Non-traditional fertilizers as soil ameliorants: the study of usefulness

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Abstract. The research studies the chemical, agrochemical, biological and toxicological impacts of non-traditional fertilizers (compost based on sewage sludge and the sawdust of hardwood and softwood trees) on soil and ecological conditions of a recultivated site (a sand quarry). It is indicated that it will be feasible to use non-traditional fertilizers with a 5-year composting period as an ameliorant for sandy soils.

1 Introduction

The reclamation of disturbed lands improves the environmental situation and ensures the reuse of these lands for different economic activities. When recultivating quarries for non-metallic building materials, including sand quarries, where topsoil is destroyed, it is important to use organic fertilizers to increase fertility. In this case, sewage sludge can be used as a source of organic matter. There is a lot of experimental data on sewage sludge disposal [1–3]. However, it is worthwhile to study the feasibility of using sewage sludge and sludge-based composts on a regional level taking into account the differences in the chemical composition of sludge, soil and climatic conditions and even the type of anthropogenic transformation experienced by an ameliorated site. Thus, this issue is still important. The use of sewage sludge in agriculture is limited because it contains heavy metals, pathogenic flora, etc. Some specialists believe it would be more appropriate to use sludge in forestry rather than agriculture [4–6]. However, even in forestry, the use of such ameliorants requires control.

This work assesses the safety of compost, based on sewage sludge for the environment.

2 Methods

The laboratory tests were carried out using the equipment of the Centre of ecology, biotechnology and clean fuels in the Volga State University of Technology.

Cellulose-digesting and proteolytic actions of soil were determined in field conditions by the application method [7]. The ammonifying action was evaluated in a laboratory, based on the technique developed by T.V. Aristovskaya [8].

Sample collection and preparation were done according to state standards [9]. Biotesting was carried out on three standardized test-organisms [10–12] and seeds of radish.

The population of micro-organisms was assessed by the swab method involving selective nutrient media. The total population of micro-organisms was defined based on Vinogradsky method, modified by Schulgina. The following types of agar were used to count the number of micro-organisms: meat-and-peptone agar for bacteria that assimilate the organic compounds of nitrogen; starch-and-ammonia agar for the population of micro-organisms that use mineral nitrogen; acidified wort-agar for micromycetes; soil agar for oligotrophic plants; nitrate agar for indigenous micro-organisms. Nitrite bacteria were counted based on Skerman agar medium, while cellulose digestors and azotobacter were calculated by the method of lump fouling in Hutchinson and Ashby medium [13].

The chemical analysis (atomic absorption method) was done according to ISO 11466 and ISO 11047 on AAnalit-400 atomic absorption spectrometer. [14]

The statistical assessment of obtained data was carried out with Statistica 6.0.

3 Results

Laboratory tests were used to analyze the content of heavy metals in non-traditional ameliorants, evaluate their levels of toxicity and determine their danger classes by means of biotesting.

The mobile forms of heavy metals can disturb the regulation of cell mechanisms and accumulate in plants. That’s why this indicator is important for new ameliorants. The content of heavy metals was determined in compost, based on sewage sludge and hardwood and softwood sawdust that didn’t reach the thermophilic state: Pb – 7.17 mg/kg; Cu – 16.99 mg/kg; Zn – 38.49 mg/kg ;Cd – 1.62 mg/kg; Ni – 8.78 mg/kg.

The biotesting of soil ameliorants was done with three test organisms (daphnia, chlorella, bacterium). The
results have shown that the sensitivity of test organisms to the components of waste is different (table 1).

The biotesting of compost samples (sewage sludge + sawdust) taken at different stages of composting indicates that compost which didn’t get through the thermophilic stage (a 3-year composting period) is more toxic: the analysis involving two test organisms showed IV class of hazard. The toxicity of compost after the thermophilic stage (a 5-year composting period) decreases: IV class of hazard was only for one organism (algae). The tests involving bacteria showed no toxicity of ameliorants. The values are distributed within the V hazard class.

As hazard class is determined based on the test organism that was the most sensitive to analyzed medium, the toxicity of both types of compost belongs to the IV hazard class (hypotoxicity).

Thus, the evaluation of non-traditional ameliorants based on sewage sludge showed their hypotoxicity, while the most sensitive test organism, in this case, is *Chlorella vulgaris* algae.

In field conditions, the evaluation of soil ameliorants was carried out on experimental plots in a sand quarry to be recultivated.

Most soils in the Mari El republic are sod-podzolic with low natural fertility. The research showed that the sand quarry soil has a low content of humus (0.72 %) which is only a half of humus content in new soils on adjacent territories. The amount of mobile phosphorus and exchangeable potassium is low: 1.2 mg/100 g and 1.7 mg/100 g of absolute dry soil correspondingly. The reaction of the medium is strongly acidic (pH=4.7). The quarry soil is heavily compacted in comparison with natural soils (1.7 times).

The content analysis of heavy metals in the quarry soil and adjacent forest territory didn’t find the exceedance of tolerable levels. However, in forest soil, their concentration was higher than in the quarry (table 2). This is probably due to the lack of the most contaminated layer of soil in the quarry.

The evaluation of the biological activity of soil in the quarry showed no significant differences in terms of such parameters as ammonifying and proteasic activities as well as the increase in transformation of complex organic substances in the soil of the sand quarry in comparison with the natural territory (Table 3).

Biotesting involving three test organisms (daphnia, chlorella and radish) showed no toxicity in soil extracts both from natural territory (SDF=1; TDF=1; factor toxicity index (FTI)=1.02) and the sand quarry (SDF=1; TDF=1.51; FTI=0.99).

The changes in physical and agrochemical properties in anthropogenically transformed soil are obviously reflected in the structure of the microbial community (table 4).

The results of studying quantitative, trophic and taxonomic compositions of prokaryotic cells and mycelial organisms showed that the soil of the sand quarry contains the prevailing oligotrophic population of micro-organisms and decreased quantity of aerobic cellulose-digesting bacteria and mycelial fungi. The increase in pedotrophy and oligotrophic coefficients with equal mineralization of organic substances in soil indicates the activity of processes connected with humus and humus-bearing substances disposal.

Using criteria and indicators for soil degradation [15] allowed for making the conclusion about the extent of the sand quarry transformation: physical and chemical parameters show the fourth grade of soil degradation, while biological parameters don’t differ much from the indicators of natural territory.

### Table 1. The class of hazard for non-traditional ameliorants determined with biotesting methods involving daphnia, bacteria, and algae

| The variants of the experiment | The toxicity indicators in case of daphnia | The toxicity indicators in case of bacteria | The toxicity indicators in case of algae | Hazard class |
|--------------------------------|------------------------------------------|-------------------------------------------|-----------------------------------------|--------------|
|                               | Lethal dilution factor (LDF) |
| Fertilizers with a 5-year composting period | – | 1 | V | -1.13 | V | 6.03 | IV | IV |
| Fertilizers with a 3-year composting period | 4.68 | 10.8 | IV | -13.56 | V | 8.13 | IV | IV |

### Table 2. The content of heavy metals in the soils of studied sites

| The variants of the experiment | Cu mg/kg | Cd mg/kg | Zn mg/kg | Sr mg/kg | Pb mg/kg |
|--------------------------------|----------|----------|----------|----------|----------|
| Natural territory (forest)     | 2.75±0.045 | 0.18±0.024 | 2.49±0.411 | 0±0.00 | 4.13±0.376 |
| Sand quarry                    | 1.27±0.021 | 0±0.00 | 2.37±0.142 | 0±0.00 | 0.72±0.022 |
| Maximum permissible concentration | 3.0 | 0.5 | 23.0 | 7.0 | 32.0 |

### Table 3. The biological activity of soil at studied sites

| The variants of the experiment | The biological activity of soil |
|--------------------------------|--------------------------------|
|                               | Cellulose-digesting activity, % | Ammonifying activity, pH of air environment | Proteolytic activity, % |
| Natural territory (forest)    | 13.57 | 7.33 | 0.71 |
| Sand quarry                   | 27.67 | 6.67 | 0.51 |
| LSD 05                        | 3.35 | * | * |

* - the differences at the 5 % level of significance are not reliable
The soil of the sand quarry was fertilized with a non-traditional organic fertilizer (sewage sludge + sawdust) with a 5-year composting period (120 tones/ha) and the same non-traditional fertilizer but with a 3-year composting period (120 tones/ha).

When planning ameliorating activities, it is necessary to consider their influence on soil biota. The indicators of biological activity allow for identifying the direction of changes in soil and ecological conditions, soil fertility. This becomes obvious even earlier than changes in other fertility indicators happen (e.g. the content of humus). The most useful ameliorating techniques are identified as a result of the comparison. That’s why the field experiments first involved the determination of the actual biological activity of soil three months after the introduction of ameliorants.

The evaluation of the biological activity of soil on experimental sites showed that there were significant differences between experimental variants and control samples (excluding cellulose-digesting activity in the case of fertilizers with a 3-year composting period) (Table 5). The monitoring of changes in chemical, physical and biological parameters of soil and phytotoxicity was carried out by biotesting for 8 years.

The agrochemical analysis shows that the degree to which main nutritional substances are available, as well as the content of humus in the soil at the site, are decreasing (Table 6). The content of humus is decreasing in all variants of the experiment in comparison with initial values. This is due to the activity of micro-organisms that started to use less available organic matter (humus) because the available ameliorants are lacking.

However, in comparison with control samples, the variants of the experiment indicate a better situation with humus and the availability of main nutritional substances. The exception is the variant involving fertilizers with a 3-year composting period. In this case, the content of potassium is 2 times lower than in the control sample. Also, the soil becomes less acidified in the variants of the experiment.

The introduction of non-traditional ameliorants doesn’t significantly impact the content of heavy metals in soil (Table 7) and their content doesn’t exceed the maximum permissible concentrations.

The study of the possible toxicity of soil at the experimental site which was carried out by biotesting for the whole period of research (2011–2016) showed low toxicity of soil ameliorated with compost having a 3-year composting period. Since 2015 the biotesting was performed only on radish seeds. The results have shown no phytotoxicity in all variants of the experiment and the state of bio-organisms is normal (FTI from 0.96 to 1.0).

The analysis of biological activity indicators has shown that involved ameliorants activate cellulose-digesting and ammonifying activities both in terms of fertilizers with 3 and 5-year composting periods (Table 8).

Table 4. The population of main ecological and trophic groups of micro-organisms and the indicators of activity of microbiological processes in podsolic sandy soil

| Groups of micro-organisms and the indicators of activity of microbiological processes | Sand quarry | Natural territory (forest) |
|-------------------------------------------------------------------------------------|------------|---------------------------|
| Ammonifiers, million CFU / gram of absolute dry soil                                | 1.02±0.06  | 1.05±0.05*                |
| Aminoautotrophs, million CFU / gram of absolute dry soil                            | 0.48±0.02  | 0.49±0.02*                |
| Actinomycetes, million CFU / gram of absolute dry soil                              | 0.21±0.01  | 0.14±0.01                 |
| Oligotrophic plants, million CFU / gram of absolute dry soil                        | 1.36±0.05  | 1.05±0.04                 |
| Humus destructors, million CFU / gram of absolute dry soil                          | 0.92±0.03  | 0.21±0.01                 |
| Mycorrhizae, thousands CFU / gram of absolute dry soil                              | 0.007±0.35 | 0.084±3.94                |
| Cellulose destructors,**                                                            | 40.0±1.16  | 54.0±1.83                 |
| Nitrogen fixers,**                                                                  | 14.0±0.71  | 0.0±0.0                   |
| Mineralization coefficient (meat-and-peptone agar/starch-and-ammonia agar)          | 0.47       | 0.47                      |
| Pedotrophy coefficient (soil agar/meat-and-peptone agar)                           | 1.34       | 1.00                      |
| Oligotrophic coefficient (nitrite agar/meat-and-peptone agar)                       | 0.90       | 0.21                      |

* – the differences at the 5 % level of significance are not reliable;  
** – % of soil lumps fouling

Table 5. The biological activity of soil at the experiment site

| The variants of the experiment | The biological activity of soil |  |
|--------------------------------|-------------------------------|---|
|                                | Cellulose-digesting activity  | Ammonifying activity | Proteasic activity |
| Fertilizers with a 3-year composting period | 34.82 | 7.82 | 1.11 |
| Fertilizers with a 5-year composting period | 44.05 | 7.59 | 1.36 |
| Control sample                 | 27.67 | 6.67 | 0.51 |
| LSD<sub>0.05</sub>             | 14.94 | 0.72 | 0.45 |

* – the differences at the 5 % level of significance are not reliable
The introduction of compost based on sewage sludge in podzol sandy soil contributed to the increased population of ecological and trophic groups of microorganisms, taking part in mineralization of organic matter. For example, the total population of microorganisms determined by direct microscopic examination accounts for 2,1×10⁶ CFU/g. of absolute dry soil. The introduction of compost based on sewage sludge leads to an increase in the population of microbes by 1.5–2.5 times in comparison with control samples. The most active process of ammonification, which is the initial stage of organic matter transformation, takes place after the introduction of compost based on sewage sludge with a 3-year composting period (table 9).

The population of microfungi and actinomycetes in ameliorated soil is not big but positively grows in comparison with control samples. The increase in the population of microfungi in sandy soil under the influence of compost based on sewage sludge also indicates the high level of organic compounds mineralization. The increase in the population of actinomycetes in soil, modified by non-traditional organic fertilizers, indicates quite deep mineralization of hard-to-degrade of nitrogen compounds.

The most significant changes in the population of microflora in happened during the first year of soil optimization. This is due to the development of microorganisms related to the transformation of organic matter.

For the next years of research, the number of ammonifying microorganisms slightly decreases, but their population stays positively higher than control values. The third year of recultivation is characterized by a significant increase in the number of fungi and cellulose-digesting microorganisms, performing the first stage of organic matter humification, and actinomycetes, taking part in its last stage.

In comparison with other groups of microorganisms, actinomycetes use hard-to-digest components of plant tissue due to a more powerful enzymatic apparatus. And this trend keeps on. It’s worth noting the low population of nitifying bacteria in the ameliorated sandy soil of the quarry. The recultivation of podzol sandy soil by non-traditional fertilizers ambiguously affected nitrogen fixers.

It was determined that the frequency of occurrence of azotobacter in soil, ameliorated by compost based on sewage sludge, decreases. In general, the occurrence of azotobacter in soil was low (from 3 to 14 %).

One of the research tasks is to evaluate the influence of non-traditional ameliorants on the growth of Scots pine at the recultivated site.

In the variants with 3 and 5-year composting periods, the average height of Scots pine increased by 37.03 и 37.6 times respectively during the whole time of research. In the control variant, the average height of plants during the same period increased by 13.2 times (table 10).

Thus, the analysis of chemical, agrochemical, biological and toxicological parameters of soil in the sand quarry, ameliorated by non-traditional organic fertilizers based on sewage sludge and sawdust of softwood and hardwood, showed that the introduction of fertilizers optimizes soil and ecological conditions and contributes to the intensification of growth of scots pine plantlets. However, because compost with a 3-year composting period is characterized by phytotoxicity, it is more appropriate to use organic fertilizer with a 5-year composting period to reclaim disturbed soils and create forests on them.

Table 6. The agrochemical parameters of soil (2017).

| The variants of the experiment | The agrochemical indicators | pH (acidity level) | Humus, % (availability) |
|-------------------------------|----------------------------|-------------------|-------------------------|
|                              | Mg per 100 g of soil (the degree of availability) | (very low) | (very low) | |
|                               | P₂O₅ | K₂O | NO₃ | 5.68 (close to neutral) | 0.43 (very low) |
| Fertilizers with a 3-year composting period | 3.46 | 1.88 | 0.27 | |
| Fertilizers with a 5-year composting period | 1.86 | 0.73 | 0.26 | 5.47 (slightly acidic) | 0.51 (very low) |
| Control sample                 | 0.97 | 1.36 | 0.03 | 5.27 (slightly acidic) | 0.11 (very low) |

Table 7. The content of heavy metals in the ameliorated soil of the sand quarry.

| The variants of the experiment | The content of metals in soil, mg/kg |
|-------------------------------|-----------------------------------|
|                              | Cu | Cd | Zn | Pb | Ni |
| Fertilizers with a 3-year composting period | 3.04±0.504 | 0±0.00 | 7.21±0.985 | 1.51±0.376 | 1.95±0.113 |
| Fertilizers with a 5-year composting period | 1.64±0.197 | 0±0.00 | 4.17±0.502 | 1.06±0.261 | 1.89±0.102 |
| Maximum permissible concentration | 3.0 | 0.5 | 25.0 | 32.0 | 4.0 |

Table 8. The dynamics in the biological activity of soil at the recultivated site.

| Variant of the experiment | The parameters of the biological activity of soil | Ammonifying activity, pH of air environment |
|---------------------------|-----------------------------------------------|------------------------------------------|
|                           | 2012  | 2014  | 2015  | 2017  | 3-year composting period | 5-year composting period | Control sample | LSD (0.5) | 3-year composting period | 5-year composting period | Control sample | LSD (0.5) |
| Cellulose-digesting activity, % | 12.50 | 60.4 | 76.16 | 59.30 | 4.94 | 10.66 | 18.69 | 12.25 |
| 3-year composting period | 19.50 | 28.0 | 29.61 | 25.18 | 4.94 | 10.66 | 18.69 | 12.25 |
| 5-year composting period | 5.67 | 8.7 | 8.50 | 8.75 | 4.94 | 10.66 | 18.69 | 12.25 |
| Control sample | 5.25 | 7.3 | 7.50 | 7.75 | 4.94 | 10.66 | 18.69 | 12.25 |
| LSD (0.5) | 0.50 | 0.81 | 1.05 | 1.29 | 4.94 | 10.66 | 18.69 | 12.25 |
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