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Agrochemical Characteristics of Sawdust-Derived Compost

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Abstract

The problem of sawdust utilization represents a challenge for almost all regions of Russia. At the same time, agricultural lands suffer from acute deficiency of organic fertilizers. The technology of sawdust composting using an association of microorganisms, which has been developed at the Irkutsk Institute of Chemistry SB RAS, allows, at least partially, addressing both of these problems. The paper deals with the main agrochemical indicators of the fertilizer produced from sawdust. Composting is carried out using different types of sawdust (deciduous and coniferous) over different years in various regions of Russia. It is shown that regardless of the substrate composition, time and place of composting, the fertilizer is stable in terms of composition and basic agrochemical indicators. The total amount of nitrogen, phosphorus, and potassium in the compost is comparable to that in high-quality organic fertilizers like high-moor peat, while the content of the mobile forms of main biogenic elements is higher. These substances, as well as humic acids, which are contained in the fertilizer, ensure the effective growth and development of plants during the vegetation season. The finished compost has a high cation exchange capacity and low hydrolytic acidity, which allow decreasing the removal of cations from plough layers. The advantages of the compost include close-to-neutral pH value and the absence of weed seeds and phytopathogens. The fertilizer does not contain phytopathogenic microorganisms and parasites, and the amount of toxic and hazardous substances is much lower than the maximum permissible concentrations established for soils. The use of this compost will not only increase the yield of agricultural crops but also permit to eliminate the large-tonnage waste of timber processing enterprises.

Keywords: compost, sawdust, agrochemical indicators

INTRODUCTION

In 2016, the total world amount of recorded wood felling was 3.73 billion m^3 [1]. It was increasing annually by 0.8 during the recent five years. Russia is among five leading countries in the amount of wood felling (214 million m^3). Only half of felled wood is used appropriately. The utilisation of sawdust and chips is governed by the Federal Laws No. 89-FZ [2] and No. 7-FZ [3]. In agreement with these documents, the residues from wood sawing are considered as industrial wastes, so strict neutralization requirements are posed on them. To conserve the environment, all enterprises producing sawdust should utilise this waste in the proper way. According to legislative acts, sawdust utilization may be carried out only by specialised licensed organisations. Special vehicles are to arrive to the enterprises of woodworking industry according to a schedule and to carry the formed wastes away. Then sawdust and chips are transported to the place of neutralization. Sawdust stacking, which occurs everywhere, is unacceptable because high flammability risk is thus generated, first of all due to the ability of sawdust to self-ignition. Therefore, sawdust utilisation is a complicated and expensive process; reduction of the expenses for this process would cause significant saving of the operating costs for sawmill owners.

At the same time, the majority of agricultural lands in the RF suffer from the lack of organic fertilizers. For example, the amount of fertilizers introduced in the Irkutsk Region is 21 times lower than the necessary amount [4]. A consequence of this lack is a decrease in crop productivity and worsening of product quality. During the recent years, a trend to increase the amount of organic fertilizers introduced into fields. For instance, in 2018 the amount of organic fertilizers introduced in the Irkutsk Region was 350 thousand tons, which is more by 25 % than the amount introduced the year before [5].

A usual practice of modern agriculture has become the introduction of only mineral fertilizers. This causes additional losses of humus as a consequence of an increase in the activity of soil microflora, which satisfies its need in carbon mainly through the decomposition of humus in the case of the lack of free organic matter and the absence of a sufficient amount of nitrogen [6]. The loss of 0.1 % of humus every year leads to the loss of grain crops in the amount of 1 c/ha. For stable functioning of agrocenoses, their periodic recovery is necessary, which first of all involves the introduction of the organic matter into the soil. Recovery of humus losses may be provided by the introduction of substrates rich in lignin, in particular straw, peat, sawdust, mixtures of bark with mineral substances, and composts based on the mentioned substrates. Along with other positive effects, organic fertilizers serve as additional sources of biologically active substances for plants [7]. In addition, they stimulate the reproduction of rhizospheric microflora, which is also an active supplier of these substances.

Thus, the use of sawdust as an organic substrate is profitable from the ecological and economical points of view. The use of sawdust as fertilizer has both positive and negative features. On the one hand, sawdust provides a good mulching effect. On the other hand, lignocellulose raw material possesses increased ability to the physical and chemical absorption of mineral substances due to the presence of functional groups and high surface activity of the particles. It was established that 1 t of sawdust is able to bind physically and chemically the whole amount of nitrogen present in 1.8 t of hen droppings and 42 L of ammonium hydroxide (aqueous ammonia) [8]. Because of this, the additional introduction of the high doses of mineral nitrogen is necessary, which provokes superfluous reproduction of soil microorganisms, generally causing a decrease in the content of humus in the soil [9]. A negative effect of lignocellulose wastes may be also caused by the presence of rapid liberation of biologically active substances during microbial degradation in soil. First of all, these substances include low-molecular phenol compounds. Thus, small amounts of cinnamic, coumaric, salicylic and benzoic acids, which are the products of lignin decomposition, inhibit plant growth, while many phenolcarboxylic acids have a negative effect on seed germination [10]. Therefore, to use sawdust as a fertilizer, it is necessary to process it.

The most convenient method is the microbial composting. Wood sawdust is widely used as a substrate to prepare compost both in Russia and abroad [11–16]. However, most frequently sawdust is used as only a small part in the mixture of various organt5ic substrates. The mixtures in which the fraction of sawdust is not less than 90 % are practically not composted at all. A method of accelerated sawdust composting using a specially selected composition of wood-destroying fungi was developed at the A. E. Favorsky Irkutsk Institute of Chemistry SB RAS (IrICh SB RAS) [17]. This method allows using organic monosubstrate with mineral additives and slaked lime to neutralize sawdust. The physiological activity of microorganisms incorporated into the association was demonstrated [18]. The introduction of the microbial association allows one to stimulate the process and to improve the quality of the product.

The goal of the present work was to compare agrochemical parameters of composts prepared as a result of industrial experiments with wood sawdust of different compositions carried out in different regions of Russia. For comparison, highmoor peat was used as one of the most frequently used organic substrates.

EXPERIMENTAL

Research procedures

Industrial sawdust composting was carried out at the following sites at different time (sawdust composition and the volume of compost are indicated in parentheses):

Arkhangelsk Region, Sovetskiy settlement; 2008 (aspen, 60 m^3) (1)

Irkutsk; 2014 (pine/larch mixture, 30 m^3) (2)

Chita; 2010 (larch with small inclusions of pine, 30 m^3) (3)

Arkhangelsk Region, Bereznik village; 2018 (pine/spruce mixture, 60 m^3) (4)

Fresh sawdust of deciduous and coniferous trees was used for composting. Sawdust composition (averaged over all samples, mass %); C (53.9), N (3.4), H (6.7), humidity 10.9, pH of water extract (pH_{aq}) 5.6, pH of saline extract (pH_{KCl}) 5.9. The composition of the microbial association: *Acremonium* sp., *Phanerochaete chrysosporium* Burds. 1 MR-1 (Institute for Water and Environmental Problems, FEB RAS, Khabarovsk), *Trametes versicolor* (L.: Fr.) Pilat, provided by D. I. Stom (Research Institute of Biology at the ISU, Irkutsk), *Phanerochaete chrysosporium* Burds. ATCC-24725 (VNPO Gidrolizprom, St. Petersburg), *Sporotrichum pulverulentum* (conidial stage of *P. chrysosporium*) Novobr. 1767 (All-Russia collection of microorganisms, Pushchino). Microorganisms were grown individually on a liquid medium, then dried in the nonsterile mode on zeolite with granule size 3–5 mm. Fertilizers used as mineral additives were: ammonium nitrate phosphate (N/P/K = 17 : 17 : 15) – 8 kg/t, carbamide – 8 kg/t, slaked lime or dolomite powder – 5 kg/t. For compost (4), the fraction of carbamide was two times lower. The substrate was wetted to the humidity of 60 %. Composting was carried out on open sites with natural wetting and aeration. An average sample was taken for analysis after composting for 4 months.

Methods of investigation

Agrochemical analysis of the samples was carried out in agreement with the State Standard procedures for organic fertilizers: acidity of the medium (pH) was determined according to GOST 26423–85, total nitrogen content - according to GOST 26715–85, P_2O_5 – GOST 26717–85, K_2O – GOST 26718–85, the content of the mobile forms of P_2O_5 – GOST 27894.5–88, ammonium nitrogen – GOST 27894.3–88. Determination of nitrate nitrogen was carried out using the reaction with diphenylamine in Rim modification [19]. Humic acids were determined according to GOST 9517–76, the sum of absorbed bases – according to GOST 27821–88, cation-exchange capacity – according to GOST 17.4.4.01–84, hydrolytic acidity – GOST 26212–91.

Vegetation experiments

Vegetation experiments were carried out in vessels 0.25 L in volume, the amount of soil was 200 g. The compost was added in the amount of 5 g per vessel. In each vessel, 5 seeds of tomatoes, cucumbers or wheat, 10 seeds of radish or 2 seeds of pea were sown. Experiments were carried out with 5 times repetition. Results were calculated after two weeks for cucumbers, radish, tomatoes, wheat and after three weeks for pea. After the experiment, germination capacity was estimated, the length of seedlings and roots was measured, the masses of aerial and ground parts of all plants were determined. For the discussion of results, the length and mass were reduced to the same number of plants. Results of the experiments were treated according to [20].

Field experiments

Field experiments were carried out on light-grey soils of the teaching ground of the Irkutsk State Agricultural Academy (Molodezhniy settlement, Irkutsk Region). The soil is heavy loam in the granulometric composition, it is characterized by the acid reaction of the plough layer (pH_{KCl} 4.6). Humus content (2.4 %) and total nitrogen (0.1 %) are low. Exchangeable potassium content in the plough layer is 18 mg/100 g of soil, mobile phosphorus 40 mg/100 g of soil. Potato seeds of Nevskiy variety were used in the work. Compost was introduced manually before spring digging (1 kg/m^2) or during potato planting into each hole (0.2 kg). The plot area was 10 m^2. The experiment was repeated 4 times.

The determination of heavy metals and arsenic was carried out on the basis of A. P. Vinogradov Institute of Geochemistry SB RAS (accreditation certificate of the analytical centre No. ROSS RU.0001.513593, date of issue: February 16, 2009); the sanitary hygienic report was obtained after tests carried out by the Centre of Hygiene and Epidemiology in the Irkutsk Region (accreditation certificate RA.RU.710079, issued July 30, 2015).

RESULTS AND DISCUSSION

Fresh sawdust, independently of composition, is extremely poor in the major biogenic elements (Table 1). For instance, phosphorus, potassium, humic acids are completely absent, while the amount of nitrogen varies from the trace level to 0.2 mass %. With the high fraction of organic

TABLE 1

Qualitative and quantitative composition of composts

Parameter, units	Sawdust[1]	Compost (1) (aspen)	Compost (2) (pine/larch)	Compost (3) (larch)	Compost (4) (pine/spruce)	High-moor peat[2]
Appearance	Light yellow structured mass	Dark-brown powder with admixture of wood sawdust	Friable brown mass with the inclusions of structured sawdust	Friable brown mass with the inclusions of structured sawdust	Friable brown mass with the inclusions of structured sawdust	Friable mass with saturated black colour or black-brown tint
Mass fraction of organic matter, %	82	44.6	61.8	53.8	66.1	72–94
Cation exchange capacity, mg-equiv/100 g	1.2	8.98	10.25	9.11	10.75	10–12
Hydrolytic acidity, mg-equiv/100 g	7.3	1.14	1.14	1.17	1.12	5–10
Sum of absorbed bases, mg-equiv/100 g	16.2	31.5	31.8	35.6	37.6	60–90
pH of water extract (pH_{aq})	4.5	6.2	7.2	6.9	7.7	2.5–3.5
pH of salt extract (pH_{KCl})	4.2	6.4	6.8	6.5	7.2	3.0–3.9
Mass fraction of humic substances, calculated for the dry substance, %	0	5.3	11.3	9.2	9.4	9–14
Mass fraction of ash, %	2.9	20.7	20.1	18.5	12.55	2–12
Mass fraction of total nitrogen (N), calculated for dry substance, %	0.18	1.62	2.22	1.87	1.65	0.7–1.35
Content of ammonium nitrogen (N/NH_4), mg/100 g	0	500	1200	800	250	5–20
Content of nitrate nitrogen (N/NO_3), mg/100 g	0	140	150	140	20	n/d
Mass fraction of phosphorus (P_2O_5) calculated for the dry substance, %	0	0.22	0.28	0.24	0.44	0.1–0.3
Content of the mobile forms of phosphorus (P_2O_5), mg/100 g	0	1200	1250	1300	1500	n/d
Mass fraction of potassium (K_2O) calculated for the dry substance, %	0	0.5	0.4	0.45	0.4	0.01–0.24
Content of the mobile forms of potassium (K_2O), mg/100 g	0	1000	1000	1000	1000	n/d
Mass ratio C/N	19.7	6.8	6.2	8.4	8.7	24.1

Note. N/d means “not determined”.
[1]Average over all types of sawdust.
[2]Literature data [25].

TABLE 2

Results of vegetation studies of the crops after the introduction of compost (1)

Crop	Seedling		Root	
	Length, %*	Mass, %*	Length, %*	Mass, %*
Pea	122	143	100	158
Wheat	100	121	147	137
Radish	n/d	179	n/d	212
Cucumber	112	114	144	186
Tomato	153	145	171	185

Note. N/d means "not determined".
* With respect to the reference for the introduced dose 1 kg/m^2.

TABLE 3

Effect of compost (1) on potato productivity

Version	Productivity	An increase in productivity	
	c/ha	c/ha	%
Reference	164	–	–
Compost 0.2 kg/hole	244	80	49
Compost 1 kg/m^2	228	64	39
LED_{05}	34	–	–

Note. 1. Dash means the absence of data. 2. LED_{05} is the least essential difference with a 5 % significance level.

matter, ash percentage is only 2–3 mass %, which leads to a high mass ratio of C/N. Fresh sawdust exhibits low cation exchange capacity and is unable to absorb bases efficiently, but it has high hydrolytic acidity. Initially, high activity of both aqueous and salt extracts (pH 4.5 and 4.2, respectively) increases jumpwise during storage (pH decreases to 3–3.5). These facts provide evidence of the impossibility to use sawdust as fertilizer without modification.

Transformation of sawdust (in the case of aspen sawdust, the product is ready after the treatment for 2 months, while in the case of coniferous sawdust it is ready after the treatment for 4 months) leads first of all to an increase in pH to the values corresponding to the neutral medium, an increase in the amount of total nitrogen by an order of magnitude as average, the appearance of phosphorus, potassium and humic acids in the substrate. Similar results were obtained in [21]. A positive aspect may be the appearance of the mobile forms of major agrochemically important elements. Cation exchange capacity increases to the level characteristic of high-moor peat, and hydrolytic acidity turns out to be substantially lower. These parameters are extremely important for the conservation of soil homeostasis [22]. Because of this, the introduction of the fertilizer allows stabilizing the wash-out of bases from agricultural soil. This is especially important for lean sod-podzol and grey forest soil. Thus, it was demonstrated that with an increase in the soil absorption capacity due to the introduction of ion-exchange sorbents, wash-out from the sod-podzol soils of the North-Western Region decreases by a factor of 1.5–3 as the average [23].

It is interesting that variation of the composition of sawdust, site and time of composting had almost no effect on the agrochemical parameters of the final product (see Table 1). Total nitrogen content varied from 1.62 to 2.22 mass %, and phosphorus from 0.22 to 0.44 mass %. A sharp decrease in the amount of mobile nitrogen in compost sample (4) is connected with a lower dose of mineral additives introduced in the beginning of composting. Coincidence with the high-moor peat in many parameters allows us to conclude that the quality of the ready product is high, while a substantially larger amount of the mobile forms of biogenic elements and optimal pH allow using sawdust compost without the introduction of the additional amounts of nutrients. One more positive quality of the resulting fertilizer is the absence of the seeds of weeds and pathogens. At the same time, microorganisms participating in composting are active in sup-

TABLE 4

Content of toxic and dangerous substances (average results over all composts)

Microelements and heavy metals	Content, mg/kg	MPC, mg/kg
Zn	36	100.0
Ni	<2.0	85.0
Co	<1.0	5.0
Cu	4.2	55.0
Cd	0.21	0.5
Pb	0.40	30.0
Hg	0.007	2.1
As	<3.0	10.0

Note. MPC is the maximum permissible concentration.

pressing the development of pathogens, in particular fusarium [18].

For compost (1), vegetation experiments were carried out (Table 2). Radish and tomatoes turned out to be most responsive to the introduction of fertilizers, all the studied parameters increased by more than 50 %. The development of other agricultural species was accelerated, too, especially the growth of the roots was noticeable. Field experiments with compost (1) were limited to the determination of the productivity of potatoes. An increase in the productivity reached 40–50 % after the introduction of compost in the dose of 0.2 kg per hole before planting or in the dose of 1 kg/m^2 during ploughing up (Table 3).

Investigation of the ready composts for the content of heavy metals, arsenic and pathogenic microorganisms (Table 4) demonstrated complete correspondence of the products to the sanitary epidemiological standards and maximum permissible concentrations. Similar results were obtained by the authors of [24].

According to the data of the Centre of Hygiene and Epidemiology in the Irkutsk Region, all compost samples do not contain lactose-positive colibasillus, pathogenic microorganisms including salmonellae, faecal streptococci, clostridia, viable helminth eggs, larvae and chrysalides of flies.

CONCLUSION

Fertilizer manufactured according to the technology developed by us is based on wood sawdust; it is stable in composition and main agrochemical parameters independently of the substrate, time and site of composting. The fertilizer contains nitrogen, phosphorus, potassium in the form easily assimilated by plants and in well-balanced form. These substances, as well as humic acids incorporated in the fertilizer, provide efficient growth and development of plants during the vegetation period. The fertilizer obtained by us is comparable with the high-moor peat in the major agrochemical parameters but exceeds it in the content of the mobile forms of major biogenic elements. An advantage of the resulting compost is a nearly neutral medium (pH about 7) and the absence of weed seeds, phytopathogenic microorganisms and parasites. The amount of toxic and dangerous substances in the fertilizer is much lower than the maximum permissible concentrations established for soil. The use of this compost provides an increase in crop productivity, which allows a rational utilization of large-scale wastes from the woodworking industry.

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