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RESEARCH ARTICLE

MICROORGANISMS AND NITROGEN TURNOVER IN THE SOIL DRIED BY RIDGED PLOWING

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ABSTRACT

Cultivation of spring grain crops in the Non-Chernozem Area of the Russian Federation is based on flat plowing. Moreover, flat plowing on sod-podzol drainage soils is done to the whole topsoil depth. However, ridged plowing (in the system of autumn plowing) provides a shorter time and higher quality of fieldwork, faster and more even spring soil drying up to its tilth, creates favorable conditions for biological events therein. This paper presents results of studies conducted in All-Russian Research Institute of Reclaimed Lands that suggest an effect of autumn ridged plowing on the crop-producing power of spring fodder-grain crops, soil microorganisms, soil nitrogen turnover in conditions of draining. Field tests for the ridged plowing studies were carried out on two cereals: oats and barley. Our experiments showed that the ridged plowing – without any additional expenditures – raised the productivity of the spring cereals by 16.9-17.5 % compared to the ordinary plowing. The ridged plowing provided more favorable conditions for soil nitrogen transformations, enhanced nitrification, improved nitrogen nutrition for the plants, promoted a total increase in the number of soil microorganisms including actinomycetes, autochthonous and nitrogen assimilating ones – but simultaneously lowered the number of the microscopic fungi, vascular wilt causing microorganisms and denitrifiers.

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INTRODUCTION

In the situation of excessive soil wetting and measures taken by the Russian Federation to dry the soil in order to provide a more stable agriculture – active land improvement techniques such as soil improvement tillage, surface planning, narrow-rotation plowing, etc. are recommended. The land-improvement trend in tillage suggests solving problems in improving the drainage, antioverwetting in autumn and early spring, reserving more soil moisture by its accumulation in the root layer, providing more soil moisture for the plant in its critical vegetation periods (Gulyuk *et al*., 2003; Kiyazev *et al*., 2013; Concept of ridge seedbed technologies…, 2014; Improved land-reclaiming tillage techniques…, 2012). At the present time, full topsoil depth plowing is the most popular technique of basic tillage in the spring grain crop cultivation in the Non-Chernozem Area of Russia (including its drainage lands).

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Studies performed in All-Russian Research Institute of Reclaimed Lands showed that the ridged plowing as a component in the system of autumn tillage was an effective land-improvement measure to make the technologies of spring grain crops cultivation on the drainage lands more adaptable. Usually the soil surface profiling is done for a more even soil drying in spring, faster advent of the soft elastic state and tillage of the soil, higher sowing quality, better water and air supply, and – summing up – to create more favorable soil conditions for physical, chemical and biological processes. In estimation if a tillage technique is suitable, the crucial criterion is the situation in the soil microorganism population, its stability in changing conditions, capability to restore fast after an impact done by men.

MATERIALS AND METHODS

Our field experiments in ridged plowing studies were conducted using the generally-accepted method (Dospekhov, 1979), on two cultures: oats and barley. The soil was a sod-and-podzol one, slightly loamy, gleyey, being dried with a closed drainage. Humus content was 2.0 %, accessible phosphorus and exchangeable potassium concentrations were

elevated, pH was 5.5-6.0. Such sorts as Abava barley, Sang and Skakun oats were cultivated. Mineral fertilizers were added according to the crop planned, amounts of seeds sown were as generally accepted. In the crop rotation, barley followed potatoes and oats followed lupine. The following basic experiments were compared: the ordinary 20-22 cm deep plowing (reference) and 20-22 cm deep ridged plowing. The reference plowing was done using a PLN-4-35 plow, whereas the ridged plowing was done with the same plow reequipped for the ridged plowing. The ridges were made 21.7-24.8 cm high, 70.2-73.8 cm between their centers. By spring the ridges settled down to the height of 14.6-16.1 cm. There, the soil surface ridgeness was 18.1 % in autumn and 15.6 % before tillage in spring. The ridging increased the evaporating surface by 15-20 %. The contents of the physiological groups of microorganisms (Zvyagintsev, 1991) and some agrochemical parameters (according to the All-Russian State Standards GOST 26489-85 and GOST 26951-86) were evaluated in the soil samples during the vegetation season.

RESULTS AND DISCUSSION

It was established (Concept of ridge seedbed technologies…, 2014) that the positive agricultural production effect of the ridged plowing on timely spring grain crops was achieved thanks to a longer vegetation period and an optimized time of the spring fieldworks – that promoted a higher crop yield and formed an effective soil productivity. An increase in the barley and oats yields on the gleyey soil was 0.61 ton/ha (17.1 %) and 0.55 ton/ha (16.9 %) in the average for five years. Our experiments on different soils showed that this technique gave the greatest barley production increases on gley soils – 0,72-1,64 ton/ha. In that experiment, productivity on the gleyey and slightly-loamy low-gley soils rose by 0.59 and 0.51 ton/ha, respectively. However, the ridged plowing had no effect on the barley production on a sandy-loamy low-gley soil. The grain production increase was caused by a greater number of ear-bearing stalks, more grains in each ear or head, a greater mass of 1000 grains. The ridged tillage of the soil elevated the field germination of the barley and oat seeds by 2.3-7.4%, their tilling capacity by 0.2-0.4 units, and their plant biomass (at the stage of stalk-shooting) – by 16.2-33.8 %.

The theoretical substantiation of the positive effect of the ridged plowing (according to the physical criteria of soil productivity) is based on the idea of the soil as a porous system, the state of which determines its basic functional properties such as water permeability, moisture capacity, water-retaining capacity, air content, events of accumulation, transformation and consumption of soil resources for plant life support. In its turn, the soil porosity is a function of many physical criteria (soil structure state, bulk weight, solid phase density, swelling, etc.). The porous space of the soil is most closely related to the density (bulk weight) of the latter. The soil density and porous space state are the main criteria to determine the physical state of the soil medium, its water-, water-and-air and nutrition turnovers, plant water supply, the types and directions of the microbiological processes, root system development, the level of effective fertility and productivity of the plant on the drainage lands (Concept of ridge seedbed technologies…,2014; Mitrofanov *et al*., 2015; Mitrofanov, 2012; Agrienvironmental land appraisal…, 2005; The analysis of the physical state of the soil in the ridged plowing showed that this technique substantially changed the water and physical parameters of the topsoil in autumn, winter and early spring, slowed the drift and self-compaction, maintaining its positive effect on the physical state of the soil during the crop vegetation. First of all, the ridged soil consolidates slower than that in the ordinary plowing. During the period of time from the tillage to the physical spring ripeness, the topsoil density drift was 0.15 g/cm^3 and just 0.10 g/cm^3 in cases of the ordinary and ridged plowing, respectively. The difference still remained after ridge levelling. By the end of vegetation, the ordinary plowing showed the soil compaction to its equilibrium state (its bulk weight exceeded the critical level by 0.04 g/cm^3, while that for the ridged plowing was only 0.01 g/cm^3). The greatest bulk weight changes due to the ridged plowing were observed in spring, before tillage.

Changes in the soil bulk weight and moisture turnover in case of its ridged surface change its porosity, compaction, the ratios of solid, liquid and gaseous phases in the soil. The total porosity during autumn and early spring in case of the ridged plowing compared to the ordinary one was by 1.6 and 2.1 % higher, and the aeration porosity was higher by 7.8 and 9.9 %. In case of the ridged plowing, the water to air ratio was more favorable for plants and biological soil events, shifting towards a higher topsoil aeration in comparison to the reference. In the ridged plowing that ratio was 1 : 1,56 in autumn, 1 : 1 in spring and summer - in comparison to the references 1 : 0,94, 1 : 0,48, 1: 0,85 in autumn, spring and summer, that is the topsoil aeration in case of the ordinary plowing was substantially lower. Our studies also showed that the ridged plowing had a substantial effect on the activity of the soil microorganisms, mineralization of organic nitrogen-containing compounds, and nitrogen transformations. In the Non-Chernozem Area soils, the mineralization of nitrogen-containing organic compounds depends significantly on the water, air and heat processes in the soils. The soil and fertilizer nitrogen depends strongly on its physical environment. Mineral nitrogen depends on many factors including weather, physical parameters of the soil, organic matter content, the microbiological events crucial for the soil nitrogen transformations, mineralization of the nitrogen-containing organic compounds, mineral nitrogen immobilization. The content of ammonium and nitrate nitrogen in the soil is the total expression of all nitrogen transformation events. Nitrate accumulation in the soil is due to nitrification, that is ammonium nitrogen oxidation into nitrate one. Coupling between nitrification and ammonification makes nitrate accumulation dependent on the content of an energy-yielding material for the ammonificating microorganisms in the soil. When the water and air parameters are unfavorable, the mineralization, decomposition of organic fertilizers and nitrate accumulation slow down. Even a short-time insufficient aeration and anaerobic conditions have a strong negative effect on nitrification (Zaidelman, 1992). That is why the creation of favorable water and air parameters for the plants and soil microorganisms by different agrotechnical and land improvement techniques is one of the most important ways to make the soil nitrogen and fertilizers more effective. The tillage – including the ridged plowing (as shown by our

studies) - plays a big part in solving this problem. We analyzed the mineral nitrogen content in the soil before the spring tillage and in vegetation, for major plant development stages. The mineral nitrogen content in the topsoil in spring, before the tillage, averaged 28.1-38.5 mg/kg. The mineral nitrogen was mostly the ammonium one. The nitrate nitrogen was 8.4-13.9% of the total mineral one. Some differences among the mineral nitrogen accumulated in individual fields seem to be due to the amount and quality of the energy-yielding material remained from the previous crops. The effect of types of the autumn plowing on the mineral nitrogen content in the topsoil in early spring (before the spring tillage) was ambiguous. After lupine, the mineral nitrogen content in the soil was greater in case of the ordinary plowing, and the ridged plowing gave 4.3 mg/kg less soil nitrogen. On the contrary, after potatoes the ridged plowing provided more nitrogen. After an autumn ridged plowing, the mineral nitrogen content in the soil after potatoes was 6.5 mg/kg higher than the reference (Fig.1).

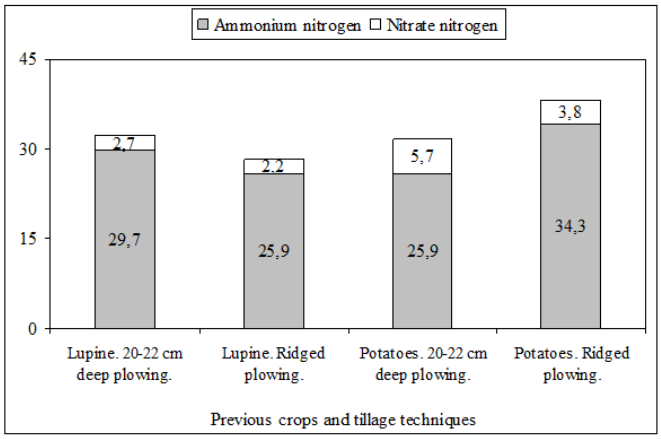
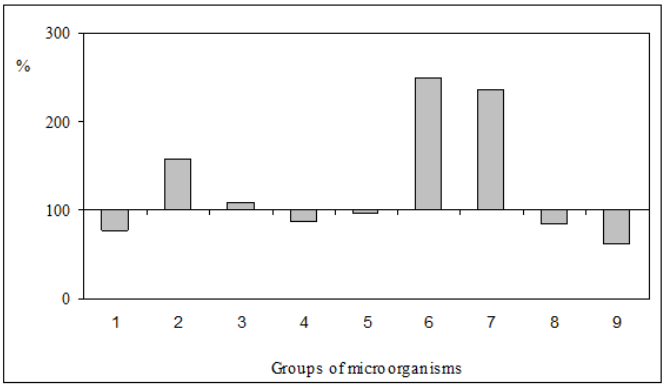


Figure 1. The effect of basic tillage techniques on the mineral nitrogen content in the topsoil (mg/1 kg soil) before sowing spring grain crops

The difference in the spring mineral nitrogen accumulation as an effect of the autumn tillage techniques was mostly formed by the ammonium nitrogen. It seems to be dying to the way how the energy-yielding material is distributed in the topsoil, as well as the soil temperature behavior in autumn and winter. After the ordinary, subsurface or ridged plowing the vegetative remains of the crops, straw and organic fertilizers are in different soil layers of different water, air and heat behavior and decomposition conditions for the organic matter. After lupine, most vegetative remains were in the lower topsoil after the ordinary plowing, but in the middle and upper one after the ridged plowing. The upper topsoil vegetative remains are more frozen and less moistened, thus less ammonified by the poorer amonification in the soil left unfrozen in late autumn and winter. After potatoes, the energy-yielding material distribution in the soil after different tillage types was somewhat different that that after lupine. The main energy-yielding material in the soil after potatoes is the remains of the peat-manure compost and spring rye straw plowed under it earlier. While plowing after the potatoes harvest, they move to the upper soil layer and occupy in the area of faster transformation of the biological materials; the ridged plowing leaves the above remains mostly in the lower topsoil, where the biological events last longer while the soil gets frozen. This idea is confirmed by microbiological analyses showing an increasing number of autochthonous microorganisms, the microorganisms which use mineral forms of nitrogen, and, in particular, aerobic and anaerobic nitrogen-fixing microorganisms (Fig.2). At the same time, the spring analyses carried out before the pre-sowing ridged plowing, compared to the ordinary plowing, showed 22.6 % less fungi, 38 % less microorganisms causing vascular wilt, 12.5 % less actinomycetes and 15.5 % less denitrifiers.

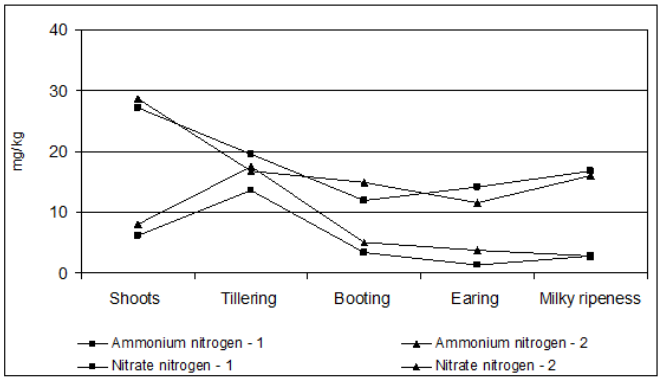


1 – fungi, 2 – autochthonous microorganisms, 3 – mineral nitrogen users, 4 – actinomycetes, 5 – ammonifiers, 6 – Azotobacter, 7 - anaerobic nitrogen-fixers, 8 – denitrifiers, 9 – microorganisms causing vascular wilt.

Figure 2. Soil microorganisms after the ridged plowing (% from the ordinary plowing ones taken for 100%) in early spring, averages on two years, three plant types and two agriculture systems

During vegetation, the mineral nitrogen includes nitrogen in the soil and fertilizers. The maximum mineral nitrogen accumulation under the plants was observed in the early phase. At the stage of barley shoots (preceded by potatoes) 1 kg soil contained 30.8-29.7 mg mineral nitrogen, whereas at the stage of oats shoots (preceded by lupine) 33.4-36.5 mg/kg mineral nitrogen. By that time the soil had accumulated the nitrate nitrogen, but the ammonium one still amounts to 78.3-84.5 % of the total mineral nitrogen. The soil ammonium nitrogen lowered through both the nitrification and a more active consumption of the ammonium nitrogen by the plants at the early stages of their development. The ridged plowing gave a greater increase of the soil nitrate nitrogen and a more significant lowering of the ammonium nitrogen. The ammonium nitrogen content under oats from shoots to tillering lowered by 11.9 mg/kg and 7.6 mg/kg after the ridged and ordinary plowing respectively, the same under barley was 9.9 and 3.9 mg/kg respectively. The maximum nitrate nitrogen content in the soil was observed at the stage of tillering. In spite of the total mineral nitrogen decrease in the soil, the nitrate nitrogen content in the soil grew from 6.18-7.94 mg/kg (stage of shoots) to 13.6-17.5 mg/kg under the oats and from 4.59-5.81 mg/kg to 7.25-7.72 mg/kg under the barley. Considering the effect of the ridged plowing on the mineral nitrogen dynamics under the plants within the whole vegetation period, it should be noted that the maximum effect of the ridged plowing was observed on the nitrate nitrogen dynamics. The amount of the ammonium nitrogen under the oats (a vegetation period average) after the ridged and ordinary plowing was the same, but at different stages of plant

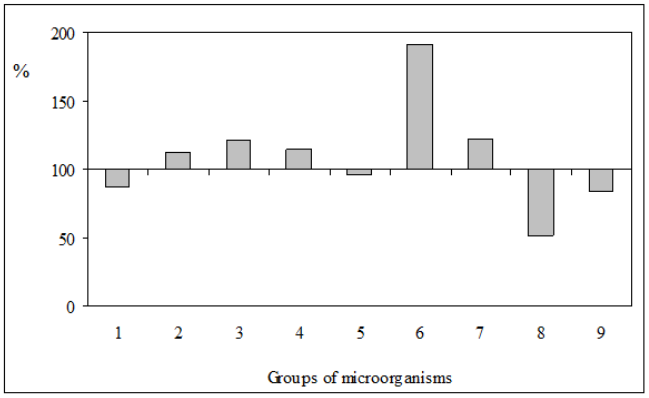
development it varied from 12.0 to 27.2 mg/kg in reference and from 11.6 to 28.6 mg/kg after the ridged plowing. The ridged plowing provided substantially more nitrate nitrogen: averaged results from five measurements done during vegetation showed that it could elevate the concentration of nitrates by 2.1 mg/kg (from 5.56 to 7.65) or by 37.6 %. At different stages of the plant development, the nitrate nitrogen content was different: from 1.25 mg/kg in shooting to 13.6 mg/kg in tillering in the reference, but from 3.69 to 17.5 mg/kg respectively in the ridged plowing. During some stages of oats growth the ridged plowing provided the nitrate nitrogen content by 28.4-29.5 % greater than the ordinary plowing. After the ridged plowing, the portion of the nitrate nitrogen in the total nitrogen at all development stages of the oats was always greater than the reference: 14.9 – 51.2 % compared to 6.6 – 40.7 % respectively. Figure 3 shows the effect of the ridged plowing on the nitrate and ammonium nitrogen dynamics.



1 – 20-22 cm deep plowing, 2 – 20-22 cm deep ridged plowing

Figure 3. The effect of basic tillage techniques on the topsoil mineral nitrogen dynamics under the oats (after lupine): average values for three years and two plowing types

The minimum content of the mineral nitrogen in the soil during the vegetation of the spring grain crops was observed under the oats at the stages of booting and earing, as well as under the barley at the stage of earing. Under the oats and barley, the mineral nitrogen content lowered to 15.2-15.3 mg/kg and 14.0-14.3 mg/kg respectively at those stages. Both ammonium nitrogen and nitrate nitrogen lowered, but it was the nitrate nitrogen that lowered most significantly, which was due to both the nitrate consumption by the plants and possible physical and biological losses. The effect of the ridged plowing on the microbiological events during the vegetation of the plants and early spring manifested itself in a greater total amount of microorganisms including the autochtonous ones, actinomycetes, nitrofen-fixers. During vegetation after the ridged plowing, the content of Azotobacter and free-living anaerobic nitrogen-fixers rose 1.9-fold and by 22.1%, respectively. Simultaneously, the ridged plowing lowered the amount of the fungi and denitrifying microorganisms. Generally, the ridged plowing made the soil healthier: it lowered the amount of the microorganisms causing the vascular wilt. The development of denitrification is enhanced by a lower oxygen content in the soil air, as well as organic matter forms easily available to the soil microorganisms. Denitrification leads to irreversible nitrogen losses and is one of the factors lowering the use of nitrogen from fertilizers and soil. The ridged plowing created better conditions for the soil aeration and lowered the amount of denitrifiers by 48.5 % during the vegetation (Fig.4). With the growth and development of the plants, their rhizosphere can provide favorable conditions for both biological and chemical acceleration of the denitrification. This is caused by the growth of roots and their air oxygen consumption, as well as excretions containing aminoacids, sugars and organic acids. The lowered mineral nitrogen content can also be greatly caused by an immobilization of the mineral nitrogen in the soil and its transformation to the nitrogen of the organic compounds in the microorganisms and their metabolites. All microorganisms that can assimilate the ammonium nitrogen and nitrate nitrogen are involved in this process. The ridged plowing compared to the ordinary plowing elevated the amount of the microorganisms using mineral nitrogen by 13.2%.



1-9 – the same as in Fig. 2.

Figure 4. Soil microorganisms after the ridged plowing (% from the ordinary plowing ones taken for 100%) during the vegetation of the plants, averages on two years, three plant types and two agriculture systems

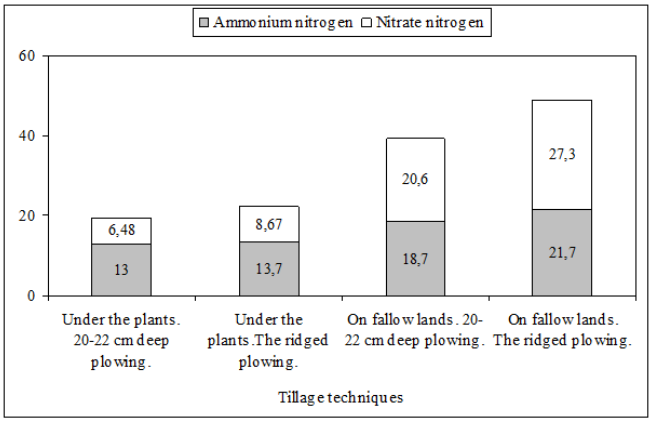


Figure 5. The mineral nitrogen content under the oats and on fallow lands (averagis on three tests and two agriculture systems)

NH_4 and NO_3 accumulation by the soil microorganisms in summer increased due to the soil temperature more favorable for their growth. Moreover, the immobilization was more active in the rhizosphere because the better developed plants produced more root excretions. The more excretions are

produced into the soil, the more active the immobilization is, and consequently the greater the rhizosphere microorganisms mass is. By the end of vegetation, the amount of the mineral nitrogen in the soil both under the barley and oats rose, mostly due to the ammonium nitrogen. It can be caused by the beginning of the plant roots dying off, decreasing nitrogen uptake by the plants, weaker metabolism and immobilization in the rhizosphere, dying microorganisms and a nitrogen release from their cells. The lower soil aeration by the end of vegetation had less effect on ammonification than on nitrification. The positive effect of the ridged plowing on the mineral nitrogen content in the soil and on the nitrification was the clearest on fallow lands. If the effect of plants on the mineral nitrogen content in the soil is excluded, the latter mostly depends on microbiological activities. In the average on three tests after the ridged plowing, the fallow lands showed their mineral nitrogen content 24.1 % greater than after the ordinary plowing (the ammonium nitrogen and nitrate nitrogen were 16.0 % and 32.5 % greater, respectively) (Fig.5). In contrast to the mineral nitrogen content under the plants, where the ammonium nitrogen predominated, the mineral nitrogen in fallow lands was rather the nitrate nitrogen than the ammonium one. The nitrate nitrogen contents versus total nitrogen ones under the plants were 33.2 % and 38.7 after the ordinary plowing and the ridged one, respectively. The fallow lands showed the nitrate nitrogen contents versus total nitrogen ones equal to 52.1 and 55.7 % after the ordinary plowing and the ridged one, respectively. In case of barley the effect of the ridged plowing was less noticeable.

The vegetation-average amount of the ammonium nitrogen after the ridged plowing and ordinary one was the same too, whereas various plant development stages showed the ammonium nitrogen content 14.0-25.0 mg/kg and 14.3-25.1 mg/kg in reference and after ridged plowing, respectively. As for the nitrate nitrogen content (the average on five tests during one vegetation), the ridged plowing did not bring any substantial advantages too: the amount of nitrates grew just by 0.09 mg/kg, from 4.69 mg/kg to 4.78 mg/kg). Considering plant development stages, the nitrate nitrogen content changed from earing to tillering as follows: from 1.31 mg/kg to 7.72 mg/kg (reference) and from 1.84 mg/kg to 7.56 mg/kg (after ridged plowing). At the same time, the nitrate nitrogen percentage in the total mineral nitrogen content after the ridged plowing was always higher during the basic stages of barley or oats development, i.e. it varied from 8.1 % to 26.8 % (reference) and from 10.1 % to 31.3 % (after ridged plowing). It is also essential that the ridged plowing advantage in nitrate accumulation occurred during the maximum nitrogen consumption by the plants, at the stages of booting and earing. After the ridged plowing, the nitrate nitrogen was by 14.7 % - 40.4 % higher than after the ordinary plowing.

Conclusion

The above studies showed that the ridged plowing of the sod-podzol, slightly loamy, gleyey soil (dried by a subsurface tile drainage), compared to the ordinary plowing, provided – practically without any additional expenses – a spring grain crops productivity rise by 0.55-0.61 ton/ha, which saves on resources for fodder grain production. Moreover, the ridged plowing of the drainage soil (in the system of the autumn soil preparation for the spring grain crops) should be considered as a special technique that creates better conditions for the nitrogen transformation in the soil, activates nitrification and stimulates the nitrogen consumption by the plant. The ridged plowing elevated both the total amount of the microorganisms and the amount of their individual physiological groups (such as actinomycetes, autochtonic and – especially – nitrogen-fixing ones) in the soil during the plants vegetation. The ridged plowing compared to the ordinary one elevated the amount of Azotobacter 2.5 times higher and 1.9 times higher (before sowing and in the vegetation period respectively). Moreover, the amount of different negative soil microorganism (including the fungi causing vascular wilt and denitrifiers) decreased.

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