Problems and Ways of Straw Use in Ecologically Friendly Agriculture Use of Straw in Ecological Agriculture

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Abstract: In the system of ecological farming, new methods and techniques for enriching the soil with organic matter, including straw, as by-products of grain crops, which account for more than 50% of the sown area, are widely used. A some-year-long experience studied the use of straw both in Russian and foreign practice, shows that physiologically active substances in the presence of nitrogen in the soil quickly decompose in the soil and straw fertilizer does not increase clogging. Moreover, the decomposition of straw depends on many reasons: temperature, humidity, fertilizer, soil biota, its abundance, specialization and compaction. With an increase in the share of mineral fertilizers, the enzyme complex of the soil is activated. When using anhydrous ammonia, the number of bacteria involved in the transformation of nitrogenous substances of the soil increases. In any form, nitrogen fertilizers enhance the development of nitrifying microorganisms, weaken negatively affecting ammonifiers. Thus, in its effect on the humus content in the soil, straw can compete with manure. The use of straw as an organic fertilizer is an important reserve for increasing productivity and stabilizing soil fertility, which should be more actively used in ecological farming.

Keywords: straw, use of straw, ecological farming, green manure, fertilizers.

1. Introduction

Structure of the sown area in the country is more than by 50% occupied by crops, by-products of which (straw) are used very poorly and are burned to a large extent. Research conducted in the first half of the twentieth century led to a change in outlook on the use of organic fertilizers. There was a desire to find a new form of providing soil with organic matter. The burning of stubble and straw, which is widely used to prepare the soil for further cultivation, from the point of view of ecological farming is not only unprofitable, but also harmful and should be abandoned.

As for ecological farming, any by-products of crop production, especially straw, should be correctly and efficiently used to increase not only productivity, but also soil fertility. There is clearly insufficient evidence on the effect of straw as a fertilizer on soil structure. Thus, in a 6-year experiment (H. Schaeffer, I. Eckoldt, 1960) it was established that the water resistance of soil aggregates was the same both after the introduction of straw and after the introduction of manure [1]. The precursor was more influential here than straw. In other experiments, when using straw, the soil quickly reached physical ripeness, and the stability of soil aggregates increased.
The effectiveness of straw as a fertilizer increases if it is applied in combination with appropriate doses of mineral fertilizers, with green manure, with slurry; in its effect on the content of humus in the soil, it can quite compete with manure. Thus, the introduction of slurry with slurry together with the stocking of chopped straw increases the humus content as well as even higher than with straw manure (H.D. Patterson H.D. 1960 [2]; W. Sauerlandt, 1960 [3]).

2. Literature Review

The study of straw as fertilizer began in the 18th century. In 1808, Humphrey Devy (England) pointed out the possibility of burying fresh straw as fertilizer [4]. Later it became known about the negative impact of straw on the crop. The reason for this has also become clear - the use of soil nitrogen by microorganisms that assimilate and convert mineral soil nitrogen into organic form. Peterson in 1936 came to the same result [1].

It has been established that physiological active substances are released during straw decomposition, which negatively affect seedlings of the subsequent culture. Extracts from straw in the Witer's experiments restrained the development of wheat seedlings [5]. According to Shenbek and Klap, even soil extracts from the plots where straw was burying negatively affected the root system [6]. Oat straw was more toxic than winter rye straw. Physiologically active substances decompose quite quickly in the soil, especially when nitrogen is present in the soil. Fertilizer with straw does not cause an increase in clogging [5].

3. Materials and Methods

The chemical composition of straw is largely determined by the nature of soil and climatic conditions. Studies have shown that the yield of non-forage cereal straw 2.5-3.0 t/ha contains an average 12-15 kg of nitrogen, 7-8 kg of phosphorus, 27-30 kg of potassium, 5-6 kg of magnesium, about 5 kg sulfur, as well as various trace elements such as boron, copper, manganese, molybdenum, cobalt. The above plant nutrients and natural soil resources, with the exception of nitrogen, satisfy the need of plants for them to obtain a grain yield exceeding 20 centner/ha [7, 8].

4. Results

In recent years, some countries have been increasing attention to the harmful effects on subsequent crops of straw embedded in the soil. In the USA, the causes of the sometimes harmful effects of stubble mulching have been studied. The researchers concluded that a possible cause could be the formation of high concentrations of phenolic acids in decaying plant residues. Australian researchers showed that extracts prepared in cold water from wheat straw, decayed for up to 6 weeks at different times, depressed the development of wheat and oats, grown under aseptic conditions. The degree of inhibition depended on the duration of the ripening and was the greatest one when the straw decomposed within 26 days. Prolonged storage of straw or weathering of wheat stubble in the field reduced this inhibitory effect. Experiments in Western Australia showed that 4% emerged from the seeds of wheat sown 6 mm below the layer of oat straw; if the seeds were sown 6 mm above this layer, the germination rate was 47%, while in the control plots without straw it increased to 88%.
These findings were confirmed by work carried out in the UK, which indicates that under certain conditions some toxic substances are formed from the remains of crop decomposing in the vicinity of seedlings.

These results are of great importance when cereals are sown after cereals and with minimal processing [9].

The British found that the negative effect of fragrant straw on seedlings is not due to a nitrogen deficiency in the soil, but to the inhibitory effect of acetic acid, which is formed by the decomposition of straw under anaerobic conditions. Therefore, chopped straw should be embedded in the topsoil, as recommended by I.E. Ovsinsky also received a positive effect without the use of nitrogen [10].

In recent decades, agricultural science and practice, both abroad and in Russia, have paid increased attention to straw introduction into the soil as the most rational way of using it. In some countries, straw fertilizer has in many cases already been widely used. So, mulching with straw is used to protect soils from erosion and evaporation of water, and in South Africa, straw, most often corn, is not removed from the fields, and is often crushed and smelled only before sowing.

The experiments conducted abroad showed different responsiveness of crops to the application of straw in the soil. Of the row crops, potatoes and then sugar beets respond better to straw than others (S. Borbjer, 1962 [11]; R. Kampf, 1966 [2]).

In other long-term experiments (H. Ansorge, 1967 [12]; Schaeffler H., Eckoldt I., 1960 [13]; J. Kohnlejn, H. Vetter, 1958 [5]), which were carried out on soils with different mechanical compositions with the annual introduction of straw with nitrogen fertilizers and manure, there was no difference in the degree of influence of these fertilizers on the yield of ears and row crops. Even without the introduction of additional mineral nitrogen, the fertilizing effect of straw on potato yields was not inferior to that of the introduction of manure (E. Klapp, 1961 [6]).

At present, it is generally recognized that for more complete processing of straw by microorganisms, it is necessary to make at least 10 kg of nitrogen fertilizers per every ton of straw. These costs frightened off the producers, and they preferred to get rid of the straw by burning or storing it outside the field.

In France, Sweden, Switzerland, Germany, the use of straw directly for fertilizer gives not only an increase in yield and increases soil fertility, but also frees from the high costs of its collection and transportation. For example, in Germany, it is believed that labor and cash costs for harvesting with this method of using straw are reduced by 60%. The direct use of straw for fertilizer by about 8 times reduces labor costs compared with the preparation and introduction of straw manure.

As for methods of using straw there is a single opinion neither in foreign no in Russian science. More than a century ago, two technologies for the use of straw were developed in Europe.

The first one is:

1. Straw is crushed during harvesting.
2. Straw is buried late in autumn or early in the spring.
3. Plowing is combined with fertilizer application. According to the second technology, crushed straw is buried immediately and at the same time with crop sowing. A study of straw embedment depth has led to the conclusion that shallow embedding is advantageous. According to foreign authors, cereal straw consists by 33-35\% of cellulose, 21-22\% of hemicellulose, 18-21\% of lignin, 3.0-4.7\% of protein, 4.3-5.5\% of ash. The process of decomposition of straw is faster at a ratio of C:N - 30-40:1.

The rate of microbial decomposition of straw in the soil is determined by many factors: the presence of food sources for microorganisms in the soil, their abundance, species composition and activity, soil type, cultivation, temperature, humidity, aeration.

5. Discussion

In the experiments of S.A. Vorobyov (1979) [14] on the sod-podzolic soil of central regional Russia with the stocking of straw, the yield of potatoes and barley did not change significantly; without making 10 kg of nitrogen per 1 ton of straw, there was a tendency to a decrease in productivity in potatoes by 2.7\%, in barley by 3.9\% and to increase it with the addition of nitrogen (respectively, by 8.1 and 10.9\%). The positive effect of straw as an organic fertilizer was noted in the experiments of the Ukrainian Research Institute of Irrigated Agriculture (URIIA), where rapid straw decomposition was observed, which is explained by the influence of optimal moisture, which contributes to intensive microbiological activity.

In the URIIA experiments on soddy-podzolic heavy loamy soil, the application of crushed winter wheat straw at a rate of 4 t/ha for potatoes in autumn for autumn plowing did not reduce the yield of potatoes, but increased the yield of the subsequent barley culture by an average of 2.4 c/ha over 2 years.

A further study of straw as a fertilizer recorded a different reaction of field crops to this agricultural practice. When cultivating row crops, as well as spring late sowing, as a rule, they get a high positive result. When sowing winter crops after planting spiked straw, the increase in yield was weak. These results are easily explained by the degree of decomposition of straw by microorganisms before the growth of subsequent crops.

S. Ya. Polyansky (2000) [15], referring to S.S. Sdobnikova, provides data on the effectiveness of plowing straw as a source of replenishment of organic matter in the Non-Black Earth Zone. In the best case study, when plowing 7 t/ha of chopped straw and 60 kg of nitrogen – there was an increase in barley yield of 2.5 c/ha, green mass of corn of 37 c/ha, winter wheat grains of 1.3 c/ha were obtained with nitrogen.

To stabilize and replenish humus stocks, farms of the Ryazan Region are recommended to make wider use of sideral crops - clover, white mustard, and rapeseed.

In the Tambov Region, on the black soil typical of a perennial hospital, in the 10-field steam-grain-row-crop rotation, the effect of various fertilizer systems and the use of by-products of field crops on yield and fertility were studied. The highest yields of vetch-oat mixture, green mass of corn and winter rye grain with application of 40 t/ha of litter manure once per rotation and optimal doses of NRK for the corresponding crop. Yield increments from the introduction of 40 tons of manure and equivalent doses of mineral fertilizers were almost the same. Only the yield of green mass of corn was slightly higher
on the background of mineral nutrition compared with organo-mineral, which the authors explain the moisture deficit in 1997 and 1998 and lower rates of decomposition of organic matter [16].

Fertilizer systems and the use of by-products in the background without fertilizing affected the humus content in the arable layer. Its greatest decline was in 1996 and 1997 compared with the original (1990) content at burning of stubble and crop residues. When stubble and crop residues were smelted, the decrease in humus content was less significant.

On the options with the introduction of manure, doses of mineral fertilizers, the loss of humus was less. So on the options with the introduction of only 40 t/ha of manure for rotation, there was a weak tendency to decrease in humus.

In general, the following conclusions can be drawn from experience: stubble burning contributed to the maximum loss of humus even with the combined application of organic and mineral fertilizers. Smelling stubble reduced the loss of humus, but did not exclude them. When straw is smelted, even without fertilizer, humus is stabilized.

The burying of stubble, crop residues and by-products (straw) against the backdrop of organic, mineral, and organo-mineral fertilizers contributed to an increase in humus content.

So the 12th experiment (sizing of all by-products + bedding manure 40 t/ha for rotation + NRK equivalent to their content in the dose of manure + optimal doses of NRK) showed the humus content in field №1 increased from 7.63 (initial content) to 7.82%; in field №2 from 7.33 to 7.55%; in field №3 from 7.94 to 8.11%.

Observations showed that a more intensive decomposition of straw and crop residues occurs in the soil layer of 0-10 cm. The best results were obtained with the introduction of mineral, as well as with their combination with manure (40 t/ha). The introduction of only manure without mineral fertilizers had a weak effect on the degree of decomposition of straw.

Microbiological studies have shown that burning stubble stably reduced the number of microorganisms in the soil. So, in option 1 (stubble burning, without fertilizing) the number of bacteria on beef-extract agar was 4 times less than in option 12, bacteria on starch-and-ammonia agar were 2.0-2.2 times less, actinomycetes 1.8-2.0 times less.

The burying of stubble, crop residues, and straw contributed to an increase in the content of available nutrients (ammonia nitrogen, available phosphorus, and exchange potassium). In this case, the straw should be well chopped, distributed and scented more carefully than other organic fertilizers, especially on heavy soils. The most favorable is the small embedment of straw into the soil (mulching, peeling), since in the upper layers of the arable horizon it decomposes faster, and existing weeds are provoked and destroyed by subsequent treatments.

The timing and intensity of decomposition of straw in the soil is largely determined by the degree of grinding, which is associated with an increase in the area of contact with the soil. For grinding straw, various devices are used: PUN-5, which is installed on the SK-5 combine, or a grinder 65-136 on the SK-6-11 combine.
Many authors noted that without the introduction of additional nitrogen, the depressive effect of a large straw amount increases [10, 17–20]. For example, in the experiments of the Krasnodar Research Institute of Agriculture named after P.P. Lukyanenko obtained the following data (Table 1).

**Table 1.** The effect of systematic straw application on winter wheat productivity

| Experience option | Unfertilized background | Fertilized background |
|-------------------|-------------------------|-----------------------|
|                   | Productivity, c/ha     | Increase of productivity | Productivity, c/ha | Increase of productivity |
|                   | c/ha | %   | c/ha | %   |
| 1. The introduction of 5.0 tons of straw per 1 ha | 26.6 -1.5 -5.3 | 49.0 +1.6 +3.4 |
| 2. The introduction of 5.0 tons of straw per 1 ha + N₅₀ | 32.0 +3.9 +13.9 | 49.0 +1.6 +3.4 |
| 3. Control       | 28.1 - - | 47.4 - - |

The introduction of nitrogen and 5 t/ha of straw against the background without fertilizers and fertilized increased the yield by 13.9 and 3.4%, respectively.

When various types of straw are introduced into the soil, the rate of its decomposition is different, which is explained by the unequal content of nitrogen in it. The more nitrogen in the straw, the more intensively it decomposes. Least of all nitrogen enters the soil when winter wheat and rye straw are added, slightly more when oat is added, 1.5 times more when millet is applied and 2 times as pea. However, given that oat and millet straw have the best nutritional advantages, soil should be fertilized mainly not with fodder, but with rye and wheat straw [21].

It is better to introduce straw before sowing or shortly before sowing spring grain and row crops in the upper soil layer. In the presence of moisture in the early period and sufficient aeration, it decomposes faster and organic acids harmful to plants do not form.

The methods of introducing straw under spring row crops must be coordinated with the accepted methods of tillage. The best depth and time of embedding straw, methods of accelerating its decomposition should not, in general, contradict, but supplement the accepted agricultural technology of agricultural crops.

The systematic application of straw and mineral fertilizers reduced the density of the soil and increased its overall porosity. The lowest equilibrium soil densities were observed with the combined application of straw and mineral fertilizers, which decreased by 0.4 and 0.11 g/cm³, respectively, compared with the control. At the same time, there was an increase in the number of water-resistant units (> 0.25 mm).
In the field of Bashkirtia, the introduction of 3 t/ha of chopped pea straw and the average doses of organic and mineral fertilizers adopted there did not negatively affect the structural-aggregate composition, water-physical properties and water regime of a typical chernozem. With the combined introduction of manure and straw, the content of water-resistant aggregates increased somewhat compared with the control, and with the introduction of NRK it stabilized at a certain level.

Observations of the dynamics of microflora showed that the number of microorganisms was not the same and depended on the time of straw incorporation. When straw was introduced in the fall, the maximum number of bacteria was observed in September and October, and in the spring fell on May and June, i.e., when autumn straw was introduced (early August), the primary processes of decomposition of organic matter before sowing spring wheat or another crop were intense and its negative effect as substances with a wide ratio of C:N did not appear. When straw is introduced as early as possible, its effectiveness as fertilizer increases sharply at all doses and depths of incorporation.

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When cereal straw is introduced into the soil due to the low nitrogen content in it, the degree of fixing it with microorganisms must be taken into account until the C:N ratio in fresh straw from 100:1 decreases to 20:1. Upon reaching this degree of decomposition, the nitrogen used by microorganisms is mineralized and becomes available again for plants. If the mobilization of nitrogen in time coincides with the period of assimilation of nutrients by cultivated non-leguminous cultivated plants, then the latter may lack nitrogen. Therefore, in advance it is necessary to make mineral nitrogen fertilizers. According to experiments, the rate of nitrogen fertilizer application ranges from 0.7 to 1.3 kg of nitrogen per 1 centner of straw.

The intensity of decomposition of straw by microorganisms in the soil is determined, first of all, by its chemical composition. The bulk of the straw of most cereals is represented by fiber, lignin and pentosans. First of all, the most accessible components of straw decompose, namely pentosans, simple sugars, proteins. At this time, a large group of non-spore-forming bacteria, mainly of the genus *Psuedomonas*, as well as mucous and pycnidoid fungi develop. Later, fungi of the genus *Mucor, Aspergillus* are included in the decomposition of straw; then *Bacillus* decomposing pectin substances: *Bac. Surilis, Bac. mesentericu*.

Extensive experiments conducted on typical chernozems in the Tambov Research Institute of Agriculture [22] showed that only when stubble, straw, and sugar beet tops were sown in the crop rotation link did the humus content stabilize, and when mineral and organomineral fertilizers were introduced, tendencies to increase humus; the process of decomposition of straw most intensively occurred in the upper layers of the soil and with a high supply of moisture on options with the introduction of mineral nutrition; burning of stubble significantly reduced the number of microorganisms in the soil compared with the smell of stubble and by-products (1.5–2 times). The greatest number of microorganisms was observed against the background of straw scrubbing on options with the introduction of mineral and organo-mineral fertilizers [22, 23].

The chemical composition of cereal straw is characterized by a high content of nitrogen-free substances (cellulose, hemicellulose, lignin) and a rather low content of protein.
(nitrogen) and minerals. The lack of nitrogen for the synthesis of cellular protein by microorganisms can inhibit the decomposition of straw with the rapid consumption of available soil nitrogen by cellulose-depleting microflora, which can negatively affect yield. With various sources of nitrogen, the intensity of cellulose destruction increases, the yield of humic substances increases, and the process of their synthesis and mineralization accelerates. Cellulose is destroyed 5-6 times more actively compared to control when adding ammonia and nitrate salts.

On soils poor in phosphorus, the additional introduction of phosphorus together with straw accelerates its decomposition, while the processes of ammonification and mineralization of organic phosphorus are intensified.

Calcium cyanamide accelerates the decomposition of straw.

The introduction of trace elements (Mn, Mo, B, Cu) also stimulates the process of cellulose decomposition. The most intensively is the bio-fixing of cellulose microorganisms B, Mn.

The rate of decomposition of cellulose is largely determined by the types of soil, the characteristic composition of cellulose-decomposing microflora is not the same for different types of soils and varies depending on the content of organic matter, physical, chemical properties of each soil. The rate of fiber decomposition is determined by latitudinal zonality and increases in the genetic sequence of soils from podzols to sod-podzolic, gray forest soils and chernozems. The greatest cellulose activity is possessed by microorganisms isolated from black soil, reddish-brown forest soil; the least activity is observed in microorganisms isolated from the ash gray soil.

Cellulose-decomposing bacteria develop poorly in acidic soils, preferring neutral and slightly alkaline. Fungi predominate in the composition of fiber-degrading microorganisms on more acidic infertile soils. The most active destruction of fiber is observed at optimal temperatures of +280°; +300°. At low temperatures (less than + 80 °C) and at high (more than + 550 °C), the decomposition of cellulose is suspended [20].

Currently, studies are being conducted on the effectiveness of ASD (activator of stubble decomposition) and ASM (activator of soil microflora). Thus the experiments of the Oryol State Agricultural University (conducted by Yu.V. Basov, 2002) established the following regularity: the introduction of ASD increases the activity of microflora by 8-25%, the introduction of AMS - by 10-29%, and the combined introduction of these drugs - by 19-33% ; the introduction of straw without APC increased buckwheat productivity by 2%, and in the ASD variant, straw + ASD + AMS increased by 9.5% [16].

The largest increase in buckwheat yield (44.5%) was obtained by adding 5 t/ha of straw + ASD + AMS to a fertilized background (NRK). To process straw, microorganisms themselves must be provided with elements of mineral nutrition.

6. Conclusion

The decomposition of straw depends on many reasons: temperature, humidity, fertilizer and, most importantly, on soil biota, its abundance, and specialization. In chernozem soils, compaction has a particularly strong effect on the number of microorganisms. So, a change in soil density from 0.9-1.0 to 1.17-1.23 g/cm³ reduces 1.5-2 times the number of cellulose-degrading microbes, 3 times actinomycetes, and 30% nitrification. In a crop
rotation during processing by 30-35 cm, humus decreases at a speed of 2.2-2.5 t/ha, the microbial load increases 3 times. To stabilize the humus content during treatments of 20-22 cm/ha of arable land, it is necessary to add 4 tons of organic matter. With an increase in the share of mineral fertilizers, the enzyme complex of the soil is activated. When using anhydrous ammonia, the number of bacteria involved in the transformation of nitrogenous substances of the soil increases. In any form, nitrogen fertilizers enhance the development of nitrifying microorganisms, weaken negatively affecting ammonifiers. Anhydrous ammonia depresses the vital activity of free-living nitrogen-fixers and, in particular, nitrogen-bacteria (1.7 times), the number of soil fungi decreases. Ammonium nitrate causes less noticeable changes in soil biota, so its introduction is especially desirable when smelling stubble and straw.

Based on the foregoing material, it follows that the use of straw as an organic fertilizer is an important reserve for increasing productivity and stabilizing soil fertility, which can and should be used in ecological farming. It should be remembered that the effectiveness of straw as an environmentally friendly fertilizer can be significantly increased by embedding straw section in the top soil layer to a depth of 10-15 cm; burying it if possible 4-5 weeks after harvesting; introduction of compensating doses of nitrogen (10 kg per 1 ton of straw), preferably in ammonium form.

References

(1) Patterson, H. D. An Experiment on the Effects of Straw Ploughed in or Composted on a Three-Course Rotation of Crops. *The Journal of Agricultural Science* **1960**, *54* (2), 222–230. https://doi.org/10.1017/S0021859600022395.

(2) Kampf, R.; Weichert, K. Untersuchungen über die wirkung der Strohdungung auf die Bodenkrumelung (in German). *Landwirtschaftliches Jahrbuch für Bayern* **1966**, *43*, 701–711.

(3) Sauerlandt, W. Werd und Wirung gütter Strohdecken auf dem Ackerbaden (in German). *Mitt. DLGB* **1960**, *75* (29), 915–916.

(4) *The Collected Works of Sir Humphry Davy*; Davy, J., Knight, D., Eds.; University of Durham, Thoemmes Press: Bristol, 2001; Vol. 9.

(5) Vetter, H. Strohverwertung und Humusversorgung (in German). *Landwirtschaftsverlag Münster* **1958**, *87*, 115–118.

(6) Klapp, E. Die Humuswirkung (in German). *Deutsche Landwirtschaftliche Presse* **1961**, *42*, 430–431.

(7) Cherepukhina, I. V.; Bezler, N. V. The Use of Cereal Straw. The Use of Cereal Straw with Humicola Fuscoatra VNIISS 016 to Increase the Crop Productivity of Arable Crop Rotation (in Russian). *Zemledeliye (Agriculture)* **2018**, *1*, 35–41.

(8) Cherepukhina, I. V.; Bezler, N. V.; Kolesnikova, M. V. Dependence of the Efficiency of Usage Straw of Cereal Crops with Additional Components on the Weather Conditions of the Year (in Russian). *Agrochemistry* **2019**, *6*, 64–71.
(9) Maslov, G. G.; Malashikhin, N. V.; Lavrentyev, V. P. Effective Ways to Reduce Soil Com-Paction to Preserve Its Fertility (in Russian). *Polythematic Online Scientific Journal of Kубан State Agrarian University* 2019, 146 (2), 24–37. https://doi.org/10.21515/1990-4665-146-003.

(10) Ovsinskiy, I. E. New farming system (in Russian), Reprint of the publication of 1899 (Kiev, publishing house S.V. Kulzhenko; AGRO-SIBERIA: Novosibirsk, 2004.

(11) Borbier, S. Arbeitsverfahren bei der Strohdungung (in German). *Der Fortschrittliche Landwirt* 1962, 40, H. 15 8 67.

(12) Ansorge, H. Untcrsuchungen Über Die Wirkung Iangjähriger Strohdüngung Bei Unterschiedlichen Stickstoffgaben (in German). *Archives of Agronomy and Soil Science* 1967, 11 (1), 49–58. https://doi.org/10.1080/03650346709413731.

(13) Schaeffler, H.; Eckoldt, I. Einflub verschiedener Formen der Stroh und der Stallmist dungung auf Bjdefruchtbarkeit und Bodenleistung (in German). *Landwirtschaftliches Jahrbuch für Bayern* 1960, 37, 325–347.

(14) Vorobyov, S. A. Crop Rotation of Intensive Farming (in Russian); Kolos: Moscow, 1979.

(15) Polyansky, S. Ya. Ways of Agriculture Stabilization as an Object of Management (in Russian). In *Anniversary collection of scientific works of the Ryazan SRPTi AIC*; Ryazan State Agrotechnological University: Ryazan, 2000.

(16) Basov, Yu. V. The Use of Elements of Biologized Technologies in the Cultivation of Buckwheat in the Conditions of the Oryol Region (in Russian). Abstract of PhD thesis, Oryol, 2002.

(17) Gvozdov, A. P.; Bulavin, L. A.; Pyntikov, S. A.; Sinitskiy, V. P. The Influence of Precursor Straw and Methods of Soil Cultivation on Grain Productivity of Various Winter Wheat Varieties (in Russian). In *The collection: Scientific innovations - agricultural production materials of the International scientific-practical conference dedicated to the 100th anniversary of the Omsk State Agrarian University*; 2018; pp 99–102.

(18) Gladysheva, O. V.; Svirina, V. A. Elements of Technology of Reproduction of Soil Fertility (in Russian). *Agrarian science* 2019, 330 (7), 43–46. https://doi.org/10.32634/0869-8155-2019-330-7-43-46.

(19) Zelenev, A. V.; Seminchenko, E. V. The Use of Field Crop Straw as an Organic Fertilizer in the Cultivation of Sorghum for Grain in the Volgograd Region (in Russian). In *Modern trends in the scientific support of the agricultural sector of the Upper Volga region: Collective monograph: in 2 volumes*; Upper Volga Agrarian Scientific Center: Ivanovo, 2018; pp 303–311.

(20) Lazarev, V. I.; Bashkatov, A. Ya.; Minchenko, Zh. N.; Rusakova, A. A. The Effect of Microbiological Preparations on Straw Destruction and Sugar Beet Yield under the Conditions of Chernozem Soils in Kursk Region (in Russian). *Agrarian Science* 2019, 323 (3), 34–37. https://doi.org/10.32634/0869-8155-2019-323-3-34-37.
(21) Skirukha, A. Ch.; Gribanov, L. N.; A.A, U. Economic Balance of Nitrogen in Field Crop Rotation Depending on the Structure of Crops and the Use of Straw (in Russian). Zemledeliye i selektsiya v Belarusi (Agriculture and Selection in Belarus) 2019, 55, 4–9.

(22) Vanyushin, P. N. The Influence of Fertilizers and By-Products of Field Crops on the Yield and Fertility of a Typical Chernozem in the Link of Grain-Crop Rotation in the Tambov Region (in Russian). Abstract of PhD thesis, Ryazan, 2000.

(23) Naimi, O. I. Peculiarities of Using Straw as an Organic Fertilizer (in Russian). International Journal of Humanities and Natural Sciences 2019, 9 (1), 10–13.

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