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Influence of precipitation and moisture reserves on the yield of crops under different tillage

G. Mokrikov, T. Minnikova*, K. Kazeev and S. Kolesnikov

Southern Federal University, Academy of Biology and Biotechnology by D.I. Ivanovsky's, Department of Ecology and Nature Management, av. Stachki 194/1, RU344090 Rostov on Done, Russia
*Correspondence: loko261008@yandex.ru

Abstract. Tillage technologies that promote resource-saving and increase in the yield of agricultural crops are being increasingly involved into the agriculture of arid territories of Russian Federation. Studies of the impact of new tillage on soil quality and yield in Russian Federation are necessary owing to the high soils and climate diversity. Yield enhancement of major crops - winter wheat and sunflower - have been observed in Russian Federation in recent years. During 2014–2019 in the south of the European part of Russian Federation (Rostov region), the effect of No-Till (NT) on soil quality and yield of field crops was studied. The studies were carried out over an area of 5,500 hectares in comparison with adjacent fields, where conventional tillage (CT) of soils with mould board plowing was used. The yield of sunflower and winter wheat depended significantly on the amount of precipitation during the growing season. In 2014–2017 the use of No-Till increased the yield of winter wheat by 26–114%, of sunflower - by 27–92% as compared with farms, where the conventional tillage of soil treatment was used. No-Till helped to save motor fuel, increase yields of agricultural crops and lower the cost of winter wheat and sunflower.

Key words: conventional tillage, crop yield, fertility, ordinary chernozem, no-till, sunflower, winter wheat.

INTRODUCTION

The population of the Earth increases yearly by an average of 1.00–1.22% (up to 100.0–122.2 million people). Regular increase in population size compels people to look for new food sources and intensively develop new agricultural land or the use of existing ones. Along with the need to develop the agricultural sector, the question of the rational use of non-renewable energy sources such as oil and gas arises. In recent years, Russian Federation has been actively discussing the possibility of saving motor fuel in agriculture without affecting the yield of agricultural crops and soil fertility. Modern tillage technologies include a set of measures for the mechanical and chemical tillage: mould board plowing, fertilizer application and pesticide treatment, etc. Different tillage techniques change the agrophysical properties of the soil (Ivelic-Sáez et al., 2015; Zúñiga et al., 2015; Gailis et al., 2017; Bai et al., 2018; Dridiger et al., 2018; Zelensky et al., 2018; Trofimova et al., 2018). The most significant is a change in soil structure and a decrease in soil permeability compared with conventional soil treatment. In case

of mould board plowing a violation of soil aggregates takes place, cementation of soil particles depending on precipitation is observed, and the structure stabilizes due to the activity of soil macro-, meso and microfauna (Soane et al., 2012).

Conventional soil treatment with plowing leads to erosion, deflation, dehumification, soil aridization in southern Russian Federation, changing the soil structure and ecosystem related functions of carbon content, greenhouse gas emissions and soil moisture preservation (Valkov et al., 2008; Baybekov, 2018). When reducing the use of conventional tillage, a rational, cost-effective and environmentally friendly technology is needed. These technologies include a number of processing techniques having a minimal impact on the soil of agricultural land by analogy of nature. These nature-like technologies include No-Till. Using No-Till can save on fuel consumption, carbon content and as a result reduce soil erosion processes and increase the carbon – humus content (Tebrügge & Düring, 1999; Soane et al., 2012; Palm et al., 2014; Shekhovtsov & Chaikina, 2018).

This tillage technology is widespread in the United States, Argentina, Brazil and several other countries of the world (Handbook direct sowing, 2004; Soane et al., 2012; Kiryushin, 2013). Due to the absence of mechanical treatment, No-Till preserves the soil structure, soil porosity, and allows retaining water in the soil in the root area, which is necessary for plant growth and development (Uteau et al., 2013). The use of No-Till contributes, along with saving resources, to increasing fertility and reducing the negative impact on agrocenoses. To assess soil treatment techniques for physical condition and structure, it is necessary to take into account the ground relief, amount of precipitation and temperature of the soil (Khitrov & Chechuyeva, 1994; Rusanov et al., 2012; Bogunovic, 2018).

The weak spread of No-Till in Rostov region is due to the conservative thinking of agronomists and the low level of agricultural security with high-performance agricultural equipment, including, among other things, its high cost. According to the ratio of tillage types by 2020 in the structure of the cropped lands of the Rostov region, the largest area of arable land will be processed with surface, shallow processing and No-Till - 43.9%, deep ploughing, chisel and flat-cut treatments – 21.4%, and deep mould board plowing - only 12.5% (Zonal systems, 2013). The use of No-Till technology in the Rostov region has a beneficial effect on the biological state of the soils. When using No-Till, an increase in the carbon content of the post-harvest residues of the plants of the previous harvest is observed; the plant mulch converts the microbiota into humus during its activity (Soane et al., 2012; Zúñiga et al., 2015). No-Till technology has a beneficial effect on the nitrification process of flax, barley and winter wheat (Minnikova et al., 2017a). The nitrification values with the use of the No-Till technology are by 2–3 times higher for flax and barley in comparison to the conventional technology. The maximum nitrification was noted during the period of earing of grain crops and entering the flax into the flowering phase in June. When the soil's agrophysical properties change, not only the nutritional regime of the soil is disturbed, but also the production of enzymes due to the metabolic activity of the soil biota. The activity of soil oxidoreductases and hydrolases in the upper soil layer (0–10 cm) with the use of No-Till depended on the retention of moisture in the soil (Minnikova et al., 2018). Compared to conventional tillage, the closest links are found between hydrothermal indicators and β-fructofuranosidase activity, the activity of which, as it is known, is closely related to soil fertility and humus content (Valkov et al., 2008). Similar results were obtained by

A.V. Zushenitsena et al. (2018) when comparing various technologies for ordinary chernozem treatment in Krasnoyarsk forest-steppe, where increased soil moisture with minimal treatment and No-Till caused a significant increase in cellulose degrading activity by 27–38% and soil respiration by 17–24% (Zushenitsena et al., 2018). The beneficial effect of No-Till technology was confirmed on binary sunflower seeding together with melilot and vetch (Minnikova et al., 2017b). Ordinary chernozem had a high activity of catalase and invertase with all plant crops. In the process of studying binary seeds of sunflower, it was found that the activity of oxidoreductases as a whole decreases with a simultaneous decrease in humidity during the vegetation period, the activity of the protease, on the contrary, increases from June to September.

With different agricultural crops, rainfall and yield were estimated. Crops differ in their methods of sowing and growing with a sowing distance between crops of 2–5 cm (continuous sowing) and 20–25 cm (row crops). In this regard, for agricultural crop, the vegetation period and the amount of rainfall in this period were taken into account. According to the need for critical moisture, row crops, such as sunflower, form a powerful root system, as a result of which they consume moisture from arable (soil layer 0–22 cm) and subsoil soil (deeper than 22 cm), as well as from continuous seeding crops, like winter wheat in arable soil (soil layer 0–22 cm).

The purpose of our study is to assess the effect of productive moisture reserves and rainfall in spring-summer and autumn on agricultural crop yields when using No-Till in the south of the European part of Russian Federation (Rostov region).

MATERIALS AND METHODS

The effect of No-Till on soil quality and field crop yields was investigated in the south of the European part of Russia (Rostov region, Oktyabrskiy district) (Fig. 1). Areas with No-Till and conventional tillage were selected as objects of study.

The soils belong to ordinary chernozems of different thickness (Voronic Chernozems, WRB), degree of leaching from carbonates and humus content (Shishov et al., 2004; Valkov et al., 2008). According to No-Till, chernozems are treated on an area of about 5 thousand hectares over the last 9 years. The territory of the Oktyabrsky district of the Rostov region is located in a region with significant thermal resources. The sum of positive air temperatures (above 10 °C) is 3,200 °C. Summers are hot (temperature July is +24.3 °C),winters are moderately cold (temperature January is -2.5–2.7 °C). At the same time, the major part of the Rostov region belongs to the territory of insufficient and unstable moisture. According to reference data, the average annual rainfall is 423 mm (Khrustalev, 2002).

Figure 1. Location of the research region.

In 2014–2018 years 28 fields with different grown crops were studied: winter wheat (*Triticum aestivum* L.) and barley (*Hordeum vulgare* L.), spring barley (*Hordeum sativum distichum*), sunflower (*Helianthus annuus* L.), oilseed flax (*Linum usitatissimum* L.), coriander (*Coriandrum sativum* L.), chickpeas (*Cicer arietinum* L.), rape (*Brassica napus* L.). Studies were carried out in grain and grain grass eight-field crop rotations with the following alternation of crops (in % of the area seeding):

1) winter wheat + barley (100%);
2) sunflower + perennial leguminose grasses (80%) + safflower (20%);
3) winter wheat + barley (100%);
4) corn grain (80%) + cruciferous (false flax, rape, mustard) (20%);
5) winter wheat (100%);
6) grain legumes (chickpeas, lentils, peas) (66%) + cruciferous (false flax, rape, mustard) (33%));
7) winter wheat + barley (100%);
8) flax (33%) + coriander (50%) + buckwheat (17%).

Sowing agricultural crops was made with the use of Buhler Versatile Tractor 2375 + Great Plains NTA 3510 (10.7 m) and Case Magnum 315 + Great Plains NTA 3510 (10.7 m). All crops were sown with a row spacing of 19.1 cm. Motor fuel consumption with No-Till amounts to 26 liter per hectare, with CT - 74.1 liter per hectare. When using No-Till in all tillage operations, diesel powered equipment was used meeting international standards for carbon and nitrogen oxide. At the same time, the consumption of diesel fuel for the main tillage at No-Till is 26 liter per hectare, which is 3 times less than with the use of conventional technology (CT). The highest costs were observed at the stage of pre-sowing tillage and harvesting of crops - 31 and 58% respectively, while with the use of CT the main costs at the stage of primary tillage - 44% and harvesting of crops - 20% were observed. No-Till fields are located at a distance of 50–100 m from CT fields.

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The soil temperature was determined by electronic pocket thermometer HANNA Checktemp at depth of 0–10 cm. Analytical repetition of the analysis execution is 3–10-fold. Soil moisture was determined by volumetric method in the field conditions with humidity meter of Fieldscout TDR 100 in 10-fold repetition in the layer of 0–10 cm at each site. Analytical repetition of the analysis execution is 3–10-fold.

According to the Federal State Statistics Service in 2018, the area under winter wheat and sunflower in the Rostov region in relation to other regions of Russia amounts to 9.3 and 10.3%, respectively. In the Rostov region, winter wheat occupies more than 43–45% of arable land, sunflower - about 15–20%. Winter wheat belongs to the one-year grain-growing agricultural crops of continuous sowing, and sunflower - to the tilled agricultural crops. Agricultural crops differ in the physiological characteristics of the root system structure, the need for moisture, the phases of development, sowing of seeds and agrotechnical manipulations. According to BBCH scale (1991) crops differ in the period of maximum vegetation: in winter wheat these are the phases of stem elongation, heading and full flowering and late milk: from April till June. In sunflower, these phases differ significantly in the growth stage, inflorescence separated, physiological ripeness and over ripe: from June till September. In addition, the ripening of sunflower seeds and winter wheat is influenced by the reserves of productive moisture and the amount of precipitation in the spring-summer and autumn periods.

Yield data for winter wheat and sunflower with No-Till (NT) and conventional technology (CT) are presented by agricultural producers and according to the data of Federal State Statistics Service of Russia. Monthly precipitation for 2014–2018 is presented according to the Rostov-on-Don Weather station.

Statistical processing of the data obtained during the study was carried out using the software package of STATISTICA 12.0. The indicators of variation statistics (mean values, dispersion error of mean), reliability of differences between the variants using dispersion analysis (Student-t) and correlation analysis (Pearson correlation coefficient) were determined.

RESULTS AND DISCUSSION

The total annual precipitation in the Rostov region in 2014, 2015, 2016, 2017 and 2018 was 520, 522, 707, 567 and 722 mm (Fig. 2). In relation to precipitation the years 2014 and 2015 are considered uniformly hydrated during the wheat growing season - 218 and 228 mm in 2014 and 2015 respectively. Substantially less moisture was observed during the growing season of sunflower, which amounted to 65 and 25 mm in 2014 and 2015 respectively.

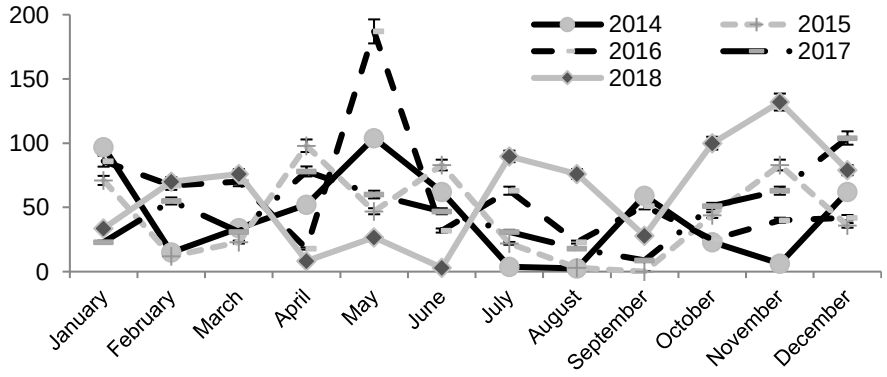

Figure 2. The amount of precipitation in the Oktyabrsky district of the Rostov region in 2014–2018 according to Rostov-on-Don meteorological station.

In 2016 and 2017 the amount of precipitation during the growing season of winter wheat was 237 and 185 mm respectively, and the one of sunflower- 137 and 58 mm. According to the climatic conditions, in 2016 the over precipitation by 66% was shown compared to the normal level, in 2017 – by 34%. In terms of precipitation, 2016 was very wet due to the precipitation in May and July – 187 and 63 mm. In 2016, during the growing season of winter wheat, the precipitation amounted to 237 mm, and the one of sunflower – 169 mm. In 2017, during the growing season of winter wheat the precipitation amounted to 185 mm, the one of sunflower – 105 mm. The greatest amount of precipitation was after the seasons of the critical vegetation of sunflower and winter wheat in October, November and December 2017 – 51, 63, 104 mm, respectively. With an annual high amount of precipitation in the Rostov region (722 mm) in 2018, the growing season of winter wheat was very dry: at a critical growth period from April till June, there was 79–83% less precipitation than in previous years. The lack of precipitation in spring and early summer of 2018 led to a decrease in the yield of winter wheat by 17% throughout Russian Federation, including by 10% in the Rostov region. During the growing season of sunflower (from June till September) there was enough precipitation to form and ripen seeds – 197 mm. Compared with the previous year (2017), there was an increase in the yield of sunflower by 25% in Russian Federation, while only a slight decrease by 10% was observed in the Rostov region.

With the use of No-Till in 2014 and 2015 and the amount of precipitation of 520–522 mm, the yield of winter wheat with No-Till in the Rostov region was higher by 51 and 114% than with the use of CT (Table 1). In 2016–2017 the yield of winter wheat in the Rostov region with the use of No-Till was higher than the one with CT by 36 and 26%, with the overall high yield of winter wheat in the region.

Table 1. Yield of main agricultural crops in the Rostov region with no-tillage (NT) and conventional tillage (CT) (2014–2018), ton·ha^{-1}

Agriculture crop	Type of land use	2014	2015	2016	2017	2018
Winter wheat	NT	36.3	50.7	54.2	56.0	29.8
	CT	24.1	23.7	39.0	44.5	41.0
Sunflower	NT	18.5	27.2	27.5	27.0	25.0
	CT	14.0	14.0	14.3	15.7	19.7

In 2018 due to the drought in the spring-summer period (April-June), the yield of winter wheat decreased by 16% compared with CT and by 46%compared with the harvest of 2017. The prime cost of winter wheat in high-yielding years (2015, 2016 and 2017) was lower than the cost of CT by 41, 45 and 10% respectively. In 2014 and 2015 the yield of sunflower in the study area with the use of NT was higher than the one with CT by 32 and 92%, respectively. Sunflower grown on soils where No-Till was used, in the Rostov region in 2016 and 2017, also had a high yield, especially in 2016 – by 92% compared with CT. Despite the lack of moisture in the growing season of 2014, 2015 and 2017, the yield of sunflower grown with the direct sowing varied in the range of 27.0–27.2 kg ha^{-1}. The yield of sunflower in 2018 compared with 2017 decreased by 10%, but exceeded the yield of the one grown with mouldboard plowing by 27%. Preservation of the harvest field, forming a mulch layer, improving the soil structure and retaining moisture in the soil with technology NT reduces the likelihood of erosion in the soil (Mancinelli et al., 2013; Kazeev et al., 2017; Zhelezova et al., 2017; Mokrikov et al., 2018; Papp et al., 2018). A 3-fold reduction in fuel consumption in case of sowing allows saving motor fuel, which leads to a reduction in greenhouse gas emissions. The reduction of soil treatment stages with NT reduces the soil compaction equipment, which also has a positive effect

on the physical and biological state of the soil. Taking into account the decrease in the cost of fuel resources at all stages of sunflower processing, the cost with the use of NT was lower by 35–68% than the one with the conventional technology.

Earlier under the conditions of the production experiment in the agrocenoses of the Oktyabrsky district (Rostov region), on average, for two years, the highest yield was obtained when growing winter wheat by using the NT (4.19 ton ha^{-1}), which is 18% higher than the yield obtained with the use of conventional technology (CT) (Zelensky et al., 2012). The best economic indicators of production were obtained when growing winter wheat with the use of NT, which is due to obtaining the lowest cost of grain and the highest profitability of production. There was also an increase in the yield of sunflower by 49% (22.5 kg ha^{-1}) in the No-Till variant, as compared to mouldboard plowing (Zelensky et al., 2014). This is associated with the increased soil moisture reserves when using NT. In the early spring period, the moisture reserves in the soil layer of 0–150 cm in the NT variant were higher by 15.5 mm, and during the sowing of sunflower - by 20.4 mm. The main indicator of soil restoration when using No-Till includes the accumulation of humus, which is an indicator of fertility due to the activity of the soil microbiota (Kudeyarov, 2015). With a high content of humus and preservation of available moisture in the soil with the use of NT with various agricultural crops, physical properties are improved, the number of soil nitrogen-fixing and cellulose bacteria increases; soil enzymatic activity is stimulated (Soane et al., 2012; Akimenko et al., 2016; Sharkov et al., 2016; Minnikova et al., 2017b; Mokrikov et al., 2017; Kazeev et al., 2017; Shirokikh et al., 2017; Mokrikov et al., 2018).

CONCLUSIONS

NT allows retaining moisture reserves in the soil during the growing season and improves the agrophysical state of the soil, which contributes to an increase in the yield of winter wheat and sunflower. The use of NT can improve the ecological condition of the soil due to the activation of the microbiota, the accumulation of organic matter, the preservation of moisture and the improvement of the structural state. NT results in lower costs due to significant savings in motor fuel. In the long-term dynamics of 2014–2018, when using NT, the cost of winter wheat and sunflower is reduced by 41–45% and 32–92% compared to the CT.

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