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Paddy Soil Properties in Nangarhar Province, East Afghanistan

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Abstract

Paddy soil properties in 20 villages in Nangarhar province, East Afghanistan were investigated. The soils, which were mostly classified as sandy loam or loam, were alkaline and contained carbonate ranging from 4.9 to 16.9 g C kg^{-1}. The average total N and organic C, (0.36 N and 6.2 C g kg^{-1}) was low compared to the average values in tropical Asian paddy soils. Calcium was the predominant exchangeable cation followed by Mg, K and Na in that order. The available P (Olsen-P) content was 20.7 mg P_2O_5 kg^{-1} on average and did not vary significantly throughout the study area, while the available Si content, (261 mg SiO_2 kg^{-1}) was comparable with the level in tropical Asia. The available micronutrients (DTPA-TEA extraction) Fe, Mn, Cu and Zn, were 35.9, 9.6, 4.75 and 0.33 mg kg^{-1} on average. The paddy soil properties were generally low in fertility compared to those in tropical Asia, while the available P and Zn contents were deficient for rice growth. Paddy fields in Nagarhar province could be divided into groups according to the location. The paddy soil properties varied in Kabul and Kunar watersheds and were influenced by spot distribution of different types of parent materials such as limestone, dolomite and lava.

Discipline: Soil, fertilizer and plant nutrition
Additional key words: available Zn, micronutrients

Introduction

Decades of war destroyed infrastructure in Afghanistan and decimated its development. The national population is about 30 million, about 80% of whom are engaged in agriculture (CIA 2012). In an effort to rebuild the country, the international community has focused on the agricultural sector due to its strategic role. Various projects have been conducted in Afghanistan by several countries and international organizations to improve the agricultural sector. Wheat, rice, maize and barley are the major crops with production of 4532, 672, 437 and 301 x 10^3 ton per year, respectively (FAO 2012). Rice has the highest yield of 3.4 ton ha^{-1} among the 4 major crops according to FAOSTAT (FAO 2012). The price of polished rice ranged from 0.26 to 0.6 US$ kg^{-1} depending on the variety and quality, and exceeding the prices (0.16 US$ kg^{-1}) of wheat and maize (JICA 2007). Accordingly, efforts to improve agriculture must focus on increasing rice production and quality in Afghanistan. However, there are also severe constraints to achieving the desired improvement, including irrigation facilities destroyed in war, lack of accessibility to fertilizer and agrochemicals for farmers, lack of basic knowledge of agricultural practices among both farmers and government officials, and lack of basic information on local resources such as soil and water qualities. Lack of soil property data is one of the major constraints; not only for local farmers but also other interest groups involved in agricultural development in Afghanistan. There is little information available on Afghan soil properties. Watts and Mitchell (2009) reported on the iodine status in soils in Kabul and Nangarhar, but not on any other parameters, while other reports of FAO (1973) and ICARDA (2002) also provided only limited details of soil properties such its pH and electrical conductivity (EC). To achieve the improvement long sought in Afghan agriculture, it is important to provide more information for both Afghans and other development agencies concerned in Afghan agricultural development. The present article aimed to report on the soil properties of lowland paddy fields in Nangarhar province, East Afghanistan, which is a main rice production area. To discuss the soil

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characteristics, we compared the analytical results of the soil with the tropical Asian paddy field soil properties (Kyuma 2004) as reference values, despite the differing climatic conditions.

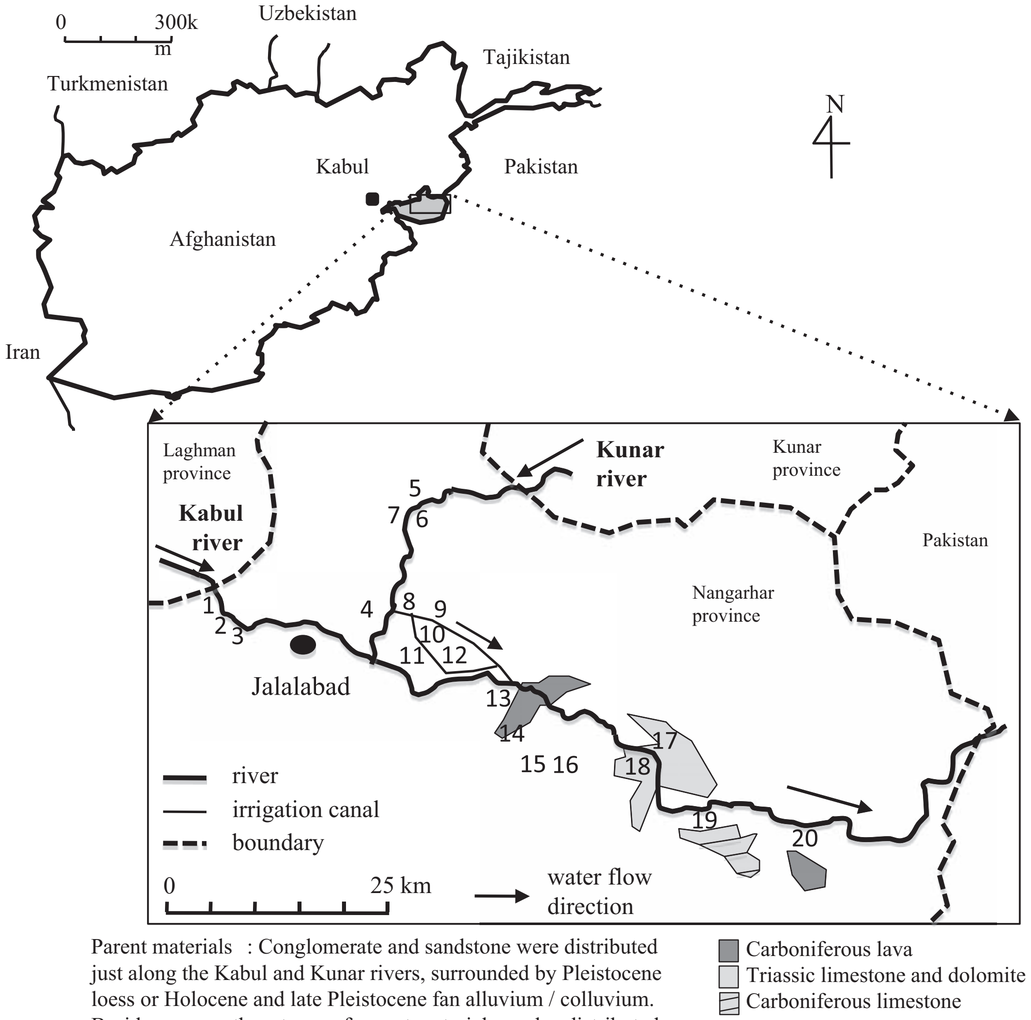
Materials and Methods

1. Description of the study area

The study area, Nangarhar province, one of the major rice producing areas, is located in East Afghanistan (Fig. 1). Annual precipitation ranges from 90 to 200mm and the monthly mean temperature from less than 10ºC in December and January, to more than 30ºC during the July to September period at the provincial capital, Jalalabad (ICARDA 2002). Here, a technical cooperation project, named "Improvement of Rice-based Agriculture in Nangarhar Province", was operated by the Japan International Cooperation Agency (JICA) from September 2007 to March 2011. In this project, 20 villages we could safely access from Jalalabad were selected for soil sampling. Conglomerate and sandstone were distributed just along the rivers of Kabul and Kunar, surrounded by Pleistocene loess or Holocene and late Pleistocene fan alluvium / colluvium (USGS 2006). Paddy fields are distributed on these parent materials, while some other types of parent materials, such as Triassic limestone / dolomite and carboniferous lava, are distributed elsewhere (Fig. 1). Major soil types in the present study sites included Xerothents, Xeropsamments, Xerochrepts and Calcixeralfs (USDA-NRCS 2001).

2. Rice cultivation practices

The Afghan Survey Unit of Coordination of Afghan Relief (ASU-CoAR 2008) reported that rice yield, (unhusked) in this region ranged from 1750 to 2800 kg ha^{-1}. According to the ASU-CoAR report (2008), land is ploughed using oxen or tractors, irrigated from June to July and, harrowed and leveled by oxen or tractor a few days later. Diammonium phosphate (DAP) of 125 to 250 kg ha^{-1}



Parent materials : Conglomerate and sandstone were distributed just along the Kabul and Kunar rivers, surrounded by Pleistocene loess or Holocene and late Pleistocene fan alluvium / colluvium. Besides, some others types of parent material are also distributed, as shown in the above figure.

Fig. 1. Location of sampling sites

is applied in the field. Some farmers who can afford it apply additional DAP and urea after weeding. A nursery is prepared in the field and 30-40 days after seed sowing, seedlings are transplanted in rows. The cultivated rice varieties were not surveyed in detail and were said to be local and improved ones. A month after transplanting, farmers weed by hand, usually with no application of herbicide. When the rice is infected by stem borer, farmers apply insecticide sold in Jalalabad city if they can afford it. The rice is harvested by hand. Agrochemicals such as fertilizers and insecticides used here are mainly imported from Pakistan and China. However, they have not been inspected and the quality has not been guaranteed by any organization.

Although there was no accessible survey report on irrigation practices, we observed that irrigation water was intermittently supplied to the fields. Once water is applied to the paddy fields, the farmer waits until the water disappears from the soil surface before the next irrigation.

3. Sampling and laboratory analyses

Soil samples were collected from 20 villages in 6 districts during the period June to August 2008 in Nangarhar Province. Surface soils at a depth of 0 to 20 cm were sampled from 5 points in each rice field and used to form a composite sample. The soil samples were then air-dried, ground and passed through a 2 mm sieve for laboratory analyses. Soil texture was determined by the pipette method (Gee & Bauder 1986). Soil pH and electrical conductivity (EC) were determined by the glass electrode method with a soil:water ratio of 1:5. Total C (TC) and N (TN) were determined by the dry combustion method using an N-C analyzer (MT-700 J-Science Co., Ltd., Kyoto, Japan). To determine the content of carbonate as inorganic C (C_{inorg}), CO_2 released by acid dissolution was trapped by 1M NaOH absorbent (Bundy & Bremner 1972), while the content of CO_2 trapped by NaOH was determined using an electrical conductivity method (Lindsay & Norvell 1978, Rodella & Saboya 1999). Organic C (C_{org}) content was calculated as the balance of TC and C_{inorg}. The carbon and nitrogen ratio (C/N) was calculated from C_{org} and TN and used to indicate soil organic matter quality. Available P was extracted by the Olsen method (Olsen-P, Olsen & Sommer 1982) to unify the analytical method with a deficiency criterion of Doberman and Fairhurst (2000). The P content was determined by the molybdenum blue method, which was also used to determine the available (available) Si extracted in 1 mol L^{-1} acetate buffer (pH 4.0) (Imaizumi & Yoshida 1958). Exchangeable (ex.) Ca, Mg, K and Na were extracted by 1 M NH_4OAc (pH 7.0) at a soil to solution ratio of 1:10. Available (available) Zn, Cu, Fe and Mn were extracted in DTPA-TEA (diethylene triamine pentaacetic acid – triethanolamine, pH 7.3) solution (Lindsay & Norvell 1978, Reed & Martens 1996). Ex. cations and available Zn, Cu, Fe and Mn were determined using an inductively coupled plasma atomic emission spectrophotometer (ICPE 9000 Shimadzu Co. Ltd., Kyoto, Japan).

4. Statistical analysis

The correlation coefficient was calculated to examine the relationship between soil parameters, while principal component analysis (PCA) was also performed to summarize the data obtained and investigate the relationship between soil properties (Kosaki & Juo 1989). All statistical analyses were employed by JMP version 4.0.2 (SAS 2001).

Results and discussion

1. General soil properties

Table 1 shows the soil properties, reference values of tropical Asia paddy fields (Kyuma 2004) and deficiency criteria of selected parameters (Doberman & Fairhurst 2000).

The soil textural classes were loam and sandy loam, except for Kachara 2 classified as sand. The soil pH was 8.4 on average and ranged from 7.8 to 8.9. This alkaline soil condition was due to carbonate accumulation, the content of which is shown as C_{inorg} in Table 1. The contents of C_{inorg} accounted for 30 to 90% of TC. The high carbonate content and pH in the paddy soils were caused by carbonate-rich geology and dry climate conditions not common in Asian paddy fields. Carbonate dissolves and does not accumulate in the acidic soil conditions found in Asian paddy fields. Such carbonate accumulation and high-pH paddy soils were also observed in the mid-highlands of Kenya, where Vertisols were developed from calcareous-basalt and a dry season (Kondo et al. 2001). The rice yield in this region exceeded 6 ton ha^{-1}, indicating that it was not constrained by carbonate accumulation and alkaline condition in the paddy fields. The content of C_{org} was generally low compared with the average TC content in tropical Asia, in which TC is considered almost equal to C_{org} as carbonate does not accumulate. TN content was also low compared with the average in tropical Asia. Local farmers usually do not apply organic matter in their paddy fields. In our brief observation of organic waste management in study sites, rice straw is removed from the fields and fed to animals, while animal dung is dried and used as fuel. In addition, the wet and dry cycles of the soil caused by intermittent irrigation might enhance the soil organic matter decomposition and these factors might account for the low C_{org} and TN levels. The average C/N ratio (18.3) exceeded the mean value in tropical Asia (Table 1) and sites with higher C_{org} had a higher C/N ratio (Table 2). Plant residues with soil samples less than 2 mm in size had a high C/N value compared with soil C/N, possibly resulting in a high C/N value under a low C_{org} condition.

The average value of EC was 0.20 dS m^{-1}, while the

Table 1. Soil properties in paddy fields in Nagarhar province

Site No	District	Village											Exchangeable						Available			
			Sand	Silt	Clay	pH	TC	C_{inorg}	C_{org}	TN	C/N	EC	Ca	Mg	K	Na	Olsen-P	Avail. Si	Fe	Mn	Cu	Zn
			(%)				(g kg^{-1})					(dS m^{-1})	(cmolc kg^{-1})				(mg P_2O_5 kg^{-1})	(mg SiO_2 kg^{-1})	(mg kg^{-1})			
1	Surkh Rod	Amirkbail 1	51.4	38.9	9.7	8.6	16.8	12.3	4.5	0.38	11.9	0.14	40.2	2.5	0.23	0.09	27.5	179	32.6	10.1	5.83	0.37
1	Surkh Rod	Amirkbail 2	59.1	34.6	6.3	8.7	15.3	14.4	0.8	0.07	12.3	0.15	39.0	3.2	0.28	0.13	14.9	189	18.3	3.6	3.69	0.17
1	Surkh Rod	Amirkbail 3	55.6	40.3	4.1	8.6	14.8	12.3	2.5	0.17	14.8	0.13	39.7	2.5	0.21	0.01	11.1	182	17.6	6.0	3.99	0.20
2	Surkh Rod	Zulmabad 1	55.4	38.2	6.4	8.7	18.0	13.6	4.3	0.36	12.0	0.15	40.3	3.4	0.29	0.09	16.8	219	31.6	2.9	5.65	0.22
2	Surkh Rod	Zulmabad 2	49.5	45.6	4.9	8.6	17.1	14.1	3.0	0.36	8.3	0.15	41.6	3.8	0.29	0.15	12.2	247	28.8	8.7	6.13	0.20
2	Surkh Rod	Zulmabad 3	50.6	43.1	6.4	8.6	15.9	13.5	2.4	0.22	10.8	0.14	40.5	3.5	1.02	0.55	13.2	214	29.1	3.5	5.36	0.17
3	Surkh Rod	Sabz Abad 1	42.6	51.0	6.4	8.7	16.2	13.4	2.8	0.30	9.4	0.16	41.7	5.5	0.66	0.12	46.5	321	17.8	3.6	5.27	0.40
3	Surkh Rod	Sabz Abad 2	48.3	47.0	4.7	8.7	19.7	14.5	5.2	0.45	11.6	0.17	39.4	3.9	0.43	0.13	29.6	255	26.1	6.3	5.45	0.43
3	Surkh Rod	Sabz Abad 3	43.9	46.4	9.8	8.7	21.8	16.3	5.4	0.52	10.4	0.20	39.9	5.7	1.25	0.13	55.5	410	18.7	3.5	5.78	0.53
4	Beshud	Janankhan Qala 1	55.4	33.9	10.7	8.6	15.9	5.6	10.2	0.34	30.6	0.14	37.2	1.7	0.25	0.12	27.2	172	52.8	12.3	6.28	0.24
4	Beshud	Janankhan Qala 2	50.3	32.8	16.9	8.4	15.7	5.2	10.5	0.35	29.7	0.13	39.4	2.1	0.29	0.14	27.3	188	48.7	15.4	6.34	0.22
4	Beshud	Janankhan Qala 3	48.0	32.6	19.4	8.4	15.1	4.9	10.2	0.45	22.8	0.13	41.4	2.2	0.22	0.13	13.3	230	20.1	11.8	5.11	0.15
5	Kuz Kunar	Khiwacapital	52.5	37.1	10.4	8.4	15.8	11.0	4.9	0.16	30.4	0.13	35.9	1.0	0.13	0.05	23.4	196	44.0	13.1	5.01	0.32
5	Kuz Kunar	Qaria Markaz	52.8	39.3	7.9	8.3	17.2	10.9	6.2	0.33	18.8	0.15	35.8	0.8	0.18	0.06	22.3	288	55.2	13.4	5.01	0.98
6	Kuz Kunar	Kachara 1	57.7	34.9	7.4	8.3	13.7	13.4	0.3	0.03	10.9	0.16	33.7	1.4	0.12	0.05	16.6	229	46.3	18.6	5.66	0.53
6	Kuz Kunar	Kachara 2	90.8	6.9	2.3	8.5	9.1	9.0	0.1	0.03	6.0	0.11	25.5	0.5	0.05	0.04	8.4	98	14.6	6.7	2.23	0.21
6	Kuz Kunar	Kachara 3	71.3	22.6	6.1	8.5	12.6	11.1	1.5	0.03	44.0	0.01	33.7	1.1	0.01	0.05	12.0	177	19.1	7.0	3.44	0.27
7	Kuz Kunar	Darbakhel 1	56.4	29.8	13.8	8.3	12.0	5.7	6.4	0.32	19.6	0.15	38.2	1.8	0.21	0.07	28.1	223	31.7	9.6	4.22	0.25
7	Kuz Kunar	Darbakhel 2	51.7	32.1	16.2	8.3	15.6	6.3	9.3	0.50	18.7	0.17	38.6	2.8	0.31	0.09	19.3	303	38.1	10.0	6.03	0.66
7	Kuz Kunar	Darbakhel 3	56.0	28.8	15.3	8.3	14.3	5.9	8.5	0.38	22.2	0.14	35.6	1.8	0.30	0.06	20.7	294	36.2	7.2	5.18	0.52
8	Kama	Goch	38.8	48.5	12.8	8.4	18.3	10.8	7.5	0.38	19.5	0.15	36.7	1.4	0.44	0.06	23.1	308	51.2	13.6	5.61	0.54
9	Kama	Kakalaw Bajawri 1	40.5	42.8	16.7	8.4	15.5	11.9	3.6	0.42	8.7	0.20	36.2	2.4	0.17	0.13	23.4	267	62.5	16.1	5.51	0.29
9	Kama	Kakalaw Bajawri 2	55.8	38.9	5.3	8.5	13.4	11.6	1.8	0.01	18.0	0.13	35.8	1.6	0.16	0.05	13.8	218	28.5	8.6	4.72	0.37
9	Kama	Kakalaw Bajawri 3	46.3	48.0	5.7	8.5	16.9	11.8	5.1	0.36	14.2	0.14	36.7	1.4	0.19	0.05	18.1	282	39.4	9.8	5.74	0.52
10	Kama	Saba Sherali 1	36.6	40.0	23.5	8.2	20.1	8.8	11.4	0.84	13.6	0.18	37.0	1.8	0.27	0.06	28.8	279	66.6	10.1	7.11	0.63
10	Kama	Saba Sherali 2	38.1	54.3	7.5	8.3	16.1	7.3	8.8	0.54	16.3	0.15	31.6	1.1	0.16	0.07	19.5	178	75.8	12.2	6.99	0.28
10	Kama	Saba Sherali 3	35.2	39.3	25.4	8.2	18.5	7.7	10.8	0.77	14.0	0.18	35.2	1.6	0.23	0.09	32.0	215	81.5	11.8	8.13	0.40
11	Kama	Mastali 1	37.9	45.5	16.6	8.4	15.9	7.8	8.1	0.42	19.1	0.14	37.7	1.1	0.11	0.06	44.4	153	48.6	6.2	5.05	0.24
11	Kama	Mastali 2	54.4	39.2	6.4	8.3	16.3	6.8	9.5	0.42	22.4	0.17	27.6	0.8	0.12	0.05	39.4	136	54.3	6.1	6.68	0.28
11	Kama	Mastali 3	50.6	41.9	7.6	8.3	18.1	9.8	8.2	0.61	13.6	0.18	35.6	1.3	0.22	0.11	25.5	188	66.2	10.1	6.70	0.33
12	Kama	Gaik 1	42.8	43.4	13.8	8.4	16.5	11.8	4.7	0.26	18.5	0.21	36.1	1.9	0.22	0.12	19.5	278	43.3	10.8	5.30	0.38
12	Kama	Gaik 2	48.4	37.9	13.6	8.2	17.1	12.8	4.3	0.26	16.4	0.15	37.0	2.8	0.18	0.08	18.1	316	30.1	12.0	5.71	0.59
12	Kama	Gaik 3	47.3	40.6	12.2	8.4	16.7	12.6	4.1	0.30	13.7	0.16	37.4	2.1	0.16	0.07	20.2	238	54.3	12.3	5.08	0.42
13	Bati Kot	Lachapur	72.3	15.5	12.1	7.8	17.4	10.4	7.1	0.45	15.6	0.22	30.6	4.1	0.67	0.20	27.5	917	3.5	11.3	0.53	0.22
14	Bati Kot	Barikaw	71.0	19.2	9.8	8.4	19.5	11.0	8.5	0.33	25.8	0.12	25.4	2.0	0.25	0.11	22.3	209	5.0	4.7	1.21	0.15
15	Bati Kot	Saypay 1	73.9	18.2	7.9	8.0	24.7	16.4	8.3	0.22	37.8	0.11	25.5	1.7	0.36	0.07	24.1	175	17.6	3.9	2.48	0.27
15	Bati Kot	Saypay 2	70.1	21.1	8.8	8.1	24.4	14.6	9.8	0.23	43.4	1.12	29.7	1.8	0.14	0.07	13.1	181	23.7	11.0	2.67	0.26
15	Bati Kot	Saypay 3	62.7	25.7	11.6	8.3	22.1	13.9	8.2	0.22	37.2	0.11	33.6	2.6	0.17	0.07	10.3	227	18.5	9.2	2.68	0.20
16	Bati Kot	Shabdeyani 1	52.1	30.7	17.2	8.5	24.2	14.7	9.5	0.53	18.0	0.11	35.9	3.6	0.26	0.09	10.7	360	10.8	5.7	2.48	0.30
16	Bati Kot	Shabdeyani 2	66.3	23.5	10.2	8.6	19.2	12.0	7.2	0.31	23.2	0.13	30.6	2.0	0.17	0.07	11.0	200	12.5	9.0	2.12	0.13
16	Bati Kot	Shabdeyani 3	57.2	29.5	13.3	8.6	23.6	15.6	8.0	0.30	26.4	0.14	36.2	3.0	0.24	0.08	16.0	249	29.7	10.9	3.41	0.28
17	Bati Kot	Raghah	47.4	46.4	6.2	8.5	24.1	14.9	9.1	0.77	11.8	0.42	40.1	10.0	0.26	0.58	7.2	261	74.6	20.0	6.82	0.30
18	Bati Kot	Chine Kala	56.2	37.7	6.1	8.5	24.1	16.9	7.2	0.52	13.6	0.82	36.5	13.5	0.23	1.48	18.9	415	36.5	9.7	3.38	0.34
19	Muhmand Dara	Basawol 1	54.4	38.3	7.3	8.6	21.0	15.5	5.5	0.58	9.5	0.28	38.0	11.9	0.20	0.62	11.4	366	41.4	14.4	5.13	0.26
19	Muhmand Dara	Basawol 2	54.8	39.1	6.1	8.7	19.2	14.1	5.1	0.50	10.4	0.21	37.4	9.7	0.18	0.39	7.9	285	35.6	12.2	4.89	0.21
20	Muhmand Dara	Gardi Ghowse	59.5	35.4	5.1	8.9	16.9	13.8	3.1	0.28	11.0	0.16	36.5	10.1	0.24	0.21	7.5	419	8.6	7.7	1.61	0.13
	Mean		53.7	35.9	10.3	8.4	17.7	11.5	6.2	0.36	18.6	0.20	35.9	3.2	0.28	0.16	20.7	261	35.9	9.6	4.75	0.33
Tropical asia (n=529)[14]			23.3	30.5	41.2	5.6	20.7			1.7	11.5		9.3	5.6	0.4	1.5	30 (Bray-P)	237				
Deficiency criteria [5]													< 1	< 1	< 0.2		< 25	< 86	< 5	< 1	< 0.3	< 0.8

Table 2. Correlation matrix of soil properties

	Sand	Silt	Clay	pH	TC	C_{inorg}	C_{org}	TN	C/N	EC	Ex. Ca	Ex. Mg	Ex. K	Ex. Na	Olsen-P	Available Si	Available Fe	Available Mn	Available Cu
Silt	-0.88**																		
Clay	-0.45**	-0.02																	
pH	-0.12	0.35*	-0.42**																
TC	-0.06	0.03	0.08	-0.09															
C_{inorg}	0.15	0.08	-0.47**	0.33*	0.60**														
C_{org}	-0.24	-0.05	0.61**	-0.46**	0.49**	-0.40**													
TN	-0.56**	0.38**	0.46**	-0.14	0.46**	-0.13	0.67**												
C/N	0.36*	-0.48**	0.15	-0.38**	0.19	-0.16	0.39**	-0.30*											
EC	0.12	-0.07	-0.11	-0.17	0.47**	0.31*	0.20	0.14	0.18										
Ex. Ca	-0.63**	0.65**	0.11	0.54**	-0.07	0.06	-0.15	0.23	-0.41**	-0.01									
Ex. Mg	-0.03	0.17	-0.27	0.41**	0.44**	0.53**	-0.07	0.34*	-0.37*	0.39**	0.31*								
Ex. K	-0.17	0.21	-0.04	0.15	0.18	0.24	-0.06	0.15	-0.24	-0.06	0.30	0.19							
Ex. Na	-0.01	0.13	-0.22	0.20	0.37	0.38**	0.01	0.29	-0.25	0.52**	0.19	0.81**	0.14						
Olsen.P	-0.41**	0.31*	0.27	-0.16	-0.02	-0.23	0.23	0.27	-0.07	-0.11	0.09	-0.20	0.45**	-0.18					
Available Si	0.02	-0.07	0.09	-0.23	0.22	0.20	0.04	0.27	-0.24	0.12	0.07	0.43**	0.43**	0.28	0.09				
Available Fe	-0.64**	0.55**	0.32*	-0.20	-0.02	-0.34*	0.35*	0.53**	-0.17	0.05	0.16	-0.11	-0.24	0.05	0.20	-0.26			
Available Mn	-0.25	0.15	0.24	-0.23	0.02	-0.16	0.20	0.24	-0.02	0.18	0.09	0.10	-0.37	0.12	-0.23	0.09	0.59**		
Available Cu	-0.77**	0.73**	0.25	0.07	-0.15	-0.33*	0.18	0.46**	-0.30*	-0.13	0.50**	-0.12	0.04	-0.05	0.34*	-0.32*	0.81**	0.33*	
Available Zn	-0.37*	0.31*	0.21	-0.24	-0.00	-0.06	0.07	0.19	-0.14	-0.03	0.14	-0.17	0.07	-0.14	0.29	0.13	0.37*	0.24	0.41**

EC tended to be higher in Raghah and Chine Kala than elsewhere. Ex. Ca was the dominant cation due to carbonate accumulation in the soils. Ex. Mg and K contents exceeded the deficiency criteria of 1 and 0.2 cmolc kg^{-1} in most sites, although the averages were lower than those in tropical Asia at 5.6 and 0.4 cmolc kg^{-1} respectively. Ex. Mg and Na were higher in the sites downstream of the Kunar river. These relatively high levels of ex. Mg and Na and EC might be due to the parent materials, limestone and dolomite around site Nos. 17 to 19 in Bati Kot and Muhmand Dara districts as compared to sandstone distributed in study sites (Fig. 1).

The Olsen-P content ranged from 7.2 to 55.5 mg P_2O_5 kg^{-1}, with site differences possibly reflecting differences in the cumulative amount of phosphorus fertilizers applied in the paddy fields. Thirty-four of forty-six sites showed Olsen-P values lower than the deficiency level of 25 mg P_2O_5 kg^{-1}. This low P availability was probably due to the scarcity of P supply through fertilizer or other amendments to the soil and phosphorus fixation by calcium under the alkaline soil condition.

Avail. Si ranged from 98 to 917 mg SiO_2 kg^{-1} and exceeded the deficiency criterion of 86 mg SiO_2 kg^{-1} in all sites. Site No. 13, Lachapur, showed the highest available Si content and the lowest soil pH, and available Fe and Cu content among all sites. The distribution of carboniferous lava around this site (Fig. 1) might account for the differences in these properties. Site No. 20, Gardi Ghowase, where the same type of rock was distributed nearby also showed relatively high available Si and low available Fe and Cu content. Meanwhile the average value was comparable to that in tropical Asia. It could be concluded that the available Si content seemed sufficient for rice cultivation in the paddy fields.

The availability of micronutrients such as Zn, Cu, Fe and Mn was expected to be generally low for plant growth due to the alkaline nature of the soil, while the available Zn content was deficient at less than 0.8 mg kg^{-1}, except for 1 site, as expected. However, the available Fe, Mn and Cu contents exceeded the deficiency criteria, except available Fe for 2 sites. Zn deficiency resulting in low availability probably influences plant growth and Zn content in crops, which may, in turn, further influence human Zn intake through foods. Approximately 4 percent of deaths in children under 5 were attributed to Zn deficiency in Afghanistan (Levitt et al. 2010). Taking Zn supplements and Zn-enriched foods are generally recommended to improve Zn deficiency (Bouis et al. 2011, Castillo-Duran et al. 1987). Moreover, applying Zn fertilizer to paddy fields may help improve not only rice growth and production but also malnutrition among Afghans through Zn enrichment in rice grain.

2. Correlation between soil analytical parameters

Table 2 shows the correlation matrix of the parameters and sand and silt contents showed very strong negative correlations in this region. The lower sand content and higher silt content revealed higher soil fertility parameters such as TN, ex.Ca, Olsen-P, and available Fe and Cu. Although clay was also negatively correlated with sand, it was not correlated with silt. The clay content was less than silt and only reached 20% in 2 fields of site 10. The clay content also positively correlated with C_{org} and TN, indicating that it contributed to the accumulation of organic matter in soil. Silt and clay contents were the key factors behind soil fertility in this region.

Among exchangeable cations, ex. Mg and Na showed strong correlation and were also positively correlated with EC. These high correlations resulted from the specific distribution of parent materials in site Nos. 17 to 19 that differed from the other sites, as described above. Olsen-P positively correlated with TN and ex. K. These are important macronutrients normally applied as fertilizer. As soil fertility in this region was generally low, the application of chemical fertilizer and organic amendments might have influenced analytical results in Table 1 and the correlation. However, we could not verify that as no information on fertilizer management was obtained in the present study. The available micronutrients positively correlated with each other, except between available Mn and Zn.

3. Extraction of factors characterizing soil properties by PCA

The first four principal components (PC1 to PC4) were derived as components with eigenvalues exceeding 1.0, and accounted for about 70% of total variance (Table 3). The first component, PC1, showed high loadings with Sand, Silt, TN, available Fe and available Cu. Since these properties were related to soil texture and soil fertility parameters relating to silt content, PC1 was referred to as "silt factor". PC2 was referred to as "parent material factor", as the factor showed high loadings with pH, C_{inorg}, ex. Mg and ex. Na. Ex. Mg and ex. Na were specifically high in sites 17 to 20 where limestone and dolomite were distributed (Fig. 1). PC3 showed relatively high loadings with TC, C_{org} and EC, which showed positive correlations to each other in Table 2. Subsequently, we simply referred to PC3 as "carbon factor". PC4 showed high loadings with ex. K and Olsen-P and was referred to as the "K and P factor". The paddy soil properties of this region were summarized into 4 factors independent of each other.

With these 4 factors, we could determine the site difference of soil properties. Figures 2 and 3 show ordination diagrams of PC1 and PC2, and PC3 and PC4, respectively. The study sites were divided into 5 groups according to location as follows: sites 1-3 upstream of Kabul river, sites 4-7 and 8-12 along Kunar river, sites 13-16 in the middle stream of Kabul after joining with Kunar river, and sites 17-20 in downstream Kabul river surrounded by several types of parent materials. In Fig. 2, sites 4-7 and 8-12 showed lower scores of PC2 irrespective of the PC1 score, indicating a relatively low carbonate content of paddy soils along Kunar river. In contrast, sites 17-20 showed relatively high PC2 scores. Although all factors, PC1 to PC4 were theoretically independent, sites 1-3 and 13-16 showed

Table 3. Factor loadings, eigenvalues and cumulative contribution ratio of total variance

Variables	PC1	PC2	PC3	PC4
Sand	-0.92	-0.01	0.15	-0.06
Silt	0.77	0.35	-0.35	-0.06
Clay	0.49	-0.46	0.35	0.24
pH	-0.04	0.58	-0.56	-0.13
TC	0.06	0.41	0.71	0.11
Cinorg	-0.30	0.74	0.09	-0.01
Corg	0.39	-0.34	0.72	0.13
TN	0.71	0.17	0.48	0.11
C/N	-0.36	-0.51	0.40	-0.02
EC	-0.06	0.32	0.61	-0.26
Ex. Ca	0.54	0.44	-0.37	0.01
Ex. Mg	0.03	0.87	0.28	-0.14
Ex. K	0.13	0.42	-0.08	0.75
Ex. Na	0.05	0.72	0.37	-0.24
Olsen-P	0.44	-0.14	-0.06	0.65
Available Si	-0.00	0.38	0.36	0.46
Available Fe	0.80	-0.22	0.09	-0.41
Available Mn	0.40	-0.11	0.30	-0.58
Available Cu	0.87	-0.01	-0.25	-0.18
Available Zn	0.48	-0.13	-0.01	0.12
Eigenvalue	4.89	3.80	3.02	2.01
Cumulative contribution (%)	24.4	43.4	58.5	68.6

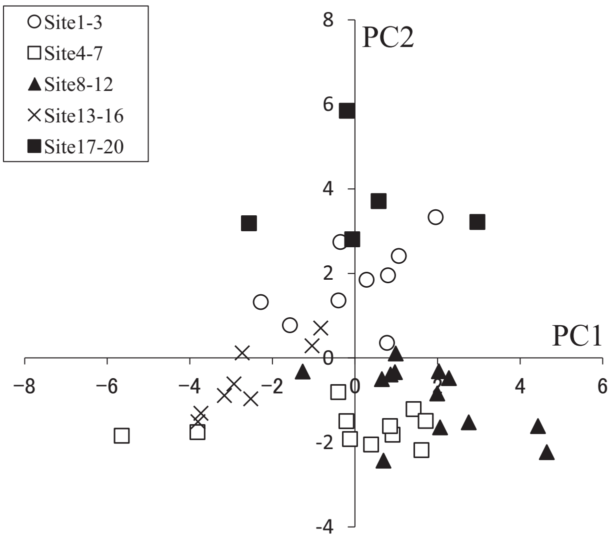


Fig. 2. PCA ordination diagram of PC1 and PC2

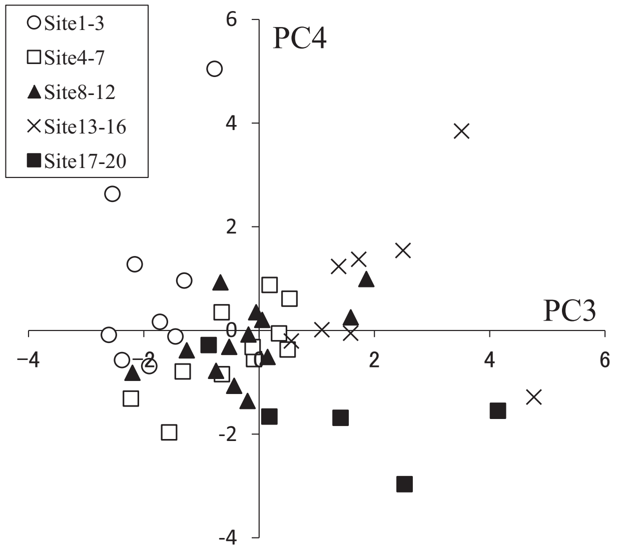


Fig. 3. PCA ordination diagram of PC3 and PC4

a positive correlation between PC1 and PC2 (r = 0.86**). The carbonate content of sites 1-3 and 13-16 seemed determined by silt content, whereupon it was assumed that silt containing carbonate had been transported by irrigation and had accumulated in these sites. Among the sites along the Kunar river, 8-12 showed higher PC1 scores than 4-7, while paddy fields located in the downstream portion of Kunar river were relatively fertile compared to those in the upper position.

In Fig. 3, sites 1-3 and 13-16 showed relatively low and high PC3 scores respectively. The PC3 score varied considerably in other sites, while PC4 was distributed within a narrow range between -2 and 1 in most sites compared to the other factors. Only some fields in sites 1-3 and 13-16 showed relatively high scores, which meant that Olsen-P and ex. K contents were generally not characterized in site or village levels.

PCA revealed that paddy fields in Nagarhar province could be divided into certain groups based on location. For example, the parameters related to PC2, i.e. C_{inorg}, and ex. Mg and ex.Na, varied in Kabul and Kunar watersheds and were also influenced by the spot distribution of different types of parent materials such as limestone, dolomite and lava (USDA-NRCS 2001). The distribution pattern of parent materials is closely related to soil properties, which means geological information such as a geological map provided by USGS (2006) or other organizations will be useful in providing a preliminary prediction of the paddy soil properties in this region.

4. Recommendation on paddy soil management in Nangarhar province

The results of the present study revealed that paddy soil properties in Nangarhar province were alkaline due to the accumulation of carbonate and were generally low in fertility, particularly available P and Zn levels. Stakeholders in Afghan agricultural development aiming to improve rice production must bear in mind this result, since most sites showed values less than the deficiency criteria (Table 1).

Local farmers and government officials in Afghanistan relied solely on the application of chemical fertilizer as a paddy soil management strategy to improve fertility. Nitrogen and phosphorous fertilizers imported from Pakistan and China were available and used depending on farmers' economic condition in this region. However, micronutrient management has never been considered. This research revealed that the available Zn content was in deficiency level. Wastewater treatment sludge such as sewage sludge high in Zn content (Beckett et al. 1983) is a viable alternative for Zn fertilizer, although its availability and the feasibility of using it in relation to culture and custom must be examined. We therefore propose a trial Zn application test in paddy fields. Applying zinc has the potential to enhance rice grain quality and will therefore ameliorate human malnutrition on Zn; not only in Nangarhar province but also elsewhere in Afghanistan.

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