Research Article

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Characterization and classification of coconut-growing soils of Maddur, Karnataka, India and comparative evaluation of their suitability towards tender coconut production

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Abstract

A study was conducted along the coconut-growing soils of Karnataka to assess the potential of soils and consequences towards tender coconut production and marketing system. Major coconut-growing soils across the different agro-climatic zones of Karnataka were investigated for their development by studying the soil profiles. It was observed that the soils are moderately well to well-drained, moderately deep to deep black, gravelly or non-gravelly red loamy and clayey in central, eastern and southern dry, southern transitional and coastal zones, with good water holding capacity and medium to high fertility. Soils in Maddur were characterized and classified in this study. It was found that the soils in Maddur are deep, well-drained, gravelly clayey with low available water capacity on undulating inter-fluves, with moderate erosion, classified to clayey-skeletal, mixed, semi-active, isohyperthermic *Typic Rhodustalfs* at the family level and found to be ideal for tender coconut cultivation due to better rainfall distribution, suitable temperature, the elevation of the area, rooting conditions, moisture availability to roots, favourable soil reaction, higher base saturation, N, K and B levels along with gravelly clayey sub-soil and gravelly sandy loam surface texture.

Keywords: Karnataka, Land suitability, Soil characterization, Soil classification, Tender coconut production

Introduction

Coconut, the second important horticultural crop in Karnataka, is being grown in an area of 5.15 lakh ha with production and productivity of 6773.05 million nuts and 13181 nuts ha^{-1}, respectively, thus contributing a major share in coconut industry in the country (CDB, 2016-17) ranking second behind Kerala and Tamil Nadu in area and production, respectively. About 60 per cent of coconut produced in Karnataka is utilized as raw nuts, and 15 per cent is used for tender coconut purpose (Shashikumar and Chandrashekar, 2014). Karnataka owns the monopoly of tender coconut and desiccated coconut industry in the country. Coconut is grown in almost all the parts of Karnataka, and the major seven districts are Tumkur, Hassan, Chikmagalur, Mandya, Mysore, Udupi and Dakshina Kannada (DES, 2009-10). Coconut grows well in a wide range of soil conditions with light to well structured heavier soil textures, alluvial soils and sandy soils near the coast. The required minimum soil depth is 0.5 m and well-drained conditions, pH range 4.5-8.5 and an optimum pH of 5.2-7.5 (Sys *et al.*, 1993). Highly suitable soils should have a base saturation of >35 per cent, the sum of basic cations >2.8 cmol (+) kg^{-1} soil, organic carbon content >1.5 per cent and EC 0-8 dS m^{-1} (Sys *et al.*, 1993). The mean annual temperature should be 26 to 29 ^{o}C with rainfall 1500 to 2500 mm, with <3 dry months were found highly suitable for coconut (Naidu *et al.*, 1997).

There are no notable differences in the soil requirements towards the cultivation of tender coconuts as the requirements remain almost the

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same. When the tender coconut industry is considered, Karnataka is the largest producer of tender coconuts in the country (Krishnakumar, 2009). Presently almost 40 per cent share of the total coconut production is in the form of tender coconuts in the state. Maddur in Mandya district is the only place in the country having tender coconut auctions, and Maddur leads the tender coconut market in Karnataka covering an area of 6300 ha, with a production of 760 lakh nuts and productivity of 12,060 nuts ha^{-1}.

This study aims at assessing the potentials of the coconut-growing soils for tender coconut production in Karnataka, which is carried out by evaluating the major coconut-growing soils of different agro-climatic zones along with their consequences towards the tender coconut production and marketing system.

Material and methods

Major coconut-growing soils of Karnataka were studied, taking the help of SRM data and report (Scale-1:2,50,000) of Karnataka (Shivaprasad *et al.*, 1998; Avinash, 2017). Soils and climatic conditions of major coconut-growing areas were studied for their suitability to identify potential areas. Extensive field traversing was done to identify these areas. Based on the suitability assessment, Hosadurga in Chitradurga (Central dry zone), Gubbi and Thuruvekere in Tumkur (Eastern dry zone), Arasikere in Hassan (Southern transition zone), Krishnarajapet and Maddur in Mandya (Southern dry zone), Brahmavara in Udupi and Belthangadi in Dakshina Kannada districts (Coastal zone) were identified as the most potential areas for coconut cultivation (Fig.1). Table 1 summarizes the climatic conditions, slope, elevation, soil type and geology of the major coconut-growing soils in Southern Karnataka, which are briefly explained hereunder.

Central dry zone

Hosadurga experiences hot moist semi-arid climate with an annual rainfall of 536-622 mm and Length of Growing Period (LGP) of 90-120 days. The dominant soils of this region are deep and well-drained gravelly clay soils on gently sloping interfluves, with slight erosion.

Eastern dry zone

Gubbi and Thuruvekere possess semi-arid climate with an annual rainfall of 560-866 mm and 810-925 mm and LGP of 120-150 and 150-180 days respectively. Soils in this zone are deep and moderately well-drained clayey soils of valleys with problems of drainage and slight salinity in patches.

Southern transition zone

Arasikere has semi-arid to sub-humid climate with an annual rainfall of 780-920 mm with LGP of 150-180 days. The dominant soils are deep and moderately well-drained clayey soils of valleys with problems of drainage and slight salinity in patches associated with deep and imperfectly drained, clayey over sandy soils.

Southern dry zone

Krishnarajapet and Maddur have a semi-arid climate with an annual rainfall of 570-876 mm and LGP of 120-150 days. The dominant soils are deep and somewhat excessively drained very gravelly clayey soils on gently sloping interfluves, with moderate erosion.

Coastal zone

Belthangadi in Dakshina Kannada representing foothills of Western Ghats has a humid climate, which receives an annual rainfall of 3950-4850 mm and LGP of 210-240 days. Dominant soils are very deep and well-drained gravelly clay soils with low AWC on granite gneissic midland hills, with slight erosion, low AWC and surface crusting.

Brahmavara in Udupi belonging to coastal plain has a hot and humid climate, which receives an annual rainfall of 3200-3900 mm with LGP of 180-210 days. The dominant soils are very deep and well-drained gravelly clay soils with surface crusting and compaction on undulating uplands.

Horizon-wise soil samples were collected from the pedons for the analysis of physical and chemical properties. Morphological properties of the soils were studied as per the procedure outlined in Soil Survey Manual (Soil Survey Staff, 1951). Particle-size analyses were done by International pipette method (Sarma *et al*., 1987). The pH was determined in 1:2.5 soil-water suspension and electrical conductivity in its supernatant portion (Jackson, 1973).

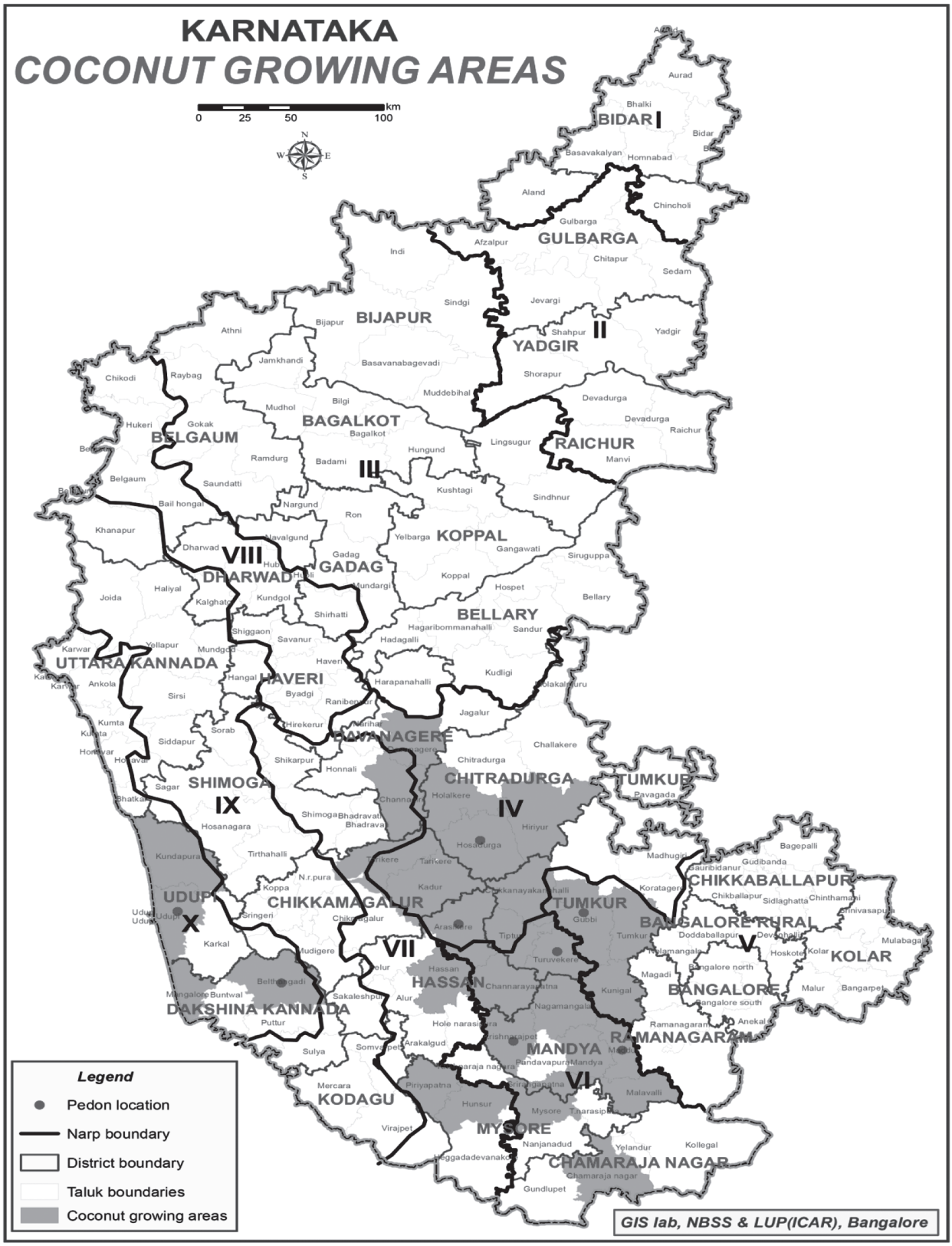

Fig. 1. Map showing areas cultivated with coconut in Karnataka

Table 1. Climatic characteristics, landform, soil type and geology of the pedon locations

Sl. No.	Agro-climatic zone	Pedon	Rainfall (mm)	Temperature Max (°C)	Min (°C)	Relative humidity (%)	LGP (days)	Elevation (m)	Slope (%)	Soil type	Geology
1.	Central dry zone	Hosadurga	536-622	31	21	69	90-120	739	1-3 %	Red loamy soils	Peninsular gneiss
2.	Eastern dry zone	Gubbi	560-866	30	19	65	120-150	788	5-10 %	Alluvio-colluvial soils	Peninsular gneiss
		Thuruvekere	810-925	30	19	74	150-180	794	1-3 %	Partly saline sodic Alluvio-colluvial soils	Peninsular gneiss
3.	Southern transition zone	Arasikere	780 -920	30	20	79	150-180	806	1-3 %	Red gravelly clayey soils	Dharwars
4.	southern dry zone	K. R. Pet	570-876	30	18	82	120-150	790	1-3 %	Red clayey soils	Dharwars
		Maddur	770	31	19	81	120-150	678	5-10 %	Red clayey soils	Dharwars
5.	Coastal zone	Belthangadi	3950-4850	35	24	92	210-240	685	3-5 %	Coastal lateritic soils	Peninsular gneiss
		Brahmavara	3200-3900	35	23	97	180-210	10-300	1-3 %	Coastal alluvial soils	Laterite

Table 2. Area, production, productivity of major coconut-growing regions

Sl. No.	District	Year	Area (ha)	Change (%)	Production (Lakh nuts)	Change (%)	Productivity (Nuts ha^{-1})	Nuts $tree^{-1}$ $year^{-1}$	Change (%)
1.	Chitradurga	2004-05	43,354	10.67	1903.09	56.54	4390	24.80	75.24
		2014-15	38,729		2979.15		7693	43.46	
2.	Tumkur	2004-05	1,10,937	34.69	5474.91	134.47	4936	27.89	74.07
		2014-15	1,49,419		12,836.92		8592	48.54	
3.	Hassan	2004-05	61,098	0.13	2536.83	50.83	4153	23.46	51.00
		2014-15	61,019		3826.29		6271	35.43	
4.	Mandya	2004-05	18,165	51.79	650.82	320.52	3583	20.24	177.03
		2014-15	27,573		2736.82		9926	56.08	
5.	Dakshina Kannada	2004-05	15,652	17.60	668.17	322.24	4269	24.12	259.05
		2014-15	18,407		2821.27		15328	86.60	
6.	Udupi	2004-05	14,464	23.24	617.45	407.81	4269	24.12	312.06
		2014-15	17,825		3135.47		17,591	99.38	

Adapted from: Horticulture Division, Dept. of Agriculture & Cooperation, Ministry of Agriculture, Govt. of India

The cation exchange capacity of the soils was determined by the ammonium acetate leaching method (Sarma *et al.,* 1987). Climatic data recorded by Indian Meteorological Department for Karnataka from 1966 to 2002 was used in the present study and arriving at climatic parameters.

Results and discussion

Area, production and productivity of coconut in the major coconut-growing areas of southern Karnataka

The changing trend of coconut with respect to area, production and productivity is indicated in Tables 2 and 3. Table 2 represents the area, production and productivity during 2004-05 and its change in 10 years indicated by the 2014-15 data. The area increased by 51.79 per cent in Mandya with a huge increase in its production (320.52 %). A whopping increase in the productivity of coconut was observed in the coastal zones as shown by 312.06 per cent in Udupi and 259.05 per cent in Dakshina Kannada, followed by Maddur in Mandya by 177.03 per cent.

Table 3 indicates the taluk wise area, production and productivity of coconuts in different agro-climatic zones. The area under coconut in Hosadurga (Chitradurga) decreased due to the increased competition with other systems but production and productivity considerably increased due to the increased demand for coconut-based products such as coconut oil (Hiriyur, the oil hub of Karnataka) in this area. In Tumkur (Gubbi and Thuruvekere), the area increased, and the production and productivity doubled over ten years. However, in Hassan (Arasikere), the area remained more or less the same but production and productivity increased considerably. In coastal areas like Belthangadi and Brahmavara, there was an increase of 4 to 5 times in production and 3 to 4 times in productivity due to high LGP and very high rainfall.

Maddur in Mandya represents the tender coconut-growing belt in Karnataka. The tender coconut hub experiences a semi-arid tropical climate with annual precipitation of 770 mm and a mean annual temperature of 27.3 ºC. The length of the growing period is 120-150 days. In Maddur, even though LGP and total annual rainfall are less, the production and productivity continued to increase due to increased market for tender coconuts, where the farmers are more attracted to harvest the tender nuts rather than matured ones. The productivity of coconut was higher (0.12) in Maddur, indicating higher suitability towards coconut production.

Table 3. Area, Production and productivity of major coconut growing regions and taluks of Karnataka (2013-14)

Sl. No.	Agro-climatic zone	Name of the taluk	Area (ha)	Production (lakh nuts)	Yield (lakh nuts ha^{-1})	Productivity of nuts $palm^{-1}$ $year^{-1}$	Marketed main produce
1.	Central dry zone	Hosadurga	24,739	2474.00	0.10	56.50	Coconut oil and copra
2.	Eastern dry zone	Gubbi	28,940	2488.84	0.08	45.20	Coconut oil and copra
		Thuruvekere	30,963	2662.82	0.08	45.20	Dry coconuts and tender coconuts
3.	Southern transition zone	Arasikere	26,411	2112.88	0.08	45.20	Dry coconuts and tender coconuts
4.	Southern dry zone	K.R.Pet	12,341	1234.00	0.09	50.85	Tender coconuts and dry coconuts
		Maddur	6,300	760.00	0.12	67.80	Tender coconuts
5.	Coastal zone	Belthangadi	5,095	503.50	0.09	50.85	Copra and coconut oil
		Brahmavara	7,730	1159.00	0.14	79.10	Copra and coconut oil

Characterization and classification of tender coconut-growing soils of Maddur

Climate and site characteristics

Maddur comes under hot semi-arid tropical climate, at an elevation of 678 m above MSL, under gently sloping Bangalore plateau with annual precipitation of 770 mm and drained by Kabini river. As the nuts attain full maturity at 44 months after initiation of inflorescence primordium, rainfall, evaporative demand and dry spell and temperature of the preceding years shall decide the number of nuts per bunch and their quality. This view has been endorsed by Vishweswar *et al.* (2020) in a study at Arasikere taluk of Hassan district, in which they have conclusively proved using weather-based regression model that precipitation quantity and distribution and duration of dry spell resulting in moisture stress during 3-4 years from primordium initiation and ovary development stage, emergence and button development stage, while maximum and minimum temperature influence more during the spadix stage.

Morphological properties

The soil was deep (126 cm). The Munsell colour hue (soil colour) ranged from 2.5 YR to 10 YR, value 3 and chroma from 3 to 6 (Table 4). Soil colour varied from dark brown in the surface to dark reddish brown to dark red in the lower horizons. This may have resulted from a decrease in organic matter and intense leaching of bases leaving sesquioxide and further oxidation. The variations in soil colour are a result of chemical and mineralogical composition coupled with texture and topographic position (Walia and Rao, 1997).

Physical properties

The textural class of soil is gravelly sandy loam in surface horizon and sandy clay to clay in sub-soil horizons (Table 4). The sand content in upland soils of Maddur ranged from 47.3 to 77.6 per cent, silt from 4.7 to 8.5 per cent and clay from 17.1 to 47.7 per cent. The sand content was higher in surface horizons of upland, whereas higher clay content was found in the sub-surface horizons because of the illuviation of fine fractions from the surface layers. Sand content in soils of uplands of higher altitude was higher and decreased with increasing depth. The silt content in the pedon had irregular trend with depth. The sand per cent remained high compared to silt and clay per cent in all the horizons.

Soils are deep, well drained, gravelly clayey with low AWC on undulating inter-fluves, with moderate erosion, which belong to clayey-skeletal, mixed, semi-active, isohyperthermic *Typic Rhodustalfs*, which are ideal for tender coconut cultivation.

Chemical properties

The soils were slightly acidic to neutral with pH ranging from 5.6-7.3. The electrical conductivity ranged between 0.06 to 0.09 dS m^{-1}. The organic carbon was 1.25 per cent at the surface and declined with depth (Table 5).

The cation exchange capacity (CEC) increased from 5.5 to 14.3 cmol (p+) kg^{-1} with depth, which could be due to an increase in the clay content. The dominance of smectitic clay mineral is responsible for the higher CEC. The exchangeable bases had distinct pattern regarding their sequential dominance.

Table 4. Morphological characteristics of tender coconut growing soils of Maddur, Mandya

Depth (cm)	Horizon	Particle size distribution (mm)			Gravel	Textural class	Colour
		Sand	Silt	Clay	%	(USDA)	
		% of < 2mm					
0-16	Ap	77.6	5.3	17.1	39	vgsl	10YR 3/3
16-33	Bt1	58.5	4.7	36.8	56	vgsc	2.5YR 3/6
33-62	Bt2	49.0	5.5	45.5	63	egsc	2.5YR 3/4
62-94	Bt3	47.3	5.0	47.7	42	vgsc	2.5YR 3/4
94-105	Bt4	58.8	5.9	35.3	29	gsc	2.5YR 3/6
105-126	BC	61.3	8.5	30.2	42	vgscl	2.5YR 3/6

In the pedon, the order followed was Ca>Mg>Na>K. The base saturation was higher in sub-soils than the surface indicating the effect of leaching of bases. The variation observed in base saturation indicates the degree of leaching, which is used as a diagnostic characteristic for classifying the soils. High base saturation was due to high calcium followed by magnesium, sodium and potassium (Patil and Dasog, 1996). Available nitrogen varied from 218.2 to 386.4 kg ha^{-1}, available P_2O_5 from 3.96 to 15.47 kg ha^{-1}, available K_2O from 181.28 to 398.28 kg ha^{-1} and the nutrient status decreased with increase in depth.

The soils recorded an available boron content of 0.77 mg kg^{-1} of soil at the surface and B concentration increased with depth. This could be due to lesser clay content on the surface in Maddur soils which allowed leaching of boron beyond B horizon. The increased distribution of boron was indicated by increased native boron liberated from weathering of minerals and vegetative matter intact in the solum.

Classification

The soils of major coconut-growing areas of southern Karnataka were characterized and classified to understand its suitability to coconut cultivation by Avinash *et al.* (2019). Maddur soils belong to the order *Alfisols* having an argillic horizon with an increase in clay content with depth and clay accumulation in the sub-surface. *Ustalfs* sub-order is keyed due to ustic moisture regime represented by soil moisture control section dry in some or all parts for more than 90 cumulative days in a year. Maddur pedon was keyed out to great group of *Rhodustalfs* owing to a hue of 2.5 YR or redder and moist value of 3 or less in major part of the argillic horizon in the top 100 cm of the soil profile, thus classifying the soil into *Typic Rhodustalfs*. Owing to the cation exchange capacity of 24 to 40 cmol (+) kg^{-1} clay (by 1N NH_4OAc pH 7), Maddur soils are keyed to *Typic* sub-group, as it did not qualify for *Kanhaplic* sub-group, mixed mineralogy and semi-active CEC class at the family level.

Comparative evaluation of land suitability towards a tender coconut production system

Maddur soils have contributed towards the production of tender coconuts in the country, and a comparative evaluation of land qualities of coconut-growing soils have been carried out to understand the soil and climate-based reasons towards the improved quality of Maddur tender coconuts (Table 6).

Climatic parameters

Table 1 summarizes the climatic parameters of major coconut-growing areas of Karnataka. Land suitability of Maddur towards coconut cultivation was found to be highly suitable in terms of temperature, the elevation of the area, rooting conditions, moisture availability to roots. However, rainfall was not found to be highly suitable according to the land suitability criteria for coconut (Naidu *et al.,* 1997). But still, a comparative evaluation of weather parameters gives an understanding that tender coconut production is

Table 5. Chemical characteristics of tender coconut-growing soils of Maddur, Mandya

Depth (cm)	pH (1:2.5 Water)	EC (dS m^{-1})	Exchangeable bases (cmol (p+)- kg^{-1} soil) Ca	Mg	Na	K	CEC Total	Base (cmol (p+) kg^{-1} soil)	Organic saturation (%)	Av. N carbon (%)	Av. (kg ha^{-1})	Av. P_2O_5 (kg ha^{-1})	Av. B K_2O (kg ha^{-1})	CEC/ (mg kg^{-1}) soil	Clay
Soil Classification: Clayey-skeletal, mixed, semi-active, isohyperthermic *Typic Rhodustalfs*															
0-16	5.6	0.09	3.2	1.0	0.06	0.07	4.33	5.5	78	1.25	386.4	15.47	398.28	0.77	0.32
16-33	6.8	0.07	3.5	3.5	0.03	0.07	7.10	11.7	61	1.24	327.2	13.46	356.21	0.75	0.32
33-62	7.3	0.09	7.5	4.3	0.11	0.15	12.06	13.1	92	1.12	320.2	8.56	245.95	0.72	0.29
62-94	7.3	0.07	8.0	4.8	0.27	0.16	13.23	14.1	94	0.96	270.9	4.18	187.50	0.89	0.30
94-105	7.3	0.06	9.0	3.6	0.22	0.14	12.96	14.3	91	0.89	218.2	3.96	181.28	0.93	0.41
105-126	7.3	0.06	3.3	1.9	0.12	0.09	5.41	10.0	54	0.07	ND	ND	ND	0.94	0.33

Table 6. Comparative evaluation of land qualities towards tender coconut production system

Parameters	Hosadurga	Gubbi	Turuvekere	K R Pet	Arasikere	Belthangadi	Brahmavar	Maddur
Elevation (m above MSL)	739	788	794	806	790	685	10-300	678
Total Rainfall (mm)	661	813	728	758	733	4440	3842	770
Length of dry period (days)	168	178	175	144	161	112	168	144
Temperature (Max.) (°C)	31	30	30	30	30	35	35	31
Temperature (Min.) (°C)	21	19	19	18	20	24	23	19
Relative Humidity (%)	69	65	74	79	82	92	97	81
Irrigation facility available	Ground water	Ground water	Feeder canals from tank	Ground water	Ground water	Ground water	Ground water	Irrigated by Kabini river
Surface: Soil Colour	**7.5 YR 3/4**	5 YR 3/4	5 YR 3/4	**7.5 YR 3/4**	**7.5 YR 3/3**	**7.5 YR 3/4**	7.5 YR 4/6	**10 YR 3/3**
Soil Texture	scl	scl	c	scl	gscl	gscl	gscl	gsl
Clay Content (%)	34.65	28.53	48.82	33.70	32.89	29.46	28.89	17.10
Soil gravelliness (%)	-	-	15	-	30	50	30	30
Soil reaction (pH)	8.17	8.31	8.08	7.59	8.39	5.64	5.52	5.60
Soil EC (dS m^{-1})	0.08	0.08	0.12	0.07	0.08	0.03	0.04	0.09
Soil OC (%)	0.42	0.76	0.78	0.61	0.48	1.49	1.49	1.25
Exch. Ca (cmol(+) kg^{-1} soil)	24.1	13.3	22.3	1.80	22.7	1.60	1.30	3.20
Exch. Mg (cmol(+) kg^{-1} soil)	8.60	3.6	7.9	1.70	7.0	0.60	0.60	1.00
Exch. Na (cmol(+) kg^{-1} soil)	1.50	0.74	0.8	Tr	0.24	0.20	0.10	0.06
Exch. K (cmol(+) kg^{-1} soil)	2.90	0.36	1.8	0.5	0.36	0.30	0.20	0.07
Base saturation (%)	88.55	82.15	93.42	86.74	91.79	24.65	23.73	78.00
CEC (kg^{-1} clay)	0.48	0.37	0.59	0.42	0.42	0.27	0.27	0.32
Available N (kg ha^{-1})	134.40	206.17	257.60	282.52	170.88	221.26	329.46	386.40
Available P (kg ha^{-1})	12.13	26.48	16.85	20.05	10.72	6.13	6.25	15.47
Available K (kg ha^{-1})	310.03	215.55	321.25	206.97	224.34	168.45	189.50	398.28
Available S (mg kg^{-1})	15.18	14.27	14.17	8.75	16.69	2.79	18.93	10.80
Available Ca (mg kg^{-1})	383.19	217.64	353.24	294.75	216.95	75.13	55.69	140.0
Available Mg (mg kg^{-1})	127.73	74.54	112.80	98.25	81.56	168.45	25.43	31.0
Available Fe (mg kg^{-1})	20.81	13.57	14.38	11.42	9.53	18.81	73.00	6.06
Available Mn (mg kg^{-1})	18.71	27.21	19.05	16.76	18.23	13.37	53.60	9.30
Available Zn (mg kg^{-1})	0.30	0.53	0.33	0.43	0.47	1.03	0.70	0.14
Available Cu (mg kg^{-1})	1.48	1.25	2.12	1.11	0.85	6.60	1.00	3.68
Available B (mg kg^{-1})	0.49	0.42	0.34	0.32	0.31	0.33	0.13	0.77

favoured by the semi-arid climate of Maddur experiencing rainfall of 770 mm. A higher relative humidity of 81 per cent could be another favourable criterion to increased productivity (0.12 lakh nuts ha^{-1}) of coconut, which is also strengthened by the higher productivity (0.14 lakh nuts ha^{-1}) of the coastal zone (Brahmavara), having a very high relative humidity (97 %). The lower elevation of Maddur also has contributed to favour the productivity of coconut in Maddur, compared to the major coconut growing areas of Karnataka. The other areas are elevated than Maddur except Bramhavara representing the coastal zone. Table 6 indicates that the length of the dry period is less in

Maddur, compared to the other areas, owing to better rainfall distribution. The crop is irrigated using water from Kabini river during the days of water scarcity indicating that due attention is given to maintain the quality of coconut in Maddur.

Soil parameters

It was found that Maddur surface soils are gravelly sandy loam in texture with lower clay content (17.10 %) in comparison to all other coconut-growing soils (Table 6). The soil colour at the surface was 10 YR 3/3 (dark gray). Potassium is the nutrient very much essential in growth, development and quality of coconut, and this was found to be sufficient in Maddur soils (398.28 kg ha^{-1}). The K content was relatively higher than that of other major coconut-growing soils. A similar observation was recorded in the case of nitrogen too, and the N concentration in soils was 386.28 kg ha^{-1}. Nitrogen is the second most essential nutrient in case of coconut palm among the primary nutrients. This N and K sufficiency would have contributed towards tender coconut production in Maddur. In Maddur, however, low concentrations of exchangeable K (0.07 cmol (+) kg^{-1} of soil) and available Zn (0.14 mg kg^{-1}) in the surface soil resulted in slight deficiencies of K and Zn which need to be replenished by applying K in splits and $ZnSO_4$ in soils. The major observation among micronutrients is the higher B content (0.77 mg kg^{-1}) in soils in comparison with the other soils. From the comparative evaluation of qualities towards tender coconut production system, it could be inferred that the higher base saturation, moderately acidic soil reaction (pH 5.6) along with higher K, N and B status are well suited for tender coconut production. Correlating the yield of coconut in Maddur with the soil properties confirms the finding that higher productivity (0.12 lakh nuts ha^{-1}, given in Table 2) as a result of the favourable climate and landform and associated soil properties to coconut production.

Potentials and consequences towards tender coconut production and marketing system

Maddur in Mandya district has been evolved as a tender coconut production and marketing hub. The water from these tender coconuts is very popular and is known for its sweeter nature than the tender nuts from other areas. Tender coconut water is the natural source of electrolytes, minerals, vitamins, complex carbohydrates, amino acids and other nutrients. The natural carbohydrate content is between 4-5 per cent of the liquid solution, and it is being regarded as a very healthy drink.

At APMC, Maddur, tender coconuts arrive from Maddur and adjoining areas of Kollegal, Channarayappattana, Mandya and Pandavpura and around four to seven lakh tender coconuts are traded daily, with the number reaching nine lakhs during summer months. The tender nuts from Maddur are dispatched to many Indian cities like Delhi, Mumbai, Pune, Nagpur, Aurangabad and Hyderabad with each nut fetching a minimum price of ten rupees. The market was established to facilitate an auction platform to enable farmers to fetch better prices; but, recent reports indicate that the mechanism, which is active in the market is "mutual negotiation", where the price is finalized through bargaining between the trader and individual seller, resulting in an on-the-spot cash payment. The majority, who comes to the market to sell the tender nuts, are the middle-men, rather than farmers, though in the eyes of officials they are "farmers". Traders pay APMC a market fee of 1.5 per cent of total sales, which at times reach up to ₹ 60,000-65,000 in a day. Thus, middlemen remain the real beneficiaries of this system, and the farmers succumb to the market price of ten rupees per nut. Tender coconuts are currently sold in Bangalore at ₹ 20-25 and ₹ 30-35 in markets like Delhi. This attractive price of tender coconuts has caught the attention of coconut farmers tempting them to harvest tender coconuts than mature nuts, enhancing the per year per palm productivity to the tune of 65-70 compared to that of 30-35 of Kerala state, the land of coconuts.

Conclusion

An evaluation of land suitability of Maddur towards coconut cultivation revealed that Maddur was found to be highly suitable in terms of high relative humidity, better rainfall distribution, low dry spell, mean annual temperature, low elevation of the area, rooting conditions and better moisture availability to roots. The soil parameters such as higher base saturation and cation exchange capacity, moderately acidic soil reaction (pH 5.6) along with

higher K, N and B status in Maddur soils were found to contribute well towards tender coconut production. The soils of Maddur were characterized and classified in this study which keyed out the soils to clayey-skeletal, mixed, semi-active isohyperthermic *Typic Rhodustalfs* at the family level.

However, it is also clear from the ten years change analysis that southern Karnataka has immense potential towards tender coconut cultivation. The coastal areas possess high rainfall (2900-4670 mm), high LGP (180-240 days) and high soil organic carbon (1.23-4.90 %). These areas are more prone for sheet erosion due to heavy rainfall, and the bases are leached from the surface soil leading to the development of acidity, which ultimately results in a decline in soil fertility. The soil acidity needs to be ameliorated by the application of lime, and the soil erosion may be controlled by the construction of soil conservation structures like bunds and bench terraces, staggered soil and water conservation pits *etc.,* or by growing erosion-resistant crops like grasses *etc*.

The coconut-growing soils of central, eastern and southern dry zones, southern transitional zone and coastal zone are characterized by moderately well to well-drained, moderately deep to deep black and red loamy and clayey soils, with good water holding capacity, and medium to high soil fertility. But low rainfall in these areas results in low LGP or increased dry spell, increase in soil salinity, sodicity and calcareousness. Hence suitable management measures need to be adopted to overcome these soil constraints, which could be by leaching with good quality irrigation water in saline soils, by the application of gypsum in sodic soils or by providing micro-irrigation in areas with prolonged dry spells. The quality of tender nuts must be ascertained by ensuring proper refrigerated storage and transportation facilities and with improved marketing efficiency. Equal participation from all the stakeholders and sharing of benefits have to be ensured for the smooth and efficient running of the present marketing system in place.

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