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Physical and Chemical Properties of Major Upland Soils in Shandong Province of China

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In the present study, physical and chemical properties of major upland soils in Shandong Province, China, were examined for the purpose of sustainable and continuous use of agricultural land. The particle density ranged from 2.58 to 2.67 Mg/m^3 and the bulk density ranged from 1.30 to1.39 Mg/m^3. The organic matter content was in a generally low level of 10.1 to 20.8 g/kg and was found to be a controlling factor of soil productivity in Shandong Province. The contents of plant–available nitrogen, phosphorus and potassium were strongly affected by the plant–nutrient management practice of soils. The cation exchange capacity ranged from 18.2 to 25.8 $cmol_c/kg$, indicating the high potentiality of soils for fertilizer retention.

INTRODUCTION

Shandong Province makes a major base of food production in China, supported by the suitable agro–climatic conditions. The agricultural production of Shandong Province is in a first–rank in the country. Main products are wheat, cotton, peanut, tobacco, vegetables and fruits. Especially since 1980s production of vegetables has been promoted in Shandong Province, and now the export of vegetables is in a top position of the country.

Shandong Province is located in 34°22'～38°23' north latitude and 114°19'～122°43' east longitude. The total land area of Shandong province is 157,800 km^2. The flowers north plain spreads over the western part, and the eastern side is bordered by the Bo and Yellow Seas. In physiography Shandong Province is divided into the Luxibei alluvial plain, Jiaolai plain, Luzhongnan low mountain hill and Jiaodong low mountain hill. The whole region is classified as the temperate, continental monsoon climate zone. Annual precipitation is 600～900 mm and gradually decreases from southeast to northwest. Eighty–five to 90% of the annual precipitation occurs in May through October with a maximum in July to September. The mean annual temperature of Shandong Province is 11～13°C.

In the present study, some physical and chemical properties of major upland soils of Shandong Province were examined from the viewpoint of the establishment of sustainable and continuous use of agricultural land. Four major soil types of Shandong Province were selected for this purpose. They are Brown soil (Albic Luvisol), Cinnamon soil (Haplic Luvisol), Alluvial soil (Calcaric Cambisol), and Black Clay soil (Calcic Vertisol), which have been formed under the different landform and climatic conditions prevailing in Shandong Province. The soils were evaluated according to the standard applied to upland soils of Northeast China (Egashira *et al.*, 2000), and practices for improvement were proposed based on the comparison with the target values set for upland soils of different soil types in Japan (National Council Meeting for Soil Conservation and Survey (ed), 1991).

MATERIALS AND METHODS

Soil samples

The soil samples were collected at 12 locations in Shandong Province, which are shown in Fig. 1. Brief description of soil samples is given in Table 1. Sampling was done in October 2005, and 1 kg of soil sample was taken from the surface layer. Samples S1 and S2 were taken from the tea garden and sample S5 from the vegetable field. Other samples were taken from the wheat or maize field. Concerning the fertility management, more chemical fertilizers have been applied to the tea

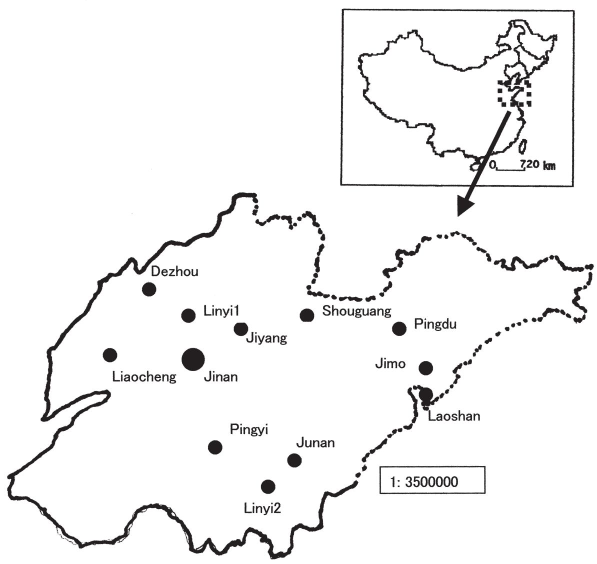

Fig. 1. Sampling locations of soils in Shandong Province of China.

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Table 1. Brief description of soil samples used in the study

Soil type	Sample No	Location (Commune)	Main crops	Soil classification by FAO/UNESCO
Brown soil	S1 S2 S3	Laoshan Jimo Junan	Tea, maize, wheat, vegetables, fruits, and peanut	Albic Luvisol
Cinnamon soil	S4 S5 S6	Jinan Shouguang Dezhou	Maize, wheat, vegetables, fruits, and peanut	Haplic Luvisol
Alluvial soil	S7 S8 S9	Liaocheng Linyi–1 Jiyang	Maize, wheat, vegetables, fruits, and peanut	Calcaric Cambisol
Black Clay soil	S10 S11 S12	Pingdu Linyi–2 Pingyi	Maize, wheat, vegetables, and fruits	Calcic Vertisol

garden and the vegetable filed than to the wheat and maize fields. Collected soil samples were air–dried at room temperature followed by the physical and chemical analyses.

Physical and chemical analyses

Physical and chemical properties of soils were mainly analyzed by the soil standard methods of analysis (Committee for Soil Standard Methods for Analyses and Measurements (ed), 1986). The particle density was measured by the pycnometer method. The bulk density was measured for soil collected in a 100–mL can. The pH was measured in the suspension having a soil:water ratio of 1:2.5. The organic carbon content was determined by the Tyurin method and multiplied by the coefficient of 1.724 to give the organic matter content. The total nitrogen content was determined by the Kjeldahl method. The total phosphorus content was determined by the ascorbic acid method after decomposition with perchloric acid. The soil was digested by the $HF–HNO_3–HClO_4$ acid treatment and analyzed for the total potassium by an atomic absorption spectrophotometer. The available nitrogen content was determined by the alkalinolysis–distillation method (Nanjing Soil Institute, Academia Sinica, 1978). The available phosphorus content was determined by the Bray P–2 method (Committee for Soil Standard Methods for Analyses and Measurements (ed), 1986). The non–exchangeable potassium content was determined by the 1M–nitric–acid extraction method (Committee of Agricultural Chemistry in Chinese Pedology Association (ed), 1984). The cation exchange capacity (CEC) and contents of exchangeable cations were determined by the method proposed by Muramoto *et al.* (1992).

RESULTS

The physical and chemical properties examined for the soils in Shandong Province are shown in Tables 2 and 3.

Table 2. Physical and chemical properties of soils in Shandong Province

Soil type	Sample No	Particle density	Bulk density	Porosity	pH	Organic matter	Total N	Total P_2O_5	Total K_2O
		(Mg/m^3)		(%)		(g/kg)			
Brown soil	S1	2.59	1.31	49.4	5.8	19.8	1.4	1.3	28.7
	S2	2.59	1.30	49.8	6.3	15.0	1.1	1.2	28.6
	S3	2.60	1.30	50.0	6.5	11.8	0.7	1.2	24.3
	Average	2.59	1.30	49.7	6.2	15.5	1.1	1.2	27.2
Cinnamon soil	S4	2.58	1.32	48.8	7.6	12.3	0.6	1.1	26.2
	S5	2.59	1.33	48.6	6.7	20.8	1.5	1.2	28.8
	S6	2.58	1.35	47.7	7.1	13.8	0.6	1.1	24.9
	Average	2.58	1.33	48.4	7.1	15.6	0.9	1.1	26.6
Alluvial soil	S7	2.60	1.35	48.1	7.0	11.9	0.7	1.0	25.6
	S8	2.62	1.36	48.1	7.1	10.8	0.6	1.0	26.2
	S9	2.60	1.38	46.9	7.1	12.1	0.6	1.0	26.3
	Average	2.61	1.36	47.7	7.1	11.6	0.6	1.0	26.0
Black Clay soil	S10	2.67	1.39	47.9	6.8	10.1	0.6	0.8	25.2
	S11	2.63	1.38	47.5	6.9	10.6	0.7	0.8	23.8
	S12	2.67	1.38	48.3	7.0	10.9	0.7	0.9	22.9
	Average	2.66	1.38	48.1	6.9	10.5	0.7	0.9	24.0

Table 3. Chemical properties of soils in Shandong Province

Soil type	Sample No	Available N	Available P	Non–ex–changeable K	Exchangeable cations ($cmol_c$/kg)				CEC ($cmol_c$/kg)
		(mg/kg)			Ca^{2+}	Mg^{2+}	K^+	Na^+	
Brown soil	S1	166	167	680	15.1	3.4	0.25	0.10	18.9
	S2	144	159	579	14.4	3.5	0.23	0.09	18.5
	S3	86	112	322	14.0	3.7	0.23	0.09	18.2
	Average	132	146	527	14.5	3.5	0.24	0.09	18.5
Cinnamon soil	S4	90	113	349	15.8	2.7	0.21	0.06	18.8
	S5	186	188	689	15.6	3.0	0.43	0.12	21.2
	S6	91	121	351	15.3	2.1	0.18	0.08	17.9
	Average	122	141	463	15.6	2.6	0.27	0.09	19.3
Alluvial soil	S7	82	122	390	15.2	2.3	0.18	0.05	18.6
	S8	79	112	364	15.3	2.8	0.16	0.06	18.9
	S9	87	131	396	15.2	2.6	0.17	0.05	18.3
	Average	83	122	383	15.2	2.6	0.17	0.05	18.6
Black Clay soil	S10	76	109	351	17.6	4.5	0.31	0.10	22.6
	S11	72	112	350	18.2	5.2	0.38	0.09	25.3
	S12	80	123	362	18.1	5.7	0.40	0.12	25.8
	Average	76	115	354	18.0	5.1	0.36	0.10	24.6

Physical properties

The particle density and bulk density of soils were in ranges of 2.58 to 2.67 and of 1.30 to 1.39 Mg/m^3, respectively. The particle density of soils of the Alluvial soil and Black Clay soil was over 2.60 Mg/m^3 and a little higher than that of the Brown soil and Cinnamon soil. Parent materials of the Alluvial and Black Clay soils are recent sediments of the Yellow River, Huai River and their tributaries, while those of the Brown and Cinnamon soils are mainly weathered materials of loess and rocks. Variation of the particle density is mainly ascribable to the differences in the parent material among the soil types. The porosity was in a range of 46.9 and 50.0%, and a large difference due to the soil type was not observed.

Chemical properties

The pH of soils of the Cinnamon, Alluvial and Black Clay soils was in a range between 6.7 and 7.6 and was in a neutral to slightly alkaline range. In contrast, the pH of soils of the Brown soil was 5.8 to 6.5, showing the slight acidity. The pH was especially low to S1 with a value of 5.8, followed by S2. S1 and S2 were taken from the tea garden, and heavy application of chemical fertilizers can be considered to be responsible for their lowest pH among the soils examined in the present study. In addition, the pH of S5 was 6.7 and was lower than the pH of the other two soils of the Cinnamon soil. S5 was taken from the vegetable field, and the heavy application of chemical fertilizers may be a reason for its lower pH, similar to S1 and S2.

The organic matter content of soils ranged from 10.1 to 20.8 g/kg with an average of 13.3 g/kg and was found to be low in general. Among the samples, S1 and S2 of the Brown soil and S5 of the Cinnamon soil showed the relatively high organic matter content of 19.8, 15.0 and 20.8 g/kg, respectively, whereas the organic matter content of all samples of the Alluvial and Black Clay soils was below 12 g/kg. Three samples of S1, S2 and S5 were taken from the tea garden and vegetable field, as stated in the above. Organic fertilizers such as chicken excrements and cowdung, in addition to chemical fertilizers, have been applied to the tea garden and vegetable field in Shandong Province. This practice is probably leading to the increase in the organic matter content of soils in the tea garden and vegetable field.

The total N content of soils was in a range between 0.6 and 1.5 g/kg. It was higher for S1 and S2 of the Brown soil and S5 of the Cinnamon soil having the values of 1.4, 1.1 and 1.5 g/kg, respectively, than for the other samples having the values below 0.7 g/kg. The first three samples were taken from the tea garden and vegetable field, and the reason considered for the higher organic matter content is similarly applicable to their higher total N content. The total P_2O_5 content of soils ranged from 0.8 to 1.3 g/kg and was in the order of Brown＞Cinnamon＞Alluvial＞Black Clay soils in average. The total K_2O content of soils was in a range between 22.9 and 28.8 g/kg and was lowest for S12 of the Black Clay soil and highest for S5 of the Cinnamon soil. Among the soil types, it was highest for the Brown soil with an average value of 27.2 g/kg and lowest for the Black Clay soil with an average value of 24.0 g/kg.

The available N content of soils ranged from 72 to 186 mg/kg and was highest for S5, followed by S1 and S2, and lowest for S11. Among the soil types, it was highest for the Brown soil (132 mg/kg), followed by the Cinnamon soil (122 mg/kg) and then Alluvial soil (83 mg/kg), and lowest for the Black Clay soil (76 mg/kg). The available P content of soils ranged between 109 and 188 mg/kg and was highest for S5, followed by S1 and S2, and lowest for S10. Similar to the available N content, it was highest for the Brown soil (146 mg/kg), followed by the Cinnamon soil (141 mg/kg) and then Alluvial soil (122 mg/kg), and lowest for the Black Clay soil (115 mg/kg). The non–exchangeable K content of soils was in a range of 322 to 689 mg/kg and was highest for S5, followed by S1 and S2, and lowest for S3. Similar to the available N and P contents, it was highest for the Brown soil (527 mg/kg), followed by the Cinnamon soil (463 mg/kg) and then Alluvial soil (383 mg/kg), and lowest for the Black Clay soil (354 mg/kg). The above results were evaluated to indicate that the levels of available N, available P and non–exchangeable K of soils were more strongly affected by the fertility management and cropping patterns than the characteristics of parent materials.

Exchangeable cations were mainly Ca^{2+} and Mg^{2+} for the soils of all soil types examined. The content of exchangeable Ca^{2+} was highest for the Black Clay soil with an average value of 18.0 $cmol_c$/kg and lowest for the Brown soil with an average value of 14.5 $cmol_c$/kg. Similar to the exchangeable Ca^{2+}, the content of exchangeable Mg^{2+} was highest for the Black Clay soil (5.1 $cmol_c$/kg) and lowest for the Cinnamon soil and Alluvial soils (2.6 $cmol_c$/kg). The content of exchangeable K^+ was highest for the Black Clay soil (0.36 $cmol_c$/kg) and lowest for the Alluvial soil (0.17 $cmol_c$/kg). The exchangeable Na^+ was highest for the Black Clay soil (0.10 $cmol_c$/kg), followed by the Brown and Cinnamon soils (0.09 $cmol_c$/kg), and lowest for the Alluvial soil (0.05 $cmol_c$/kg).

The CEC of soils ranged from 18.2 to 25.8 $cmol_c$/kg. The CEC of soils of the Brown, Cinnamon and Alluvial soils was in a narrow range of 18.2 to 18.9 $cmol_c$/kg, except S5 having the value of 21.2 $cmol_c$/kg, and was considerably lower than the CEC of the Black Clay soil (22.6～25.8 $cmol_c$/kg). The relatively high CEC of S5 can be ascribed to a little higher organic matter content. Soil samples of the Alluvial soil were taken from the slightly sloped land, while those of the Black Clay soil were from the flat land. Variation of CEC of soils is considered to be due to the general effects of parent material, landform and cultivation management.

DISCUSSION

Table 4 shows the criteria for evaluation of the status of available N, available P, non–exchangeable K and CEC, which were tentatively applied to upland soils of Northeast China for assessment of the chemical fertility status of soils by Egashira *et al.* (2000). Assessment of the chemical fertility status of upland soils in Shandong Province was attempted based on the criterion–evaluation relationship of Table 4 and is shown in Table 5, in order to understand the present status of fertility of soils in Shandong Province. The available N was evaluated to be in the high level for S1 and S5, in the middle level for S2, and in the low level for the remaining samples. It indicates that the fertility status of soil on the available N is strongly affected by the plant–nutrient management practice to soil. This is because the high to middle level of available N was observed only to the soils collected from the tea garden and vegetable field which have been subjected to intensive organic and chemical fertilization and because all soils collected from the maize and wheat

Table 4. Criteria for evaluation of the status of available nitrogen and phosphorus, and non-exchangeable potassium, tentatively applied to upland soils of Northeast China by Egashira *et al.* (2000)

Evaluation item	Available N			Available P (mg/kg)			Non–exchangeable K			CEC ($cmol_c$/kg)		
Criterion	＞150	150～100	＜100	＞200	200～100	＜100	＞700	700～350	＜350	＞25	25～15	＜15
Evaluation	High	Middle	Low	High	Middle	Low	High	Middle	Low	High	Middle	Low

Table 5. Evaluation of the fertility status of upland soils in Shandong Province

Soil type	Sample No	Available N	Available P	Non–ex–changeable K	CEC
Brown soil	S1	H	M	M	M
	S2	M	M	M	M
	S3	L	M	L	M
Cinnamon soil	S4	L	M	L	M
	S5	H	M	M	M
	S6	L	M	M	M
Alluvial soil	S7	L	M	M	M
	S8	L	M	M	M
	S9	L	M	M	M
Black Clay soil	S10	L	M	M	M
	S11	L	M	L	H
	S12	L	M	M	H

H: high level; M: middle level; L: low level.

Table 6. Evaluation of chemical properties of upland soils in Shandong Province based on the comparison with the target values set for upland soils in Japan

Soil type	Sample No	pH	Organic matter (g/kg)	Exchangeable cations ($cmol_c$/kg)			CEC ($cmol_c$/kg)
				Ca^{2+}	Mg^{2+}	K^+	
	Target value	6.0〜6.5	＞30	＞8.0	＞1.0	0.3〜0.6	＞15
Brown soil	S1	— [a]	—	≡	≡	—	≡
	S2	≡ [b]	—	≡	≡	—	≡
	S3	≡	—	≡	≡	—	≡
Cinnamon soil	S4	—	—	≡	≡	—	≡
	S5	—	—	≡	≡	≡	≡
	S6	—	—	≡	≡	—	≡
Alluvial soil	S7	—	—	≡	≡	—	≡
	S8	—	—	≡	≡	—	≡
	S9	—	—	≡	≡	—	≡
Black Clay soil	S10	—	—	≡	≡	≡	≡
	S11	—	—	≡	≡	≡	≡
	S12	—	—	≡	≡	≡	≡

[a] —: out of the target value.
[b] ≡: within the target value.

fields showed the low level of available N. The available P was in the middle level for all soils examined in the present study, suggesting accumulation of available P by application of chemical fertilizers. Concerning the non–exchangeable K, most soils showed the middle level, except S3, S4 and S11 which were in the low level.

In contrast to the available N and non–exchangeable K contents, the CEC was in the high level for S11 and S12 belonging to the Black Clay soil and in the middle level for the other samples. The high to middle level of CEC indicates the high potentiality of soils for fertilizer retention. The highest CEC for the Black Clay soil along with its highest exchangeable cations content (Table 3) suggests the highest inherent potentiality of the Black Clay soil among the four soil types in Shandong Province. It is easy to expect the higher clay percentage and domination of smectitic clay to soils of the Black Clay soil, and this is probably a reason for the highest CEC of the Black Clay soil.

The selected chemical properties of soils in Shandong Province were compared with the target values set for upland soils of different soil types in Japan (National Council Meeting for Soil Conservation and Survey (ed), 1991), in order to recommend appropriate practices for improvement of soil chemical properties. The results are shown in Table 6. The organic matter content of all soils was lower than the target value. It is a greatest limiting factor of productivity of soils in Shandong province. In addition, the level of exchangeable K of most soils should be improved by continuous application of chemical fertilizers.

CONCLUSIONS AND PROPOSAL

Based on the evaluation of chemical properties of soils from four major soil types in Shandong Province, China, it is concluded that the inherent potentiality of soils is mainly determined by the soil type, probably controlled by the amount and type of clay minerals, and that the nutrient status of soils is strongly affected by the plant–nutrient management practice.

The urgent and first–priority task in the plant–nutrient management practice in Shandong province is the continuous application of organic amendments to improve and keep the organic matter status of soils. In addition, more nitrogen and potassium and less phosphorus should be applied in the form of chemical fertilizers.

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