Genesis, Characteristics and Classification of Sodic Vertisols in India

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Introduction

Vertisols is one of the important soil orders in the Soil Taxonomy. Vertisols are churning heavy clay soils with a high proportion of swelling clays. These soils form deep wide cracks from the surface downward when they dry out, which happens in most years. These soils have a vertic horizon within 100 cm from the soil surface; possess 30 per cent or more clay in all horizons to a depth of 100 cm or more and possess cracks which open periodically.

Vertisols are dark montmorillonite-rich clays with characteristic shrinking/swelling properties. A few, however, have mixed or even kaolinitic mineralogy. Soils with smectitic mineralogy, unlike other soils, show high swell-shrink potential resulting in different morphometric configuration in profiles. Since the phenomenon is concomitant to the volume changes of the soil mass with the changes in soil moisture content, these soils impose a distinct problem in their management. As a result of wetting and drying, expansion and contraction of the clay minerals take place. Contraction leads to the formation of the wide and deep cracks. The cracks close after rain when the clay minerals swell. During expansion of the clay minerals high pressures are developed within these soils, causing a characteristic soil structure with wedge-shaped aggregates in the surface soil and planar soil blocks in the subsoil.

Shrinking-swelling (SS) is the main pedogenic process in Vertisols responsible for their genesis, behavior and properties. Repeated SS impacts the vertical and lateral (spatial) distribution of all physical and chemical properties including soil organic matter (SOM). SS is responsible for the formation of deep and large cracks, vertical sequence of structures (from granular through massive to wedge-shaped), slickensides, microrelief, and complex soil cover in Vertisols areas including subsurface cycling. All these attributes together determine the specificity of SOM properties and distribution in Vertisols.

The Vertisols make up a relatively homogeneous order in a morphologic sense. Nevertheless, variations in moisture regimes and in the related soil colours are wide. There are also differences in base saturation, percentage of carbonates and depth to a lithic or parallithic contact. The term "swell-shrink soils" is used for describing such soils which have characteristics of shrinking when dry and swelling when wet. The swell-shrink properties of these soils pose special problems for their management and optimum utilization. On sodification, these soils are coined as kharland or black alkali soils and taxonomically coined as Sodic Vertisols.

Extent and Distribution

Vertisols cover a total of about 340 Mha in the world. Most Vertisols occur in the semiarid tropics, mainly in Africa (the Gezira and other part of central Sudan, South Africa, Ethiopia and Tanzania), Asia (the Deccan plateau of India), America (mostly in USA, Venezuela and Argentina), and Australia. Vertisols and associated black soils occur in Peninsular India between 8°45′ to 26° N latitude and 66° and 83° 45′ E longitude and occupy about 76.4 million ha area (Murthy *et al*, 1982) which is 23.2% of the total geographical area of the country (Table 1).

Table 1. Distribution of Vertisols and associated black soils in India

Sr. No.	State	Area (Mha)	Per cent of total black soil area of the country	Per cent of total geographical area of country
1	Maharashtra	29.9	39.1	9.1
2	Madhya Pradesh	16.7	22.0	5.0
3	Gujarat	8.2	10.7	2.5
4	Andhra Pradesh	7.2	9.4	2.2
5	Karnataka	6.9	9.0	2.1
6	Tamil Nadu	3.2	4.2	1.0
7	Rajasthan	2.3	3.0	0.7
8	Orissa	1.3	1.7	0.4
9	Bihar	0.7	0.9	0.2
Total		76.4	100.0	23.2

(Source: Murthy *et al*, 1982)

These swell-shrink soils are distributed mainly in the states of Maharashtra, Madhya Pradesh, Gujarat, Andhra Pradesh, Karnataka, Tamil Nadu, Rajasthan and to some extent in Orissa and Bihar. These soils are cultivated mainly with sorghum, pearl millet, cotton, pigeon pea, groundnut, chick pea, and at places with wheat and soybean under rain fed conditions. Major area under these soils is cultivated with kharif (July-September) crops while some area receiving winter rains (October-December) is cultivated with rabi crops. Rice and sugarcane cropping is also practiced where irrigation facility is available. The yields of crops grown on these soils under the *rainfed* condition are comparatively low but there is a great potential to increase the same. One of the reasons of low agricultural productivity in the black soils region is the unreliability of rainfall. Whenever irrigation is provided, cultivators have reaped rich harvest but in long run problems of salinity and sodicity do crop up and these soils have become saline and/or sodic. The problem of water stagnation and moisture stress are common features of the Vertisols of the semi-arid regions which further intensify on sodification. Thus, crop suffers badly due to oxygen stress in the initial stage and moisture stress after the termination of monsoon or delay in irrigation.

Mapping of salt affected soils of India by the NRSA and Associates, (1996) indicated occurrence of about 3.77 m ha of sodic soils in India, out of which about 1.77 m ha represents the sodic nature among the irrigated/unirrigated black soil region (Vertisols) occurring in Gujarat, Madhya Pradesh, Maharashtra, Andhra Pradesh, Karnataka, Rajasthanand Tamil Nadu States.

In south Gujarat (Bharuch, Surat, Valsad and Navsari districts) sodic soils occupy about 55000 ha area. Typical soil profile characteristics of sodic Vertisols from Bharuch district is given in tables 2. In Ukai-Kakrapar command area about 40% of soils are affected by sodicity problem (Patel *et al*, 2000). Paddy and sugarcane are the prominent crops in this command area due to availability of perennial irrigation facility and productivity of these crops is declining due to salinity/sodicity and waterlogging problems (Rana and Raman, 1999).

Table 2. Properties of Sodic Haplusterts at village Sadathala, District- Bharuch (Gujarat)

Horizon	Depth (m)	Sand (%)	Silt (%)	Clay (%)	WHC (%)	CEC (cmol/kg)	ESP	$CaCO_3$ (%)	O.C. (%)
Ap	0.00-0.21	13.3	17.4	69.3	58.1	49.5	19.0	9.9	0.35
Bw1n	0.21-0.53	10.0	18.0	72.0	69.2	50.3	30.2	9.7	0.39
Bss1n	0.53-0.96	7.4	16.8	75.8	72.1	44.0	26.2	11.3	0.41
Bss2n	0.96-1.32	9.0	15.0	76.0	83.2	35.5	26.5	13.1	0.39
BC	1.32-1.70	15.0	25.0	60.0	70.0	46.6	29.4	19.8	0.43

Depth (m)	pH	ECe (dS/m)	Extractable cations (meq/l)				Extractable anions (meq/l)			SAR $(meq/l)^{1/2}$
			Ca	Mg	Na	K	Cl	CO_3+HCO_3	SO_4	
0.00-0.21	9.1	1.6	4.0	2.7	8.6	0.1	10.0	2.0	3.2	4.7
0.21-0.53	9.1	1.9	4.0	2.3	8.7	0.1	13.0	2.0	1.0	4.9
0.53-0.96	8.5	4.1	3.0	3.3	30.4	0.1	31.0	2.0	3.0	17.1
0.96-1.32	8.4	10.9	7.0	6.5	76.1	0.4	75.0	2.5	13.0	26.0
1.32-1.70	8.5	11.6	10.0	7.1	152.0	0.2	156.0	1.5	11.5	58.6

Soil Formation/Genesis

The soil forming factors i.e. parent material, climate, topography, vegetation and time, established by Docuchaev are still the best element to comprehend the formation of Vertisols. These soil forming factors are interdependent and highly variable. They influence the property of Vertisols in many ways. The difference in the intensity of processes as conditioned by each of these factors within and among the regions is responsible for the global diversity in Vertisols. Each of the factors among them is described with the focus on the responsible for inducing sodicity in Vertisols.

Parent Material: The parent materials must provide, from inheritance of weathering, a high content of clay with high surface area and generally a high base status. The distinction between inherited and neo-formed clay minerals is still speculative, especially in the case of sedimentary deposits. A high base status favours formation and stability of clay minerals abundant in Vertisols. However, the base status may be relatively low in certain types of parent materials. With time the base status may increase due to release of bases from weathering and /or from external source e.g. leaching from upland, flood waters, base rich water tables or aeolian deposits. Weathering of sodium feldspar and/or base rich water tables are the causes for the development of Sodic Vertisols in India.

Climate: The pedo-climatic environment supporting Vertisols vary from the semi-arid to the sub-humid tropic in India. Such climates are characterised by hot and dry pre-monsoon summer months (March to May) followed by well expressed summer monsoon months (June to September). The subsequent short period of October and November receives uncertain and infrequent shower followed by fairly dry mild winter (December to February). The mean annual (air) temperature (MAT) ranges from 24 to 27°C. The mean summer (April, May & June) and mean winter (December, January & February) temperature vary respectively from 30 to 33°C and from 15 to 22°C. The mean annual rainfall ranges from 500 to 1500 mm, of which 80 to 90 per cent is received during monsoon months. It represents 42 to 77 per cent of mean annual potential evapotranspiration (PET). The soil moisture control section (SMCS) remains dry either completely or in part for 4 to 8 months in a year, suggesting an ustic moisture regime. Periodicity, duration, intensity of rainfall events or other hydrological events such as runoff, surface run-in, and fluctuation of groundwater table or flooding may influence Vertisols formations. Surface run-in, fluctuation of base rich groundwater and flooding are the factors inducing sodicity in Vertisols.

Topography: Vertisols occur normally on the lower elements of the topography, comprising gently undulating, gently sloping to nearly level piedmont, flood and coastal plains and favours the accumulation of silica, thus promoting the formation of chemical equilibrium of smectites. Such soils likely have a high CEC and smectitic mineralogy. The associated Vertic intergrades are observed normally on relatively higher elements of the topography, comprising gently sloping to moderately steep subdued plateau, mesa and pediment surfaces. Micro-topography may also cause for formation of sodic Vertisols by modifying distribution of water across the landscape.

Genesis of Sodic Vertisols

It is discussed in the light of Sodic Vertisols formed at Purna valley in Central India (Pal, 2004). The chemical degradation of the soils of the Purna Valley in terms of increase in ESP and/or EMP (exchangeable magnesium percentage) with depth has adversely affected the hydraulic and other properties important for crop growth. The general increase of both COLE (coefficient of linear extensibility) and WDC (water dispersible clay) and the decrease of HC (saturated hydraulic conductivity) with depth suggest that the swelling of clay smectite, together with dispersion of the clay, have adversely affected the hydraulic properties of these soils. The observed correlation between WDC and EMP indicates that saturation of these soils, not only with Na^+ ions but also with Mg^{2+} ions leads to greater dispersion of the clay, which is the opposite effect from that of saturation with Ca^{2+} ions, which leads to the blocking of small pores in the soil. Recent work by Kadu *et al*. (1993) clearly shows that an HC of 1.0 mm h^{-1} represents the lower limit for a satisfactory physical condition in these highly smectitic soils in which magnesium behaves negatively.

The absence of carbonate ions in the saturation extract suggests that during high evaporative demands for soil-water in the semi-arid climatic conditions, maintenance of a proper Ca/Mg ratio in the soil solution becomes difficult because Ca^{2+} ions get precipitated as $CaCO_3$ resulting in an increase in the SAR of the soil solution and the ESP of the soil. Although the correlation between carbonate clay and SAR was not significant, the HCO_3/Ca ratio of the saturation extract has a significant positive correlation with SAR (r = 0.57 at the 1%) (Balpande *et al.*, 1996). This suggests that if this ratio increases, then SAR will also increase and as will the ESP. The mean monthly temperature is higher in the western region throughout the year by 0.2-1.1^{o}C. Akola receives less rainfall than Amravati in almost all months, with the total annual rainfall being 100 mm less at Akola. This indicates that the Akola region is more arid than Amravati, and this appears to be most important factor in the development of sodicity in soils in the southwestern part of the valley.

Vertisols - Processes

Vertisols form under multiple genetic pathways which are complex. In general, soil forming processes that lead to the formation of Vertisols are those which control the formation and stability of smectites in the soil. However, subsidiary processes, such as fluctuations in the moisture status, accumulation of organic matter, carbonates, gypsum or soluble salts and acidification processes through leaching, result in the differences within the Vertisols.

The development of Vertisols requires conditions that ensure the formation and preservation of smectites. These clay minerals may form either in situ through the weathering and development of a solum (autochtonous Vertisols) or from a sediment which is composed of materials that can produce vertic properties (allochtonous Vertisols). The latter is geographically more extensive and occupies the lower parts of the landscape. The development of smectitic clays is favored by a high pH with sufficient Ca^{2+} and Mg^{2+} in the soil system. The presence of a relatively impermeable layer at some depth within the soil prevents the leaching of the various components needed to form smectites.

Shrinking and swelling cause shearing and consequently the formation of slickensides. This process is attributed to smectitic clays and alternations in dry and wet seasons. As a result of this process, Vertisols develop deep and wide cracks in a polygonal pattern.

Pedoturbation (churning) is a process which homogenizes the soil profile due to the infilling of the cracks by surficial material during dry season. The process in Vertisols is also called self-mulching or self-swallowing.

During the drying cycles, cracks develop, whereas on moistening, shear stresses form which result in the formation of slickensides and/or smoothened surface of sphenoids. Both features require the material to be in a plastic state. The lateral pressures developed in these soils are much greater than the vertical swelling pressures. Within the soil, the vertical component of the swelling pressures includes the weight of the overlying material. The moisture conditions above and below a point within the soil determines the net pressure and angle of shear. As such, the near surface horizon develops cracks and may have only a few slickensides since both the horizontal and vertical pressures are small (the net pressure being much lower than the sheat strength of the material). In deeper horizons, typically from 50 to about 125 cm below the surface, slickensides development is maximum. In these deeper layers, the net pressure is much greater than the shear strength of the material and soil movement occurs with swelling. Sphenoids develop as a result of the existence of much lower vertical and horizontal pressures in comparison to that needed for the development of slickensides. In the typical case, sphenoids would be found in between the surface horizon with cracks and deeper horizons with slickensides. Their development has been related to lower clay contents, as well as smaller proportions of smectitic clays in the colloidal fractions.

Clay translocation is not phenomenal in Vertisols, nevertheless, the presence of smectitic clays has all the conditions necessary for dispersion, translocation, and accumulation in subsurface horizons in Vertisols. In some Vertisols there is some evidence of illuviated clays in the lower soil profile, which is subjected to the least amount of pedoturbation. This process tends to obliterate all evidence of the illuviation process and it is unlikely that well-defined clay skins will be preserved, instead any translocated clay is probably engulfed in the matrix and/or slickensides as a result of shrink-swell processes.

Pedogenic Models for the Formation of Vertisols

(I) Pedoturbation Model (Self-Swallowing Model)

Pre-requisite for the formation of Vertisols is the presence of expanding clays (smectites). After clay formation shrink-swell processes begin to operate. During the dry season the soil cracks. While the cracks are open, surface soil material falls into them due to wind, animal acitivity, or water erosion. On rewetting the clays hydrate and expand. As expansion takes place, the cracks close, but because of the 'additional' material now present in the lower parts of the profile, a greater volume is required and the expanding material presses and slides the aggregates against each other developing slickensides.

(II) Soil Mechanistic Model

This model is based on the failure along shear planes (slickensides) of plastic soil material when swelling pressures generated by hydration of clays exceed the shear strength of the soil material. Stress is relieved by an upward movement that is constrained by the weight of the overlying soil material, resulting in a failure shear plane that is usually inclined at 10 - 60° above the horizontal. This model does not require that surface material falls into cracks. Instead, surface material is transported upward along the slickensides to produce the microknolls of the gilgai-relief. Once microrelief is established, soil processes are driven largely by small-scale variations in hydrology and microclimate, and less so by pedoturbation.

Characteristics of Vertisols

Dry Vertisols have a very hard consistence; wet Vertisols are (very) plastic and sticky. It is generally true that Vertisols are friable only over a narrow moisture range but their physical properties are greatly influenced by soluble salts and/or adsorbed sodium.

Infiltration of water in dry Vertisols with surface mulch or fine tilth is initially rapid. However, once the surface soil is thoroughly wetted and cracks have closed, the rate of water infiltration becomes almost nil. If, at this stage, the rains continue (or irrigation is prolonged), Vertisols flood readily. The highest infiltration rates are measured on Vertisols that have a considerable shrink/swell capacity, but maintain a relatively fine class of structure. Vertisols, by and large, are soils with good water holding properties. However, a large proportion of all water held between the basic crystal units; is not available to plants.

These soils (Vertisols and associated soils) are heavy textured soils and have clay content varying from 40 to 70%. These soils are low in organic carbon content and are generally calcareous in nature. When these soils are irrigated, the high seepage leads to a shallow water table build-up causing secondary salinisation or sodiumisation.

Most Vertisols have a high cation exchange capacity (CEC) and a high base saturation percentage (BS). pH values are in the range of 6.0 to 8.0. Higher pH values (8.0-9.5) are seen in Vertisols with high ESP. Salinity in Vertisols may be inherited from the parent materials or may be caused by over-irrigation. Leaching of excess salts is hardly possible. It is possible to flush salts that have precipitated on the wall of cracks. Surface leaching of salts from the paddy fields in India was achieved by evacuating the standing water at regular intervals.

The electrolyte concentration, exchangeable sodium per cent and 2:1 swelling clay are important parameters governing the swell-shrink behaviour of saline Vertisols. In the soils with dominantly smectitic clay mineralogy, the increase in 2:1 swelling clay, pH and ESP increase the swelling potential where as the increase electrolyte concentration of the soil solution decreases the swelling potential.

Saline Vertisols

Saline soils contains excess neutral soluble salts like chlorides and sulphate of sodium, calcium and magnesium with ECe > 4 dS m^{-1}, pH <8.2 and ESP <15. Saline black soils due to its inherent physico-chemical properties, high clay content, low hydraulic conductivity and narrow working moisture range are very difficult to manage. Osmotic effect of salt, toxic concentration of soluble ions like Na, Cl, B and reduced availability of essential nutrients due to competitive uptake affect plant growth in this type of soil. Excess salinity in these black soils results into delay germination, poor crop stand, stunted growth and reduced yield.

Sodic Vertisols

The distinguishing characteristics of sodic soils are high exchangeable sodium percent, electrical conductivity (ECe) less than 4 dS m^{-1}, pH more than 8.2 and presence of higher amount of carbonate and bicarbonates of sodium. Some sodic soils are also termed as saline sodic as they contain large quantity of soluble salts and ECe is more than 4 dS m^{-1}. In sodic soils the dominant cation on the exchange complex is sodium which disperses clay and imparts adverse soil physical conditions such as low permeability, crusting and hardening of the surface soils upon drying. Dense, slowly permeable sodic sub-soils reduce supplies of water, oxygen and nutrients necessary to obtain optimum yield (Rengasamy and Olsson, 1991). Besides, high Na content is often toxic to many plants, which exhibit poor growth and yield in these types of soils.

Sodic Vertisols are characterized by high pH (>8.2), high exchangeable sodium, high $CaCO_3$, very low organic matter content, poor physical conditions. The critical values of ESP depend on the electrolyte concentration of soil solution and range from 5 to 15 (Shainberg, 1984). Loveday and Pyle, (1973) working on a range of soil types from two regions of Australia reported that the differences in critical ESP are due to the differences in EC of the soil solution. They put forward a critical value of ESP 8 and above which the surface soils are found to disperse. Northcote and Skene, (1972) suggested that above ESP 6, the soils begin to disperse. Kadu et al, (1993) reported that drainage in these soils gets completely impaired due to higher dispersion of clay even at an ESP of 5. Robinson, (1971) working on Vertisols of Sudan reported highest cotton yields were associated with ESP of 8-16. The hydraulic conductivity of the sodic soils is affected by the initial swelling followed by clay dispersion (Gupta and Verma, 1984; 1985). Swelling reduces the pore size and dispersion clogs the soil pores. The sodicity increases the bulk density, which limit the root perforation. The plant cannot take up all of the water remaining in the root zone as rapidly as needed because it is held too tightly by the soil particles. Even at sufficient moisture content, the survival of crops in such soil is very difficult in the absence of sub-soil contribution due to low hydraulic conductivity and diffusivity. The hydraulic conductivity is an important property affected by the salinity and sodicity and can serve as the basis for classification for the degree of degradation. Chaudhari, (2001) reported that an increase of EC from 0.5 to 5 dS m^{-1} resulted in more than threefold increase in the hydraulic conductivity irrespective of SAR. A threshold electrolyte concentration (TEC) in the soil solution is necessary for flocculation. Nayak *et al*, (2004) reported that at electrolyte concentration (EC) < 2 dS m^{-1}, Vertisols can be grouped as sodic if the ESP is > 6 and > 10 in clayey and silty clay soils respectively and at EC of < 4 dS m^{-1}, Vertisols can be grouped as sodic if the ESP is >13 and >21 in clayey and silty clay soils respectively.

Available water capacity is greatly retarded in sodic Vertisols. Surface waterlogging gives rise to high rates of evaporation and rapid drying of the surface soil and can result in the development of hard setting or surface crusting to an extent depending on the soil texture.

Vertisols - Classification

The requirements to qualify for a Vertisol are the following:

- Clay content of at least 30% to a depth of at least 50 cm, or a lithic or paralithic contact, duripan, or a petrocalcic horizon if shallower,

- Cracks that open and close periodically,
- Evidence of soil movement (e.g. slickensides, wedge-shaped aggregates),
- Any soil temperature regime, except pergelic (i.e., Gelisols),
- Soil moisture regime must be erratic to allow for cracking in dry season and swelling in wet season

Six suborders are recognized in the Vertisol order. They are differentiated by aquic conditions, soil moisture regime, and on the cracking characteristics of the soil.

Aquerts: Vertisols which are subdued aquic conditions for some time in most years and show redoximorphic features are grouped as Aquerts. Because of the high clay content the permeability is slowed down and aquic conditions are likely to occur. In general, when precipitation exceeds evapotranspiration ponding may occur. Under wet soil moisture conditions iron and manganese is mobilized and reduced. The manganese may be partly responsible for the dark color of the soil profile.

Cryerts: They have a cryic soil temperature regime.

Xererts: They have a thermic, mesic, or frigid soil temperature regime. They show cracks that are open at least 60 consecutive days during the summer, but are closed at least 60 consecutive days during winter.

Torrerts: They have cracks that are closed for less than 60 consecutive days when the soil temperature at 50 cm is above 8°C.

Usterts: They have cracks that are open for at least 90 cumulative days per year. Globally, this suborder is the most extensive of the Vertisols order, encompassing the Vertisols of the tropics and monsoonal climates in Australia, India, and Africa.

Uderts: They have cracks that are open less than 90 cumulative days per year and less than 60 consecutive days during the summer.

Great groups are differentiated by subsurface diagnostic horizons (e.g. salic, calcic, natric, gypsic horizons), the presence of a duripan (e.g. Duraquerts, Durixererts), organic carbon content (e.g. Humicryerts), or reaction (electrical conductivity is less than 4 dS/m and pH in 1:1 water of 5 or less in 25 cm or more within top 50 cm - e.g. Dystrusters, Dystraquerts).

Several soil moisture regimes are considered at subgroup level ranging from dry to wet conditons: Xeric (e.g. Xeric Epiaquerts), aridic (e.g. Aridic Epiaquerts), udic (e.g Udic Haplusterts), ustic (e.g. Ustic Dystraquerts), and aquic (e.g. Aquic Dystrusterts, Aquic Salitorrerts).

Shallow Vertisols are classified using the designation 'leptic' (soil with a densic, lithic, or paralithic contact within 100 cm of the mineral soil surface) or 'lithic' (e.g. Leptic Salaquerts or Lithic Haploxererts).

Vertisols which are low in clay content are differentiated as 'entic'. To meet the 'entic' designation the Vertisol must have a layer 25 cm or more thick that contains less than 27 percent clay in its fine-earth fraction and has its upper boundary within 100 cm of the mineral soil surface (e.g. Entic Salaquerts, Entic Haplotorrerts).

Soils are defined by the designation 'halic' if their salt content is high. They must meet the following criterion: throughout a layer 15 cm or thicker the electrical conductivity must be at least 15 dS/m or more (1:1 soil:water) for 6 or more months per year in 6 or more out of 10 years. Vertisols with a high sodium content are classified as 'sodic' (e.g. Sodic Haplusterts). They must have an exchangeable sodium percentage of 15 or more (or a sodium adsorption ratio of 13 or more) for 6 or more months per year in 6 or more out of 10 years.

Salt Affected Vertisols in the Bara Tract of Gujarat

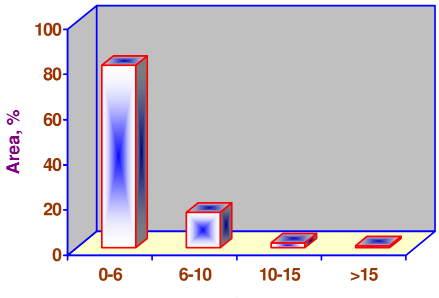

Fig. 1. Area under different ESP classes in Bara Tract (Surface

The prevalence of low to moderate exchangeable sodium is observed in association of with soil salinity in some part of the Bara tract. The exchangeable sodium percentage (ESP) of the surface soils of the Bara tract varies from 0.24 to 22.9 with a mean of 4.5 (SD = 3.9). The value of ESP to distinguish sodic soils from non-sodic soil is found to be much less in case of Vertisols as compared to light textured soils. Accordingly these soils are classified into different sodic classes. The soils with electrolyte concentration (EC) ≤ 2 dS m^{-1} and ESP >6 are classified as sodic soils whereas the soils with EC >4 dS m^{-1} and the ESP >13 are also termed as sodic soils. Accordingly most of the surface soils (90%) of the Bara tract are free from sodicity (Fig 1).

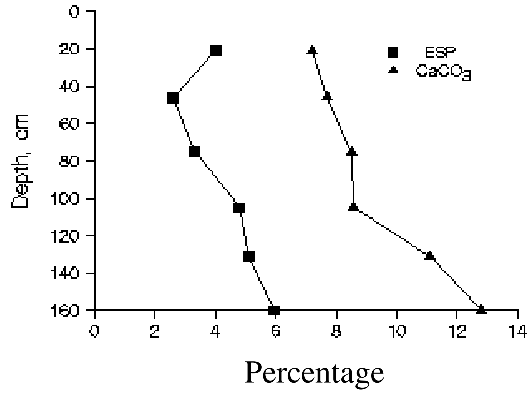

Fig. 2. ESP and $CaCO_3$ content of typical Vertisols of Bara tract (Vagra village)

However the problem of subsoil sodicity is encountered in a fairly large area of the Bara tract. Salinity of these soils shows a greater degree of temporal variation, the marginal case of 8-10 ESP with soil salinity of 2 dS m^{-1} having temporal variation of 0.5 dS m^{-1}, need no gypsum application, as the increase electrolyte concentration in some part of the year may lead to the flocculation of soil colloids. The soils of the Bara tract are alkaline; pH varies from 7.2 to 9.3.

These soils exhibit higher pH at the lower horizon than the upper layer. This is due to progressively increasing accumulation of $CaCO_3$ in the lower horizon. (Figs 2 and 3). The lime content of the lower horizon varies from 2.7 to 27.4 per cent. In the lower layer where calcium carbonate has accumulated during pedo-genesis, sodium accumulation generates sodium bicarbonate and carbonate increasing the soil pH above 9.0, in addition to the toxicity of carbonate and bicarbonate species. This may lead to Fe, N, Cu, Zn and P deficiency. The subsoil salinity (transient salinity) occurring in dry land dominated by subsoil sodicity may lead to further complication with rising saline ground water.

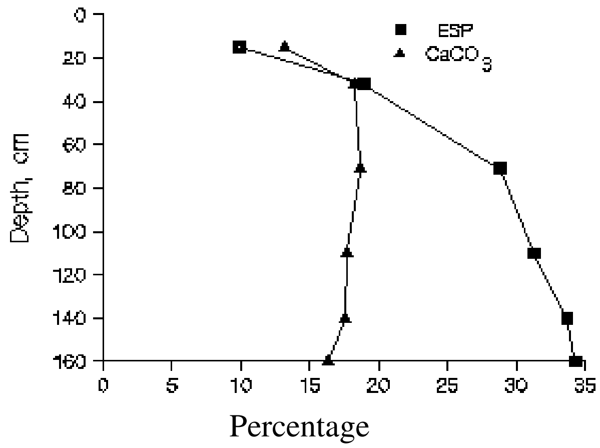

Fig. 3. ESP and $CaCO_3$ content of sodic Vertisols of Bara tract (Sadathala village)

Production Constraints

Moderate length of growing period, difficult land preparation, low fertility status, poor drainage, soil erosion and high ESP are the major factors affecting crop stand (Plate 1) and yield in salt affected Vertisols and significant loss to crop productivity (Table 3). The length of growing season is highly variable depending upon the uncertainty of the onset of monsoon as well as poor rainfall distribution over time and also varies with water holding capacity and plant available water capacity of soils which largely influences the moisture availability during the growing season. This uncertainty of onset of monsoon and the unsure of moisture availability during the critical phase of crops growth often force farmers of the Vertisol regions to keep their land fallow during monsoon season. This practice is often followed by the farmers of the Bhal region and Ghed area of Gujarat where salt affected Vertisols and associated soils gets inundated with monsoon water because of inherent physico-chemical properties like very low hydraulic conductivity, poor drainage and high swell-shrink type clay. However it helps farmers for removal of salt from the root zone through leaching effect and creating favorable condition for rabi season crops like wheat, dill etc.

Plate 1. Poor crop stand in Salt affected Vertisols

Table 3. Expected loss of soil productivity due to ESP in different soils

ESP	Loss of Productivity (%)	
	Alluvium derived soils (Inceptisols/Alfisols)	Black soils (Vertisols)
Up to 5	Nil	Up to 10
5-15	<10	10-25
15-40	10-25	25-50
>40	25-50	>50

(Source: Velayutham and Bhattacharya, 2000)

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