Soil effects due to crop residue removal and possible measures to reduce impacts

Exploratory report on the effects on soil carbon for scenarios of crop residue management

Authors:
Jan Peter Lesschen
Wolter Elbersen

With input from:
Dr Nikolay Roik, Oleg Prysyazhnyuk, and Oksana Maliarenko of the Bioenergy Crops and Sugar Beet Institute, Kiev, and Annelotte van der Linden, Wageningen Environmental Research

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AUTHORS
Dr. Jan Peter Lesschen
Dr. Wolter Elbersen

ADDRESS
P.O. Box 47
6700 AA Wageningen

TELEPHONE
+31 (0)317 484687

E-MAIL
janpeter.lesschen@wur.nl

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1 Introduction

1.1 Background

In Ukraine crop residues are more and more being used as biomass for heat production to decrease the use of imported natural gas. This is leading to concerns about the effect of removing crop residues on soil quality. The famous Chernozem soils of Ukraine have been formed over thousands of years under a grassland vegetation with relatively low rainfall. Since the fall of the Soviet Union the use of fertilizers, both chemical and manure, has decreased, contributing to a lowering of soil carbon and nutrient contents of the soil and therefore the productivity of the soil.

At the same time Ukraine has suffered severely from increasing natural gas prices which cost billions of Euros in foreign exchange. This has led to the conversion of natural gas fired boilers for local heating, into biomass boilers. The feedstock consists of locally sourced biomass such as processing residues (for example sunflower husks). Increasingly also field residues are being collected and used, as illustrated by the pictures of a straw burning facility in central Ukraine.

The cost for these bails was quoted to be below €20 per ton delivered to the local bale storage. This cost seems quite low considering that the value of nutrients in the straw would be expected to be between €5 and €10 per ton of straw and the cost of collection, baling and local transport should be close to €15 per ton of straw. The farmer apparently did not appreciate the value of the nutrients to the soil, and also did not value the organic matter of the straw to the soil. The fact that farmers are not happy to leave straw on the field was illustrated by the pictures taken on the same day near the straw boiler location, showing straw being burned in the field. A practice which is not allowed but does happen frequently in Ukraine and in many countries in the world.

The apparent lack of interest in using straw to maintain soil organic matter can be explained however. Straw in the field is a nuisance during ploughing and seeding of a following crop and may increase disease pressure. In addition straw can immobilize nutrients when ploughed under, which can potentially lower the yield of the following crop. The benefit of maintaining soil organic matter and soil nutrients is mainly relevant in the long term, and of little value to a farmer leasing land for short periods of a few years. Removal of straw would be less of a problem if fertilisation rates would be adequate and yields would be much higher than they are now and if manure or other organic fertilizer would be applied. Actually, the yield gaps for wheat and corn are close to 60% in Ukraine, meaning that current yield are 40% of potential rainfed yields. Applying optimal agronomic practices could double the yield for these crops (www.yieldgap.org) and thereby increase the amount of harvestable straw. Many explanations can be provided why farmers in Ukraine do not apply optimal agronomic practises. Ukraine produces crops for the world market where prices are low and can fluctuate unpredictably. Also, droughts can occur (as was the case in 2017), reducing the effectiveness and return on investment of fertilisation. This means that investments in fertilizers, high quality seeds, pesticides irrigation systems and precision agriculture may be uneconomical, the investment is lost.

In Ukraine, harvesting crop residues comes at a cost to soil quality but it can also reduce the cost of natural gas imports, increase energy security and save a lot of money and reduce GHG emissions. It may however be possible to use the money saved by using crop residues instead of natural gas to take measures that maintain soil quality. Would this still make using crop residues attractive?

1.2 Objectives

This short project aims to generate information to be presented at workshops for policymakers and financing institutions in Ukraine and Europe. In the workshops the soil quality problem is explained and measures to harvest residues while reducing soil quality problems are put forward. The purpose is to elicit an interest in setting up projects to implement research on this subject and to provide input for policy makers in Ukrainian and EU and for funding agencies and companies investing in bioenergy. This report was partially funded by the Netherlands Enterprise Agency as part of the partners for international business project Biomass Ukraine (http://www.biobased-ukraine.nl/).

1.3 Outline of report

This report describes the results of the preliminary analyses and model runs for different scenarios of crop residue removal. In Chapter 2 the methodology, the model and the input data are described. The results of the model analysis are presented and discussed in Chapter 3.

The first results have been presented at a workshop “New opportunities for rural areas” at the Saxion Hogeschool in Enschede at 20 March 2018. Another workshop is planned for September where results will be presented in in Kiev at a workshop on this issue.

2 Methodology

2.1 Overall approach

In this study we evaluated the effect of crop residue removal on the soil and the effect of methods to alleviate negative effects on soil quality. The focus was on wheat straw and corn stover removal for heat production. A soil model (RothC) (Coleman and Jenkinson, 1999) was used to evaluate the soil effects of the measures proposed and results will be compared to residue removal and field burning of residues.

Wageningen Research has done previous analyses based on calculations with the RothC model, a soil carbon model, linked to the environmental assessment model MITERRA-Europe, to assess potential residue removal at regional scale for the Ukraine. In this project the RothC model will be used for a more detailed analysis for one Ukrainian site at field level. The Ukrainian institute of bioenergy crops and sugar beet provided soil and crop data for this analysis. Ideally data should be from long term field experiments should be used to validate these model calculations, but such data were unfortunately not available.

Mitigation effects of residue removal was modelled with the model and Ukrainian case data. The following options have been proposed to mitigate the negative effects of crop residue removal for soil carbon/quality:

- No-till planting – no ploughing
- Harvesting straw only once every 2 or 3 years
- Planting a green manure crop after harvest
- Use stems, leaves for the soil. 2/3 nutrients left in the field + 1/3 of organic matter
- Returning ash from straw burning to the field
- Requiring balanced fertilisation from farmers
- Apply other organic fertilizers: biogas digestate, manure, ..
- Better use maize straw not wheat straw

2.2 RothC soil carbon model

The RothC model (Coleman and Jenkinson, 1999) was used to calculate the SOC balance. RothC (version 26.3) is a model of the turnover of organic carbon in non-waterlogged soils that allows for the effects of soil type, temperature, moisture content and plant cover on the turnover process. It uses a monthly time step to calculate total organic carbon (ton C ha^{-1}), microbial biomass carbon (ton C ha^{-1}) and Δ14C (from which the radiocarbon age of the soil can be calculated) on a years to centuries timescale (Coleman and Jenkinson, 1999).

In RothC model, SOC is split into four active compartments and a small amount of inert organic matter (IOM). The four active compartments are Decomposable Plant Material (DPM), Resistant Plant Material (RPM), Microbial Biomass (BIO) and Humified Organic Matter (HUM), see Figure 1. Each compartment decomposes by a first-order process with its own characteristic rate. The IOM compartment is resistant to decomposition.

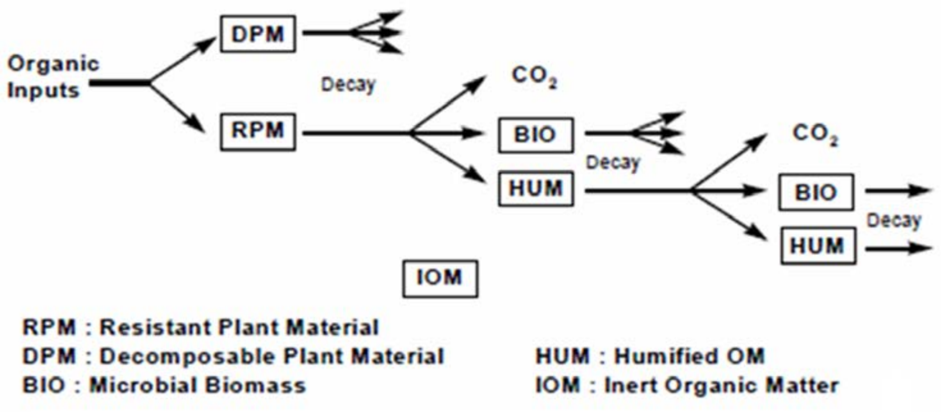

Figure 1*. Structure of the Rothamsted Carbon Model*

RothC requires the following input data on a monthly basis: rainfall (mm), open pan evaporation (mm), average air temperature (ºC), clay content of the soil (as a percentage), input of plant residues (ton C ha^{-1}), input of manure (ton C ha^{-1}), estimate of the decomposability of the incoming plant material (DPM/RPM ratio), soil cover (if the soil is bare or vegetated in a particular month) and soil depth (cm). Initial carbon content can be provided as an input or calculated according to long term equilibrium (steady state).

2.3 Input data

For the analysis we used soil, climate and crop data, which are representative for the Vinnytsia oblast. The Vinnytsia oblast is located in the central western part of Ukraine and is a region where mainly cereals and sugar beet are grown.

Climate data

The average annual temperature is 7.6 ºC and annual rainfall about 624 mm (Table 1), which makes this region on average more productive compared to other drier regions of Ukraine.

Table 1. *Average climate data for Vinnytsia oblast used for soil carbon modelling*

Month	Temperature (ºC)	Precipitation (mm)	Evapotranspiration (mm)
January	-5.3	38	11
February	-3.9	36	12
March	0.6	32	31
April	8.5	48	67
May	14.4	63	112
June	17.7	88	123
July	19.0	92	134
August	18.4	62	122
September	14.1	49	77
October	8.2	33	43
November	2.3	40	18
December	-2.2	42	11

Crop data

The two main cereal crops, wheat and grain maize, have been assessed for the modelling, the properties of these crops are stated in Table 2. Crop yield is based on statistical data and the carbon input for the different residue components are calculated based on different formulas. The total amount of aboveground residues is based on new formulas from JRC (Camia et al., 2018), see also Figure 2. The ratio between straw and stubble is based on Panoutsou and Labalette (2007), who proposed a straw:stubble ratio of about 55%, however, if a farmer aims to harvest most of the straw a higher ratio can be obtained, therefore we used for the modelling an average straw:stubble ratio of 60%. The belowground C input is set at 25% of the total assimilated carbon, based on Taghizadeh-Toosi et al. (2014). The carbon content of residues is set of 45% of the dry matter fraction.

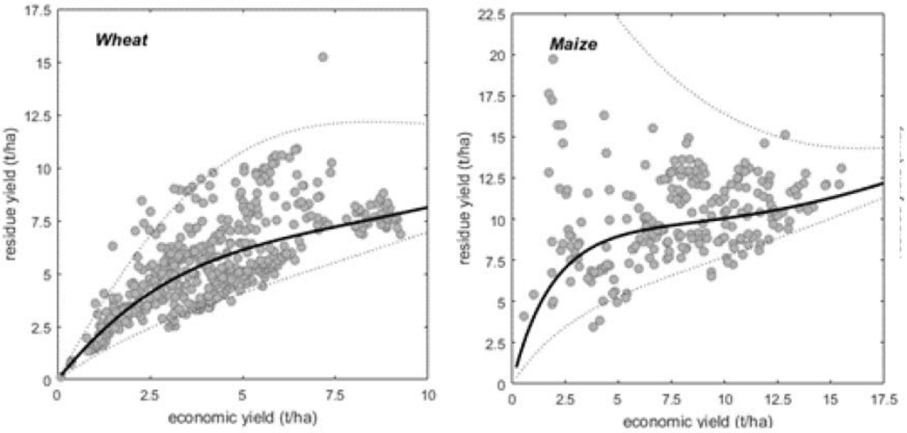

***Figure 2**. Relation between economic yield and crop residue yield (Camia et al., 2018)*

***Table 2.** Crop data used for baseline soil carbon modelling*

Parameter	Unit	Wheat	Maize
Yield	kg FM/ha	5250	6790
DM content product	Fraction	0.85	0.85
Aboveground residues	kg/ha	6315	9321
DM content residue	Fraction	0.85	0.70
Stubble	kg FM/ha	2526	3728
Straw / stover	kg FM/ha	3789	5593
Belowground C	kg C/ha	1474	1844
Stubble C	kg C/ha	966	1174
Straw / Stover C	kg C/ha	1449	1762
Total C input	kg C/ha	3890	4781

Soil data

For the soil data we used two representative soil types from the ISRIC WISE database. One profile is a Haplic Chernozem with high C content and the other profile a Luvic Phaeozem with lower C content. The characteristics of both soil types are provided in Table 3. For the modelling a soil depth of 25 cm is assumed.

***Table 3.** Soil data used for soil carbon modelling*

	Org C content	Bulk density	Depth	C Stock	Clay content
	%	kg/dm^3	cm	ton/ha	%
Chernozem	3.3	1.18	25	97.4	34
Phaeozem	2.2	1.31	25	72.1	20

2.4 Parameterisation of options

Not all options stated in Chapter 2.1 were assessed with the RothC model, as this is a preliminary and exploratory study, which does not have the budget for a full scale analysis of all options. Furthermore, some of the options only have an effect on the nutrient balance, and not on the soil carbon stocks (e.g. balanced fertilization and returning ash from straw burning to the field.

The following options have been assessed:

- Full straw removal (baseline)
- Incorporation of straw (baseline)
- Straw removal in combination with no-till planting (no ploughing)
- Increased crop yield (requires improved fertilization)
- Harvesting straw every second year

Based on preliminary model runs, the carbon pools were initiated, which depend on the soil type and the carbon input (Table 4). The resistant plant material (RPM) and humified organic material (HUM) pools are the main carbon pools, whereas the decomposable plant material (DPM) and microbial biomass (BIO) pools are only small, as these have a quick turnover.

Table 4. *Initial distribution over soil carbon pools (ton C/ha) for soil crop combinations*

	DPM	RPM	BIO	HUM	IOM	Total
Chernozem - wheat	0.8	18.4	2.0	67.2	8.9	97.4
Phaeozem - wheat	0.6	15.0	1.5	48.5	6.4	72.1
Chernozem - maize	1.3	29.9	1.7	55.6	8.9	97.4
Phaeozem - maize	0.9	21.3	1.3	42.1	6.4	72.1

The RothC model does not have a clear parameter for simulation a scenario with no tillage, as the model does not have a plough factor and only simulates for one soil layer. However, we assumed that zero tillage results in a soil that will not become bare, but remain covered with crop residues. Therefore we assumed this could be simulated through the ground cover factor, which we kept as covered for the whole year. As we did not have data to verify this assumption, this remains an uncertain outcome.

For the option with increased yield, we looked at the potential yield from the Yield Gap Atlas (http://www.yieldgap.org/). In this project yield gaps are estimated for the main crops in a range of countries, including Ukraine. For wheat the potential water limited yield could be 8.2 ton/ha, compared to the average current crop yield of only 4.1 ton/ha. We assumed that 80% of the water limited potential crop yield should be feasible with good fertilization and crop management. This means that wheat yield could increase by 60%. In that case also more crop residues from roots and stubble become available.

3 Results

3.1 Results for baseline scenarios

In Figure 3 the baseline scenario results are shown for removal of straw every year, or incorporation in the soil, for both wheat and maize for a Chernozem soil. The scenarios with straw removal have a stronger decline compared to straw incorporation, for maize the soil organic matter declines to 5.3% when straw is harvested, whereas for straw incorporation the organic matter content remains at 6.1% after 30 years. For wheat the difference is a bit smaller with 4.9% in case of straw removal and 5.5% without removal. The soil organic matter trends show a clear annual pattern with higher content after the crop harvest when carbon input from plant residues become available. For all scenarios there is a decline during the first 5 years, which might be an effect of the initialisation.

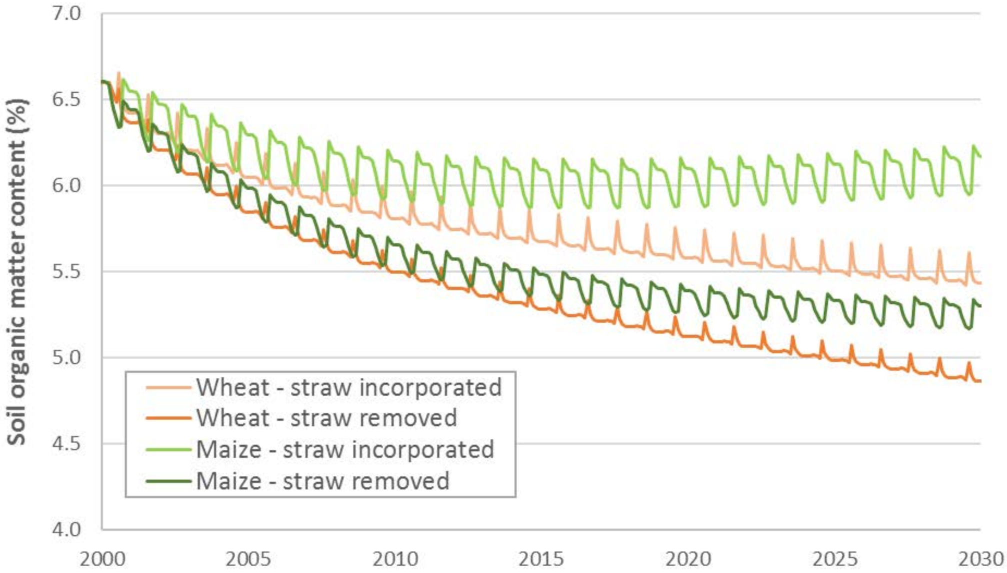

***Figure 3**. Results of baseline simulation with and without straw removal for wheat and maize for a Chernozem (high carbon) soil*

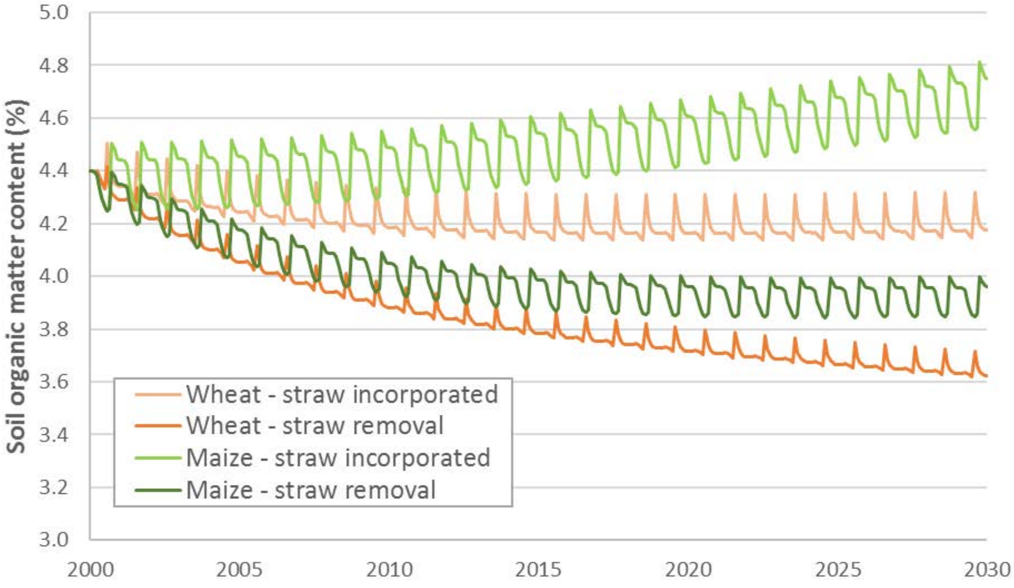

***Figure 4**. Results of baseline simulation with and without straw removal for wheat and maize for a Phaeozem (lower carbon) soil*

In Figure 4 the baseline scenario results are shown for a Phaeozem soil, which has a lower soil organic matter content. Also here the scenarios with straw removal have a lower soil organic matter content, however, for this soil the incorporation of maize straw can increase the soil organic matter content and for wheat straw it remains stable.

3.2 Effect of improvement options

For this study we simulated the effect of three alternative options to use the straw for bioenergy purposes and reduce the negative effects on the soil organic matter content. The three options assessed were:

- Yield increase
- Use of no tillage
- Remove straw every second year

The results for wheat on a Chernozem soil are shown in Figure 5. All three options increase the soil organic matter content compared to the baseline where straw is removed. The zero tillage option has even a higher organic matter content compared to the scenario where straw is incorporated. This effect might be large as these soils are losing carbon even in the scenario where straw is left on the field, in that case it can be effective to prevent further soil disturbance by ploughing. In case of the yield increase option, also the straw yield increases from 3.8 to 4.6 ton/ha.

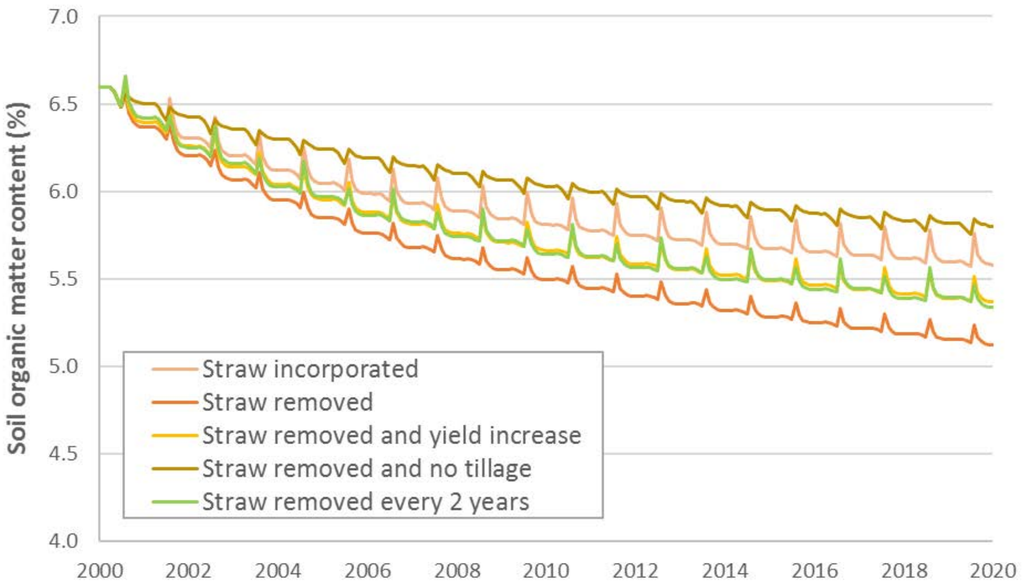

Figure 5*. Results of simulation of improvement options for wheat on a Chernozem soil*

4 Discussion and conclusion

The results show that for soils with a high soil carbon content, such as Chernozems, the baseline trend is a decrease in soil carbon, even if all straw is not removed but incorporated in the soil. These Chernozem soils have been formed over thousands of years with a steppe vegetation, which resulted in accumulation of soil carbon. Since these soils have been converted to arable land, the disturbance due to ploughing and the lower input of organic material, make that these soils are losing carbon. Since the soil horizon with high carbon content is rather thick for a Chernozem, the loss of carbon does not have a direct negative effect on the agricultural production, but on the long-term the productivity will decline. To compensate these losses, these soils should be converted either to grassland vegetation, which has much higher carbon inputs, or high inputs of external organic material such as manure or compost.

The three simulated improvement options all increased the soil organic matter content compared to the baseline where straw is removed. Zero tillage seems a very good option to increase the soil organic matter content of the soil. However, this is not a common practice in Ukraine and should be tested whether this can be effective, and if weed problems can be suppressed without large amounts of herbicides.

These model simulations of trends in soil organic matter should also be tested in practice, as models are always a simplified representation of the reality. For example, the effects of crop rotations have not been taken into account and the model has not been validated for Ukraine, as we don't have the data from long-term experiments. However, models are very useful for assessing the long term effects of improvement practices, and can give good insights into the relative differences in how these strategies perform.

Crop residue removal can further decrease soil quality and the amount of organic matter in the soil. Different strategies may be available to avoid this problem and the model results demonstrate that these can be effective. Still we do need to understand better how these strategies can be applied, in order to use crop residues for energy and other added value applications, without having negative effects on the soil. Knowledge on the economic and environmental effects of these strategies and their application in practice needs to be further developed and tested in the field. Ultimately, this kind of knowledge needs to be incorporated in policies that aim to use crop residues for energy production. Also financiers and donors can include these recommendations as prerequisite for loans or subsidies for sustainable use of crop residues.

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