Original Research Article

Profile Distribution of Available Plant Nutrients in Western Hilly Tracts of Cuttack District, Odisha

ABSTRACT

Aims: An investigation was conducted to examine the distribution of available plant nutrients and the relationships between soil properties and available nutrient status in soil profiles in the Western Hilly Tracts of the Cuttack District, Odisha.

Place and Duration of Study: The research area, *i.e.* the Narasinghpur block, is located in the western part of the Cuttack district in Odisha and is characterized by lateritic uplands and mountainous terrain. Three soil profiles were exposed *i.e.* upland, medium land and low land were exposed before the rainy season (February, 2020).

Methodology: For experiments, five layers demarcated at 20cm intervals up to a depth of 100cm were sampled, processed, and stored. Several parameters, including particle size, pH, EC, OC, and available Ca, Mg, S, Fe, Mn, Cu, and Zn, among others, were analysed and interpreted using standard protocols.

Results: Sand content was observed to decrease with pedon depth, whereas clay content showed the opposite trend. With increasing soil depth in all pedons, soil pH increased while EC and soil organic carbon content declined. The available Ca, Mg, and S in surface soils varied from 4.11 to 6.56 [cmol (p^+)/kg], 2.15 to 3.54 [cmol (p^+)/kg] and 9.85 to 12.06 mg kg^{-1}, respectively. The corresponding subsurface ranges for these nutrients were 4.31 to 8.52 [cmol ($p^{+)}$/kg], 2.41 to 4.52 [cmol (p^+)/kg], and 6.95 to 11.41 mg kg^{-1}, respectively. The range of available Fe, Mn, Cu, Zn, and B in surface soils were 127.85-278.81, 68.48-144.98, 0.64-0.9, 0.54-0.63 and 0.37-0.47 mg kg^{-1}, respectively. The subsurface ranges for these nutrients were 102.32–234.46, 53.21–118.28, 0.28–0.89, 0.17–0.50, and 0.29–0.91 mg kg^{-1}. The status of micronutrients in the present study region was as follows: Fe > Mn > Cu > Zn > B. With increasing soil depth, available Ca and Mg increased, but available S, Fe, Mn, Cu, Zn and B declined. Positive correlations between available Fe, Mn, Cu, and Zn with the soil organic carbon content of the soil and negative correlations with the soil pH were observed.

Conclusion: Plant nutrients in the research area varied with topography, although the differences weren't substantial between upland, medium land and lowland. However, accelerated decomposition of soil organic matter and agricultural residues likely led to higher micronutrient concentrations at the soil's surface compared to subsurface.

Keywords: [Soil fertility, Micronutrients, pedon, soil profile, topography, Soil Organic Carbon]

1. INTRODUCTION

Micronutrients are elements that are required for plant growth in minute concentrations. Despite being required in less quantities, micronutrients have the same functional impor.tance as macronutrients and play critical roles in plant growth [1]**.** These elements include, Zinc (Zn), Iron (Fe), Copper (Cu), and Manganese (Mn) amongst others. Majority of micronutrients are linked to plant enzymatic processes. Zn is known to increase the generation of growth hormones, starch, and seed development, Fe is crucial in chlorophyll formation, Cu in photosynthesis, and Mn is important in photosynthesis and metabolism [2]. Origin and sources of soil micronutrients are very diverse in nature. Parent materials, sewage sludge, municipal waste, farmyard manure, organic matter, and atmospheric depositions are their principal sources [3]. Trace elements become trapped in the crystal lattice of minerals (such as clay) during the process of weathering, making them unavailable. Trace elements are easily absorbed by clay minerals, but their displacement into the soil is complicated. Micronutrients in soil exist in a variety of forms, including water-soluble, exchangeable, complex and chelated forms, as well as in structure of primary and secondary minerals [4]. Numerous studies have demonstrated that the availability of micronutrients in the rhizosphere relies on soil pH, organic matter, clay content, and other physical, chemical, and biological factors [1]. According to [5], Fe and Mn are prevalent in silicate minerals including biotite and hornblende. Zinc may also replace some of the principal elements of silicate minerals, whereas Cu and Mn are frequently bound firmly by organic matter. Micronutrient availability is also altered by interactions between other soil nutrients. The soil formation process, lithology, parent material, and pedogenesis play a significant effect in the regional variation of nutrient availability. Thus, information on the status of micronutrients in the soil of a region is crucial for determining the nature and extent of their deficiency/toxicity in order to formulate agricultural strategies that will assist farmers in understanding the problems associated with soil nutrients and the amount of fertilisers to be added to the soil for cost-effective production. In order to better comprehend the behaviour of trace elements in the soil environment, the primary purpose of this study was to examine the status of available nutrients in soil profiles and their relationship with other soil properties.

2. MATERIALS AND METHODS

The study area was the Narasinghpur block of the Cuttack district, which is situated in the Mid-Central Table land agro-climatic zone of Odisha, India. The study region was split into three broad physiographic divisions based on slope and elevation, including gently sloping upland (337 feet above MSL, slope of 3-5%), very gently sloping medium land (307 feet above MSL, slope of 1-3%), and virtually level low land (294 feet above MSL, slope of 0-1%). Using a GPS device, the landform of the research region was determined by traversing the area and collecting elevation data above Mean Sea Level (MSL) at various sites (Garmin make; model: GPSmap 76CSx). After a general traversal of the research region, three representative soil profiles were selected and exposed from three different topographic positions, including upland (20°37'16.5"N 84°55'37.5"E), medium land (20°31'23.8"N 85°01'43.3"E), and low land (20°27'36.8"N 85°02'55.4"E). Pedon 1, 2, and 3 related to the soil profiles of highland, medium land and low land respectively. Five layers delineated at 20cm intervals up to a depth of 100cm were sampled, processed, and stored for laboratory analysis. The soil samples were tested for texture using the Bouyoucos Hydrometer method [6], pH (1:2.5) and EC (1:2.5), organic carbon [7], exchangeable Ca & Mg [8], sulphur [9], DTPA extractable iron, manganese, copper, and zinc [10] and hot water extractable boron [11]. Pearson correlation analyses were conducted using [12].

3. RESULTS AND DISCUSSION

3.1 PHYSICO-CHEMICAL CHARACTERISTICS

3.1.1 Particle size distribution

Table 1 presented the various size distributions of the fine earth fraction of soil particles. The data showed that in Pedon 1, sand (%) ranged from 75 to 81, silt (%) ranged from 8.4 to 12.4, and clay (%) ranged from 9.6 to 14.6. In Pedon 2, the percentages of sand, silt, and clay ranged from 65 to 76, 6.4 to 13.4, and 13.6 to 27.6 respectively. Sand percentages in Pedon 3 ranged from 62 to 68, silt percentages from 15.4 to 13.4, and clay percentages from 18.6 to 32.6. Sand content was observed to decrease with pedon depth, whereas clay content showed the opposite pattern. It was due to the percolating water and the leaching of clay and colloidal fractions of soil from the surface to the subsurface layers. Statistically significant negative correlation between sand and clay (r= -0.947**) in Table 3 suggested that clay had been created through transformation of sand to silt and/or neosynthesis of clay [13].

3.1.2 Soil reaction (pH)

The surface soil of Pedon 1 was found to be slightly acidic with a pH value of 6.27, which increased with soil depth to a value of 7.12 at a depth of 60-80 cm before decreasing to 7.09. The surface soils of Pedon 2 were moderately acidic with pH values of 5.76, whereas those of Pedon 3 were neutral with pH values of 6.73. The pH was found to be increasing with depth in both Pedon 2 and 3. (Table 1). The increase in soil pH with soil depth could be due to leaching of basic cations from upper to lower horizons, primarily during periods of intense rainfall [14].

3.1.3 Electrical conductivity (EC)

The EC of all soil profiles remained below 1 dSm^{-1}, showing that they were non-saline in nature and suitable for all crop production. This low electrical conductivity could be related to soluble salt leaching and easy drainage during heavy rainfall [15].

3.1.4 Organic carbon (OC)

The surface layers of Pedon 1, 2, and 3 contained 0.59, 0.73, and 0.57 percent organic carbon, respectively (Table 1). In all soil profiles, a consistent decline in organic carbon with increasing soil depth was observed. Higher organic carbon content in the surface layers of all three pedons may be linked to the continuous accumulation and decay of crop residues [16].

Table 1. Distribution of particle size, soil pH, EC and organic carbon with respect to depth in representative pedons

Pedon Depth (cm)	Sand (%)	Silt (%)	Clay (%)	pH (1:2.5)	EC (dS m^{-1})	OC (%)
Pedon 1 (upland)						
0-20	81	8.4	10.6	6.27	0.15	0.59
20-40	79	11.4	9.6	6.73	0.13	0.41
40-60	78	9.4	12.6	6.77	0.11	0.27
60-80	76	9.4	14.6	7.12	0.09	0.24
80-100	75	12.4	12.6	7.09	0.05	0.14
Pedon 2 (medium land)						
0-20	76	9.4	14.6	5.76	0.18	0.73
20-40	73	13.4	13.6	6.02	0.07	0.49
40-60	70	6.4	23.6	6.54	0.06	0.29
60-80	66	7.4	26.6	7.04	0.03	0.22
80-100	65	7.4	27.6	6.78	0.02	0.21
Pedon 3 (lowland)						
0-20	68	13.4	18.6	6.73	0.19	0.57
20-40	65	13.4	21.6	6.98	0.17	0.41
40-60	63	10.4	26.6	7.33	0.06	0.24
60-80	62	5.4	32.6	7.25	0.02	0.22
80-100	63	7.4	29.6	7.58	0.01	0.18

3.2 Distribution of available secondary and micronutrients

3.2.1 Exchangeable Calcium and Magnesium

The surface layers of Pedon 1, 2, and 3 contained 4.11, 6.12, and 6.56 [cmol (p^+)/kg] exchangeable Ca, respectively (Table 2). Distribution of Exchangeable Ca followed an increasing trend with depth in all pedons and found to be highest in a depth of 60-80 cm i.e. 7.85, 8.52 [cmol (p^+)/kg] in pedon 1 and 2 respectively while for pedon 3 highest value was observed in a depth of 80-100 cm. The surface layers of Pedon 1, 2, and 3 contained 2.15, 3.12, and 3.54 [cmol (p^+)/kg] exchangeable Mg, respectively (Table 1). Distribution of Exchangeable Mg followed similar trend as that of exchangeable Ca. In all soils calcium and magnesium deficiency is not so high because of substantial quantity of Ca and Mg in the parent rock and minerals. Conscious farmers of the Cuttack district are applying agricultural liming materials frequently which also act as a source of the nutrients. The surface soils contained lower amount of exchangeable Ca and Mg than the sub surface layers of a profile. This may be due to removal of exch. Ca and Mg by the crop/vegetation from the surface horizons [17].

3.2.2 Available sulphur

In pedon 1, the uppermost layer (0-20 cm) contained the maximum concentration of sulphur (9.85 mg kg^{-1}), while the lowest concentration (7.89 mg kg^{-1}) was detected in the bottom layer (80-100 cm). In pedon 2, the upper layer (0-20 cm) contained the most available S (11.76 mg kg^{-1}) and the lower layer contained the least (6.95 mg kg-1) (80-100 cm). In Pedon 3, the highest concentration of available S (12.06 mg kg^{-1}) was found in the surface layer (0-20 cm), while the lowest concentration (7.03 mg kg^{-1}) was found in the lower layer (80-100 cm) (Table 2). Surface layers included more available sulphur than subsurface layers, which could be attributed to higher organic matter content in surface layers than deeper layers, as well as variable land usage and parent material [18].

3.2.3 Available iron

The range of available Fe in surface and subsurface soils was 127.85-278.81 mg kg^{-1} and 102.32-234.46 mg kg^{-1}, respectively. In pedon 1, the upper layer (0-20 cm) contained maximum available iron (127.85 mg kg^{-1}) and the bottom layer contained the least (102.32 mg kg^{-1}). In Pedon 2, the surface layer (0-20 cm) contained the most of the available Fe (150.28 mg kg^{-1}) and the lower layer contained the least (105.68 mg kg^{-1}) (80-100 cm). In pedon 3, the surface horizon (0-20 cm) contained the maximum concentration of available Fe (278.81 mg kg^{-1}) and the lower horizons (80-100 cm) contained the lowest concentration (163.38 mg kg^{-1}) (Table 2). The decreasing trend of available Fe with increasing soil depth may be a result of increased biological activity and organic carbon in the surface soils. This was further corroborated by the positive correlation (r= 0.346**) between available Fe and organic carbon and the negative correlation (r= -0.447**) between available Fe and soil pH (Table 3) [19, 20]**.**

3.2.4 Available manganese

The availability of manganese in surface and sub-surface soils varied between 68.48 and 144.98 mg kg^{-1} and 53.21 and 118.28 mg kg^{-1}, respectively (Table 2). The decreasing trend of accessible Mn with soil depth may be a result of humic material deposition in the surface layers. The greater concentration of available Mn in surface soils was attributable to the chelating of organic compounds produced during the decomposition of crop residue and addition of FYM [21]**.** These results were corroborated by a positive correlation of accessible Mn with organic carbon (r=0.356**) and a negative correlation with soil pH (r=-0.137**) (Table 3) [20]**.**

3.2.5 Available copper

In Pedon 1, the surface (0-20 cm) and bottom layer (80-100 cm) contained the maximum (0.86 mg kg-1) and minimum (0.31 mg kg^{-1}) concentrations of available copper, respectively. In Pedon 2, the surface layer (0-20 cm) contained the most available Cu (0.64 mg kg^{-1}) and the bottom layer contained the least (0.28 mg kg^{-1}) (80-100 cm). In Pedon 3, the surface (0-20 cm) contained the maximum available Cu (0.90 mg kg^{-1}) and the lowest (0.37 mg kg^{-1}) was found in the lowest horizon (80-100 cm) (Table 2). Due to its positive correlation (r=0.728**) with organic carbon and negative correlation (r= -0.313**) with soil pH, available Cu declined as soil depth increased (Table 3) [22].

3.2.6 Available zinc

The range of available zinc in surface and sub-surface soils were 0.54 to 0.63 mg kg^{-1} and 0.17 to 0.50 mg kg^{-1}, respectively. Due to lack of organic carbon in the deeper soil layers, Zn availability decreased with increasing soil depth (Table 2) [21]. Organic matter acts as a chelating agent for complexation, which reduces Zn adsorption, oxidation, and precipitation into unavailable forms, as evidenced by the positive correlation (r= 0.822**) between organic carbon and Zn availability and the negative correlation (r= -.571*) between Zn and soil pH (Table 3) [20].

3.2.7 Available boron

Boron availability in surface and sub-surface soils were between 0.37 and 0.47 mg kg^{-1} and 0.29 and 0.91 mg kg^{-1}, respectively. In Pedon 1, the subsurface layer (20-40 cm) contained the maximum quantity of available boron (0.52 mg kg^{-1}) and the lowest (0.29 mg kg^{-1}) was observed in the bottom layer (80-100 cm). In Pedon 2, the subsurface layer (40-60 cm) contained the maximum concentration of available B (0.52 mg kg^{-1}) while the lowest concentration (0.35 mg kg^{-1}) was found in the lowest horizon (80-100 cm). In Pedon 3, the subsurface (40-60 cm) contained the maximum concentration of available B (0.91 mg kg^{-1}) while the lowest concentration (0.46 mg kg^{-1}) was observed in the lowest layers (80-100 cm). Boron's greater buildup in the subsurface was aided by the leaching of boron in soluble form, which occurred in soils with a light texture and an acidic pH.

Table 2. Depth-wise distribution of available secondary and micronutrients in pedons

Pedon Depth (cm)	Exch. Ca [cmol(p^+)/kg]	Exch. Mg [cmol(p^+)/kg]	Avail. S (mg kg^{-1})	Fe (mg kg^{-1})	Mn (mg kg^{-1})	Cu (mg kg^{-1})	Zn (mg kg^{-1})	B (mg kg^{-1})
Pedon1 (upland)								
0-20	4.11	2.15	9.85	127.85	68.48	0.86	0.56	0.37
20-40	4.31	2.41	9.07	123.65	64.30	0.59	0.50	0.52
40-60	5.63	2.70	8.82	110.54	57.48	0.44	0.44	0.43
60-80	7.85	4.16	8.38	106.54	53.40	0.36	0.35	0.35
80-100	7.81	3.36	7.89	102.32	53.21	0.31	0.17	0.29
Pedon2 (medium land)								
0-20	6.12	3.12	11.76	150.28	78.15	0.64	0.54	0.45
20-40	6.21	3.34	9.63	127.52	66.31	0.51	0.45	0.49
40-60	6.53	3.46	9.33	120.96	62.90	0.45	0.43	0.52
60-80	8.52	4.52	7.11	116.16	60.40	0.36	0.39	0.41
80-100	8.21	4.21	6.95	105.68	54.95	0.28	0.36	0.35
Pedon3 (lowland)								
0-20	6.56	3.54	12.06	278.81	144.98	0.90	0.63	0.47
20-40	7.21	3.68	11.41	227.46	118.28	0.89	0.48	0.66
40-60	7.84	4.08	10.98	192.19	99.94	0.68	0.46	0.91
60-80	8.18	4.29	8.11	170.97	88.90	0.43	0.26	0.52
80-100	8.24	4.44	7.03	163.38	84.96	0.37	0.31	0.46

Table 3. Pearson correlation coefficient among several physico-chemical properties and available nutrients of pedon soil

	Sand	Silt	Clay	pH	EC	OC	Exch. Ca	Exch. Mg	Avail. S	Fe	Mn	Cu	Zn	B
Sand	1													
Silt	0.248	1												
Clay	-.941**	-.560*	1											
pH	-.582*	-0.212	.572*	1										
EC	0.492	.565*	-.617*	-.543*	1									

OC	0.435	0.366	-0.5	-.815**	.830**	1								
Exch. Ca	-.779**	-0.268	.760**	.642**	-.654**	-.669**	1							
Exch. Mg	-.840**	-0.331	.834**	.621*	-.632*	-.584*	.957**	1						
Avail. S	0.141	.561*	-0.316	-0.463	.832**	.761**	-0.429	-0.392	1					
Fe	-0.47	0.392	0.265	-0.447**	0.464	0.346**	0.072	0.154	.672**	1				
Mn	-0.465	0.389	0.262	-0.137**	0.468	0.356**	0.058	0.139	.675**	1.000**	1			
Cu	0.109	0.492	-0.264	-0.313**	.819**	.728**	-.520*	-0.445	.866**	.726**	.737**	1		
Zn	0.275	0.339	-0.353	-.571*	.795**	.822**	-.646**	-0.498	.762**	0.472	0.481	.805**	1	
B	-0.459	0.167	0.334	0.215	0.078	0.023	0.06	0.144	0.502	.527*	.526*	0.443	0.288	1
** Correlation is significant at the 0.01 level (2-tailed).														
* Correlation is significant at the 0.05 level (2-tailed).														

4. Conclusion

Plant nutrients in the research area varied with topography, although the differences weren't significant between upland, medium land and lowland. Sand decreased with pedon depth, while clay increased. It's caused by percolating water and leaching of clay and colloidal soil from the surface to the subsurface. In all pedons, soil pH increased but EC and organic carbon declined with depth. Surface soils have less exchangeable Ca and Mg than subsurface layers. This may be due to crop/vegetation removing Ca and Mg from surface strata. Micronutrient status in the study region: Fe>Mn>Cu>Zn>B. Available Ca and Mg increased with soil depth, but S, Fe, Mn, Cu, Zn, and B decreased. Available Fe, Mn, Cu, and Zn correlated positively with soil organic carbon and negatively with soil pH. Higher micronutrient levels on the surface compared to subsurface soils presumably resulted from the enhanced breakdown of soil organic matter and agricultural residues. Secondly, root distribution and rooting depth affect micronutrient concentrations because nutrients taken up by deeper roots are transported aboveground and redeposited on the soil surface [23, 24, 25].

References

1. Nazif W, Perveen S, Saleem I. Status of micronutrients in soils of District Bhimber (Azad Jammu and Kashmir). J. Agric. Biol. Sci. 2006; 1: 35-40.

2. Mustapha S, Voncir N, Umar S, Abdulhamid NA. Status and Distribution of some Available Micronutrients in the Haplic Usterts of Akko Local Government Area, Gombe State, Nigeria. International Journal of Soil Science. 2011; 6: 267-274.

3. Wimmer, Monika A, Sabine Goldberg, Gupta U C. "Boron." Handbook Of Plant Nutrition. 2015: 305.

4. Moraghan JT, Mascagni HJ. Environmental And Soil Factors Affecting Micronutrient Deficiencies And Toxicities. Micronutrients In Agriculture Micronutrients. 1991: 371-425.

5. Brady NC, Weil RR. The Nature and Properties of Soil. 13th Edn., Macmillan Publishing Co., New York, USA., 2005; pp: 960.

6. Piper CS. Soil and Plant analysis. Inter-Science Publication., New York; 1950.

7. Jackson ML. Soil Chemical Analysis, Prentice Hall of India. Private limited, New Delhi; 1973.

8. Page AI, Miller RH, Keeney DR, Baker DE, Roseoc Ellis JR. Rhodes J. Methods of soil analysis Part 2: Chemical and Microbiological Properties, 2nd Edition Agronomy Monograph No. 9. American Society of Agronomy and Soil Science Society America Madison, Wisconsin, USA; 1982.

9. Chesnin L, Yien CH. Turbidimetric determination of available sulphates, Proceedings of Soil Science Society of America. 1950; 14: 149-51.

10. Lindsay WL, Norvell WA. Development of a DTPA soil test for zinc, iron, manganese, and copper, Journal of Soil Science Society of America. 1978; 42:421-448.

11. John MK, Chuah HH, Ndufeld JH. Application of improved azomethine-H method to the determination of boron in soils and plants. Analytical Letters. 1975; 8: 559-568.

12. Gomez K, Gomez A. Statistical procedure for agricultural research, 2nd edition, an International rice research institute book, A Wiley-Intersclence Publication; 1983.

13. Karmakar RM. Genesis and classification of soils of Northern Brahmaputra Valley of Assam. Ph.D. Thesis, IARI, New Delhi; 1985.

14. Rajeshwar M, Ramulu V. Vertical distribution of available macro and micronutrients in soil profiles of Ganapavaram pilot area of Nagarjuna Sagar left canal command area of Andhra Pradesh, Asian Journal of Soil Science. 2016; 11(1): 202-218.

15. Beeman K, Hegde R, Vasundhara R, Anil KKS, Dharumarajan S, Lalitha M, Singh SK. Characterization and classification of soils of Bilalgodu micro- watershed, Chikmagalur district, Karnataka,International Journal of Chemical Studies. 2018; 6(1): 1812-1815.

16. Zhang J, Wang M, Wu S, Muller K, Cao Y, Liang P, Cao Z, Christie P, Wang H. Land use affects soil organic carbon of paddy soils: empirical evidence from 6280 years BP to present. Journal of Soils and Sediments. 2015.

17. Karmakar RM, Rao AEV. Soils on different physiographic units in Lower Brahmaputra Valley zone of Assam. I. Characterization and classification. Journal of the Indian Society of Soil Science. 1999; 47: 761-767.

18. Srinivasan R, Natarajan A, Kumar KSA, Kalaivanan D. Distribution of available macro and micronutrients in cashew growing soils of Dakshina Kannada district of Coastal Karnataka, Madras Agricultural Journal. 2013; 100 (1-3): 747-750.

19. Ravi P, Raj GB, Rao PC. Distribution of DTPA extractable Micro Nutrients in Rice growing soils of Karimnagar district of Andhra Pradesh, Helix. 2014; 1:494- 497.

20. Bungla P, Pachaury SP, Srivastava S, Pathak PC, Singh RK. Macro- and micro-nutrients statas in some soils of Pithoragarh district of Uttarakhand.Annals of Plant and Soil Research. 2019; 21 (2): 108-115.

21. Satish S, Naidu MVS, Ramana KV. Vertical distribution of available nutrients in soils of Brahmanakotkur watershed of Kurnool district in Andhra Pradesh, International Journal of Chemical Studies. 2018; 6(5): 2916-2925.

22. Giri JN, Sadanshiv NS, Metkari PM. Status and distribution of available micronutrients along a toposequence at Bazargaon plateau, Maharashtra, An Asian Journal of Soil Science. 2017; 12 (02): 300-306.

23. García-Marco S, Gómez-Rey MX, González-Prieto SJ. Availability and uptake of trace elements in a forage rotation under conservation and plough tillage. Soil and Tillage Research. 2014; 137:33-42.

24. Jiang Y, Zhang YG, Zhou D, Qin Y, Liang WJ. Profile distribution of micronutrients in an aquic brown soil as affected by land use. Plant, Soil and Environment. 2009; 55(11):468-476.

25. Franzluebbers AJ, Hons FM. Soil-profile distribution of primary and secondary plant-available nutrients under conventional and no tillage. Soil and Tillage Research. 1996; 39(3):229-239.