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INFLUENCE OF NO-TILL TECHNOLOGY ON WATER-PHYSICAL AND CHEMICAL PROPERTIES OF SOIL AND YIELD OF CULTIVATED CROPS

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Keywords: No-till technology, recommended technology, plant residues, moisture, soil structure, soil density, nitrogen, phosphorus, yield.

ABSTRACT

The research studies were aimed at examining the influence of No-till technology on the properties of the ordinary black soil in the Stavropol Krai and yield of cultivated crops. The studies were carried out for soybean-winter wheat-sunflower-corn crop rotation. The technology recommended by the scientific institutions implied that the primary soil tillage for soybean, sunflower, and corn involves primary tillage in two traces, and fall tillage; double tillage with disk harrow and pre-sowing cultivation were performed for winter wheat. When No-till technology had been used, 5.78t of plant residue were on the soil surface, which provided two times greater accumulation of snow in winter and 25% more preservation of moisture in soil than according to the recommended technology. For both technologies soil density ranged within optimal values for the growth of plants. Fertilization in No-till technology led to a reliable increase in the content of the available phosphorus in the upper soil layer with respect to the 10-20cm layer, while in the recommended technology the content of this element in both layers was identical. However, it caused no decrease in the yield of cultivated crops.

Keywords: No-till technology, recommended technology, plant residues, moisture, soil structure, soil density, nitrogen, phosphorus, yield.

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I. INTRODUCTION

Water-physical and chemical properties of soil are essential in the technology for cultivating any crop, since they substantially influence the degree to which the plants are supplied with water, nutrient elements, and, finally, the yield of cultivated crops and economic effectiveness of plant-growing (Kiryushin 2019; Congreves et al., 2016). In traditional technologies, optimal properties of soil are created and maintained by the system of primary, intermediate, pre-sowing, and other types of soil tillage by different tools and to a different depth (Kulintsev et al., 2013; Pykhtin 2015). To this end, in science and practice, special combined tillage machines and tools are created, which in one-pass tillage across the field produce optimal consistency, structure, and density of soil, improve its water-accumulating and water-retaining properties that ensure optimal conditions for growth and development of cultivated plants (Lipkovish et al., 2006; Petrova et al. 2007; Agaras et al., 2014).

Soil in No-till technology is not treated by mechanical tools, and its favourable water, physical, and chemical properties should be provided by the root systems of cultivated plants, plant residues left on the surface, fertilization, and other technological methods (Dridiger et al., 2018; Crovetto 2013). Hence, the purpose of the authors' research studies was to examine the capability of No-till technology for creating soil density optimal for the growth of plants, providing them with water and available nutrient elements, that enable gaining the yield of crops at least equal to or higher than the yield of crops cultivated using traditional technologies.

The working hypothesis for this study involved the supposition that when alternation of crops is scientifically justified in crop rotation, and the technology is followed for their cultivation without soil tillage (No-till technology) on the ordinary black soil in the Central Pre-Caucasian region zone of unstable moistening, which has good water, physical, and chemical properties, it is possible to create soil structure and density optimal for the growth of plants, provide the plants with water and nutrient elements, which facilitate producing the yield of cultivated crops at least equal to that gained using the technologies with soil tillage recommended by scientific institutions.

II. MATERIALS AND METHODS

The studies were carried out in the experimental field of the North-Caucasian federal scientific agrarian centre, in the Stavropol Krai zone of unstable moistening. Annual amount of effective temperatures here is 3400-35000C. The length of the frost-free season is 180-185 days. Annual precipitation ranges from 540 to 570mm, there is 350-400mm during vegetation period, Selyaninov hydrothermal index is 0.9-1.1 (Badakhova & Knutas 2007).

Soil in the experimental segment is represented by the ordinary deep heavy loam chernozem/black soil, formed on loessoid calcareous loams. Its bulk density ranges from 1.10 to 1.30g/cm3, structure index is more than 1 (number of agronomically valuable aggregates from 0.25 to 10mm amounts to 60% and more), the structure is lumpy-powder- granular-like.

Prior to trial establishment, soil was characterised by low content of humus substance in the 0-20cm soil layer – 3.87%, and low content of nitrate nitrogen – 11.9mg/kg. The degree of movable phosphorus supply is average and amounted to 18.7mg/kg (according to Machigin), and it is extremely low in the 20-30cm soil layer – 9.6mg/kg. Content of movable potassium is average (245mg/kg), the reaction of soil solution is neutral pH = 6.32.

Years of studies by weather conditions were basically typical of the unstable moistening zone but differed in the amount of precipitation. With 554mm annual climatological norm of precipitation, in 2013, 2014 and 2017 there were 652, 626 and 659mm, respectively, and in 2015, 2016 and 2018 – 528, 501 and 549mm.

The studies were carried out in soybean – winter wheat – sunflower – corn crop rotation. In one case all crops of rotation were cultivated according to the technology with soil tillage, recommended by the regional institutions of science. In the second case, all crops of the same rotation were cultivated using No-till technology. In both cases, crop rotation involved alternating narrow-leaved plants with fibrous root system (winter wheat, corn) and broad-leaved plants with tap-root system – soybean, sunflower. All fields of both crop rotations are expanded in space.

The experiment was established in 2012. Prior to trial establishment in 2011, the test area was ploughed to the 22-24cm depth with further soil surface levelling and levelling sowing of all crops of both rotations in 2012. Within six years of studies (2013-2018), all crops had been alternately cultivated on all fields of both crop rotations.

Basic cultivation of soil in the test crop rotation for spring crops involved primary tillage in two traces immediately after forecrop harvesting and fall tillage to the 20-22cm depth. Double tillage with disk harrow (6-8 and 8-10cm) and pre-sowing cultivation were performed for winter wheat. When No-till technology had been used for cultivating the analysed crops, no tillage of soil was performed, however, 5-7 days before sowing spring crops the soil surface was sprayed with nonselective glyphosate group herbicide. Prior to sowing winter wheat (after soybean) no herbicides were applied.

On the first part of plots for all crops of both crop rotations, no fertilization was performed. On the second part, the quantities of mineral fertilisers recommended by scientific institutions were applied. The ratio for soybean was N35P45K30, for sunflower N32P32K32, which were row-applied when sowing. N90P60K60 for winter wheat when sowing, and supplementary fertiliser of 88kg/ha of ammonium nitrate in spring were applied. The ratio of fertilisers for corn was N64P32K32, applied when sowing and spraying of plants 4 weeks after the emergence of seedlings with 70kg/ha of urea dissolved in water.

The experiment involved cultivation of crops authorised for using in the Stavropol Krai, according to the technology (timing, sowing methods, rate of sowing, depth of seed placement, etc.) recommended by scientific institutions. Winter wheat and soybean were seeded according to the recommended technology by row disk seeder СЗ-3.6, sunflower and corn – by row-crop seeder Optima, in no-tilled soil all crops were seeded using seeder Gimetal

(made in Argentina), equipped with corrugated disks (coulters) and double disk openers to sow seeds and apply fertilisers.
The structure of soil was experimentally defined by dry screening using N.I. Savinov method, its density (by cylinder method) and content of productive moisture by thermostatic-weight method – using methodologies proposed by B.A. Dospekhov and his colleagues (Dospekhov et al., 1987). Nitrate nitrogen in soil was determined according to Grandval-Lajoux (Turchin 1965), movable phosphorus and exchangeable potassium in 1% ammonium carbon extract were determined by Machigin (GOST 1992). Yield of all crops was registered using the method of mechanical harvesting with Sampo-130 combine harvester by swathing halfway across the plot with the subsequent recalculating the yield with reference to specific moisture content and purity. Test replication is 3-fold, plot area is 300 m2, record plot area is 90m2.

III. RESULTS

Besides no-tillage of soil, the difference of No-till technology from the technology recommended by the regional scientific institutions with the required soil tillage, lies in the plant residues of cultivated plants available on the surface. On average, over the years of studies after harvesting for both technologies, almost equal amount of plant residues was annually brought per 1ha of crop rotation area, namely, 5.25t for recommended technology and 5.78t for No-till technology. However, the recommended technology implied that during primary fall tillage all plant residues were buried in soil, but in No-till technology they remained untouched on the surface and in winter, on average for all crop rotation fields, contributed to accumulation of snow two times more than in the recommended technology (Table 1).

TABLE 1. – Influence of field crops cultivation technology on accumulation of snow in winter, cm

Technology	Forecrop	Year						Average
		2012-2013	2013-2014	2014-2015	2015-2016	2016-2017	2017-2018	
Recommended	corn	4	18	10	27	9	10	13
	soybean	3	23	12	26	8	6	13
	winter wheat	5	19	8	27	9	10	13
	sunflower	10	22	9	27	9	7	12
Average		6	20	10	27	9	8	13
No-till	corn	17	40	24	30	16	17	24
	soybean	4	31	18	30	9	4	14
	winter wheat	19	54	36	36	17	18	30
	sunflower	31	64	30	35	14	18	32
Average		13	47	27	33	14	14	25

Maximum amount of snow, namely, 32 and 30cm on average over the years of studies, was accumulated after sunflower and winter wheat, the least amount of snow was retained by the residues of soybean – 14cm, or 2.3 and 2.1 times less. With that, in No-till technology snow melted 8-12 days longer than in

soil tilled using the recommended technology, and by the time of sowing spring crops (soybean, sunflower, corn) a metre-deep layer of
untilled soil contained, on average over 2013-2018, 148mm of productive moisture, what is 16mm or 12.1% more than in the tilled soil.
During heading stage of winter wheat and blossoming of spring crops, a metre-deep soil layer contained 17mm or 25% more productive moisture in No-till technology than in the recommended technology (Table 2).

TABLE 2. – Influence of cultivation technology on productive moisture content in a metre-deep layer of soil
during vegetation of plants, mm

Technology	Crop	Year						Average
		2013	2014	2015	2016	2017	2018	
Recommended	soybean	59	55	67	91	58	53	**64**
	winter wheat	45	95	70	78	126	57	**79**
	sunflower	51	61	71	49	47	22	**50**
	corn	81	93	82	80	58	92	**81**
Average		**59**	**76**	**72**	**74**	**72**	**56**	**68**
No-till	soybean	76	43	81	103	56	85	**74**
	winter wheat	63	116	97	94	126	61	**93**
	sunflower	71	70	95	76	103	46	**78**
	corn	128	88	95	96	78	93	**96**
Average		**84**	**79**	**92**	**92**	**91**	**71**	**85**
Increase using No-till technology	mm	25	3	20	18	19	15	17
	%	42.4	3.9	27.8	24.3	26.4	26.8	25.0

The biggest differences in the content of productive moisture in a metre-deep soil layer in favour of No-till technology were observed for sunflower: 28mm. The differences in favour of No-till technology for corn and soybean were considerably smaller and amounted to 15 and 10mm.

It should be noted that the 150cm layer of soil, when using No-till technology, contained 146mm of productive moisture at that time, while by the recommended technology there were 118mm, or the difference in favour of the first one increased to 28mm. By the time of complete ripeness of all cultivated crops, the amount of productive moisture in a metre- and one-and-a-half-metre-deep soil layers became identical.

Major indicators of physical properties of soil involve its structural state and density, on which water, air, and thermal regime of soil depends. In the authors' studies prior to trial establishment in 2012, the number of agronomically valuable 10-0.25mm aggregates and structure soil index for both technologies were identical, since minor differences with respect to these indicators were within the limits of experimental error (Table 3).

TABLE 3. – Influence of technology on the number of agronomically valuable aggregates and
structure index in the 0-10cm soil layer

Technology	**Crop**	**Agronomically valuable aggregates, %**		**Structure index**	
		2012	**2016**	**2012**	**2016**
Recommended	soybean	69.8	67.1	2.31	2.04
	winter wheat	71.9	69.2	2.56	2.25
	sunflower	72.2	70.2	2.60	2.36
	corn	72.6	71.2	2.65	2.47
No-till	soybean	71.6	72.2	2.52	2.60
	winter wheat	70.9	71.0	2.44	2.45
	sunflower	71.9	72.1	2.56	2.58
	corn	72.3	72.6	2.61	2.65
$HCP_{0.95}$		3.8	3.6	0.15	0.15

4 years after, upon completion of the first crop rotation, the number of valuable aggregates, on average over crop rotation, in the recommended technology decreased by 2.2%, while in No-till technology under all cultivated crops within the same years, there was an increase, although mathematically unprovable, in the number of agronomically valuable aggregates by 0.3% on average. It caused a reliable decrease in structure index of the 0-10cm soil layer in the recommended technology for all analysed crops, while for No-till technology this indicator increased, although in a minor way, for all crops as well.
The same dependences with respect to changes in soil structure were observed in the 10-20cm layer, when an increase in agronomically valuable aggregates in No-till technology was within the limits of experimental error, and structure index was reliably higher using this technology than using recommended technology. In the 20-30cm soil layer all changes in these indicators were within the limits of experimental error.
Bulk density of soil is an essential indicator of the physical soil state, especially, in the root habitable soil layer. In the authors' studies, the density in the 10-20cm soil layer, where the major mass of roots of growing plants is placed and developed, was identical during heading of winter wheat, and soybean, sunflower and corn blossoming on average over the years of studies for both technologies, and small differences were not significant (Table 4).

TABLE 4. – Influence of technology for cultivating field crops on the soil bulk density
in the 10-20cm layer during vegetation of plants, g/cm3

Techn	**Crop**	**Year**	**Average**

ology		**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	
Recommended	soybean	1.22	1.42	1.37	1.27	1.33	1.29	**1.32**
	winter wheat	1.20	1.29	1.30	1.25	1.29	1.23	**1.26**
	sunflower	1.26	1.37	1.28	1.22	1.08	1.24	**1.24**
	corn	1.27	1.22	1.25	1.21	1.19	1.17	**1.22**
No-till	soybean	1.30	1.34	1.38	1.32	1.25	1.44	**1.34**
	winter wheat	1.25	1.24	1.22	1.20	1.33	1.34	**1.26**
	sunflower	1.26	1.28	1.28	1.25	1.22	1.33	**1.27**
	corn	1.26	1.27	1.29	1.26	1.31	1.30	**1.28**
$HCP_{0.05}$		0.07	0.08	0.08	0.06	0.07	0.08	**0.08**

In occasional years, a certain consolidation of soil under some rotation crops was observed for both technologies, specifically, under soybean and, sometimes under sunflower.

Cultivation technologies and applied fertilisers substantially influenced the content and distribution of nutrient elements available for plants, and phosphorus, in particular, across soil. Prior to trial establishment, the 0-10cm soil layer contained 20-23mg of movable phosphorus per kilogram of soil, 10-20cm – 18-20mg/kg of soil. Upon completion of the first crop rotation, its amount without applying fertilisers for both technologies decreased layer-wise to 16-18 and 13-15mg/kg of soil, respectively, what corresponds to mean and low supply with this element. Here, there were minor differences between the technologies, being within the limits of experimental error (Table 5).

TABLE 5. – Influence of technology and fertilisers on movable phosphorus content in soil
prior to sowing cultivated crops in 2017, mg/kg

Technology	**Fertilisers**	**Soil layer, cm**	**Crop**				**Average**
			soybean	**winter wheat**	**sunflower**	**corn**	
Recommended	with no fertilisers	0-10	16.8	15.5	16.0	16.6	**16.2**
		10-20	12.6	13.6	16.7	17.5	**15.1**
		20-30	10.0	14.8	13.7	15.2	**13.4**
	fertilisers	0-10	26.7	30.4	24.8	22.6	**26.1**
		10-20	24.6	28.6	22.0	21.5	**24.2**
		20-30	16.0	15.4	18.8	19.9	**17.5**
No-till	with no fertilise	0-10	18.6	16.3	16.6	19.0	**17.6**
		10-20	16.6	13.6	16.8	16.8	**15.9**

	rs	20-30	14.2	10.2	14.1	16.6	**13.8**
	fertilisers	0-10	40.3	31.5	25.4	24.6	**30.4**
		10-20	20.2	19.8	20.2	20.4	**20.1**
		20-30	18.8	15.0	15.9	15.7	**16.4**
$HCP_{0.95}$			4.7	2.8	3.3	3.5	**3.6**

Application of phosphorous fertilisers for all rotation crops in both technologies increased the content of movable phosphorus in the 0-10 and 10-20cm soil layers. However, when using traditional technology, by the end of the first crop rotation on average over all analysed crops the amount of movable phosphorus in the 0-10cm soil layer was 26.1, 10-20cm – 24.2mg/kg of soil. The difference between layers was within the limits of experimental error and amounted to 1.9mg/kg, or 7.8%. According to No-till technology, the content of this element across the same layers amounted 30.4 and 20.1mg/kg of soil, respectively. In this case, a reduction in movable phosphorus concentration from the upper to the deeper soil layer was mathematically reliable and amounted to 10.3mg/kg, or 51.2%.

However, a higher content of movable phosphorus in the upper soil layer and reduction in its concentration with the depth of soil layer in No-till technology didn't cause suppression of all the experimentally cultivated plants within all the years of observations, especially, when applying fertilisers. Hence, there was no reliable reduction in the crop yields observed on a fertilised soil. Here, winter wheat and corn provided the biggest increase in crop yield, which, in No-till technology reliably increased crop yield by 0.88 and 0.23t/ha on average over six years of studies as compared to the recommended technology. However, with no fertilization, a decrease in the yield of all crops was observed for the new technology, and a decrease for winter wheat and corn was mathematically provable (Table 6).

TABLE 6. – Influence of cultivation technology and fertilisers on yield of rotation crops, t/ha
(mean value over 2013-2018)

Technology	**Crop**	**Fertilisers**	**Crop yield**	**Increase due to**	
				technology	**fertilisers**
Recommended	soybean	with no fertilisers	1.57	-	-
		fertilisers	1.56	-	-0.01
	winter wheat	with no fertilisers	2.68	-	-
		fertilisers	4.49	-	1.81

	sunflower	with no fertilisers	1.71	-	-
		fertilisers	1.95	-	0.24
	corn	with no fertilisers	3.45	-	-
		fertilisers	4.20	-	0.75
No-till	soybean	with no fertilisers	1.47	-0.10	-
		fertilisers	1.52	-0.04	0.05
	winter wheat	with no fertilisers	2.49	-0.20	-
		fertilisers	5.37	0.88	2.89
	sunflower	with no fertilisers	1.64	-0.07	
		fertilisers	1.96	0.01	0.32
	corn	with no fertilisers	3.04	-0.41	
		fertilisers	4.43	0.23	1.39
$HCP_{0.95}$ for technologies			0.13	-	-
$HCP_{0.95}$ for fertilisers			0.18	-	-
$HCP_{0.95}$ for particular mean values			0.24	-	-

Mineral fertilization caused a rising yield of all crops, except for soybean in the recommended technology. However, an increase in the yield due to applying these fertilisers according to No-till technology was higher than according to recommended technology. Here, the maximum increase in the yield due to the applied fertilisers using this technology was provided by winter wheat and corn – 2.89 and 1.39t/ha. It is by 1.09 and 0.64t/ha, respectively, more than using recommended technology.

IV. DISCUSSION

Plant residues of cultivated crops, which are constantly present on the soil surface, substantially influence water, physical, and chemical properties of soil and, primarily, retention and accumulation of snow in winter. However, not only the mass of plant residues (correlation coefficient (r)=0.444), but also their height over the soil surface (r=0.611) considerably and even more greatly influences the depth of snow cover. Plant residues of sunflower, scythed at a height of 83cm, and soybean the least, harvested at a close cut, accumulated maximum amount of snow. The authors have worked out the regression equation, which enables predicting the snow cover depth depending on the height of plant residues:

$$У = 0.36\ x + 15.57 \qquad (1)$$

where: У – depth of snow cover, cm
x – height of plant residues, cm
0.36 and 15.57 – regression coefficients.

Hence, when analysing the role of plant residues in accumulation of snow with and without soil tillage, it is necessary to take into consideration the attributes of crops and methods for their harvesting. Therefore, it is better to harvest spiked cereals by the method of combing plants leaving all the plant residues on the field surface with no milling and spraying them (Dridiger 2012).

Longer snow melting in spring in No-till technology occurs due to an immense amount of snow, which requires more time for melting, and plant residues on the soil surface reflect sun rays and facilitate reduction in air temperature near surface, while black background of the field tilled using the recommended technology contributes to the increase in air temperature on its surface and, hence, the acceleration of snow melting. All this leads to a greater accumulation of productive moisture by the time of sowing spring crops.

Plant residues on the soil surface also facilitate better preservation of moisture in soil during vegetation of cultivated plants, and especially during early vegetation, when the plants are still small and are not capable for covering the field area with their vegetative mass for protection from the direct sun rays. According to the authors' observations, at this time plant residues of forecrops had reduced the temperature of the soil surface by 4-50C (Dridiger 2018), two times - wind velocity (Dridiger 2016), what was the reason for better preservation of moisture using this technology, than in the tilled soil with no plant residues on the surface.

The most significant differences in the content of productive moisture in a metre-deep soil layer in favour of No-till technology under sunflower are explained by multiple plant residues uniformly distributed across the plot surface after harvesting the antecedent winter wheat in the amount of 7.48t/ha on average over the years of studies. 3.75t/ha of them remained by the time of sowing sunflower, and due to scything winter wheat during harvesting at a height of 25-30cm, residues of this crop were rather slowly decompounded by microorganisms. Hence, they properly protected the plot surface from sun rays and considerably reduced physical evaporation of moisture from soil.

Considerably smaller differences in favour of No-till technology under corn and soybean are due to the lower amount of plant residues, left by sunflower and corn. Lower amount of plant residues of sunflower relates to the biological attribute of the crop, a small number of which is left after harvesting. Corn after harvesting leaves the largest amount of frondiferous mass – 7.85t/ha on average over 7 years of studies. However, its leaves, constituting the greater part of plant residues, are very quickly decompounded by microorganisms, and by the time of sowing soybean only 4.2t/ha of them remain, mostly stems, which cannot uniformly cover the soil surface, what is responsible for inefficient losses of moisture from soil due to physical evaporation.

In No-till technology greater accumulation of moisture in one-and-a-half-metre-deep soil layer than in the soil tilled using recommended technology, is noted due to its entering and accumulating in the deeper layers during snow melting and heavy precipitation. And equal amount of productive moisture in a metre- and one-and-a-half-metre-deep soil layers for both technologies during ripening of cultivated crops is indicative of utilising moisture, further accumulated in soil according to No-till technology for production of yield.

Plant residues also considerably influenced physical soil properties. Prior to trial establishment in 2012, the number of agronomically valuable aggregates and structure index of soil for both technologies were identical and, according to the classification of A.A. Okolelova and her colleagues (Okolelova 2013), represented good indicators of structural soil state.

4 years after, upon completion of the first crop rotation, the difference between technologies in the number of agronomically valuable aggregates was minor for the whole of crop rotation: there was a tendency for their reduction under all rotation crops when cultivating field crops in traditional technology and their mathematically unprovable increase in No-till technology. However, cultivated crops and soil tillage method influenced the soil structure. Maximum reduction according to the recommended technology in the number of valuable aggregates in the 0-10cm soil layer – by 2.7% occurred after surface tillage of soil with disk tools for winter wheat and after tilling for soybean. After soil tillage for sunflower and corn, the amount of agronomically valuable aggregates decreased by 2.0 and 1.4%. hence, it can be concluded that the decrease in the number of aggregates of 10-0.25mm size according to the recommended technology is related to annual repeated soil tillage (Mazirov 2012).

However, insignificant decrease in the number of agronomically valuable aggregates according to the recommended technology and mathematically unprovable increase in their number for No-till technology led to reliable differences in the structure index, which in No-till technology was 0.25 units or 11.0% higher on average for all rotation crops than according to recommended technology. It indicates that the ordinary black soil, when there is no mechanical influence, can restore its structure, while this is not the case after its annual tillage.

For both technologies, under all the cultivated crops the soil density ranged within optimal values for black soils (Kuzychenko 2012). Some soil consolidation was seen in occasional years during the periods of severe atmospheric and soil drought and, it appears to be associated with the specific features of tap-root system of soybean and sunflower, incapable of withstanding soil consolidation during drought. The reduction in the soil density under all the rotation crops after precipitation is indicative of this, what was seen in the period of the complete ripeness of cultivated plants.

In other words, cultivation of crops on the ordinary black soil with no tillage does not lead to soil overconsolidation. Root system of crops and precipitation have greater influence on this indicator. Here, all changes in the soil density according to No-till technology are within the limits of optimal values for the growth of cultivated plants.

Within four years (first crop rotation) the content of movable phosphorus without applying phosphorous fertilisers for both technologies decreased to the natural level in the ordinary black soil (Kuprichenkov 2002). With that, during this period, plant residues left on the field surface when cultivating the analysed crops using No-till technology didn't lead to a substantial increase in content of this nutrient element in soil as compared to traditional technology, where soil was mechanically tilled each year. However, a minor increase is seen in the content of movable phosphorus in the upper ten-centimetre soil layer under all the crops when cultivating them using No-till technology.

More uniform distribution of movable phosphorus across the upper soil layers when applying phosphorus fertilisers according to the recommended technology is explained by the annual mouldboard tillage for spring crops to the depth of 20-22cm, which causes mixing of soil and, respectively, phosphorus contained therein. A higher content of movable phosphorus in the upper soil layer when cultivating field crops according to No-till technology is due to application of phosphorus fertilisers concurrently with sowing to the depth of seed placement (not more than 5-7cm) and no-tillage of soil over all the years of studies. I.e., in No-till technology even in the first 4 years, there is a differentiation of movable phosphorus content across soil layers with its higher concentration in the upper ten-centimetre layer, what is negative, according to O.G. Nazarenko (Nazarenko 2015). She reinforces her opinion by the fact that in this case root system of plants is concentrated in the upper soil layer and during drought season, which frequently occurs in the Stavropol Krai zone of unstable moistening, plants, with no root system which penetrates deep into soil, suffer from lack of water, what can cause reduction in the yield of cultivated crops. Hence, to prevent this phenomenon, it is recommended that phosphorus fertilisers should be embedded in soil by ploughs during tilling to the depth of at least 18-20cm (Kiryushin 2015).

However, in Argentina, where crops have been cultivated using No-till technology for more than 30 years, no suppression of plants and reduction in their yields due to near-surface application of phosphorus fertilisers was observed (Crovetto 2013). Such a phenomenon is explained by the availability of moisture in the upper soil layers due to plant residues remained on the surface, which prevent ineffective losses of moisture contained in soil due to its physical evaporation from its surface (Dridiger 2017; Seeding using No-till technology 2007; Li et al., 2016).

The similar situation was noted for the content of exchangeable potassium in soil. Its amount in the upper ten-centimetre soil layer was substantially higher than in the lower 10-20cm layer. In recommended technology, the distribution of this nutrient element across the twenty-centimetre soil layer was almost uniform.

At the same time, there was no influence of cultivation technologies and fertilisers on the amount of nitrate nitrogen in the 0-30cm soil layer. For all test options, over all the years of studies the amount of this nutrient element was from 2 to 8mg per kg of soil in the phase of spring crops blossoming and winter wheat heading, what corresponds to its very low content (Kaurichev 1986).

A decrease in the yield of the experimentally cultivated crops with no fertilization using No-till technology is likely to be due to insufficient supply of plants with nutrient elements, including nitrate nitrogen, the amount of which in soil was very low in the authors' experiments for both technologies. But in the recommended technology, the occurring nitrification processes facilitated improvement in nitrogenous nutrition of plants as compared to No-till technology, in using which nitrogen released during nitrification was consumed by soil microorganisms, decompounding crop and root remains, on the surface and in soil (Belyaeva 2013). It is therefore necessary to be certain of applying mineral fertilisers and primarily nitrogenous ones at the initial stage of embracing No-till technology.

Application of compound mineral fertilisers improved supplying plants with not only nitrogen, but also phosphorus and potassium for both technologies. However, a higher content of the available moisture in No-till technology made it possible to gain a substantially higher crop yield due to fertilization, than in recommended technology, specifically for winter wheat and corn. A considerably smaller increase in crop yield of soybean and sunflower is due to biological attributes of these crops, the yield of which does not rise because of applying fertilisers or it rises insignificantly (Kondratova 2004; Belyakov 2008). Hence, for example, in Argentina, no fertilisers are used for soybean and sunflower, but they are applied for such their forecrops as corn and winter wheat, which provide a much larger increase in crop yields (Dridiger 2013).

V. CONCLUSIONS

1. No-till technology implies that due to plant residues available on the surface, soil accumulates more moisture and better preserves it. This moisture is further used by the plants cultivated in the field alternate crop rotation for production of crop yield.

2. When cultivating crops using No-till technology, soil density ranges within optimal values for growth and development of plants in the ordinary black soil, and no-tillage of soil contributes to the improvement in its structural state.

3. At the initial stage of embracing No-till technology, cultivated plants are supplied with nitrate nitrogen worse than in the recommended technology, and content of the available phosphorus and exchangeable potassium increases with certainty in the upper ten-centimetre layer of soil with the concurrent decrease in their content in the 10-20cm soil layer.

4. Without mineral fertilization, yield of field crops cultivated using No-till technology is lower than using recommended technology. Applying fertilisers leads to a considerable growth in crop yields for both technologies, however, an increase in crop yields due to applied fertilisers using No-till technology is substantially bigger since plants are better supplied with water.

COMPLIANCE WITH ETHICAL STANDARDS

Conflict of Interest

The authors declare that they have no conflict of interest.

Research involving Human Participants and/or Animals

The study does not contain any studies with human participants or animals performed by any of the authors.

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