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Systematic Soil Survey to Identify Potential Sodicity Areas in Parts of Tawa Command, Madhya Pradesh

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Abstract : Detailed soil survey was carried out in parts of Tawa Command area which lies in the flood plain of Narmada and Tawa rivers. The soils belong to Vertisols and associated shrink-swell soils. Properties of two soil series, *viz.* Rohana-1 (Rh1) and Rohana-2 (Rh2) are described; the former being cultivated and the latter uncultivated. Clay content of the two soils is comparable, through Rh1 soils have higher clay content. Infiltration rate is lower in Rh1 than in Rh2 soils. There is an increasing trend of Na, Mg/Ca ratio and ESP values with depth for Rh1, but usually insignificant for Rh2. Well water (W1) has higher values of pH, Na, Mg/Ca ratio, residual sodium carbonate (RSC) and SAR than canal irrigation water. It is thus envisaged that use of such ground water with lower EC and higher Na values (which is potentially sodic), may deteriorate the soil structure and decrease the infiltration rate by causing dispersion of clays. Moreover, systematic soil survey helped to identify and show that for shrink-swell deep black soils, irrigation even with slightly poor quality water may be hazardous for soil environment in the Tawa Command region. (***Key words** : Soil survey, Tawa Command, sodicity, Vertisols*)

Vertisols and associated shrink-swell soils occupy about 72.9 Mha (22.2% of the total geographic area) in India (Murthy *et al.* 1982). Soils of Tawa Command area in Hoshangabad district of Madhya Pradesh, falling mainly under the above category, lie in the flood plain of Narmada and Tawa rivers and are mainly drained by these rivers. Low values of hydrualic conductivity and infiltration rate, higher swelling and dispersing characteristics and inherent ionic environment limit water and oxygen supply to the root zone and cause ramification of roots (Naidu & Rengasamy 1995). This makes the management of these soils difficult. Moreover, being highly dispersive, these soils are prone to water erosion. The swelling and dispersive characteristics are accentuated by higher amounts of Na and Mg especially in the subsoil (Balpande *et al.* 1996). Further it is known that continuous use of poor quality irrigation water may be hazardous (Gupta & Abrol 1990). However, detailed soil survey which gives an idea about the extent of the sodicity problem is lacking (Abrol 1982). Therefore, an understanding of the causes of these factors in shrink-swell black soils through soil survey may be useful and enable one to arrive at feasible possible reclamatory measures to be undertaken.

Materials and Methods

Previous Soil Survey : As part of pre-irrigation survey, a detailed soil survey of Hoshangabad tehsil was undertaken by Government of Madhya Pradesh, in splits during 1970-77 under Tawa Command area (M.P. State Soil Survey Scheme 1977). Budhwara series (cultivated) identified by them

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covered the largest area and it may be correlated with present Rohana-1 series (Rh1). Budhwara series soils are very dark greyish brown (10 YR 3/2) to dark greyish brown (10 YR 4/2); clay texture and possess medium to coarse, clay, subangular blocky structure; and close to neutral pH in surface horizon. Colour of the subsurface horizons varies from very dark greyish brown (10 YR 3/2) to dark yellowish brown (10YR 4/4); silty clay, sandy clay to clay texture; moderate to strong, medium to coarse, subangular to angular blocky structure and pH from 7.1 to 7.5. Slickensides, $CaCO_3$, Fe and Mn nodules and concretions are present. Another report on soil resource mapping of Madhya Pradesh in 1:250,000 scale (Tamgadge *et al.* 1996) is available. However, owing to its small scale, information at detailed soil survey level could not be suitably accomplished.

Geology and parent material : Deccan trap basaltic basic rocks are the most dominant geological formations (Wadia 1989). However, sandstone may be found along fault zones forming the course of the Narmada river, and also scattered at few places, are exposed Gondwanas and Archaeans. Parent material is basaltic Narmada alluvium of the Pleistocene and soils formed therefrom are shrink-swell black soils or Vertisols and associated soils.

Climate and vegetation : Climate of the region seems to be gradually shifting towards slightly drier side since 1961. Data from 1961-73 show that the average annual rainfall was about 1290 mm and that from 1974-94 was about 1100 mm. The average annual maximum and minimum temperatures (1974-94) are 31.6° and 18.7°C, respectively. Climatic classification is "dry subhumid, large seasonal water surplus, megathermal, summer concentric type", based on 20 years meterological data. The length of growing period was calculated by FAO method to be 169 days.

Natural vegetation includes *babul* (*Acacia arabica*), *palas* (*Butea frondosa*), *tamarind* (*Tamarindus indica*), *bargad* (*Ficus bengelena*), *ber* (*Ziziphus zuzuba*), *neem* (*Tamarindus indica*), *kher* (*Acacia fernaciana*), *doob* (*Cynodon dactylon*), *kans* (*Saccharum spontaneum*), etc. Present land use includes mainly *kharif* soybean and *rabi* wheat and gram.

Classification : Rh1 series soils (cultivated) belong to very fine, montmorillonitic, hyperthermic, calcareous, family of Typic Haplusterts correlated from 20 soil profiles at various sites and Rh2 series soils (uncultivated) belong to fine, montmorillonitic, hyperthermic, Typic Haplusterts correlated from 5 soil profiles at various sites. Unlike Rh1 series soils, Rh2 series soils have almost negligible presence of $CaCO_3$ and hence the two series were keyed out based on $CaCO_3$.

Infiltration study and analytical methods : Infiltration study was done in soils of both the series using double ring cylinder infiltrometer method. The pH and EC were determined in 1:2.5 soil-water suspension. Particle-size fractions were estimated by hydrometer method. CEC was determined in 1*N* NH_4OAc at pH 7.0, exchangeable Ca^{2+} and Mg^{2+} by KCl-triethanolamine method followed by titration with EDTA and exchangeable Na^+ and K^+ in 1 *N* NH_4OAc extract at pH 7.0 on flame photometer. Organic carbon was determined by Walkley and Black (1934) method and $CaCO_3$ equivalent by acid neutralisation method (Black 1965). Two irrigation water samples, *viz.* well water (W1) and canal water (W2) were analysed for Ca^{2+}, Mg^{2+}, Na^+ and K^+ by the above procedures. The carbonate and HCO_3^- were analysed by titration with H_2SO_4 using phenolphthalein and methyl orange as indicators and Cl^- was analysed by silver nitrate titration using potassium chromate as indicator (Vogel 1978, modified by Sharma *et al.* 1987).

Results and Discussion

Particle-size distribution : Particle-size characteristics show relatively greater uniformity in Rh1 than in Rh2 series as shown by sand/silt ratios (Table 1). The surface horizon (A1) of Rh2 has more silt than the underlying horizons. This may be due to the fact that being uncultivated and adjacent to major drainage channels, the soils are flooded seasonally with sediment-loaded water. This is reflected in sand/silt ratios with a characteristics change from A1 (0.10) to Bw1 (0.31) horizon in case of Rh2. With the exception of this, the amount of silt remains uniform and its value is in general, quite

Table 1. Some physical properties of the two soil series

Horizon	Depth (Cm)	Sand	Silt (%)	Clay	Sand/ silt ratio	Water retention (%) -33 kPa	Water retention (%) -1500 kPa	-1500 kPa/ clay ratio	Available water (%)
				Rohana 1 series (Rh1)					
Ap	0-15	9.4	32.6	58.0	0.29	34.4	20.9	0.36	13.5
Bw1	15-38	5.6	31.9	62.5	0.18	28.3	19.9	0.32	8.4
Bw2	38-64	7.0	28.5	64.5	0.25	30.7	22.3	0.35	8.4
Bss1	64-115	10.7	24.3	65.0	0.44	31.4	23.3	0.36	8.1
Bss2	115-151	10.3	24.7	65.0	0.42	34.4	23.3	0.36	11.1
				Rohana 2 series (Rh2)					
A1	0-16	4.0	55.5	0.10	31.3	17.8	0.32	13.5	
Bw1	16-45	9.8	31.7	58.5	0.31	28.2	14.5	0.25	13.7
Bw2	45-70	6.9	33.1	60.0	0.21	26.5	14.4	0.24	12.1
Bss1	70-112	11.2	28.3	60.5	0.40	26.4	14.0	0.23	12.4
Bss2	112-151	27.9	59.5	0.45	26.7	14.0	0.24	12.7	

high indicating that the parent material may be calcareous in nature and alluvium in origin. Sand is relatively higher in some subsurface horizons of Rh1 than in Rh2 and the amount of sand has little consequence in the pedological development of these soils. Clay is slightly higher in Rh1 than in Rh2 and this is reflected in all properties associated with it.

Water retention characteristics: Water retention characteristics at -1500 kPa (15 bar suction) do not show much significance and follow a slightly increasing trend down the profile in case of Rh1, but not in Rh2 (Table 1). However, there are some increasing trends down the profile for water retention at -33 kPa (1/3 bar suction) which may be due to the little increase in sodium concentration in the same order (Table 2). This is because at low electrolyte concentration (as in this case), Na-smectite systems (these soils are smectitic as shown by CEC/clay ratio, Table 2) have more than twice shrink-swell potential than Ca-and Mg-smectites up to a pressure of about-1000 kPa (Wilding & Tessier 1988). However, above -1000 kPa (10 bar suction), Ca and Mg smectites and

Table 2. Some chemical characteristics of the two soil series

Depth (cm)	pH 1:2.5	EC (dS m^{-1}) 1:2.5	O.C. g kg^{-1}	CaCO$_3$ equv. g kg^{-1}	Exchangeable cations Ca^{2+} cmol (p$^+$) kg^{-1}	Mg^{2+}	Na$^+$	K$^+$	CEC	Base satn. (%)	ESP	CEC/ clay ratio	Ma/Ca ratio
					Rohana 1 series (Rh1)								
0-15	8.1	0.44	7.3	75.9	30.6	13.6	0.28	0.55	45.4	99.2	0.62	0.78	0.44
15-38	8.2	0.41	6.0	64.5	35.4	8.0	0.26	0.42	46.1	95.6	0.56	0.74	0.23
38-64	8.4	0.50	4.4	92.5	32.0	10.4	0.30	0.43	44.5	96.9	0.67	0.69	0.33
64-115	8.5	0.52	3.3	151.9	27.0	10.6	0.35	0.44	38.4	100.0	0.91	0.59	0.39
115-151	8.5	0.69	3.1	130.7	24.2	13.0	0.45	0.46	38.6	98.7	1.17	0.78	0.54
					Rohana 2 series (Rh2)								
0-16	7.1	0.41	15.0	N	23.8	8.1	0.22	0.34	33.4	97.2	0.66	0.34	
16-45	7.5	0.36	7.1	N	25.8	7.0	0.18	0.35	33.3	100.0	0.54	0.57	0.27
45-70	7.2	0.48	5.8	N	26.2	6.0	0.20	0.35	32.9	99.5	0.61	0.53	0.23
70-112	7.3	0.33	5.4	N	25.2	4.4	0.17	0.31	30.7	98.0	0.55	0.51	0.17
112-151	7.5	0.63	4.5	N	25.4	6.2	0.24	0.29	32.2	99.8	0.75	0.54	0.24

N-negligible

high electrolyte Na-smectites behave similarly and retain more interlayer water than low electrolyte Na-smectites. Though exchangeable Na$^+$ concentration is very low (0.17 to 0.47 cmol (p$^+$) kg^{-1}; Table 2), the increasing trend down the profiles shows that there may be slight contribution of Na$^+$ towards water retention. Thus, the ratio of -1500 kPa/clay values shown in table 1 are expectedly higher for cultivated Rh1 soils, whereas, the values are relatively lower for uncultivated Rh2 soils.

Infiltration characteristics: The nature of infiltration curves (Fig. 1) for Rh1 and Rh2 in general, shows similarity in permeability behaviour. The infiltration rate for Rh1 soils ranges from 0.7 to 0.9 mm h^{-1} and that for Rh2 is 1.1 to 1.4 mm h^{-1} which may suggest that Rh1 soils exhibited greater swelling characteristics than the Rh2 soils. The quantities of clay, CEC/clay ratio and Na$^+$ are slightly higher in Rh1 and this may have been reflected by a decrease in infiltration rates. Higher CEC/clay ratios in Rh1 owing to higher smectite content (Smith 1986) together with increasing Na$^+$ concentration at depths below 150 cm, may have decreased the infiltration rate for Rh1 series soils. This is because smectitic clays are more prone to dispersion than other clays (Frenkel *et al.* 1978) and thus reduces infiltration.

Reaction: Soil pH shows that Rh1 soils are moderately to strongly alkaline, whereas Rh2 soils are almost neutral as the latter being uncultivated is not irrigated, thereby showing that some form of irrigation water or perched water table may be responsible for pH rise. Electrical Conductivity values are very low and not of much consequence except for aggravating the effect of sodium. The CaCO$_3$ equivalent in Rh1 varies from 64.5 to 151.9 g kg^{-1}, whereas in Rh2 it is almost negligible, which is also reflected by the pH values. This may be due to relatively greater leaching conditions in Rh2 because of flooding. Visual observations for treatment with dilute HCl showed strong effervescene for Rh1 and no effervescence for Rh2. Pedological formations of iron and manganese concretions (which do not dissolve completely in 0.5 *N* HCl) are observed in all profiles, suggesting that the soils have formed after long periods of drying and wetting conditions. Organic carbon has a decreasing trend down the profile and the values are more or less comparable in both the soils except for the surface horizon of Rh2 (15 g kg^{-1}) which may be due to uncultivated grassland vegetation.

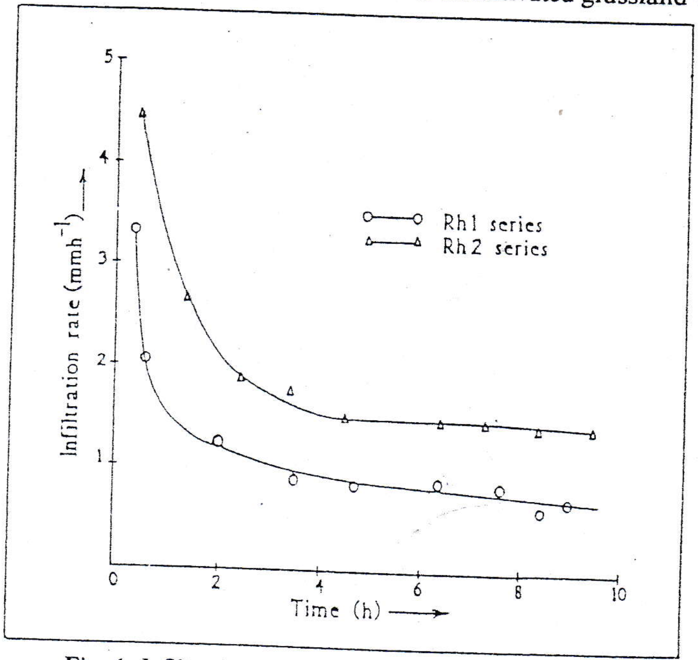

Fig. 1. Infiltration rate curves of the two soil series

Exchange characteristics : With increasing depth, exchangeable Ca^{2+} and Mg^{2+} values have antagonistic trends as the former decreases and the latter increases in the same order with some exceptions (Table 2). Sodium ion increases and K^+ decreases with increasing depth. The sum of (Ca^{2+} + Mg^{2+}) is greater in Rh1 than in Rh2. Exchangeable Na^+ and K^+ are not of much consequence as their values are very low compared to those of Ca^{2+} and Mg^{2+} and this is reflected by ESP values which are less than 1.2.

Irrigation water quality : Two types of irrigation namely, well (W1) and canal (W2) are used in the region. Data on irrigation water quality (Table 3) show that W1 has higher pH, Mg^{2+}, Na^+ and carbonates than W2, resulting in a higher SAR in W1 [1.80 $(mmol_cL^{-1})^{1/2}$] than in W2 [0.29 $(mmol_cL^{-1})^{1/2}$]. Further Mg/Ca and $Na^+/(Cl^- + SO_4^{2-})$ ratios for W1 (8.83 and 2.92) are much higher than W2 (0.31 and 0.27), respectively, indicating that continuous use of well water for irrigation may render the top soil layers with more exchangeable Mg and Na and larger Mg/Ca ratio (8.83) thus promoting dispersion of clays on one hand and causing sodicity hazards on the other (McNeal *et al.* 1966a; Arora & Coleman 1979; Gupta *et al.* 1984; Sumner 1995). Increase in Na^+ in the system decreases infiltration rate (Rengasamy & Olsson 1991) due to increased dispersion and thus affects crop growth. Well irrigation water with low EC (0.7 dS m^{-1}) and high Na^+ (3.10 $mmol_cL^{-1}$) may therefore be the cause of increased dispersion in these soils. However, canal water (W2) despite having high pH (8.7), apparently does not seem to be deleterious with respect to dispersion and sodicity hazards. Residual sodium carbonate (RSC) defined as RSC = (HCO_3^- + CO_3^{2-}) - (Ca^{2+} + Mg^{2+}) by Eaton (1950) is also considered as a means to assess irrigation water quality and its value above 2.50 is considered potentially hazardous, whereas values less than 1.25 are usually safe. Considering this range, W1 is potentially hazardous, whereas W2 is safe for use as irrigation water.

Table 3. Characteristics of irrigation water used in the area

Sl. No.	pH	EC (dS m^{-1})	Ca^{2+}	Mg^{2+}	Na^+	K^+	CO_3^{2-}	HCO_3^-	Cl^-	SO_4^{2-}	SAR [$(mmol_cL^{-1})^{1/2}$]	Mg^{2+}/Ca^{2+}	$Na^+/(Cl^-+SO_4^{2-})$
			$mmol_cL^{-1}$										
					Well water (Deep tube well)								
W1	9.2	0.70	0.60	5.30	3.10	0.01	2.12	5.83	0.50	0.56	1.80	8.83	2.92
					Canal water (Tawa Command)								
W2	8.2	0.20	2.90	0.90	0.29	0.05	–	3.05	0.50	0.59	0.21	0.31	0.27

Source of sodium : The literature for the source of sodium in these soils is very scanty, though precipitating from basalt rock parent material seems to be more logical. Albite ($NaAlSi_3O_8$), aegirine of commonly acmite ($NaFeSi_2O_6$) -sodium equative of diopside, and analcite ($NaAlSi_2O_6.H_2O$) - one of the zeolites may be the major sodium enriching minerals (Wadia 1989). Subsequent to weathering and deposition of soil material by various streams, sodium may have been leached to lower layers and thereby, also increasing its concentration in ground water.

Soil survey information : This soil survey was aimed at identifying and demarcating problems and potentials of soils of the area. Morphological features such as colour, structure, consistency, etc were initial indicators in identifying problems in Vertisols. In soils of Rh1 series, at depth below 1 m, the structures were angular blocky with weak columnar features, followed by 'firm' consistency (wet) of soil, indicating the possibility of the presence of higher amount of Na^+. However, supporting laboratory data (Tables 2 & 3) showed the initiation of sodicity development in soils of Tawa Command area. From the meagre available data of previous soil survey carried out in 1977, some contrasting morphological as well as physical and chemical properties were evident compared to present day survey, *e.g.* pH of the cultivated soils changed from 7.5 to 8.4, suggesting that other properties related to pH may have also been altered. Well water of poor quality (Table 3) was used to cater the needs of changing crop scenario of the region which indicated slight development of sodicity as evidenced by higher pH and ESP in Rh1 soils than in Rh2 soils (uncultivated). Moreover, irrigation by various canals and minors of Tawa Command may have raised the overall ground water level.

It can be concluded that the high clay content of Vertisols in Tawa Command area along with subsoil sodicity affected infiltration and downward movement of water due to dispersion. In low electrolyte concentration, small quantity of exchangeable sodium may cause sodicity hazards by affecting the soil structure and associated properties. Irrigation with water of low EC and reasonable amount of Na^+ may be more hazardous, especially for soils with high shrink-swell potential than irrigation with water of low EC and low Na^+. Canal irrigation water was found to be suitable, whereas groundwater from well was found to be potentially hazardous for irrigation on long-term basis.

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