EFFECT OF LONG-TERM TREATMENT ON DENSITY OF CALCIC CHERNOZEM (ARIC) AND CROP YIELD IN CROP ROTATION

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Abstract. The transition to mini-till, strip-till and no-till farming is associated with a reduction in fuel and lubricants costs, optimization of the composition of the machine and tractor fleet, as well as with a deterrent effect of falling soil fertility. The studies have been carried out for 9 years using deep-till (DI), mini-till (MT) and no-till (NT). The influence of processing technologies on soil density and crop yield in crop rotation was studied in: (1) chickpeas; (2) spring wheat; (3) sorghum; (4) spring wheat; (5) sunflower; (6) barley on calcic chernozem (Aric). The main tillage was carried out to a depth of 10-12 cm with the OPO-4.25 tool in the unit with the Case Magnum 310 tractor. Deep loosening (DI) was performed to a depth of 30-35 cm with the Case Magnum 310 + 2OPO-4.25 machine-tractor unit, the second option - Case IH Ecolotiger 530C with the Case Magnum 310 tractor. In spring, both variants used a Brandt Commander 7000 harrow in a unit with a Case Magnum 310 tractor to cover moisture, and a Case Magnum 310 + 2OPO-4.25 unit for pre-sowing cultivation. Seeding on all variants was carried out with the Case Magnum 310 + Primera DMC 601 unit, with anchor-type coulters, spraying with the Terrion ATM 3180 + AMAZONE UG-3000 unit. The hypothesis that soil compaction and yield reduction on NT occurs only in the first years of its use, in the future the soil density decreases and stabilizes at values close to equilibrium, and its productivity increases, was confirmed.

Keywords: soil density, zero tillage, no-till, mini-till.

Introduction

Traditional tillage methods negatively affect the productivity of arable land in the long term, due to erosion and organic matter loss. In this regard, the rejection of plowing and the transition to conservation tillage is considered by many scientists as inevitable [1-4]. Preserving treatments, among which the most widespread are small loosening (mini-till), deep loosening, strip-till (strip-till), and especially zero processing (no-till), stop the fall in the content of organic matter, improve physical, chemical and microbiological soil properties [5]. According to R. Derpsch "zero tillage is not a fashion or a passing trend, it is a production system that is becoming more widespread due to its obvious advantages, as well as due to environmental and economic problems" [6]. No-till is defined as a tillage system in which at least 30% of plant residues remain in the field, and it is an important environmental practice [7]. The advantages of no-till over plowing are reduction of production costs [8], reduction of soil temperature fluctuations, soil organic matter accumulation, and soil moisture preservation [9]. No-till most closely approximates the conditions for the existence of soil and plants in natural cenoses.

Changes in soil density significantly affect the plant growth and development [10; 11]. Crops greatly reduce their productivity when the soil reaches a critical density value [12], which limits the root growth. Sandy soils usually have a higher density (1.3-1.7 $g \cdot cm^{-3}$) than silty and clay soils (1.1-1.6 $g \cdot cm^{-3}$). Soils rich in organic matter (for example, peat soils) may have a density of less than 0.5 $g \cdot cm^{-3}$ [13], but in general, a bulk mass above 1.6 $g \cdot cm^{-3}$ tends to slow the root growth [14]. The critical values of the density of chernozems are more than 1.35 $g \cdot cm^{-3}$ in heavy-loamy varieties and more than 1.30 $g \cdot cm^{-3}$ in light-loamy varieties [15].

The variation in soil density directly depends on the tillage method. Thus, in a 13-year experiment conducted in the north-eastern Turkey in a semiarid climate, with an average annual air temperature of 5.6 ºC and rainfall total of 427 mm, i. e. very close to the climate in the considered zone, the density on the plowed area in a layer of 0-30 cm was 1.25 $g \cdot cm^{-3}$, with minimal processing – 1.24 $g \cdot cm^{-3}$, with No-till – 1.29 $g \cdot cm^{-3}$[16].

Soil compaction is considered an important problem, so the bulk mass is among the most significant indicators used to assess the impact of cultivation on the soil and yield [17; 18]. Density integrates a number of soil fertility indicators, with which it has a close relationship. They correlate with porosity, and hence with hydrological processes (runoff, infiltration rate, and water retention capacity) and aeration [19], while being determined by simple, fast, and inexpensive methods.

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The main hypothesis was that zero tillage caused soil compaction and a decrease in yield in comparison with traditional methods only in the first years of use. In the future, the soil density decreases and stabilizes at values close to equilibrium, and its productivity increases.

The research objective was to assess the impact of long-term use of modern processing methods and technologies on soil density and crop yield in the fruit-bearing crop rotation in the semi-arid zone.

Materials and methods

The study was conducted in the training and experimental field of the Orenburg State Agrarian University, located in the zone with a semi-arid climate of moderate latitudes (BSk) of the Orenburg Urals in the Orenburg region (Russia) with coordinates 51º78 ‘ 72 “N-55º28’80” E. The average monthly temperature ranges from -24.3 to -27.4 ºC in January and from + 19.9 to + 22.4 ºC in July, and the average annual temperature is + 5.3 ºC. The average annual precipitation reaches 367 mm. The 0-30 cm Calcic chernozem (Aric) layer contains: humus-4.1%, readily hydrolyzable nitrogen (N) – 8.4 mg, mobile phosphorus (P2O5) – 3.25 mg, exchangeable potassium (K2O) – 27 mg and exchangeable calcium (CaO) – 39.0 mg per 100 g of soil. The field experiment was conducted in 2011 and organized in four repetitions with three methods of tillage, as the main factor: (1) Zero processing – no-till (NT); (2) Fine processing – mini-till (MT); (3) deep loosening (DI). The area of the plot for processing in repetition was 2160 sq. m(30m*72m), the total area of the first repetition was 6480 sq. m.; experience - 25920 sq. m. Plots of the first order (blocks according to the method of tillage) were used for plots of the second order (blocks according to crops of crop rotation) and were superimposed perpendicular to the direction of plots of the first order. The crop rotation was fruit-bearing and included 6 crops, which alternated in the following order: (1) chickpeas; (2) spring wheat; (3) sorghum; (4) spring wheat; (5) sunflower; (6) barley. The size of the plots under the crops was 360 sq. m. (12 m x 30 m). According to the scheme of the experiment, only weed sowing and destruction with herbicides was conducted using NT:7 days before sowing or 2-3 days after sowing with preparations containing glyphosate, a selective herbicide was additionally applied to grain crops, if necessary, during their tillering phase. Sunflower was grown using Clearfield ® technology. The main processing was carried out to a depth of 10-12 cm with the gun OPO-4.25 in the unit with the tractor Case Magnum310 in the autumn on MT. To destroy the second wave of weeds, the crops were sprayed with a selective herbicide. On (DI) deep loosening until 2014 was carried out at 30 cm with the CaseMagnum310 + 2OPO-4.25 unit, since 2015 at 35 cm-Case IH Ecolotiger 530C with the CaseMagnum310 tractor. In spring, in both cases were used the Brandt Commander 7000b harrow with the Case Magnum310 tractor unit to close the moisture, as well as the CaseMagnum310 + 2OPO-4.25 unit for pre-sowing cultivation. These techniques made it possible to keep the field clean of weeds, except for wet years, when herbicides had to be used during the tillering phase of the grain .Seeding on all variants was carried out with the Case Magnum310 + Primera DMC 601 unit, with anchor-type coulters, and spraying with the Terrion ATM3180 + AMAZONE UG-3000 unit.

The soil density was determined by the most common method –selecting a known amount using a metal ring pressed into the soil, and determining the weight after drying[20,14].Sampling was carried out outside the track of the wheels of sowing and harvesting equipment.

Results and discussion

Studies have shown that deep loosening allows to maintain the soil density in the arable horizon of 0-30 cm in a loose state. Under these conditions, the soil density did not exceed 1.22 $g \cdot cm^{-3}$, with a minimum of 1.15 $g \cdot cm^{-3}$ (Fig. 1).

On shallow loosening, the soil density varies over the years in the range from 1.26 $g \cdot cm^{-3}$ to 1.29 $g \cdot cm^{-3}$. On NT, until 2017, the soil density exceeded its values on DI and MT, and then became lower than MT, but remained higher than on DI. The soil density in the arable layer 0-30 cm, as we expected, gradually increased to 1.36 $g \cdot cm^{-3}$ in 2015, and then by 2020 decreased to 1.23 $g \cdot cm^{-3}$. Since the sampling was carried out outside the track of the wheels of the sowing and harvesting equipment, it can be assumed that the soil compaction was mainly under the influence of natural factors. This assumption is confirmed by our previous studies, where it was found that the density of the subsurface layer of 35-40 cm a year after the first treatment significantly exceeds its value before treatment [2]. The fluctuations in density over the years, which are clearly visible in Fig. 2 for all variants, are caused by the influence of the prevailing weather conditions.If we proceed from the position put forward byI.V. Kuznetsova[15], the value of 1.35 g·cm^{-3} is a critical threshold for heavy-loamy chernozem, it can be argued that the average soil density in the arable horizon only once and only in NTB 2015 exceeded the optimal threshold.Meanwhile, the analysis of the soil density in the layer of 10-15 cm, which in all variants is subjected to the compacting effect of the seeder, and in the variants with traditional treatment, also of the cultivator, during pre-sowing treatment, shows that it is almost always higher than the critical value on MT (Fig. 2).

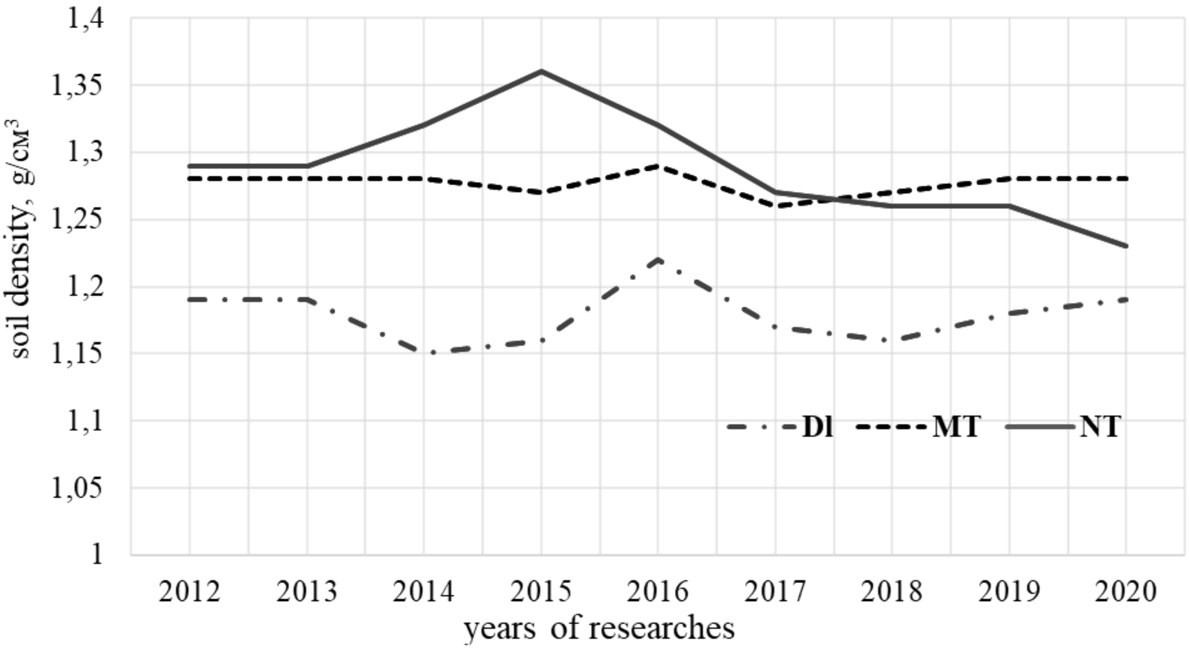

Fig. 1. **Dynamics of soil density in 0-30 cm layer with different processing methods:**
DI – deep loosening; MT – small processing (mini-till); NT – zero processing (no-till)

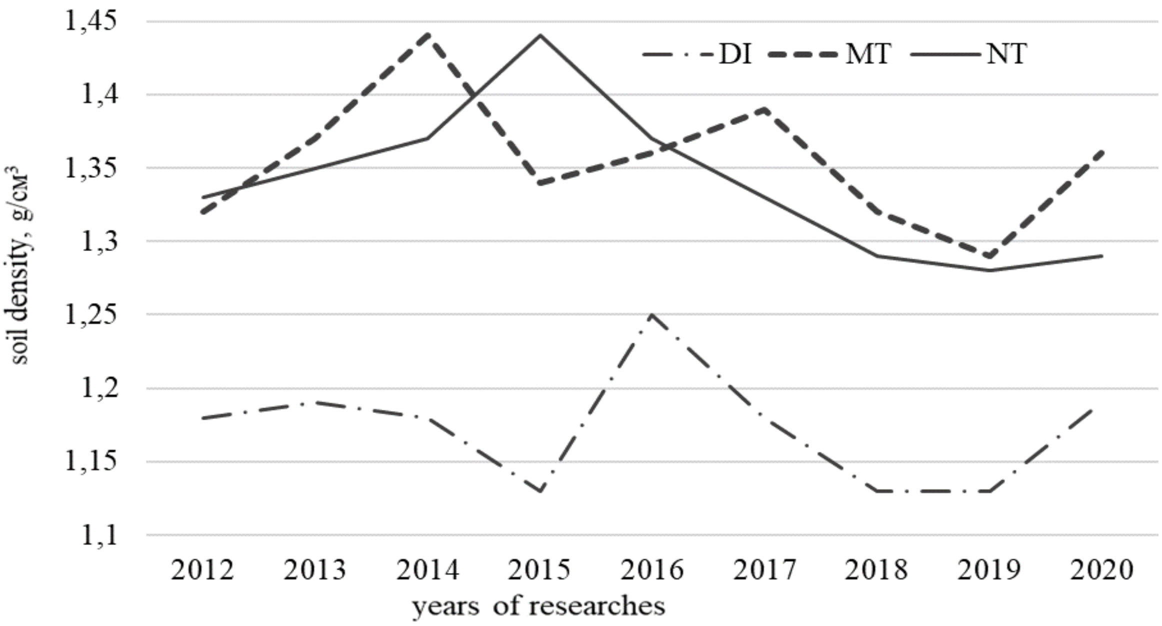

Fig. 2. **Soil density dynamics in layer of 10-15 cm with different processing methods**

The over-compaction of this layer can also be determined by the state of the crop root system. On excessively compacted soils, the plant rootdevelopmentshape and direction changes, which is clearly visible on sunflower (Fig. 3).On DI, the stem of the sunflower root, in accordance with its nature, grows deep into the strictly vertical (3 A). On NT, there is a deviation from the vertical axis and a significant deformation of the main root, its thickening at the base, and then a sharp thinning (3B). On MT, where the greatest soil compaction is shown in a layer of 10-15 cm, the weak development of the central root and its horizontal placement above the compacted layer are noted.

By autumn, the soil density increases in all variants and in all layers of the arable horizon. There is a pattern: the looser the soil was, the more it is compacted (Table 2).

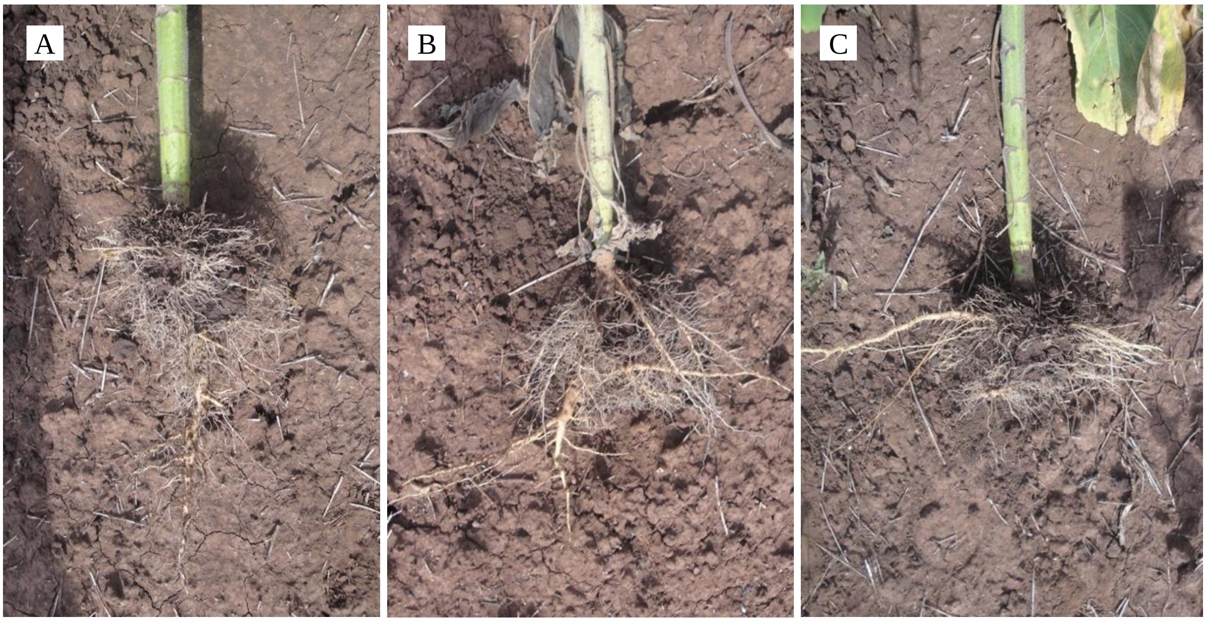

Fig. 3. **Influence of soil density on rootdistribution in soil:** A – DI; B – NT; C – MT, 2015

Table 2. Soil densitydynamics (g·cm^{-3}) by layer and over time (2020)

Soil layers, cm	DI		MT		NT	
	spring	autumn	spring	autumn	spring	autumn
0-5	1.12	1.19	1.14	1.10	0.98	1.13
5-10	1.13	1.26	1.23	1.35	1.25	1.29
10-15	1.19	1.34	1.36	1.40	1.29	1.29
15-20	1.20	1.31	1.34	1.39	1.28	1.30
20-25	1.24	1.32	1.32	1.35	1.29	1.32
25-30	1.25	1.34	1.33	1.35	1.32	1.33
30-35	1.24	1.33	1.32	1.34	1.34	1.33
35-40	1.36	1.38	1.36	1.39	1.36	1.35

Therefore, it is quite understandable that the greatest changes occur on DI. By autumn, the soil density increases in all treated layers by 0.70-0.15 g·cm^{-3}, and in the untreated 35-40 cm itchanges slightly. The smallest density drift from spring to autumn occurs on NT. Here, the deviations of the autumn values from the spring values range from 0.00 to 0.05 g·cm^{-3}. This is explained by the relatively high initial density in the spring and probably by the approach of its values to the equilibrium values for this soil. It is 1.24 g·cm^{-3} for the 0-30 cm layer, and without taking into account the 0-5 cm layer, which is looser due to the impact of the working bodies of the seeder, it is 1.29 g·cm^{-3}[15].

Every year, for nine years, studies on the cultivated crops yields were conducted using three technologies: DI, MIT and NT. The crop yield analysis (Fig. 5) shows that the no-till technology, despite the compaction of the soil, provides almost the same or even higher yield than deep loosening.The reason for this lies primarily in the fact that the soil density on the NT rarely goes beyond the upper limit of the optimum, and when this happens, crop yields fall sharply (Fig. 6).For example, the barley stable yield lies in the density range from 1.22 to 1.35 g·cm^{-3}. At values above 1.35 g·cm^{-3}, it is decreasing.In 2015, when the density of the arable soil layer on no-till was 1.36 g·cm^{-3}, the yield of barley was 0.89 t·ha^{-1}, and on the variant with deep loosening 1.17 g·cm^{-3} and 1.6 t·ha^{-1}, respectively.Sunflower adapts best to the switch to no-till.A negative average (r = -0.603) correlation was established between the soil density and the barley yield on the NT of the soil (Fig. 6).

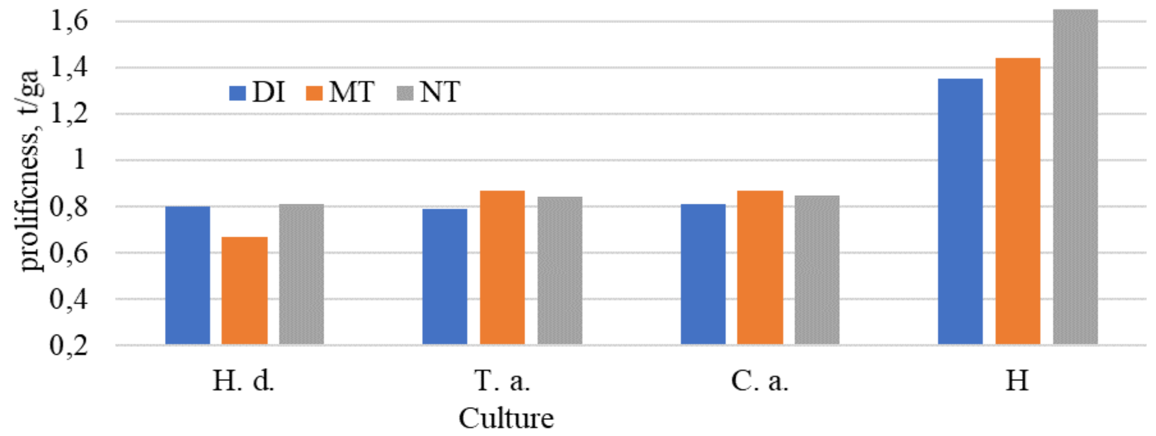

Fig. 5. **Average for 2012-2020 crop productivity with prolonged use of various tillage methods:** H. d. – *Hordeumdistichon* L; T. a. – *Triticumaestivum* L; C. a. – *Cicerarietinum* L; H–*Helianthus*

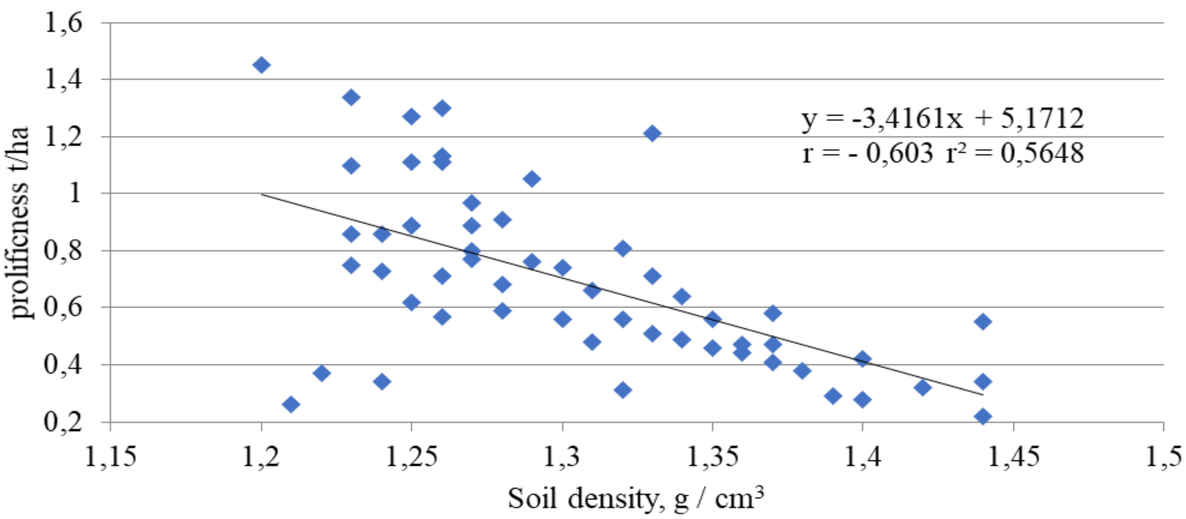

Fig. 6. **Relationship between barley yield and soil density in a layer of 0-30 cm per NT**

Based on the studies performed on the barley yield, when cultivated according to the no-till system (Fig. 7), it is clear that the yield has a positive trend. Thus, the initial increase in the soil density from 2012 to 2015 led to a decrease in the yield. Then, stabilization (2016) and the subsequent decrease in the soil density from 1.35 $g\cdot cm^{-3}$ to 1.23 $g\cdot cm^{-3}$ led to an increase in the yield from 0.4 to 1.1 $t\cdot ha^{-1}$.

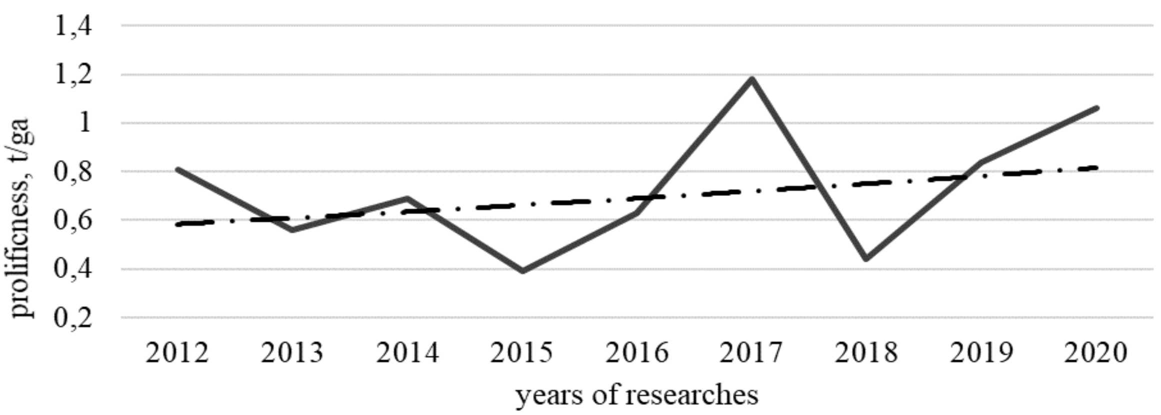

Fig. 7. **Dynamics of barley yield for 9 years on zero tillage (no-till)**

Conclusions

The studies have confirmed the established maxim that the transition to zero tillage (no-till) leads to an increase in the soil density and, as a result, to a decrease in the yield. Our hypothesis was confirmed that soil compaction and yield reduction on no-till, in comparison with traditional methods of cultivation, occur only in the first years of its use, and in the future, the soil density decreases and stabilizes at values close to equilibrium, and its productivity increases.

To maintain the soil density in the range of optimal values for field crops, it is advisable to use the DI system with the following set of equipment: for the main processing, the Case Magnum 310 + 2OPO-4.25 or Case IH Ecolotiger 530Cc with the Case Magnum 310 tractor; for closing moisture, the Brandt Commander7000 harrow in the unit with the Case Magnum 310 tractor; for pre – sowing cultivation, the Case Magnum 310 + 2OPO-4.25 unit. The MT system, when used for a long time, leads to over-compaction of the 10-20 cm layer and a decrease in the crop yield.In this connection, it is probably necessary to interrupt the MT after two or three years by deep loosening with the Case IH Ecolotiger 530 and the CaseMagnum 310 tractor. In the NT system, it is sufficient to carry out seeding with the Case Magnum 310 + Primera DMC 601 unit, with anchor-type coulters, and herbicide treatment with the the Terrion ATM 3180 + AMAZONE UG-3000 unit.These techniques allow to keep the field clean of weeds, except for wet years, when herbicides have to be used during the tillering phase of grain. To kill weeds during the secondary seeding, crops must be sprayed with a selective herbicide.

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