A. No. 551

Journal of Plantation Crops, 2006, 34 (3):323-329

Pedochemical characterization of rubber growing soils of north eastern upland zone of Kerala

G.C. Satisha[1]*, D.V.K. Nageswara Rao[2], Radha Lakshamanan[3], and M.A. Nazeer[2]

[1]*National Research Centre for Oil Palm, Pedavegi-534 450, Andhra Pradesh*

[2]*Rubber Research Institute of India, Kottayam-686 009, Kerala*

[3]*Regional Research Station, Padiyoor P.O., Kannur-670 703, Kerala*

Abstract

Typical pedons developed on different geomorphic conditions namely hill and upper ridges, residual hill, pediments, undulated plain with hummocks, intervening basin and valley in Rubber Research Station, Padiyoor representing north eastern upland zone of Kerala were studied for their morphology and pedochemical characteristics, together with assessment of their potential for rubber cultivation. The soils in general were moderately deep to very deep and they had sub-angular blocky surface horizons and weak angular to sub-angular blocky sub-surface horizons. The soils contained higher amounts of clay fractions irrespective of geomorphic conditions. The clay content in soils of upper ridges varied from 48 to 70 per cent while in soils of lowlands/valley, it range between 32 to 70 per cent. Despite the high clay content, the soils were well drained with good soil-water-air relationship indicating favourable edaphological property for rubber cultivation. The soils were strongly acidic and considerably high in organic matter contents that showed a decreasing trend with depth. Per cent base saturation of the soils was low to moderate (17 to 76 %) and the cation exchange capacity (CEC) of the soils was low, varied from 5.4 to 15.0 cmol (p+)/kg suggesting that they are subject to very rapid decline in fertility demanding specific management measures to maintain soil fertility. The presence of 1:1 layer silicate clays (kaolinite) and oxides of Fe and Al in the clay fraction indicates poor release of nutrients through mineral weathering to meet the demands of rubber for rapid growth and high yield.

Key words : Rubber, Kerala, Geomorphic units, soil morphology, pedochemical characteristics

Introduction

Although rubber (*Hevea brasiliensis*) grows over wide areas of the humid tropics in Kerala, geographical segregation over a range of environments is common (Krishnakumar, 1989) and adaptation to particular ecology and soil conditions is also frequently encountered. Performance and economic viability of rubber can be severely restricted where very acid peat, rocky parent material is present and due to undulated topography, soil erosion and low nutrient supplying capacity (Bennama, 1963; Eshett and Omueti, 1989). The performance of rubber plantations is directly related to the characteristics of the soils influencing the plant growth (Kharche *et al.*, 1995; Bhattacharyyya *et al.*, 1998a and 1998b; Satisha *et al.*, 2002). Soil forming factors and anthropogenic activities govern the interpretation of soils for optimum land use planning, conservation of soil resources and agrotechnology transfer

* For Correspondence

(Yadav, 2002). North eastern upland zone of Kerala occupies considerable area under rubber where the performance of rubber is not satisfactory. The Regional Rubber Research Station, Padiyoor represents the soils of this zone. Virtually no information is available about the soils of this area and hence, in this paper, we report detailed morphological and pedochemical characteristics of eight representative soil profiles developed on different geomorphic conditions, together with assessment of their potential for rubber cultivation.

Materials and Methods

Four pedons (P1-P4) occurring on upper ridges/ residual hills and four pedons (P5-P8) lying in lowlands/ plain/valley in the Regional Research Station, Rubber Research Institute of India (RRII), Padiyoor, North Kerala were selected for the study. The research station is situated at 75° 36' E longitude and 11° 58' N latitude at an elevation of 20 to 80 m above msl. The study area has warm humid sub-tropical climate. It is influenced by the southwest monsoon from May to September and the northeast monsoon from October to April. The total annual rainfall ranging from 2500 to 3400 mm, recorded in almost all the months but the distribution is uneven. Total rainy days in the year averages to 122. The relative humidity remains very high throughout the year varying from 80 to 94 per cent. Ambient temperatures are uniformly high all the year round, except during the harmattan months (December - January). The mean maximum and minimum annual temperature ranges from 28.9 to 36.6 °C and 18.3 to 23.5 °C respectively, while mean annual soil temperature at 5 cm soil depth (1430 hrs IST) varies from 30.4 to 44.8 °C. Table 1 shows the agro-climatic data for Regional Research Station, RRII, Padiyoor over a period of five years.

Horizon-wise soil samples of all eight profiles were collected, air-dried for three days, crushed and sieved (2 mm mesh). The processed soils were analysed for particle size distribution by international pipette method (Singh, 1989). Organic carbon, pH, cation exchange capacity (CEC) and exchangeable cations were determined following the standard methods (Black, 1965). Calcium and magnesium were estimated using an atomic absorption spectrophotometer, while Na and K were estimated by the flame emission spectrophotometry.

Results and Discussion

Pedogenic development of soils corresponds to the geomorphological types in the study area. The geomorphological units identified were hill/residual hills, pediments, undulated plain, intervening basis and valley (Tripathy *et al.*, 1996). The site and morphological characteristics of the soils developed on these geomorphological units are described in Tables 2 and 3.

The soils in general were moderately deep to very deep (170 cm depth) and well drained with rapid permeability. The morphological characters indicate highly leached surface horizon especially soil profiles of upper ridges and distinct horizonation with differentiation. They had moderately developed sub-angular blocky surface horizons and weak angular to sub-angular blocky sub-surface horizons. The consistence of soils did not vary much between the pedons irrespective of geomorphic conditions. Consistence was very friable to friable when moist, and slightly sticky and slightly plastic under wet condition. The consistence

Table 1. Agro-climatic data for Regional Rubber Research Station, Padiyoor, North Kerala (2000-2004)

Month	Mean maximum temperature (°C)	Mean minimum temperature (°C)	Mean relative humidity (%)	Mean total monthly rainfall (mm)	Mean number of rainy days	Mean soil temperature (°C) (5 cm depth -1430hrs IST)
January	34.8	19.5	82.6	16	1	40.5
February	35.2	20.8	87.8	3	0.8	42
March	36.6	22	86.6	3.5	0.3	44.8
April	35.5	23.5	89.2	140	7	42.5
May	33.9	23.4	90.3	142.5	10.8	38.9
June	30.6	22.3	94.3	807.9	24.3	31.4
July	28.9	22.1	94.2	761.8	26.8	30.5
August	28.9	22.1	93.4	646.1	22.5	31
September	31.3	21.9	92.5	180.4	10.3	35.8
October	31.4	21.8	94	515.9	15.3	34
November	33.7	21.1	90.7	92.5	3.3	38.8
December	33.9	18.3	79.5	31	0.3	39

Table 2. Site characteristics of typical pedons

Soils	Geomorphology	Parent material	Topography	Effective soil depth	Drainage class	Erosion class
Pedon 1	Hill and ridges	Basaltic gibbsite	Moderately steep	Moderately deep	well	moderate
Pedon 2	Hill and Elongated ridges	Basaltic gibbsite	steep	Moderately deep	well	severe
Pedon 3	Residual hill	Basaltic gibbsite	steep	Moderately deep	well	severe
Pedon 4	Residual hill with plateau	Basaltic gibbsite	steep	Moderately deep	well	severe
Pedon 5	Plain with hummocks	Basaltic gibbsite	gently	deep	Moderately well	moderate
Pedon 6	Intervening basin	Alluvium	very gently	deep	well	slight
Pedon 7	Undulated plain/lower ridges	Basaltic gibbsite	gently	Moderately deep	well	slight
Pedon 8	Plain with valley	Alluvium	nearly level	deep	well	slight

Table 3. Morphological characteristics of the soils

Horizon	Depth (cm)	Texture	Gravel (%)	Structure	Consistence Dry	Moist	Wet	Clay cutans
Pedon 1. Hill and upper ridges								
A1	0-17	gc	57.2	f1sbk	sh	fr	ss sp	-
Bt1	17-55	gc	53.1	f1sbk	sh	fr	Ss sp	pytn
Bt2	55-75	gc	60	f1abk	sh	fr	sp	pytn
C	75+	laterite rock						
Pedon 2. Hill with elongated ridges								
A1	0-13	gc	51.1	m2sbk	sh	fr	sp	-
A2	13-33	gc	48.5	m2sbk	sh	fr	sp	-
Bt1	33-52	gc	61.5	f1abk	sh	fr	sp	pytn
Bt2	52-77	gc	67.4	m2sbk	sh	fr	sp	pytn
C	77+	laterite rock						
Pedon 3. Residual hill with pediments								-
Ap	0-12	c	47.2	m2sbk	sh	fr	ss sp	-
Bt1	12-36	gc	52.4	f1sbk	sh	vfr	ss sp	-
Bt2	36-77	c	47.3	f1abk	sh	fr	ss sp	pytn
C	77+	laterite rock						
Pedon 4. Residual hill with plateau								
A1	0-14	c	35.7	f1sbk	sh	fr	ss sp	-
Bt1	14-30	gc	48.9	m2sbk	sh	vfr	sp	pytn
Bt2	30-57	c	46.2	f1abk	sh	fr	sp	pytn
C	57+	parent rock						
Pedon 5. Undulated plain with hummocks								-
Ap	0-16	c	28.5	m2sbk	h	fr	sp	-
Bt1	16-34	c	30.2	f1sbk	sh	fr	sp	-
Bt2	34-91	c	46.5	f1abk	sh	fr	sp	-
Bt3	91-130	c	44.1	f1abk	h	fr	sp	-
Pedon 6. Intervening basin								
Ap	0-13	scl	31.7	c3sbk	sh	fr	sp	-
Bt1	13-39	gscl	62.7	m2sbk	sh	fr	sp	-
Bt2	39-60	gscl	56.8	m2sbk	sh	fr	sp	-
Bt3	60-134	gscl	70.6	m2sbk	sh	fr	sp	-

Pedon 7. Lower ridges/plain								
A1	0-10	c	32.8	m2sbk	sh	fr	ss sp	-
Bt1	10-28	gc	58.4	m2sbk	sh	v fr	ss sp	-
Bt1	28-59	gc	61.2	f1abk	sh	fr	sp	-
Bt2	59-95	gc	70.6	f1abk	sh	v fr	sp	pytn
Pedon 8. Plain with valley								
Ap	0-13	c	39	f1sbk	sh	vfr		-
Bt1	13-28	gc	55.1	f1abk	sh	fr		-
Bt2	28-44	gc	48.7	m2abk	sh	fr		-
Bt3	44-87	gc	63	f1abk	sh	fr		pytn
Bt4	87-163	gc	63.5	f1abk	sh	fr		-

indicated a good soil-water-air relationship in these soils. This is advantageous for early establishments of the rubber trees.

Tables 4 and 5 show physico-chemical and ion exchange properties of the soils. The soils of upper ridges contained higher content of gravel compared to those from lowlands/valley. The soils contained higher amounts of clay fractions irrespective of geomorphic conditions. The clay content in soils of upper ridges varied from 48 to 70 per cent while in soils of lowlands/valley, it ranged between 32 to 70 per cent. Despite the high clay content, the soils were well drained. This was

Table 4. Physico-chemical characteristics of the soils

Depth (cm)	Particle distribution (%) Sand	Silt	Clay	Soil texture	Soil ratios Silt/clay	Clay/clay+silt	pH	EC (dS/m)	Organic Carbon (%)
Pedon 1. Hill and upper ridges									
0-17	21	14	60	gc	0.23	0.81	5	0.094	2.6
17-55	17.5	13	65	gc	0.2	0.83	5.1	0.067	2.38
55-75	19	11.5	66	gc	0.17	0.85	4.9	0.032	2.2
Pedon 2. Hill with elongated ridges									
0-13	31	6.5	58	gc	0.11	0.9	5.1	0.057	2.8
13-33	24	6	65	gc	0.09	0.92	5.1	0.027	1.79
33-52	25	6	66	gc	0.1	0.86	5	0.033	1.2
52-77	23.5	6.5	68	gc	0.1	0.91	5.1	0.034	0.89
Pedon 3. Residual hill with pediments									
0-12	26	6	62	c	0.06	0.94	5.1	0.05	3.58
12-36	28.5	4	63	gc	0.07	0.94	5	0.034	3.36
36-77	22.5	3	70	c	0.04	0.96	4.9	0.025	3.08
Pedon 4. Residual hill with plateau									
0-14	33	10	48	c	0.21	0.83	5.2	0.051	2.5
14-30	32.5	9.5	50	gc	0.17	0.84	5.3	0.046	2.44
30-57	37	8.5	50	c	0.19	0.85	4.8	0.032	2.39
Pedon 5. Undulated plain with hummocks									
0-16	17.8	13	63.5	c	0.2	0.83	5.4	0.033	2.01
16-34	15	11	70	c	0.16	0.86	5	0.033	1.7
34-91	14.6	11	68.5	c	0.18	0.85	4.9	0.033	1.62
91-130	16	12	70.5	c	0.19	0.84	4.8	0.035	0.6
Pedon 6. Intervening basin									
0-13	46.5	19	31.8	scl	0.6	0.63	5.1	0.073	1.87
13-39	49.6	10	35.7	gscl	0.28	0.78	5.1	0.033	1.82
39-60	36.7	17	42.4	gscl	0.51	0.66	5.1	0.03	1.79
60-134	41.6	9.1	44.8	gscl	0.26	0.79	5.1	0.028	1.3
Pedon 7. Lower ridges/plain									
0-10	36	13	48	c	0.27	0.83	5.3	0.049	1.82
10-28	35	11	52	gc	0.21	0.83	4.8	0.039	1.58
28-59	28.5	10	59	gc	0.2	0.79	4.7	0.037	1.22
59-95	33	10	52	gc	0.21	0.83	4.8	0.036	0.67

Pedon 8. Plain with valley									
0-13	32	10	50	c	0.2	0.83	5.5	0.05	1.87
13-28	29	6.5	58	gc	0.11	0.9	5.2	0.038	1.82
28-44	30.5	8	54	gc	0.15	0.87	5	0.035	1.62
44-87	30	9	56	gc	0.17	0.85	4.8	0.048	1.03
87-163	25	5	61.5	gc	0.08	0.92	4.8	0.03	0.56

Table 5. Ion exchange properties and base saturation of the soils

Depth (cm)	CEC (cmol(p+)/kg)	CEC / Clay ratio	Exchangeable cations (cmol(p+)/kg) Calcium	Magnesium	Potassium	Sodium	Per cent Base saturation
Pedon 1. Hill and upper ridges							
0-17	8	0.133	1.73	1.04	0.24	0.27	38
17-55	7.5	0.115	0.84	0.62	0.22	0.26	26
55-75	8.5	0.129	0.53	0.43	0.21	0.25	17
Pedon 2. Hill with elongated ridges							
0-13	8.5	0.147	2.04	1.13	0.26	0.24	51
13-33	7.8	0.12	1.26	0.59	0.21	0.29	38
33-52	9	0.141	1.64	1.48	0.15	0.28	39
52-77	10.5	0.154	2.41	1.6	0.18	0.3	43
Pedon 3. Residual hill with pediments							
0-12	8	0.129	2.2	1.17	0.32	0.29	49
12-36	7.2	0.12	1.69	0.86	0.21	0.2	44
36-77	7.8	0.111	2.04	1.14	0.14	0.19	39
Pedon 4. Residual hill with plateau							
0-14	15	0.3	5.08	1.5	0.45	0.25	48
14-30	8.9	0.178	2.47	1.05	0.38	0.26	49
30-57	10.5	0.219	1.75	1.45	0.26	0.26	35
Pedon 5. Undulated plain with hummocks							
0-16	9.7	0.139	2.98	3.23	0.35	0.35	71
16-34	10.2	0.161	1.08	0.71	0.18	0.23	22
34-91	14	0.231	1.34	0.74	0.21	0.23	18
91-130	10.1	0.157	1.07	0.6	0.15	0.28	21
Pedon 6. Intervening basin							
0-13	9.3	0.292	3.41	1.13	0.26	0.24	54
13-39	7.8	0.182	1.39	2.04	0.21	0.39	50
39-60	3.7	0.114	1.95	0.58	0.12	0.17	76
60-134	5.4	0.155	0.66	0.33	0.12	0.23	25
Pedon 7. Lower ridges/plain							
0-10	8.5	0.173	2.4	1.05	0.31	0.29	69
10-28	7.5	0.144	1.69	1.3	0.26	0.28	50
28-59	8	0.167	1.44	1.2	0.24	0.22	54
59-95	7.7	0.16	1.83	0.55	0.19	0.22	48
Pedon 8. Plain with valley							
0-13	9.5	0.164	4.47	1.43	0.31	0.22	72
13-28	9	0.18	2.19	2.44	0.36	0.34	59
28-44	8.2	0.152	1.33	1.59	0.23	0.28	42
44-87	8	0.151	1.36	1.33	0.17	0.27	39
87-163	7.2	0.117	1.36	0.79	0.16	0.27	36

a favourable edaphological property for rubber cultivation. The absence of hard pans coupled with deep soil especially in profiles of lowland provides adequate rooting volume for the tap root system of the rubber plant. In addition, these provide the soils with a great capacity to store moisture, a prerequisite for growth and survival of crops during the dry season (Eshett, 1987). Since the ability of soils to retain moisture also depends upon the amount of clay and silt present (Satisha *et al.*, 1998; Krishnakumar *et al.*, 2003). Presence of large amounts of clay in sub-soils, as obtained in the soils under study, reduces leaching and increases the amounts of nutrients stored, however, restricts water infiltration, impedes aeration and retards root penetration (Forth and Turk, 1972). Another important consideration is that as a result of the extremely fine texture of these soils and the friable to crumb conditions, the tiny pores are bound to become saturated with water during peak rainfall period, resulting in temporary soaking of the soil. This is not inimical to survival of rubber plants.

The ratio of silt to clay was slightly higher in the surface horizons of the pedons and decreased with depth. The lower ratios in the sub-surface horizons were probably caused by downward clay migration, which is commonly associated with ferruginous and ferrallitic soils of rainy tropical regions. The ratio of clay to clay + silt showed a slight increase from surface downwards in the illuvial horizons suggesting an increasing degree of weathering and clay translocation form the surface layers.

In general, the soils were strongly acidic. The pH of the soils ranged from 4.7 to 5.4 and showed a decreasing trend with depth in all the profiles. This indicates that these soils have developed on non-calcareous parent materials under conditions of high rainfall and good drainage. As a result, they were low in soluble salts, free of $CaCO_3$, throughout the profile depth (Table 4). A slightly higher pH in the surface horizons of the profile can be attributed to the recycling of bases by the canopy litter and cover crop.

The data (Table 4) indicate that the organic matter content of the soils were considerably high, particularly in the surface horizons, probably high leaf litter must have been a contributory factor. The soils of upper ridges contained relatively higher content of organic matter compared to those from lowlands and undulated plain/ valley. The presence of high levels of organic matter in the surface horizons of profiles is expected to act as a granulating agent by improving the hydraulic properties of the clay textured soils, possibly by making the soil more friable through promotion of crumb structure. Infiltration is consequently improved. The resultant more porous structure would also positively influence aeration. The leaf litter also forms mulch on the surface of the soil, which helps to regulate soil temperature, enhances microbial activity and reduces leaching, run-off and erosion. The litter is also of particular relevance in the nutrient re-cycling process, which is significant in soil fertility maintenance, especially under rubber monoculture. Total exchangeable bases ranged from low to moderate. Calcium was the dominant cation in the exchange complex and moderate to high in surface horizons. The CEC of a soil is of much consequence in the humid tropics and governs the nutrient dynamics and soil fertility to a great degree. The CEC of the soils was low, varied from 5.4 to 15.0 cmol (p+)/kg (Table 5). This suggests that they are subject to very rapid decline in fertility under intensive cultivation associated with plantation agriculture, demanding specific management measures to maintain soil fertility. Despite high clay content, CEC showed a decreasing trend with depth. High content of organic matter must have been a contributory factor for the high values of CEC in the surface horizons whereas low values in the sub-surface may be attributed to the pH-depended exchange sites occupied by either hydrogen ions or hydroxy aluminium ions at low pH (Patil and Dasog, 1997). Base saturation of the soils was low to moderate (17 to 76 %). The low percentage of base saturation, especially in the lower layers of the profiles may be due to the nature of the parent materials.

Conclusions

The study revealed that the soils were good in physical properties (soil-water-air relationship), thus advantageous for early establishment of the rubber trees. The soils contained higher amounts of clay fractions irrespective of geomorphic conditions. Presence of large amounts of clay in sub-soils, restricts water infiltration, impedes aeration and retards root penetration especially in soils of upper ridges. The presence of high levels of organic matter in the surface horizons of profiles is expected to act as a granulating agent by improving the hydraulic properties possibly by making the soil more friable through promotion of crumb structure and resulting porous structure would positively influence aeration. The CEC of the soils was low suggesting that they are subject to very rapid decline in fertility, thus demanding specific management measures to maintain soil fertility. Moreover, the presence of 1:1 layer silicate clays (kaolinite) and oxides of Fe and Al in the clay fraction may lead to poor release of nutrients through mineral weathering to meet the demands of rubber for rapid growth and high latex yield.

References

Bennama, J. 1963. Red and yellow soils of the tropical and sub-tropical uplands. *Soil Sci.* **95**: 250-257.

Bhattacharyya, T.,Sarkar, D., Gangopadhyay, S.K., Dubey, P.N., Baruah, U., Chamuah, G.S., Mukhopadhyay, S., Nayak, D.C., Maji, A.K., Saxena, R.K., Barthwal, A.K., Krishna, N.D.R., Mandal, C., Sehgal, J., Bhowmick, K.R., Sinha, K., Chakrabarty, R., Nandi Majumdar, S., Pal, P.K., Krishna Kumar, A.K. and Sethuraj, M.R. 1998a. Soils of Tripura. I. Characterisation and classification, *Agropedology* **8**: 47-54.

Bhattacharyya, T.,Sarkar, D., Gangopadhyay, S.K., Dubey, P.N., Baruah, U., Chamuah, G.S., Mukhopadhyay, S., Nayak, D.C., Maji, A.K., Saxena, R.K., Barthwal, A.K., Krishna, N.D.R., Mandal, C., Sehgal, J., Bhowmick, K.R., Sinha, K., Chakrabarty, R., Nandi Majumdar, S., Pal, P.K., Krishna Kumar, A.K. and Sethuraj, M.R. 1998b. Soils of Tripura. II. Suitability for Rubber, *Agropedology* **8**: 55-60.

Black, C.A. 1965. *Methods of Soil Analysis*, ASA, Monograph, Madison, Wisconsin, USA.

Eshett, E.T. 1987. The basaltic soils of south eastern Nigeria: Properties, classification and constraints of productivity. *J. Soil Sci.* **38**(4): 565-571.

Eshett, E.T. and Omueti, J.A.J. 1989. Potential for rubber (*Hevea brasiliensis*) cultivation on the basaltic soils of south-eastern Nigeria : Climatic, pedochemical and mineralogical considerations. *Indian J. Natural Rubber Res.* **2**(1) : 1-8.

Forth, H. D. and Turk, L.M. 1972. *Fundamentals of Soil Science*, 5th Ed. John Wiley & Sons Inc., New York, 454 p.

Kharche, V.K., Sehgal, J. and Challa, O. 1995. Evaluation of soil-site conditions of suitability of rubber. *Agropedology* **5**: 69-78.

Krishnakumar, A.K. 1989. *Soil under Hevea in India: A physical, chemical and mineralogical study with reference to soil moisture cation influence on yield of Hevea brasiliensis.* Ph.D Thesis, Indian Institute of Technology, Kharagpur, West Bengal, India.

Krishnakumar, A.K., Karthikakuttyamma, M., Datta, B., Potty, S.N., Mary, C.P., Thomas, M.J. and Augusthy, A. 2003. Soils under *Hevea* in Inidia: Physical, chemical and mineralogical investigations. *Indian J. Natural Rubber Res.* **16**(1&2): 1-20.

Patil, P.L. and Dasog, G.S. 1997. Low land soils of the western ghat region: I. Characterisation, genesis and classification. *Agropedology* **7**(2): 71-77.

Satisha, G.C., Pal, T.K., Dey, S.K. and Varghese, Y.A. 1998. Characteristics, genesis and classification of soils under *Hevea brasiliensis* in Mizoram, North-East India, *Indian J. Natural Rubber Res.* **11**(1&2): 38-45.

Satisha, G.C., Karthikakuttyamma, M., Pal, T.K., Dey, S.K. and Varghese, Y.A. 2002. Rubber growing soils of northern Mizoram - their characteristics, and limitations. *J. Indian Soc. Soil Sci.* **50** (4): 497-501.

Singh, R.A. 1989. *Soil Physical Analysis*, Kalyani Publishers, New Delhi.

Tripathy, J.K., Panigrahy, R.C. and Vinod Kumar, K. 1996. Geological and geomorphological studies of a part of Ganjam District, Orissa by remote sensing techniques. *J. Indian Soc. Remote Sensing* **24**: 169-177.

Yadav, J.S.P. 2002. Inaugural address. 67th Annual Convention. *J Indian Soci. Soil Sci.* **50**(4): 322-325.