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Performance of Coleus *(Coleus forskohlii)* in Different Agro-climatic Zones of Tamil Nadu, India

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Abstract: A study was undertaken to characterize the Coleus-growing soils in different agro-climatic zones of Tamil Nadu to identify the yield limiting soil properties and management. The soil characteristics were rated for their quality as low, medium and high of three zones to assess. The horizon-wise soil samples from Typifying soil profiles and surface samples were collected from representing agro-climatic zones and soils were analysed. Soils were shallow to deep, well to somewhat poorly drained, dark brown to dark reddish brown in colour. The soils were sandy clay loam to sandy clay in texture and the clay content ranged from 28 to 45% being highest in Muthur soils. The organic carbon in soils ranged from 0.30 to 0.90% and cation exchange capacity from 10.2 (Rajapatty soils) to 22.8 cmol (p^+) kg^{-1} (Andipudur soils). Soils were low in available nitrogen, low to medium in available phosphorus and potassium. DTPA-extractable micro nutrients were sufficient in all the zones. Coleus yields were significantly correlated with available phosphorus, potassium and manganese.

Keywords: *Coleus, yield, soil properties, agro-climatic zones*

Introduction

Coleus is a perennial herb with fleshy, fibrous roots and grows wild in the warm sub-tropical temperate areas in India because of its unique diterpenoid content. It has been used for over 3,000 years to treat heart and lung diseases. In recent years, the plant has gained pharmacological importance as the only known plant source of the adenylate cyclase activating compound (Balasubramanian *et al.* 2020).

Increasing realization of the health hazards and toxicity associated with indiscriminate use of synthetic drugs and antibiotics has renewed the interest in the use of plants and plant-based drugs. Subsequent global inclination towards herbal medicine has advanced the expansion of plant-based pharmaceutical industries. Only a small percentage of medicinal plants traded in India are solely cultivated. Coleus (*Coleus forskohlii*) belonging to the family of Lamiaceae is an Indian medicinal herb (Valdes *et al.* 1987). It also grows in the subtropical temperate climates, Nepal, Burma, Sri Lanka and Thailand. Apparently, it has been distributed to Egypt, Arabia, Ethiopia, tropical East Africa and Brazil. In India, the plant is found mostly on the dry and barren hills (Anonnymous 1950). It is the most important species of genus coleus popularly known as '*garmar*' in Maharastra and '*makandiberu*' in Karnataka. It is cultivated to a limited extent in Maharastra, Tamil Nadu, Gujarat and Karnataka, for the tuberous roots which are pickled and eaten (Krishnan *et al.* 2011). In Tamil Nadu,

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medicinal and aromatic plants are cultivated in an area of 11684 hectares, out of that coleus alone occupied 3869 hectares (DHPC 2018). In Tamil Nadu, Salem, Tiruvannamalai, Villuppuram and Vellore districts are the major coleus producing districts. The coleus is cultivated on about 700 hectares in Salem district and Attur, Thalaivasal and Kallakurichi are the major coleus production centers in the district.

Soil characterization related to the assessment of physical, chemical and nutrients status of the soils, are important in sustainable agriculture (Karthikeyan *et al.* 2013; Karthikeyan *et al.* 2014). Suitable soil management and amendments are required to optimize the productivity of the soil for specific crops at the specific location (Vasundhara *et al.* 2017). Specific spatial assessment and monitoring of the limitations in nutrient uptake and coleus yield at regional scales is need of the hour to identify the problem for management. The present study was aimed to assess the yield limiting soil properties and to improve the crop productivity by altering crop management practices.

Materials and Methods

Field surveys were undertaken in high, medium and low yielding coleus fields during September-October (2013 to 2016) in the villages namely Unathur, Siruvachur, Manivilundan colony of Thalaivasal block of Salem district (North western zone) Vellithiruppur village of Andiyur block of Erode district (Western zone), East Rajapatty, West Rajapatty and Sevappur villages of Kadavur block of Karur district (Southern zone).

The area of North western, Western and Southern zones falls under the semi arid tropical climate. The mean annual rainfall of 849 mm is received in North western zone and about 42% is during the south west monsoon. The temperature ranges from 23^{0}C to 42^{0}C. In Western zone, mean annual rainfall of 720 mm is received with 49% during the North east monsoon period. The temperature ranges from 27^{0}C to 42^{0}C. Average rainfall of 776 mm is received in 43 rainy days in Southern zone. The North East monsoon is dominant in the zone contributing 50-60% of total rainfall. The temperature ranges from 30^{0}C to 37.5^{0}C.

The field survey was conducted in selected villages of three different Agro-climatic zones. The profiles were exposed and studied for their morphological characteristics (Soil Survey Division Staff 1993) in high, medium and low yielding areas of Coleus.

The horizon-wise soil samples and village-wise surface soil samples (15 cm depth) were collected, air dried and sieved through 2 mm sieve (0.2) mm sieve for organic carbon, labeled and stored, analysed for particle-size distribution following international pipette method and chemical properties (pH, EC, OC, CEC, exchangeable cations, ESP and BS) were determined by standard methods (Jackson 1973). The village-wise soil samples were analysed for organic carbon (Walkley and Black 1934). The available nitrogen was estimated through alkaline permanganate method as suggested by Subbiah and Asija (1987). The available phosphorus was extracted as per the method described by Olsen *et al.* (1954) and available potassium was estimated by flame photometer after extraction with neutral normal ammonium acetate solution (pH 7.0). The available micro nutrients cations (Fe, Mn, Cu and Zn) were extracted using DTPA (Lindsay and Norvell 1978). Plant height, number of branches plants^{-1}, yield and quality characters were recorded during field work. Pearson's linear correlation coefficient is used to establish relationships between the selected soil properties and yield of the coleus using SPSS version 22.0.

Results and Discussion

Morphological properties

Morphological characteristics of soils (Table 1 and 2) indicated that soil depth varied from slightly deep (<60 cm) to deep (120 cm). These soils were well to somewhat poorly drain. The colour varied from dark yellowish brown (10 YR 3/4) to reddish brown (2.5 YR 3/4) in surface and dark yellowish brown (10 YR 4/2) to reddish brown (2.5 YR 3/4) in sub-soils. The soil colour appears to be the function of chemical and mineralogical

Table 1. Morphological characteristics of soils

Depth	Colour	Texture	Structure	Effervescence	Root distribution
Pedon 1: Manivilundan colony soils(North Western Zone)					
0-20	5YR 3/4	Scl	m2sbk	Nc	Cf
20-47	2.5 YR 3/4	Scl	m2sbk	Nc	Mf
47-80	2.5YR 3/4	Scl	m2sbk	Nc	Cf
Pedon 2: NehruNagar soils (North Western Zo ne)					
0-30	7.5 YR 4/3	Scl	m2 sbk	Nc	Cf
31-56	2.5YR 4/4	Scl	m2sbk	Nc	Ff
57-93	2.5YR4/4	Scl	m2sbk	Nc	Ff
Pedon 3: Siruvachur soils(North Western Zone)					
0-31	2.5 YR 3/4	Sc	m2 sbk	Nc	Mf
32-56	2.5 YR 3/6	Sc	m2sbk	Nc	Cf
57-80	5YR3/4	Sc	m2sbk	Nc	Cf
Pedon 4: Mœlanur soils (Western Zone)					
0-20	2.5 YR 4/4	Scl	M2sbk	Nc	Mf
21-45	5 YR 4/4	Scl	m2sbk	Nc	Ff
46-75	5 YR 4/4	Scl	m2sbk	Nc	Ff
Pedon 5: Muthur soils (Western Zone)					
0-23	10 YR 4/2	Sc	m2 sbk	Nc	Cf
24-47	5 YR 5/2	Sc	m2sbk	Nc	Ff
48-68	5 YR 5/2	Sc	m2 sbk	Nc	Ff
69-110	2.5 YR 3/4	Sc	m2sbk	Nc	Ff
Pedon 6: Kurumbanur soils (Western Zone)					
0-26	10YR 4/2	Scl	m2 sbk	Profuse	Cf
27-52	10YR3/3	Scl	m2sbk	Profuse	Ff
53-72	7.5 YR3/3	Scl	m2sbk	Profuse	Ff
73-90	7.5 YR3/3	Scl	m2sbk	Profuse	Ff
Pedon 7:Andipudur soils (Southern Zone)					
0-25	5YR 4/4	Sc	m2sbk	Nc	Cf
26-42	5 YR 4/4	Sc	m2sbk	Nc	Ff
43-68	2.5YR 3/4	Sc	m2sbk	Nc	Ff
69-90	2.5YR 3/4	Sc	m2sbk	Nc	Ff
Pedon 8: Rajapatty soils (Southern Zone)					
0-20	5 YR 3/3	Sl	m2 sbk	Nc	Cf
21-40	5YR 3/4	Scl	m2sbk	Nc	Ff
41-80	5 YR3/3	Sc	m2sbk	Nc	Ff
81-120	5YR 3/4	Sc	m2sbk	Nc	Ff
Pedon 9: West Rajapatty soils (Southern Zone)					
0-20	5 YR 3/3	Scl	m2 sbk	Nc	Cf
21-60	2.5 YR 3/4	Scl	m2sbk	Nc	Ff

Texture; Sl-sandy loam, Scl- sandy clay loam, Sc- sandy clay:Structure; M- medium, 2- moderate, Sbk-sub angular blocky: Effervescence; Nc- non-calcareous:Root distribution; C-common, f- few, F-fine

Table 2. Physico-chemical properties of typifying pedons in different zones of coleus growing soils

Depth	Sand	Clay	Silt	pH	EC	OC	CEC	Exchangeable				ESP	BSP
								Ca	Mg	Na	K		
	%				dSm^{-1}	%		cmol (p^+) kg^{-1}				%	
Pedon 1: Manivilundan colony soils (North western zone)													
0-20	55	30	10	7.8	0.1	0.7	15.8	8.8	2.8	1.9	0.26	11.0	87.3
20-47	55	30	10	8.0	0.3	0.5	13.9	7.9	1.9	1.8	0.10	11.2	84.2
47-80	56	30	8	7.9	0.1	0.4	12.8	7.8	1.6	1.3	0.05	10.1	84.3
Pedon 2: Nehru Nagar soils													
0-30	65	25	10	8.0	0.1	0.6	14.3	8.0	2.2	1.6	0.15	11.2	83.6
31-56	50	30	10	8.1	0.2	0.3	12.9	7.8	1.7	1.3	0.08	10.1	84.5
57-93	60	30	10	8.0	0.1	0.3	13.3	7.6	1.2	1.5	0.10	11.3	82.0
Pedon 3: Siruvachur soils													
0-31	50	40	10	8.2	0.1	0.5	14.8	8.0	2.3	1.5	0.8	10.2	85.1
32-56	50	40	10	8.1	0.1	0.5	12.4	7.6	1.8	1.3	0.1	10.5	87.1
57-80	50	40	10	8.3	0.1	0.4	13.2	7.9	1.9	1.1	0.4	8.3	85.6
Pedon 4: Moolanursoils (Western zone)													
0-20	60	30	10	7.8	0.1	0.5	13.3	7.8	1.7	1.5	0.62	11.3	87.2
21-45	55	35	10	7.9	0.1	0.4	12.4	6.9	1.5	1.4	0.58	11.3	83.4
46-75	55	35	10	8.0	0.1	0.4	11.9	6.8	1.6	1.2	0.41	10.4	84.1
Pedon 5: Muthur soils													
0-23	45	45	10	8.3	0.1	0.4	14.4	8.1	2.1	1.5	0.54	10.4	84.7
24-47	50	40	10	8.0	0.2	0.4	13.3	8.2	1.6	1.4	0.58	10.5	88.7
48-68	50	40	10	8.2	0.1	0.3	13.9	8.4	1.7	1.1	0.46	7.9	84.2
69-110	50	40	10	8.0	0.1	0.3	11.8	7.6	1.3	1.0	0.38	8.5	87.3
Pedon 6: Kurumbanur soils													
0-26	55	35	10	8.4	0.2	0.45	15.8	8.4	2.1	1.9	0.62	12.1	82.3
27-52	52	38	10	8.2	0.1	0.53	14.1	7.7	2.2	1.6	0.58	11.3	85.8
53-72	55	35	10	8.1	0.2	0.33	13.8	7.6	1.8	1.4	0.41	10.2	81.2
73-90	55	35	10	8.2	0.1	0.47	12.4	7.2	1.6	1.5	0.38	12.1	86.3
Pedon 7: Andipudursoils (Southern zone)													
0-25	50	40	10	7.9	0.5	0.4	21.8	13.3	3.3	2.1	0.62	9.6	88.5
26-42	50	40	10	8.0	0.5	0.3	22.8	12.6	3.6	1.9	0.58	8.3	82.0
43-68	50	45	5	8.0	0.5	0.3	20.6	11.8	2.8	2.2	0.41	10.7	83.5
69-90	52	40	8	7.8	0.5	0.3	12.8	8.1	1.9	0.9	0.51	7.0	89.0
Pedon 8: Rajapatty soils													
0-20	80	15	5	7.7	0.4	0.4	10.2	5.4	1.6	0.8	0.42	7.8	80.6
21-40	67	25	8	7.8	0.4	0.5	13.2	7.7	2.2	0.7	0.38	5.3	83.3
41-80	45	40	15	8.1	0.4	0.3	22.5	12.1	4.1	2.6	0.41	11.6	85.3
81-120	45	40	15	8.2	0.4	0.3	21.2	11.8	3.8	2.4	0.32	11.3	86.3
Pedon 9: West Rajapatty soils													
0-20	67	25	8	7.8	0.5	0.4	14.8	8.4	2.1	0.9	0.6	5.9	81.1
21-60	43	42	15	7.7	0.5	0.9	19.7	11.2	3.1	1.1	0.6	5.6	81.2

composition as well as textural make up of soils and topographic position and moisture regime (Gaikwad *et al.* 2021). The wide textural variation might be due to variation in parent material (granite-gneiss and dolomite), topography, *in-situ* weathering and translocation of clay. The structure of the soils was sub-angular blocky. (Sharma *et al.* 2004).

Physical and physico-chemical characteristics of the soils are presented in table 2 and table 3. The sand and silt contents ranged from 43 to 67 and 5 to 15% respectively. The sand content was higher in surface horizons, whereas higher clay content was found in the sub-surface horizon because of the alleviation of fine fractions from the surface layers. The increase in clay content in Bt horizons of all the soils could be attributed to vertical migration or translocation of clay (Srinivasan *et al.* 2013).

The pH of soils ranged from 7.7 to 8.4 and electrical conductivity ranged from 0.1 to 0.5 ds m^{-1}. Organic carbon content varied from 0.3 to 0.9%. The higher organic carbon content in surface soils is high is due to plant dry matter and root biomass accumulation (Balasubramanian *et al.* 2020). Low OC content indicated poor nutrient management and high removal of crops (Srinivasan *et al.* 2017). Cation exchange capacity of typifying pedons ranged from 10.2 to 11.6 cmol (p^{+}) kg^{-1} being maximum in high yielding coleus growing soils southern zone. The CEC increased with increase in clay content of the pedons. The exchangeable bases had sequential dominance in the order of Ca> Mg > Na>K. High base saturation was due to high Ca^{2+} followed by Mg^{2+}, Na^{2+}, K^{+} (Patil and Dasog 1997). Exchangeable sodium percentage (ESP) varied from 7.8 to 11.6 % and ESP was higher in high yielding soils and lower in medium yielding soils of Southern zone respectively.

Fertility status

The village-wise fertility was assessed in three climatic zones (Table 4). The available N content varied from 82.7 to 121.3 kg ha^{-1} at different sites of coleus cultivation and over all rated as low. Similarly, available

Table 3. Range and mean value of physico-chemical properties of different zones

Ranges	Sand (%)	Clay (%)	Silt (%)	pH	EC (dSm^{-1})	OC (%)	CEC	Exchangeable cations (cmol [cmol $(p+)^{-1}$] kg^{-1}				ESP %	BSP %
								Ca	Mg	Na	K		
Min	43.0	15.0	5.0	7.7	0.1	0.3	10.2	5.4	1.2	0.7	0.05	7.8	81.1
Max	67.0	45.0	15.0	8.4	0.5	0.9	11.6	13.3	3.1	2.6	0.8	11.6	89.0
Mean	55.0	30.0	10.0	8.1	0.3	0.6	10.9	9.35	2.2	1.7	0.4	9.7	85.1

Table 4. Fertility status of surface soil in different zones

Zones	Yield criteria	Sample size	pH Range (1:2)	EC (dSm^{-1}) Range	Available macro nutrients (kg ac^{-1})			Available micro nutrients (ppm)			
					N	P	K	Zn	Cu	Mn	Fe
NWZ	High	22	7.5-8.2	0.1-0.4	121.3	16.6	170.8	1.4	1.7	14.8	7.3
	Medium	20	6.9-8.3	0.1-0.6	108	14.9	134.0	1.3	2.0	13.3	5.5
	Low	20	7.6-8.3	0.1-0.4	95.6	11.7	132.7	0.8	12.1	10.3	5.4
WZ	High	20	7.7-8.4	0.1-0.2	82.7	8.1	128.4	1.14	1.3	9.3	7.1
	Medium	20	7.6-8.4	0.1-0.3	106.4	12.5	118.4	1.33	1.3	10	5.3
	Low	20	7.9-8.4	0.1-0.3	108.2	7.3	99.5	1.02	1.4	9.4	6.4
SZ	High	20	7.1-8.4	0.1-0.4	83.4	11.9	159.7	1.05	2.84	12.9	9.3
	Medium	20	7.6-9.0	0.1-0.6	113.2	11.5	115.9	0.7	2.09	10.1	5.9
	Low	20	7.7-8.1	0.1-0.6	117.2	7.5	99.5	1.4	1.31	9.1	8.3

P and K varied from 7.3 to 16.6 and 98 to 170.8 kg ha^{-1} in surface soils of different sites. The DTPA-extractable Zn ranged from 0.70 to 1.40 mg kg^{-1}, Fe (5.3-9.3 mg kg^{-1}), Mn (9.1-14.8 mg kg^{-1}) and Cu (1.3-2.8 mg kg^{-1}). Soils were deficient in all the nutrients except few sites with medium to high in available Fe, Mn and Cu.

Coleus plant growth and yield limiting soil parameters

Plant height, number of branches, stem girth, number of leaves, lamina length and breath, petiole length, shoot fresh weight, number of tubers, length of tubers, girth of tubers and fresh weight of tuber were recorded at 30 days interval up to harvest (120 days). Plant growth parameters are significant with coleus tuber yield (Table 5) as healthy plants yield higher tuber production (Balasubramanian and Jegadeesan 2014). The yield limiting soil parameters are depth, heavy texture, poor structure, high sodium and calcium concentration, low organic carbon and poor soil fertility status (Kavitha *et al.* 2010). Among the soil variables, available P, K and Mn have a significant correlation with coleus yield. Soil properties like pH, and DTPA-Fe were negatively correlated. Soil properties that retain nutrients are necessary for coleus growth and development for sustainable production.

Table 5. Coleus plant growth and yield parameters in different zones

S. No	Particulars	NWZ			Western			Southern		
		Low	Medium	High	Low	Medium	High	Low	Medium	High
1	Yield /ac	5500	7500	12000	1200	1753	3750	900	2750	4250
2	Plant height (cm)	62	50	45	60	54	60	62	50	45
3	No of branches/plant	109	15	56	38	57	59	63	15	56
4	Stem girth (cm)	5	6	6	6	7	7	5	6	6
5	No of leaves/plant	380	430	650	256	360	353	440	430	650
6	Lamina length (cm)	6	7	7.5	6.2	6.7	6.7	7.6	7	7.5
7	Lamina breath (cm)	3.2	2.8	3	2.8	2.4	2.6	3.2	2.8	3
8	Petiole length (cm)	1.8	1.1	1.3	1.9	1	1.1	1.5	1.1	1.3
9	Shoot fresh weight (g)	525	575	935	310	450	690	620	575	935
10	No of tubers	12	22	27	8	14	21	12	22	27
11	Length of tubers (cm)	22	28	36	11	12.6	15	12	28	45
12	Girth of tubers (cm)	6,2	6.8	7	5	5.2	6	6,6	6.8	7
13	Fresh weight of tubers (g)	77.5	435	659	275	350	750	230	435	480

Table 6. Correlation between soil nutrients and yield in different zones

Properties	Yield	pH	EC	N	P	K	Zn	Cu	Mn	Fe
pH	-0.513	1								
EC	0.072	-0.222	1							
N	0.628	-0.225	-0.026	1						
P	0.831**	-0.501	0.238	0.738*	1					
K	0.837**	-0.531	-0.116	0.813**	0.755*	1				
Zn	0.248	-0.572	-0.027	0.015	0.211	0.145	1			
Cu	0.209	-0.328	0.333	0.594	0.367	0.515	-0.183	1		
Mn	0.877**	-0.667*	0.201	0.696*	0.871**	0.869**	0.311	0.572	1	
Fe	-0.021	-0.261	0.003	0.098	-0.224	0.296	0.248	0.462	0.182	1

Conclusion

From the present investigation, it can be concluded that varying soil properties in different climatic zones had significant influence on the yield of coleus plant. Soil characteristics like soil depth, texture, drainage and poor soil fertility decrease the yield of coleus in Western and Southern zones of Tamil Nadu and hence site-specific nutrients management is to be applied to enhance the yields and soil quality.

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