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Possibility of using organo-mineral substrate in agriculture

P A Kotyak[1], E V Chebykina[1], N V Vaganova[2] and M Yu Ivanova[1]

[1]Department of Ecology, Yaroslavl State Agricultural Academy, 58, Tutayevsky Highway, Yaroslavl, 150042, Russia
[2]Department of Agronomy, Yaroslavl State Agricultural Academy, 58, Tutayevsky Highway, Yaroslavl, 150042, Russia

E-mail: p.kotyak@yarcx.ru

Abstract. The paper presents the development of eco-friendly organo-mineral substrate technology. It is intended to use the material of greenhouse-made vegetation mats and poultry (chicken) manure. Based on the conducted studies to determine the influence of various fertilizer systems on the toxic status of sod-podzolic gleyic middle loamy soil in the conditions of Yaroslavsky region, the nutrient status with the introduction of organo-mineral substrate both separately and together with complete fertilizers has the best characteristics. Under these conditions, the soil toxicity is reduced thus indicating the ecological well-being of soil using the studied agricultural methods. The placement of such fertilizers on its own contributed to the growth of the soil units by 29.34%, and when applied with mineral fertilizers – by 34.76% without deteriorating the quality of products due to the absence of the soil toxic effect.

1. Introduction

The result of intensive greenhouse and poultry farming is not only the increase in the volume of basic production, but also the accumulation of production wastes, such as used greenhouse mats and poultry manure in poultry farming. In Russia, 250 million tons of organic waste are generated annually, of which 150 million tons account for livestock and poultry production, 100 million tons – crop production.

Both wastes are environmentally hazardous and require special care in their disposal. All wastes have the following hazardous characteristics:

- toxicity – ability to cause serious, prolonged or chronic human diseases, including cancer, when ingested through respiratory and digestive organs;
- fire hazard – ability of wastes to spontaneously heat up under normal conditions or to heat up when in contact with air, and then to burn when interacting with water or to release flammable substances in dangerous amounts;
- content of infectious disease agents – presence of living microorganisms or their toxins, which can cause diseases of humans and animals.

If there are technologies for its composting and other processing methods for poultry manure, there are still no such methods for vegetation mats. Therefore, the development of the method of greenhouse substrate disinfection, its enrichment with nutritious elements due to the use of poultry manure and commercialization of the technology of receiving organo-mineral substrate as fertilizers for field cultures are quite relevant for agricultural producers and ecology [1].

Given the negative aspects of organo-mineral substrate components, special attention should be paid to the problem of the toxic state of soils, which has recently had a significant impact on the production of eco-friendly agricultural products, which will not affect the human health [2–4].

However, it should be noted that the excess of MPC chemicals in the studied substructures is only an indirect indicator of their toxicity. It was not always possible to establish direct relations between the content of a pollutant in the environment and its relevance to living organisms. The soil can be highly contaminated but non-toxic or weakly toxic and, conversely, weakly contaminated but highly toxic. The current effect of some components may be neutralized or enhanced by others, so the soil toxicity is not determined by the toxicity of individual compounds contained therein. It is necessary to evaluate the integrated toxicity of soil reflecting the effect of the whole complex [5, 6].

Soils are considered toxic if they inhibit seed germination or germination of seedlings and roots by 20 % or more compared to control.

Thus, the purpose of the study was the agroecological assessment of the impact of used vegetation mats and poultry manure introduced into soil as organo-mineral substrate on changes in soil toxicity and crop productivity.

2. Materials and methods

The work was carried out in 2017 and 2018 in sod-podzolic gleyic middle loamy soil in vetch and oats crops (oat of Krechet spring variety, vetch of Yaroslavskaya-136 sowing variety) and spring wheat (Darya variety). In order to fulfill the set objective, the study was based on the three-factor stationary field experiment in the test field of Yaroslavl State Agricultural Academy. The experiment was carried out by the split-plot method with random placement of variants in replications. The experiment was carried out in three replications.

Diagram of field stationary three-factor (2 × 6 × 2) experiment:

Factor A. Main soil treatment system, "O": 1) Dump, "O_1"; 2) Surface, "O_2".

Factor B. Fertilizer system, "U": 1) Without fertilizers, "U_1"; 2) Used mineral wool IZOVOL AGRO UNIVERSAL, "U_2"; 3) Organo-mineral substrate, "U3"; 4) Decontaminated chicken manure, "U_4"; 5) Organo-mineral substrate + NPK, "U_5"; 6) NPK, "U_6".

Factor C. Plant protection system, "P": 1) Without pesticides, "P_1"; 2) With pesticides, "P_2".

Azophoska and ammonium nitrate as the forms of mineral fertilizers. Azophoska was introduced under the main treatment in spring, and calurea – before sowing. In 2017, the norm of mineral fertilizers was $N_{80}P_{80}K_{80}$, in 2018 – $N_{120}P_{20}K_{100}$.

Vegetation mats received from LLC Yaroslavsky Greenhouse Plant were used for the study. Vegetation mats are produced by IZOVOL AGRO UNIVERSAL from eco-friendly mineral wool based on basalt rocks. Approximate chemical composition of raw materials: SiO_2 45–65 %; Al_2O_3 10–20 %; CaO 5–15 %; MgO 5–10 %; Fe_2O_3 + FeO 10–15 %; Na_2O + K_2O 1–3 %. Poultry (chicken) manure was obtained from a poultry farm.

Chicken manure, spent vegetation mats and organo-mineral substrate were introduced in the spring of 2017 under the main treatment. Chicken manure was filled at a rate of 41 c/ha, which is $N_{80}P_{65}K_{40}$ in terms of active ingredient. The norm for mineral wool was 2.1 c/ha.

The soil plate method was used to determine the toxic state of the sod-podzolic soil under the influence of different agrogenic loads. The total toxicity of soil is determined by the number of germinated seeds, the length of sprouts, and the number and length of roots of the test culture (white mustard). The plants developing on water-wetted filter paper were used as the control. The crop yield was determined by a split-plot method with conversion to absolutely clean products. DISANT programs were used for statistical processing of experimental data.

3. Results and Discussion

During the first stage of the study, we conducted laboratory analyses of both poultry manure and used vegetation mats to ensure their bioecological safety and to select ways to disinfect them.

The analysis of existing sources of information allowed establishing the unresolved problem of greenhouse vegetation mats recycling in Russia. At the moment, the spent greenhouse substrate is simply stored in waste disposal sites or, after grinding, is introduced into soil, which poses a threat to the agricultural landscape in general and the agrocenosis of the land in particular.

Vegetation mats are known to be mineral wool synthesized from basalt rock. After use, mineral wool is not recovered, but the European factories take the substrate back, melt and include in the production cycle. Recycled substrate is also used in brickmaking, production of road pavements, and even compact discs.

The issues of poultry manure processing have been dealt with by agronomists for a long time and there are various versions of its composting (with peat, sawdust, straw, chemicals), thermal drying. It should be noted that there are patents for poultry manure processing methods, but they have a number of disadvantages. When composting poultry manure, the period of organic fertilizer production is at least 30 days. When processing poultry manure with chemicals the latter ones having toxic properties can get into soil.

As a result of laboratory analyses, we determined the following:

- clean, unused vegetation mats do not contain nutritional elements (NPK). In mineral wool, about 0.43–0.58 % nitrogen remains after growing, the exchange acidity is 6.8, the exchangeable base status is 118.40 mg eq/100 g of substrate, heavy metals were not found;
- content of macroelements in dried poultry manure: nitrogen – 0.96–1.09 %; readily available phosphorus – 2.08–2.28 %; exchange potassium – 1.24–1.39 % for air-dry manure, exchange acidity of dried poultry manure – 7, heavy metals were not found;
- no weed seeds, infecting agents and eggs of insect pests were recorded in vegetation mats used in greenhouse production, the level of their phytotoxic effect is lower than that of clean mineral wool;
- vegetation mats of basalt wool have sufficiently high moisture-holding capacity amounting to 900 %;
- phytosanitary state of prepared poultry manure is satisfactory, it does not contain pathogenic microflora, worm eggs, larvae of insect pests, viable weed seeds.

When developing the composition of organo-mineral substrate, the above-mentioned characteristics of components were taken into account. In order to prepare fresh poultry manure for use as an organic fertilizer, the most effective is its utilization as a micro-biological agent, which makes it possible to process it into a uniform dispersed mass in a sufficiently short period of time with preservation of nutrient elements at the level: N – 4.0 %, P_2O_5 – 2.5 %, K_2O – 2.0 %. Before mixing with disinfected chicken manure, the used mineral wool was moistened to a condition of the minimum moisture-holding capacity and crushed to the size of pieces of 1 cm. The optimum ratio of basalt cotton wool and chicken manure was found, which made 1:19 (1 part of the mineral wool to 19 parts of chicken manure).

Phytotoxicity of soil is the ability of soils to have a suppressive effect on plants, leading to disruption of physiological processes, deterioration of plant production quality and reduction of its yield [7].

The total level of soil toxicity in the test site was quite high; on average the decrease in germination of white mustard was 46.5 %.

Soil toxicity was determined twice during crop vegetation, at the beginning and end. The soil samples were taken from two layers of the arable horizon, and white mustard was used as a test culture.

The results obtained from the total toxicity analysis of the sod-podzolic soil show that the conditions developing towards the end of crop vegetation contributed to the improvement of soil inhibiting properties as compared to the beginning of crop vegetation for all studied factors (Table 1, 2).

The analysis showed the following trends. At the beginning of crop vegetation (Table 1), the embedding of disinfected poultry manure contributed to the increase of phytotoxic effect (U_4), this variant was characterized by the germination decrease of the test culture over all layers of the arable

horizon at substantial values in the 0-20 cm layer. The use of organo-mineral substrate did not have a toxic effect on white mustard, on the contrary, the variants with its use (U_3, U_5) were characterized by plant development compared to control, especially in the application of mineral fertilizers.

Table 1. Total soil toxicity at the beginning of crop growing on average by years of study (test culture development indicators – white mustard)

Variant	Test culture development indicators								
	germination, %			germ length, cm			root length, cm		
	soil layer, cm								
	0-10	10-20	0-20	0-10	10-20	0-20	0-10	10-20	0-20
Without fertilizers, U_1	32.84	30.69	31.74	11,56	10.99	11.28	5.34	5.34	5.34
Use of mineral wool IZOVOL AGRO UNIVERSAL, U_2	27.32	33.00	30.19	9.44	8.99	9.22	4.33	3.64	4.01
Organo-mineral substrate, U_3	35.67	33.99	34.85	10.20	9.21	9.71	4.16	4,07	4.09
Disinfected poultry manure, U_4	25.49	22.49	23.99	10.43	12.22	11.35	6.02	4,48	5.27
Organo-mineral substrate + NPK, U_5	52.17	47.00	49.59	15.56	15.92	15.74	8.06	7,70	7.88
NPK, U_6	36.32	37.32	36.82	10.92	11.99	11.48	7.93	6.62	7.27
LSD_{05}	9.53	8.96	6.66	$F_f<F_{05}$	$F_f<F_{05}$	$F_f<F_{05}$	$F_f<F_{05}$	$F_f<F_{05}$	$F_f<F_{05}$

The embedding of the mineral wool (U_2) into the soil did not contribute to the increase of phytotoxic effect, the total toxicity indicators were at the level of control. When mineral fertilizers were introduced independently (U_6), the phytotoxicity of soil appeared in some stimulation of development of both seedlings and root system.

At the end of the vegetation, the phytotoxic effect remained approximately the same as at the beginning (Table 2).

The increase in the toxic effect on the soil compared to the control without fertilizers (U_1) was observed with the application of mineral fertilizers (U_6), and significant changes were observed in the 0-10 cm layer. When disinfected poultry manure (U_4) was introduced, the phytotoxicity of soil was evident only in germination. The embedding of used vegetative mats (U_2) and organo-mineral substrate (U_3) into the soil constrained the overall phytotoxicity of soil and increased the length of seedlings and roots.

Table 2. Total soil toxicity at the end of crop vegetation on average by years of study (test culture development indicators – white mustard)

Variant	Test culture development indicators								
	germination, %			germ length, cm			root length, cm		
	soil layer, cm								
	0-10	10-20	0-20	0-10	10-20	0-20	0-10	10-20	0-20
Without fertilizers, U_1	22.59	15.24	18.94	3.33	2.24	2.81	1.64	1.71	1.67
Use of mineral wool IZOVOL AGRO UNIVERSAL, U_2	22.92	18.81	20.89	3.98	3.53	3.78	2.49	1.85	2.19
Organo-mineral substrate, U_3	20.67	18.84	19.75	3.13	3.14	3.13	1.94	2.38	2.16
Disinfected poultry manure, U_4	15.84	12.38	14.29	3.44	3.13	3.28	2.16	2.46	2.33
Organo-mineral substrate + NPK, U_5	27.02	19.24	23.13	2,81	3.10	2.95	1.53	2.27	1.90
NPK, U_6	18.25	14.27	16.24	2.85	2.88	2.86	2.10	1.91	2.00
LSD_{05}	4.09	2.94	3.11	$F_f<F_{05}$	0.76	0.84	0.84	0.74	$F_f<F_{05}$

The use of complete mineral fertilizers together with organo-mineral substrate did not contribute to the toxic effect. At the same time, it should be noted that the change in germination, length of white mustard seedlings in this version was reliable compared to the background “Without fertilizers”.

The productivity of field crops is the main efficiency indicator of vegetation technologies in general or individual agricultural methods. The productivity is influenced by a large number of factors, both internal (variety) and external, such as agricultural landscape conditions, meteorological conditions during vegetation and especially soil fertility.

The increase in the background of nutrition provided the increase in the productivity of crops by 11.14–21.55 c/ha of feed units, except for the variant with the application of complete mineral fertilizers. The use of NPK contributed to a significant reduction of crop productivity by 3.62 c/ha of feed units.

Among the studied fertilizer systems, substantial increases are ensured in the backgrounds with organic-mineral substrate both separately and together with mineral fertilizers, as well as in the version of disinfected poultry manure. The highest yield level was obtained according to the version of joint application of organo-mineral substrate with complete mineral fertilizers and amounted to 83.54 c/ha of feed units.

4. Conclusion

Thus, the development of organo-mineral substrate of the used mineral wool and the disinfected chicken manure has a number of advantages:

- at 17 % moisture content the planned nutrient content in a substrate when it is obtained from poultry manure should be 4.54 % nitrogen, 3.65 % phosphorus and 1.74 % potassium, which is several times higher than their content in nesting manure and straw;
- the granulated form of a proposed fertilizer to solve a serious problem of producers on its application in fields;
- the presence of ground basalt wool in a substrate, which almost does not decompose in soil, will allow changing its particle-size distribution, and then water-air and thermal modes of soil;
- thermal treatment of substrate components will allow obtaining fertilizers clean from phytopathogenic organisms;
- the improvement of the environmental situation in the region.

Based on the conducted studies to determine the influence of various fertilizer systems on the toxic status of sod-podzolic gleyic middle loamy soil in the conditions of Yaroslavsky region, the nutrient status with the introduction of organo-mineral substrate both separately and together with complete fertilizers has the best characteristics. Under these conditions, the soil toxicity is reduced thus indicating the ecological well-being of soil using the studied agricultural methods. The placement of such fertilizers on its own contributed to the growth of the soil units by 29.34 %, and when applied with mineral fertilizers – by 34.76% without deteriorating the quality of products due to the absence of the soil toxic effect.

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