Chemical and mineralogical properties of the soils in the semi-arid steppe region in Kazakhstan

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Introduction

The northern steppe of Kazakhstan is widely known as one of the centers for cereal production in the world. The history of reclamation in the area has started 1950's and the fertile soils, chernozems, has greatly contributed to crop production in the former Soviet Union. However, it is recently recognized that continuous cereal cultivation for a long period has caused serious land degradation in the area.

The annual precipitation in northern Kazakhstan is rather small, that is, it ranges from 250 to 350 mm, which is most serious constraint for crop production in the area. To ensure enough amount of moisture during cropping season, several measures relating to tillage, such as summer fallow (black fallow) or subsoil cutting after harvest, have been developed. Such methods would, on the other hand, promote soil degradation through erosion of surface soils and/or decomposition of organic matter. Hence the crop production in the area seemed to face on essential problems in terms of its sustainability.

In order to obtain basic information for establishing appropriate management system of land resources in the area, the authors investigated soil properties relating to mineralogical properties, salt distribution, and organic matter-related resources.

Materials and methods

Extensive soil survey was performed in natural steppe or cropland of Shortandy, Kokchetau, Ruzaefka, and Kustanai regions in northern Kazakhstan and also in Transili Alatau hillslopes in southern Kazakhstan for comparison. Surface soils were intensively collected in the experimental field of Shortandy Cereal Crop Institute. The location of representative profiles was given in Fig. 1. Most of them were classified into Usual Chernozem, Southern Chernozem, Dark Chestnut or Solonetz in Russian Classification. The soil samples were analyzed for following items: soil pH and contents of water-soluble salts (for saturation extract), contents of organic C and total N, $CaCO_3$ equivalent, gypsum content, particle size distribution, and clay mineral composition.

Results and discussion

1. Mineralogical properties of the soils.

Particle size distribution of the soils in representative profiles is presented in Table 1. X-ray diffractograms of parallel oriented clay specimens from selected soils are given in Fig. 2A.

Fig. 1. Study sites.

Table 1 showed that the soils from Transili Alatau hillslopes in southern Kazakhstan (WCZs and DCNs), which were mostly originated from loess deposit, were rich in the fine sand and silt fractions and contained less than 30% of clay. In contrast, the soils from sedimentary deposit in Shortandy region (SCZ1n and SNZ1n) showed a quite fine texture with often higher than 50% of clay, a half of which was composed of fine clay fraction. Some of the soils from Kustanai region (SCZ15n) were, however, more sandy with less than 30% of clay.

In general, a dominant component of fine clay fraction was smectite, whereas coarse clay fraction was mixture of smectite, mica, and kaolin minerals (Fig. 2B). Therefore, the fine-textured, smectite-rich properties of the soils from Shortandy were considered to affect physicochemical properties such as high dispersibility of smectite clay. Indeed, profile differentiation due to clay translocation, which was attributable to eluviation and illuviation of smectite-rich fine clay, was often observed in this area (e.g. SNZ1n).

2. Salt distribution in the soil profiles.

Some chemical properties including soluble salt contents of the soils from representative profiles are presented in Table 1. Generally speaking, accumulated layers of carbonates, gypsum, and water-soluble Na were observed in this order from the surface in the soil profiles. The subsoils in Shortandy (SCZ1n and SNZ1n) were especially rich in soluble Na and gypsum, which may be a potential for secondary soil salinization. Since the area was covered typically by Southern Chernozem derived from sedimentary materials, the parent materials and water balance between precipitation and evapotranspiration may be

Fig. 2. X-ray diffractograms from oriented clay specimens of the selected soils.

causes for the salt accumulation in the subsoils. The Southern Chernozem from Kustanai (SCZ15n) also showed a gypsum accumulation around 40 to 80 cm depth though the amount was not so high as in Shortandy. These Southern Chernozems have shallow carbonates-accumulated layers below 20 to 40 cm. In Solozetz (SNZ1n), which seemed to be formed on small depression, accumulation of gypsum and soluble Na with a quite high SAR occurred below 20 cm depth.

The subsoils of Chernozem around Kokchetau (CZ2n and CZ14n), Ruzaefka (CZ17n), and Kustanai (CZ20n) also contained significant amounts of gypsum and/or soluble salts. In contrast, in the soils collected from the southern steppe in Alatau region, which were derived from loess deposit, such a notable accumulation of gypsum and/or soluble salt was not observed within 2 m depth in the soil profiles, presumably because of a better water penetration due to silty soil texture and a larger precipitation there. This aspect was supported by the fact that a significant amount of carbonates was detected below 60 cm in WCZs, whereas it mostly appeared around 30 cm depth.

3. Soil organic matter-related properties of the soils.

In general, the organic matter content of soil is widely accepted to be an important factor affecting soil physical and/or chemical fertility through making good soil structure, moisture retention, high CEC, etc. The content of organic C in the surface 10 cm layer of the Chernozem or Southern Chernozem studied often leached 3%, indicating an inherent high fertility of the soils in the area

Figure 3 shows contents of organic C and total N in the upper 30 cm layer of soils both from virgin steppe and cropland in Shortandy Experimental field. As indicated here, organic matter storage in the surface soils in the cultivated field was noticeably low compared to that in the natural soil in each soil series, i.e. Southern Chernozem, Solonetz, and Meadow Southern Chernozem, indicating that continuous grain production brought a significant soil deterioration for the past three to four decades. Total N also gave a similar figure. Suppose that the decrease of organic matter content in the cropping field on Southern Chernozem was all caused by decomposition of organic matter and the contribution of winderosion was negligible in such fine-textured soils, average release of mineralized N in annum was estimated to have amounted 25 to 50 kg N ha^{-1}, suggesting that the conventional crop production have largely depended on such a N mineralization.

The decrease in organic matter content may not cause an apparent reduction in grain yield at this moment because of high inherent soil fertility, but such a high rate of organic matter decomposition would pose some adverse effects on grain production in near future. To mitigate soil degradation and to improve soil fertility, organic matter should be constantly applied into the cropland to maintain soil productivity.

Fig. 3. Contents of organic carbon and total nitrogen in the upper 30 cm layers of soils from natural steppe and cropland in the Shortandy Experimental Station.

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