Accurate technologies of agricultural crops cultivation for organic farming

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Abstract. The article presents the results of many years of experiments on the development of energy-saving farming systems. Preference in crop rotations should be given to multi-depth combined treatments that provide high productivity and are characterized by high-energy efficiency. Data on the yield of grain and leguminous crops in a six-field grain crop rotation with constant dump and combined longline tillage shows that the yield of oats in the first year of rotation according to the experimental variants was the same and amounted to 3.60 t/ha. In the second year of winter wheat yield in the variant with longline tillage was by 0.20 t/ha more in comparison with a plow on row, in the third year the difference in yield of spring barley on options for primary processing amounted to 0.30 t/ha in favor of combined tiered processing, in the fourth year the yield of peas has also been found to 0.40 t/ha more, also on the option of combined longline processing in the fifth year of the rotation crop of winter triticale. The yield of oats was 0.30 t/ha higher, and in the sixth year the yield of oats was 0.40 t/ha higher on the variant of combined longline processing.

1. Introduction

Due to the increase in world prices for energy carriers, mineral fertilizers and chemical plant protection products, the efficiency of crop cultivation using high-intensity technologies has become inferior to resource-saving technologies of organic farming [1, 2, 3].

Despite the higher level of yield under intensive cultivation, the additional costs of fertilizers, pesticides, grain drying, and wages are recouped only in years with epiphytic development of pathogens. The integrated technology proved to be the most cost-effective and environmentally safer. A differentiated approach to the use of fertilizers in these technologies, depending on the results of soil and plant diagnostics, biological characteristics of the variety, herbicides when exceeding the economic limits of harmfulness, fungicides depending on the degree of variety and retardants resistance, provides not only a sufficiently high level, but also a better return on all additional costs [4, 5].

The need to switch to resource-saving technologies in agriculture is associated not only with the increase in the cost of energy carriers, but also with a significant loss of fertile soil properties due to the widespread use of chemical preparations, and this increases the interest of farmers in biologized farming systems for obtaining environmentally friendly products [6, 7].
Long-term research on the development of energy-saving farming systems shows that spring grains, peas, and buckwheat are most responsive to dump tillage in cultivated areas. Surface and non-tillage cultivation is preferred for winter crops and annual grasses. The energy and environmental assessment of tillage systems in crop rotations indicates that, despite the relatively high productivity of crops under deep tillage, the energy efficiency coefficient of cultivators using only surface treatment (without plowing) is slightly higher due to lower processing costs, and this treatment contributes to a greater accumulation of humus in the soil. Therefore, preference in crop rotations should be given to multi-depth combined treatments that provide high productivity and are characterized by high energy efficiency [8, 9].

2. Material and methods

Studies revealed the high efficiency of the system of combined-tiered tillage, based on the scientific discovery: "The phenomenon of activation of humus formation during the decomposition of high-carbon organic compounds in the soil." Author's certificate of the IAA (International Association of Authors of Scientific Discoveries) No. 187, Patent of the Russian Federation "Method of increasing the yield of agricultural crops" No. 2393659, priority until 30.10.2028.

The proposed discovery relates to the field of soil biochemistry, to the section organic matter of the soil, humus formation.

According to modern concepts, humus is formed from the higher and lower plants or their residues entering the soil after the separation, microorganisms, soil-dwelling animals and waste products, as well as applied organic fertilizers. The transformation of primary organic matter into humic substances is the main process of soil formation and takes place in three stages.

At the first stage, there is a chemical interaction between the dead plant individual chemical substances (for example, aromatic compounds of the cell membranes can enter into chemical reactions with the proteins of plant cells). The chemical interaction between individual compounds can be accelerated by biological and mineral catalysts. Phenol oxidases, which catalyze the oxidation of polyphenols to quinones, are often mentioned as the first ones. The high reactivity of the latter is manifested in their energetic interaction with nitrogen-containing protein compounds.

At the second stage, the mechanical preparation and mixing of plant residues with the soil takes place with the help of soil fauna.

At the third stage of the transformation of fresh organic matter in the soil, it is mineralized with the help of microorganisms. First of all, water-soluble organic compounds are mineralized, as well as starch, pectins and protein substances. Cellulose mineralizes much more slowly, and its decomposition releases lignin, a compound that is highly resistant to microbiological degradation.

The primary organic matter transformations final products re mineral products (CO₂, H₂O, nitrates, phosphates, under anaerobic conditions, hydrogen sulfide and methane). In addition, low-molecular organic acids (formic, acetic, oxalic, etc.) accumulate in the soil as products of the microorganisms metabolism.

Part of the primary organic matter biological decomposition products is transformed into a special group of high - molecular compounds-specific, actually humic substances, and the process itself is called humification. The formation of specific humic substances in the soil runs parallel to the process of primary organic matter mineralization and its consolidation in the form of microbial plasma. Specific humic substances, due to their nature, are relatively resistant to microbiological cleavage, which contributes to their accumulation in the soil.

The formation of specific humic substances in most cases begins at the stage of plant and animal residues biological decomposition, when carbohydrates are hydrolyzed to monosaccharides, protein substances - to peptides and amino acids, aromatic compounds - to simple phenols. In addition to these compounds, simpler decomposition products (triosein, ammonia, etc.) also take part in the formation of humic substances. It is customary to divide specific humic substances into three main groups of compounds: humic acids, fulvic acids, and humins.
Humic acids are a fraction of dark-colored high-molecular nitrogen-containing compounds extracted from the soil by alkaline solutions, when acidification of the extract precipitates in the form of humates. Humic acids contain 52-62% of carbon, 3.0-5.5% of hydrogen, 30-33% of oxygen, and 3.5 - 5.0% of nitrogen.

Fulvic acids (humic substances of alkaline extraction that are not precipitated during acidification) are organic oxycarboxylic nitrogen-containing acids. Fulvic acids contain: carbon - 45.3%; hydrogen - 5.0%; oxygen - 47.3%; nitrogen - 2.4%. Compared to the elemental composition of humic acids, fulvic acids contain less carbon and nitrogen, and more acid.

Humins are the most inert part of the soil humus, which is not extracted from the soil during the usual treatment with alkaline solutions. In their composition, humins are close to humic acids. At the same time, this fraction of humus substances is more strongly connected with the mineral part of the soil, which significantly changes its properties.

Stimulating the formation of specific humic substances increases the formation of humus in the soil and accelerates soil formation processes.

The ancestor of modern hypotheses about humification is Trusov [10]. In his opinion, humic substances are formed in the process of oxidation and condensation of the decomposition products of proteins, lignin and tannins. He considered air oxygen, ammonia, and microbial oxidases to be the stimulators of humification.

A major contribution to the development of ideas about the essence of the humus formation process was made by the research of Tyurin [11], which expands the idea of the mechanism of humification by polycondensation processes, by the oxidation of phenols and their interaction with amino acids or with other nitrogen-containing organic substances. Based on his experimental studies, he concludes that humification is the process of carboxylation of organic compounds, resulting in a constant addition and loss of nitrogen. According to the author, the main criterion in biochemical processes belongs to nitrogen, and the main components of humification are oxidative acid formation, the formation of the nitrogenous part of the molecule, fractionation, the system of humic substances formed, followed by further aromatization, hydrolytic cleavage, and sorption.

The structure of humic substances or their chemical nature has not yet been fully disclosed. The available data relate mainly to their lateral functional groups, leaving the structure of their main core not sufficiently elucidated.

According to these data, in various soils, humus contains from 0.55 to 0.02% of carbon, 0.12-0.83% of nitrogen and 0.15-0.8% of hydrogen, which indicates the dominant role of carbon in the formation of new functional (carboxyl, hydroxyl, methoxyl, amide, etc.) groups that are part of all humus compounds.

Thus, knowing the General nature of the process of humification, which is carried out outside a living cell from the products of their partial decomposition, but conflicting information about the value of the teachings of the various components making up the organic part of the soil and the extent of their influence on this process.

3. Results and discussion

The essence of the discovery is that the previously unknown property of high-carbon organic substances under certain conditions to stimulate the formation of humus in the process of decomposition of organic substances in the soil was experimentally established for the first time. It is implemented in the technology of crop cultivation, based on a one-time deep plowing per rotation of the crop rotation with the incorporation of organic fertilizers and ameliorants and smaller treatments in subsequent years. This creates a model of the arable layer profile, when the most fertile organic layer is located in the lower part, and the upper part is periodically replenished with fresh organic matter (straw, green manure) and plowed to the lower part to form a more powerful root layer and reproduce soil fertility [5].

The theoretical basis of the mentioned development is the established pattern of arable layer differentiation by fertility and the advantage of its opposite to natural, heterogeneous structure with
the presence of a fertile layer in the lower layer of arable land revealed in experiments. At the same time, depending on the placement of a more fertile layer within the arable layer during the growing season, the root system of plants develops more intensively due to chemotropism in the layer that has nutrients and, due to the use of meliorants as water sorbents (zeolites, lime), a more stable moisture regime.

When the roots are placed on the surface during the dry growing season, the plants are exposed to periodic moisture deficiency. In conditions of even short-term drought, the top layer (0-0.100 m) dries up to a dead moisture reserve in two decades. As the result, the most favorable conditions for moisture and the availability of nutrients during the vegetation are observed in areas with variants where the nutrients are located in the lower layer, which is characterized by more stable moisture. This situation is confirmed by the results of field and small-scale experiments, when in dry years the content of productive moisture in the soil layer of 0.200-0.300 m was 15-20 mm higher than with the surface distribution of nutrients. Especially the lack of moisture in the upper placement of the root system was observed in the middle of the growing season, when the spring moisture reserve is exhausted.

The studies carried out on microfield experiments confirmed the regularities of the differentiation of the arable layer in terms of fertility, root chemotropism, and the advantages of creating a fertilized layer in the arable layer lower part, which makes it possible to obtain guaranteed grain yields even in extremely dry years.

In the arable layer lower part, when organic fertilizers and ameliorants are placed in it, due to a decrease in the concentration of oxygen as a result of its active consumption by microorganisms and limited air exchange with the atmosphere, the redox potential of the soil decreases to the optimal value. The microbiological activity of the soil, while maintaining a high level of the processes of general biological activity (CO₂ release, urease activity, nitrification ability), changes in the direction of increasing the transformation of the soil organic matter by endothermic reactions of the humus compounds formation with the decrease in exothermic decomposition processes to the final products.

As the result of experimental work, it was found that during annual plowing due to the wrapping and mixing of the soil, the fertility indicators of the upper and the arable layer lower parts are aligned. When wrapping stops, the fertility of the upper layer increases, and the lower layer decreases. Therefore, for crop rotation, using different depth and method of organic fertilizers soil incorporation, it is possible to form a different structure of the arable layer fertility: homogeneous (aligned to fertility), heterogeneous (taking advantage of the top layer), and with periodic wrap up of the arable layer after a number of years or subsurface cultivator treatment and back-heterogeneous (taking advantage of the lower layer).

The research allowed to formulate the position on the need for the arable soil layer heterogeneous structure formation with a predominant location of the fertile layer in the lower part of the arable and in the sub-arable layer. In chestnut soils, this position can be realized to a certain extent by using the natural process of soil fertility differentiation, when the mobile forms of nutrients accumulated in the upper layer of the soil after a number of years of exposure to atmospheric phenomena are sealed down by periodic complete rotation of the formation. At the same time, two principles apply: nature improves fertility in the upper layer, and the farmer periodically transforms the soil structure, creating a back-heterogeneous structure of the arable layer that is favorable for plants.

For low-humus non-chestnut soils, where natural fertility resources need constant replenishment, the inversely heterogeneous structure of the arable soil layer is created by periodically embedding in the lower part of the layer enriched with organic matter in the form of compost, siderate or a layer of perennial grasses mixed with the upper soil layer. Plowing down various types of organic fertilizers and their subsequent transformation with the lack of oxygen ensures more efficient use of mineralization products and increases the return on fertilizers.

On this basis, agrotechnical methods of forming the reverse heterogeneous structure of the arable layer were developed and mastered by periodically embedding organic fertilizers of meliorants, previously mixed with the upper layer of soil, in the lower part of the arable layer by using modern revolving plows.
The recommended tillage system, which includes alternating periodic deep plowing with reservoir turnover and surface or non-tillage treatment, supports a continuous process of organic matter transformation in the lower part of the arable land with an increase in the return from organic fertilizers while increasing the humus growth compared to annual plowing.

The developed agricultural technologies consist of basic and superstructure parts. In the basic part of the technologies, at the beginning of the crop rotation, deep tiered plowing is carried out with the incorporation of extra-hay organic fertilizers (compost and ameliorants) in the amount necessary to create a deficit-free balance of humus in the soil. In dry years, 3-4 t/ha of lime, zeolites and other organic substances with the properties of water sorbents are added to the main fertilizer to mobilize moisture from the subsurface horizons. The depth of plowing for planting fertilizers is determined by the depth of the arable layer with the plowing of 0.020-0.030 m of the subsurface horizon. On chestnut and gray forest soils, the plowing depth is brought to 0.300-0.350 m, on sod-podzolic soils-0.250-0.270 m. For all subsequent crops of the crop rotation, a shallow or non-dump treatment is used to the depth of up to the lower organic layer (0.250 m). Mineral fertilizers are applied under presowing tillage and in rows during sowing, and all other elements of agricultural technology are used based on the agrotechnical features of the crop.

In riser technology periodically, 2-3 times per rotation, holds Xia shallow suggestion manured to the lower stratum of fresh organic fertilizer that can be perennial grasses, chopped straw or green manure.

According to the generalized data of the Federal Research Center Nemchinovka, for two rotations, the average productivity of crop turnover in this agrotechnology increased by 25%, and the realization of the potential of plant productivity - by 23%.

Plowing of fresh organic fertilizers is carried out to the depth of 0.060-0.080 m less than in the basic composting, providing contact between two organic layers and additional activation of aerobic and anaerobic microbiological processes in the fertilizer concentration zone. The advantage of the new technology in all weather conditions is confirmed by the results of production tests conducted in various years of research.

The study of soil density as a factor of fertility shows that its optimum for the majority of field crops on different soils is in the range of 1.1-1.3 t/m³.

**Table 1.** Optimal values of soil density and porosity for the main field crops.

| Depth of processing | Density, t/m³ | Porosity, % |
|---------------------|--------------|-------------|
| The top layer       |              |             |
| 5.7 cm - for spring and winter grain crops; 7.10 cm - for large-seeded (peas) | 0.98-1.04 | 60-63 |
| - for spring grain crops; | 1.0-1.2 | 54-61 |
| - for winter grain crops; | 1.1-1.3 | 51-58 |
| - for large-seeded (peas) | 0.9-1.1 | 58-62 |

According to the distribution of the equilibrium density in the arable horizon by depth, all soils are classified into 4 types, and it can be in one of the state variants (Figure 1). The addition of the soil density along the horizon and depth determines the method and depth of cultivation.

The resulting situation of adding the soil density along the horizon and depth determines the method and depth of cultivation. Science recommends that machine technologies be formed taking into account the criterion of difference and aftereffect during the technological process, both in the crop rotation and taking into account the variety technology, i.e. in time and space.

The study of soil density as the factor of fertility by numerous studies in different soil and climatic zones shows that its optimum for most field crops on different soils is in the range of 1.1-1.3 t/m³.
Option 1. The density of the soil in the treated layer is higher than optimal. Such soils should be brought to the state of optimal density throughout the entire surface layer. To do this, use ploughshare tools of continuous loosening-dump or non-dump. Moreover, it is necessary to loosen the sub-arable horizons in order to reduce the density in order to involve them in the production of agricultural crops.

Option 2. The density of the soil in the treated layer and below is in the state of optimal density. Such soils do not require mechanical action. They need to develop technologies aimed only at controlling weeds, pests and diseases. In fields with such a density distribution, a humus content of more than 4% and sufficient moisture for self-sealing, it is possible to use the "no-till" technology.

Option 3. The top layer of the soil is over-compacted, but the lower layers of the arable horizon are in the state of optimal density. It is possible that this distribution of density is the result not so much of their natural development, but of man-made impact on the upper layer-compaction by running systems of equipment, spraying of the upper layer with tillage tools and irrigation with large norms. This condition of the soil depends on the aftereffect of deep processing, which must be taken into account when selecting crop rotation. In fields with such a density distribution, it is necessary to bring only the upper over-compacted layer to the optimal density. The processing depth depends on the size of the over-compacted layer. These soils are a testing ground for surface and shallow tillage.

Option 4. The upper part of the arable horizon is in the state of optimal density, the lower part is compacted. In such fields, it is necessary to bring the compacted soil layer to the state of optimal density, and the main mechanical impact should occur only on the lower compacted layer and does not require a continuous mechanical impact on the entire arable layer. This effect is carried out by chisel rippers. Chestnut (dark and light) soils are predisposed to this density distribution over depth.

Figure 1. Classification of soil types by the distribution of the equilibrium density in the arable horizon by depth.
So, in the Republic of Tatarstan for the period in 2014-2020, the productivity of grain crop rotation with equal doses of organic and mineral fertilizers for the annual deep plowing was 24.800 t/feed units, and for the combined longline processing 26.700 t. The results of accounting for crop yields and the total collection of feed units for rotation of the crop rotation confirmed the high efficiency of the combined-tier system of tillage and the use of fertilizers (Table 2).

Table 2. Crop yield per rotation of crop rotation (2015-2020).

| Experience options | Oats, 2015 | Winter wheat, 2016 | Barley, 2017 | Peas, 2018 | Winter triticale, 2019 | Oats, 2020 | Productivity, t/feed unit |
|-------------------|------------|-------------------|------------|-----------|----------------------|------------|--------------------------|
| 1. Annual plowing of 25-30 cm (control) | 3.60 | 5.50 | 3.40 | 2.80 | 5.10 | 3.90 | 24.800 |
| 2. Combined-tiered tillage | 3.60 | 5.70 | 3.70 | 3.20 | 5.40 | 4.30 | 26.700 |
| NSR 05 t/ha | 0.08 | 0.12 | 0.18 | 0.24 | 0.21 | 0.18 | |

Data on the grain and leguminous crops yield in the six-field grain crop rotation with constant dump and combined longline tillage show that the yield of oats in the first year of rotation according to the experimental variants was the same and amounted to 3.60 t/ha. In the second year of winter wheat yield in the variant with longline tillage was by 0.20 t/ha more in comparison with plowing, in the third year the difference in yield of spring barley on options for primary processing amounted to 0.30 t/ha in favor of combo detail: fit-longline bath treatment, in the fourth year the yield of peas has also been found to 0.40 t/ha more, also on the option of combined longline processing in the fifth year of the rotation crop of winter triticale, The yield of oats sown after peas was 0.30 t/ha higher, and in the sixth year, the yield of oats after winter triticale was 0.40 t/ha higher in the combined longline treatment option compared to the dump plowing option.

The conditional net income from each hectare of arable land for annual deep plowing amounted to 6239.6 rubles, and for combined longline processing 8244.7 rubles.

So, if before laying the experiment, the content of humus in the soil [12] in the layer of 0-0.200 m of leached chestnut soil was 6.5%, and in the layer of 0.200-0.400 m – 6.2%, then at the end of the rotation of the crop turnover in the control variant, respectively, 6.6% and 6.4%, and for combined-tier processing, 6.6% and 6.8%.

4. Conclusion
The presented material shows the elements of organic farming technology in the system of combined-tiered tillage and the use of fertilizers in crop rotation, which contribute to the reproduction of soil fertility and the growth of crop yields. The technology of crop cultivation, which covers the entire cycle of plant cultivation, provides a higher yield with compensation for the removal of nutrients, with the use of agricultural waste as organic fertilizers. It is used in optimal natural and climatic conditions, as the sum of processes in which the plant’s productivity and quality capabilities are used by 85% or higher.

The potential of such technologies in the conditions of Russian landscapes can be at the level of the best achievements of European farms.

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