Methods for restoring fertility and improving physical and mechanical properties of soils

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Abstract. Insufficient intake of organic matter into the soil, non-compliance with crop rotations result in the soil degradation. Only due to the use of mineral nutrition, it is impossible to maintain a high level of soil fertility. To compensate for the lack of humus, the most optimal is the use of green fertilizers. The costs of producing and applying cover crops are significantly less than the costs of using organic fertilizers. In terms of peasant farms conditions in the Tambov region, two types of crop rotations with the introduction of sideral crops are recommended. It is important to carry out grinding and embedding of sideral crops specifically so that it can provide optimal parameters for the decomposition of organic mass and promote humus formation. Currently, four processing techniques are used for harvesting and embedding sideral crops. The recommended scheme involves mowing and step-by-step grinding of the grass stand with a mower-shredder located in front of the tractor, followed by embedding in the soil with a disc harrow. The analysis shows that small producers segment has no affordable machines for high-quality grinding of sideral crops with low specific energy consumption. To ensure stems cutting with minimal specific energy consumption, a mower has been developed, which, due to the trough-shaped type of its body, forms plants tilted forward in a mass and then, they fall into the grinding zone with the angle of inclination of the stems in this mass close to the angle of body inclination. In the grinding zone, the plant stems are exposed to knives rotating in plane surfaces perpendicular to the longitudinal surface of the mower body. As a result of operational tests of the mower-shredder of sideral crops and crop residues, it was found that technological process of plants grinding is carried out steadily and with a quality that meets agrotechnological requirements.

1. Introduction

The decline in soil fertility is a major challenge for both Russian and global agriculture. Low intake of organic matter in the soil and frequent cultivation lead to soil degradation. To provide the population with food, it is necessary to constantly increase the productivity of agriculture [1–4].

The importance of maintaining a positive balance of humus in soils is recognized by both agricultural producers and executive authorities. Calculations show that the balance of nutrients in arable soils of the region at the actual level of mineral and organic fertilizers is reduced to a significant deficit: nitrogen – 42.6 %, phosphorus – 57.9%, potassium – 80.4% [1, 5]

It is impossible to keep and maintain a high level of soil fertility only through the use of mineral nutrition and increased mechanical impact on the soil without the use of organic fertilizers [2, 6–8].
However, as a matter of fact, low volumes of organic fertilizer application, non-compliance with crop rotations lead to a negative balance of nutrients in the soil, a decrease in natural fertility, which reduces the gross harvest and yield of agricultural crops [2, 5]. The relevance of the issue under consideration is confirmed by studies that indicate an increase in the humus content in the soil by 1% on average per year increases the productivity of arable land by at least 10 centners of forage unit / ha [9]. Therefore, at the present stage of development, maintaining a positive balance of humus is an urgent problem in Russia and around the world.

2. Materials and methods
The decrease in the number of cattle in the Tambov region more than 2 times over the past 15 years has sharply reduced the amount of manure introduced. And the increase in the number of poultry and pigs is unable to compensate for the loss of organic matter [10] due to the complex and costly process of processing and application of bird droppings and pig manure. [11, 12] (Figure 1). According to Rosstat, over the past 15 years, the number of organic fertilizers introduced by agricultural enterprises of the Tambov region has decreased by more than 2.5 times [9].

In modern conditions, the use of sideral crops is one of the most optimal and affordable means to compensate for the lack of humus (Figure 1). [2, 8, 13].

The use of cover crops in crop rotations ensures the supply of nitrogen (between 170 and 400 kg/ha), phosphorus (between 40 and 90 kg/ha), potassium (between 110 and 310 kg/ha) to the soil, which is equivalent to the introduction of 40-90 t/ha of litter manure for nitrogen, 25-45 t/ha for phosphorus and 25-55 t/ha for potassium [14].

At the same time, the costs of their production and usage are 3-4 times less than the application of organic fertilizers [13]. Green fertilizers play a significant role in accumulation and preservation of productive moisture, increase microbiological activity of the soil, reduce soil compaction and plant disease, ensure the reproduction of soil fertility and increase crop yields. [2, 7, 8, 13].

The decomposition of phytomass of green manure fumes cultures is characterized by a number of features. First, the plowed green aboveground biomass contains a lot of moisture (75-80%), which is especially important in the conditions of moisture shortage in the Central chernozem region during summer. Secondly, the green phytomass of cover crops contains significantly less difficult - to - decompose compounds (lignin, cellulose) than mature plants, and more easily accessible to microorganisms (mono- and disaccharides, proteins). Finally, the time of plowing of phytomass of cover crops can be attributed to the period when the soil still contains significant moisture reserves of autumn-winter precipitation [2, 7, 13].
Various soils require a diversified approach to the preservation of fertility. Therefore, it is impossible to provide universal recommendations for maintaining a deficit-free balance of humus, reflecting the diversity of local conditions [2, 15, 16].

It is necessary to develop zonal technologies aimed at preserving soil fertility and improving their physical and mechanical properties.

3. Results and Discussion

One of possible solutions to this problem is the introduction of sideral crops into the existing crop rotation structures. Variants of such crop rotations relating to the conditions of peasant farms in the Tambov region are presented in Table 1.

| Table 1. Recommended crop rotation structure |
|--------------------------------------------|
| **Four-field crop rotation** | **Crop rotation with pasture feed wedge** |
| 1. Preceding crops of winter crops (green manure fume) | 1. Preceding crops of winter crops (green manure fume; vetch+oats) |
| 2. Winter crops (wheat, rye) | 2. Winter crops (wheat for grain, rye for forage grass, grain legumes) |
| 3. Row crops (sunflower, sugar beet, corn for grain) | 3. Barley + perennial herbs |
| 4. Spring grain crops (barley, spring wheat, oats, cereal crop, grain legumes), if necessary, one can place row crops on this field | 4. Perennial herbs |
| 5. Perennial herbs | 5. Perennial herbs |
| 6. Corn for silage; corn for grain | 6. Corn for silage; corn for grain |
| 7. Corn for forage grass, postcut oil seed rape; fodder root crops | 7. Corn for forage grass, postcut oil seed rape; fodder root crops |

There are two main recommended ways of using sideral crops: full, when the sideral plant that has reached a certain stage of growth is completely plowed, and partial, when the sideral crop gives one or more mowing for forage, and the overgrown after-grass is plowed for green fertilizer [15].

The task of cover crops is not only to enrich the soil with organic matter, but also to bring the equilibrium density of the arable layer of chernozems of heavy loamy granulometric composition for plants, which varies within the following limits: optimal – 1.10-1.25 g/cm$^3$; permissible – 1.25-1.35 g/cm$^3$; critical – more than 1.35 g/cm$^3$; within limits – 1.0-1.3 g/cm$^3$. This ensures the best root growth, the formation of optimal water, air, heat and nutrient regimes of the soil [15]. For this purpose, it is essential to ensure such grinding and embedding of sideral crops, which would allow achieving optimal parameters of organic mass decomposition promoting humus formation.

Studies have shown that soil density is largely determined by the methods of tillage practice (table 2). [1, 15, 16, 17].

| Table 2. Soil density at different soil tillage methods, g / cm$^3$ |
|--------------------------------------------|
| Tillage methods | Soil layer, cm |
|                | 0-10 | 10-20 | 20-30 |
| Plowing        | 1.24 | 1.34  | 1.27  |
| Tillage by AKP -2.5 | 1.17 | 1.27  | 1.28  |
| Disk harrow BDT-3 | 1.17 | 1.27  | 1.28  |

The review of the most widely used technologies for grinding and embedding sideral crops is presented in Figure 2.

Currently, several tillage techniques are used for grinding and embedding sideral crops.

The 1st scheme – plowing with molboard plows that almost completely eliminates the grinding of sideral crops [2, 18].

The 2nd scheme [2, 18] involves cover crops grinding, including the use of non-specialized machines, but the subsequent embedding due to plowing with molboard plows results in additional
compaction of the soil, which negatively affects the physical and mechanical properties of the soil, and optimal degree of cover crops grinding is also in doubt.

The 3rd scheme [2, 18] involves insufficiently high-quality grinding of cover crops, as well as compaction of soils as a result of machines double run.

In our opinion, the 4th scheme [2, 18] is preferable, due to the use of combined units that allows optimal grinding and embedding sideral crops with a single run of the machines.

Figure 2. Technologies of shredding and embedding of cover crops

However, option 4a provides for the use of expensive foreign trailed machinery, which, firstly, is not always affordable to small and medium-sized agricultural enterprises, and, secondly, increases the energy intensity of the shredding process as a result of jamming shredded grass by the mulcher following the tractor.

We recommend scheme 4b, which involves mowing and step-by-step grinding of the grass stand with a mower-shredder located in front of the tractor, followed by embedding in the soil with a disc harrow.

The analysis of machines offered on the market shows that in the segment of small producers there are practically no available machines for high-quality grinding of sideral crops with low specific energy consumption. [2, 8].

The ISN-2.2-1 mower-shredder proposed by scheme 4b (Figure 2) [18, 19] in an aggregate with MTZ-80L tractor and a disc harrow works as follows. During the forward movement of the tractor with the mower, plant stems bend forward in the direction of movement with the front part of the deflected back body, due to the trough-shaped type of the body, plant stems form into a mass of plants tilted forward and fall into the grinding zone with the angle of inclination of the stems in this mass close to the angle of body inclination. In the grinding zone, plant stems are exposed to knives rotating in plane surfaces perpendicular to the longitudinal surface of the mower body. Thus, the most rational method of cutting is provided – across the stems with a minimum cutting area. The design of the body allows quick removal and assembling of cutting knives and does not prevent the passing of shredded particles.
Figure 3. Mower-shredder of sideral crops and crop residues ISN-2.2-1 combined in the unit with the tractor MTZ-80L

4. Conclusion
As a result of real-life tests (Figure 3) of the mower-shredder of sideral crops and crop residues ISN-2.2-1 [18, 19] in the unit with the tractor MTZ-80L, it was found that the technological process of grinding plants is carried out steadily and with a quality that meets agrotechnological requirements, at the same time the cutting length was between 20 and 60 mm, the productivity – 1.7...2.3 ha/h. Fuel consumption – 5.8...7.6 kg / ha.

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