Agropedology, 2003, 13, 30-38

Transformation of soil characteristics under continuous irrigation in rice-based farming system - A case study of Hirakud Command of Orissa

M. Taha[1] *and S.S.K. Nanda*[2]

Regional Research and Transfer Technology Station, Chiplima (Sambalpur) - 768 025, India

[1]Central Farm, RRTTS, Bhubaneswar-751 003, India

[2]College of Agriculture, OUAT, 536, Jagamara, Bhubaneswar-751 030, India

Abstract

Morphological, physical and chemical characteristics of six typifying pedons of Hirakud Command area both under irrigated and unirrigated conditions were studied. A compact plough sole layer is developed below the surface horizon under continuous rice cultivation. Higher acidity and lowering of base saturation are the other adverse effects of continuous irrigation. However, organic matter content has increased under irrigated rice farming. The soils on high and medium lands belong to Alfisols and those on low lands to Inceptisols. Low land irrigated soils are grouped as Aquepts and those unirrigated are Ochrepts.

Additional key words : Plough sole, rice-rice farming, irrigation.

Introduction

Continuous irrigation over the years has resulted in induction of soil salinity in arid climate and drainage impedance in humid region (National Commission of Agriculture, 1976). In the state of Orissa, decline in rice productivity during *kharif* season in rice-rice cropping system in major irrigation commands was reported by Nanda (1987). Vast stretches of the irrigated land have been rendered unsuitable for crop growth. An investigation was made in Hirakud Command of Orissa to ascertain the causes of above phenomenon and suggest remedial measures.

Materials and methods

The study was conducted in farmers' field at Kujapali, an intensively irrigated area for at least 30 years under Hirakud Command, Orissa and for unirrigated area at nearby Kedupali. The study area is located at 20°21' North latitude and 80°55' East longitude at an elevation of 179 m above msl. The climatic data of 20 years show a mean annual rainfall of 1424 mm, evaporation 1484 mm, maximum temperature 40.2°C and minimum temperature 13.0°C. The area falls under hot and humid climate. The soil remains moist for more than 130 days and dry for the remaining period of the year in most years. Therefore, it qualifies for ustic moisture regime. The mean annual soil temperature at a depth of 50 cm is 24.5°C; the mean summer temperature and the mean winter temperature are 29.7°C and 18.6°C, respectively. Hence, the area belongs to 'hyperthermic' temperature regime (Soil Survey Staff 1998). Six profiles were studied, three from irrigated: high (P_1), medium (P_1) and low (P_3) land and three from unirrigated; high (P_4), medium (P_5) and low (P_6) land. Horizonwise soil samples were collected and their physical characteristics such as texture, bulk density, porosity, hydraulic conductivity and plasticity and chemical characteristics such as soil reaction, total soluble salts, organic carbon, and cation exchange capacity were estimated following the standard methods (Black 1965) and taxonomically classified (Soil Survey Staff 1998)..

Results and discussion

Morphological characteristics : Morphological properties of irrigated and unirrigated soils are presented in Table 1. The most important morphological feature in these soils is the colour. Besides soil colour, the colour of the mottles is also important since it reflects the moisture regime of the soil profile throughout the year.

Table 1. Morphological properties of irrigated and unirrigated soils of Hirakud Command area

Hori-zon	Depth (cm)	Soil colour	Mottles Colour	Mottles Abundance & contrast	Texture	Structure
Kujapali (Irrigated) : P_1 (Highland)						
Ap	0-12	10YR 5/1	--	--	Sandy loam	2msbk
A_{12}	12-19	10YR 6/4	7.5YR 5/6	fd	Sandy loam	2msbk
Bt_1	19-35	10YR 7/6	7.5YR 4/4	cp	Clay loam	1msbk
Bt_2	35-52	10YR 6/4	5YR 5/6	cp	Clay loam	1fm
Bt_3	52-75	10YR 6/4	5YR 5/6	cf	Clay loam	1fm
Cn	75-95	10YR 6/4	5YR 5/6	ff	Clay loam	0fm
Kujapali (Irrigated) : P_2 (Mediumland)						
Ap	0-15	10YR 5/3	5YR 5/4	Nil	Clay loam	1fsbk
Bt_1	15-24	7.5YR 5/6	5YR 5/4	fd	Clay loam	2msbk
Bt_2	24-46	5YR 5/4	5YR 5/6	mf	Clay loam	2cabk
Bt_3	46-72	5YR 5/4	5YR 5/6	md	Clay	2fabk

Cond.

Cn-	72-90	5YR 4/1	5YR 5/6	fp	Clay	0fsg
Cn_2	90-115	5YR 4/1	--	Nil	Clay	0fm
Kujapali (Irrigated) : P_3 (Lowland)						
Ap	0-27	5YR 4/1	5YR 5/8	ff	Clay loam	1mc
Bw	27-77	5YR 4/1	5YR 5/8	cd	Clay loam	1fm
C	77-115	5YR 4/1	--	Nil	Sandy clay	0fm
Kendupali (Unirrigated) : P_4 (Highland)						
Ap	0-15	10YR 6/4	--	Nil	Sandy clay loam	1fsg
Bt_1	15-48	10YR 6/4	--	Nil	--do--	1msbk
Bt_2	48-75	10YR 8/6	--	Nil	--do--	2csbk
Bt_3	75-115	10YR 8/6	--	Nil	--do--	2mabk
Cn	115-130	10YR 6/4	--	Nil	--do--	2fm
Kendupali (Unirrigated) : P_5 (Mediumland)						
Ap	0-30	7.5YR 4/0	--	Nil	Clay loam	1fsg
B1	30-60	2.5YR 6/2	--	Nil	Clay	3msbk
Bw1	60-75	2.5YR 6/2	10YR 6/6	cd	Clay	3msbk
Bw2	75-105	2.5YR 7/2	10YR 6/6	md	Sandy clay	1msbk
Bw3	105-130	2.5YR 7/2	--	Nil	Sandy clay	1fsg
Kendupali (Unirrigated) : P_6 (Lowland)						
Ap	0-20	5YR 7/6	2.5YR 5/6	fd	Sandy clay loam	1fsg
Bw1	20-45	7YR 5/6	2.5YR 5/6	cp	--do--	2msbk
Bw2	45-85	10YR 5/6	2.5YR 5/6	cp	--do--	2msbk
Bw3	85-100	7.5YR 5/4	10YR 5/6	fd	Sandy loam	1fsbk

The dominant matrix colour is brown of different shades ranging from strong brown to yellowish brown, a colour natural under the hot and humid climate prevailing in the study area. This is ascribed due to a mixture of organic matter and iron oxides. But in the lowland under irrigated condition, the colour is dark gray throughout the profile due to continuous rice cultivation (rice-rice) under wet moisture regime. This may be due to the presence of iron in ferrous form under reduced condition and relatively higher organic matter content (Ponnamperuma 1972). In contrast the lowland soil matrix colour in unirrigated condition is reddish yellow to yellowish brown of higher value and chroma. Similar colour features in

Hirakud command area have been reported by Mishra and Nanda (1984).

The soil mottle colour reflects oxidation-reduction status of iron oxides under fluctuating water table condition due to ferrolysis. The irrigated conditions have shown a strong brown to yellowish red colour in highland, reddish brown to yellowish red in medium land and no mottles in subsoil. But under non-irrigated conditions, upland and medium land do not show mottles, whereas yellowish brown mottles are present in the lowland in substratum only. This is ascribed to the oxidizing-reducing situations in rice farming under alternate wet and dry conditions of the soil profile (Buol *et al.* 1973).

Physical characteristics : Physical properties of soils are reported in Table 2. Soils in the rolling toposequence are sedentary. Surface soil texture in the highland situation under irrigated and unirrigated condition is sandy loam and sandy clay loam, respectively (Table 1). In medium land situation, surface soils in both the conditions are clay loams, whereas in lowland situation, surface soils are clay loam and soils of substratum are loamy. Thus, in topo-sequence, the soil texture could chiefly be attributed to the transportation of finer soil properties down the slope through runoff and their deposition in lower physiographic position. The loss of clay in the surface horizon down the slope are ascribed to be due to both lateral movement and eluviation. Argillic horizons are well manifested in the subsoil horizons in high and medium land situations, whereas in lowland, accumulation of finer particles through lateral slope wash have rendered the surface soil to be finer in texture overlying the coarser substratum (Table 2).

In irrigated land rice followed by rice by transplantation is the cropping system. Under transplantation, the field is puddled by cross ploughing several times under wet condition followed by planking before transplanting the seedling. From top of the surface layer, fine clay particles are translocated to immediately below the plough layer and through planking a compact plough sole layer is developed, just below the Ap horizon of thickness about 10 cm. In irrigated condition in high and medium land, this compact plough sole layer is manifested in the second successive layer from the soil surface layer (12-19 cm in P1 and 15-24 cm in P-3). Occurrence of such plough sole layer has been explained by Ghildyal (1976) in wetland puddled rice soils. Translocation of the fine clay particles and clogging the prevailing pores result in decrease of the non-capillary pores, as a result bulk density increases from 1.62 to 1.71 Mg m^{-3} (Table 2). In lowland under irrigated condition and in all the land types under unirrigated conditions no such compact plough sole layer is developed. In the later case, no continuous rice cropping is practiced. Rice-fallow or rice-pulses system is practiced. Compaction developed during the *kharif* rice is broken under aerated condition during non-rice growing season.

Table 2. Physical properties of irrigated and unirrigated soils of Hirakud Command area

Depth (cm)	Sand	Silt	Clay	B D. ($Mg\ m^{-3}$)	Total	Porosity Non-capillary	Capi-llary	Sat.Hyd. Conduc-tivity ($cm\ hr^{-1}$)
	------------- (%) -------------					--------- (%) --------		
Kujapali (Irrigated) : P_1 (Highland)								
0-12	74.3	16.8	08.9	1.61	39.2	10.1	29.1	0.061
12-19	74.1	17.2	08.7	1.70	35.8	09.3	26.5	0.053
19-35	62.3	15.5	22.2	1.68	36.6	14.6	22.0	0.056
35-52	61.3	14.5	24.2	1.63	38.5	15.0	23.5	0.045
52-75	60.2	11.4	28.4	1.65	37.7	12.1	25.6	0.054
75-95	52.4	15.2	32.4	1.56	41.1	13.2	27.9	0.045
Kujapali (Irrigated) : P_2 (Mediumland)								
0-15	62.4	10.0	27.6	1.62	38.9	14.6	24.3	0.065
15-24	60.4	10.0	29.6	1.71	35.5	14.1	21.4	0.065
24-46	51.0	13.4	35.6	1.55	41.5	19.3	22.2	0.044
46-72	53.0	11.4	35.6	1.60	39.6	18.6	21.0	0.047
72-90	47.5	13.8	38.5	1.45	45.3	13.7	31.6	0.050
90-115	45.0	12.6	42.4	1.68	36.6	10.1	26.5	0.048
Kujapali (Irrigated) : P_3 (Lowand)								
0-27	44.8	27.2	28.0	1.45	45.3	10.6	34.7	0.096
27-77	39.0	29.0	32.0	1.50	43.4	08.8	34.6	0.075
77-115	62.8	14.1	23.1	1.62	38.9	11.5	27.4	0.067
Kendupali (Unrrigated) : P_4 (Highland)								
0-15	65.4	10.0	24.6	1.65	37.7	09.2	28.5	0.078
15-48	55.4	13.0	31.6	1.61	39.2	11.0	28.2	0.081
48-75	53.6	12.0	34.4	1.56	41.1	12.1	29.0	0.090
75-115	51.8	14.0	34.2	1.55	41.5	13.2	28.3	0.085
115-130	51.0	11.5	37.5	1.56	41.1	11.3	29.8	0.088
Kendupali (Unrrigated) : P_5 (Mediumland)								
0-30	37.0	23.5	39.5	1.44	45.1	09.6	35.5	0.070
30-60	34.5	23.9	41.6	1.48	44.2	08.9	35.3	0.058
60-75	38.2	18.5	43.3	1.50	44.4	09.7	34.7	0.067
75-105	60.6	09.6	29.8	1.61	39.2	10.4	28.8	0.072
105-130	51.7	12.8	35.5	1.62	38.9	09.5	29.4	0.045

Cond.

Kendupali (Unrrigated) : P_6 (Lowland)

0-20	48.6	12.2	39.2	1.45	45.2	07.7	37.5	0.053
20-45	54.6	14.9	30.5	1.56	41.1	08.4	32.7	0.064
45-85	59.7	15.7	24.6	1.66	37.4	09.5	27.9	0.068
85-100	69.9	15.3	14.8	1.72	35.1	10.2	24.9	0.076

Similar findings of soil compaction under continuous rice farming in irrigated regime have been reported in Mahanadi Delta Command (Sahu *et al.* 1986).

Chemical characteristics : Chemical characteristics of pedons are reported in Table 3. Under irrigated conditions, surface layer is strongly acidic (pH is less than 4.5) whereas in lower layers pH is higher by 0.6 to 0.7 units. Under unirrigated conditions soils are moderately acidic in high land, neutral in medium land and moderately acidic in lowland. Increase in soil acidity under continuous irrigation in Deltaic Command of Orissa has been reported by Sahu et al. (1986). No appreciable acidity is observed in the surface layers. Under irrigated condition organic carbon is high in all land types in the surface layers, having 9.6, 10.6 and 15.1 g kg^{-1} in high, medium and low land, respectively. Under unirrigated condition in all the land types organic carbon is low, having 2.7, 2.2 and 3.5 g kg^{-1} in high, medium and low land, respectively. Under irrigated condition in high and medium land types per cent base saturation is lower in the surface layer (59.8 and 62.7%, respectively). In irrigated conditions with rice-rice cropping system under impounded water, bases are leached from the surface layers and soils are rendered acidic. Nanda and Maharana (1988) have reported transformation of alluvial soils from neutrality to slightly acidic condition in Mahanadi Deltaic Command of Orissa. In irrigated condition organic matter content increases in the surface layer, which may be attributed to application of farmyard manure and decomposition of hydrophytes prevailing under wetland rice cultivation and incorporation of rice stubbles. In addition, reduced rate of decomposition under waterlogged condition might have enriched the organic matter status.

Soil Taxonomy: The classification at family level is stated below.

Land situation	Type of land	Family
Irrigated	High	Fine-loamy, mixed, hyperthermic Udic Haplustalf
	Medium	Fine-loamy, mixed, hyperthermic Udic Haplustalf
	Low	Fine-loamy, mixed, hyperthermic Typic Endoaquept
Unirrigated	High	Fine-loamy, mixed, hyperthermic Udic Haplustalf
	Medium	Fine, mixed, hyperthermic Udic Ustochrept
	Low	Fine-loamy, mixed, hyperthermic Dystric Eutrochrept

Table 3. Chemical properties of some irrigated and unirrigated soils of Hirakud Command area

Depth (cm)	pH (1:2.5)	pH (KCl)	E.C. (dS m^{-1})	O.C. (g kg^{-1})	CEC	Ca^{2+} Mg^{2+}	Na^+	K^+	B.S. (%)
					---------- cmol(p+) kg^{-1}			----------	
Kujapali (Irrigated) : P_1 (Highland)									
0-12	5.1	4.0	0.05	9.6	6.93	5.0	0.10	0.05	60
12-19	5.7	4.8	0.03	2.9	5.78	4.5	0.15	0.10	82
19-35	6.8	5.6	0.05	1.1	6.02	4.5	0.05	0.10	77
35-52	7.1	5.8	0.06	1.1	5.70	4.0	0.10	0.15	74
52-75	7.3	5.8	0.04	1.0	7.46	6.0	0.15	0.15	84
75-95	6.7	5.8	0.14	0.8	9.24	6.5	0.80	0.15	81
Kujapali (Irrigated) : P_2 (Mediumland)									
0-15	5.2	4.3	0.06	10.5	9.16	5.5	0.15	0.10	63
15-24	6.9	6.0	0.04	3.7	6.78	5.0	0.15	0.05	76
24-46	6.7	4.7	0.04	2.1	11.34	10.5	0.15	0.05	94
46-72	7.0	4.8	0.04	1.0	11.87	10.5	0.05	0.25	91
72-90	6.5	5.6	0.07	0.6	14.40	12.5	0.40	0.20	91
90-115	6.8	5.7	0.06	0.5	12.92	11.5	0.55	0.20	95
Kujapali (Irrigated) : P_3 (Lowand)									
0-27	5.8	4.7	0.07	15.[illegible]	12.08	11.5	0.30	0.10	98
27-77	5.9	5.6	0.03	4.7	11.34	10.5	0.35	0.05	97
77-115	6.4	5.6	0.03	1.4	8.72	7.5	0.40	0.10	92
Kendupali (Unrrigated) : P_4 (Highland)									
0-15	5.8	4.7	0.03	2.7	6.09	5.0	0.13	0.30	89
15-48	5.9	4.8	0.02	2.1	7.14	4.8	0.40	0.36	78
48-75	6.1	4.8	0.03	1.3	6.72	4.5	0.01	0.08	68
75-115	5.8	4.8	0.03	1.0	9.80	9.5	0.03	0.23	99
115-130	6.7	5.3	0.02	0.5	11.30	10.5	0.08	0.25	90
Kendupali (Unrrigated) : P_5 (Mediumland)									
0-30	6.8	5.2	0.03	2.2	19.01	16.5	0.16	0.32	89
30-60	7.5	6.1	0.07	1.3	23.52	21.5	0.03	0.21	93
60-75	8.0	6.9	0.11	1.3	22.05	20.5	0.14	0.34	100
75-105	8.4	7.2	1.00	0.4	12.02	11.5	0.26	0.12	99
105-130	8.3	7.3	1.01	0.2	14.18	13.5	0.19	0.19	98
Kendupali (Unrrigated) : P_6 (Lowland)									
0-20	5.7	5.0	0.03	3.5	13.44	11.5	0.17	0.13	88
20-45	6.8	5.5	0.04	1.6	13.92	13.5	0.17	0.09	99
45-85	6.9	5.4	0.05	1.3	13.94	10.0	0.07	0.06	73
85-100	6.6	4.3	1.11	0.3	13.76	12.0	0.16	0.15	89

Soils on high land situation, both under irrigated and unirrigated conditions, are Haplustalfs, whereas soils in lowland situations are transitional soils, belonging to Inceptisols. In irrigated regime soils have acquired aquic properties, and are grouped into aquepts. The soils under unirrigated condition are grouped as ochrepts. Similar findings are reported in Hirakud Command by Mishra and Nanda (1984).

There is trend for development of compact layer in the near surface under irrigated condition where continuous wetland rice cultivation is practiced. This makes the land unfit for crop diversification. Concurrently higher acidity and lowering of base saturation are adverse effects for sustainable productivity. Hence, continuous rice-rice farming should be discouraged. Water management practices need to be adopted, avoiding impounding of water, as is the common practice with farmers for cultivation.

References

Black, C.A. (1965). Methods of Soil Analysis, Part 1 and 2. American Society of Agronomy, Madison, Wisconsin, U.S.A.

Buol, S.W., Hole, F.D. and McCracken, R.J. (1973) Soil Genesis and Classification. The Iowa State University Press, Ames, Iowa.

Ghildyal, B.P. (1976) Fertility and properties of submerged rice soils. *In*: Soil Fertility Theory and Practices, ICAR, New Delhi.

Mishra, D.P. and Nanda, S.S.K. (1984) Characterisation of some Entisols of Hirakud Command area, Orissa, in relation to taxonomy. *The Andhra Agricultural Journal* **31**, 142-145.

Nanda, S.S.K. (1987) Coastal ecosystem of Orissa - its potentiality and problems in relation to land and water management. *Journal of the Indian Society of Coastal Agricultural Research* **5**, 93-100.

Nanda, S.S.K. and Maharana, G. (1988) Soil related constraints of wetland rice soils of Orissa. *Abstr.* National Seminar on Current Trends in Soil Research, Indian Society of Soil Science, held at Bhubaneswar, p.7.

National Commission of Agriculture (1976) Report, Part V: Resource Development. Ministry of Agriculture and Irrigation, Government of India, New Delhi.

Ponnamperuma, F.N. (1972) The Chemistry of Submerged Soils. *Advances in Agronomy*, **24**, 29-96.

Sahu, G.C., Panda, N. and Nanda, S.S.K. (1986) Genesis and mineralogy of some Entisols in Orissa. *Indian Agriculture* **30**, 21-28.

Soil Survey Staff (1998) Keys to Soil Taxonomy, 8th Edition. USDA, Washington, D.C.

Received : February, 2002 ; Accepted : May, 2003