Modelling of Soil Organic Carbon Dynamics in Kazakhstan

Elena Valkama[1*], Marco Acutis[2], Gulya Kunypiyaeva[3], Rauan Zhapayev[3], Muratbek Karabayev[4]

[1]*Natural Resources Institute Finland (Luke)/ Bioeconomy and environment,Turku, Finland*
[2]*University of Milan/Agricultural and Environmental Sciences - Production, Landscape, Agroenergy*
[3]*CIMMYT-Kazakhstan, Almaty, Kazakhstan*
[4]*CIMMYT-Kazakhstan, Astana, Kazakhstan*
[*]*Corresponding author: elena.valkama@luke.fi*

Abstract

Traditional farming systems, involving intensive tillage, returning low amounts of organic matter to the field and frequently monoculture, lead to a decrease in soil organic carbon (SOC) and land degradation. In contrast, conservation agriculture (CA) has a large potential for carbon sequestration. The objective of this study is to assess the potential of CA for soil C sequestration in one Kazakhstan site, proposing a methodology that could be extended to other conditions in Kazakhstan. We performed a comparative assessment of SOC changes over 20 years under CA and conventional cropping systems in the Almaty region by using a dynamic simulation model ARMOSA. We simulated the carbon dynamics in the first metre of soil, using a set of daily data of T_{max}, T_{min} and rain from 2012 to 2017. To obtain a 20 years meteorological data series, 6-years data were extended by using the Climate weather generator. Conventional cropping system shows a constant decrease of organic carbon over time, with an annual average of 0.74% that is equivalent to a loss of about 800 kg ha^{-1} y^{-1}. The decrease stems from straw removal, which is not compensated by the carbon in the roots and from ploughing creating SOC oxidation. In contrast, conservation cropping system shows a 1.14% increase of SOC per year (equivalent to 1200 kg ha^{-1} y^{-1}). Such an increase is double than the objective of "4 per 1000" initiative aimed to halt the increase in the CO_2 concentration in the atmosphere related to human activities. Conservation agriculture has a large potential for C sequestration in Kazakhstan, particularly in irrigated areas allowing for rotation high-yielding crops together with cover crops. Future studies should be aimed to assess the performance of these cropping systems during field experiments in different climatic zones of Kazakhstan.

Key words: conservation agriculture; maize; modeling; no-till; soil organic carbon; wheat.

Introduction

Traditional farming systems, involving intensive tillage, returning low amounts of organic matter to the field and frequently monoculture, lead to a decrease in soil organic carbon (SOC) and land degradation. In contrast, conservation agriculture (CA) has a large potential for carbon sequestration. CA implies minimum soil disturbance, permanent soil cover with crop residues and crop rotation. In the Americas, CA occupies more than 50% of agricultural land.

In Kazakhstan, the areas under no-till have been increasing from virtually nothing in 2000 to 2.5 million ha in 2016 that is, however, only about 1.1% of agricultural lands. Therefore, FAO consider Kazakhstan to be "high" in terms of the potential area for the further spread of CA.

Since changes in SOC are a very slow process, long-term experiments (at least 10 years) are required to obtain reliable data and to assess the carbon sequestration of agricultural systems. There is a need to evaluate the performance of alternative cropping systems in different pedo-climatic conditions, and to assess their potential in terms of the SOC increase, yield and environmental impact. The objective of this study is to assess the potential of CA for soil C sequestration in one Kazakhstan site, proposing a methodology that could be extended to other conditions in Kazakhstan.

Materials and Methods

We performed a comparative assessment of SOC changes over 20 years under CA and traditional cropping systems in the Almaty region by using a dynamic simulation model ARMOSA that simulates the cropping systems at a daily time-step at field scale (Perego et al., 2013). The model simulates agrometeorological variables, the water balance, the carbon and nitrogen balance, and the crop development and growth. The model consists of four modules, which are:

I. micrometeorological model simulating the energy balance (latent and sensible heat) and allowing the evapotranspiration estimation;
II. crop development and growth model that uses global radiation and temperature;
III. model of soil water balance;
IV. model of soil nitrogen and carbon balance. The water dynamics can be simulated according to the physically based approach of the Richards' equation, or through the empirical cascading approach.

ARMOSA estimates the photosynthesis for five layers along the vertical profile of the canopy, selected on the basis of a Gaussian integration, to obtain an integrated value of photosynthesis of the whole canopy. The maximum potential photosynthetic rate is a function of CO_2 concentration in the atmosphere; therefore, the model was also used in studies of climate change effects (Perego et al. 2014).

Crop production was estimated under water and N limited conditions by linking growth to the soil water and N balance. The effect of water stress on plant growth is calculated as a function of soil water content by using logistic function that simplifies the original step function proposed by Sinclair et al. (1987).

Compared to a previous version (2013), the updated ARMOSA contains specific procedures to better simulate the effects of tillage and conservation agriculture:

1. Crop biomass lying on the soil surface is considered to be a specific pool with their characteristics in terms of degradation and with effects on soil water dynamic controlling the evaporation losses.
2. Bulk density and hydrological characteristics (the alpha and N of the van Genuchten retention function parameters, saturated conductivity, and water content at saturation) evolves in relation to the change in soil carbon contents and changes in relation to the different tillage operation, considering the type of tillage, its depth and the percentage of soil tilled.
3. More calibrations are available due to the use of the model in several international ring tests of the model (Pirttioja 2015; Fronzek et al. 2018).

We simulated the carbon dynamics in the first metre of soil in the Almaty region, using a set of daily data of T_{max}, T_{min} and rain from 2012 to 2017. To obtain a 20 years meteorological data series, 6-years data were extended by using the Climate weather generator. Global solar radiation was computed by using Hargeaves method (Hargeaves et al. 1985). The soil used for the simulation has characteristics reported in Table 1.

Table 1. Soil characteristics used for simulation

Soil layer (cm)	Sand (%)	Silt (%)	Clay (%)	Organic C (%)	Bulk density (t m^{-3})	Skeleton
0-20	11.5	67.9	20.7	1.41	1.25	0
20-35	8.7	71.0	20.3	1.34	1.32	0
40-80	9.9	67.5	22.6	0.70	1.30	0
80-200	7.3	70.6	22.1	0.40	1.33	5

We simulated the following cropping systems:

1) Conventional (CONV), i.e., continuous wheat cultivation, with ploughing at 0.25 m, and crop residual (straw) removed.
2) Conservation (CONS), i.e., wheat-soybean-maize rotation, with Italian ryegrass as a cover crop sowing between wheat and soybean, and soybean and maize. We have simulated a no-till system, leaving residuals on the soil surface and direct sowing. For wheat and maize, we simulated irrigation to fulfil the crop water requirement.

In the simulation, both systems were fertilized with 80 kg N ha^{-1} by using urea.

Results and Discussion

Trends in total organic carbon in CONV and CONS cropping systems appear in Figure 1. CONV shows a constant decrease of organic carbon over time, with an annual average of 0.74% that is equivalent to a loss of about 800 kg ha^{-1} y^{-1}. The decrease stems from straw removal, which is not compensated by the carbon in the roots and from ploughing creating SOC oxidation. In contrast, CONS shows a 1.14% increase of SOC per year (equivalent to 1200 kg ha^{-1} y^{-1}).

Such an increase is double than the objective of “4 per 1000” initiative aimed to halt the increase in the CO_2 concentration in the atmosphere related to human activities (Minasny et al. 2017).The mechanism underlies SOC increase is an accumulation of biomass returned to the soil through residuals and cover crops that are not subjects to oxidation due to no tillage of soil. However, it should be noticed that an increase in stable carbon is only expected after several years of CA application that is amounted to 20% of the total increase, mainly due to the presence of litter laying on the soil surface.

Moreover, even if the percolation is slightly increased (+11%) due to irrigation in CONS, nitrogen leaching shows a 56% reduction (8.9 kg ha^{-1} y^{-1} N-NO_3), compared to that in CONS (3.9 kg ha^{-1} y^{-1} N-NO_3), due to nitrogen uptake by cover vegetation continuously presented on the soil.

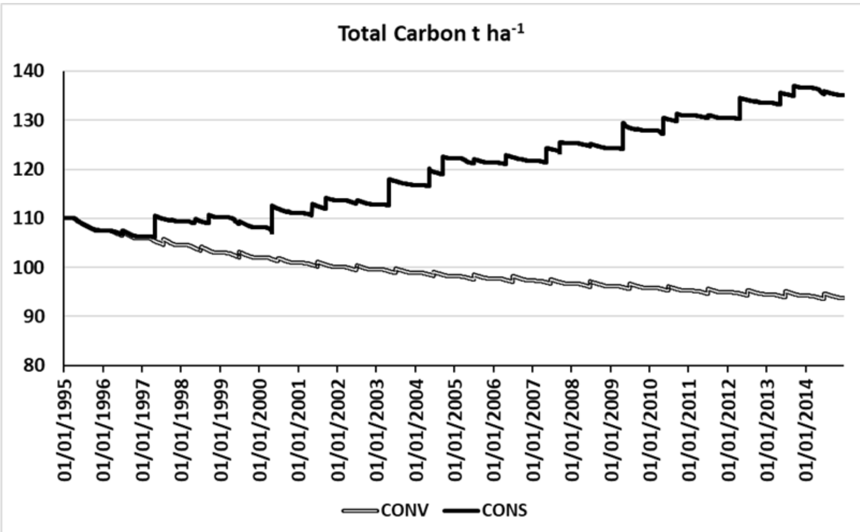

Figure 1. Simulated total organic carbon trend for conventional (CONV) and conservative (CONS) cropping systems (1995–2015)

Conclusions

Conservation agriculture has a large potential for C sequestration in Kazakhstan, particularly in irrigated areas allowing for rotation high-yielding crops together with cover crops, and also offering benefits in terms of environmental quality. Future studies should be aimed to assess the performance of these cropping systems during field experiments in different climatic zones of Kazakhstan. In particular, attention should be paid to cover crops, which seem to have significant role in C sequestration, but are not yet widely spread in practical farming in Kazakhstan.

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