*Agropedology, 2000, **10**, 195-204*

Evaluation of sediment stratification and classification of alkali soils in the Chitravathi River Basin, Andhra Pradesh

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Abstract

Three representative alluvial soils developed in the basin of Chitravathi river in Cuddapah district were examined to understand the effects of intermittent sediment stratification for the development of strong alkalinity and changes in morphological and textural characteristics. The soil morphology displayed low contrast in the solum with gradual change in the B horizon from slight colour to minimal textural contrast. The soil development index based on morphology indicated that the process of profile development is in the order of Penzuvi (P2) > Jammalamadugu (P1) and Chautupalli soils (P3). The soils were classified under three textural groups on the basis of profile textural formulae and denoted as 'Bs' sequence in Penzuvi (P2), 'A' sequence in Chautupalli (P3) and 'X' sequence in Jammalamadugu soils (P1). The vertical textural properties as defined in terms of sand ratios and the difference in sand/silt ratios in successive layers were employed to understand the effects of intermittent sediment stratification and mode of deposition. The results suggested that the sand ratios are sensitive indicators of depositional stratigraphy than total sand. The alkalinity in soils of Chitravathi basin resulted due to perched water table developed in colluvial deposits enriched in alkaline earth carbonates and subsequent accumulations of exchangeable sodium on exchange complex due to evaporative demand. Based on morphology, physical and chemical characteristics, these soils are classified under the subgroups of Aridisols.

Additional keywords : Soil Development Index, low contrast solum, sand ratios, Aridisols.

Introduction

Salt affected soils in Andhra Pradesh are estimated to occupy an area of about 1.8 lakh ha (Reddy *et al.* 1996) which are mostly confined to valleys, plains and command areas of semi-arid tropics in Anantapur, Kurnool, Cuddapah, Mahboobnagar, Nalgonda, Nellore, Guntur and Ongole districts. These soils occur in the basin of Chitravathi river in Cuddapah district in a mosaic pattern and have

poor structure and low productivity. These soils received little attention as they occupied very small area, usually surrounded by productive soils and remained problem soils for the local farmers. The information available on characteristics of these soils is scanty. Therefore, the study was carried out to examine the effects of intermittent sediment stratification in bringing out vertical changes in morphology and factors responsible for alkalization of these soils.

Materials and methods

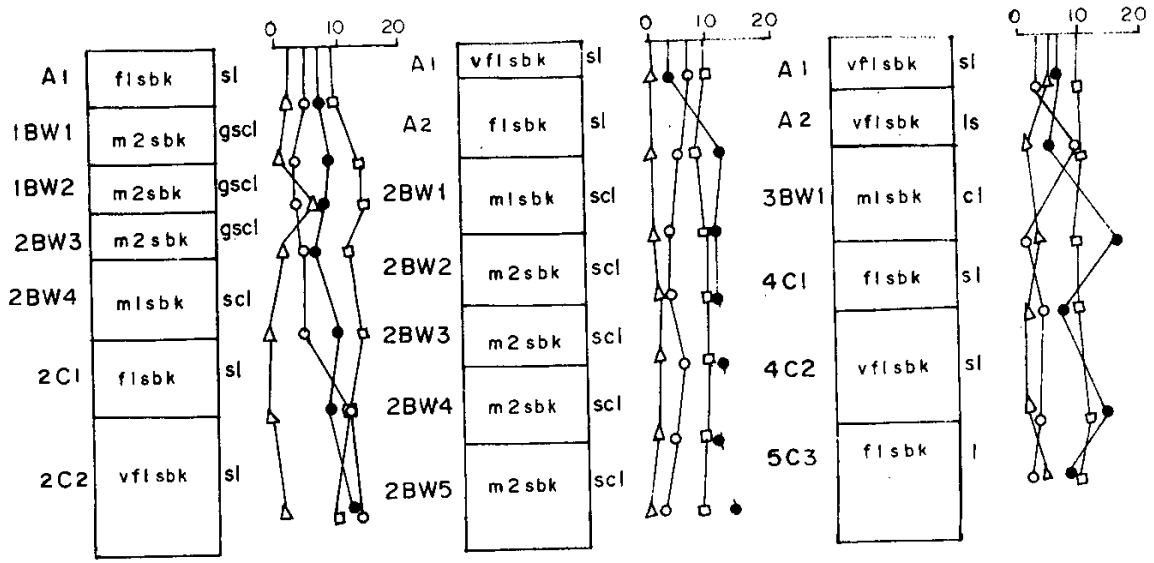
The study area forms part of a crescent shaped Cuddapah basin, situated between 14°31' to 14°40' N latitudes and 77°55' to 78°28' E longitudes. The area comprises of structural hills, pediments, buried pediments and valley floors of the Chitravathi river system with an elevation of 130 m above MSL. The geological formations are mainly quartzites of Gandikota hills overlying Tadipatri shales along with dolomite and limestone (Nagaraja Rao *et al.* 1987). The mean annual rainfall is 543 mm, of which more than 60 per cent is received between June to September. The soil moisture regime is aridic (Eswaran *et al.* 1990) with isohyperthermic soil temperature regime. Three representative alluvial soils developed on basin floor which differ basically in their degree of dissection and sediment stratification were selected at Jammalamadugu (P1), Penzuvi (P2) and Chautupalli (P3) locations. Soil morphology was described (Soil Survey Staff 1951) and soils were classified upto subgroup level as per Soil Taxonomy (Soil Survey Staff 1998). Horizonwise soil samples were collected and textural particle size fractions were estimated by international pipette method. The pH, EC, ionic composition in 1:2.5 soils : water ratio was determined as per Richards (1954). The profile textural formulae was designed by six symbols where each symbol represented textural class of 25 cm thickness. Based on the sequence of texture in each profile, the soils were classified together as textural group (Holmes and Western 1969). The soil development index was calculated from the lowest horizon as per the scheme developed by Harden (1982).

Results and discussion

Morphology : Soil morphology (Table 1) showed that the changes in matrix colour were evident due to sediment stratification. Soils have a hue of 10YR except in the A11 and 2Bw5 horizons and Penzuvi (P2) and the A11 horizon of Chautupalli (P3) soils which have a hue of 2.5Y. The grey to brownish grey matrix colours indicate the effect of seasonal wetness prevailing in lower reaches of the basin. The value and chroma of the matrix varied from 2 to 8 having a difference greater than 2

between dry and moist colours in Penzuvi (P2) and Chautupalli soils (P3). This large difference in value and chroma of matrix is due to low organic matter content and presence of uncoated sand and silt particles mixed with alkaline earth carbonates in high proportion. Texture in the solum of Jammalamadugu (P1) and Penzuvi soils (P2) was sandy loam to sandy clay loam and in Chautupalli (P3) soils, it was loamy sand to clay loam. The textural pattern in a profile is defined in term of six symbol formulae upto a depth of 1.5 m by following textural classes of Soil Survey Staff (1951) as coarse texture (L) coarse medium (M), fine medium (H) and fine (V). A fractional horizon is introduced where strata do not correspond to 25 cm depth interval and are denoted by capital letter for major horizons of 15 cm thickness and lower case letter for minor fractional horizon of 10 cm thickness. The textural groups (Fig. 1) based on six symbol formulae indicate 'A' sequence which comprises of LM textural class throughout the profile depth in Chautupalli soils (P3), 'BS' sequence in which LM (<50 cm) overlie on 'HV' in Penzuvi soils (P2) and 'X' sequence in which 'LM' and 'HV' textural groups occupy approximately equal proportion in upper horizons of Jammalamadugu soils (P1). The soil structure shows single grain in the 2C1 horizon (P3) to medium, moderate, subangular blocky aggregates in the B horizon (P1, P2 and P3) with slightly hard and friable to very firm consistency. The effervescence was strong in all the soils. Appreciable horizon development has taken place and soils have ABC (P1 and P3) and AB (P2) horizon sequence.

Soil development index : Soil morphology exhibits feable evidence of these processes with sedimentary stratification remaining prominent. The morphology has been widely used to define degree of profile development by assigning points for differences between properties of soil horizons and properties of assumed parent material (Harden, 1982). The eight important soil properties viz. rubification, melanisation, texture, structure, dry and moist consistency, clay films and pH are considered for deriving the soil development index. The profile index (Fig. 1) shows that the higher degree of ordering of properties in the soil system is observed in Penzuvi soils with an index value of 71.3 in comparison to Jammalamadugu (61.7) and Chautupalli soils (54.7). The coefficient of variation of Harden's index is high i.e. 47.5 per cent in Chautupalli soils (P3). The differences in index value within these soils is due to the physical alteration that is movement of soil particles by the river system resulting in fine stratification of sand, silt and clay.



	P 1. Sodic Ustic Haplocambids	P 2. Ustic Haplocambids	P 3. Ustic Fluventic Haplocambids
1. Soil Taxonomy			
2. Textural code	$M/h.H^{2}H/m\,m^{2}$	$Mm/H\,H^{4}$	$M/\lambda\lambda/H\,m^{3}$
3. Textural group	X	Bs	A
4. Soil development index.	61·74	71·28	54·74

LEGEND

- Sand / Silt ratio
- pH (1:2·5 soil water ratio)
- Organic carbon (g kg^{-1})
- Soil development index

Fig. 1. Depth function of sand/silt, pH, organic carbon and soil development index in alluvial soils of Chitravathi river basin.

Table 1. Morphological characteristics of the soils

Depth (cm)	Horizon	Colour		Texture	Structure	Consistency	Effervescence
		Moist	Dry				
Profile 1 Jammalamadugu - Sodic Ustic Haplocambids							
0-19	A1	10YR 5/3	10YR 6/6	sl	f1 sbk	fr sh sp po	ev
19-37	Bw1	10YR 5/2	10YR 6/4	gscl	m2 sbk	fi vh ss po	ev
37-51	Bw2	10YR 5/4	10YR 6/2	gscl	m2 sbk	vh fi ss po	ev
51-66	2Bw3	10YR 7/4	10YR 7/2	gscl	m2 sbk	sh fr ss po	ev
66-91	2Bw4	10YR 7/6	10YR 7/4	sl	m1 sbk	vh fi s p	ev
91-117	2C1	10YR 8/8	10YR 8/6	sl	f1 sbk	1sh so po	ev
117-150	2C2	10YR 8/6	10YR 8/6	sl	gr	1 so poev	
Profile 2 Penzuvi - Ustic Haplocambids							
0-10	A1	2.5Y 4/3	2.5Y 6/4	sl	vf1 sbk	fr sh ss sp	es
10-36	A2	10YR 4/6	10YR 6/2	sl	vf1 sbk	sh ss sp	es
36-60	2Bw1	10YR 7/3	10YR 7/6	scl	m1 sbk	sh fr ss sp	ev
60-81	2Bw2	10YR 3/4	10YR 5/4	scl	m2 sbk	sh fr ss sp	ev
81-105	2Bw3	10YR 5/3	10YR 7/3	scl	m2 sbk	vh fi spev	
105-126	2Bw4	10YR 6/4	10YR 8/6	scl	m2 sbk	vh fi spev	
126-150	2Bw5	2.5Y 3/6	2.5Y 5/6	scl	m2 sbk	vh fi spev	
Profile 3 Chautupalli - Ustic Fluventic Haplocambids							
0-16	A1	2.5Y 5/2	2.5Y 6/8	sl	f1 sbk	1o so sp	es
16-34	2C1	10YR 6/6	10YR 8/4	ls	sg	1so po es	
34-64	3Bw1	10YR 3/3	10YR 6/6	cl	m1 sbk	h fr sp ev	
64-85	4C1	10YR 4/4	10YR 7/6	sl	f1 sbk	fr ss sp es	
85-121	4C2	10YR 2/2	10YR 4/3	sl	vf1 sbk	1 so poes	
121-139	5C3	10YR 3/2	10YR 4/6	l	m1 sbk	sh fr ss sp	es

* Symbols as per Soil Survey Manual (1951).

The lowering of index value in soil horizons indicate low contrast solum stage with changes in B horizon from slight colour contrast to minimal textural contrast. The sand with rounded gravel and cobbles of quartzite as noticed in Jammalamadugu (P1) indicates that these horizons were influenced by colluvium of local origin, since quartzite is common in local geology. Chautupalli soils (P3) have 'B' horizon with a

thickness (30 cm) at a depth of 0.34 to 0.64 m. The thickness of 'B' horizon is 113 cm in Penzuvi (P2) and 72 cm in Jammalamadugu (P1) soils indicating the slight pedogenic development in this environment.

Particle-size distribution : The variations in particle size distribution indicate lithological discontinuities (Table 2) within the soils. The sand is the dominant fraction exceeding 50 per cent except in the 3Bw1 and 5C3 horizons of Chautupalli soils (P3). The total sand distribution in horizons shows inconsistent trends indicating the sediment stratification. The profile weighted mean values for silt content varied from 21.7 to 11.5 per cent (P1). The silt content shows an increasing trend to a depth of 0.81 m in Penzuvi soil (P2), decreasing trend except in the 1Bw1 horizon (17%) in Jammalamadugu soils (P1) and an irregular trend with depth in Chautupalli soils (P3). The higher sand/silt ratio (>11) as observed at a depth of 0.91 m in Jammalamadugu soils (P1) is due to high sand and low silt content indicating that lower strata is a colluviated alluvial deposit dominated by dolomite quartzite sediments (Fig. 1). The difference in successive values of sand/silt is >0.8 (Raad and Protz 1971) in both surface and subsurface layers indicating the differential rates of silting processes, specially turbulent mixing up of sand and silt at the time of sedimentation in the basin. The zone of mixing up of sand and silt is identified by examining the relative proportion of fine and very fine sand to medium and coarse sand. This zone of mixing is the 2Bw4 horizon in Jammalamadugu soils (P1) and the 4C1 horizon in Chautupalli soils (P3) where the same ratio decreased. In case of Penzuvi soils (P2), the sand ratio is about 0.53 at 0.81 m with a sharp rise in Harden's index. Particle size class for Penzuvi (P2) and Chautupalli (P3) soils was fine loamy at family level whereas loamy-skeletal for Jammalamadugu (P1) soil where coarse fragments in control section is greater than 35 per cent. The clay content varied from 8.0 per cent in the 1C1 horizon of Chautupalli soils (P3) to 34 per cent in the 1Bw2 horizon of Jammalamadugu soils (P1).

Organic carbon : The depth function of organic carbon (Fig. 1) shows irregular trend indicating fluventic nature of sediment stratification. The organic carbon content ranges from 0.1 g kg^{-1} in the 2Bw4 and 2C horizons to 5.6 g kg^{-1} in the 1Bw2 horizon of Jammalamadugu (P1) and the 2Bw3, 2Bw4 and 2Bw5 horizons of Penzuvi (P2) showed that these soils have older sediments which reached a minimum level less than 0.1 g kg^{-1}.

Table 2. Particle-size distribution of the soils

Depth (cm)	Coarse fragments (>2 mm) (%)	Particle size distribution (%) (mm)						Silt (0.0625–0.002)	Clay (<0.002)	(fs+vfs)/(cs+ms)	ΔD*
		Sand									
		Very coarse (2.0–1.0)	Coarse (1.0–0.5)	Medium (0.5–0.25)	Fine (0.25–0.125)	Very fine (0.125–0.0625)	Total				
Profile 1 Jammalamadugu - Sodic Ustic Haplocambids											
0–19	23	07.6	10.4	08.5	25.9	14.8	67.1	14.4	18.5	2.20	–
19–37	43	12.7	11.4	12.0	10.4	05.8	52.3	17.01	30.7	0.69	1.6
37–51	32	10.7	12.9	11.3	09.7	05.6	50.2	15.8	34.0	0.63	0.1
51–66	40	15.6	12.7	13.8	11.0	04.6	57.7	13.2	29.1	0.59	1.2
66–91	12	08.3	12.5	12.1	09.1	14.1	56.0	13.6	30.4	0.94	0.3
91–117	18	22.6	23.3	18.0	07.5	02.7	74.1	06.8	19.1	0.25	6.8
117–150	19	25.5	23.6	15.6	09.0	03.3	77.1	06.4	16.5	0.31	1.2
Profile 2 Penzuvi - Ustic Haplocambids											
0–10	10	5.1	21.4	21.6	19.3	8.1	76.3	11.4	12.3	0.66	–
10–36	08	5.7	19.7	23.5	20.4	6.9	76.2	14.7	09.1	0.63	1.5
36–60	11	5.9	18.6	15.6	10.5	5.7	56.3	15.1	28.6	0.47	1.5
60–81	06	4.4	18.1	18.9	11.7	5.6	58.7	16.6	24.7	0.47	0.2
81–105	05	6.1	20.5	15.8	13.8	5.8	62.0	12.0	26.0	0.53	1.7
105–126	04	4.0	34.1	01.1	11.9	7.1	58.2	13.6	28.2	0.54	0.9
126–150	04	4.0	14.7	13.6	10.9	7.4	50.6	19.4	30.2	0.65	1.7
Profile 3 Chautupalli - Ustic Fluventic Haplocambids											
0–16	04	3.4	7.7	10.5	28 3	17.5	67.5	20.0	12.5	2.5	–
16–34	02	2.6	7.4	14.7	40 5	18.3	83.4	08.6	08.0	2.7	6.4
34–64	03	0.2	1.9	04.2	16 4	16.7	39.5	31.3	29.2	5.4	8.4
64–85	01	0.7	2.0	04.4	34.2	23.8	65.1	18.9	16.0	9.1	2.1
85–121	02	1.5	8.7	14.5	23.2	14.3	62.1	19.2	18.7	1.6	0.2
121–139	08	0.4	4.0	06.8	18.5	19.6	49.1	28.5	22.2	3.5	1.5

* ΔD - Difference in sand silt ratio in successive horizons of each profile.

Ionic composition : These soils have pH varying from 8.8 to 10.4 with increase of alkalinity at a depth of 0.6 in Penzuvi (P2), 0.91 m in Jammalamadugu (P1) and at

0.85 m in Chautupalli soils (P3). The weighted mean of pH is 10.2 in Penzuvi soils (P2) but with a mean of 9.6 in Jammalamadugu (P1) and 9.3 in Chautupalli soils (P3). These soils have low salinity as indicated by EC value less than one dS m^{-1} except in Jammalamadu soils (P1) where EC greater than one is observed below 0.66 m depth (Table 3). The increasing trend of EC values is observed in Jammalamadugu (P1) and in Chautupalli (P3) soils whereas in Penzuvi soils, the EC values remain irregular. Among water soluble cations, sodium is dominant with increasing trend in Jammalamadugu (P1) and Chautupalli profiles (P3). The soluble sodium in Jammalamadugu soil (P1) increases to 96.5 per cent at 0.51 m but reaches 99.2 per cent level at 1.5 m depth whereas in Chautupalli soils (P3), it reaches to 89 per cent at a depth of 0.14 to 0.64 m and then decreases 84.9 per cent at a depth of 0.85 to 1.21 m. The soluble calcium, magnesium and potassium contents remain low with irregular trends of distribution. The weighted mean of Ca is 0.099 cmol(p+) kg^{-1} for Jammalamadugu (P1) and for Chautupalli soils (P3) but in Penzuvi soils (P2), the weighted mean of soluble calcium content is 2.8 cmol(p+) kg^{-1}. The soluble sodium per cent (SSP) has a significant positive correlation with SAR (R^2=0.48**) and yielded a regression equation as SSP=54.6+1.4 (SAR). The weighted mean of SAR for Jammalamadugu profile (P1) is 23.7 it is 1.8 for Penzuvi (P2) soils and 9.1 for Chautupalli soils (P3).

Table 3. Ionic composition of soils

Depth (cm)	pH	EC dS m^{-1}	Cations {mmol (c) l^{-1}}				Anions {(mmol (c) l^{-1}}			SAR	SSP	Na/Cl	Cl/HCO_3 +CO_3
			Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3^-	$CO_3^=$	Cl^-				
Profile 1 Jammalamadugu - Sodic Ustic Haplocambids													
0–19	8.8	0.12	0.1	0.4	0.4	0.05	0.5	–	1.1	0.8	50.0	0.4	2.2
19–37	9.5	0.67	0.007	2.4	4.6	0.05	3.2	2.1	1.4	4.2	65.9	3.3	0.3
37–51	9.7	0.84	0.004	1.5	7.8	0.3	4.8	1.1	3.4	9.0	84.4	2.3	0.6
51–66	9.6	0.98	0.005	0.4	9.9	0.07	4.2	1.7	5.0	23.5	96.5	2.0	0.9
66–91	9.1	1.04	0.022	0.1	10.1	0.07	3.7	1.1	6.5	36.6	98.6	1.6	1.4
91–117	9.7	1.03	0.018	0.1	10.1	0.06	2.7	2.1	7.3	51.1	99.2	1.4	1.5
117–150	9.7	1.06	0.33	0.1	10.3	0.04	3.7	2.1	4.0	22.2	96.0	2.1	0.9
Wx	9.6	0.86	0.094	0.56	8.2	0.08	3.2	–	4.6	23.7	86.5	1.8	1.1

Profile 2 Penzuvi - Ustic Haplocambids													
0–10	9.5	0.8	5.8	0.9	0.5	0.2	3.3	–	1.7	0.3	9.5	0.3	0.5
10–36	10.1	0.6	3.8	0.7	1.2	0.3	2.1	–	1.6	0.8	25.0	0.8	0.8
36–60	10.4	0.7	3.4	1.1	2.9	0.3	2.4	–	2.0	1.9	41.6	1.5	0.8
60–81	10.3	0.5	2.5	0.7	1.6	0.4	1.6	–	2.1	1.3	38.5	0.8	1.3
81–105	10.2	0.3	0.9	0.6	1.8	0.5	1.2	0.4	2.7	2.1	60.7	0.7	1.7
105–126	10.2	0.5	2.1	0.4	1.6	0.3	2.8	0.6	1.5	1.4	43.2	1.1	0.4
126–150	10.4	0.8	2.4	0.9	4.8	0.4	4.7	0.9	2.3	3.7	61.2	2.1	0.4
Wx	10.2	0.6	2.8	0.8	2.2	0.4	2.5	–	2.0	1.8	42.5	1.1	0.9
Profile 3 Chautupalli - Ustic Fluventic Haplocambids													
0–16	8.9	0.3	0.6	0.4	1.6	0.09	0.8	–	2.0	2.3	63.7	0.8	2.5
16–34	9.0	0.3	0.04	0.3	2.8	0.07	1.3	–	2.5	6.7	89.1	1.1	1.9
34–64	9.0	0.4	0.03	0.5	4.7	0.1	2.0	–	2.5	8.9	89.7	1.9	1.3
64–85	9.7	0.4	0.05	0.4	3.1	0.05	1.9	–	2.7	6.4	85.6	1.2	1.5
85–121	9.5	0.5	0.03	0.9	4.8	0.3	2.1	–	2.9	7.2	84.9	1.7	1.4
121–139	9.3	0.6	0.06	0.08	6.5	0.01	3.5	–	3.0	24.4	97.9	2.2	0.9
Wx	9.3	0.4	0.09	0.5	4.1	0.12	2.0	–	2.7	9.1	86.2	1.5	1.5

SAR = Sodium Adsorption Ratio; SSP = Soluble Sodium percent;

The presence of carbonates is observed throughout profile with a concentration of 1.1 to 2.1 mmol L^{-1} in Jammalamadugu soils (P1) and between 0.81 m and 1.5 m depth in Penzuvi soils (P2) with concentration of 0.4 to 0.9 mmol L^{-1}. The chlorides and bicarbonate and carbonate ratio is less than 1 in the horizons of Jammalamadugu soil (P1) and in Penzuvi soils (P2), indicates high concentration of bicarbonate in soil solution. But high chloride concentration is evident in Chautupalli soils (P3) where chloride to bicarbonate ratio is greater than one.

Soil classification : Based on morphological, physical and chemical characteristics, these salt-affected soils are classified upto subgroup level in the order Aridisols (Soil Survey Staff 1998). These soils have a soil moisture regime that borders ustic and are dry in all parts of moisture control section for less than three fourth (cumulative) of time when soil temperature is 5°C or higher at a depth of 50 cm. Hence, the Penzuvi soils (P2) having characteristics of a Cambic B horizon with strong effervescence are classified as Ustic Haplocambids, whereas Chautupalli (P3) soils showing irregular trends of organic carbon with depth are classified as Ustic Fluventic

Haplocambids. The Jammalamadugu (P1) soils having 40 cm thick Cambic B horizon within 100 cm of soil surface with an SAR of 23.5 to 36.6 and a soluble sodium per cent of 96.5 to 98.6 are classified as Sodic Ustic Haplocambids.

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(Received : June, 1999; Accepted : October, 2000)