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Research Article

Influence of Rice Straw Utilization Methods and Biological Humifiers on Nutrient Status of Soil

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ABSTRACT:

The present paper proves the high efficiency of rice straw as an organic fertilizer, both in pure form, and in combination with compensating nitrogen fertilizer and biological products. Upon adding to the soil of 6.9 t/ha of shredded straw, the content of exchangeable ammonium in the 0-20 cm soil layer increased during vegetation by 7.4% on average, compared with the option without straw, while the mobilizing effect of decomposing straw was gradually increasing while approaching the phase flowering. Additional application of urea in the amount of 1% of straw weight increased its mobilizing effect by 8.4%. The content of mobile phosphates during the addition of straw increased on average during vegetation by 9.3%. The greatest mobilizing effect of straw was manifested in the content of exchangeable potassium, which increased on average during vegetation by 12.3%.

Keywords: Rice, Straw, Nutrient Status of Soil

INTRODUCTION

Grassfields and chernozem soils have a fairly high fertility potential, but much of the nutrients in the soil are in the form of complex organic or insoluble mineral compounds and therefore cannot be absorbed by plant roots. At the same time, the applied system of rice fertilizer and the technology of its cultivation in general have a significant impact on the factors that play an important role in the regulation of the nutritional status [1].

The usage of organic fertilizers activates the vital activity of soil microorganisms, thereby increasing the availability of basic nutrients and improving the conditions for their absorption by rice, which contributes to a higher yield [2-4].

The need to apply organic fertilizers for rice is dictated by the high dehumification rate of rice soils, which is 0.94 t/ha per year [5], due, among other things, to the widespread burning of straw.

The method of utilization of by-products of the precursor significantly affects the course and direction of soil processes, in particular, the nitrogen status of the soil. Namely, the risks associated primarily with the biological immobilization of nitrogen increase; the degree of immobilization significantly depends on weather conditions, the quantity and physicochemical properties of crop residues, the way they are embedded in the soil [6].

The presence of a large amount of plant residues in the soil reduces the rate of mineralization of humus and inhibits the transfer of organic nitrogen compounds into inorganic forms available to plants. In poor agrochemical conditions, this phenomenon can lead to nitrogen starvation of plants, a negative impact on crop productivity and the need to introduce compensatory doses of mineral fertilizers [7].

At the same time, in conditions of intensive farming with a positive balance of nutrients, the addition of extra nitrogen is not a mandatory technique [8]. At the same time, the enrichment of upper soil layers with plant substrates with a C:N ratio in the range of 70–80:1 can have a number of agro-ecological advantages. In particular, the microbiological fixation of nitrogen does not exclude it from the circulation, but, on the contrary, ensures its preservation in the soil, contributes to a better absorption of it by plants and an increase in the yield of crops [9].

It should also be noted that the influence of various methods of utilizing rice straw on the mode of absorbed nutritional compounds has not been studied sufficiently, and it is also controversial when evaluated by different scientists, and therefore requires further research in order to optimize the nutrient status.

Technnology

The field experiment was carried out using the rice irrigation system OL-2 (irrigation map 41, check 2) of the Federal State Unitary Enterprise “Krasnoarmeysky” Rice-growing Breeding Plant of the Krasnoarmeysky district. The soil of the test site is grassfield-chernozem, low alkaline, heavy loam, and is characterized by the following indicators: the pH of the aqueous extract is 7.49, the content of humus, the general forms of nitrogen, phosphorus and potassium are, respectively, 3.17, 0.23, 0.21 and 0.73%. The amount of easily hydrolyzable nitrogen is 7.4, nitrates - 1.32, exchangeable ammonium - 0.67, mobile phosphorus - 2.58, mobile potassium - 29.1 mg/100 g.

The scheme of experiment included 11 options:

1. Straw is removed from the field (control option)
2. Burning of straw
3. Shredded straw (basic component)
4. Shredded straw + urea (1% of straw weight)
5. Shredded straw + Stimix® Niva (1 l/ha)
6. Shredded straw + Stimix® Niva J (1 l/ha)
7. Shredded straw + Stimix® Niva B (1 l/ha)
8. Shredded straw + Trichodermine® (7 l/ha)
9. Shredded straw + Trichodermine® (7 l/ha) + lactobacillus (2 l/ha)
10. Shredded straw + Extrasol® (2 l/ha) + urea (0.5% of straw weight)
11. Shredded straw + Extrasol® (3 l/ha) + urea (0.25% of straw weight)

Plot area: 0.42 ha (length - 95 m, width - 44 m). The repetition of the experiment is threefold, the method of using the plots is systematic, the precursor plant is rice.

As biodestructors of stubble, the following preparations were used: Stimix® Niva, Stimix® Niva J, Stimix® Niva B, Atlantis, trichoderma, lactic acid bacteria, Extrasol®.

Extrasol® is a microbial preparation of complex action based on Bacillus subtilis developed in the All-Russian Research Institute of Agricultural Microbiology, which has a fertilizing, growth-stimulating and fungistatic effects, and, in case of "starting" nitrogen nutrition, a pronounced lignin-destructive and cellulose-lytic activity as well. It is used as a decomposition accelerator and activator of the primary humification of plant residues.

Trichodermine® is a biological product created on the basis of the most active species of *Trichoderma lignorum*. When this preparation produced from the spores of the fungus is added to the soil, the mycelium develops, releasing up to 9 antibiotics (gliotoxin, viridin, allicin, etc.), which have a protective effect from more than 40 pathogens, including root rot. A typical saprophyte, actively decomposes fiber and other plant residues in the soil. Trichodermine® actively influences the change of soil structure, improves its fertility, has a stimulating effect on the development of plants.

Lactic acid bacteria (*Lactococcus*) produce lactic acid from sugar and other carbohydrates. Lactic acid is a strong sterilizer. It inhibits harmful microorganisms, accelerates the decomposition of organic matter and at the same time reduces (by binding) the loss of nitrogen. In addition, lactic acid bacteria promote the decomposition of lignins and cellulose and ferment these substances. Lactic acid bacteria can suppress the spread of *Fusarium*, a harmful microorganism which causes plant diseases.

Stimix® is an inducer of immunity and an antidote, a growth stimulator of complex action, a stimulator of photosynthesis. It is a complex of biologically active substances obtained by complex controlled hydrolysis. The basis of the preparation is a composite of amino acids, microbial cultures, salts of silicic acids, biologically active substances, salts of humic acids.

Rice straw shredding was performed simultaneously with the threshing of windrows using a TORUM 740 combine harvester.

Taking into account the yield of straw at the experimental site before the experiment (6.94 t/ha), the dose of compensating nitrogen fertilizer in option 4 was 69.4 kg / ha, and in options 10 and 11 – 34.7 and 17.4 kg/ha, respectively. Fertilizer was applied with SZ-3,6 seed-fertilizer.

Straw was inoculated with biological preparations using a P 128/5 mounted sprayer, followed by embedding into the soil with a 3×4 BDM disk header at a depth of 0–10 cm.

Evaluation of the effectiveness of the options was carried out against the background of incomplete mineral fertilizer (kg rate of application/ha): $N_{98}P_{26}$ ($N_{52}P_{26}$ - presowing fertilizer, N_{46} – compensatory nutrition in the tillering phase). Fertilizers used: carbamide, ammophos.

The experiment was carried out in accordance with the generally accepted method of field experience [10].

The content of nitrate nitrogen, ammonium nitrogen, mobile phosphorus and potassium was determined in selected soil samples [11, 12].

RESULTS AND DISCUSSION

The most important task of agrochemical science is the creation of an optimal plant nutrition system ensuring the full realization of the genetic potential of the cultivated crop. Purposeful regulation of the nutrient status of the soil to a large extent makes it possible to manage the growth and development of plants in order to create a high yield with predetermined indicators of the final products' quality.

Monitoring the dynamics of the content of mobile forms of the main nutrients in the soil during the growing season of rice has shown that the studied methods of straw utilization affect the nitrogen, phosphorus and potassium soil statuses.

Different methods of straw utilization and the use of biological humifiers in general did not affect the dynamics of mobile forms of nitrogen in the soil during the rice growing season. At the same time, they affected the absolute indices of the content of exchangeable ammonium and nitrates in the soil in certain phases of plant development, since the amount of nitrogen in different options of the experiment was not the same. After flooding the rice field, the redistribution of mobile forms of nitrogen occurs: the amount of nitrate nitrogen decreases and the ammonium nitrogen increases, which is associated with a decrease in the value of the redox potential and the predominance of reduction processes in the soil [13]. The content of nitrate nitrogen in the soil in the seedling phase varied from 3.0 to 3.6 mg/kg, averaging 3.2 mg/kg (see Table 1). The highest concentration of this ion was found in Option 4 with the embedding of straw with compensating nitrogen fertilizer, and the smallest concentration - with embedding without fertilizer (Option 3). This is due to the biological fixation of mobile nitrogen compounds during soil enrichment with organic matter with a wide C:N ratio.

Table 1 - Dynamics of the content of nitrate nitrogen and ammonium nitrogen in the soil in different methods of rice straw utilization, mg/kg

Option	Nitrate nitrogen			Ammonium nitrogen		
	Stage of monitoring					
	Seedlings	Tillering	Ear emergence	Seedlings	Tillering	Ear emergence
1	3.4	1.4	no	25.1	24.2	19.4
2	3.3	1.4	no	24.6	23.9	19.3

3	3.0	1.6	no	26.4	24.7	21.8
4	3.6	1.8	traces	28.1	27.9	23.0
5	3.1	1.4	no	26.7	24.8	21.9
6	3.1	1.4	no	26.6	24.9	22.2
7	3.1	1.5	no	26.9	25.0	22.2
8	3.1	1.3	no	26.8	24.9	21.9
9	3.2	1.3	no	26.9	24.8	22.0
10	3.3	1.4	no	27.0	25.3	22.3
11	3.3	1.4	no	26.8	25.1	22.2
$\bar{x}$	3.2	1.4	—	26.5	25.0	21.7
$s_{\bar{x}}$	0.047	0.028	—	0.41	0.39	0.31
σ	0.18	0.12	—	1.58	1.47	1.26

$\bar{x}$ – medium value, $s_{\bar{x}}$ – standard error, – σ standard deviation.

Burning of straw, removal from the field, as well as its embedding into the soil in combination with biologicals did not have a significant impact on the content of nitrate nitrogen. At the tillering stage, the presence of this form of nitrogen was atypically high, due to the discharge of water from checks during this period for the treatment of crops with herbicide. In the ear emergence phase, nitrates were practically absent. Such dynamics is mainly due to the denitrification and washing out of nitrates from the soil [14].

Considering the general nature of the dynamics of nitrate nitrogen in the soil, it can be stated that it does not play an important role in plant nutrition during the growing season of rice, since from the tillering stage, when the intensive intake of mineral nutrients by plants starts, its content in the soil is significantly reduced.

The dynamics of ammonium nitrogen in the soil, unlike nitrate nitrogen, had a different character (see Table 1). On average, by the seedling phase, its content increased 1.4 times compared with the initial value. The increase in ammonium nitrogen after flooding is due to a decrease in the rate of biological immobilization, the release of ammonium ions from a fixed state during soil swelling and the development of the process of ammonification of soil organic matter.

In options with the embedding of straw with a compensating nitrogen fertilizer and the use of biologicals, the content of ammonium nitrogen in the seedling phase was 5.6-12.0% more compared to the control option (removal of straw from the field) and 7.7-14.2% more compared to the option of burning. A somewhat higher concentration of ammonium in the control variant seems to be connected with the embedding of a part of straw (≈ 15–20%) into the soil in the form of stubble. The highest value of the studied indicator is noted in the variant with the addition of compensating nitrogen fertilizer to the straw in the amount of 1% of its mass.

Treatment of straw before embedding into the soil with various biological humifiers contributed to an insignificant (0.4–2.3%) increase in the concentration of the ion in relation to the option with the embedding of straw in its pure form, which is due to its mobilization from the soil and decomposing organic matter under the influence of saprophytic microflora [15].

From the seedling to tillering period of rice plants, the ammonium content in the soil decreased in the experimental options by 0.7-7.8%, and further, from the tillering to ear emergence period, by another 10.9-20.0%. This decrease was greatest in Options 1 and 2 (removal of straw from the field and burning), as well as with the use of compensating nitrogen fertilizer (Option 4) due to its significant consumption in this option by the most developed plants. At the same time, the differences in the variants of the experiment remained: with the addition of extra nitrogen in autumn, the content of exchangeable ammonium increased in comparison with the control option by 12.0-19.0%, while when the straw was inoculated with Extrasol® with different doses of compensating nitrogenous fertilizer (Options 11, 12), the content of exchangeable ammonium increased by 3.7-15.2%.

Thus, with an increase in the amount of added nitrogen, the content of its ammonium form in the soil increased. Nitrogen nutrition of plants was also improved when straw was embedded into the soil, especially when inoculated with biologicals.

The phosphorus status of the soil during the embedding of straw underwent changes as significant as in the previous cases. The nature of the dynamics of the content of its mobile forms in the phases of plant development, regardless of the option, was identical: the flooding of the rice field caused an increase in the content of mobile phosphorus in the soil as a result of a decrease in the redox potential and as a result of the conversion of slightly soluble ferric phosphates to more soluble ferrous phosphates [16]. The maximum values of this indicator were registered by the end of the irrigation period. At the same time, the absolute indices of the content of mobile phosphorus in the options of the experiment changed in each phase (Table 2). Thus, in the rice seedling phase, its content varied from 40.2 in the option with the removal of straw from the field to 41.3 mg/kg when it was embedded with urea.

During the vegetation period, an increase in the content of mobile phosphorus was observed on average by 5.0% by the tillering stage and by another 4.5% by the ear emergence stage. The use of organic fertilizer had the greatest impact on the studied indicator. By the end of the growing season, in the option with the embedding of straw without mineral nitrogen and biologicals, the concentration of phosphates in the soil increased compared to the control option by 8.3%. This is due, firstly, to the addition of extra phosphorus (3.2 kg/ha) to the soil with straw, and secondly, and more importantly, to the increase in phosphorus mobility as a result of the embedding of straw.

Table 2 - Dynamics of the content of mobile phosphorus and potassium in the soil in different methods of rice straw utilization, mg/kg

Option	Mobile phosphorus			Mobile potassium		
	Stage of monitoring					
	Seedlings	Tillering	Ear emergence	Seedlings	Tillering	Ear emergence
1	40.2	41.1	42.3	242.3	223.1	215.1
2	40.5	41.9	44.3	244.5	227.6	221.5
3	40.9	43.2	45.8	255.1	239.4	236.7
4	41.3	43.4	45.4	262.0	244.5	238.2
5	41.1	43.5	45.2	257.4	240.3	235.4
6	41.0	43.3	45.1	258.2	239.5	235.7
7	41.1	43.4	45.5	257.1	240.7	234.3
8	41.0	43.3	45.1	258.3	241.4	232.0
9	41.1	43.2	45.0	257.5	240.6	233.3
10	41.2	43.5	45.4	260.6	242.7	233.7
11	41.1	43.3	45.2	258.7	242.5	236.1
$\bar{x}$	41.0	43.0	45.0	255.7	238.6	232.4
$S_{\bar{x}}$	0.12	0.36	0.39	1.39	2.11	2.23
σ	0.46	1.39	1.50	5.26	7.98	8.46

Phosphorus mobility increases due to its binding in the form of various phosphorus-organic compounds, better used by the plant than hard-to-reach mineral phosphorus compounds, and due to the displacement of phosphate ions absorbed on the surface of colloidal particles as a result of their replacement with humate ions.

In addition, organic substances formed in the process of microbiological decomposition of straw, covering mineral colloids of sesquioxides with a thin film, reduce the fixation of phosphorus in the soil, or, forming complex compounds of organic ions with sesquioxides, weaken the binding of phosphorus to the sedentary forms, or adsorbed in the form of hydroxy acids in the soil together with phosphorus, increasing the amount of mobile phosphorus available to plants [17-19].

The additional application of nitrogenous fertilizer and biological products did not have a significant effect on the mobilizing effect of straw. An insignificant increase in the amount of mobile phosphorus in comparison with the option without straw is also observed when burning straw, which, apparently, is connected with its mixing with the soil along with the ash.

The role of potassium for rice plants is mainly due to its biochemical functions that it performs in the metabolism of the plant cell. Since soil minerals are the main source of potassium for plants, an increase in the content of mobile potassium in the soils of rice fields is the result of a complex change in the state of the environment under the influence of weathering and hydrolysis of aluminosilicates, prolonged flooding and rapidly changing redox conditions.

In the experiment, the effect of rice straw on the dynamics of exchangeable potassium forms has been studied.

The experiment has shown that the embedding of rice straw contributes to the increase of exchangeable potassium in the soil.

At different periods of rice development, the content of exchangeable potassium in the soil is not the same. The maximum amount is detected at the beginning of the growing season of rice (seedling stage), and the minimum - in the flowering phase. The decrease in potassium in the soil during the flowering period of rice is caused by its intensive consumption by the developing plants.

In each phase of rice plant development, the amount of exchangeable potassium varied in the options depending on the method of utilization of straw within fairly wide limits (Table 2). Moreover, these differences were mainly due to its lower content in the option with the removal of straw from the field, as a result of which more than 95 kg/ha of potassium were removed from the soil. When burning straw in the windrows, the content of exchangeable potassium increased slightly compared with the control option.

The processes of weathering of potassium-containing minerals in the soil are closely related to the intensity of the biological processes. In the presence of decomposing organic matter, the release of potassium from biotite, white mica and illite occurs in much larger quantities than in its absence [20].

The introduction of straw into the soil increased the content of exchangeable potassium in the seedlings, tillering, and ear emergence stages by 5.3, 7.3, and 10.0% respectively. The addition of compensating fertilizer to the straw, as well as its inoculation with various biologicals, did not contribute to a further significant increase in the content of exchangeable potassium, which is probably due to the increased removal of this element from the soil by fertilized plants.

Thus, the use of the non-grain part of the rice crop as an organic fertilizer both separately and with biological preparations, and especially with compensating nitrogen fertilizer, allows increasing the amount of nitrogen, phosphorus and potassium available to plants.

CONCLUSION

1. The shredded rice straw embedded into the soil in autumn has a significant effect on increasing the mobility of nitrogen, phosphorus, and potassium compounds available for plant nutrition, which is due to the complex nature of the effect of degradable plant residues on soil fertility. First, the nutrients available in plant material and released as a result of mineralization directly increase their reserves in the soil. Secondly, due to the decomposition processes themselves, as a result of increasing microbiological activity, the availability of soil nutrients to plants changes. The basis of the influence of decomposing straw is the acidic interaction between biological products and the mineral part of the soil.

2. Different methods of utilization of rice straw have different effects on the mobilization of mineral nutrients. When embedding in the soil of 6.9 t/ha of shredded rice straw, the content of exchangeable ammonium in the 0-20 cm soil layer increased, compared with the option without straw, on average during vegetation by 7.4%. At the same time, the mobilizing effect of decomposing straw increased towards the flowering phase.

3. The usage of urea as a compensating nitrogen fertilizer in the amount of 1% of straw weight increased its mobilizing effect by 8.4%. The content of mobile phosphates during the introduction of straw increased on average during the growing season by 9.3%. The greatest mobilizing effect of straw was manifested in the content of exchangeable potassium, which

increased on average during the growing season by 12.3%.

4. To speed up the mineralization and humification of straw, reduce the toxic effect of the products of its half decay, as well as to ensure a deficit-free balance of soil organic matter, it is necessary to use shredded straw in combination with compensating nitrogen fertilizer (urea) in an amount of 1% of straw weight or pre-spray it with solutions of biologicals: Stimix® Niva B (1 l/ha), Stimix® Niva J (1 l/ha), Extrasol® 2 l/ha + urea in a dose of 0.5% of straw weight.

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