CHAPTER 19

Improvement of soil physical and chemical conditions to promote sustainable crop production in agricultural areas of Kazakhstan

Warren Busscher & Jeff Novak
Coastal Plains Soil, Water and Plant Research Center, USDA-ARS, Florence, SC, USA

Farida Kozybaeva, Temirbulat Jalankuzov & Beibut Suleymenov
Akademgorodok, Institute of Soil Science, Almaty, Kazakhstan

1 INTRODUCTION

Soils are a source of food, clothing, and energy for Kazakhstan, the USA, and the world, so their deteriorated condition is a cause for concern. Soils are not only losing the organic carbon (Lal, 2002) that help make them fertile, but they are also losing their productivity at an estimated worldwide rate of 15 Mha per year (Buringh, 1981). They are degraded by water and wind erosion, salinity, desertification, land development, and pollution, to mention a few. Though this paper is limited to the physical sciences, soils should be studied in their entirety (physical, biological, and economic/social sciences) to develop new, rational, realistic management systems that can save them from degradation or loss while improving their beneficial use to society. To solve these problems, researchers can build on the works of their predecessors from both the east (Kononova, 1951; Kostychev 1951; Dokuchayev, 1952; Tyurin, 1965) and the west (Van Schifgaarde et al., 1956; Black, 1957; Klepper et al., 1973) who helped shape the knowledge of present-day soil science. Though the problem is worldwide and solutions have global implications, soil issues described here focus on parts of Kazakhstan.

2 GEOGRAPHY

Kazakhstan has a population of about 17 million people. It borders Russia on the north, China on the east, Kyrgyzstan and Uzbekistan on the south, and Turkmenistan and the Caspian Sea on the west (Figure 1). It covers 2.72 million square kilometers, ranging about 1600 km from north to south and 3000 km from east to west, making it the 9th largest country in the world.

Kazakhstan is a country of vast socio-economic diversity ranging from rustic camp to cosmopolitan city. It has an industrial base and important natural resources of oil, coal, iron ore, manganese, chromite, lead, zinc, copper, titanium, bauxite, phosphate, sulfur, gold, and silver. Because of years of neglect under former administrations, its industrial base and its agricultural sector are undergoing much-needed repair and updating, which are fueled by a healthy economy. Recently, Kazakhstan's economy had double-digit or near double-digit growth as a result of its energy sector aided by economic reforms, good harvests, and foreign investments.

Kazakhstan's agriculture is diverse, ranging from small farms to large cooperatives raising crops and livestock. The country's agricultural base is a historically important national resource containing fertile soils and extensive irrigation. Its renovation is fueled by a need to change from crop management systems dictated by the former centralized government to current-day market-driven forces.

Figure 1. Satellite photo of Kazakhstan showing its oblasts (states). Object from http://www.fao.org/countryprofiles/Maps/KAZ/19/im/index.html

3 TERRAIN AND CLIMATE

Because the country is so large, it has a wide variety of climate, terrain, vegetation, and soil parent material and type. Though the southeast and east are ringed by the picturesque, snow-capped Tjan Shan and Altai Mountains, most of the country is flat lowlands, less than 500 m in elevation. Other areas of the country include plateaus and lesser mountain ranges that rise 200 to 500 m above the surrounding terrain to elevations of 1,000 m above sea level.

Most of Kazakhstan has a continental climate with cold winters and hot summers. Except for the mountains of the southeast and east, most of the country is also dry. Annual precipitation for northernmost Kazakhstan is 315 mm. In central Kazakhstan, annual precipitation is about 150 mm. In the foothills of the mountains, precipitation increases to 880 mm on the forested moutainsides. Mountainside precipitation not only waters the soils locally, but excess amounts of rainfall and snowmelt flow onto the lowlands where they are used for irrigation (Brown, 2006).

The Transili Alatau piedmont in southeastern Kazakhstan is near the former capital of Almaty and is one of Kazakhstan's areas of dense agricultural production. The piedmont is characterized by large daily and annual temperature fluctuations, cold winters, and hot summers. Its minimum winter temperatures are -14^{o}C in January with relative humidity 66-67%, average snow thickness of 26-30 cm, and soils freezing to depths of 15-55 cm. As the temperature rises in spring and summer to highs of 37-43^{o}C, the piedmont's humidity falls during the region's 140-170 frost-free-day growing season.

4 SOILS

About 8% of Kazakhstan's soils are arable, 12% of which are irrigated, and another 70% of Kazakhstan's soils are pasture (Wikipedia, 2006). Soils are distributed throughout the country generally in zones changing from north to south that correspond roughly to the vegetation (Figure 2). In the northern forest-steppe, soils are deep, dark chernozems. These northern chrenozems, along with a mixture of meadow soils and small areas of saline soils, cover about 1 million ha in an area where precipitation and evaporation are approximately equal.

South of this are extensive grassland steppes where soils are moderately-droughty chernozems, less fertile chestnut soils, and brown soils. These soils are interspersed with saline soils

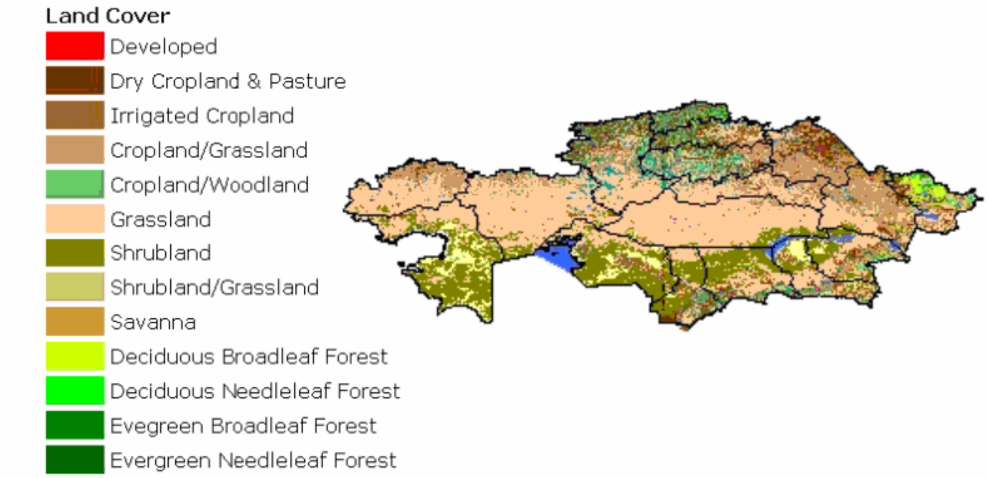

Figure 2. Zones of land cover. Object from http://www.fao.org/countryprofiles/

because evaporation exceeds rainfall. Steppe soils can be compacted, low in organic carbon, and shallow, at times shallow enough to be unsuited for cultivation, though suitable for pasture.

Further south is the desert steppe with brown soils that typically develop in semiarid climates. These soils are rich in nutrients and low in organic carbon. Still further south is the desert where sandy and gray-brown soils develop under dry conditions but can be productive with irrigation. In the southeast and east, the foothills of the Tjan Shan Mountains have sierozem soils with low organic carbon and sparse vegetation. These soils developed in areas of warm, wet springs; hot, dry summers; and moderately cold winters.

In the Transili Alatau piedmont, soils are dark-chestnut. These soils are distributed in a 447,000 ha east-to-west band across the piedmont plains. They can be divided into leached, calcareous, and eroded. They differ from the plain chestnut soils by being thinner, not alkaline, and higher in surface-horizon humus. These soils are arable enough to grow cereals, forage, and high-value vegetables. Sloping soils are used for hay and pasture. An 80 to100 ha research farm in the plateau has been used for the past 50 to 70 years to compare virgin soils to pasture, vegetable production, and various rotations.

At the research site, tillage has reduced surface-horizon aggregates of size >250 µm from 42%, as seen in the virgin soil, to 22-25%. It has also reduced micro-aggregates (>250 µm) to 67% of that seen in virgin soil. As expected, reduced aggregation also reduces infiltration (Sokolova et al., 2001) and increases bulk density, which in turn reduces yield. The addition of organic carbon through manure has been shown to improve soil properties.

Humus plays an important role in the improvement of soil physical, biological, and chemical characteristics, which in turn improve soil productivity. The humus content of virgin dark-chestnut soils is 3.6%, decreasing gradually with depth. Humus contents of production soils are 1.7 to 2.5%, also decreasing with depth to a value of 0.24% at 140- to 150-cm depths. The reduced humus contents are large when compared to other studies where humus contents decreased by 20-30%. Reductions in humus are related to decreases in cation exchange capacities (CEC). CECs are 21.62 c mol_c kg^{-1} for virgin soils, while they are 15 c mol_c kg^{-1} for the tilled soils. This is significantly lower not only because of the reduced organic carbon contents but also because of lower clay contents and increased erosion, though more research needs to be performed to verify these results.

5 DEGRADATION AND REMEDIATION

Because soil is a significant resource of Kazakhstan, it needs to be developed or remediated to provide food, clothing, and exports. Yet soil also has to be maintained as an environmentally sustained resource for future use. New management systems that take into account inherent soil properties and

Table 1. The land area and population of Kazakhstan (Kharin and Tateishi, 1996).

Land area	----------------------------------Population (x 10^3)-------------------------------------					
(x 10^3 km^2)	1959	1970	1979	1989	1999	2005
2,713	9.3	13	14.7	16.5	16.9	15.2

limitations can improve yield. Limitations include salinity (Suleimenov, 2002), reduced fertility (Suleimenov, 2000; Suleimenov and Rubinshtein, 2001), and desertification (Dregne, 1986). These problems can be ameliorated with the addition of soil organic carbon which can buffer salinity, increase cation exchange capacity, and increase water holding capacities (El-Hage Scialabba and Hattam, 2002). Management systems such as reduced tillage or green manure crops that improve soil organic carbon can help ameliorate physical, chemical, and associated biological problems while improving soil productivity (Nabiyev, 1996; Condron et al., 2000).

Another reason for improving management and increasing organic carbon is the increased demand on the land from Kazakhstan's population growth (Suleimenov, 2000), which took place in the late 1900's (Table 1). To support the increased population and ensure its security, marginal lands were brought into production to increase the food supplies and develop textile exports. Bringing marginal land into production led to land degradation, including both desertification caused by overgrazing and unsustainable cultivation caused by increased compaction, wind and water erosion, and salinity. Salinity in Kazakhstan is so severe that 60 to 70 percent of the irrigated land is affected (Suzuki, 2003). Overgrazing was the result of the previous administration's policy of centralization of the animal sector onto small farms. This increased degradation of soil physical properties (Suzuki, 2003).

Other forces degrading the land were unsustainable production practices, including deep plowing of fragile soils, cultivation of erosion-prone crops such as maize, and the use of heavy machinery that destroys soil structure through compaction. These practices led to the loss of soil organic carbon and soil fertility (German Advisory Council on Global Change, 1994; European Environment Agency, 1999). Many of these degradation processes have a direct impact on the global carbon cycle, particularly through the decrease of organic carbon and the subsequent release of greenhouse gasses into the atmosphere. Declines in organic carbon contents are attributed to tillage and agricultural management practices that fail to maintain soil organic carbon. Tillage techniques that invert the soil play a major role in this process. Lal (2002) estimated that agricultural activities in the five Central Asian countries (Kazakhstan, Kyrgyzstan, Tadjikistan, Turkmenistan, and Uzbekistan) have caused the combined loss of between 1 to 2 Pg of soil organic carbon.

From the late 18th to the early 20th centuries, country-wide changes, especially the influx of immigrants and development of settlements, disrupted the Kazak nomadic lifestyle. The most dramatic changes in land use were the establishment of centralized animal production and cultivation of the fragile rangelands. Concentration of animal production facilities near water sources caused grazing pressure on nearby lands because it eliminated the movement of large animal herds across the vast rangeland. Because animals were kept immobile, local land vegetation was unable to recover as it had in the past when the herd moved on. With limited rainfall and overgrazing, land productivity for grazing declined dramatically. According to Schillhron van Veen et al. (2005), this and other problems reduced productive rangeland to half of its original 186 Mha.

As part of the Soviet "Virgin Lands Project", the amount of marginal land brought under cultivation increased dramatically between 1950 and 1960; cultivated land went from about 8 to 28 Mha. During this period, transformation of the steppes into arable land was coined "Conquest of the Deserts" (FAO, 1995). Land was planted with cotton and wheat to provide grain and raw product for textiles to meet the demands of the growing population (Table 1). Cotton production in Kazakhstan rose to a level of almost 315 million t in 1992 (FAO, 1995). Because the region has low rainfall (100 to 200 mm y^{-1}, FAO, 1995), maintaining these yields required intensified irrigation. Large-scale irrigation consumed vast amounts of water with some areas using up to 12,800 m^3 ha^{-1} per year (FAO, 1995). Water was taken from rivers, groundwater, and the Aral Sea which, though it may be recovering, it is known more for its dry bed than its water. Because water evaporates faster than it is replenished by precipitation in this arid to semi-arid environment, irrigation with salt-laden water promoted soil salinity that reduced crop yields. The reductions could be substantial. Gardner (1997) reported that between the late 1970s and the late 1980s in the Central Asian republics, salinity reduced cotton yields from 280 to 230 t km^{-2}. Other sources list that Kazakhstan's wheat harvest declined from roughly 13 million tons in 1980 to 8 million t in 2000 - an economic loss of $900 million per year (http://www.earth-policy.org/Books/Eco/EEch1_ss2.htm, accessed January 23, 2006). Loss of income from declining yields placed economic hardships on producers. This decline plus fluctuations in the country's gross national product eventually caused vast areas of cropland to be abandoned. According to the Land Resource Management Agency (FAO, 1995), 12.8 Mha that once grew wheat were no longer used in 2000.

Over-utilization of irrigation water in Kazakhstan also had a major environmental impact on erosion. From 1961 to 1988, irrigation water removed from the Aral Sea caused an average 15-m drop in water depth (FAO, 1995). This drop exposed 25,000 km^2 of the former seabed, which in turn increased the amount of soil lost to dust storms and sand deflation (sand-size material movement). Soil losses in the area were also heightened by erosion from the abandoned cotton and wheat fields. Soil loss to wind erosion was so severe that certain areas lost 2 to 7 cm of topsoil per year in dust storms that blew former topsoil as far away as Poland and Hungary (FAO, 1995). Over-utilization of irrigation water, salinity, and other ill-advised management practices contributed to desertification of an estimated 60% of the rangeland in Kazakhstan (UNECE, 2000). Overexploitation of marginal lands never suited for large scale cultivation was one of several agricultural management practices of arid and semi-arid zones that had a detrimental effect on the Kazakhstan landscape.

Desertification in Kazakhstan can have a significant influence on the global carbon cycle, particularly through the decline in organic carbon levels and release of carbon dioxide to the atmosphere. Because of extensive above- and below-ground vegetation in the steppe regions of Kazakhstan, as much as 1.27 t ha^{-1} of organic carbon can be sequestered, mainly during the period of May to October (USAID-CRSP, 2002). Indeed, the five Central Asia countries have the potential to sequester between 1 to 2 Pg of organic carbon over a 50 yr period (Lal, 2002). Assuming sequestration across the entire Kazakhstan rangeland of 186 Mha, the amount of carbon sequestered annually can be as high as 0.24 Pg. Unfortunately, this sequestered carbon is dynamic and can easily be diminished by grass fires, overgrazing, conversion to cropland, or urban development (Schillhorn van Veen et al., 2005). Nonetheless, because of the sheer size of Kazakhstan's steppes, carbon sequestration is substantial on a global scale.

6 CONCLUSIONS

Kazakhstan is a large country with diversity of terrain and climate. Though most of the country has a dry climate, it contains a wealth of natural resources including soils, which can be managed in an environmentally safe and sustainable manner to help provide food and clothing for the country's growing population and to help provide exports to sustain the country's economy.

Because of various politically motivated programs from previous administrations, soils have undergone renovation much like the rest of the infrastructure of the country. Renovation includes increased soil carbon content. Low levels of organic carbon put Kazakhstan at risk for future production. Nevertheless, the country is in a position to sequester significant amounts of carbon, which may help reduce the greenhouse effect even if the amount sequestered fluctuates annually. Improved organic carbon through research on innovative management practices can help increase soil productivity.

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