Treatments influence on soil water-physical indicators in Nizhneje Povolzhje dry-steppe zone conditions

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Abstract. The experiment is carried out in the conditions of semi-desert flat agricultural landscapes of light chestnut soils. The object of research is a 4-field crop rotation (factor A), variants of the main tillage (factor B) and crops superimposed on the tillage options with the Don-114 seeder (a seeder for direct sowing). The placement of options (A) is sequential and options (B) are arranged in blocks in three tiers. The main soil tillage was carried out by the following tools: mouldboard tillage to the depth of 25-27 cm by plough PN-4-35; non-mouldboard tillage to the depth of 25-27 cm by the tool OCHO-5-40 with the rack “Rancho”; surface one to the depth of 8-10 cm by the tool BDM-4.2, and 4-field grain-fallow crop. It was found that a higher content of nutrients is in fallow preferably at non-mouldboard soil treatment, in some years, which has an optimal moisture supply, and control (mouldboard) one in comparison with lower levels of surface soil treatment in all years of the research. The main comparison in the change in nutrients in fallow fields is observed precisely for different methods of soil cultivation.

1. Introduction
In the context of the priority development of adaptive landscape farming systems, it is of great importance to improve the tillage systems, their differentiation depending on the landscape conditions, soil types and their properties, the choice of cultivated crops, and the biologization techniques used [1, 2]. Proper processing, which corresponds to the soil and climatic conditions, is an important means of regulating the agrophysical state of the soil, its biological properties, nutrient and water regimes, the content and reserves of humus, crop yields and product quality [3, 4, 5].

The attempts to use foreign technologies that are not adapted to the specific natural and soil conditions of the Russian Federation various regions lead to the decrease in their effectiveness [6, 7, 8]. A comprehensive analysis of the resource conservation problem and, above all, in the system of tillage indicates the need for deep research in this direction, which should be based on the principles of adapting techniques and methods to the natural features of the region and the rational use of energy resources. Together, these technologies must ensure the sustainable production of agricultural products.
and exclude soil fertility and environmental degradation caused by the processes of erosion, deflation and loss of energy resources of the soil [9, 10].

The study of the most economically and environmentally effective methods of minimizing the main tillage with long-term and short-term use in crop rotations with grain crops in the soil-climatic conditions of light chestnut soils of the Nizhneje Povolzhje region is of particular relevance in modern economic conditions of management [11, 12].

2. Materials and methods

The experiment is carried out on the experimental plot of the Nizhnevolzhsky Research Institute of Agriculture under the conditions of semi-desert plain agricultural landscapes of light chestnut soils.

A) The plot is located in the system on a slope catchment troughs western exposure with a gradient to 2°. The soil of the experimental plot is light chestnut with a humus content in the arable layer of 1.74%, total nitrogen and phosphorus of 0.12% and 0.11%, respectively.

According to the Kachinsky’s classification, the soil is silty-coarse-silty heavy loam according to its texture: it contains physical sand of 49.3% and physical clay of 50.7%. The reaction of the soil solution in the arable layer is pH 8.1. Soils are alkaline in composition.

The object of the research is 4-field rotation (factor A), the main soil tillage (factor B), and superimposed on embodiments tillage sowing by the drill Don 114 (seeder for direct sowing). Placement of options (A) sequential and options (B) in blocks in three tiers. The main soil cultivation is carried out with the following tools: mouldboard tillage to the depth of 25-27 cm by plough PN-4-35; non-mouldboard tillage to the depth of 25-27 cm by the tool OCHO-5-40 with the rack “Rancho”; surface one to the depth of 8-10 cm by the tool BDM-4.2, and 4-field grain-fallow crop rotation, which includes the following crops: autumn fallow-winter wheat-safflower-barley, sowing of crops is performed by the Don-114 seeder.

B) A plot of 4 hectares will be directly used for direct sowing. The crop rotation will be the same as in the basic tillage (chemical fallow-winter wheat-safflower-barley).

Conducting scientific research by using the No-till technology, where crops are cultivated without treatment, the selection of crops and their alternation in crop rotation has its own characteristics, since the maintenance of high agrophysical soil properties, including loosening, occurs by the root systems of cultivated plants. Therefore, in the crop rotation, plants with fibrous and tap root systems should be alternated. The fibrous root system penetrates with its numerous roots the upper, most fertile layer of the soil, thereby providing high structure, water permeability and optimal body density. Taproot crops provide loosening of deeper soil layers so that moisture from atmospheric precipitation can penetrate and accumulate in deeper soil layers.

Also, an equally important requirement is the inclusion in the crop rotation of plants that leave as much plant residues as possible on the soil surface, which reliably protect the soil from wind and water erosion, and also ensure the accumulation and preservation of soil moisture.

The works proposed for this technology include: pre-sowing herbicide application (glyphosates 5-7 days before sowing), sowing crops, harvesting crops, sowing cover crops.

Accounts and observations are carried out according to the recommendations on the methodology for conducting observations and research in the field experiment (Saratov, Research Institute of Agriculture of the South-East, 1973), the Dospekhov’s method of experimental work, features of scientific research on the technology of cultivation of agricultural crops without tillage (No-till), Kiryushin, Drigiger.

3. Results and discussion

In basic tillage, the topsoil is more dispersed and moves downward, while the lower layer, more structured, rises to the surface. It experiences the mechanical effect of cultivation tools during soil preparation and the kinetic energy of raindrops, as the result of which structural aggregates are destroyed.
When cultivating crops without tillage root layer does not undergo mechanical impact of the soil cultivation tools. Therefore, its structure remains undisturbed, which the amount of living space for soil microorganisms - noncapillary porosity and capillary is largely dependent on.

The data on the volumetric mass of the soil on fallow showed the advantage of non-mouldboard tillage in all layers from 0 to 30 cm (Table 1).

| Processing option, culture                           | Horizon, cm |
|------------------------------------------------------|-------------|
|                                                      | 0-10 | 10-20 | 20-30 | 30   |
| Mouldboard processing, PN-4-35                       | 1.12 | 1.36  | 1.38  | 1.30 |
| Non-mouldboard processing, Ocho 5-40                 | 1.09 | 1.10  | 1.22  | 1.14 |
| Surface treatment, BDM-4.2                           | 1.14 | 1.38  | 1.30  | 1.27 |
| Chemical steam                                        | 1.17 | 1.29  | 1.31  | 1.25 |
| Safflower on mouldboard treatment                    | 1.08 | 1.22  | 1.14  | 1.14 |
| Safflower for non-mouldboard processing              | 1.23 | 1.30  | 1.21  | 1.25 |
| Safflower for surface treatment                      | 1.27 | 1.39  | 1.22  | 1.29 |
| Safflower for winter wheat                           | 1.26 | 1.33  | 1.27  | 1.28 |

The soil had the highest density on the variant with surface tillage when sowing safflower by the DON-114 seeder and amounted to 1.22-1.39 g/cm³ depending on the layer. The optimum addition was provided by mouldboard and non-mouldboard tillage of 1.14-1.25 g/cm³ in the middle layer 0-30 cm. When sowing spring crops without tillage by the working bodies of the seeder (turbo disk, coulter) only the top layer of the soil is loosened to the depth of 6-8 cm. The underlying soil layers are not loosened. Therefore, and due to the physical properties of light-chestnut soils prone to self-compaction, the density of all the studied horizons before sowing was higher than according to traditional technologies and amounts to 1.26-1.27 g/cm³ in the 0-10 cm layer, in the 10-20 cm layer - 1.33-1.39 g/cm³ and in the 20-30 cm layer - 1.28-1.29 g/cm³.

For the analysis of soil compaction, evaluation criteria are used at the density of 1.15 g/cm³ and less, the soil is considered loose, 1.15-1.25 g/cm³ it is compacted, 1.25-1.35 g/cm³ - dense, above 1.35 g/cm³ - very dense. The basic tillage of the soil for grain crops should provide them with a bulk density of 1.05-1.30 g/cm³ and with its increase, the productivity of crops decreases. With the increase in density by 0.01 g/cm³, the yield of winter wheat decreases by 0.02 t/ha, of spring crops by 0.03-0.04 t/ha, while the upper limit of the optimal density for light chestnut soils is 1.32 g/cm³, which provides sufficient air regime for grain crops.

We monitored the quality parameters of the basic tillage (depth, ridges, lumpiness), determined the preservation of stubble on the soil surface, as a means of protecting the soil from blowing out small particles and allowing to retain the maximum amount of snow in the fields. In our experience, crop residues were crushed during harvesting and evenly distributed by the combine on the soil surface (Table 2).

According to the technology without tillage, all plant residues remain on the soil surface. On average, over the years of research, their number amounted to 3.58 t/ha, which is 2-6 times more than by traditional technologies, where it remained 0.6, 1.9, 1.6 t/ha, respectively.
Table 2. Influence of technology on the amount of plant residues on soil after basic tillage and direct sowing, t/ha.

| Technology               | Tillage                          | 2016 | 2017 | 2018 | 2019 | The average |
|--------------------------|----------------------------------|------|------|------|------|-------------|
| Traditional             | Mouldboard PN 4-35               | 0.72 | 0.61 | 0.47 | 0.52 | **0.58**    |
|                         | Non-mouldboard OCHO 5-40 with    |      |      |      |      |             |
|                         | rack "Rancho"                    | 1.91 | 2.07 | 1.73 | 1.93 | **1.91**    |
|                         | Surface BDM-4.2                  | 1.47 | 1.66 | 1.36 | 1.85 | **1.58**    |
| Without tillage         | Direct sowing                    | 4.21 | 4.74 | 3.81 | 1.57 | **3.58**    |

The conducted observations of the tested soil tillage quality showed that they allow to ensure the fulfillment of modern agrotechnological requirements at the proper level, deviations from the given depth did not exceed 3 cm and corresponded to the optimal technological tolerance (10-15%) (Table 3). Surface tillage, carried out to the minimum depth, leave behind a more leveled surface, deep ones - more ridged. The highest ridgeness corresponded to the option with mouldboard tillage to the depth of 25-27 cm and amounted to 30.3%. Non-mouldboard tillage to the same depth had a ridgeness of 26.3%. Surface tillage to the depth of 8-10 cm forms a ridgeness 1.5-2.0 times less than deep tillage. Lumpiness of the soil surface layer did not exceed 12-24% on stubble variants, and 44% on mouldboard tillage.

Table 3. Determination of the quality of basic tillage, 2019.

| Tillage type  | Planned depth, cm | Factual depth, cm | Coefficient of uniformity, % | Lumpiness of the surface, % | Ridgeness of the surface, % |
|---------------|-------------------|-------------------|------------------------------|-----------------------------|-----------------------------|
| Mouldboard    | 25-27             | 23.5              | 68.33                        | 44.07                       | 30.33                       |
| Non-mouldboard| 25-27             | 25.7              | 79.73                        | 24.52                       | 26.33                       |
| Surface       | 8-10              | 8.9               | 70.11                        | 12.44                       | 16.66                       |

The cultivation itself does not add anything to the soil, however, the agrophysical characteristics of the soil depend on it, which determine the water-air and thermal conditions of the soil climate, the degree and depth of plant residues incorporation. Depending on the methods of basic tillage, one or another structure of the soil profile is formed according to the distribution of particles of the solid phase, reserves of nutrients, the movement of carbon dioxide and moisture. All this can affect the dynamics and ratio of the synthesis and mineralization of humus, the formation of mobile forms of nutrients and their assimilation by plants. At present, the question of the methods and depth of soil cultivation as methods of regulating the physical state of the upper soil layer is discussed from the point of view of the transition to conservation agriculture and is associated with its structuring and the formation of a mulching layer from plant residues of different degrees of decomposition.

According to the criteria of the aggregate composition of the soil, the following structural units are distinguished: clod (10 mm), lumpy-granular (10-0.25 mm) and microaggregates (0.25 mm), where aggregates of 10-0.25 mm are agronomically valuable.

The general dynamics of aggregates can be traced through the coefficient of soil pedality (Table 4). Chemical fallow is exposed to the least mechanical stress; therefore, the Coefficient of soil pedality is the highest and is 7.73. The balance of the soil aggregate composition in the chemical fallow shows little change both macro- and in microaggregates, which indicates that the No-till technology prevents the destruction of topsoil, saves texture and prevents soil degradation.
| Index | May        | August     | Balance +/- |
|-------|------------|------------|-------------|
| Clods, > 10 mm | 6.31         | 5.96       | -0.35       |
| Macrotecture, 0.25-10 mm | 76.3         | 72.2       | -4.1        |
| Microtexture, <0.25 mm | 17.39        | 21.84      | +4.45       |
| Coefficient of soil pedality | 3.2          | 2.6        | -0.6        |
| **Non-mouldboard tillage, OCHO-5-40, "Rancho"** |             |            |             |
| Clods, > 10 mm | 4.7          | 1.69       | -3.01       |
| Macrotecture, 0.25-10 mm | 80.4         | 84.18      | +3.78       |
| Microtexture, <0.25 mm | 14.9         | 14.13      | -0.77       |
| Coefficient of soil pedality | 4.1          | 5.3        | +1.2        |
| **Surface tillage, BDM-4.2** |             |            |             |
| Clods, > 10 mm | 3.88         | 1.93       | -1.95       |
| Macrotecture, 0.25-10 mm | 79.2         | 81.67      | +2.47       |
| Microtexture, <0.25 mm | 16.92        | 16.4       | -0.52       |
| Coefficient of soil pedality | 3.8          | 4.4        | +0.6        |
| **Chemical fallow** |             |            |             |
| Clods, > 10 mm | 4.67         | 4.22       | -0.45       |
| Macrotecture, 0.25-10 mm | 88.54        | 87.9       | -0.64       |
| Microtexture, <0.25 mm | 6.79         | 7.88       | +1.09       |
| Coefficient of soil pedality | 7.73         | 7.26       | -0.47       |
| **Spring crops (direct sowing)** |             |            |             |
| Clods, > 10 mm | 5.7          | 4.88       | -0.82       |
| Macrotecture, 0.25-10 mm | 87.92        | 82.79      | -5.13       |
| Microtexture, <0.25 mm | 6.38         | 12.33      | +5.95       |
| Coefficient of soil pedality | 7.23         | 4.8        | -2.43       |
| **Winter wheat (direct sowing)** |             |            |             |
| Clods, > 10 mm | 9.94         | 1.14       | -8.8        |
| Macrotecture, 0.25-10 mm | 87.42        | 85.49      | -1.93       |
| Microtexture, <0.25 mm | 2.64         | 13.37      | +10.73      |
| Coefficient of soil pedality | 6.95         | 5.89       | -1.06       |
The number of agronomically useful aggregates (10.0-0.25) on average during the fallowing period is 88% - this is the indicator of a well-textured soil.

In crops of spring crops and winter wheat, the transition from the coarse fraction to the dusty one is much more intensive. The destruction of the blocky fraction in winter wheat crops is 90% stronger than in soils under spring wheat, but macrostructures (0.25-10) are more prone to disintegration and transition into a fine fraction in barley crops than in winter wheat. However, these figures are low and indicate that stubble conservation with No-till technology prevents soil degradation. Positive indicators in the increase in macrostructure (0.25) are the highest in the soil under winter wheat and amount to + 10.73%. On chemical fallow and barley, this figure is +1.09% and +5.95%, respectively. The Coefficient of soil pedality as a whole for the study period was on chemical fallow - 7.5, for barley - 6.0 and for winter wheat - 6.4.

The total content of macroaggregates in the soil layer 0-0.3 m under the influence of its tillage fluctuated in the interval with tillage 76.3-80.4%. Most of the macroaggregates were destroyed during the fallow through the mouldboard tillage by 4.1%, which is associated with the intense impact of mechanical treatments on the soil, while on the non-mouldboard and surface tillage, on the contrary, the increase in macroaggregates by 2-4% occurred, where due to the influence of aerobic bacteria occurs mineralization of organic matter, thereby cementing structural units.

The Coefficient of soil pedality for the main tillage by the end of fallowing was 2.6 for mouldboard, 5.3-4.4 for non-mouldboard and surface ones, respectively.

The analysis of mineral nutrients in the spring-summer period showed that nitrates in soil accumulated more intensely on mouldboard and non-mouldboard tillage, and mobile phosphorus and potassium exchange have negative balance on chemical fallow (Table 5).

**Table 5.** Food regime in the soil under the basic tillage and chemical fallow (average for 2016-2019) mg/100 g of soil.

| Option                  | Horizon, cm | NO₃  | Elements of mineral nutrition, mg/100 g of soil | P₂O₅ | K₂O |
|-------------------------|-------------|------|-----------------------------------------------|------|-----|
|                         |             | April | Augus              | +/-  | April | Augus | +/-  | April | Augus | +/-  |
| Fallow mouldboard       | 0-10        | 1.15  | 12.81              | +11.6| 5.08  | 7.25   | +2.17 | 30.00 | 33.6  | +3.6  |
| mouldboard, PN-4-35     | 10-20       | 0.86  | 10.29              | +9.43| 5.02  | 6.83   | +1.27 | 26.67 | 36.75 | +10.1 |
|                         | 20-30       | 1.2   | 7.39               | +6.19| 4.82  | 7.20   | +2.57 | 26.04 | 37.28 | +11.2 |
| Fallow non-mouldboard   | 0-10        | 1.31  | 9.45               | +8.14| 6.59  | 7.67   | +1.08 | 39.53 | 43.16 | +3.63 |
| mouldboard, OCHO 5-40  | 10-20       | 0.80  | 6.97               | +6.17| 6.3   | 7.25   | +0.95 | 27.45 | 28.85 | +11.4 |
|                         | 20-30       | 1.30  | 5.08               | +3.78| 5.06  | 7.46   | +0.02 | 21.42 | 33.08 | +11.6 |
| Fallow surface          | 0-10        | 1.17  | 4.05               | +2.88| 8.5   | 7.56   | -0.94 | 29.00 | 36.75 | +7.7  |
| tillage, BDM-4.2       | 10-20       | 1.15  | 5.25               | +4.10| 8.63  | 7.67   | -0.96 | 26.14 | 31.29 | +5.1  |
|                         | 20-30       | 1.4   | 2.79               | +1.39| 8.24  | 6.72   | -1.52 | 22.42 | 26.88 | +4.4  |
| Chemical fallow         | 0-10        | 0.34  | 1.53               | +1.19| 6.51  | 5.1    | -1.41 | 44.52 | 31.50 | -13.0 |
|                         | 10-20       | 0.59  | 1.78               | +1.19| 6.09  | 4.35   | -1.74 | 36.43 | 22.05 | -14.4 |
|                         | 20-30       | 0.48  | 1.41               | +0.93| 5.65  | 4.58   | -1.07 | 35.49 | 26.04 | -9.4  |

During the mouldboard tillage, there was nitrate nitrogen amount of 1.07 mg/100 g of soil; on non-mouldboard tillage - 1.14 mg/100 g; and on surface one - 1.24 mg/100 g of soil at the beginning of fallowing, at the end of fallowing this indicator increased to 9.1; 6.0 and 2.8 mg/100g in the soil layer 0-30 cm, respectively. The basic tillage on the accumulation of phosphorus had an effect only on the mouldboard and non-mouldboard background, the balance was +1.1, +2.6 mg/100 g, on the surface tillage and on chemical fallow its accumulation did not occur. The soil supply with exchangeable potassium was high; in all the variants of soil tillage, the negative balance was in the chemical fallow.
Negative phosphorus and potassium balance in the variant with a chemical fallow leads to the need of phosphorus-potassium fertilizer applying before sowing winter wheat.

For the most complete accounting of energy of all types in the exploitation of the landscape, it is necessary to take into account all the costs of material, energy and labor resources and bring them using energy equivalents to a single unit. As the integral criterion for the productivity of the agricultural landscape, one can take the energy efficiency coefficient, which shows how many times the energy contained in the harvest of an agricultural crop is more or less than the energy put into the technological process of tillage and harvesting. Requirements for obtaining a certain value of the bioenergy criterion make it possible to analyze any technology from the point of view of adaptive farming.

Bioenergetic assessment of crop rotation was carried out according to Udalov, energy efficiency was defined as the ratio of the energy accumulated in the crop to the total energy consumption. The coefficient of energy efficiency of technologies for growing agricultural crops \( C_{ee} \) must meet the following conditions: \( Q_y > Q_{cs} \) and \( C_{ee} > 1.0 \). The energy efficiency \( E \) is determined by the formula:

\[
C_{ee} = \frac{Q_y}{Q_{cs}}
\]

where \( Q_y \) is the energy accumulated by the economically valuable part of the crop; \( Q_{cs} \) is the total energy spent on all technological operations.

The analysis of the bioenergetic assessment of the crop cultivation in the crop rotation for the period from 2016 to 2019 showed that winter wheat cultivated by deep mouldboard tillage has the highest yield (Table 6).

Table 6. Bioenergetic assessment of crop cultivation at basic tillage and direct sowing, 2016-2019.

| Culture  | Tillage method  | Average yield, dt/ha | Total energy consumption MJ/ha | Energy stored in the harvest MJ/ha | \( C_{ee} \) |
|----------|-----------------|----------------------|--------------------------------|----------------------------------|---------|
| Winter wheat | mouldboard | 23.1 | 15987 | 44352 | 2.8 |
|           | non-mouldboard | 27.3 | 14329 | 52416 | 3.6 |
|           | surface         | 21.8 | 13833 | 41856 | 3.0 |
|           | direct sowing   | 16.7 | 10109 | 32064 | 3.2 |
| Safflower | mouldboard | 8.5 | 10407 | 9112 | 0.9 |
|           | non-mouldboard | 10.3 | 9276 | 11042 | 1.2 |
|           | surface         | 9.1 | 7112 | 9755 | 1.4 |
|           | direct sowing   | 8.7 | 5732 | 9326 | 1.6 |
| Barley    | mouldboard | 16.2 | 10903 | 26649 | 2.4 |
|           | non-mouldboard | 17.5 | 10012 | 28787 | 2.9 |
|           | surface         | 14.2 | 8561 | 23359 | 2.7 |
|           | direct sowing   | 15.5 | 6321 | 25497 | 4.0 |

The least efficient crop of crop rotation is safflower, both with basic tillage and with direct sowing, low yields at rather high costs did not exceed the efficiency indicator of 0.9-1.4 in a crop rotation with annual classical tillage. The direct-seeding crop rotation had the highest energy equivalent of 1.6 in safflower crops. At the same time, the dependence on the costs is clearly visible - the maximum for mouldboard processing is 10407 MJ/ha, the minimum for direct sowing is 5732 MJ/ha in the second crop rotation.

In the crop rotation with traditional tillage, most of the energy was accumulated in the harvest of winter wheat on autumn fallow with an annual non-mouldboard cultivation of 52416 MJ/ha with an energy efficiency coefficient of 3.6. The highest total energy costs are observed for mouldboard tillage...
of 15987 MJ/ha with $C_{ee}$ of 2.8. Thus, according to the tillage method, deep mouldboard loosening turned out to be the most effective for winter wheat.

For spring crops, the most efficient system is direct sowing, with the energy efficiency of 1.6 for safflower and 4.0 for barley. On the background of the basic tillage, the efficiency ranged from 0.9-1.4 for safflower and from 2.4-2.7 for barley, depending on the tillage option.

The comparison of the average bioenergetic efficiency by crop rotation (Table 7) showed its sufficiently high level of 2.7 in the crop rotation with annual non-mouldboard tillage, where the total energy consumption was three times covered by the energy of the crop.

**Table 7. Bioenergy efficiency of crop rotations, 2016-2019.**

| Basic tillage method | Total energy consumption, MJ/ha | Energy accumulated in the crop, MJ/ha | Energy efficiency, $C_{ee}$ (average) |
|----------------------|---------------------------------|--------------------------------------|---------------------------------------|
| Mouldboard           | 37297                           | 80113                                | 2.1                                   |
| Non-mouldboard       | 33617                           | 92245                                | 2.7                                   |
| Surface              | 29507                           | 74970                                | 2.5                                   |
| Direct sowing        | 22162                           | 66887                                | 3.0                                   |

Crop rotation with crops direct sowing had the highest energy coefficient of 3.0, which is explained by the reduction in total energy consumption of 22162 MJ/ha than for basic tillage by 7345-15135 MJ/ha, while the average crop yield was lower than the classical options.

**4. Conclusions**

The highest density of the soil was in the variant with surface treatment when sowing safflower by the DON-114 seeder and amounted to 1.22-1.39 g/cm³, depending on the layer. Optimal addition was provided by mouldboard and non-mouldboard tillage 1.14-1.25 g/cm³ in the middle layer of 0-30 cm. When sowing spring crops without tillage, the density of all the studied horizons was higher than according to traditional technologies and amounts to 1.26-1.27 g/cm³ in the 0-10 cm layer, in the 10-20 cm layer - 1.33-1.39 g/cm³ and in the 20-30 cm layer - 1.28-1.29 g/cm³.

In the crop rotation with traditional tillage, most of the energy was accumulated in the harvest of winter wheat on autumn fallow with an annual non-mouldboard tillage of 52416 MJ/ha with the energy efficiency coefficient of 3.6. The highest total energy costs are observed for mouldboard tillage of 15987 MJ/ha with $C_{ee}$ of 2.8. Thus, according to the method of tillage, deep mouldboard loosening turned out to be the most effective for winter wheat.

For spring crops, the most efficient system is direct sowing, with the energy efficiency equal to 1.6 for safflower and 4.0 for barley. On the background of the basic tillage, the efficiency ranged from 0.9-1.4 for safflower and from 2.4-2.7 for barley, depending on the tillage option.

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