Recycling the tailings as fertilizer

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Abstract. The research aimed at resolving the issues of utilizing the tailings as fertilizer is presented. The aggregate for the machine utilization of after harvesting tailings as fertilizer is described. This machine is designed to work on straw, from which it selects plant material and grinds it while simultaneously treating with a process solution of agents. The solution accelerates the decomposition process, and then the machine evenly distributes fertilizer ready for use with the possibility of simultaneous incorporation into the soil (depending on the traction class of the tractor used). The introduction of the process solution is carried out by fine spraying through centrifugal nozzles mounted on the nozzle ramp behind the distribution flaps.

Four biological agents for the preparation of a process solution accelerating the decomposition of the tailings are considered: Agrinos 1, Sterifag, Ekorost and BTU Biocomplex. The results regarding influence of the tested agents on the decomposition rate of after harvest residues are obtained. The unit proposed for recycling the tailings as fertilizer has passed operational tests during the experiment. The power reserve in terms of the volume of the technological tank was 3000 ± 20 m, which provides 4 driving strokes, with an average bout length about 700 meters for the Ryazan region. Thus, refueling of technological tank is carried out on one side of the field. Measuring the operating speed showed it was 6-8.5 km/h for different bout lengths and evenness of the field, the hourly output was 5-5.5 ha/h.

1. Introduction

The agrarians are facing the problem of providing food to the population of our planet and the resulting harvests from each soil hectare must grow taking into account that population is constantly growing. This puts an additional pressure on the soil. It is known that during the crop formation organic nutrients are removed from the soil and, if the deficiency of these substances is not made good, the soil will become poor and lose its fertility. The use of mineral fertilizers does not solve this problem completely, since they include heavy metals that accumulate in the soil. This affects the quality of the products and, as a result, people's health [1-8].

A solution to this problem can be a by-product of crop production, the tailings used as fertilizer, as its composition includes elements involved in the formation of humus, the fertile soil layer. However, the use of this fertilizer is limited in practice. This is primarily due to the fact that the plant mass embedded in the soil does not have time to completely decompose before the sowing of new crops, and the phenolic compounds released during its decomposition negatively affect the development of plants.

The decomposition rate of the tailings depends on many factors, major of which are as follows:

1. Physico-chemical composition of tailings (depending on the chemical composition of the plant mass, the decomposition reaction proceeds at different rates);
2. Uniform distribution of the crushed plant mass over the field surface (should be at least 75% of the total mass, it is necessary for uniform contact of the crushed mass with soil and for uniform decomposition, the higher the uniformity, the higher the rate of decomposition reaction);

3. The grinding degree of tailings (the content of straw particles in the crushed mass with an average cutting length of 30-50 mm should be more than 50%, this provides a large contact area of straw with the soil, which accelerates its decomposition).

4. The balance of nitrogen and carbon (C:N) should be 25:1, in the straw this balance is 80-90:1, therefore, it is necessary to introduce compensating doses of nitrogen-containing fertilizers to accelerate the decomposition process.

5. The incorporation depth of the plant mass into the soil should not exceed 10-15 cm, since decomposition is an aerobic process.

6. Soil moisture. It is known that intensive decomposition of fiber occurs when the soil moisture content is 45-50% of its full moisture capacity, the fiber content can be up to 40% of tailings.

2. Materials and methods
An aggregate for recycling the tailings as fertilizer was developed [9, 10] (Figure 1). The aggregate works by rolling straw, selects plant material from the roll, grinds it with simultaneous treatment using process solution of agents. The agents are accelerating the decomposition process, even distribution of fertilizer ready for use with the possibility of simultaneous incorporation into the soil (optionally depending on the tractor class of the tractor used). The introduction of the process solution is carried out by fine spraying through centrifugal nozzles mounted on the nozzle ramp behind the distribution flaps. The unit consists of three following main elements:

1) preparation complex for using the tailings as a fertilizer, a serial shredder-mulcher, which is additionally equipped with a supply system for a process solution of the agent accelerating the decomposition of plant material [9];

2) unit for differential incorporation of the process solution, which consists of a scanning device [9], an analytical unit and an actuator (made in the form of a pressure regulator);

3) complex for embedding finished fertilizer into the soil (made in the form of a disk tool).

![Figure 1. An aggregate for recycling the tailings as fertilizer.](image-url)
The scanning device is located in front of the tractor before the loading counterweights at a distance of 1.0-1.2 m from the field surface and represents a frame with three range finders (laser or ultrasonic) mounted on it. Before starting work, the operator sets the rangefinders in a way that one of them measures the distance to the swath in the central part (top), and the other two measure distance along its edges. The values of the swath width and its density are set manually in the analytical unit (located in the tractor cabin). Thus, the value swath height is determined automatically using the following expression:

\[ H = \frac{(H_1+H_2)}{2} - H_c \]  

where \( H_1, H_2 \) – distance from the range finder to the soil along the swath edge, m; \( H_c \) – distance from the range finder to the central part of the swath, m.

The mass of tailings in the swath is determined as follows [8]:

\[ m_t = V_t \cdot \rho = \frac{\pi B_s H V_o \cdot t \cdot \rho}{4}, \]  

where \( m_t \) is tailings mass received by device during time period \( t \), kg; \( \rho \) is density of tailings, kg/m³; \( B_s \) – width of the swath, m; \( H \) – height of the swath, m; \( V_o \) – operating speed of the machine-tractor unit, m/s.

It is assumed that the swath for tailings is represented as a half of an elliptical cylinder with a large base radius equal to half of the swath width – \( B_s/2 \), smaller than the swath height – \( H \), and a height in the form of the aggregate trip mileage \( S=V_o*t \) [8].

In August 2018, on an experimental field with an area of 12 hectares of the Research Center “Agrotehnopark” in FGBOU VO RGATU, the experiment was launched in order to determine the effectiveness of biological products for accelerating the decomposition of tailings when they are recycled as fertilizer. The following agents were used to prepare the process solution:
- Agrinos 1 (2 l/ha);
- Sternifag (80 g/ha);
- Ecorost (0.4 l/ha);
- Biocomplex BTU (1 l/ha).

The aggregate for recycling the tailings as a fertilizer, which was used for setting up the experiment, included a complex for preparing the tailings as a fertilizer and unit for differentiated introduction of process solution (MTZ-82.1+AdU tailings). Subsequent embedding into the soil was carried out by an additional K-744+BDP-6x4 machine-tractor unit (Figure 2). The diagram of a field experiment is represented in Figure 3. Winter wheat straw was used as tailings [8].

![Figure 2. Recycling of tailings.](image-url)
In order to determine the driving stroke capacity by the volume of the technological tank, a constant working pressure of 0.21 MPa was established, the machine tractor unit (MTU) moved at a constant speed of 7.5 km/h.

The unit driving stroke capacity by the volume of the technological tank is determined by the following known formula:

\[ L_{\text{t.w.}} = \frac{10^4 V_{\text{t.t.}} p_{\text{p.s.}} \lambda}{N B_p}, \]  

(3)

where \( L_{\text{t.w.}} \) is the unit driving stroke length between two successive refuelings of the technological tank, m;

\( V_{\text{t.t.}} \) – volume of technological tank, \( \text{m}^3 \);

\( p_{\text{p.s.}} \) – density of the process solution, \( \text{kg/m}^3 \);

\( \lambda \) is the volume use coefficient of the technological tank (\( \lambda = 0.8-0.95 \)).

In order to assess the quality of crushed tailings, the sample of crushed straw was taken and particles were distributed into classes depending on the average length. Crushing is considered to be of high quality if the weight ratio of fractions with particles up to 100 mm in size is at least 85%.

The moisture content of tailings was measured before and after treatment in order to determine the digestibility of the process solution by ground plant mass. The moisture content was measured using an EVLAS-2M hydrometer, at least 3 samples were taken to completely fill the aluminum box, then they were placed in the moisture tester. The device automatically measured the mass of the samples, after which they were dried at a temperature of 120 °C for 20 minutes.

3. Results

During the experiment, it was determined that the driving stroke capacity of the aggregate for recycling tailings as fertilizer was 3000±20 m. Such capacity provides 4 driving strokes with an average furrow length of 700 meters for Ryazan Oblast. Thus, refueling of technological tank is carried out on one side of the field.

Measurements of the operating speed showed it was 6-8.5 km/h for different values of the furrow length and evenness of the field, with an hourly output of 5-5.5 ha/h.

The digestibility of the process solution devoured by ground vegetable mass is more than 90% (the digestibility of the process solution introduced by standard technology using a sprayer was 85%).
The quality of grinding tailings corresponds to agrotechnical standards, the weight content of particle fractions with an average length less than 100 mm is 91.3 (Table 1).

| The percentage of the total sample mass, % | 14.6 | 46.0 | 30.7 | 5.8 | 2.9 |
|------------------------------------------|------|------|------|-----|-----|
| The average length of straw particles, mm | 0…30 | 31…50 | 51…100 | 101…150 | 150< |

Clogging of the main filter with peat crumbs was observed when using humic fertilizers (Ecorost) to prepare the process solution (the screen opening of the filter metal mesh was 0.154 mm, the nozzle filters with 0.08 mm screen opening size were not clogged). It is significant that clogging occurred through the even number of MTA driving strokes with an average net work time of 400-450 seconds. Clogging of the main filter was not detected when using the remaining studied fertilizers. Therefore, it is necessary to filter the process solution through a filter with a metal mesh with a screen opening of not more than 0.152 mm when filling it into the technological tank.

The operation of the scanning device was successful, the results are summarized in table 2. The measurements were made at a speed of 5 km/h with a measuring step of 10 meters, the swath width was 1.6 meters, the height of the scanning device above the field surface was 1 meter. A scanning device consisting of three ultrasonic rangefinders is functioning properly with a deviation of no more than 3.6%.

| Measure | Rangefinder readings, m | Swath height H_s, m |
|---------|-------------------------|---------------------|
| No.     | 1 | 2 | 3 |     |
| 1.      | 1.0 | 0.778 | 0.911 | 0.222 |
| 2.      | 1.0 | 0.751 | 1.0 | 0.249 |
| 3.      | 0.949 | 0.749 | 0.997 | 0.251 |
| 4.      | 0.999 | 0.757 | 1.0 | 0.243 |
| 5.      | 1.0 | 0.761 | 0.998 | 0.239 |
| 6.      | 0.978 | 0.753 | 0.999 | 0.247 |
| 7.      | 0.998 | 0.750 | 0.997 | 0.250 |
| 8.      | 1.0 | 0.746 | 1.0 | 0.254 |
| 9.      | 0.999 | 0.751 | 0.998 | 0.249 |
| 10.     | 0.996 | 0.749 | 0.999 | 0.251 |
| Average | 0.992 | 0.755 | 0.989 | 0.220 |

After 48 days (October), the first plate samples were dug, second were dug after 86 days (November). The average values of temperatures and precipitation during the period when plate samples were in the soil are presented in table 3.

| Value | Month   | August | September | October | November |
|-------|---------|--------|-----------|---------|----------|
| Average temperature, °C | 24.8 | 19.3 | 10.3 | 0.5 |
| Average long-term temperature values in the Ryazan region, °C | 17.4 | 12.3 | 4.65 | -1.5 |
| Atmosphere precipitation, mm | 54.9 | 49.2 | 43.9 | 38 |
| Average long-term precipitation values in the Ryazan region, mm | 69.6 | 61.4 | 41.3 | 33.1 |

Visual examination of the excavated samples on day 48 of the experiment showed the absence of pronounced decomposition traces.

After 98 days of the experiment:
- Agrinos 1 – the decomposition spot appeared (up to 4 cm in size) at a depth of 30 cm;
- Sternifag – small decomposition specks (with a diameter of less than 1 cm) at a depth of 6 cm and 12 cm;
- Ecorost – no visible signs of decomposition;
- BTU Biocomplex – decomposition spots at a depth of 10 cm and 12 cm, a large spot at a depth of 16 cm - 23 cm over the entire width of the fabric;
- Control (without treatment) – decomposition specks at a depth of 13 cm and 23 cm.

The mass loss indicators of linen in percent of the original mass are presented in table 4, and a decomposition rate graph of linen is shown in figure 4.

**Table 4.** The decomposition indicators of linen cloths, % remained from the original sample.

| Sample                  | Agent   | Agrinos 1 | Sternifag | Ecorost | Biocomplex | BTU  |
|-------------------------|---------|-----------|-----------|---------|------------|------|
| First sample (48 days)  |         | 99.48     | 96.70     | 97.50   | 96.35      |      |
| Second sample (86 days) |         | 95.30     | 87.40     | 79.40   | 86.00      |      |

**Figure 4.** Decomposition graph of linen.

4. Discussion
The aggregate for recycling of tailings as fertilizer ensures theological operation in accordance with agrotechnological requirements. The process solution digestibility of more than 90% is due to the fact that its introduction is carried out simultaneously with the grinding of plant mass, which contributes to better mixing.

The use of ultrasonic rangefinders in the scanning device design of the proposed machine is considered satisfactory.

The activity dynamics of biological preparations was not linear, but largely depended on weather conditions. The hotter temperature and the absence of heavy rainfall in August - September 2018 did not contribute to the active work of soil biota, and after the first reporting period the best
decomposition of linen cloth was with the Biocomplex BTU and Sternifag, 3.6% and 3.3% respectively. The option with the Ecorost agent showed worse results. The decomposition here is fixed at 2.5%. In the cases with Agrinos 1 and control, there was almost none decomposition process of biological mass.

Even considering the reduced temperature, precipitation in late September and early October accelerated the propagation of soil microorganisms and, in particular, cellulose-degrading bacteria. The Ecorost agent, which includes humic and fulvic acids, most effectively helped soil microorganisms in the life processes under these conditions. The decomposition dynamics of plant residues increased by more than three times.

Clogging of the filter is caused by the residue formation in the form of peat crumbs, which is common for all humic products. It should be noted that clogging of the filter in sprayers performing the introduction of the process solution using the same preparations was observed more often when using the Sternifag agent.

5. Conclusions
The research carried out showed the high efficiency of biological fertilizers and humic agents for accelerating the decomposition of crop leftovers. All groups of the following considered agents were effective: Agrinos 1, Sternifag, Ecorost and BTU Biocomplex.

The decomposition of winter wheat straw in cases with microbiological agents was higher compared to the control. The decomposition rate averagely increased by 9.13%. The highest decomposition rate was shown by the samples after treatment with the Ecorost humic agent and the Biocomplex BTU complex agent.

The aggregate for recycling the tailings as fertilizer has proven its effective and reliable operation. The driving stroke capacity for the technological tank is 3000 m. Hourly productivity is up to 5.5 ha/h, operating speed is up to 8.5 km/h. The more than 90% digestibility of the process solution by plant mass is ensured. The grinding quality of tailings corresponds to agrotechnical requirements, the weight content of the straw particle fraction with a length less than 100 mm is more than 90%. A scanning device consisting of three ultrasonic rangefinders is functioning properly with a deviation of no more than 3.6%.

When refueling a technological tank, it is necessary to additionally filter the process solution prepared using biological fertilizers and humic agents through filters with screen openings up to 0.150 mm.

The overall economic effect after using the aggregate for recycling the tailings as fertilizer, compared to technologies assuming the introduction of biological fertilizers, biological agents and humic products in the form of a process solution by sprayers is 12,474 rubles.

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