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Evaluation of soil characteristics and yield variation of coleus (*Coleus forskohlii*) in different agro climatic zones of Tamil Nadu

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Abstract
Coleus is a perennial herb with fleshy, fibrous roots and grows wild in the warm sub-tropical temperate areas in India. In Ayurvedic Medicine it has been used for over 3,000 years to treat heart and lung diseases. In India it has been cultivated for a long time as an important medicinal plant because of its unique diterpenoid content. In recent years the plant has gained pharmacological importance as the only known plant source of the adenylate cyclase activating compound. Detailed soil characterization was carried out in different yield rating (low, medium and high) zones in two Agro climatic zones of (North Eastern and Hill area zones) of Tamil Nadu to assessing the yield limiting soil factors. Typifying soil profiles and surface samples were collected from representing agro climatic zones and soils were analysed. Soils are shallow to deep, well to somewhat poorly drained, dark brown to dark reddish brown in moist colour. The soils were sandy clay loam to sandy clay and clay content ranged from 28 to 45%. The organic carbon in soils ranged from 0.10 to 1.16% and cation exchange capacity from 8.2 to 16.6 cmol (p^+) kg^{-1} soil, respectively. Soils were low in available nitrogen, low to medium in available phosphorus and low to medium in available potassium. In general, soils were deficient in DTPA-extractable Zn and other micro nutrients like copper, iron and manganese are sufficient. Plant characteristics of different climatic zones were shows significant with soil depth and other characteristics.

Keywords: Coleus, soil characteristics, plant nutrients, agro climatic zones, Tamil Nadu

Introduction
Medicinal plants continue to be an important source of lifesaving drugs for humankind, especially in the developing nations. The World Health Organization has estimated that more than 80% of the world population in developing countries depends primarily on herbal medicine for basic health care (Vines, 2004) [16]. 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) [15]. It grows wild in the subtropical temperate climates of India, 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 (Anon, 1950) [2]. 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) [6], and also used for medicinal purposes mentioned in the Hindu and Ayurvedic schools of medicines (Ammon and Muller, 1985)[1]. Coleus is the only known source of forskolin (De Souza and Shah, 1988) [4]. Though almost all parts of the plants are found to have traces of forskolin, the roots are the main source, containing 0.1 to 0.5% and are commercially preferred for its extraction (Valdes *et al.*, 1987) [15]. The tuber attachment region contains maximum (1.3 times higher) forskolin (Yanagihara, 1995) [19].Coleus contract farming is gaining popularity among the small and marginal farmers of Tamil Nadu, about 10000 tonnes of coleus roots are harvested every year. The yield variation of coleus roots were

observed among agro climatic zones of Tamil Nadu. There is need to assess the yield and plant limiting soil factors through soil resource inventory. Hence, a detailed soil survey information and fertility status of the soils are very useful tools to soil and crop management and enhances the productivity. Keeping this in view, the present study was attempted in various coleus growing villages of North Eastern and Hill area agro climatic zones of Tamil Nadu. The yield variation of coleus and yield limiting soil properties assessed for improving productivity.

Materials and methods

Study area

A field survey was under taken to study the yield variation of coleus in two Agro climatic zones (North Eastern and Hill area zones) of Tamil Nadu. Coleus crops are cultivated during September -October months of every year. Selection of study area was based on high acreage of coleus growing villages of North Eastern zone and Hill area zone of Tamil Nadu. Coleus growing North Eastern zone - Thiruvannamalai, Villupuram, Kanchepuram districts and Hill area zone is Javad hills of Thiruvannamalai districts of Tamil Nadu. A detailed soil information collected from North Eastern zone villages of Thanipady, Tharadapet, Annanagar and Kuravanodai villages of Thandrampet block of Tiruvannamalai district and Hill area zone villages of Nellimarathur, Puduran kottai and Mandarakottai where coleus cultivating predominantly in more than 500 acres in season.

Climatic condition

Study area of North Eastern and Hill area zones comes under the semi arid tropical climate. The mean annual rainfall is 1100 mm received in 53 rainy days.North East monsoon season provides the maximum amount of 566 mm rainfall in 22 days followed by South West monsoon contributing 407 mm in 21 rainy days. The moisture regime is ustic. Nellimarathur, Puduran kottai and Mandarakottai villages of Hill area zone study area has a semi arid tropical climate. The mean annual rainfall ranges from 1000 mm-5000 mm. The moisture regime is ustic.

Filed studies

The field survey was conducted during 2016- 2017 in selective villages from different climatic zones. Soil profiles study was taken in high, medium and low yielding areas of Coleus zones. Soils were characterized for morphological, physical and chemical properties and individual pedons were described as per Soil Survey Division staff (2000) [11].

Laboratory analysis

Soil horizon wise 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 like pH, EC, OC, CEC, exchangeable cations, ESP and BS were determined by adopting standard methods (Jackson, 1973) [5]. The soil fertility samples were collected in different villages at depth of 15 cm and determinate the status. Soil organic carbon was determined by the wet oxidation method (Walkley and Black, 1934) [18] .The available nitrogen (N) was estimated through alkaline permanganate method as suggested by Subbiah and Asija (1956) [14]. The assessment of available phosphorus by using 0.5M $NaHCO_3$ extract as described by Olsen *et al.* (1954) [8] and available potassium was estimated by flame photometer after extraction with Neutral normal ammonium acetate solution (pH 7.0). The available micro nutrients (Fe, Mn, Cu and Zn) were extracted using DTPA (Lindsay and Norvell, 1978) [7]. Plant characteristics like height, number of branches/plant, yield attributes, yield and quality characters were recorded during field work.

Results and Discussion

Morphological Properties

Site and morphological characteristics of soils were given in Table 1and Table 2. The soil depth varied from shallow (<50 cm) to deep (150 cm). These soils are well to somewhat poorly drained. The colour varied from brown (7.5YR 4/4 to reddish brown (2.5 YR 4/4) in surface and dark reddish brown (5YR 3/4 to 2.5 YR 3/3) in sub soils. The soil colour appears to be the function of chemical and mineralogical composition as well as textural make up of soils and conditioned by topographic position and moisture regime (Walia and Rao, 1997) [17]. The different climatic condition varied textural condition (sandy clay loam to sandy clay). The wide textural variation might be due to variation in parent material (granite-gneiss and dolomite), topography, in-situ weathering and translocation of clay by eluviation. The structure of the soils is sub-angular blocky. The blocky structure i.e., sub-angular blocky were attributed to the presence of higher quantities of clay fraction (Sharma *et al.*, 2004) [10]. Slight effervescence and fine to coarse root distribution in all the soils.

Physical characteristics

Physical and physico-chemical characteristics of the soils are presented in Table 2 and Table. 3. The sand and silt contents ranged from 45 to 65 and 7 to 15% respectively. The sand content was higher in surface horizons, where as higher clay content was found in the sub-surface horizon because of the illuviation of fine fractions from the surface layers in all the sites except site 4. 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) [12].

Physico-chemical characteristics

The pH of soils ranged from 5.5 to 8.0 and electrical conductivity ranged 0.1 to 0. 3 ds m^{-1}. Organic carbon content varied from 0.1 to 1.16%. The enrichment of OC content in surface soils are high could be plant dry matter and root biomass accumulation (Balasubramanian *et al.*, 2020) [3]. Low OC content indicated poor nutrient management and high removal of crops (Srinivasan et al., 2017) [13]. Cation exchange capacity of typifying pedons ranged from 8.6 to 16.6 cmol (p^+) kg^{-1} with maximum from site-3 low production of coleus. The CEC increased with increase in clay content of the pedons. Higher values of CEC in sub surface horizons commensurate with the amount of clay. The exchangeable bases had distinct pattern regarding their sequential dominance. In all the pedons, the order followed was Ca> Na > Mg >K. Among the cations Ca^{2+} was dominant. The variation observed in base saturation (BS) indicates the degree of leaching which was used as diagnostic character for classifying the soil group. High base saturation was due to high Ca^{2+} followed by Mg^{2+}, Na^{2+}, K^+ (Patil and Dasog, 1997) [9]. Exchangeable sodium percentage (ESP) varied from 0.1 to 8.6 %, ESP was higher in North Eastern zone soils and lower values are found in Hill Area zone.

Fertility status

The village wise fertility status was assessed in both climatic zones (Table. 4). Soil fertility exhibits the status of different soils with regard to the amount and availability of nutrients essential for plant growth. The available N content varied from 67 to 155 kg ha^{-1} in different sites of coleus cultivation, over all rated as low. Similarly available P and K varied from 2.5 to 21.0 and 48 to 233 kg ha^{-1} in different sites surface soils. The DTPA-extractable Zn ranged from 0.70 to 1.30 mg kg^{-1} others are Fe (3.7-12.7 mg kg^{-1}) Mn (5.7-18.0 mg kg^{-1}) and cu (1.8-2.9 mg kg^{-1}) respectively. Soils were deficient in all the nutrients except few sites medium to high in available Fe, Mn and Cu.

Coleus plant growth and yield limiting soil parameters

Plant characteristics like height, number of branches, stem girth, number of leaves, lamina length & breath, petiole length, shoot fresh weight, number of tubers, length of tubers, girth of tubers and fresh weight of tuber were recorded 30 days interval up to harvest (120 days) (Table. 5). Plant growth parameters are significant with coleus tuber yield i.e. healthy plant get more yield than moderate and low plants. As a result of yield limiting soil parameters are depth, heavy texture, degraded structure, high sodium and calcium concentration, low organic carbon and poor soil fertility status. Based on the soil properties yield rating classes were assessed and suggested suitable soil and land management for better coleus production.

Table 1: Morphological characteristics of different soils in NE and HAZ zones

Depth	Colour	Texture	Structure	Effervescence	Root distribution
Site-1: Annanagar-I (North Eastern zone)					
0-20	7.5 YR 4/4	Scl	m2 sbk	Nc	Cf
21-40	5 YR 3/3	Scl	m2 sbk	Nc	Ff
41-80	2.5YR 3/3	Scl	m2 sbk	Nc	Ff
81-110	2.5YR 3/4	Scl	m2 sbk	Nc	Ff
Site-2: Annanagar-II					
0-20	7.5 YR 4/4	Scl	m2 sbk	Nc	Mf
21-60	5YR 3/4	Scl	m2 sbk	Nc	Cf
Site-3: Tharadapet					
0-20	5 YR 4/4	Scl	m2 sbk	Nc	Mf
20-50	2.5 YR 3/4	Gscl	m2 sbk	Nc	Ff
Site-4: Nellimarathur (Hill area zone)					
0-30	7.5 YR 4/4	Sc	M2 sbk	Nc	Cf
30-62	5 YR 3/3	Scl	m2 sbk	Nc	Ff
62-92	2.5 YR 3/3	Sc	m2 sbk	Nc	Ff
93-150	2.5 YR 3/4	Sc	m2 sbk	Nc	Ff
Site-5: Pudurankottai					
0-30	2.5 YR 4/4	Sc	m2 sbk	Nc	Cf
31-45	5 YR 3/3	Scl	m2 sbk	Nc	Ff
46-75	2.5 YR 3/3	Scl	m2 sbk	Nc	Ff
76-110	2.5 YR 3/4	Scl	m2 sbk	Nc	Ff
Site-6: Mandarakottai					
0-20	7.5 YR 4/4	Scl	m2 sbk	Nc	Cf
21-40	5 YR3/3	Scl	m2 sbk	Nc	Ff
41-80	2.5 YR3/3	Scl	m2 sbk	Nc	Ff

Sbk-sub angular blocky; ss- slightly sticky; sp- slightly plastic; S0- no sticky; P0-no plastic

Table 2: Physico-chemical properties of different soils in NE and HAZ zones

Depth	Sand	clay	Silt	pH	EC	OC	CEC	Exchangeable cations				ESP	BSP
								Ca	Mg	Na	K		
(cm)	%			1:2.5	dSm^{-1}	%	cmol (p^+) kg^{-1}					%	
Site-1: Annanagar-I (North Eastern zone)													
0-20	55	28	8	7.8	0.1	0.30	15.8	9.8	2.8	0.90	0.26	5.7	87
20-40	55	34	10	8.0	0.3	0.20	13.9	9.0	1.9	1.10	0.20	7.9	87
41-80	56	33	9	7.9	0.1	0.10	12.8	8.2	1.6	1.10	0.31	8.6	87
81-110	55	34	9	7.7	0.1	0.20	14.4	9.4	1.2	1.20	0.23	8.3	83
Site-2: Annanagar-II													
0-20	65	28	7	7.1	0.1	0.30	14.8	9.0	2.1	1.00	0.31	6.8	83
21-60	55	34	10	7.7	0.1	0.20	13.4	8.6	1.8	0.90	0.12	6.7	85
Site-3: Tharadapet													
0-20	62	28	10	7.5	0.1	0.40	16.6	11.2	2.1	0.90	0.18	5.4	86
20-50	56	34	10	7.7	0.1	0.20	13.8	9.5	1.6	0.80	0.13	5.8	87
Site-4: Jamunamarathur (Hill area zone)													
0-30	45	40	15	6.4	0.1	0.35	13.8	7.2	1.8	0.20	0.62	1.4	71
31-62	50	35	15	5.9	0.1	0.93	8.6	4.7	1.2	0.15	0.58	1.4	77
63-92	45	40	15	5.7	0.1	0.23	12.8	6.2	1.4	0.12	0.41	0.9	63
93-150	48	37	15	5.5	0.1	1.16	11.4	5.8	1.6	0.13	0.38	1.1	69
Site-5: Pudurankottai													
0-31	58	35	7	6.3	0.1	0.43	10.2	5.4	1.6	0.07	0.42	0.7	73
31-45	60	30	10	6.6	0.1	0.48	9.1	5.1	1.2	0.05	0.38	0.5	74

46-75	45	45	10	6.6	0.1	0.32	13.2	7.1	2.1	0.04	0.41	0.3	73
76-110	45	45	10	6.5	0.1	0.28	14.4	8.4	2.2	0.02	0.32	0.1	76
Site-6: Mandarakottai													
0-20	52	28	10	5.8	0.1	0.38	8.2	4.3	1.3	0.10	0.62	1.2	76
21-40	56	34	10	6.0	0.1	0.29	9.6	5.1	0.9	0.09	0.58	1.1	69
41-80	57	33	10	6.3	0.1	0.25	9.1	4.8	1.2	0.10	0.41	1.1	71

Table 3: Comparative statements of different soil morphological characteristics

	North Eastern Zone (NEZ)			Hill Area zone (HAZ)		
Properties	**Annanagar-1**	**Annanagar-2**	**Tharadapet**	**Nellimarathur**	**Puduran kottai**	**Mandarakottai**
Yield	High	Medium	Low	High	Medium	Low
Depth of solum	110+	31	40	150+	150+	100+
Coarse fragments	15	20	25	15	10	10
Texture						
surface	Sandy clay loam	Sandy clay loam	Sandy clay	Sandy clay	Sandy clay loam	Sandy clay
Sub surface	Sandy clay loam	Sandy clay loam	Sandy clay loam	Sandy clay loam	Sandy clay loam	Sandy clay loam
Structure						
Surface	sbk	Sbk	Sbk	sbk	sbk	sbk
Sub surface	sbk	Sbk	Sbk	sbk	sbk	sbk
consistency						
Surface	Ss,Sp	S_0,P_0	Ss,S_0	Ss,Sp	S_0,p_0	Ss,Sp
Sub surface	S_0,p_0	Ss,Sp	Ss,Sp	S_0,p_0	Ss,Sp	S_0,p_0
calcareousness	Nil	Nil	Nil	Nil	Nil	Nil
Soil reaction						
Surface	Neutral	Neutral	Neutral	Neutral	Neutral	Neutral
Sub surface	Slightly alkali	Slightly alkali	Slightly alkali	Acidic	Neutral	Neutral
Drainage	Well drained	Somewhat poorly drained	Moderately well drained	Well	Well	Well

Sbk-sub angular blocky; ss- slightly sticky; sp- slightly plastic; So- no sticky; Po-no plastic

Table 4: Fertility status of surface soil in different Agro climatic Zones

Zones	**Yield criteria**	**Sample size**	**pH (1:2.5)**	**EC (dSm^{-1})**	**Available nutrients**						
					N	**P**	**K**	**Fe**	**Mn**	**Cu**	**Zn**
					Kg ac^{-1}			**ppm**			
NEZ	High	22	7.2	0.20	78	2.5	79	12.7	15.2	1.73	0.7
	Medium	20	7.1	0.20	92	21.0	48	7.5	10.8	1.8	0.9
	Low	10	7.6	0.20	155	16.1	49	8.3	9.6	2.5	1.0
HAZ	High	20	6.9	0.20	71	4.1	101	9.1	10.1	2.9	1.2
	Medium	20	7.5	0.10	103	10.0	68	3.7	5.7	2.8	0.7
	Low	10	6.3	0.10	67	16.0	233	3.7	18.0	1.9	1.3

Table 5: Coleus plant growth and yield parameters in different Agro climatic zones

Particulars	**North Eastern Zone (NEZ)**			**Hill Area Zone (HAZ)**		
	Low	**Medium**	**High**	**Low**	**Medium**	**High**
Yield (kg ac^{-1})	2000	2770	3700	3150	4280	5900
Plant Height (cm)	62	50	45	60	52	55
No of branches/plant	67	45	56	48	57	59
Stem girth (cm)	5	6	6	6	7	7
No of leaves/plant	380	430	650	256	360	376
Lamina length(cm)	6	7	7.5	6.2	6.7	6.7
Lamina breath(cm)	3.2	2.8	3	2.8	2.4	2.6
Petiole length (cm)	1.8	1.1	1.3	1.9	1	1.1
Shoot fresh weigh (g)	525	575	935	310	450	690
No of tubers	14	22	27	16	19	21
Length of tubers (cm)	22	28	36	18	22	25
Girth of tubers (cm)	6.2	6.8	7	6.8	7.2	8
Fresh weight of tubers (g)	270	435	560	380	450	750

Conclusions

From the present investigation it can be concluded that varying morphological, physical and physicochemical properties of soils in different climatic zones were significantly influences the yield of coleus plant. Soils are acidic, non saline, texture varied from sand clay loam to sandy clay. CEC was low to medium and exchange complex was dominated by Ca^{2+}. Soil characteristics like soil depth, texture, drainage and poor soil fertility status were reducing the yield of coleus in North Eastern and Hill area zones of Tamil Nadu. Hence, judicious use soil resources and application appropriate nutrient management not only paves the way for achieving sustainable yields of crops but also maintains soil health.

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