Methodological aspects of assessing conservation agriculture efficency

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Abstract. The current research is aimed at working out methodological basis of assessing conservation agriculture efficiency based on the practical experience. The traditional system of land use is now to be totally reconsidered due to its negative environmental effects with new practices to be implemented that can increase productivity, protect soil from degradation and deal with the current climatic crisis, i.e. help adapt to the climate change, decrease greenhouse gas emissions and increase soil carbon sequestration. Conservation agriculture (CA) is the technology that can help overcome all the above mentioned challenges being defined as the approach of managing agricultural ecosystems that provides for the sustainable agricultural production, lower energetic and labor expenses and higher efficiency of utilizing soil and water resources. Given its major goal of preserving soil health conservation agriculture is to be evaluated based on the combination of ecological and economic effects, rather than on the economic effect separately. The current methods of evaluating eco-economic efficiency of the technology based on estimating soil carbon changes and methods of its recovery with adding organic fertilizers cannot be applied in practice now due to the lack of organic fertilizers and high costs of chemical analyses to measure soil carbon changes. The current study presents a new methodology to assess eco-economic effect of conservation agriculture practice based on assessing already adopted economic indicators and soil carbon changes dynamics (t CO_2/ha/year) from specific agricultural practices with the subsequent estimation of carbon credit units that farmers can sell at a carbon market.

1 Introduction

Along with its major goal to provide food security for the region and country in general agriculture as an economic system should be characterized by the sustainability to provide for the long-term strategic development and defined by a number of factors the first being the economic efficiency of the branch.

The evaluation of economic efficiency of crop production is based on the system of natural and cost indicators that reflect the relation between the profit and costs both material and labor. However, agriculture is directly connected with the efficient use of its

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major resource that is the land its major characteristics being appropriate structure, nutrient sufficiency and, as a result, fertility. That is why it is of prime importance to evaluate not only the economic effect, but to provide a comprehensive eco-economic assessment of the agricultural practices being implemented.

Given the global degradation of agricultural lands and negative effects of agriculture on the climate change due to the greenhouse gas emissions it is of strategic importance to implement support measures to help farmers and agricultural enterprises adopt conservation agriculture practices that would deal with the mentioned ecological challenges. It is of common knowledge that agriculture production is evaluated based on the economic assessment ignoring soil fertility indicators with no financial support provided for farmers implementing the technologies of conservation agriculture and, thus, providing a three-pillar solution, i.e. sustaining food security, protecting soil from erosion and degradation and restoring soil fertility through carbon sequestration in soils and decreasing greenhouse gas emissions.

The current study is aimed at elaborating methodological basis and practical guidelines of evaluating eco-economic efficiency of Conservation agriculture.

1.1 Literature Review

Starting from the middle of the XXth century the productivity growth of crop production was connected with increased intensity of agricultural systems, i.e. connected with higher norms of inorganic fertilizers, wide range of herbicides, pesticides and intensive tillage. On the one hand, this approach has allowed to increase the productivity of agricultural systems [1-2], but on the other, it has led to the global decrease of soil fertility, its degradation, environmental pollution [3-8], resulting in decreased efficiency of agricultural systems, compromised food security, climate change due to the greenhouse gas emissions, desertification, lower biodiversity etc. [9-10]

Land degradation is regarded as a factor that influences the productivity resulting in lower yields and profits of agricultural business [11]. Besides, land erosion causes climate change, lengthening draught periods and consequently lower crop yields [12-13].

In Russia land degradation is increasing annually with 65% of arable lands, 28% of hay meadows and 50% of grazing lands being subject to erosion, degradation and droughts. Besides, annually Russian soils lose about 0.62 t/ha of humus that has re in the general loss of 30-40% over the last 100 years. The damage from irrational use of agricultural lands is enormous as the annual yield losses reach 43 mln tons [14].

Intensive tillage and fertilizing in crop production leads to the rise carbon dioxide emissions increasing greenhouse effect and global warming [15-16]. According to different estimates, AFOLU sector accounts for 14-28% of total greenhouse gas emissions [17-18] with 35% of CO_2, 47% of CH_4, 53% of N_2O and 21% of NO globally being emitted by soils [19].

In order to increase the productivity of agriculture, solve ecological, economic and social problems it is thus recommended to implement conservation agriculture technologies. FAO defines Conservation agriculture as a farming system that promotes minimum soil disturbance (i.e. no-till as a target technology), maintenance of permanent soil cover, and diversification of plant species which enhances biodiversity and natural biological processes above and below the ground surface, which contribute to increased water and nutrient use efficiency and to improved and sustained crop production.

Conservation agriculture is based on the following principles:

- Minimizing soil disturbance: the major objective is to reduce tillage to zero (the target technology is no-till with no tillage before planting and seeding directly into the crop residues).

- Keeping plant residues in the field on the surface of the soil (mulching) to protect soil from water and wind erosion reducing water run-off and evaporation while improving soil fertility, its physical, chemical and biological properties that determine its long-term sustainability and productivity.
- Stimulating biological diversity with crop rotations in order to control weeds, plant disease and pests and take advantage of the positive effect of crops both on soil and on the yields of the subsequent crop thus minimizing the risks of economic losses.

As it is evident from these principles Conservation agriculture is a broader concept than reduced tillage or no-till [20].

Summarizing economic effects Conservation agriculture has the potential to increase productivity and yields, help agricultural systems adapt to the climate changes, broaden the product range of fertilizer, herbicide and machinery manufactures, and broaden the variety of technologies that can be applied by the agricultural business to improve the yields and preserve soil fertility while supporting food security of the country [21].

For today Conservation agriculture is practiced in Russia on the territory of 6 mln ha with 15 mln ha applying mulching which is regarded as a transition technology. It is now estimated that a hectare under conservation agriculture can sequester up to 5 tons of carbon per year. According to the FAO Global Soil Sequestration Potential (GSOCseq) Map Russia has the highest potential of soil carbon sequestration reaching 17Me per year [22].

However, many experts claim that conservation agriculture and different other regenerative practices will be broadly adopted only if they prove to be economically viable [23]. Though sometimes delayed the economic effect of CA is evident and constitutes the decrease of operational costs, soil regeneration and protection from erosion (retaining soil fertility) [24-25]. Another potential economic benefit is related to the carbon sequestration payments through the mechanism of selling carbon credits at the carbon market [26].

In Russia we are observing a trend towards stimulating adoption and spreading of conservation agriculture technologies. Thus, in 2019 Russia ratified the Paris agreement that presupposes the decrease of greenhouse gas emissions up to 70-75% from the level of 1990 given the maximum forest absorption capacity. After that the Russian president signed an order to establish a national system of climatic regulation.

The most popular economic tools of such regulation include carbon tax and carbon market that can be regarded as stimulating measures setting carbon prices and assisting in decreasing GHG emissions. In 2021, Federal Law No. 296-FZ “On limiting greenhouse gas emissions” came officially into force that obliges related entities deliver the prescribed records on emissions and sets the concept and terminology basis to start the carbon registry and carbon market in Russia.

Thus, efficiency assessment should not be limited to the calculation of economic indicators because CA system is aimed not only at receiving high yields but also at solving such ecological issues as protecting soil from erosion, restoring soil fertility, preserving biological diversity, decreasing the emissions of greenhouse gases, and sequestering soil carbon.

Ecological assessment of different practices is usually conducted using an approach of life cycle assessment which is actively applied for evaluation of agricultural technologies in organic farming [28], crop rotations [29], no-till and for other conservation agriculture practices [30], as well as for the assessment of mineral fertilizers and other technologies. These approach estimates greenhouse gas emissions and carbon footprint, however it ignores eco-economic assessment.

There have been research papers on the comprehensive ecological and socio-economic assessment of intensive agricultural systems but they assess specific crops in specific soil and climatic conditions, thus, they cannot be applied in general practice [31].

Besides, methods of eco-economic [32-33] and bio-energetic assessment of tillage practices for several crops have also been elaborated that along with economic efficiency also assess the dynamics of soil fertility (organic matter) in terms of costs and can also be applied to evaluate the practices of conservation agriculture. For example, Golubev [33] in his paper sets the methodological basis for the comprehensive assessment of technologies and fertilizers applied and presents a practical case of assessing the changes in soil fertility using the method of standard calculations and evaluating ecological consequences of production in terms of costs.

2 Materials and methods

The current study was conducted based on the following methodology of calculating soil organic carbon [35-36]: the volume of mineralized humus was calculated based on the nitrogen concentration in the yield given the C:N ration in the leached blacksoil taken as 10:1, i.e. 1 part of nitrogen in the yields corresponds to 10 parts of humus (organic carbon) mineralized.

Eco-economic assessment of the technology was based on the economic indicators of the technological maps of cultivating crops in the "OOO Maynskaya Agrocompany" farm. Additional costs on compensating for the lost carbon were calculated based on the organic fertilizers required given that 1 ton of manure costing 1 thousand roubles/ton provides for 50 kg of humus [33-34].

3 Results

The suggested eco-economic assessment of the agricultural technology was tested at the enterprise "OOO Maynskaya Agrocompany" of the Maynsk district of the Ulyanovsk region located in the forest-steppe zone of the Middle Part of the Volga region dominated by blacksoils and grey forest soils. The enterprise cultivates such crops as winter and spring wheat, barley, peas, soy, buckwheat, rape, flax (Table 1).

Table 1. Eco-economic assessment of the major agricultural crops in the enterprise "OOO Maynskaya Agrocompany" of of the Maynsk district of the Ulyanovsk region (according to the prices for the year 2023).

Indicators \ Crops		Winter wheat*	Brewer's barley	Pea	Soy	Black wheat	Rape
Yields, t/ha		5.02	3.81	2.85	1.82	1.61	1.60
Production cost, roubles per 1 ha		50.2	45.7	37.05	47.32	35.42	38.4
Direct costs, roubles per 1 ha		27.2	23.5	22.6	24.4	15.2	22.8
Operating profit, roubles per 1 ha		23.0	22.2	14.5	22.9	20.2	15.6
Humus balance (in conversion to carbon), +/- t/ha		-2.50	-0.30	-0.29	-0.21	-0.13	-0.66
Additional costs to compensate for losses of soil organic carbon, roubles per 1 ha		65	7.9	7.4	5.5	3.4	17
Costs given the expenses to compensate for soil organic carbon, roubles per 1 ha		92.2	31.4	30	29.9	18.6	39.8
Profitability, %	Given only direct costs	84.6	94.6	63.9	93.9	133.0	68.4
	With additional costs to compensate for the losses of organic carbon	-45.6	45.6	23.5	58.3	90.4	-3.5

*- winter wheat after fallow

The calculations have shown that if the recommended technology is implemented, i.e. combination of different types of tillage with the elements of no-till, application of the calculated norms of inorganic fertilizers and herbicides, cultivation of high-intensity types

of crops allows to get a net profit from 14,5 to 23 thousand roubles per hectare with a cost-effectiveness level being more than 100% for some crops.

Harvesting leads to carrying nutrients away from the soil together with mineralizing organic matter and losing soil carbon. Our calculations have shown cultivating crops in the "OOO Maynskaya Agrocompany" even given the return of organic matter with plant residues leads to the losses of humus (in conversion to carbon) from 0.13 t/ha (black wheat) to 2.5 t/ha (winter wheat after fallow). To compensate for the carbon losses in the soil it is necessary to add organic carbon (in conversion to manure) in the amount from 3 to 50 t/ha, that is from 3,3 to 65 thousand roubles per ha.

Our calculations have shown that intensive systems of agriculture lead to the necessity of compensating carbon losses in the soil, thus, leading to additional expenses. As a result, the economic feasibility of crop production drastically falls with such crops as winter wheat and spring rape after fallow causing even significant losses.

It is also worth mentioning that traditional approaches such as organic fertilizers cannot be applied on a commercial scale as there is a substantial lack of manure in the country and its price is too high for it to be applied in the amounts required. As a result, the necessity to implement conservation agriculture practices becomes inevitable.

Recent studies have calculated the approximate effect of conservation agricultural practices on sequestering soil organic carbon:

- No-till: from 0.1 to 1.0 t C/ha/year.
- Cover crops: from 0.1 to 0.5 t C/ha/year.
- Other practices:
  - Efficient management of nitrogen fertilizers – 0.1 to 2.0 t C/ha/year.
  - Planting legumes instead of nitrogen fertilizers - 0.1 to 3.0 t C/ha/year.
  - Optimizing cultivating land structure - 0.1 to 2.0 t C/ha/year.
  - Applying biological treatments – up to 2.0 t C/ha/year.

  Thus, the overall effect may reach 10.5 t C/ha/year.

4 Discussion

In the course of the study it has been found that given the amount of carbon sequestered by the soil through the CA practices for the "OOO Maynskaya Agrocompany" to compensate for the soil carbon losses it is enough to stop using fallow, turn to no-till and introduce cover crops. Thus, according to the recommendations given in 2023 the enterprise started to introduce the abovementioned practices.

It is evident that Conservation agriculture is a promising and potentially efficient system for the forest-steppe Middle Volga region, however today there is a significant lack of methodological approaches and guidelines to the assess the efficiency of the practice. To solve the problem we suggest a modified method of eco-economical assessment based on the methods already elaborated and literature reviews published.

We propose to carry out eco-economic assessment of the conservation agriculture based on the following methodology:

- General eco-economic efficiency (EEe) of specific practices is calculated based on the following formula:

$$EEe = Ecc \pm Ecs, \text{ roubles/ha [1]} \quad (1)$$

Where: *Ecc* – economic effect from crop cultivation; *Ecs* – economic effect from carbon sequestration.

- Economic effect from crop cultivation (Ecc) is calculated based on the following formula:

$$Ecc = Y*P - C = OP, \text{ roubles/ha [2]} \quad (2)$$

Where: Y – yields, t/ha; P – sell price of the crop, roubles/ton; C – overall production costs for a specific crop, roubles/ha; OP – operating costs, roubles/ha.

- Economic effect from carbon sequestration (Ecs) is calculated based on the following formula:

$$Ecs = Ci - Cf = \pm\Delta C * Cc \text{ [3]}, \quad (3)$$

Where: Ci and Cf – carbon stocks before (initial) and after (final) a practice is implemented; $\pm\Delta C$ – changes of carbon stocks, t/ha; Cc – cost of a carbon unit, roubles/t CO_2 u/ha/year.

This method of assessing eco-economic efficiency of the Conservation agriculture has demonstrated that regenerative practices can help sequester up to 1 t C/ha/year with additional economic effect of 1 thousand roubles per hectare if we take the price of 1 ton of carbon per hectare to be 3.67 thousand roubles. However, if carbon markets develop the prices and farmers' profits are to grow.

Besides, soil organic carbon is a key factor and indicator of soil fertility, thus the increase of soil carbon content results in higher soil productivity and will have a positive economic effect in future which is to be considered as well if we discuss the prospects of CA adoption.

5 Conclusion

Conservation agriculture assessment should not be limited to the economic effect of crop cultivation which is, however, also higher in comparison with traditional methods due to decrease of spending on fuel, herbicides and fertilizers but extend to the eco-economic assessment of soil carbon changes.

Traditional crop cultivation is always accompanied with soil carbon losses even if it is partly returned with plant residues and hay or compensated with the organic manure fertilizers which can be too expensive and too often inefficient.

Such CA practices as optimizing cultivating areas, surrendering to use fallow, turning to no-till and cover crops can provide for the zero or even positive carbon balance of more than 1 ton of C/ha/year. The presented eco-economic assessment allows to calculate this effect and subsequently get additional profit from soil carbon sequestration.

Besides, conservation agriculture practices have a long-term positive effect as soil carbon sequestered in the soil allows to improve soil fertility and productivity of agricultural crops which is also to be considered when new eco-economic assessment methodologies are developed.

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