Technological, Agronomical and Economic Efficiency of New Organic and Organo-Mineral Soil Amendments

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Abstract. The intensification of crop production coupled with current declining soil fertility needs proper plant nutrition management and improved effectiveness of fertilizer use. Sustainable practices providing new soil amendments could be a useful tool to improve soil fertility and crop productivity causing economic benefits. The technology of processing local raw materials (leonardite, bentonite, and molasses) was developed to produce new soil amendments with optimal physical and chemical properties and to meet the needs of a particular crop in the nutrients. The best ratio of components was proved in a model experiment with an estimation of the full cost of final organic and organo-mineral soil amendments. In a field experiment, the effect of new soil amendments on available nutrients in Chernozem Podzolic and corn yield was studied. Two doses and methods of application (banding and broadcasting) of new soil amendments were compared taking into account its economic efficiency. Development of technologies to improve fertilizing properties of local organic materials, compliance to recommended doses, and methods of soil inputs application could increase the efficiency of crop production emerging environmental and economic benefits.

1 Introduction

With a growing world population food security has become a global concern. Soil protection in response to increasing food demand is a great challenge, which, in turn, may contribute lasting benefits for climate change mitigation and biodiversity conservation [1, 2]. The importance of fertilizers in raising soil fertility and food production is undoubtedly high. International Fertilizer Association declares that fertilizers play an important role in achieving several of the Goals of the 2030 Sustainable Development Agenda and contribute to Goals: 1 (No Poverty); 2 (No Hunger); 9 (Sustainable Industrialization); 13 (Climate Change); and 15 (Life on Land). Fertilization is essential element of all quality systems in primary production, such as Integrated Production, Good Agriculture Practice or Sustainable Agriculture Initiative [3]. On the one hand, our modern society would not exist without the invention of the Haber–Bosch process and synthetic nitrogen (N) fertilizers, which have become significant factor for increasing agricultural productivity worldwide [4]. On the other hand, the high rate application of synthetic nitrogen requires strategies to mitigate associated environmental damage, such as eutrophication of waters, greenhouse gases emission, soil degradation [5].

To minimize these environmental problems related to the use of chemical fertilizers, organic fertilizers are of increased interest as an alternative source of nutrients for crops. Organic fertilizers have long since been known to increase the organic matter content of the soil, therefore stimulating flourishing of beneficial soil organisms, which, in turn, improves nutrient mobilization and decomposition of toxic substances. They release nutrients slowly and contribute to the residual pool of organic N and phosphorous (P) in the soil, improving the exchange capacity of nutrients [6, 7].

Organic fertilizers serve as both fertilizers and soil amendments. It is known that application of organic amendments is an effective tool to improve soil structure, increase soil water retention as well as to buffer the soil against acidity, alkalinity, salinity, pesticides and heavy metals. Organic amendments have an increasing impact on

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aggregate stability and organic carbon content in macro- and micro-aggregate scale [8].

Locally available organic materials are an essential source of carbon and nutrients for arable soils. The most common soil organic amendments are animal manure and compost, but also peat moss, wood chips, straw, sewage sludge, sawdust *etc.* Meanwhile, several organic by-products coming from manufacturing processes such as residues from sugar extraction, biochar, distillery waste, biosolids from paper mill can be applied to soil [9].

Sound organic materials management contributes to environmental, economic and social benefits [10]. A socially inclusive and low-carbon economy is achieved by tapping into waste as a resource and increasing the use of secondary materials. Organic amendments are gaining popularity on the market within the European Union, if they come from approved or registered enterprises or plants [11]. The significance of production new soil amendments has become even clearer considering the escalating prices of chemical fertilizers. Involvement of local raw materials for the production of fertilizers is an important issue in agriculture today.

Integrated use of organic materials and chemical fertilizers is beneficial in increasing available nutrients content and organic carbon content in soil [12, 13]. Scientifically based application of organo-mineral amendments stimulates biological activity, improves soil structure, water retention and preserves soil fertility. Organo-mineral amendments provide essential nutrients [14], enhance soil physicochemical properties [15] and re-establish microbial populations [16].

Weak market and low application rate of organic amendments lead to a gap between the actual and potential crop yields. The lack of policy and institutional support in a changing technological environment may lead to negation of organic amendments efficiency by farmers before any economic or environmental benefits would appear. Increasing interest arises in production of organic amendments that can improve soil fertility, stabilize soil organic carbon and allow a sufficient release of mineral nutrients to sustain crop yields.

2 Materials and methods

There is an insufficient availability of organic materials in Ukraine connected with decreasing livestock production (in three times since 1992). That is why the role of alternative soil amendments is constantly increasing in Ukraine. As the main component of new soil amendments, a leonardite was chosen. Leonardite moisture content is 55.8 %, ash content 9.0 %, content of total nitrogen 0.06 %, phosphorus 0.001 %, potassium 0.02 % in dry matter, pH 5.3. To assess the role of organic fertilizer as source of humus, the data on its organic matter composition is necessary. Leonardite contains 48.3 % of carbon, while in pyrophosphate extract was determined carbon content 5.7 %.

To increase the degree of humification of leonardite and to improve its agrochemical characteristics different materials were used: bentonite, $FeSO_4$ and molasses. Model experiment was conducted to determine the best ratio of these components for production high-quality soil amendment with optimal physical and chemical properties.

The effectiveness of new soil amendments was studied in field experiment (table 1). Research was conducted on the experimental field «The impact of different levels of biologization of agriculture on soil fertility» (at State Enterprise «Experimental Farm Grakivske» NSC ISSAR, Kharkiv oblast, v. Novy Korotich). Geographic coordinate: 49°58'12.4"N 36°01'31.7"E. Natural-climatic zone – Forest-Steppe. Climate – temperate continental, sum of positive temperatures about 2400-2900 °C. The average annual precipitation is 465-680 mm. Soil of the experimental field - Chernozem Podzolic, low-humus heavy loamy formed on loess loam with humus content by the Tyurin method 4.1%; total nitrogen content - 0,21%; phosphorus by the method of Chirikov - 111 mg kg^{-1}; potassium by the method of Chirikov - 90 mg kg^{-1}.

Table 1. Field experiment design.

Treatment	Abbreviation	Total N fertilization (kg N ha^{-1})	Method of application
Without fertilizer	WF	0	-
Mineral fertilizer	MF	30	Banding
		60	Broadcasting
Organic amendment	OA	30	Banding
		60	Broadcasting
Organo-mineral amendment	OMA	30	Banding
		60	Broadcasting

The three-replicate trials was set up according to the randomized complete-block design. The elementary plot size was 4 sq. m. Maize (Zea mays) was cultivated. Soil samples were collected after harvest.

Analytical research was carried out in the certified laboratories. Total nitrogen content was determined by Kjeldahl method. Phosphorus and potassium content in soil amendments were determined by sample mineralization during heating with sulfuric acid followed by photometric determination. Mineral nitrogen (NH_4-N + NO_3-N) in soil was determined by modification of the method of NSC ISSAR named after O. N. Sokolovsky: nitrogen extraction from the soil using potassium sulfate then nitrates determined photometrically with disulfophenol acid, and ammonium with Nessler’s reagent. Available phosphorus and potassium in soil was determined by the Chirikov method, extracting P_2O_5 and K_2O by 0.5M acetic acid with a ratio of soil to a solution 1:25 followed by photometric determination. All measurements were performed in triplicate. Analysis of variance was performed using Statistica 10 software.

Calculation of cost of soil amendments production to assess the economic efficiency of their use was carried out taking into account the methodological approach and standards given in papers [17-19]. Evaluation of the economic efficiency of soil amendments and mineral fertilizers was carried out using the author's scientific and methodological approach, which provides an assessment of the impact on effective fertility (crop yield) and profitability of agricultural production [20]. In the calculations were used the following: the average cost of NPK 16% fertilizer - 11440 UAH/t; the average cost of organic soil amendment – 2984 UAH/t; the average cost of organo-mineral soil amendment – 5243 UAH/t; average costs NPK 16% fertilizer application – 1350 UAH/t; average costs of soil amendments application – 125 UAH/t.

3 Analysis and discussion

3.1 Production of new organic and organo-mineral amendments

Leonardite is an oxidized lignite, which has not completed process of coalification. It has high content of carbon (about 50 %) and considerable aromaticity. Leonardite and humic substances derived from leonardite used in many sectors agriculture [21, 22].

To increase humic substances content in leonardite and to improve its agrochemical characteristics were used different components (figure 1). Catalysts of the process of humic substances synthesis can serve variable-valent metals, such as iron; a bentonite was used as matrice to their synthesis. Bentonite is a complex mineral ($Si_8Al_4O_2 (OH)_4 \times nH_2O$) and it include amorphous silicon which is an center for the formation of organo-mineral complexes due to the polyvalence of this element. It is also used to improve soil quality and to prevent leaching of fertilizers from a soil [23]. Molasses (sugar refinery waste) were used as the binder during granulation of new soil amendments.

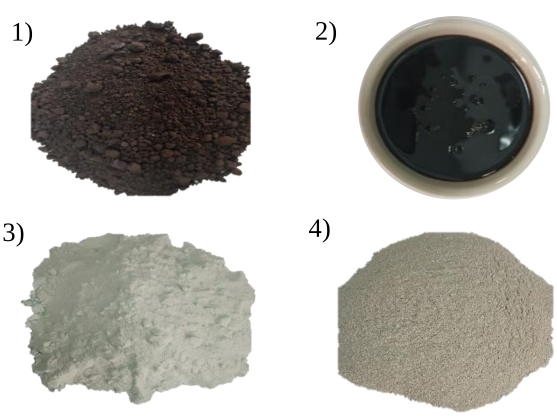


Fig. 1. The initial components for new soil amendments production: 1) leonardite; 2) molasses; 3) $FeSO_4$; 4) bentonite

Bentonite increases the strength of granules and as well as molasses make the granules denser. In addition, due to high hydrophilicity of bentonite its particles intensively absorb moisture that leonardite contains. The following technological scheme of production of soil amendment was developed (figure 2).

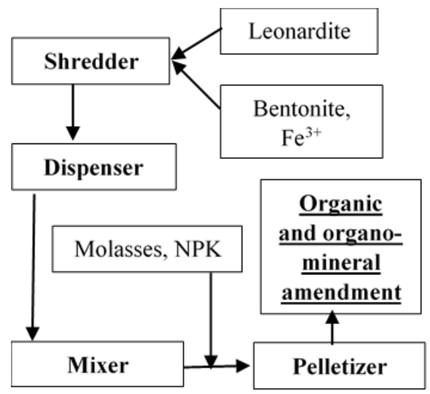


Fig. 2. The scheme of technological process of production of organic and organo-mineral amendments.

Granulation of amendments allows obtaining homogeneous granules of spherical forms, reducing consolidation of a product and preventing the destruction of a product during transportation. The technological solution for production organo-mineral amendment (OMA) involves the combination of organic compounds and mineral fertilizers in organo-mineral form (figure 3). The period of nutrients releasing from organo-mineral mixtures into a soil is longer compared to organic materials. The organo-mineral amendment production could be adapted to meet different specific needs (soil type, particular crop requirements for nutrients *etc.*).

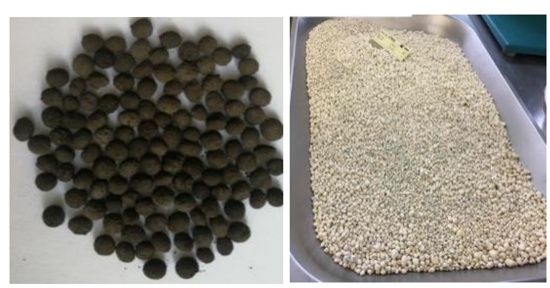


Fig. 3. Final organic soil amendment (left side of figure) and organo-mineral soil amendments (right side of figure)

In model experiment, it was proved that the best ratio of components for production of organic amendment with optimal physical and chemical properties is leonardite:bentonite:molasses:$FeSO_4$ in the mass ratio 1:0.5:0.5:0.01; to produce organo-mineral amendment the best mass ratio of components is leonardite:bentonite:molasses:$FeSO_4$:NPK 16 % fertilizer - 1:0,5:0,7:0,01:0,7.

Nutrients ratio in finished organic amendment (OA) is N:P:K = 1:0.1:2.7, while organo-mineral amendment have a balanced composition for particular crop and soil and promote a balanced crop nutrient uptake. OMA contents nutrients in ratio – N:P:K = 1:0.86:0.95 (according to the corn need).

Expert calculation showed that the estimated cost of 1 ton of organic soil amendment is 3134 UAH, and organo-mineral amendment - 5393 UAH (table 2).

Table 2. Calculation of the estimated cost of organic and organo-mineral amendment, 2020.

Cost	Cost per 1,000 tons, thousand UAH		Structure of production costs, %	
	OA	OMA	OA	OMA
The cost of raw materials	2876.5	5135.2	96.4	97.9
Remuneration	8.8	8.8	0.3	0.2
Fuel	17.2	17.2	0.6	0.3
Amortization	29.2	29.2	1.0	0.6
Current repairment	41.9	41.9	1.4	0.8
Other expenses	10.4	10.4	0.3	0.2
Production cost	2984.0	5242.7	X	X
Selling expenses	150	150	X	X
Total cost	3134.0	5392.7	X	X
Full cost of 1 ton, UAH	3134	5393	X	X

3.2 The effect of new organic and organo-mineral amendments on soil chemical indicators and crop yield

Soil pH plays a central role in many chemical properties and biological soil processes including solubility and availability of nutrients and trace metals. Soil pH value under different types and methods of application of organic and organo-mineral amendments do not change compared to the control, where no amendments was ever applied. Only high dose of organic soil amendment led to an increase in pH value of Chernozem Podzolic (table 3).

Nutrients in synthetic fertilizer are soluble and immediately available to the plants. Therefore, the effect of mineral fertilizer is fast, while from soil amendments nutrients slowly released into soil that makes them have prolong effect. Nutrients are easily lost from soils through fixation, leaching or gas emission and can lead to reduced fertilizer efficiency.

Nitrogen is one of the most important inputs in crop production and the main limiting factor for productivity in agroecosystems. It was found that the application of soil amendments significantly affects the nitrogen regime of chernozem podzolic with both broadcasting and band application, promotes the accumulation of mineral nitrogen (NH_4-N + NO_3-N) in the soil that increases proportionately with the application doses. The broadcasting application of organic and organo-mineral amendments increases the mineral nitrogen content by 0.7 mg/100 g (7 % compared to the control) and 2.0 mg/100 g (19 % compared to the control). Ammonium-nitrogen is accumulated in 1.2–1.4 times more intensive under broadcasting application of soil amendments than under banding. The amount of NO_3-N provided by new soil amendments was less than the amount provided by mineral fertilizer.

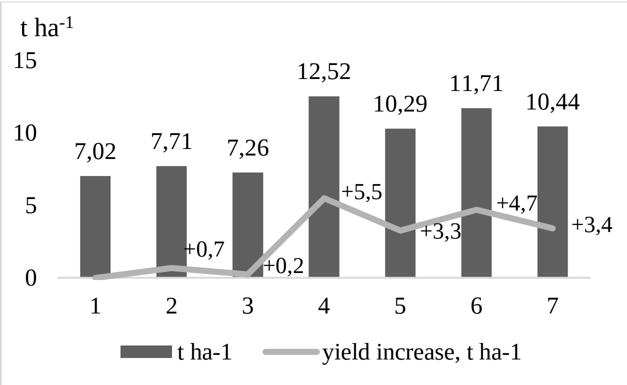
Table 3. Effect of new soil amendments on available nutrients content in the 0-20 cm layer of chernozem podzolic

Treatment	pH	NH_4-N, mg kg^{-1}	NO_3-N, mg kg^{-1}	P_2O_5, mg kg^{-1}	K_2O, mg kg^{-1}
Without fertilizer	6.1	59.0	45.0	70.0	120.0
MF banding	6.1	57.7	75.4	67.5	112.5
MF broadcasting	6.1	86.3	74.7	72.5	130.0
OA banding	6.1	56.1	43.5	67.5	117.5
OMA broadcasting	6.2	59.4	51.5	70.0	125.0
OA banding	6.1	55.8	46.5	67.5	120.0
OMA broadcasting	6.1	59.2	64.5	67.0	127.5
LCD_{05}	0.1	3.2	5.8	3.1	6.7

Phosphorus is the second most limiting nutrient in crop production. Unfortunately, the reserves of phosphate rock are finite; estimates of the reserve suggest that at the current rate of use this resource will become exhausted within some hundreds of years [24]. Phosphorus is abundant in soil; however, the concentration of plant available P in the soil solution is generally low [25]. New soil amendments do not have significantly effect on the content of available phosphorus in the soil. However, the application of new soil amendments (organic amendment as well as organo-mineral one) caused an increase in the content of available potassium in Chernozem Podzolic compared to the control.

Potassium is also an essential and unsubstitutable nutrient for plants. Although most soils are rich in K minerals, its availability to plants is relatively little. Hence, the demand for K fertilizer is increasing worldwide [26]. After broadcasting application of organic and organo-mineral amendment, the potassium content was increased by 0.5 mg/100 g (4%) and 0.8 mg /100 g (7%) compared to the control. Meanwhile, another study found the effects of leonardite applications on nutrient contents in soil were statistically significant [22].

With a growing world population, food security require appropriate management greater demand of fertilizers to increase yield per unit land. Corn is one of the most important food crops in the world and demand for maize is constantly increasing. Studies showed the increase of corn yield under the band application of organic and organo-mineral amendments by 5.5 and 4.69 t ha^{-1} compared to the control, respectively (LSD_{05} = 2.09) (figure 4).



Note. 1 – without fertilizer; 2 – mineral fertilizer (banding); 3 – mineral fertilizer (broadcasting); 4 – organic amendment (banding); 5 – organic amendment (broadcasting); 6 – organo-mineral amendment (banding); 7 – organo-mineral amendment (broadcasting)

Fig. 4. Effect of new organic and organo-mineral amendments on corn yield.

3.3 Economic efficiency of new organic and organo-mineral amendments

The results of calculation of economic efficiency of application of organic and organo-mineral amendment showed (table 4) that the total cost of band application of organic soil amendment was 15545 UAH/ha, meanwhile the cost of broadcasting method of their application - 31090 UAH/ha; for organo-mineral soil amendment these indicators were equal to 4026 and 8052 UAH/ha, respectively.

Table 4. Model calculation of cost indicators of application of new soil amendments, 2020.

Treatment	The rate on 1 ha, t physical mass	The cost of fertilizers, UAH/ha	Application costs, UAH / ha	Total costs, UAH / ha
MF broadcasting	0.375	4290	506	4796
MF banding	0.188	2151	254	2405
OA broadcasting	10.000	29840	1250	31090
OA banding	5.000	14920	625	15545
OMA broadcasting	1.500	7864	188	8052
OMA banding	0.750	3932	94	4026

Respectively, 96 and 97 % of the total costs for the use of both soil amendments belong to their value. Differences in costs are due to different application rates as well as different production costs of soil amendments. The use of soil amendments is much more expensive compared to the total cost of NPK 16% fertilizer.

Conditional additional income from band application of organic soil amendment was 23580 UAH/ha, while broadcasting application of OA characterized by conditional additional loss of 6950 UAH per hectare (table 5). At the same time, band application of organo-mineral soil amendment can provide conditional additional income 28898 UAH/ha, and broadcasting application of OMA - 16076 UAH/ha. Therefore, the conditional level of profitability of band application of organic amendment can reach 158% and band application of organo-mineral amendment - 204.4-734.9%, while the broadcasting application of organic soil amendment was unprofitable (as well as the application of NPK 16%).

Table 5. Model calculation of indicators of economic efficiency of application of new soil amendments, 2020.

Treatment	Cost of additional income, UAH/ha	Additional profit (loss), UAH/ha	Level of profitability (loss), %
Without fertilizer	-	-	-
MF broadcasting	1680	-2610	-60.8
MF banding	4830	2679	124.5
OA broadcasting	22890	-6950	-23.3
OA banding	38500	23580	158.0
OMA broadcasting	23940	16076	204.4
OMA banding	32830	28898	734.9

Note. The calculations take the average realization price of corn (October 2020) at the level 7000 UAH/t.

As a result, it was defined a higher economic efficiency of the application of organo-mineral soil amendment, compared to organic one, because application of OMA characterizes by the conditional additional income and the level of profitability which is significantly higher than similar indicators for OA. Moreover, the application of organic soil amendment was found to be economically inefficient.

It should be noted that the calculations are based on one-year data and need to be clarified on the basis of at least three-year field experiments. It is clear that in case of other price of harvested corn, as well as in case of cultivation of another crop, the economic efficiency may be completely different. Therefore, future research would be related to an effectiveness of new soil amendments for production of various crops.

4 Conclusions

1. Large use of synthetic inputs and soil fertility decline have emerged as major impediments to sustainable

agricultural production causing a large pressure on the environment. Soil amendments are an environmentally friendly alternative to recover soil fertility and they might offer the potential for sustainable agriculture through adaptation against climate change and lifting farmers out of poverty. Proposed technological scheme makes the production of soil amendments more efficient and effective. New soil amendments based on local raw materials and their efficient use is an option of maintaining soil quality and increasing crop production per unit of land from economic and environmental perspectives.

2. In model experiment on production of new soil amendments from local raw materials, it was proved that the best ratio of components is leonardite:bentonite:molasses:$FeSO_4$ in the mass ratio 1:0.5:0.5:0.01 to produce organic amendment with optimal physical and chemical properties. Moreover, soil amendments could be produced to meet the needs of particular crop in the nutrients though addition of NPK in calculated doses.

3. Correct dose and method of fertilizer application plays an important role in its efficient use. The results of field trial indicated that the application of new soil amendments can provide significant benefits for crop yield and provide an impact on accumulation of main nutrients in a soil. Band application of organo-mineral amendment increased corn yield, available N content in soil but had no effect on P_2O_5 and K_2O. Meanwhile, broadcasting application of organo-mineral amendment enhanced available potassium content in a soil. The plot with the broadcasting application of mineral fertilizer showed the highest nutrients concentrations; while it had the smallest yield increase compared the control plot, where no amendment was applied.

3. The higher economic efficiency of application of organo-mineral soil amendment in comparison with organic soil amendment is established. Thus, conditional additional profit of band application of organo-mineral soil amendment is by 22.6 % higher compared with organic soil amendment. Estimated level of profitability of organo-mineral amendment band application is in 4.7 times higher than profitability of organic amendment.

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