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Trees
Structure and Function

ISSN 0931-1890
Volume 35
Number 2

Trees (2021) 35:621-635
DOI 10.1007/s00468-020-02064-w

Springer

Trees (2021) 35:621–635
https://doi.org/10.1007/s00468-020-02064-w

ORIGINAL ARTICLE

A comparative assessment of nutrient partitioning in healthy and root (wilt) disease affected coconut palms grown in an Entisol of humid tropical Kerala

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Received: 27 November 2019 / Accepted: 18 November 2020 / Published online: 3 January 2021

Abstract

Key Message **Nutrient uptake in the biomass of healthy and root (wilt) disease affected coconut palms are different.**

Abstract Root (wilt) is a predominant phytoplasmal disease affecting coconut (Cocos nucifera L.) palms and to sustain the palm health and productivity, better nutrient management practices are required. The objective of this research was to understand the uptake pattern and the partitioning of nutrients in the total biomass of healthy and root (wilt) diseased palms grown in humid tropical Entisol of Kerala. 5 coconut palms each were selected from diseased palms viz., Early (DE), Middle (DM) and Advanced (DA) category along with the control, which is Apparently Healthy palm (AH), without any diseases. The total biomass component with respect to each part viz., leaf (L), petiole (P), spadix (S), spathe (Sp), stem (St), leaf sheath fiber (LSF), husk (H) and nuts (copra:C + shell (S*h*)) (N) were estimated. Nutrient uptake by the entire biomass uptake is classified as 1. Recyclable portion (L, P, S, Sp, H, LSF and S*h*) 2. Removable portion (C) 3. Reserve biomass (St) and then computed the nutrient partitioning by standard analytical procedures. For all nutrients except Mg, reserve biomass had the greatest nutrient uptake followed by recyclable biomass and removable biomass components. Among the nutrients, potassium recorded the highest total uptake. In AH palm, the total uptake of potassium was 1075 g per palm, whereas it was 407.3 g per palm in the diseased palms. The total uptake of nutrients which showed a significant relation with disease index followed the order K > N > Ca > S > P > Mg in apparently healthy palms and N > K > Ca > S > P > Mg in diseased palms. The percentage reduction in total uptake of N, P, K, Ca, Mg, S and B by diseased palms in comparison with healthy palms was 36.5, 37.6, 57.5, 44.1 23.3, 43.7 and 48.9. The results of the study indicated that the pattern of nutrient uptake in the different biomass components of apparently healthy and root (wilt) disease affected palms are significantly different. This can instigate the formulation of appropriate nutrient management strategies in coconut with emphasis on its residue recycling potential.

Keywords Coconut · Nutrient partitioning · Uptake · Biomass

Introduction

Coconut, 'the tree of life' is a perennial plantation crop, geographically distributed in more than 90 countries all over the world with a global production of 61 million nuts per year. India is the third major producer of coconut in the world. The present productivity of coconut in India is 10614 nuts per ha (Coconut Development Board 2018). The monocotyledonous crop of coconut (*Cocos nucifera*) belonging to the family of Arecaceae grows up to a height of 30 m with pinnate leaves of 4–6 m long. On the basis of growth characteristics, palms are generally classified as tall and dwarfs. Coconut palms of tall variety, usually flower 4–5 years after planting. Nuts are harvested once in 45 days and it is a continuous process

Communicated by LeBoldus.

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wherein the productive life of the palm lasts for 6–7 decades. Hence, there is a continuous removal of nutrients from the system through the harvesting of nuts and also through the various palm residues. Earlier studies by Pillai and Davis (1963) have shown that the annual exhaust of nutrients computed from 1 hectare of 173 palms in sandy loam soil was 65.6, 29.7, 84.5, 47.4 and 20.3 kg of N, P_2O_5, K_2O, CaO and MgO, respectively, from nuts, fallen leaves spathe and the stem growth. Biddappa et al. (1996) found that 6–8 tons of organic matter would be available in the form of leaves, spathe, bunch waste and husk from a well managed coconut plantation offering excellent potential for in situ crop residue recycling. Residue recycling in coconut can be achieved through leaf mulching, husk burial, coir pith composting, vermicomposting, biochar production with coconut shells and composting of all the available palm residues within the basin itself (Coconut Cultivation Practices 2007).

The innate nutrient profile of each of the components depend on factors such as variety, soil fertility, age of the palm, stage of bearing as well as the general palm health status. In arecanut, Bhat and Sujatha (2012) observed that uptake of major and micro-nutrients varied significantly between low and high yielding arecanut palms which showed that the combined effect of greater biomass production and nutrient uptake had direct effect on the marketable yield.

Pests and diseases affect the palm productivity and performance through reduction in the photosynthetic area of the leaf and thereby reducing the photosynthetic activity and ultimately drastic reduction in nut production (Eyzaguirre and Pons Batugal 1999). In general, coconut palms are affected by around 50 diseases worldwide. Among the diseases, Cadang Cadang, Lethal Yellowing disease and root (wilt) disease have received a lot of attention. The coconut root (wilt) disease was first recorded in 1882 at Erattupetta (Meenachil Taluk, Kottayam District of erstwhile Travancore State, Kerala in India) following the great floods in 1882 (Butler 1908). Though the disease is being termed as root (wilt) disease, the most consistent symptoms are flaccidity, yellowing and the necrosis of leaves. It causes 35% yield reduction and the losses may extend up to 80% in severe cases. In India, the annual loss due to this disease was estimated around 968 million nuts per year (Manimekalai et al. 2010). Thus, it is a serious disease in most of the coconut plantations of Kerala.

The major symptoms of root (wilt) are flaccidity (ribbing) of leaflets, yellowing and necrosis in leaflets. However, this disease is often found superimposed (65%) with leaf rot disease. The quantitative evaluation of foliar symptoms of 7000 palms of varying ages has led to the better understanding of the symptamatology by Radha and Lal (1972). However, though the phytoplasmal disease cannot be cured, the palm health can be managed through standardized practices such as integrated nutrient management including soil test-based application of nutrients, water management, high-density multi-species cropping system. The intensity of disease is expressed in terms of root (wilt) index. Wahid and Kamalam (1988) reported the accumulation of N in the young and expanding leaves of root (wilt) diseased palms as compared to that of the healthy palms. Increased respiration rate (Michael 1978), decreased concentration of reducing and non-reducing sugars (Mathew 1977) and low C: N ratio (Varkey et al. 1979) were reported in the earlier studies. Reduced concentration of leaf nutrients in the diseased palms was observed by George (2016). Such results points to the differential nutrient assimilation pattern between the healthy and the diseased palms. Being a phytoplasmal disease, yield reduction will occur significantly (Krishnakumar and Maheswarappa 2010), however, adoption of integrated nutrient management strategies with the application of recommended dose of fertilizers and organic manure resulted in the improvement of disease index, i.e., the disease middle category palms shifted to disease early category. Hence, it is mandatory to adopt appropriate nutrient management strategies to revitalize the palm health, making the palms stronger, in addition to sustainment of overall productivity. In other words, a balanced nutrition is important for restoring the health of the diseased palms.

Relation between diseases and nutrition in several crops were studied in detail, however, with respect to coconut, since it is perennial in nature only few studies have been conducted with regard to diseases such as stem bleeding (Rawther 1963), basal stem rot (Bhaskaran and Ramanathan 1984) and grey leaf blight (Sugata Ghose 2014). Since root (wilt) disease causes a slow but steady decline in the productivity of coconut palms, effective management with sound agronomic practices will improve the yield in disease affected palms. Linking the plant nutrition and diseases infestation in such a perennial crop of coconut will give useful insights for effective management of such diseases. Moreover, in a perennial tree crop as that of coconut, computing the biomass and dry matter content of each palm component for estimating the uptake by them is a difficult task, since it involves the entire uprooting of palm (destructive) and do the analysis and such studies are very rare. The present study was conducted to understand the uptake and distribution of major, secondary and micronutrients in healthy and root (wilt) diseased palms grown in a tropical Entisol, the knowledge of which could formulate appropriate nutrient management strategies.

Materials and methods

Experimental site

The investigation was conducted during 2016–2017 at ICAR—Central Plantation Crops Research Institute, Regional Station, Kayamkulam geographically situated at 9° 8′ N latitude and 76° 30′ E longitude. The area forms the part of Agro Ecological Zone I (AEZ I) and Agro Ecological Unit 3 (AEU 3) forming the Onattukara tract. The tropical monsoon climate provides a mean rainfall of 2448 mm from May to December. The relative humidity ranges from 75.0 to 90.0%, and the dry season lasts from December to April and is characterized by high temperatures (Max 32 °C).

Soil analysis

Samples were taken from the cultivated soil layer (0–30 cm and 31–60 cm) and combining eight samples evenly distributed over the field to one composite sample. The samples were air dried, crushed, and gravel and other particles of more than 2 mm were removed with a sieve. The samples were analysed in the soil laboratory for the parameters listed in Table 1. The site characteristics and analysis of soil results are presented in Table 2. The soil is sandy loam with a particle size distribution of 58.5% coarse sand, 17.3% fine sand, 15.5% silt, and 8.7% clay. The cation exchange capacity is 3.2 cmol per kg, which indicates the nutrient retention capacity is low and the bulk density is 1.58 Mg m^{-3}. The major soil fertility parameters of the experimental site indicates that the soil is strongly acidic, low in organic carbon, high in available P, medium in available K (121.35 ppm),

Table 1 Methods of analysis of soil samples and plant samples

S. no.	Estimation	Method	References
Soil parameters			
1	Mechanical analysis (soil texture)	International pipette method	Piper (1966)
2	Physico-chemical properties		
	EC	Conductometry	Jackson (1973)
	pH	Potentiometry	Jackson (1973)
	CEC	Neutral normal NH_4OAc	Jackson (1973)
3	Chemical properties		
	Organic carbon	Chromic acid wet digestion method	Walkley and Black (1934)
	$KMnO_4$-N	Alkaline permanganate method	Subbiah and Asija (1956)
	Available P	Bray and Kurtz extraction method using 0.03 N Ammoniium flouride and 0.025 N HCl	Jackson (1973)
	NN NH_4OAc-K	Neutral Normal NH_4OAc using flame photometer	Stanford and English (1949)
	Calcium	Neutral Normal NH_4OAc using AAS	
	Magnesium	Neutral Normal NH_4OAc using AAS	
	Sulphur	Turbidimetry	Chesnin and Yien (1950)
	Micronutrients Cu, Zn, Fe, Mn	Extraction using 0.1 N HCl and estimation using Atomic Absorption Spectrophotometer	Lindsay and Norvell (1978)
	Boron	Hot water extraction method	Berger and Truog (1939)
Plant parameters			
1	Nitrogen	Microkjeldahl method	Humphries (1956)
2	Tri acid extract	Nitric acid, Sulphuric acid and Perchloric acid 9:2:1 ratio	Piper (1966)
3	Phosphorus	Vanadomolybdate yellow colour method	Jackson (1973)
4	Potassium	Flame photometry	Stanford and English (1949)
5	Calcium	Atomic absorption Spectrophotometry	
6	Magnesium	Atomic absorption Spectrophotometry	
7	Sulphur	Nitric – perchloric acid (9: 3) digestion and turbidemetry	Tabatabai and Bremner (1970)
8	Micronutrients Cu, Zn, Fe, Mn	Nitric – perchloric acid (9: 3) digestion and Atomic Absorption spectrophotometry	Lindsay and Norvell (1978)
9	Boron	Azomethine –H colorimetric method	Bingham (1982)

Table 2 Characteristics of the study area

1a. Site characteristics	
Districts/AEU	Alapuzha/Agro Ecological Zone I
Latitude/longitude	9° 8′ N latitude and 76° 30′ E longitude
Elevation (above mean sea level) (m)	750 m above msl
Mean annual maximum temperature (°C)	31.63
Mean annual minimum temperature (°C)	23.42
Mean annual rainfall (mm)	2448
Major soils	*Entisols*
Major crops grown	Coconut, Coconut based mixed cropping system, Paddy
1b. Soil characteristics	
Soil series	Aquic Usti Psamment
Texture	Sandy loam
pH	5.56
CEC (cmol per kg)	3.20
Organic carbon (%)	0.412
Available P (ppm)	29.35
Available K (ppm)	121.35
Calcium (ppm)	104.51
Magnesium (ppm)	18.62
Sulphur (ppm)	5.2
Iron (ppm)	6.87
Manganese (ppm)	2.99
Copper (ppm)	0.79
Zinc (ppm)	0.24
Boron (ppm)	0.45

deficient in Ca and Mg, high in available Fe and Mn and low in deficit in Cu, Zn and B, respectively.

Experimental materials

Coconut palms Var. West Coast Tall aged 30 years planted at a spacing of 7.6 m × 7.6 m in a compact block at the Regional Station were selected for the study. The intensity of disease was expressed in terms of root (wilt) index as per the formula designed by George and Radha (1973).

$$\text{Disease index} = \frac{(F + Y + N)\times 10}{L}$$

F, Y and N are the grade points assigned to a leaf, for flaccidity, yellowing and necrosis, L is the total number of leaves. Those palms having disease index in the range 0–20: Disease Early (DE): 21–50: Disease Middle (DM); above 50: Disease Advanced (DA) category. 5 palms were selected from DE, DM and DA category along with the control, which is Apparently Healthy palm (AH), without any diseases. The disease index of root (wilt) affected palms in our study varied in the range of 6–56 with average index as 10.8, 31.6 and 53.8, respectively for DE, DM and DA category, respectively. A photo showing an apparently healthy and root wilt affected palm is attached as Plate 1.

Estimation of biomass

Coconut palms identified for the study were uprooted using an excavator during October 2016 and the total length of each uprooted palm was measured from the tip of the trunk to the base of the palm. The crown was then detached from the trunk and they were segregated as leaf (L), petiole (P), spadix (S), spathe (Sp), stem (St), leaf sheath fiber (LSF), husk (H) and nuts copra (C), shell (Sh) (Details attached as plate 2). The stem was cut into small pieces of one meter length and the parts were weighed in an electronic balance to estimate the actual fresh weight of each part and later the total weight of the entire stem was computed by summing up the weight of individual parts (Plate 3). Likewise the palm components such as leaf, petiole, spadix, spathe and the leaf sheath fiber were weighed separately and the total fresh weight of the parts were recorded. Coconuts were de husked and the fresh weight of the nut as well as the husk was recorded. After estimation of the total fresh weight of each biomass component, they were sub segregated into representative units of 50 g and dried in the hot air oven at 65–70 °C to a constant weight. The copra weight was recorded after drying the fresh kernel to a moisture content of 6%.

The entire biomass of coconut was segregated into three portions. (i) Recyclable parts such as leaf (L), petiole (P), spadix (S), spathe (Sp), leaf sheath fiber (LSF), husk (H) and Shell (S*h*), (ii) Removable parts as Nuts Copra (C) and (iii) Reserve parts as stem (St). This was classified as on the basis of nutrients which can be recycled back to the system (Recyclable) as well as those nutrients which are removed from the system once the nuts are harvested (Removable) and nutrients which are stored for longer period in the stem (Reserve).

Nutrient analysis, uptake of nutrients and yield

The dried palm parts were powdered and digested in di acid mixture of concentrated Nitric acid and Perchloric acid (9:3) for the estimation of nutrients. The concentration of N, P, K, Ca, Mg, S, Mn, Cu and Zn were estimated as per standard procedures listed in Table 1. The total uptake of nutrients in each of these components was estimated by multiplying nutrient content and the dry weight of biomass. Coconut

Plate 1 **a** Healthy coconut palm, **b** Root wilt affected palm

yield was also accounted for all these four categories, AH, DE, DM and DA and this yield was regressed with nutrient uptake.

Statistical analysis

Nutrient uptake by different disease categories were compared using ANOVA for one-way classified data. Coefficient of correlation was used to know about association between nutrient uptake and the disease index. For statistical analysis SPSS version 21.0 was used (IBM 2016).

Results

Biomass partitioning in different parts

Significant difference in the partitioning of biomass into the three categories (recyclable, removable and reserve) was observed between the apparently healthy (AH) and the disease affected palms. Results showed that the removable, recyclable and reserve biomass were significantly higher in apparently healthy (AH) palms compared to different categories of root (wilt) diseased palms (Table 3). However, the difference in the biomass among the DE, DM and DA categories was not significant except in case of removable biomass which was significantly different between DE and DA.

The biomass partitioned in the reserve (stem) was 80.7 kg per palm in the AH category and the value varied from 59.83 to 63.02 kg per palm among the diseased categories (DE, DM and DA). Recyclable biomass comprising the palm residues which can be incorporated through in situ palm residue recycling was significantly higher in the apparently healthy palm (20.42 kg palm^{-1}) compared to disease affected categories (DE, DM, DA) and the recyclable biomass in the disease categories was not significant and ranged from 12.29 to 12.91 kg palm^{-1}. The removable biomass was also significantly higher in AH palm (1.74 kg palm^{-1}) compared to disease affected categories. The removable biomass in DE category (1.05 kg palm^{-1}) was significantly higher over DA category (0.812 kg palm^{-1}) but at par with DM category (0.998 kg palm^{-1}). However, there was no difference between DM and DA categories.

Analyzing the pattern of distribution of biomass components indicate that in the apparently healthy palms, 78 per cent constitute the reserve biomass, whereas in the diseased palms, it comes to 82%, i.e., a greater allocation of biomass in the stem (Fig. 1).

Total nutrient uptake in palms with different disease intensities

Understanding the magnitude of nutrient uptake in the different components of coconut palm, a perennial plantation crop is an essential pre requisite to develop appropriate nutrient management strategies. The total uptake of each nutrient viz., N, P, K, Ca, Mg, S Mn, Cu and Zn and B as influenced by the different intensities of root (wilt) disease is presented in Table 4. Since the difference in nutrient uptake between different disease categories was not significant, the average uptake of three categories was computed and compared with uptake in apparently healthy palms. Among the macronutrients, the uptake of N, P, K, in apparently healthy palms (889.0, 109.4, 1075.0, g/palm, respectively) was significantly higher compared root (wilt) diseased palm (560.5,

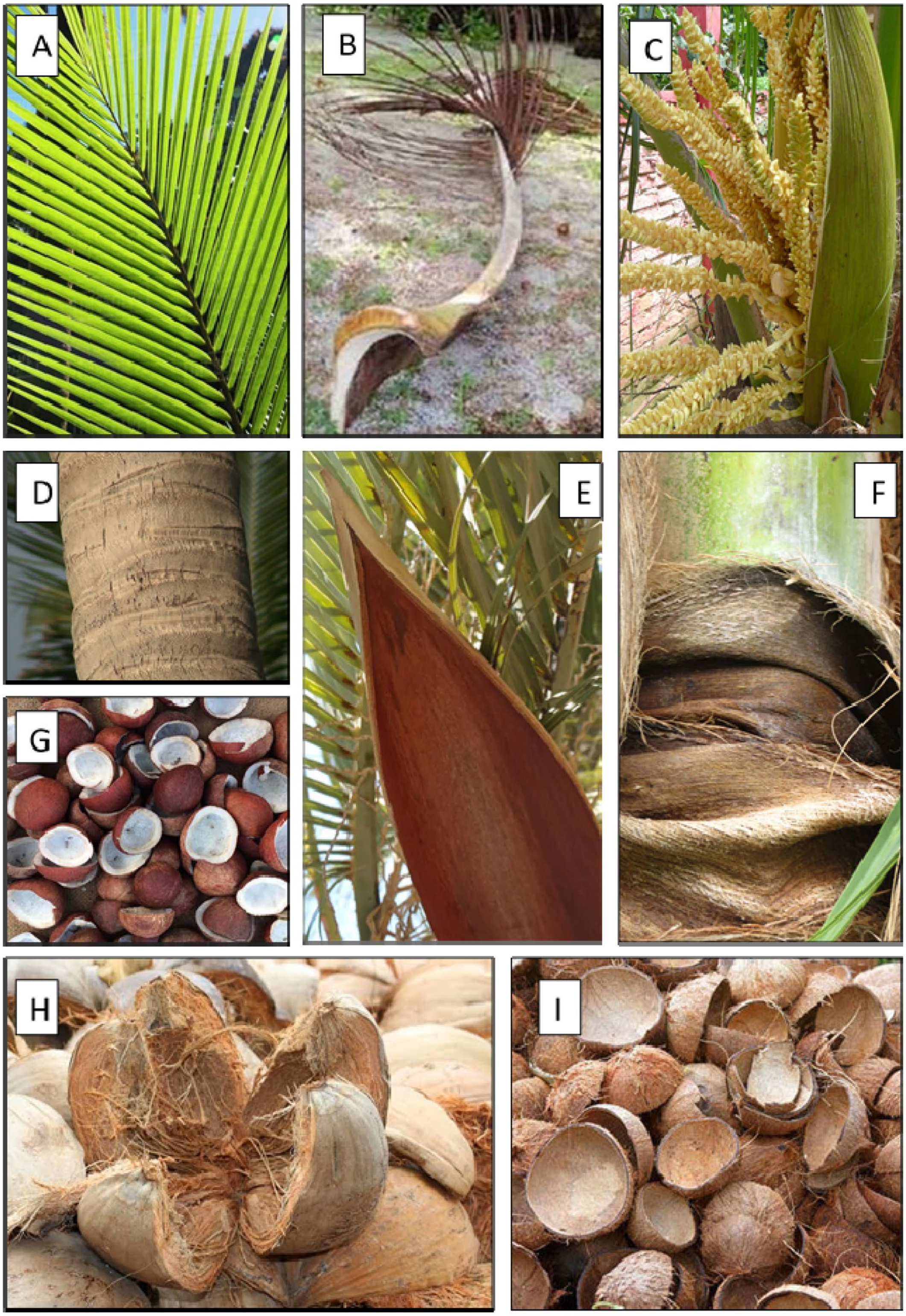

Plate 2 a Leaf, **b** petiole, **c** spadix, **d** stem, **e** spathe, **f** leaf sheath fibre, **g** nuts copra, **h** husk, **i** shell

Plate 3 Images showing the uprooting of coconut with trunk

Table 3 Biomass partitioning in the different palm categories

Palm category	Removable biomass	Reserve biomass	Recyclable biomass
	kg palm^{-1}		
AH	1.74^{a}	80.70^{a}	20.42^{a}
DE	1.05^{b}	63.02^{b}	12.91^{b}
DM	0.998^{bc}	62.40^{b}	12.59^{b}
DA	0.812^{c}	59.83^{b}	12.29^{b}

*Figures with different suffix in a column are significantly different ($P < 0.05$)

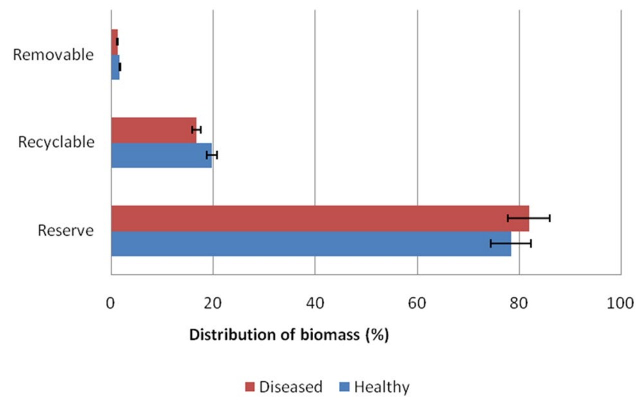

Fig. 1 Biomass distribution in apparently healthy and diseased palms

67.5, 407.4, g palm^{-1}, respectively). Similar is the case with the secondary nutrients of Ca, Mg and S. Among the micronutrients, only Cu and B were significantly higher in apparently healthy palm (569.0 and 321.6 mg palm^{-1}, respectively) compared to diseased palm (478.9 and 164.5 mg palm^{-1}, respectively). The uptake of Mn and Zn was at par in apparently healthy and diseased palms.

The total uptake of all the nutrients was more in the apparently healthy palms as compared to the root (wilt) disease affected palms. The percentage reduction of the uptake of N, P, K, Ca, Mg, S and B in the biomass of disease affected palms in comparison with healthy palms was 36.5, 37.6, 57.5, 44.1 23.3, 43.7 and 48.9 in order. This indicates that the highest percentage reduction between apparently healthy and diseased palms is for the uptake of K followed by B, Ca, S and P. Regarding the magnitude of uptake, the highest uptake in the apparently healthy palm followed K > N > Ca > S > P > Mg > B, whereas in the case of the diseased palms, the uptake pattern followed the order N > K > Ca > S > P > Mg > B.

To explain further a detailed analysis nutrient ratios were worked out to understand how the interaction of nutrients are affecting the disease incidence. Mean nutrient ratio of diseased and healthy palms were compared for N: P, N: K, K: Ca, K: Mg and Ca: Mg, respectively (Fig. 2). Results showed that N: P and N: K ratio is high with respect to diseased palms than the healthy palms. The primary reason is that uptake of P and K is less in diseased palms and hence the ratio is high, when compared to healthy palms. Similarly, K: Ca, K: Mg is found to be high with respect to healthy palms than the diseased palms. This indicated that K uptake is significantly reduced in diseased palms, whereas in the case of Ca and Mg, even though there is a reduction, it is not to the magnitude of K. This confirmed that K nutrition has a significant role in imparting disease resistance.

Table 4 Total nutrient uptake by palms with disease as compared to apparently healthy palms

Category	N (g palm^{-1})	P	K	Ca	Mg	S	Mn (mg palm^{-1})	Cu	Zn	B
Apparently Healthy	889.0	109.4	1075.0	389.7	71.6	229.7	1784.0	569.0	2304.0	321.6
Diseased palms	560.5	67.5	407.4	214.0	54.5	129.4	1313.0	478.9	1792.0	164.5
't'	7.06**	7.16**	8.24**	4.44**	2.73*	5.39**	NS	2.18*	NS	7.96**

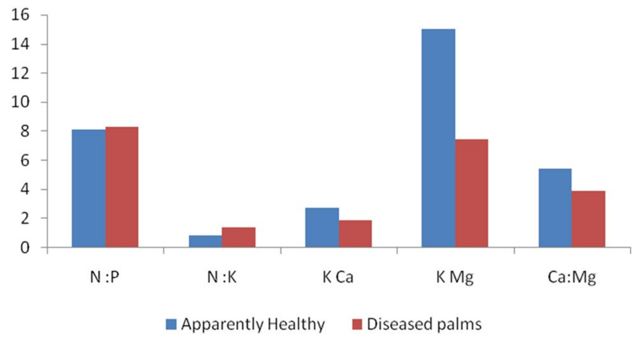

Fig. 2 Mean nutrient ratio in healthy and diseased palms

Uptake of nutrient by the different palm components

The uptake of major (N, P and K), secondary (Ca, Mg and S) and micronutrients (Cu, B, Zn, Mn) in the different biomass categories viz., removable, recyclable and reserve portion of the palm are elaborated in this section and depicted in Tables 5 and 6.

Nutrient uptake in the recyclable biomass

The data on the uptake of nutrients in the recyclable biomass indicated the enhanced uptake of all the nutrients in the apparently healthy palms compared to the palms affected by diseases of varying intensity. The uptake of N, P, K in the recyclable biomass were 168.4, 12.9, 260.3 g palm^{-1}, respectively (Table 5). Though the uptake of N is higher for the DM category (122.9 g palm^{-1}), it was almost the same as DE palms. However, there is no significant difference between the palms of different disease intensities in the case of uptake of P and K. No significant difference between different palm categories was observed for the uptake of Ca in the recyclable biomass. However, Mg and S uptake in the recyclable biomass of apparently healthy palms, which was significantly superior to the diseased palms, was 35.1 and 45.9 g palm^{-1}, respectively, (Table 6). The uptake of these nutrients exhibited no significant variation between the palms of different disease intensities. B uptake in the recyclable biomass was 79.8 mg palm^{-1} in the apparently healthy palms. The DE palms had an uptake of 47.7 mg palm^{-1} and followed a declining trend with increase in disease intensity.

Nutrient uptake in the removable biomass

Data on the nutrient uptake by the removable biomass provide an idea on the magnitude of nutrients which are inevitably removed through the harvest of nuts. Obviously, uptake by removable biomass is the lowest among the three biomass categories. Uptake of N, P and K in the apparently healthy palm was 34.4, 3.0 and 23.4 g palm^{-1} respectively (Table 5). In the case of N and P, the DE and DM palms were not significantly different. The uptake of K in the diseased palms were on par with each other with the highest value of 11.4 g palm^{-1} recorded by the DE palms.

Uptake of Ca, Mg and S in the apparently healthy palms which was significantly superior to the other categories was 2.3, 3.2, 2.6 g palm^{-1}, respectively (Table 6). B uptake in the apparently healthy palm was 7.2 mg palm^{-1}. The uptake in the DE and DM palms for Ca and Mg was 1.9 and 2.2 g palm^{-1}, respectively, having no significant difference. In the case of uptake of S, DE palms recorded significantly superior uptake (1.6 g palm^{-1}) compared to the other two categories.

In both the apparently healthy and diseased palms, the highest uptake is that of N followed by K. On the basis of the estimate of nutrient uptake in the removable biomass, it

Table 5 Uptake of major nutrients in the different biomass components

Category	N (g palm^{-1})			P (g palm^{-1})			K (g palm^{-1})		
	Removable	Recyclable	Reserve	Removable	Recyclable	Reserve	Removable	Recyclable	Reserve
AH	34.4^{a}	168.4^{a}	686.7^{a}	3.0^{a}	12.9^{a}	93.4^{a}	23.4^{a}	260.3^{a}	791.9^{a}
DE	26.8^{b}	109.9^{bc}	449.9^{b}	1.9^{b}	8.9^{b}	53.9^{b}	11.4^{b}	147.9^{b}	305.9^{b}
DM	23.8^{bc}	122.9^{b}	404.4^{b}	1.8^{b}	9.5^{b}	59.1^{b}	9.3^{b}	150.1^{b}	315.6^{b}
DA	18.5^{c}	104.3^{c}	434.8^{b}	1.3^{c}	8.1^{b}	58.7^{b}	7.9^{b}	136.7^{b}	271.1^{b}

*Figures with different suffix in a column are significantly different ($P < 0.05$)

Table 6 Uptake of secondary and micro nutrients in the different biomass components

	Ca (g palm^{-1})			Mg (g palm^{-1})			S (g palm^{-1})			B (mg palm^{-1})		
	Removable	Recyclable	Reserve	Removable	Recyclable	Reserve	Removable	Recyclable	Reserve	Removable	Recyclable	Reserve
AH	2.3^{a}	65.8^{a}	321.7^{a}	3.2^{a}	35.1^{a}	33.3^{a}	2.6^{a}	45.9^{a}	181.1^{a}	7.2^{a}	79.8^{a}	234.7^{a}
DE	1.9^{b}	53.2^{a}	195.6^{b}	2.2^{b}	21.9^{b}	37.0^{a}	1.6^{b}	25.8^{b}	99.2^{b}	3.2^{b}	47.7^{b}	139.9^{b}
DM	1.7^{b}	50.5^{a}	142.5^{b}	1.6^{b}	24.4^{b}	25.3^{a}	1.0^{c}	22.4^{b}	128.6^{b}	1.8^{c}	43.6^{b}	130.3^{bc}
DA	1.3^{c}	52.8^{a}	142.5^{b}	1.3^{c}	22.7^{b}	27.2^{a}	0.92^{c}	17.2^{c}	91.7^{b}	2.4^{bc}	34.9^{c}	89.6^{c}

*Figures with different suffix in a column are significantly different ($P < 0.05$)

can be seen that an apparently healthy palm having an average yield of 60 nuts year^{-1} removes 2040 g N and 1404 g K annually through nuts. The increasing order of nutrient uptake by the removable biomass in both the apparently healthy and diseased palms is N > K > Mg > P > S > Ca > B. During harvest, nutrient in nuts are removed from the system making, it mandatory to adopt appropriate replenishment strategies. This can be done through the addition of fertilisers/organic manures and through the recycling of the palm residues so as to offset the occurrence of nutrient deficiency symptoms through the exhaustive crop removal.

Nutrient uptake in the reserve biomass

Nutrient uptake in the reserve biomass was comparatively higher than the uptake by the other two biomass components. The uptake of N, P, and K in the reserve biomass of the apparently healthy palms was 686.7, 93.4 and 791.9 g palm^{-1}, respectively. Irrespective of the index, the diseased palms recorded the uptake of these nutrients at par with each other.

There was no significant difference between healthy and diseased palms in the Mg uptake in the reserve biomass. The magnitude of Ca, Mg and S in the apparently healthy palms were 321.7, 33.3, 181.1 g palm^{-1}, respectively. However, Ca and S uptake in the diseased palm categories were at par with each other. Boron uptake in the reserve biomass was 234.7 mg palm^{-1} in the apparently healthy palm.

Distribution of nutrients in the biomass components

Analysis of the distribution pattern of K in the healthy and diseased palms (Fig. 3) indicated that in the healthy palms 74% is distributed in the stem/ trunk, whereas in the diseased palms, only 66% is distributed in the trunk. The proportion of K in the recyclable biomass of the palm is 32% in the diseased palms and 24% in the healthy palms. This indicated that though a certain portion of K is immobilized in the trunk, proper recycling of palm residues can add K to the system.

In our study, it is found that proportion of K in the reserve biomass in the healthy palms is greater than their distribution in the diseased palms. But in the case of Mg and S, the proportion distributed in the reserve biomass of healthy palms is less than that in the diseased palms. It was also found that in the case of N uptake, the quantity lost from the system through the harvest of nuts is less compared to the uptake in the recyclable components, which indicate that incorporation of palm residues has the potential to recycle the N back to the system.

To explain further a detailed analysis based on the category of DE, DM and DA in comparison with AH is depicted in Fig. 4. The results showed that K content was too low in

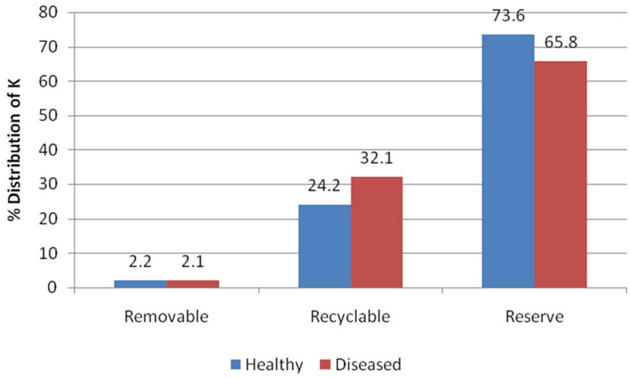

Fig. 3 Per cent distribution of potassium in healthy and diseased palms

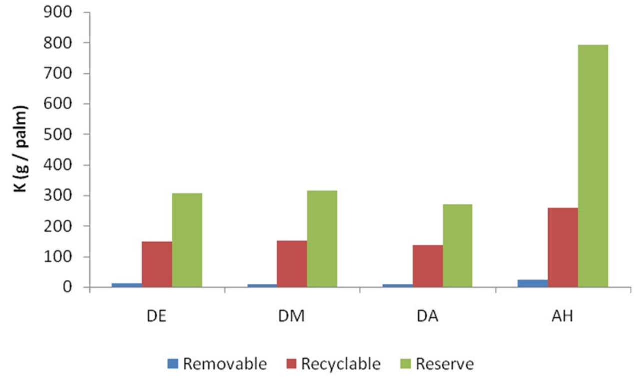

Fig. 4 Comparative assessment of potassium in healthy and different category of diseased palms

DA category in all the three portions of removable, recyclable and reserve. This confirmed that K nutrition has a significant role in disease resistance and K content was proportionately reduced with stage of advancement of disease.

Distribution of Ca (Fig. 5) in the biomass components followed the same trend as that of K with 75% Ca being distributed in the trunk of the diseased palms and 82% being distributed in the trunk of the healthy palms.

Pattern of Mg uptake in the different biomass components indicated that the Mg uptake in recyclable biomass (49%) was more than their distribution in the reserve biomass (47%), but in the diseased palms, the trend was just the reverse with the recyclable biomass of 42% and reserve biomass of 55% (Fig. 6).

Distribution and uptake of S, a functionally important nutrient for oilseed crop between the different palm categories is depicted in Fig. 7. The figures indicated that the proportion of S removed through the harvest of nuts remain more or less the same in both diseased and healthy palms. Yellowing in the outer leaf whorls due to reduction in the chlorophyll had caused the reduced Mg in the recyclable biomass of the diseased palms. Hence in the diseased palms, there is a greater immobilization of Mg in the trunk compared to the healthy palms. Recycling the crop residues within the palm basin itself can contribute substantially to the Mg which is being lost from the system through the harvest of nuts and those being immobilized in the trunk.

Though the magnitude of uptake of B, an important nutrient with regard to coconut nutrition, was found to be significantly varying between the different disease categories for the three palm components, its percentage distribution in the different components was almost the same, with only 1% variation in the recyclable and reserve biomass components between the healthy and diseased palms. The proportion in the reserve biomass was the same for the AH and the palms of disease categories (73%).

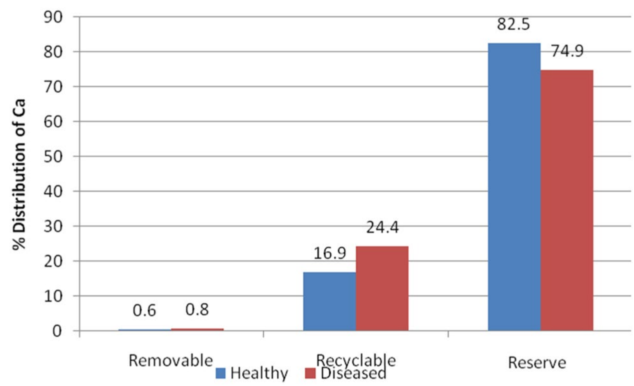

Fig. 5 Per cent distribution of Calcium in healthy and diseased palms

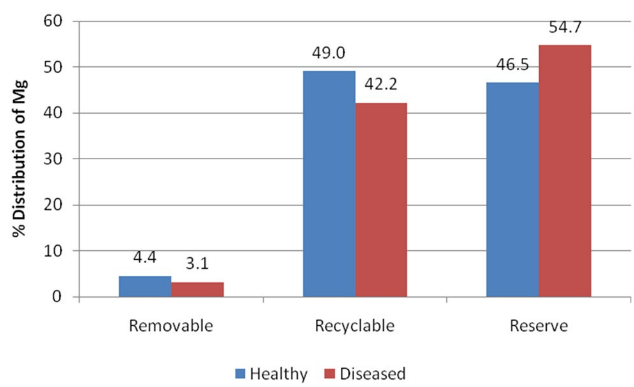

Fig. 6 Per cent distribution of Magnesium in healthy and diseased palms

Yield data of palms

Yield data showed that disease severity significantly influenced the yield and lowest yield was obtained with DA category with 16.2 nuts /palm. Yield data when compared with the nutrient content (N, K and Ca), through scatter diagram

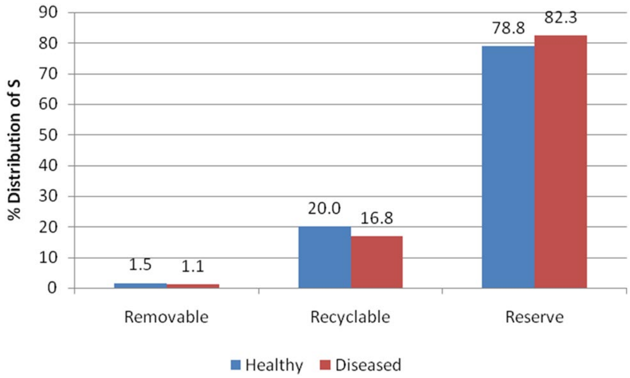

Fig. 7 Per cent distribution of sulphur in healthy and diseased palms

showed that, yield is significantly influenced by the disease categories with the R^2 value of 0.63, 0.66 and 0.71 for N, K and Ca, respectively (Fig. 8a, b and c).

Correlation analysis

Regarding the relation between root (wilt) and total nutrient uptake, it was observed that the negative correlation between nutrient uptake and disease index was significant for N, K, Ca and Mg ($P < 0.01$) (Table 7). With regard to nutrient P and Mn, correlation was significant at $P < 0.05$. However, correlation with disease index is not significant for Cu and Zn.

Discussion

Partitioning of biomass into the three categories (recyclable, removable and reserve) was studied between the AH and the disease affected palms and reported in kg palm^{-1} and nutrient uptake in these parts were computed as g palm^{-1} based on the nutrient content. Nutrient ratios were also worked to understand the distribution pattern between AH and the disease affected palms.

Partitioning of biomass into the three categories (recyclable, removable and reserve) for disease affected palms and AH palms showed significant difference. Yellowing of outer leaf whorls and necrosis of the leaflets are the associated symptoms of root (wilt) disease along with flaccidity (ribbing) of leaves, which hampers the metabolic activity and result in the reduced photosynthetic capacity of the diseased palms and consequently the reduced biomass. This type of reduction in plant biomass and lower photosynthetic capacity and carbon assimilation due to leaf necrosis and vascular wilt resulting from biotic stress such as pathogen attack was discussed by Li et al. (2018). Understanding the magnitude of nutrient uptake in the different components of coconut palm, a perennial plantation crop is an essential pre-requisite

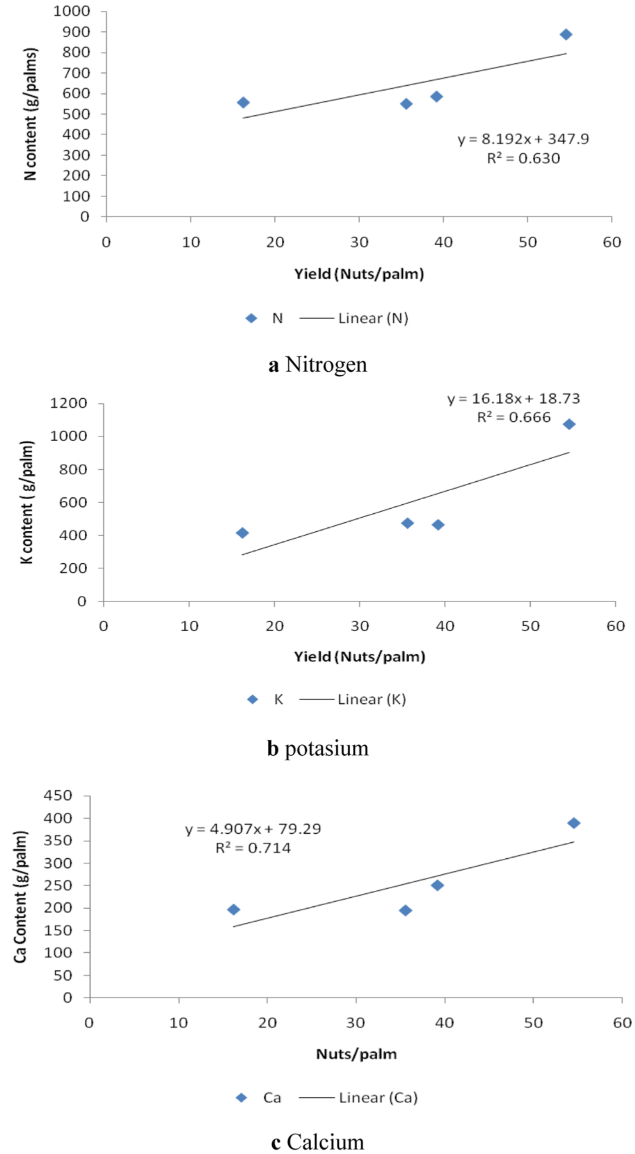

Fig. 8 Linear regress of yield Vs nutrient content **a** N, **b** K and **c** Ca

to develop appropriate nutrient management strategies. In the recyclable and removable biomass, apparently healthy palms had greater distribution (20% and 2% respectively) out of the total biomass than the diseased palms (17% and 1% respectively). This clearly indicated that after disease infestation plant metabolic activities were not proper and hence photosynthesis and translocation of nutrients might not have happened resulting in lesser production of recyclable and removable categories. This difference in proportion of biomass distribution as well as the reduction in biomass with increasing disease intensity might have caused the reduction in nutrient uptake by these biomass constituents of the diseased palms. The difference in biomass partitioning indicates that balanced nutrition is necessary for restoring the health of the diseased palms from the early stage onwards.

Table 7 Correlation between disease index and total nutrient uptake

Nutrient	Coefficient of correlation
N	−0.667**
P	−0.527*
K	−0.608**
Ca	−0.609**
Mg	−0.567**
Mn	−0.445*
Cu	−0.256
Zn	−0.277
S	−0.588**
B	−0.800**

*Significant at 5%

**Significant at 1%

Results of our study showed that diseased palms were in a state of imbalanced nutrition with wide ratios of N: K; K:Mg and Ca: Mg indicating a lower content of K and Mg in proportion to other major nutrients (Fig. 9). Similar imbalance in cationic ratios like K:Na, K:Mg, K: (Ca + Mg) and K:(Ca + Mg + Na) and anionic ratios like P:S and N:S were also reported to be associated with the diseased conditions of the palm (Pillai et al. 1975). A critical evaluation of the earlier studies on the quality of nutrition in relation to the disease suggested that the palms in the disease-affected areas, whether apparently healthy or visibly diseased, are in a state of an unbalanced nutrition, possibly the result of a relatively higher content of N and P on the one hand and a lower content of K, Ca, Mg and S on the other (Cecil, 1975). The state of imbalanced nutrition for the palms in the disease affected areas was hinted by Khan and Krishnakumar (2019).

The total uptake of all the nutrients was more in the AH palms as compared to the root (wilt) disease affected palms. It can be observed that N uptake is more than K uptake in the diseased palms and all the other nutrients followed the same order for both category of palms. Healthy palms have taken up more K compared to the diseased palms, emphasizing its positive role on imparting disease resistance (Khan et al. 2000). Studies by Rossi et al. (2010) found the K and Mg imbalances following infestation by phytoplasma in apricot leaves. Hence external addition of K along with palm residue recycling is required to sustain palm health. Among the micronutrients, the uptake of both Cu and B are significantly different between the healthy and disease palms and the greater difference between the two categories is that for B (48.9%). Mathew et al. (2018) studied the positive role of B on enhancing the nut yield and reducing the deficiency symptoms such as crown choking, inflorescence necrosis and button shedding in coconut.

Organic matter recycling in coconut gardens is very poor as besides coconut kernel, most of the crop residues like dry leaf fronds, dry spathes, coconut husks, coconut shells etc. are taken out of the plantation for various purposes like thatching, burning as fuel, coir retting, etc. The poor organic matter recycling may be one of the reasons for the declining soil health and low yield in coconut based cropping systems. It was stated that in humid tracts, next to poor rain water management, depletion of nutrients caused by organic matter deficiency is an important cause of soil degradation. The information from our study on the nutrient uptake by the recyclable biomass components augment the benefits of palm residue recycling as a means of nutrient contribution. These residues can also enrich the soil organic matter. Earlier studies by Biddappa et al. (1996) found that from a well-managed coconut plantation, 6–8 tonnes of organic matter become available in the form of leaves, spathe, bunch waste and husk. Coconut leaves can be effectively turned to granular vermicompost using the Eudrilus sp of earthworm (Prabhu et al. 1998). Coir pith, which is a major by-product in coir industry, could be used to maintain and improve the organic matter content of depleted soils. Sushma et al. (2007) highlighted the benefits of adding coir pith compost along with other organics on improving crop yield and soil quality. The benefits of biomass recycling in coconut using husks for the supply of K and enhancing the soil moisture holding capacity as well as vermicompost for improving the soil organic matter status was elaborated by Malhotra et al. (2017).

Apparently healthy palms had greater nutrient uptake in the recyclable biomass as compared to the diseased palms. Both in the healthy as well as in the diseased palms, greatest quantity of uptake in the recyclable biomass is for K followed by N. The nutrient uptake in the recyclable biomass followed the order K > N > Ca > S > Mg > P > B in the healthy and diseased palms, which follows the same order as that of total nutrient uptake except P. These biomass components can fit into the in situ palm residue recycling, which will supply nutrients as well as enrich the soil organic matter.

Nutrients stored in the reserve biomass (stem) are considered to be either sequestered or are slowly available. The translocation of nutrients from the stem during wood senescence has been studied in tree crops by Inagaki and Tange (2014). Information on the uptake of nutrients by the reserve biomass i.e., the stem gives an idea on the magnitude of nutrients which are either available only when the palm is felled off, or when mobilized from the stem to the growing points under conditions of deficiency. Moreover, understanding the nutrient uptake in the reserve biomass requires destructive sampling and hence very little information are available on the aspect. Khan et al. (2000) reported that in coconut, besides leaves, inflorescence and nuts, which are

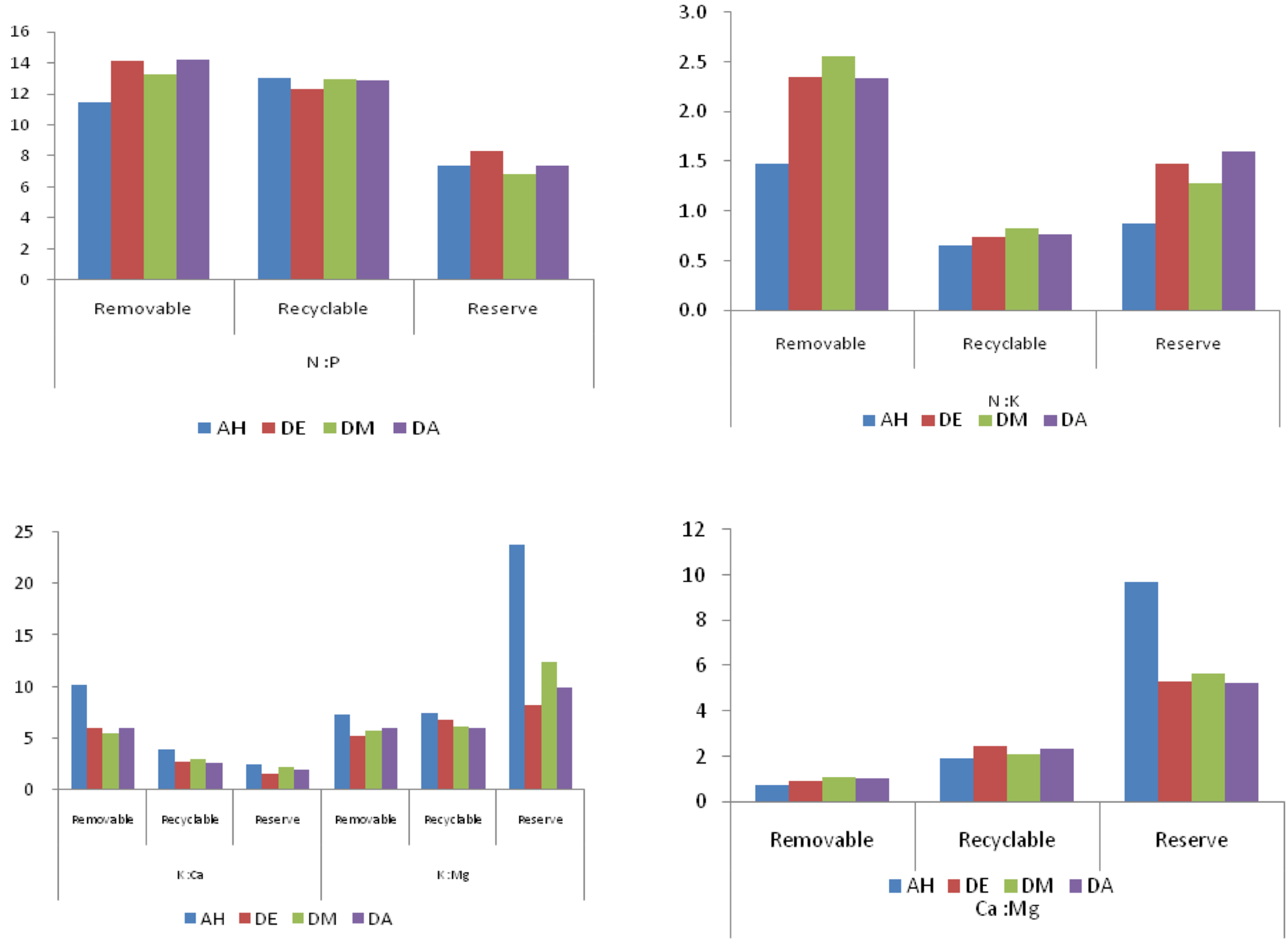

Fig. 9 Mean nutrient ratio (N:P, N:K,K:Ca, K:Mg and Ca:Mg in different palm categories

removed from the garden, a substantial portion of nutrients is also retained in the growing stem.

The nutrient which showed the greatest deviation in uptake between the different disease category palms and that of the AH palm was K, highlighting its role in root (wilt) disease management. Production of biochemical compounds like jasmonic acid and Reactive Oxygen Species (ROS) during K deficiency, which may trigger the susceptibility to pathogen attack, was studied by Davis et al. (2018). This property of K, might have resulted in the comparatively lower uptake in the disease affected palms than the healthy palms. K reduces the intensity of many diseases caused by pathogenic fungi, bacteria, viruses, and nematodes; however, it cannot be generalized. Enhanced silicification of cell walls and anatomical changes influenced by K is the possible reason for increased disease resistance.

K significantly decreased the incidence of fungal diseases by 70%, bacteria by 69%, insects and mites by 63%, viruses by 41% and nematodes by 33%. Meanwhile, K increased the yield of plants infested with fungal diseases by 42%, bacteria by 57%, insects and mites by 36%, viruses by 78% and nematodes by 19% (Perrenoud 1990). The coconut palm is highly responsive to K which increases its resistance to drought and disease, hastens maturity and increases fruit set and the number of harvested nuts (von Uexkull 1985).

In our study, reserve biomass presented the highest uptake of all the nutrients except Mg, in both the AH palms as well as in the diseased palms. This is evidently due to the high dry matter content in the stem. It is documented by Mori et al. (2010) that during their growth, tree crops increase the ratio of structural organs (stem) to metabolic organs (leaf). Among the nutrient uptake by the reserve biomass, in the healthy palms, the order of uptake was K > N > Ca > S > P > Mg > B. In the diseased palms, the order was N > K > Ca > S > P > Mg > B. In the case of Mg, the uptake was lower than that of recyclable biomass in the AH palms, which indicate the altered plant metabolism due to the attack of pathogens.

Sulphur is an important nutrient parameter particularly with regard to the oilseed crops. Rubbery copra is a symptom of S deficiency in coconut palms (Southern 1969). Improvement in nut yield and copra content due to the addition of S has been reported by Silva et al. (1985). But its proportion in the stem accounted for about 82% in the palms of diseased category and 79% in the healthy palms. Hence, crop residue recycling along with addition of S containing fertilizers is essential for sustaining palm health in the diseased palms. Relations between S in plants and the pathogenic stress were studied by Bloem et al. (2015). They recorded that optimizing the S nutrient status of a plant enhances its ability to cope up with pathogenic stress. The concept of Sulphur Induced Resistance (SIR) by Schung et al. (1995) emphasizes positive role of S on plant defense mechanism. Hence, the comparatively higher S uptake in the healthy palms can also be related to the superior health status of the AH palms.

The absolute values in B uptake was significantly different in the various category palms and a greater B uptake in the healthy palms was observed.

In general, a balanced nutrition to coconut will always play as a first line of defense against development of any disease including root (wilt) disease. But the palms may not be able to revive its health beyond a stage of disease development.

Conclusion

Coconut being a perennial plantation crop, formulation of nutrient management strategies should be on real time basis rather than adopting a blanket recommendation of fertiliser schedule. The monthly production of a new inflorescence in the leaf axils and the sequential harvest of nuts every 45 days warrant the adoption of nutrient management strategies to compensate for the exhaustive crop removal. The present study analysed the pattern of nutrient uptake by coconut palms which are affected by root (wilt) disease of varying intensity as well as AH palms grown in an acidic sandy soil. Acidic sandy soils are innately low in organic matter, available K, Ca, Mg, S and B making the addition of external inputs mandatory to improve palm health and productivity. In our study, an estimate of the proportion of nutrients in the different biomass components showed the suitability of palm residue recycling to sustain nutrient balance in the perennial production system.

The potential of biogeochemical cycling of nutrients in coconut is evident from the nutrient uptake pattern by different palm categories. This study enabled to understand the nutrients which are stored in trunk as well as the magnitude of nutrients present in the recyclable portion of the palm. It also provided the magnitude of nutrients in the nuts so as to get an estimate of the nutrients which might be removed from the system through the harvest. The total uptake of nutrients which showed a significant relation with disease index followed the order K > N > Ca > S > P > Mg in AH palms and N > K > Ca > S > P > Mg in diseased palms. The above aspects on nutrient partitioning can help in the evolving need based fertiliser recommendation for coconut and managing the root (wilt) disease in an effective manner without compromising the productivity. The study points out that adoption of balanced fertiliser recommendation to enhance the nutrient status as well as the nutrient balance of coconut palms will improve the palm health status.

Author contributions statement All authors conceived and designed the research. JM and AAH performed the experiment. KM performed statistical analysis. All authors revised and approved the manuscript.

Acknowledgements The authors sincerely acknowledge the Director, ICAR, Central Plantation Crop Research Institute, Kasaragod for supporting this research programme.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

References

Berger KC, Truog R (1939) Boron determination in soils and plants. Ind Eng ChemAna. Ed 11(10):540–545

Bhaskaran R, Ramanathan T (1984) Occurrence and spread of Thanjavur wilt disease of coconut. Indian Coconut J 15(6):12–14

Bhat R, Sujatha S (2012) Influence of biomass partitioning and nutrient uptake on yield of arecanut grown on a laterite soil. Communic Soil Sci Pl Anal 43:1757–1767

Biddappa CC, Upadhyay AK, Hegde MR, Palaniswami C (1996) Organic matter recycling in plantation crops. J Plantn Crops 5:71–85

Bingham FT (1982) Boron In methods of soil analysis, Part 2, 2nd edn. Page AL (eds) No. 9. American Society of Agronomy and Soil Science Society of America, Madison, pp 437–447

Bloem E, Haneklaus S, Schung E (2015) Milestones in plant sulfur research on sulfur-induced-resistance (SIR) in Europe. Front Plant Sci 5:779

Butler EJ (1908) Report on coconut palm disease in Travancore. Agric Res Inst Pusa Bull 9:23

Cecil SR (1975) Mineral composition of coconut leaves in relation to root (wilt) disease. J Plantn Crops 3:34–37

Chesnin L, Yien CH (1950) Turbidimetric determination of available sulphur. Proc Soil Sci Soc Am 15:149–151

Coconut Cultivation Practices (2007) ICAR-Central Plantation Crops Research Institute, Kasaragod, Kerala. Dhanapal R, Thampan C (eds). Extension publication No. 179. p26

Coconut development board (2018) Area Production and productivity statistics. http://coconutboard.nic.in/Statistics.aspx

Davis JL, Armengaud P, Larson TR, White PJ, Newton AC, Amtmann A (2018) Contrasting nutrient disease relationships: K gradients in barley leaves have opposite effects on two fungal pathogens with different sensitivities to jasmonic acid. Plant Cell Environm 41:2357–2372

De Silva AT, Pillai GM, Mathes DT (1985) The S Nutrition of Coconut. COCOS. 3:22–28

Eyzaguirre PB, Batugal P (1999) Farmer Participatory Research on Coconut Diversity: workshop report on methods and field protocols. International Fund for Agricultural Development, IGFRI, Consultative Group on International Agricultural Research

George SB (2016) Absorption and translocation of ^{32}P by root (wilt) affected coconut palms. MSc. Thesis submitted to the Department of Soil Science and Agricultural Chemistry. College of Horticulture, Vellanikkara, P. 101

George MV, Radha K (1973) Computation of disease index of root (wilt) disease of coconut. Indian J Agric Sci 43:336–370

Ghose S (2014) Studies on coconut leaf diseases in Orissa and their management. PhD Thesis. Orissa University of Agriculture and Technology, Bhubaneswar. p.78

Humphries EC (1956) Mineral components and ash analysis. Modern methods of plant analysis, vol 1. Springer-Verlag, Berlin, pp 465–502

IBM Corp (2016) IBM SPSS Statistics for Windows, Version 24.0. Armonk, NY: IBM Corp. (Released 2016)

Inagaki M, Tange T (2014) Nutrient accumulation in aboveground biomass of planted tropical trees: a meta-analysis. Soil Sci Plant Nutr 60:598–608

Jackson ML (1973) Soil chemical analysis. Prentice Hall of India Pvt. Ltd., New Delhi, p.498

Khan HH, Krishnakumar V (2019) Soil Productivity and Nutrition. In: Nampoothiri KUK, Krishnakumar V, Thampan PK, Nair MA (eds.) The Coconut Palm (Cocos nucifera L.) - Research and development Perspectives: 323–442

Khan H, Upadhyay AK, Palaniswami C (2000) Integrated nutrient management of plantation crops. XIV Plantation Crops Symposium, Hyderabad

Krishnakumar V, Maheswarappa HP (2010) Integrated nutrient management for root (wilt) diseased coconut palms. Indian J Agric Sci 80:384–398

Lindsay WL, Norvell WA (1978) Development of a DTPA Soil Test for Zinc, Iron, Manganese, and Copper. Soil Sci Soc Am J 42:421–428

Li Z, Song Z, Yan Z (2018) Silicon enhancement of estimated plant biomass carbon accumulation under abiotic and biotic stresses. A meta-analysis. Agron Sustain Dev 38:26

Malhotra SK, Maheswarappa HP, Selvamani V, Chowdappa P (2017) Diagnosis and management of soil fertility constraints in coconut (Cocos nucifera): A review. Indian J Agric Sci 87(6):711–726

Manimekalai R, Soumya VP, Sathishkumar R, Selvarajan R, Reddy K, Thomas GV, Sasikala M, Rajeev G, Baranwal K (2010) Molecular detection of 16SrX1 Group phytoplasma associated with root (wilt) disease of coconut (Cocos nucifera) in India. Plant Dis 94(5):636

Mathew C (1977) Changes in carbohydrate content of coconut palm affected by root wilt disease. J Plant Crops 5:84–88

Mathew J, Krishnakumar V, Srinivasan V, Bhat R, Namboothiri CGN, Harris AA (2018) Standardization of critical B level in soil and leaves of coconut palms grown in a tropical Entisol. J Soil Sci Plant Nutr 18:376–387

Michael KJ (1978) Respiratory rate and nut yield in root (wilt) diseased coconut palms. J Plant Crops 6:1–3

Mori S, Yamaji K, Ishida A (2010) Mixed-power scaling of whole-plant respiration from seedlings to giant trees. Proc Natl Acad Sci USA 107:1447–1451

Perrenoud S (1990) Potassium and Plant Health, 2nd edn. International Potash Institute Bern, Switzerland, pp 8–10

Pillai NG, Davis TA (1963) Exhaust of macronutrients by the coconut palm - a preliminary study. Indian Coconut J 16:81–87

Pillai NG, Wahid PA, Kamala Devi CB, Cecil RPL, Amma SR, Mathew Nambiar PGKCKB (1975) Mineral nutrition of root (wilt) disease affected coconut palms. Fourth Session, FAO Tech. Working Production, Protection and Processing. Kingston, Jamaica, Proc

Piper CS (1966) Soil and Plant Analysis. Hans Publisher, Bombay

Prabhu SR, Subramanian P, Biddappa CC, Bopaiah BM (1998) Prospects of improving coconut productivity through vermiculture technology. Indian Coconut J 29(4):79–84

Radha K, Lal SB (1972) Diagnostic symptoms of root (wilt) disease of coconut. Indian J Agric Sci 42:410–413

Rawther TSS (1963) Soil conditions and disease incidence in coconut. Coconut Bull 17:3–6

Rossi G, Beni C, Socciarelli S, Marconi S, Pastore M, Del Vaglio M, Gervasi F (2010) Mineral nutrition of pear and apricot trees cultivated in Southern Italy area damaged by phytoplasma microorganisms. Acta Hort 868:433–438

Schnug E, Booth E, Haneklaus S, Walker KC (1995) S supply and stress resistance in oilseed rape. Proc. 9th Int. Rapeseed Congress 1:229–231

Southern PJ (1969) Sulfur deficiency in coconuts. Oleagineux 24:211–220

Stanford S, English L (1949) Use of flame photometer in rapid soil tests for K and Ca. Agron J 41:446–447

Subbiah BV, Asija GL (1956) A rapid procedure for the determination of available nitrogen in soils. Curr Sci 25:259–260

Sushma AR, Badrinath BPK, Sridhara MS, S. (2008) Residual effect of integrated nutrient management with coir pith compost and other organics on subsequent ragi crop yield and chemical properties of vertisols. J Indian Soc Soil Sci 55(4):500–504

Tabatabai MA, Bremner JM (1970) Arylsulfatase activity of soils. Soil Sci Soc Am J 34(2):225–229

Varkey T, Amma PGK, Ramanandan PL, Nambiar PTN (1979) Foliar yellowing in coconut palms in healthy and root (wilt) affected areas. J Plantn Crops 7:117–120

von Uexkull HR (1985) Potassium nutrition of some tropical plantation crops. In: Munson RD (ed) Potassium in agriculture. ASA/CSSA/SSSA, Madison, pp 929–954

Wahid PA, Kamalam NV (1988) Nutrient distribution in the crown of healthy and root (wilt) affected coconut palms. 1988. Indian Coconut J 18:8–12

Walkley A, Black IA (1934) An estimation of the method for determining soil organic matter and a proposed modification of the chromic acid titration method. Soil Sci 34:29–38