2002 and 1195 in 2012 and 1600 in 2015. The yields reported in national statistics of India range between 1.1 and 1.4 t ha^{-1} yr^{-1}, which is considerably lower than attainable yields of 3.0 to 3.5 t ha^{-1} yr^{-1} with advanced technologies. With respect to export potential, a small quantity of arecanut is exported mainly to meet the demand of the Indian settlers abroad in its processed form or other value added products. Major destinations of arecanut export are Vietnam, Indonesia, Malaysia, UAE, Maldives, UK, Singapore etc. From 1999 onwards, import of arecanut to India registered a significant increase due to change in global scenario in the context of trade liberalization. In view of self-sufficiency in production and lack of export potential, more attention is required for stepping up the productivity per unit area rather than increasing the area.

PRODUCTION CONSTRAINTS

Agricultural plantations have a number of socio-economic as well as ecological advantages and disadvantages. Generally, farmers manage arecanut plantations as per their preferences despite availability of standardized package for traditional arecanut growing areas of laterite soil belt. Arecanut is grown in contiguous areas in traditional belt and rapidly expanding in non-traditional areas and the problems are also increasing due to climate change scenario and several production constraints. Drought results in yield loss of 15-75% (Jose *et al*., 2004), while fruit rot inflicts a yield loss up to 90% (Jose *et al*., 2008). Rapid development of technology for solving problems is not possible due to the perennial nature of the palm. Thus, it becomes important to understand the production constraints in arecanut cultivation and to develop suitable strategies for sustainable productivity of soil and crop. This perennial palm continuously encounters several constraints and significant changes are noticed in the production and profitability of arecanut during last two decades due to recurring problems like erratic rainfall, pests, diseases and price fluctuations.

Climatic and soil constraints

The parameters like heavy rainfall, high relative humidity and low temperatures are the major climatic constraints in arecanut growing regions. Heavy rainfall leads to leaching of potassium and calcium and high relative humidity is congenial for proliferation of pests and diseases. Low temperatures at high altitude areas lead to softness of kernel and low nut recovery. Untimely rains and heavy rainfall events are commonly noticed in all arecanut growing regions. The resource use efficiency reduces considerably



Trends in area

Trends in production

Fig. 2: Trends in major arecanut growing states of India

due to water stagnation, run off, soil erosion and leaching of nutrients due to heavy rainfall events in laterite soil belt of humid regions especially in areas with undulating topography.

Arecanut is predominantly grown in acidic laterite soils in humid tropics of India and to some extent in clay and alluvial soils. Inherent constraints in laterite soil belt are undulating topography, high rainfall, low CEC (3-15 c mole kg^{-1}), poor water and nutrient retention capacity, presence of kaolinite clay mineral, leaching of K^+ and Ca^{2+}, P fixation and high zinc fixing capacity. In general, laterite soils dominated by sesquioxides and kaolinite minerals contain less available and exchangeable K (Martin and Sparks, 1985). Deficiency of N and K is reported in laterite soils of arecanut growing region (Badrinath *et al*., 1998). Low nutrient retention capacity and moisture holding capacity of laterite soils is because of low cation exchange capacity, faster infiltration rate and high hydraulic conductivity. It is also grown in clay soils in non-traditional areas without special care and microsite improvement. Cultivation on unsuitable lands like slopy/paddy fallows/eroded lands is a major problem in arecanut. Clay soils pose a problem to monocot palm due to water stagnation, poor soil aeration and drainage. Soil compaction in root zone leads to poor soil aeration and water stagnation for long time in clay soils. Arecanut needs a soil that has good aeration without water stagnation problem. The presence of sub surface hard pan and water stagnation in paddy fields results in less soil aeration, nutrient losses and fixing of nutrients. Moreover, some nutrients like zinc will be taken by paddy in large quantity and zinc deficiency in paddy soils is reported from many regions. When arecanut is grown in paddy fields, the factors like poor soil aeration and seepage of water lead to poor root growth, nutritional disorders and reduced yields.

Crop and management constraints

Non-availability of quality planting material, shallow root system, higher trunk biomass (70% of the total biomass), low nutrient use efficiency, and susceptibility to diseases and water stress are the main crop constraints in arecanut (Bhat *et al*., 2007a; Bhat and Sujatha, 2008). Due to higher nutrient immobilization and low nutrient use efficiency of 10-15% for nitrogen, 25-30% for phosphorus and 20-25% for potassium, this perennial palm requires large quantity of nutrients to support its growth and yield.

Arecanut production system might become unsustainable due to large scale adoption of unscientific practices like closer planting or high density planting, under planting in old plantations, shallow planting, zero tillage in crop rhizosphere, intercropping with competitive crops, absence of soil and water conservation measures, excessive use of inputs, and absence of shade on South-west side of the plantation that leads to sun scorching and stem breaking. Further, imbalanced and blanket nutrient application, adoption of only organic farming approach and excess soil fertility status contribute to development of nutritional disorders (Bhat and Sujatha, 2014) and yellow leaf disease (Bhat *et al*., 2016). Inter/mixed cropping of arecanut with competitive crops with cocoa, banana, coffee without optimum spacing and management might lead to unsustainability of perennial arecanut ecosystem. Higher and regular incidence of *Phytophthora* diseases like fruit rot, bud rot, crown rot and inflorescence die back is a major problem in arecanut tract in humid tropics of India. Low water use efficiency in irrigated arecanut due to conventional (basin and flood) and sprinkler irrigation methods is another drawback.

Technological and socio-economic constraints

In the climate change scenario, the need for varietal improvement towards tolerance to various biotic and abiotic stresses, and disease and pest forecasting models is increasingly felt during the last decade. In perennial crop like arecanut, blanket recommendations are followed widely and the immediate attention is required for need based input application to improve resource use efficiency. Absence of farmer friendly sprayers and harvesters is increasing the cost of production due to tall nature of palms and scarcity of skilled workers. About 85 per cent of the land holdings are small and marginal and the average size of land holding is 1.16 ha in India (NABARD, 2014). Small size holdings generate insufficient income to sustain small and marginal farmers. Adoption rate of developed technologies is very less due to small holding size. Due to migration of youth/labour to cities and construction works, the labour scarcity for agricultural activities is acute. Development of climbing devises and machinery for arecanut is a difficult task due to closer spacing, undulating topography, presence of inter/mixed crops and drainage channels, and small and marginal holdings. Besides, lack of community approach in controlling pests and diseases due to large number of small holdings is leading to spread of pests and diseases as arecanut is cultivated in contiguous areas.

SUSTAINABILITY OPTIONS IN ARECANUT

Varietal wealth

In arecanut growing regions, local varieties of that particular region are predominantly cultivated and about 50-60% of the plantations have become either senile or unproductive. Rejuvenation of senile and unproductive arecanut plantations should be carried out using high yielding varieties/hybrids. For increasing the productivity, the suitable strategy would be to increase the area under high yielding varieties (HYV's) as only 20% of the total cultivated area is occupied by high yielding varieties in India. India has vast varietal wealth of arecanut. The cultivation practices, post-harvest processing and consumption types differ in different parts of the country. In humid tropics, arecanut is cultivated mainly for full matured dry kernel. In plains, arecanut is grown for tender nut processing. In Assam and North-east regions, ripe nuts are stored and preferred by local population. The varieties suited for tender nut processing may not be suitable for mature fruit drying and vice versa. Though quite a few varieties have been released by different agencies like ICAR institutes and State Agricultural Universities, there is lack of trait specific varieties suitable for different needs.

Arecanut is a highly cross pollinated crop. It is an allotetraploid with chromosome number 2n=32. Even though *A. catechu* is the only cultivated species, it has been observed that there is a wide range of variation existing for different traits especially for nut size and shape under different geographical and agro-climatic regions (Bavappa *et al*., 2004). Though the palm is reported to be grown in several countries of the tropics, organized research work on the breeding programme is being done only in India. The Regional Station of ICAR-Central Plantation Crops Research Institute at Vittal maintains field gene bank comprising 173 accessions mainly from South-East and South Asian countries, which can be utilized for developing trait specific varieties. Indigenous collections numbering 150 are from Assam, Goa, Gujarat, Karnataka, Kerala, Maharashtra, Meghalaya, Tamil Nadu, West Bengal, Andaman and Nicobar group of Islands. About 23 exotic accessions were introduced from other areca growing countries of the world especially South-East Asian countries such as Fiji, Mauritius, South China, Sri Lanka, Indonesia, Saigon, Singapore, British Soloman Islands and Australia which represents four species viz., *Areca catechu* L., *Areca triandra* Roxb., *Areca normanbyii*, *Areca concinna* and one related genera *Actinorhytis calapparia*.

Systematic evaluation of exotic and indigenous accessions since 1957 and selection for high yield resulted in release of high yielding cultivars (Ananda, 2004). From exotic collections, the released varieties are Mangala, Sumangala and Sreemangala. From indigenous collections, the Mohitnagar accession from West Bengal with high yield potential is released for cultivation for all arecanut growing regions (Ananda and Thampan, 1999). Other promising varieties such as SAS-I, Thirthahalli and Calicut-17 are released for different agro-climatic regions of the country. Thirthahalli is primarily released for production of red tender processed nuts. Tall/semi-tall varieties (*cv*. Mangala, Sreemangala, Sumangala, Mohitnagar, Swarnamangala and Madhuramangala) with yield levels above 3 kg kernel per palm per year have been released for commercial cultivation for different agro-climatic zones. But, the major drawback is non-availability of planting material of high yielding varieties due to scarcity of mother palms and the rate of multiplication is not in tune with the huge demand. Mass multiplication of released/promising dwarf hybrids utilizing tissue culture techniques should be carried out in a public-private-participatory mode.

Due to shortage and high cost of labour for skilled farm operations like spraying and harvesting, the usefulness of dwarf varieties was also explored. A natural dwarf mutant is identified and named as Hirehalli dwarf that attains a height of 4.57 m height with low yields coupled with dark green leaves and medium sized and slightly elongated nuts of poor quality. An attempt was made to cross high yielding varieties with dwarf to exploit the dwarfing nature (Ananda, 2000). Two promising dwarf hybrids (VTLAH-1 and VTLAH-2) are released with yield level of around 2.5 kg kernel per palm per year.

Though the dwarfing genes in arecanut have been exploited to develop dwarf hybrids with yield levels at par with other varieties, the large scale multiplication of dwarf hybrid seedlings has been a tedious task. The development of varieties tolerant/resistant to yellow leaf disease and fruit rot diseases will help in reducing the input use and cost of production. The ICAR-CPCRI has developed a protocol for somatic embryogenesis and plantlet regeneration from leaf and inflorescence explants of arecanut. Protocol for somatic embryogenesis and plantlet regeneration from leaf and inflorescence explants of arecanut was developed by ICAR-CPCRI and observed to be repeatable. It was first standardized with leaf explants excised from one-year old seedlings and later modified for immature inflorescence sampled from adult palms. The protocol is being exploited mass multiplication of dwarf hybrids and identified yellow leaf disease (YLD) field tolerant palms in endemic areas (Anitha Karun *et al*., 2004). Simultaneously, mass multiplication of disease free, especially YLD tolerant/resistant dwarf hybrids/varieties is to be undertaken through tissue culture to ensure adequate supply of elite planting material for the disease affected tracts. The available tissue culture protocols need to be further refined to increase the plantlet multiplication rate and reduce plantlet production cost for enabling cost-effective mass multiplication of high yielding arecanut varieties with tolerance/resistance to biotic/abiotic stress through *in-vitro* culture.

Inter-specific and inter-generic hybridization in arecanut is a significant plant breeding tool for incorporation of desirable characters such as tolerance to fruit rot, yellow leaf disease

(YLD) and moisture deficit from wild into the cultivated arecanut in future crop improvement programme. In line with this, development of high yielding disease tolerant/ resistant arecanut varieties/hybrids using inter-specific and inter-generic hybrids between *Areca catechu* (Hirehalli Dwarf) with *Areca triandra, Normanbya normanbyi* and *Actinorhytis calapparia* is attempted. Globally, there is also a need to develop varieties with greater resource use efficiency and for different cultivation regimes. This would necessitate assessment of available germplasm for facilitating development of high yielding varieties with higher input-use efficiency as well as developing varieties suitable for low-input sustainable agriculture.

Establishment of new seed gardens of improved dwarf hybrids/varieties in public private partnership in various arecanut growing tracts is to be given priority. The *in situ* conservation/participatory plant breeding and seed production is to be given greater emphasis for enabling the farmers in up-scaling the varieties/hybrids with desirable features. Upscaling of planting material production through tissue culture techniques is to be given greater priority and is to be taken up in collaboration with different stakeholders, including private agencies and NGOs in order to facilitate replanting of old and unproductive plantations and enhance the seed replacement rate of improved arecanut varieties.

Considering the need for hastening the breeding programme for development of varieties for specific requirements and facilitate marker assisted molecular breeding, there is a need to identify trait-specific molecular markers associated with quantitative traits for robust screening of breeding lines in the juvenile stage. The studies on molecular markers in arecanut are scanty. Identification and utilization of molecular markers linked to economically important traits, viz., plant height, hybrid vigour, resistance/tolerance to biotic/abiotic stresses and higher yield is of paramount importance towards marker-assisted breeding for hastening the arecanut improvement programme. Development of molecular markers associated with quantitative traits will facilitate marker-assisted molecular breeding to enable trait-based breeding and faster development of varieties for specific requirements. Prospects of utilization of RNAi technology for management of biotic stress in arecanut is also to be explored.

PRODUCTION MANAGEMENT

Input use and precision agriculture

The right combination of two most important critical inputs like water and nutrients is a prerequisite for higher yields and good quality produce in tropics. Arecanut invariably needs irrigation and is a heavy feeder of nitrogen and potassium (Bhat and Sujatha, 2004; 2012). Establishment of optimum soil nutrient norms for laterite soils (Bhat *et al*., 2012), leaf nutrient norms for arecanut (Bhat and Sujatha, 2013), biomass partitioning and nutrient uptake pattern (Bhat and Sujatha, 2012) and constraint analysis give scope for site specific nutrient management and precision agriculture practices in arecanut. Precision agricultural practices reap benefits in terms of higher yields, lower costs, minimization of environmental impact and improvement in soil quality.

Nutrient imbalances are likely in perennial crops due to adoption of blanket recommendations continuously for years together. For sustainability of perennial monocot ecosystems, the implications of nutrient imbalances need to be understood thoroughly due to several emerging and recurring problems.

Recent reports indicated imbalanced and excess soil fertility status in arecanut growing regions due to wide spread adoption of organic farming practices, depletion of soil K, poor soil aeration and blanket nutrient additions (Sujatha and Bhat, 2012 and 2013b; Bhat and Sujatha, 2014; Sujatha *et al*., 2015). Potassium, calcium and zinc are identified as yield limiting nutrients (Bhat *et al*., 2012). This indicates the need for discontinuation of blanket recommendations and precision application of inputs based on biomass and yield levels. Thus, site specific nutrient management becomes most important for maintenance of soil health in arecanut.

Biomass partitioning and nutrient uptake pattern

Biomass and nutrient partitioning is a useful tool for suitable fertilization program and assessment of nutrient demand. Despite similar management and conditions, there are differences in biomass partitioning to trunk, leaf and kernel in arecanut palm as well as nutrient uptake and removal pattern (Bhat and Sujatha, 2012). The authors reported that low yielding palms have higher trunk biomass than high yielding palms. Direct relation between marketable yield and combined effect of higher biomass production and nutrient uptake is noticed in arecanut (Bhat and Sujatha, 2012). Higher biomass production leads to higher nutrient partitioning to kernel and high productivity in high yielding arecanut palms. The standing above ground biomass varies from 41 t ha^{-1} in 12-yr old (Bhat and Sujatha, 2012) to 50 t ha^{-1} in 15-yr old arecanut plantation (Sujatha and Bhat, 2015b). Thus, nutrients immobilized in standing biomass are very high and nutrient additions should consider both immobilized nutrients and nutrient removal. In order to maintain soil health, nutrient recommendation should consider total biomass accumulation and nutrient removal pattern.The nutrient removal by the crop makes the basis of fertilizer application to arecanut. This indicates the importance of regular application of nutrients especially during post-monsoon season for realizing higher yields.

Nutrient demand assessment

Arecanut is a heavy feeder of nutrients and application of mineral fertilizers is essential to ensure sustainable yields. Soil fertility status, leaf nutrient status and nutrient uptake pattern should be considered for nutrient demand assessment and balanced nutrition. The benefits of inorganic nutrient inputs are often minimized they contribute up to 40-60% increase in yield of several crops (Stewart *et al.*, 2005). The manurial experiments in different agro-climatic conditions indicated that 100 g N, 18 g P and 117 g K along with 14 kg of green leaf is optimum for arecanut (Bhat and Mohapatra, 1989). Further, the results indicated that the nutrient source either in organic (green leaf, cattle manure, bone meal and wood ash) or inorganic form has no influence on growth, crop yield and soil nutrient status. Suitable green manure cum cover crops for arecanut are *Pueraria javanica* and *Mimosa invisa* from the point of view of their green manure yield and nutrient addition capacity (Mohapatra *et al.*, 1970).

From long term trials, the nutrient dose is standardised at 100:40:140 g N: P_2O_5: K_2O per palm per year for low yielding local cultivars of arecanut with less than 2 kg dry kernel in laterite soils of humid tropics (Bhat and Sujatha, 2004). For Assam and plains of Karnataka, the optimum dose is 50:18:59 g N: P: K per palm per year, where arecanut is regularly irrigated. The response of high yielding cultivars to double dose of nutrients is reported (Sujatha *et al.*, 2000) and this is further substantiated by nutrient uptake and removal studies in arecanut (Bhat and Sujatha, 2012). Nutrient uptake pattern indicated that arecanut is heavy feeder of N and K and requires 350 g N and 300 g K per palm per year to produce 3 kg kernel (Bhat and Sujatha, 2012). Total uptake of macronutrients is in the order of N > K > Ca > P > Mg. In China, the importance of fertilizer application to low yielding arecanut is demonstrated for increased yields and leaf NPK, and reduction in micronutrient content of Fe and Mn (Dong *et al.*, 2009). Arecanut farmers perceive that organic farming approaches improve the yield and soil fertility. But, nutrient demand of arecanut varies with biomass production and yield level (Bhat and Sujatha, 2012) and application of organics alone cannot meet K demand (Sujatha and Bhat, 2012; Sujatha and Bhat, 2013ab).

Soil and leaf nutrient limits

Nutrient balance in soil-plant system is important for sustaining the yield and soil fertility in arecanut plantations. The need based input use is most important for sustainability of arecanut production system. The importance of optimum nutrient limits for efficient input use and diagnosing nutrient imbalances is highlighted by several authors.

Optimum leaf nutrient concentrations and ranges are established for arecanut (Bhat and Sujatha, 2013) that give scope for judicious use of fertilizer inputs. The optimum leaf concentrations are 2.70% for N, 0.23% for P, 1.12% for K, 0.61% for Ca and 0.2% for Mg for bearing arecanut. In case of micronutrients, optimum concentrations (ppm) are 146 for iron (Fe), 56.5 for manganese (Mn), 2.6 for copper (Cu), 45.8 for zinc (Zn) and 39.5 for boron (B). Optimum soil nutrient limits are vital for diagnosing nutrient constraints, judicious use of fertilizers and reducing environmental pollution. Optimum nutrient values are higher for laterite soils due to low CEC in arecanut tract than generalized guidelines for interpretation of soil analysis data (Bhat *et al.*, 2012). At 0-30 cm soil depth, the optimum nutrient concentrations of soil test P, K, Ca, Mg, Fe, Mn, Cu, Zn and B are estimated at 15, 192, 925, 179, 37, 88, 26, 5.5 and 1.4 mg kg^{-1}, respectively. The laterite soils are inherently rich in Fe and Mn, but higher optimum soil test values of Cu might be due to regular use of copper based fungicides. The studies indicated that arecanut tolerates higher micronutrient concentrations in soil (Bhat *et al.*, 2012), but not in leaf (Bhat and Sujatha, 2013). Though arecanut is tolerant to higher concentrations of Mn, Fe and Cu in soil (Bhat *et al.*, 2012), higher micronutrient concentrations in leaf reduces the yield levels compared to optimum levels (Bhat and Sujatha, 2013). The optimum leaf nutrient concentrations estimated by Zhiguo *et al* (2010) for arecanut in China also support the above findings.

Water management and drip fertigation

Globally, soil moisture is the major yield limiting factor in most agricultural systems. Irrigation has positive and significant effect on productivity and profitability of arecanut. The severe water deficit during summer and water logging during rainy season are common in arecanut production systems. Arecanut cannot withstand drought for a long time and it takes two to three years to regain the normal vigour and yield once affected by water stress. The death of palms due to moisture stress is also not uncommon. Water management is a crucial aspect of arecanut cultivation on undulating/hilly terrains and inland laterite soils to maintain soil moisture at field capacity and minimize soil erosion and nutrient losses. Water management and soil conservation are not generally practiced by arecanut farmers as per recommendations. In humid tropics where arecanut is grown traditionally (28^{o} N and S of equator), the distribution of rainfall is very poor and precipitation is confined to five months from June to October. Several parts of humid tropics experience severe shortage of water during summer months especially in April and May. This situation arises out of the fact that almost 90% of the annual rainfall occurs during monsoon season (June-September). Insufficient water during post monsoon season (December-May) limits the yield levels in this perennial palm due to high evaporative demand of arecanut (Mahesha *et al.,* 1990) and fast depletion of ground water (Mathew *et al*., 2008). Hence, the post monsoon period from December to May is highly critical for nutrient and water supply.

Arecanut requires irrigation equivalent to open pan evaporation in humid tropics and IW/CPE ratio of 1 with a 30 mm depth of water through basin irrigation is optimum (Bhat and Sujatha, 2004). Traditionally, basin and flood irrigation methods are popular among arecanut growers. Flood irrigation is still adopted by arecanut growers in non-traditional areas where canal irrigation facilities are available. Due to low irrigation efficiency of 50-60% in conventional methods of irrigation, improved methods of irrigation like sprinkler and drip are promoted since 1990’s due to declining water availability. Long post monsoon season, faster infiltration rate (8-10 cm hr^{-1}), average basic infiltration rate of 15.25 cm hr^{-1} high hydraulic conductivity (0.00923 cm sec^{-1}), less application efficiency and poor moisture retention capacity of laterite soils limit the use of flood and sprinkler irrigation. The irrigation efficiency in sprinkler irrigation method is quantified as 70% and about 40-60 l per day per palm at an irrigation interval of 3-4 days is optimum (Mahesha, 1987).

Drip irrigation is often preferred over other irrigation methods because of its high water application efficiency on account of reduced losses, surface evaporation and deep percolation. Earlier studies in arecanut demonstrated a yield increase of 45% with drip irrigation equivalent to 100% ET over basin method (Bhat and Sujatha, 2004). Micro-irrigation approach increases the yield of arecanut and cocoa with 45% water saving (Haris *et al*., 1999; Bhat and Sujatha, 2004). In drip irrigation, the irrigation efficiency is above 90%. In arecanut belt, soil and water conservation studies on water harvesting and storage structures like farm pond and check dam are done in laterite soils of humid tropics (Mathew *et al*., 2008). In arecanut, catch pit and planting of pineapple in the downstream and trench with one layer of coconut husk are the better soil and moisture conservation measures in laterite soils (Borah *et al*., 2006).

The drip fertigation technology is one sustainable option that can benefit both plant health and ecosystem. Drip fertigation ensures sustainability of arecanut production system due to substantial yield increase (Bhat *et al*., 2007a), increased mobility of soil test P and availability of soil test K (Bhat *et al*., 2007b), increased fine root production (Sujatha and Haris, 2000; Bhat and Sujatha, 2008), soil fertility improvement (Bhat and Sujatha, 2009) and reduced production cost (Sujatha *et al*., 2000; Bhat and Sujatha, 2006). The movement of available P and K in soil was beyond 30 cm depth and distance from dripping point when applied through fertigation (Bhat *et al*., 2007b). Drip-fertigation saves 50% of inorganic NPK during pre-bearing stage and 25% during bearing stage (Bhat *et al*., 2007a; Bhat and Sujatha, 2006). The advantages of drip-fertigation are reduced labour charges on fertilizer application, weeding and irrigation and diesel charges due to less operational hours (Bhat and Sujatha, 2006). This technology can be profitably adopted for sustaining arecanut production system.

Arecanut based cropping system models

Arecanut production systems are vulnerable to extreme weather variations, price fluctuations, unexpected yield losses, pests and diseases, and soil fertility imbalances during economic life span of 25-30 years. Cropping/farming systems approach is the prime requirement for development of sustainable arecanut production system in view of the current crop scenario, climate change scenario and production constraints. Congenial microclimate and improved resource use are the additional benefits due to cropping/farming system approach in arecanut (Bhat and Sujatha, 2011ab; Sujatha *et al*., 2011b; Sujatha and Bhat, 2015ab). The scope and advantages of arecanut based cropping/farming system approach are discussed in earlier review (Sujatha *et al*., 2016).

The results on arecanut based cropping systems are either summarized or reviewed by several workers highlighting the importance, benefits and problems over sole arecanut (Balasimha, 2004, Thomas and Balasimha, 2011; Bhat and Sujatha, 2011ab, Sujatha *et al*., 2011b; Sujatha *et al*., 2016). According to these critical reviews, the success of cropping system depends on the relative shade tolerance of component crops. Higher resource use efficiency and net income are reported due to intercropping in arecanut. The intercrops in these cropping models have potential to increase the net return per rupee investment by 1.66-4.50.

The benefits and ecosystem services of integrated farming systems in terms of increased output and income, nutrient recycling and reduction in adverse environmental impacts are highlighted by several workers (Bell and Moore, 2012; Ryschawy *et al*., 2012; Lemaire *et al*., 2014: Sujatha and Bhat, 2015b). A judicious mix of cropping systems with associated enterprises like dairy would bring prosperity to the arecanut farmer. Adoption rate of arecanut based farming system is less among small and marginal farmers compared to medium and large farmers. The interdependencies and ecosystem services of arecanut based mixed farming system are highlighted and arecanut based mixed farming models are developed with inclusion of livestock components like dairy and fishery for different land holdings (Sujatha and Bhat, 2015b). Small and marginal farmers with less than 2.5 ha area can increase the net income by 40-90% with inclusion of livestock components like dairy and/ or fishery over sole arecanut. The farm gate nutrient surplus is five times higher than utilization in arecanut based mixed farming system that enables farmers to earn higher profits. The hard laterite soils can be successfully used for livestock enterprises like dairy, fishery and fodder cultivation as it results in improved resource use efficiency and profits per unit area per unit time. Dairy was economical under all scenarios due to on-farm fodder availability throughout the year. The major recommendations by the authors are to include livestock components in arecanut ecosystem to adapt to climate change scenario, to provide ecosystem services and to reduce ecological imbalances arising due to continuous cultivation of perennial crop. It is observed that arecanut-pepper-poultry might be a good option in augmenting farm income of the arecanut growers as inclusion of poultry component increases the benefit cost ratio to 2.72 compared to 2.20 in sole arecanut (Viswajith *et al*., 2015).

The work on arecanut based high density multispecies cropping system (HDMSCS) involving component crops like cocoa, black pepper, clove, lemon and banana is well documented (Bhat and Sujatha, 2011a). The review by Bhat and Sujatha (2011b) emphasized the potential of organic waste recycling and the better scope for internal recycling of nutrients in arecanut based cropping system (ABCS). The component crops like clove, coffee and pineapple gave negative returns. The study clearly indicates the need for higher light requirement of both clove and pineapple due to late and low yielding behavior in the system. Several reports emphasized the economic viability of HDMSCS. At Mohitnagar, higher monetary benefit of 118% is obtained from HDMSCS involving crops like arecanut, betel vine, banana and cinnamon followed by arecanut + pepper + banana + acid lime system.

The advantages are substantial in multiple cropping due to prevention of soil erosion and nutrient loss in laterite soil belt in heavy rainfall areas. Detailed studies are required to quantify whether the input requirement in terms of water and pesticides can be lowered in inter/mixed cropping systems due to congenial microclimate. Efficient cropping system models are identified based on both biological suitability and economic viability from long term trials in different regions (Table 1). In arecanut based cropping system, the additional benefits accrued due to intercrops in terms of increase in productivity and net return per rupee investment are given in Table 2. Several long term trials in

Table 1: Efficient high density multispecies cropping models for different regions

Region	Cropping model	Reference
Plains of Karnataka	Arecanut+pepper+cocoa	Bhat and Sujatha (2011a)
Coastal Karnataka and Kerala	Arecanut+pepper+cocoa+banana	Bhat and Sujatha, (2011a)
North Bengal (Sub humid Himalayan region)	Arecanut+pepper+banana /acid lime	Sit *et al*., (2011)
High altitude areas (Wynad of Kerala and North Kannada of Karnataka)	Arecanut+cardamom; Arecanut+coffee	Korikanthamath, (1997)
Assam and Sub Himalayan Terai region	Arecanut + black pepper + banana; Arecanut + black pepper + banana + lemon + clove/ nutmeg	Ray and Reddy, (2001) Ray *et al*., (2011)

Table 2: Impact of cropping system approach on productivity and net benefit

System	Increase due to intercrops per ha		Reference
	Productivity in terms of kernel equivalent (kg)	Net return per rupee investment	
Arecanut + medicinal and aromatic plants	272-1218	1.95-4.25	Sujatha *et al*. (2011a)
Arecanut + cocoa	650-900	1.66-1.83	Sujatha *et al*. (2011b)
Arecanut + vanilla	1208	1.79-1.98	Sujatha and Bhat (2010)
Arecanut + pepper		1.56-1.84	Naik *et al*. (2013)
Arecanut + cocoa + banana + pepper	2250	4.50	Bhat and Sujatha (2011a)
Arecanut + vegetable crops	-	2.00-5.05	Ray *et al*. (2011)
Arecanut + flower crops	-	1.78-2.43	Ray *et al*. (2011)
Arecanut + gourds in summer season		1.17- 2.39	Sit *et al*. (2011)
Arecanut + black pepper + banana + lemon + clove or nutmeg	-	3.22-3.60	Ray *et al*. (2011)
Arecanut + pepper + banana + acid lime	-	3.66	Sit *et al*. (2011)
Arecanut + betelvine + banana + turmeric	-	3.85	Sit *et al*. (2011)
Arecanut + cardamom	900-1220	-	Korikanthamath, (1997)

different agro-ecological regions indicated that the medicinal and aromatic plants, vegetable crops, pepper, betelvine, banana and cocoa are highly remunerative intercrops. Intercrops increase the productivity to the tune of 272 to 2250 kg ha^{-1} and net return per rupee investment to the tune of 5.05.

Recycling of organic wastes and it's impact on crop and soil fertility

The shortage of fertilizer inputs is expected in tropical regions and there is an urgent need to explore alternate and locally available organic nutrient sources. Most of the annual crop residues are used for cattle feed purposes. The waste biomass resources are abundant in arecanut ecosystem due to rapid expansion of cultivated area in India (Sujatha *et al*., 2015). In India, arecanut generates about 4.5-5.4 million tonnes of recyclable biomass every year and are generally disposed by burning or dumping in the form of heaps. Due to these unscientific practices, the environmental problems are anticipated due to carbon emissions, leaching of phenols in to the soil and termite attack. The organic matter recycling potential of plantations crops and the impact of recycling these wastes as compost/vermicompost on crop and soil are discussed in the latest review by Sujatha *et al.* (2015) It is stated that the recyclable biomass production is 9-12 t ha^{-1} every year in arecanut. Recyclable biomass production per hectare per year from the arecanut based HDMSCS models is quantified at 8-16 (Bhat and Sujatha, 2011b). Direct recycling of these organic wastes, which are rich in lignin (36-44%), cellulose (26-42%) and polyphenols, is not advisable due to high C/N ratio (50-65) and slow biodegradable nature of wastes. Vermicomposting using *Eudrilus eugeniae* Kinberg is an efficient on-farm waste recycling technology that is easy to operate and cost effective compared to normal composting.

Recycling of organic wastes of plantation crops might reduce the load on N and P inorganic fertilizers but questions still remain about source and quantity of organics, substitution potential of organic manures for inorganic fertilizers, K nutrition, yield levels and cost effectiveness in perennial crops (Sujatha *et al*., 2015). If vermicompost is applied to arecanut continuously, the need for supplementation of potassium is emphasized for improving and sustaining the yields in laterite soils (Sujatha and Bhat, 2013b and 2016). Acharya *et al*. (2015) reported better yields of arecanut with improved soil physicochemical parameters such as pH, available N and microbial population except available P and K with vermicompost application in laterite soils of Assam. Organic matter recycling in arecanut based cropping system reduces fertilizer requirement of each component crop to 2/3rd of the recommended dose in humid tropics of Karnataka (Bhat and Sujatha, 2011b). However, the requirement of 100% recommended fertilizer dose for palm based cropping model (arecanut + black pepper + banana + turmeric + pineapple) is emphasized by Ray *et al*. (2011) for Assam region.

There are differential responses of different component crops of arecanut based cropping systems to vermicompost application on a laterite soil in humid tropics (Bhat and Sujatha, 2007; Sujatha *et al*., 2011b; Sujatha and Bhat, 2010; Sujatha *et al*., 2011a). The better response of intercrops to vermicompost in several trials might be due to less organic carbon in interspaces, low K requirement of intercrops and higher nutrient use efficiency except in cocoa. Potassium deficit is noticed in cocoa in arecanut +cocoa system with fertigation of vermicompost extract (Sujatha and Bhat, 2013a). For sustainable crop yields in perennial component crops like cocoa and banana, there is a need for precision application of K based on leaf and soil nutrient status in the long run (Bhat and Sujatha, 2007; Sujatha and Bhat, 2013a). This indicates that vermicompost alone can't sustain the plantation production systems. The above findings suggest that the response to vermicompost varies with crop, soil and weather conditions. In plantation based cropping systems, integration of both inorganic nutrition and organic matter recycling is necessary to sustain the yield levels of different component crops (Bhat and Sujatha, 2007; Jacob *et al*., 2008; Bhat and Sujatha 2011a; Ray *et al*., 2011; Sit *et al*., 2011). Thus, the agronomic approaches are to be standardised in tune with crop needs based on soil type, root system and climate.

Soil health management

Many tropical agro-ecosystems have low fertility soils on which farmers get meagre crop yields. Reversing the stagnant productivity trend in arecanut must begin with soil fertility maintenance. Maintenance of soil organic carbon (SOC) is the key to sustainable crop production in tropics due to rapid mineralization of organic matter. Though arecanut can be grown in many types of soils the dominant are laterite and clay loam soil types. Soil health problems are arising in arecanut growing regions due to excess application of inputs, production constraints.

The SOC in arecanut belt is increased from 0.9% during 1970-80 to 2.78% during 2001-2010 (Sujatha *et al*., 2017a). Inadequate knowledge of the crop nutrient status can frequently result in excessive nutrient applications and imbalances as well as undetected deficiencies or excesses within the crop. Several manifestations of nutrient imbalance are development of disorders like crown choking and bending (Bhat and Sujatha, 2014), yield depression, yellowing and higher incidence of pests and diseases in perennial arecanut. Soil fertility status in arecanut growing belt is above optimum to excess (Bhat and Sujatha, 2014; Bhat *et al*., 2016). Several long term trials in arecanut indicated that there is enrichment in SOC status both in on-station and on-farm studies due to adoption of different agronomic practices (Table 3). Inorganic nutrition also enriches SOC status in arecanut due to higher root biomass and *insitu* root decay (Bhat *et al*. 2007a; Bhat and Sujatha, 2008 and 2009). Nutritional disorders and yellow leaf disease are increasingly noticed in farmer's fields where soil organic carbon levels are very high ranging from 2.5 to 4.0% (Bhat and Sujatha, 2014; Bhat *et al*., 2016). Farmers tend to apply higher rates of organics due to strong perception that organics will improve the productivity and soil fertility.

Table 3: Variations in SOC due to different agronomic approaches

Agronomic approach	SOC (%)		Reference
	0-30	30-60	
Drip fertigation with NPK	1.83	1.17	Bhat and Sujatha, (2009)
Drip irrigation+ standard practices	2.45	1.84	Bhat *et al*., (2012)
Soil application			
a. Vermicompost (VC)	2.71	1.46	Sujatha and Bhat, (2016)
b. Chemical fertilizers (CF)	1.89	1.11	
c. VC + CF	2.27	1.16	

Processes like *in situ* root decay of crop and weeds, and litter fall from intercrops might have contributed to SOC increase in perennial arecanut systems. The compost prepared from mature tissue of plantation wastes might have contributed to enrichment of soil organic carbon.

From the studies on yield limiting nutrients for arecanut, optimum leaf nutrient limits and optimum nutrient limits for laterite soils (Bhat *et al*., 2012; Bhat and Sujatha., 2013), it is clear that the relation between SOC and yield is positive as long as yield limiting nutrient is supplied in optimum. As long as yield limiting nutrients are supplied in optimum, the antagonistic nutrient interactions are absent even at excess soil fertility status. These findings would help in formulating precise fertilizer programs instead of blanket manurial/ nutrient additions that in turn reduces the manuring cost.

Common nutritional disorders in arecanut are crown choking, crown bending, oblique nodes and nut spitting. In recent years, these problems are developing fast in paddy fallows with excess soil fertility, poor soil aeration and water stagnation. The report on loss due to nutritional disorders in arecanut is scanty. The survey in 2005 indicated that the incidence of crown choking and crown bending is more in clay soils (up to 30%) than in laterite soils (up to 9%). On the contrary, the incidence of shortened internodes and oblique nodes is more laterite soils (35%) than in clay soils (5%). Nut splitting incidence varied from 0 to 7% in both soil types. Zinc deficiency is mainly responsible for development of disorders (Bhat and Sujatha, 2014). Nutrient imbalance and excess soil test P result in development of disorders due to antagonistic nutrient interactions in soil leading to hindrance in the uptake of Zn despite optimum nutrient availability in soil. Thus, it is advisable to consider nutrient deficiency/toxicity before the development of visual symptoms with the help of plant and soil analysis for improving the health of palm. Thus, a better understanding of the impact of soil fertility on yield is critical for the accurate prediction.

Overall, soil and plant health management is a problem in paddy converted lands, and there is zinc deficit in palms in clay soil type and deficit of N and K in yellow leaf disease affected palms in laterite soil type. Severe nut drop is noticed in arecanut belt of North Kanara district of Karnataka in acidic soils with high SOC and deficit of soil test K, Zn and B (Rajakumar and Patil, 2016). In clay soils of Karnataka, nutrient rating of soils in arecanut plantations is categorized as medium with no micronutrient deficiency (Shilpashree *et al*., 2011).

SUSTAINABILITY THROUGH PEST AND DISEASE MANAGEMENT

One of the major yield limiting factor in arecanut production system is occurrence of pests and diseases throughout the year in humid tropics. Due to weather aberrations and ecological issues, the arecanut production system might experience serious sustainability issues due to reduced input use efficiency, proliferation of pests and diseases, non-adoption of timely control measures and lack of community approach in pest/disease management. The status of major pests and diseases and the effective control measures are described in Table 4. Arecanut palm is affected by number of diseases during different stages of its growth and development. *Phytophthora* diseases like fruit rot (*Phytophthora meadii*), bud rot and crown rot are serious problems in arecanut belt in humid tropics and cause yield loss of 10-90% (Jose *et al*., 2008). The control of yield losses due to *Phytophthora* diseases is a huge challenge in traditional arecanut belt. The prophylactic spraying of 1% Bordeaux mixture controls *Phytophthora* diseases, but factors like heavy rainfall, scarcity of skilled climbers for spraying, absence of machinery for effective delivery of fungicides, variability of the pathogen and occurrence of more virulent strains of the pathogen are reducing the effectiveness of existing control measures. Development of fool proof control measures for major diseases of perennial arecanut is a huge challenge due to several inherent constraints. In humid tropics, acidic laterite soils with low buffering capacity and CEC, and heavy rainfall contribute to faster multiplication of pathogenic fungi. The humid conditions of heavily shaded arecanut may actually stimulate the outbreak of pests and diseases. Provision of optimum nutrition during maximum inflorescence production period (November to February) helps in escaping the disease as nuts escape the maximum susceptibility stage to fruit rot. The nuts of 2–3 month old are highly susceptible.

Bud rot is another fatal disease of arecanut palm caused by *Phytophthora* spp. This disease is seen during southwest mon-soon as well as in the subsequent winter months (Oct -Feb.). Early detection of the disease and prompt removal

Table 4: Major pest and disease complex in arecanut in India

Pests and diseases	Causal agent	Period of occurrence	Status and yield loss	Region/congenial conditions	Effective control measure
Diseases					
Fruit rot	*Phytophthora meadii*	June-September	Major disease and recurring10-90% yield loss	Humid tropics. continuous rainfall with intermittent sunshine, low temperature (20°C-23°C) and high relative humidity (RH >90%)	1% Bordeaux mixture and covering bunches with poly bags
Bud rot and crown rot	*Phytophthora meadii*	June-February	Become major in case fruit rot is not controlled properly and continuous rains after Sepetember The yield loss is as high as 50 per cent	Humid tropics	Pasting cut end with Bordeaux paste. Drenching healthy palms with Bordeaux mixture (1%). Drenching with salt of phosphorous acid @ 0.3 per cent
Inflorescence die back	*Colletotrichum gloeosporioides*	Year round but severe during summer months (February to May	Humid tropics	Spraying of Indofil -M-45 @ 3g/l or Dithane-Z-78 @ 4g/l	
Foot rot/ basal stem rot		*-Ganoderma lucidum*		Major in endemic areas and minor in other arecanut areas	Sub humid and dry regions Drenching root zone with 0.3% Calixin (3ml/l) @ 15-20 l/palm + root feeding of 1.5% Calixin (15ml/l) @ 125 ml/palm at quarterly intervals. Application of 2kg neem cake per palm per year.
Leaf spot	*Colletotrichum gloeosporioides* and *Phyllosticta arecae*	Summer and south west monsoon	occurs in seedlings and young palms	Humid tropics	Spraying Dithane M-45 @ 0.3% (3g/l of water) or Carbendazim (Bavistin) @ 0.05 % (0.5g/l of water).
Pests					
Root grub/white grub	*Leucopholis. burmeisteri*, *L. coneophora* and *L. Lepidophora*	Year round	Major in certain pockets. Heavy yield reduction or death of palm	Western ghat region of Kerala and Karnataka	Application of plant product like *Vitex negundo* leaf extract 2% (or) Nimbecidine 2% in the root zone and soil drenching of 3 litre of Chlorpyriphos (@ 7 ml / litre of water and spraying of Imidacloprid @ 2.5 ml /litre of water in the interspaces for control of early instar grubs.
Spindle bug	*Mircarvalhoia arecae*	Peak infestation in August-September	Major pest		
Phytophagous mites	*Raoiella indica* *Oligonychus indicus*	Summer months	Chronic in young plantations		Spraying of dicofol @ 2 ml/ liter of water or dimethoate 1.5 ml/ liter of water on the lower surface of leaves

of the infected tissues will help in the recovery of the palms and also prevents further spread of the disease. However, non-availability of effective forecasting models for *Phytophthora* disease in arecanut is a hurdle in effective disease management. Identification of effective endophyte against *Phytopthtora* and development of management strategies for fruit rot disease with biocontrol agents and chemicals are also imperative. Elucidation of resistance mechanism of certain wild areca species to *Phytophthora* and identification of the genes governing resistance, and exploring the possibility of using resistance genes to develop improved arecanut varieties with resistance to fruit rot disease require greater focus.

Basal stem rot of arecanut caused by *Ganoderma lucidium* (Curtis ex. Fr.) Karst is one of the dreaded diseases of arecanut in clay and sandy loam soils in non traditional belt due to water stagnation probelm. A three pronged strategy is to be executed for the control of foot rot; i) understanding the cross infection potential of *Ganoderma* isolates to other hosts like coconut, oil palm etc., ii) Identification of effective microbial biocontrol agent by comparing the microbiome of healthy and diseased palms, iii) Study the influence of various cultural practices in the non-traditional areca growing areas on foot rot and find out the practices for management of the disease.

One of the mechanisms of disease control is induced systemic resistance (ISR) in recent years. The review by Doornbos *et al* (2012) highlights that the understanding the complex interactions between plant roots and its highly diverse and dynamic microflora are at the start. The focus of biological control of plant diseases is ISR that is effective against a wide range of pathogens and thus offers serious potential for practical applications in crop protection. Based on preliminary studies on induced systemic resistance, about 14 fungal isolates of *Trichoderma* spp and 23 bacterial isolates (11 *Bacillus* spp. and 12 *Pseudomonas* spp.) are identified from rhizosphere soil and root samples in arecanut plantations of YLD endemic areas of Karnataka (CPCRI, 2011). The screening of these isolates for competitive saprophytic ability, antagonistic activity and production of antifungal volatiles indicated that one each of *Trichoderma* isolate and *Bacillus* isolate showed highest antagonistic activity against *Colletotrichum gloeosporioides.* Antifungal volatile activity is found to be highest in *Trichoderma* and *Bacillus*.

Arecanut is infested by several insect and non-insect pests. About 90 pests have so far been reported on arecanut palm including storage pests. But the two serious pests are root grub and spindle bug. Impact of pesticides on ecosystem especially bio-magnification is a matter of concern. Screening and engagement of ecosystem compatible biorational molecules and biocontrol agents poses great challenge.

Timely spraying of plant protection chemicals continues to be the biggest problem for arecanut farmers and huge marketing potential exists for plant protection and harvesting equipments. Skilled climbers are scarce and labour charge for climbing operation is escalating. Absence of mechanization raises sustainability concerns in the present scenario. But, complete mechanisation of arecanut cultivation is also difficult due to small fragments of land with undulating topography. Absence of machinery for timely operations and sudden weather shocks reduce profits due to yield losses and higher production cost.

ECONOMIC SUSTAINABILITY

Arecanut occupy the same field for many years and require high investment during establishment stage. Long-term returns of such investments can only be expected if production system is sustained. The economic sustainability depends on assured profits, adaptation to climate change, export potential and value addition opportunities. In arecanut, the economic sustainability of arecanut can be ensured by value addition (Sujatha *et al*., 2015), judicious input use and reduced production cost to accrue assured income due to limited export potential. Unlike in other plantation crops, area expansion is rapid in arecanut due to sharp increase in prices and economic returns during the last two decades. The price of dry kernel of arecanut increased from Rs. 70 in 2000 to Rs. 200-250 per kg in 2016. In recent years, the profitability of arecanut fluctuated widely due to several production constraints. The concept of cropping systems is the best approach for arecanut growers for increased income per unit area. The efficient and economically viable cropping models are discussed in above section. The production cost per palm can be reduced by Rs. 25/- if mixed farming approach is followed due to interdependencies (Sujatha and Bhat, 2015).

To sustain economically viable yields, the crop needs should be given importance by adopting integrated approach rather than single agronomic approach as evidenced by several long term experiments (Table 5) (Sujatha and Bhat, 2013ab and 2016). For reducing the cost of production, automated irrigation systems to save water and energy either with solar or wind energy operated pumps should be strategically addressed and, development of integrated dryers (solar, agricultural wastes and electrical based) for drying economic produce of arecanut is needed to reduce the drying time and improve the quality of the produce.

Table 5: Yield gap between national productivity and different technologies

Suitable adaptation strategy	Yield level (kg ha^{-1})	% increase over national average yield (1600 kg ha^{-1})	Reference
Drip fertigation (2002-2006)	4017	151	Bhat *et al.* (2007a)
Organic matter recycling (2003-2011)	2774	73	Sujatha and Bhat, (2013b); Sujatha and Bhat, (2016)
Cropping system approach			
Arecanut+MAPs with sprinkler irrigation (2004-2007)	3010	88	Sujatha *et al.* (2011a)
Arecanut+vanilla with drip irrigation (2005-2008)	3114	95	Sujatha and Bhat (2010)
Arecanut+cocoa with drip fertigation (2008-2011)	3117	95	Sujatha and Bhat (2013a)
Mixed farming approach (2012-2014)	3418	114	Sujatha and Bhat, (2015)

CLIMATE CHANGE AND ARECANUT

Agriculture is affected by climate change and weather variability as crop development depends directly on climate. Weather variability influences the yield and sustainability of perennial plantations considerably as economic yielding life accounts for several decades. Thus, accurate assessment of yield response to future climate is needed to prioritize adaptation strategies. Proliferation of pests and diseases, reduced recovery and low resource use efficiency are the imminent consequences due to climate change scenario. The emergence of two new pests palm aphid and arecanut whitefly in arecanut is a consequence of either climate change or pest resurgence in perennial ecosystem (Josephrajkumar *et al*., 2013). The variations in rainfall from May to November and relative humidity at afternoon hours significantly affect the arecanut yield of Western ghat region of Karnataka (Tejaswani *et al*., 2014). Results of survey in South Konkan region of Maharashtra revealed that arecanut yield is directly proportional to rainfall above 4300 mm with maximum humidity (Salvi *et al*., 2015) and arecanut prefers high relative humidity particularly during the morning period throughout its growth period.

In perennial crops, the productivity is influenced not only by rainfall and temperature but also by other weather parameters like relative humidity, evaporation and sunshine hours (Sujatha *et al*., 2017b). The climatic shocks like very heavy rainfall events, more number of cloudy days, reduced monsoon rainfall and increased rainfall during summer/post-monsoon are observed during the last decade. The prominent weather change is decrease in total rainfall during 2000-2012 by 531 mm (14%) over 1970-1999. Correlations between arecanut yield and year wise weather variables were positive and significant for T_{max} (r=0.48), T_{min} (r=0.16) and RH (r=0.32 to 0.49). Correlations were negative between arecanut yield and rainfall/sunshine hours (r = -0.20 to -0.21), while no relation was observed for evaporation and rainy days.

ADAPTATION STRATEGIES

Crop management needs to fine-tuned to weather changes as an adaptation strategy. Identification of genotypes tolerant to various biotic and abiotic stresses is need of the hour. During 2000-2015, successful technologies like nutrient and irrigation management, drip fertigation (Bhat *et al*., 2007a; Sujatha and Bhat, 2013a), cropping systems (Bhat and Sujatha, 2011; Sujatha *et al*., 2011b; Sujatha *et al*., 2016) and mixed farming approach (Sujatha and Bhat, 2015) in arecanut reduced the impact of weather changes. Drip fertigation is a better adaptation strategy under changing climate scenario in humid tropics as it sustains yield levels in low rainfall years also as in 2002 and 2012 (Bhat *et al*., 2007a; Sujatha and Bhat, 2013a). In 2002, yield loss of 13 -14.5% is reported in farmer's plantations due less rainfall. Adoption of farming systems is necessary to reduce income fluctuations due to weather changes (Sujatha and Bhat, 2015b). We analyzed the efficient arecanut based cropping system models for adaptation to climate change that are given in Table 12. However, the scope for improving the productivity of arecanut by 200 to 300% and profitability is demonstrated through different technologies at ICAR-CPCRI.

MARKETING AND DEVELOPMENT OPPORTUNITIES

Arecanut is marketed in various forms as unhusked whole fruit, dehusked and dried nut, boiled and dried whole kernel or their cuts. The success of any agricultural activity depends much on the availability of an efficient market mechanism. There are various agencies/intermediaries involved in the movement of arecanut from producer to consumer. In earlier times, trade was monopolistic in nature in arecanut sector. At present, the marketing system is efficient in arecanut growing belt due to private traders, farmer's cooperatives and organizations and this is one of the reasons for rapid expansion of area under arecanut. Co-operative marketing societies play an important role in the marketing of arecanut. The establishment of

Central Arecanut Marketing and Processing Co-operative Ltd (CAMPCO) raised the farm price and wholesale price of arecanut with minor fluctuations (Karunakaran, 2014). More than 75% of the domestic trade of arecanut is in the hands of private traders. This eventually results in frequent fluctuations in prices due to poor market intelligence, market hoarding and imperfect market formation.

The availability of several marketing opportunities and the long storage life of economic produce with minimum spoilage are added advantages in perennial arecanut. Developmental agency like Directorate of Arecanut and Spices Development (DASD) is not directly promoting cultivation of arecanut but promoting technology dissemination through frontline demonstrations on arecanut based cropping systems. All these aspects made arecanut cultivation more remunerative and improved the economic conditions of arecanut farmers.

PROCESSING, ALTERNATE USES AND VALUE ADDITION OPPORTUNITIES

Arecanut is processed by two methods in different states. Dry kernel (fully ripe dehusked graded nuts) accounts for about 80% of production and tender nut (semi-ripened, dehusked, boiled, coloured and dried nuts) accounts for about 15%. The most popular type of arecanut is dried whole nuts. The processing for tender nut consists of dehusking of nuts of 6 to 7 month maturity, cutting into halves, boiling with water or dilute extract from previous boiling and drying. The chemical composition of arecanut depends on maturity of the nut. The major constituents of arecanut are carbohydrates, lipids, proteins, crude fibers, polyphenols and alkaloids (arecoline, arecaidine, guvacine and guvacoline). Among the alkaloids, arecoline is the most potent and active constituent that is suspected to cause health hazards and the World Health Organization classified arecoline as carcinogenic. Till today, the required scientific data is not available to classify arecoline as carcinogenic. Arecanut kernel contains 11-29% polyphenol and 8-15% fat. Alkaloid is present as minor and important constituent (0.11-0.24%). Among the alkaloids present in arecanut, arecoline ($C_7H_{13}O_2N$) is the main and physiologically the most active one, varying from 0.1 to 0.67 per cent (Annamalai *et al* 2004). Of these alkaloids, arecoline and arecaidine are present in the highest concentration. The medicinal uses of alkaloids for are reported by several workers. It is desirable to separate alkaloids/polyphenols from arecanut to obtain alkaloid-free polyphenols and subsequently use it for nutraceutical/therapeutic purposes and also for suitable use of arecoline in the pharmaceutical industries. Therefore, it is essential to develop an efficient method for extraction of polyphenols from arecanut with minimum arecoline content and identification of arecanut varieties with less arecoline content.

Suitable and practicable options for recycling of organic wastes of arecanut as different value added products are analysed in detail (Sujatha *et al*., 2015). Recycling potential of arecanut wastes as vermicompost, oyster mushroom (*Pleurotus sajor-caju*), fodder and other value added products are illustrated in flow diagram (Figure 3). The economic sustainability of arecanut can be ensured in future by taking up various value addition options as microenterprises. Arecanut husk is a potential source of potassium for organic farming approach. The study on the value addition and marketing efficiency of arecanut processing units indicated that the co-operative unit is dominant in both procurement as well as sale of arecanut and incurs lowest cost in value addition due to reduced cost of procurement (Kolur *et al*., 2012).

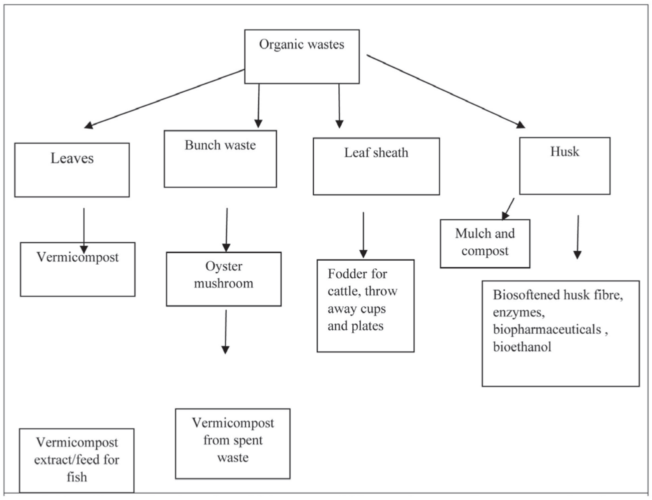


Fig. 3: Flow diagram showing value addition to recyclable organic wastes from arecanut plantation

CONCLUSIONS AND FUTURE NEEDS

Arecanut is an important and fast expanding plantation crop in South east Asia and in particular in South India. Arecanut production system experiences both inherent production constraints and technological/management constraints. For long term sustainability of arecanut system, the major need is addressing of sustainability issues in production system as the problems of marketing, and demand and supply are minimal in post-production scenario. The introduction of arecanut puts pressure on natural resources because it is often planted in paddy fallows and cleared-cut land that previously supported forest crops. Local cultivars and blanket recommendations are no longer able to improve the productivity to the potential level during the past few decades. A paradigm shift with advanced technologies is required for enhancing the system's productivity and sustainability. Resource conserving technologies and crop diversification with value added crops has been suggested to overcome the system's sustainability problems as these are not fully embraced by the farmers. The review suggests that the suitable strategies for sustenance of arecanut system are cropping/farming system approach, efficient and need based input use, recycling of organic wastes, soil fertility maintenance, and soil and plant health management.

Nutrient management strategies need to be planned for arecanut taking in to account the soil fertility status, biomass partitioning, nutrient uptake and leaf nutrient status to avoid nutrient imbalances in soil and palm. Other management strategies like nutrient and water management, drip fertigation, organic matter recycling, and soil and water conservation measures have great impact on yield stability and soil fertility improvement. The sustainability of arecanut is in question both in traditional and non-traditional areas due to impending problems like climatic shocks, soil-plant nutrient imbalances, nutritional disorders, increase in infestation/incidence of pests and diseases, farmer's preference for monocropping and poor adaptability of palms. Overall, the review suggests that the important sustainability concerns are soil fertility/nutrient imbalances in non-traditional clay soil tract, and the pests and diseases in traditional laterite soil belt. The sustainability concerns in arecanut will be applicable to other palms such as coconut and oil palm also with less intensity as more or less similar conditions exist in perennial plantations.

Additional area expansion both in traditional and non-traditional areas is to be strictly prohibited and simultaneously the arecanut based cropping systems should be encouraged in the existing arecanut plantations in the country for long term sustainability of natural resources. For economic sustainability of arecanut production system, value addition and alternative uses of arecanut for medicinal and industrial purposes have to be promoted in a wide manner. In view of emerging new problems and sustainability issues in arecanut ecosystem, future line of work should cover exploiting genetic resources for resistance to biotic and abiotic stresses, developing Good Agricultural Practices (GAP), sustainable cropping system models, evaluation of native bio-control agents for disease and pest management, developing location specific Integrated Pest Management (IPM) and impact of climate on arecanut. Comprehensive studies on carbon sequestration potential, nutrient uptake pattern and soil fertility dynamics in the cropping system are important future research areas.

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