Pros and cons of no-till technology in a long-term field experiment on sod-podzolic soil

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Abstract: In a ten-year field experiment the technologies of conventional tillage (Plowing) and resource- and soil-saving treatment (No-till and Mini-till) were compared. The pros and cons of the No-tillage in the condition of temperate humid zone on the sod-podzolic soil are shown. The cons are: significant increase of soil density, lower crop biomass, higher weed infestation, an increase of pesticides application. The pros are increased soil moisture storage capacity, potential stability of cereal crop yield and economic benefits on grain production.

1. Introduction

Conventional plowing with presowing cultivation is the main traditional method of tillage. Full cycle of presowing soil treatment is suitable for creation favorable agrophysical conditions at the topsoil for plant cultivation. This method helps to achieve optimal bulk density, porosity of soil and to optimize the air-water soil balance for plants. The effectiveness of such full processing has been proved by time and has not caused doubts among many generations of farmers. But permanent for decades use of plowing leads to the problems on a planetary scale: the rapid development of erosion, loss of fertility and organic matter stock [1]. In addition, the full cycle of tillage treatment with plowing is the most energy-consuming contribution of the complete chain of agricultural crops cultivation. For these reasons, in recent decades there has been a global trend towards resource-saving and soil-conservation technologies, including zero technologies (No-till, Zero-till) and direct seeding all over the world [2, 3]. According to FAO, Brazil, Argentina, Canada, USA, Australia are the leaders in the application of soil-saving soil conservation technologies. In the last decade, zero tillage and direct seeding technologies come to Russia. There are successful experiences of these technologies in some regions of Russia, but it is too early to consider the No-till system as a long-term, successful and well-proven technology in our country. Officially there is no complete and accurate estimate of the area of arable land under No-till technologies in Russia. According to our investigation, including oral interviews, reports, presentations and preliminary review of business agricultural press, No-till technology is rarely used and it occupies less than 1 % of total arable land of Russia. The technology of direct sowing with zero tillage in pure form as a long-term experience is still very rare in Russia. But, despite the difficulty and high cost of adaptation, in recent years interest in such technologies has increased rapidly. A few years ago Association of direct sowing followers was established in Russia (http://aspp-rf.ru).
The main advantages of direct sowing and zero treatments are saving of energy and soil conservation. Simultaneously, zero technology has significant disadvantages, which are most clearly manifested in the first years of technology adaptation. Many problems of the minimization of soil treatments and the transition to direct sowing are noted. The bulk density and compaction of the topsoil increases, the phytosanitary situation worsens with higher spread of fungal diseases and weed infestation of crops [4]. Therefore, the technology of No-till and direct sowing leads to higher quantity of pesticide applying, and as a result the phytotoxicity of the soil increases. Thus, the problem of full assessment of the soil-tillage and crop production technologies is quite relevant.

A long-term field experiment of the Center of precision agriculture at Russian State Agrarian University – Moscow Timiryazev Academy is a unique test site, where more than 10 years of comprehensive comparison of resource-saving and traditional tillage systems are carried out. This study is the part of the complex long-term field monitoring of soil fertility and crops productivity. The purpose of the study is to demonstrate the pros and cons of using zero tillage and minimal tillage under intensive crops cultivation in the complex system of four-field crop rotation on sod-podzolic soil. How to estimate the pros and cons? There are several approaches. One way is to calculate the economic efficiency of crop production under different treatment. In our experiment No-tillage practice leads to 19–20% reducing the costs of tillage, but 11–16% increasing the costs of pest control [5]. After two cycles of crop rotation, the profitability of No-tillage technology for winter wheat crop production was proven; grain production by this technology is cheaper [5]. But the economic approach does not answer what happens to the soil and how crops grow. Therefore, another approach is based on the study of soil properties and crop productivity under comparable conditions. This article focuses on evaluation of the most important agrophysical soil properties, which determine plant growth. There is penetration (connected with the soil compaction) and moisture content of arable soil layer.

2. Material and methods

2.1. Experimental Site

The investigations were conducted at the Field Experimental Station at Russian State Agrarian University – Moscow Timiryazev Academy (RSAU–MTA), Moscow, Russia (N 55,8369°; E 37,5636°). Climate in Moscow region is a humid continental, according to Köppen climate classification, climate cod is Dfb [6]. The average annual precipitation, including snow, is approximately 700 mm. Annual rainfall varies from 300 to 450 mm. The average annual mean temperature is about 6.6°C.

The object of the study is the Field research experiment of the Precision Agriculture Center (PAC). The PAC experiment includes four individual fields №№ 1–4 (figure 1). The total area of four connected experimental fields is 6 hectares at the flat area of 240×250 m, and the area of individual fields is 0.8 and 1.4 hectares.

Crop rotation is: winter wheat + mustard (as a green manure after harvesting); potatoes; spring barley; vetch-oat mixture. Crop rotation is maintained in time and space. The experiment continues from 2008 to the present.

Two technologies of tillage are compared in the experiment. Plowing treatment is a classical traditional processing of conventional tillage. It includes post-harvest disk plowing to break the stubble, autumn conventional plowing, and pre-sowing cultivation of the soil. Such standard soil tillage treatment occupies 50% of experimental field area (figure 1, stripes Plowing). Resource-saving treatment includes minimal disking (depth of 12–14 cm) before potato and barley (two years of crop rotation) and Zero-tillage (No-till) before Vetch-oat mixt and winter wheat (two years of crop rotation). The use of resource-saving technologies alternates in time according to the scheme: 2 years minimum-till, then 2 years no-till, and so on (figure 1, stripes Minim/No-till). From year to year, a tillage scheme is reproduced in each of the crop rotation fields in duplicate.
2.2. Complex study of soil properties of PAC experimental fields

The soil cover of the experimental fields is heterogeneous, since it is formed on moraine sediments with an uneven particle size distribution. The soil is sod-podzolic or Retisols by FAO soil classification [7], medium and light loamy, illuvially ferruginous, gleic.

The agrochemical survey of the soil at the PAC experiment has been carried out regularly every two years since 2008 with sampling on the grid and determining the basic agrochemical properties (according to the generally accepted methods for podzolic soils). Good soil fertility is maintained due to the annual application of mineral fertilizers according to the crops requirements. The content of labile phosphorus and exchangeable potassium in the soil is respectively 240±4 and 166±10 ppm (average ± 95% confidential interval). There are no differences on fertilization doses between two kinds of soil tillage treatment. But the distribution of elements in the depth of the topsoil varies depending on the method of tillage.

The agrophysical soil research includes spatial and time-series field observations: soil moisture, bulk density, soil compaction (soil penetrometer DICKEY-John) and electrical resistance (vertical-deep sounding). Spatial patterns of the soil cover and distribution of soil properties were surveyed on the PAS experimental fields. For example, soil hardness and moisture were estimated in early spring (during maximum moisture saturation) to compare plant-growing condition under different soil-tillage treatment.

2.3. Complex phytocenosis monitoring of PAC experimental fields

Each fields of PAC is an individual agrophytocenosis. Its research includes spatial and time-series observations of crops biometrics, vegetation indices, productivity, yield, number and species variability of the weeds communities, the spread of diseases, the impact and aftereffect of pesticide use, etc. It was noted, that the areas of different crops productivity (NDVI and yield) in the experiment fields are connected with the areas of heterogeneous soil properties. Evaluation of NDVI is carried out with the use of remote sensing (from satellites and unmanned aerial vehicles) and ground-based methods (active optical sensor GreenSeeker RT200, Trimble). For the biometric measurements of crops and counting of the segetal flora the grid mapping method with the placement of testing sites squire mini-plots (0.25 m²) in the regular grid point (3×7 m) is used. Harvesting is carried out with the yield mapping. All information of soil, crop, weeds, etc. is geo-referenced and stored in a GIS database. Weather conditions of each growing season are also recorded. The database has data from 2008 to the present. Every year all data on crop yields, weed infestation and economics aspect are evaluated according to the compared tillage treatment.
Generally, many properties and indicators were studied at the field experiment, and this article presents only a small part of the study. Soil hardness (bulk density, compaction) and moisture together determine the conditions of plant growth. These soil factors can be measured quickly, accurately and in high number of replications with the use of portable instruments.

Seasonal crops development from germination to harvesting is assessed by the NDVI.

3. Results and discussion

3.1. Soil compaction under plowing, minimum-till and no-till

It was shown that soil moisture in the 0–30 cm layer and soil hardness in the 10–20 layer cm depend on the tillage treatment. The plots under resource-saving technology are characterized by increased hardness and higher moisture content in the topsoil (figure 2). In the layer 20–30 cm the spatial pattern of the hardness distribution depends on both the tillage methods and the underlying parent subsoil moraine sediments. The soil is harder where the layer of sand underlies the topsoil.

![Spatial distribution maps of soil compaction (PSI) at the depths of 10–20 and 20–30 cm and moisture content (mm) in the layer of 0–30 cm in the field № 2 in April 2010 and 2017.](image)

**Figure 2.** Spatial distribution maps of soil compaction (PSI) at the depths of 10–20 and 20–30 cm and moisture content (mm) in the layer of 0–30 cm in the field № 2 in April 2010 and 2017.

The seasonal dynamics of soil compaction strongly depends on precipitation of the growing season, but at the plots under resource-saving technology compaction of surface layer is always higher, then at
the plots under tillage. This observation is true in all years, all fields of crop rotation and under all kind of crops (figure 3).

**Figure 3.** Seasonal dynamics of mean of soil compaction (PSI) under different methods of tillage and under different crops: (a) – winter wheat, (b) barley and vetch-oat mixture, (c) – potato (case study at the season of 2012). Error bars show 95% confidence intervals of the average means. Right vertical axis – the amount of rainfall precipitation

3.2. **NDVI and biomass of winter wheat under plowing and no-till technology**

Seasonal dynamics of crop biomass depends on weather conditions and treatment type. At the beginning of vegetation the density of seedling is higher at the plots under Plowing system. It is especially noticeable in the spring, after overwintering. At the plots of No-till seedling winter survival is significantly lower. With a sowing rate of 5,5 million seeds ha⁻¹, at the spring the number of seedlings under Plowing is 4,0–4,8 and under the No-till 3,5–4,2 million seeds ha⁻¹. So, spring vegetation of winter wheat begins with the fast start under the Plowing treatment and lower start under No-till treatment. It is well illustrated by the time series chart of NDVI (figure 4). The seasonal dynamics of cereals NDVI at the PAC field experiment studies in detail every year. NDVI strongly correlates with photosynthetically active biomass of crops. Each spring period NDVI value and biomass of winter wheat is lower at the plots under No-till then on the plots under Plowing. At the second part of vegetation season winter wheat NDVI value is higher on the plots under No-till (figure 4). Generally, under No-till technology the growing season lasts longer due to the large moisture content in the soil. From the one hand, it is pros for yield, but from another hand, it is cons for harvesting. Long-continuous growing season leads to increase yield because of the longer period of flag leaf photosynthesis. But under conditions of no-till treatment cereal crops maturation takes more long time and state of crops is not uniform. It causes difficulties in harvesting, and sometimes it is necessary to use additional desiccants. It is a disadvantage of No-till and Mini-till technology in the temperate zone with sufficient moisture.
Figure 4. Dynamics of vegetation index NDVI of winter wheat (2016) under two methods of soil treatment and precipitation.

4. Conclusions
Different methods of soil tillage treatment lead to different plant growth conditions. High soil hardness (compaction) under No-till and Minimum-till treatment causes a lag in the crop growth during vegetation season. Higher store of productive soil moisture under No-till technology is favorable for plants, but it could not be realized in conditions of high soil compaction.

For the condition of temperate humid zone with the sod-podzolic soil resource-saving technology cannot demonstrate all its features and benefits because at the first period of No-till and Mini-till adaptation soil agrophysics properties change for the worse. But it can change after some next years. The experiment continues.

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