

Effect of Fertilization with the Sheep Manure Vermicompost on the Yield of Selected Plants and Selected Properties of Soil Developed from Loess

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ABSTRACT

The experiment was carried out in 2016–2018 in Łańcut, in the Rzeszów Foothills. The effect of fertilization using the sheep manure vermicompost on sweet potato of early cultivar (Carmen Rubin) and selected soil characteristics was investigated. The experiment was based on the method of randomized sub-blocks performed in four replications. Two cultivation technologies were used, in which the differentiating factor was fertilization applied or the lack of it. In the first technology (I_{nf} – without fertilization), no fertilization was used in the years of research; in the second technology (II_{fv} – fertilization with vermicompost), the vermicompost made from the sheep manure was applied. The vermicompost increased the yield of sweet potatoes of Carmen Rubin cv. and the share of large tubers in the yield structure. It also influenced the increase of organic carbon and total nitrogen in the soil as well as the content of available forms of phosphorus, potassium and magnesium. Some of the studied soil properties were less favorable compared to their condition before the start of the experiment.

Keywords: sheep, manure, vermicompost, sweet potatoes, yield structure, soil properties

INTRODUCTION

Sweet potato (*Ipomoea batatas* [L.] Lam.) has been cultivated in Poland since 1996 [Sawicka *et al.* 2000]. The plant belongs to the Convolvulaceae family. It comes from South America and it is an annual plant in the temperate climate zone [Podbielkowski and Sudnik-Wójcikowska 2003]. *I. batatas* plants have long creeping or standing stems that have the ability to produce roots at their nodes. The shape of the stems depends on the length of shoots, which in turn is associated with the cultivar and soil as well as the climatic conditions; it can range from 1 to 6 m. The length of the internodes is also different and ranges from a few to 10 cm; the density of planting has a large influence on this characteristic. Currently, sweet potatoes are grown on around 9 million ha area in the world, including about 80% of the world's

sweet potato production in China [Krochmal-Marczak and Sawicka 2011].

In the past, most of the sweet potato production was intended for consumption. The tubers of this plant are globally recognized raw material for the production of so-called sago (a type of granulated flour or groats), sugar, alcoholic beverages, and also a component of desserts, soups and baby nutrition. Currently, the sweet potato is recognized as a very good raw material for the production of functional food, which, in addition to the nutritional function, has an additional positive effect on the human health (antioxidant, anti-inflammatory, hepatoprotective, anti-cancer and anti-diabetic properties) [An 2004; Krochmal-Marczak and Sawicka 2018]. *I. batatas* is a plant with a huge capacity for absorbing the solar energy and converting it into biological mass; hence, the sweet potato tubers can also be used

for the production of ethanol or biogas, and the fresh mass of the above-ground parts (stems and leaves) – for the biogas production, both after wilting and after ensiling [Batista *et al.* 2019].

The aim of the study was to determine the effect of organic fertilization using the sheep manure vermicompost on the sweet potato yield and its structure, as well as some soil properties.

MATERIAL AND METHODS

A three-year field experiment was carried out on an individual farm in Łañcut, located in the Rzeszów Foothills, from May to October, in 2016–2018 years. The soil, on which the experiment was conducted, belongs to heavy ones with the granulometric composition of loamy silt (sand 5%, dust 80%, loam 15%); second valuation class of arable land; a type of brown soil developed from loess [Systematics of Polish Soils 6, 2019].

Since 2011, every two years, in autumn, the experimental field has been fertilized with the bovine manure (20 Mg ha⁻¹). Before establishing the experiment, the soil was characterized by a high content of available phosphorus and average content of potassium and magnesium (155.0, 180.0 and 95.0 mg·kg⁻¹, respectively). The share of organic carbon in soil was 2.2%, and total nitrogen 0.26%.

The experiment was based on the randomized sub-blocks method in four replicates. Two cultivation technologies were used, in which the differentiating factor was fertilization used or lack thereof. In the first technology (I nf – without fertilization), no fertilization was applied in the years of research; in the second technology (II fv), fertilization with the vermicompost made of the sheep manure was used, the characteristics of which are presented in Table 1.

The soil samples (taken from the Ap horizon from a 0–30 cm depth) before and after the

experiment were subjected to chemical analyses each year. The soil samples were collected at the plant harvest directly from the place of plant growth, creating a collective sample, from which 3 samples were taken for chemical analyses. Organic C was determined with the Tiürin method, N total by Kjeldahl method, pH in 1 mol KCl [PN-ISO10390: 1997] using a digital pH-meter (Cole Parmer Model No. 59002–00), available phosphorus according to the standard [PN-R-04023 1996], available potassium according to the standard [PN-R-04022 1996], available magnesium applying the norm [PN-R-04020, 1994]. Vermicompost was analyzed according to the following procedures: nitrogen by means of the Kjeldahl method, phosphorus with the vanadium-molybdenum method, potassium and calcium by flame photometry, and magnesium by means of the AAS method. The C:N ratio was calculated as well.

During the study period, the average annual temperature from May to October in Łañcut was 16±3.4°C in 2016, 21±4.5°C in 2017, 21.9±4.5°C in 2018 [IMiGW, 2019] (Fig. 1), and the average monthly rainfall at that time fluctuated around 113±56 mm in 2016, 131±55 mm in 2017, and 155±71 mm in 2018 [IMiGW, 2019] (Fig. 2).

The research involved cultivating the sweet potatoes of the early variety – Carmen Rubin – from Israel, which are characterized by pink skin and orange flesh. Sweet potatoes were planted on 200 m² strips that were then randomly divided to 20 m² plots. The distance between plants in a row was set at 50 cm, and distance between successive rows – at 75 cm.

In technology II fv, under each plant, 1 dm³ of vermicompost was introduced into the soil twice (before and during the experiment) bringing to the soil (NPK Ca Mg), on average: N – 7.67, P – 5.96, K – 7.84, Ca – 11.93, Mg – 2.73 g for each plant, annually. Vermicompost was applied at a dose of 22.7 Mg ha⁻¹, which was calculated

Table 1. Features of the sheep manure vermicompost used in the experiment

Features	pH _{H2O}	Salinity g·dm ⁻³	Conductivity (mS)	C	N	P	K	Ca	Mg	C:N
				%						
Min-max values	6.7–6.8	0.6–5.3	3.7–3.8	17.6–19.2	0.88–0.92	0.65–0.75	0.90–0.94	1.30–1.50	0.30–0.34	20–21
X±SD	-	-	-	18.4±0.8	0.90±0.02	0.70±0.05	0.92±0.02	1.40±0.10	0.32±0.02	20±0.5
Optimal level for plants *	6.0–7.5	about 1.0		mg·kg ⁻¹						
				40–80	125–250	1000–2000	60–120	20		

* Koñczak-Konarkowska 2009.

** Granberry *et al.* 2007.

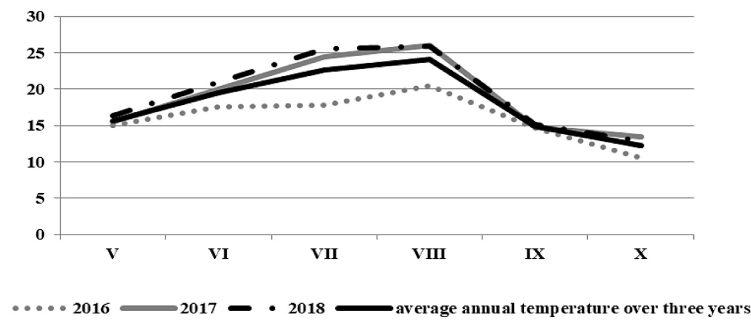


Fig. 1. Average monthly temperatures from May to October in 2016–2018 in Łańcut [°C]

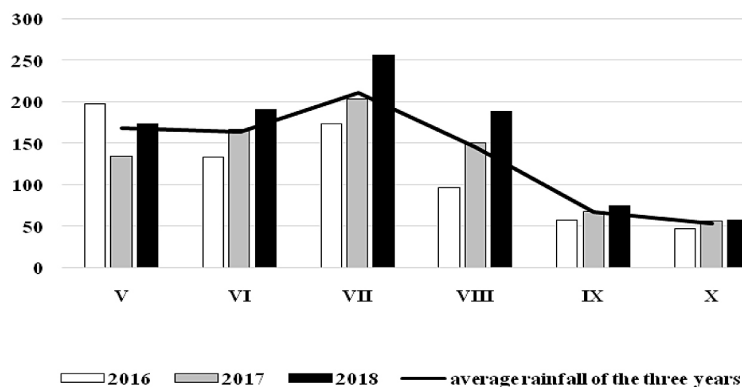


Fig. 2. Average monthly rainfall from May to October in 2016–2018 in Łańcut [mm]

on the basis of plant density per hectare and the amount of vermicompost (0.852 kg) brought under a single plant annually.

The experimental plots were covered with dark polyethylene film from the beginning of the growing season, which on the one hand was a protection against excessive weed infestation, while on the other –enabled the tested plants to use the solar energy better. The shields were kept on the plants for 4 weeks (depending on the weather conditions) and removed around mid-June.

Harvesting was performed at the end of October, after external symptoms appeared in the form of yellowing of leaves and shoots. Before harvesting, in accordance with the An [2004] recommendations, the above-ground parts of sweet potatoes were removed. After harvest, the size and structure of the yield were assessed.

The yield was divided into fractions with the mass: ≤ 0.20 , 0.21–0.40, 0.41–0.60, 0.61–0.80, 0.81–1.0, and > 1.0 kg. In each fraction, the number and weight of tubers and their percentage share in the yield, as well as the total and commercial yield of tubers were determined.

The study results are presented as mean \pm SD. The results were analyzed at the significance level

of 0.05, applying the Student's t test in Statistica ver.10 software.

RESULTS AND DISCUSSION

As demonstrated in previous studies, vermicompost is a fertilizer conducive to the size and quality of plant yields [Kostecka and Błażej 2000; Kostecka *et al.* 2001a, b; Kaniuczak *et al.* 2002; Kostecka *et al.* 2004]. Sweet potatoes are best grown on slightly or moderately acidic soil. According to Granberry *et al.* [2007], the optimal soil pH for its cultivation ranges from 4.5 to 7.0. In the experiment, the soil was characterized by an appropriate reaction for sweet potato cultivation (5.8–7.0) (Table 4).

The yield of sweet potato also depends on the type of soil and its abundance in nutrients. Sweet potatoes yield best on light, well-drained soils with a high content of organic matter. On the other hand, heavy soils with little air are, according to Burt [2008], less suitable for cultivating this species, which is confirmed by the results of the present experiment. The vegetation of these plants lasts from 130 to 150 days, and at

appropriate temperatures in the autumn, even up to 160 days. Absorption of nutrients by the sweet potato takes place throughout the entire growing season [Granberry *et al.* 2007].

The data in Table 2 shows that fertilization with the vermicompost produced from the sheep manure increased the average sweet potato yield significantly ($p < 0.05$) (Table 2).

The vermicompost used in the experiment is a fertilizer that slowly releases nutrients [Ali *et al.* 2015; Mahmud *et al.* 2018] and therefore, after its application to the soil, it could affect the sweet potato yield, securing the demand for nutrients throughout the growing season [Granberry *et al.* 2007]. This study showed the possibility of using the vermicompost made from the sheep manure for the cultivation of this valuable plant.

According to FAOSTAT [2016], the average sweet potato yield is estimated within 15 Mg ha^{-1} . The yield obtained in the experiment was much higher on the plots fertilized with vermicompost. The research conducted by Hartemnik [2003] and by Sowley *et al.* [2015] confirm these results. Sowley *et al.* [2015] showed that the yield of sweet potato of WFSP cv. (white-fleshed sweet potato) was greater on the plots fertilized with the poultry manure compared to those fertilized with mineral fertilizers (sweet potato yield with organic fertilization 12.4 Mg ha^{-1} , NPK fertilization 4.1 Mg ha^{-1}). According to Agbede and Adekiya [2011], the sweet potatoes grown on poor soils yield between 13.1 and 15.4 Mg ha^{-1} . Larger sweet potato yields can be obtained on light soils with adequate irrigation and with high nitrogen fertilization. Under such conditions, Njoku *et al.* (2001) reported a yield of $30\text{--}73 \text{ Mg ha}^{-1}$. Krochmal-Marczak *et al.* (2018) obtained similarly high yield – 31.18 Mg ha^{-1} on the soils abundant in nutrients. The soil that took part in the experiment was characterized by slightly acidic pH ($6.0\text{--}6.5$ pH in KCl), humus content (1.8%), from high to very high content of available phosphorus ($69\text{--}116 \text{ mg kg}^{-1}$) and average contents of potassium and magnesium ($90\text{--}123 \text{ mg kg}^{-1}$ K and $33\text{--}51 \text{ mg kg}^{-1}$ Mg soil dry matter). High sweet

potato yield is also obtained in China and ranges from 15 to 32.3 Mg ha^{-1} [FAOSTAT 2015–2017].

It is worth paying attention to the consumption value of sweet potato, which is determined, among others, by the yield structure. According to Sawicka *et al.* [2000] and Placide *et al.* [2013], the atmospheric conditions affect the sweet potato yield and its structure. It was found that high levels of rainfall in July and August in 2016–2018 could have reduced the number of small tubers and increased the number of the largest ones. In the author's own research, the sweet potato was growing in warmth and humidity. Similar results in the research on the structure of sweet potato yield were obtained by Sawicka *et al.* [2004].

The tubers with a mass of $0.41\text{--}0.60 \text{ kg}$ (34.4%) predominated in the yield structure of non-fertilized sweet potato (variant I nf), while the tubers with a mass in the range of $0.81\text{--}1.00$ (11.1%) had the smallest share, and there were no tubers above 1.0 kg . In variant II with vermicompost fertilization (fv), the sweet potato tubers were larger; most often they were tubers with a mass of $0.61\text{--}0.80 \text{ kg}$ (34.8%). The smallest tubers weighing $0.21\text{--}0.40 \text{ kg}$ (5.2%) were found to be the least inconvenient for a consumer. There were also tubers above 1 kg , which are easy to use (13.2%) (Table 3).

Ali *et al.* [2009] and Krochmal-Marczak *et al.* [2018] found that the sweet potato yield depends on the cultivar. In their research, the Carmen Rubin cv. had the largest tubers (from 0.60 to over 1 kg), with varying planting density from $30\text{--}50 \text{ cm}$ and different soil type.

In the present experiment, the technology using polyethylene film was employed, which could have had an influence on the yield and share of tubers in individual fractions. According to Wadas [2016], the use of covers in the cultivation of early potato cultivars improves the yield, especially the number and weight of large tubers. The use of polyethylene shield can affect the quality of tubers by increasing the content of dry matter, potassium and phosphorus and reducing the content of nitrates. This was also confirmed by the research conducted by Krochmal-Marczak *et al.* [2018].

In the case of sweet potatoes, a key role is played by the length of the frost-free period; therefore, according to some authors [Krochmal-Marczak and Sawicka 2011], commodity cultivation of this root crop is most desirable in central, south-eastern and south-western Poland.

Table 2. Commercial sweet potato yield depending on fertilization (Mg ha^{-1}) – on average from 2016–2018

Cultivation technology	Soil without fertilization (I nf)	Organic fertilization with vermicompost (II fv)
Yield amount	10.20 ± 0.47^a	24.64 ± 0.61^b

a, b – statistically significant differences.

Table 3. The effect of vermicompost fertilization on the yield structure

Mass fraction in kg	Tubers (%)				
	0.21–0.40	0.41–0.60	0.61–0.80	0.81–1.00	>1.00
Soil without fertilization (I nf)	26.4	34.4	28.1	11.1	-
Fertilization with vermicompost (II fv)	5.2	19.5	34.8	27.2	13.2

Table 4. Changes in soil characteristics due to fertilization with vermicompost after 3 years of experiment

Cultivation technology	pH in KCl	C org	N t	Content of available forms (mg kg ⁻¹)		
		%	%	phosphorus(P)	potassium (K)	magnesium (Mg)
(I nf) soil without fertilization	5.8–6.9	1.9±0.4 ^a	0.24±0.03 ^a	21.0±0.7 ^a	47.2±3.0 ^a	54.0±4.5 ^a
(II fv) fertilization with vermicompost	5.9–7.0	2.3±0.5 ^b	0.28±0.05 ^a	47.0±1.2 ^b	125.2±5.5 ^b	65.5±5.0 ^b

a, b – statistically significant differences ($p < 0.05$).

According to Krochmal-Marczak and Sawicka [2007], two periods in the growth and development of sweet potato can be distinguished in temperate climate – the first corresponding to an intensive growth of roots and leaves, the second – growth and development of tubers. Higher temperatures have a beneficial effect on the initial leaf growth and development, and later, lower temperatures are more beneficial for the tuber growth and development. No frosts were found during research in the Łańcut region.

The applied organic fertilization (sheep manure vermicompost) had a positive effect on the properties of the soil, on which the experiment was carried out (Table 4).

On the research plots fertilized in 2016–2018 with the sheep manure vermicompost, the content of available phosphorus, potassium, magnesium, as well as the share of organic carbon and total nitrogen in relation to non-fertilized plots increased significantly. However, fertilization with vermicompost in the sweet potato cultivation reduces the content of available P, K and Mg forms in the soil in comparison with the condition of these features before establishing the experiment. It probably resulted from the high demand of sweet potatoes for nutrients and also affected their average yield [Granberry *et al.* 2007]. This is generally consistent with the research of other authors. According to Jouquet *et al.* [2011], the bovine vermicompost increases the content of organic carbon and total nitrogen (both in the 0–5 cm and 5–20 cm layers) in relation to the plots fertilized with minerals. Organic fertilization with vermicompost, according to the author, did not differentiate the content of available phosphorus and potassium. In contrast, fertilization with the bovine vermicompost in a tropical climate significantly reduced the

leaching of nitrogen and potassium from the soil, compared to the mineral fertilization [Jouquet *et al.* 2011]. According to Azarmi *et al.* [2008], the vermicompost produced from the sheep manure and used at a dose of 15 t ha⁻¹, increased the content of total nitrogen, potassium and phosphorus in the soil. Pirya and Santhi [2014] reported an increase in the nitrogen and phosphorus content in the soils where fertilization with the bovine vermicompost was applied. They found an increase in the nitrogen content from 0.64% to 0.96%, and phosphorus from 0.25% to 0.47%.

CONCLUSIONS

1. The vermicompost made from the sheep manure was diversified in terms of the nutrient content. It contained the most calcium, followed by potassium, nitrogen and phosphorus, and the least magnesium. The pH of this vermicompost was appropriate for the growth and development of sweet potato, and the salinity could exceed the optimum level for this plant species.
2. The vermicompost used in the cultivation of the sweet potatoes of early cultivar (Carmen Rubin) had a positive effect on the size and structure of the yield. The share of tubers with the highest weight increased in the yield.
3. The use of the sheep manure vermicompost in the sweet potato cultivation increased the share of organic carbon and total nitrogen as well as the content of available forms of phosphorus, potassium and magnesium in soil. However, some soil features (P, K, Mg) were less favorable compared to their condition before the start of the experiment.

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