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THE EFFECT OF DIFFERENT ORGANIC FERTILIZERS AND DIFFERENT LOCALITIES ON CROP YIELD IN CONDITIONS OF ORGANIC FARMING

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Abstract

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Nitrogen fertilization of plants during the vegetation is very problematic in terms of organic farming. The balanced crop rotation and versatile nutrition are essential for maintaining good yields and high-quality products. The application of organic fertilizers and incorporation of green manure crops are one of the best options for achieving optimal results in organic farming. The goal of this long-term research was to examine the effect of several different organic fertilizers and divergent experimental stations on crop yield in conditions of organic farming. a total of 6 variants of fertilization were evaluated in this experiment: 1. unfertilized, 2. green manure (GM), 3. GM + renewable external sources, 4. GM + renewable external sources + biostimulants, 5. GM + farm fertilizers, 6. GM + farm fertilizers + biostimulants. The winter wheat was sown at the start of the experiment in autumn of 2014. Therefore, green manure was not cultivated in the first experimental year. The results from the first year of this experiment showed, that the variant with renewable external resource (digestate) provided the highest yield. The average yield of wheat grain on this variant was about 7.12 t/ha, which is increased by 0.74 t/ha in comparison with unfertilized control variant. The potatoes were used as a model crop in second year of the experiment. The highest yield of potatoes coming from the second experimental year was observed on the combination of green manure + renewable external sources (compost and digestate) + biostimulants. The average yield of potatoes on this variant was about 34.08 t/ha. The yield of potatoes observed on the unfertilized variant was lower by 9.35 t/ ha. The content of nitrogen in organic fertilizers (compost and digestate) was higher in comparison with other organic fertilizers used in the experiment, which probably caused these results. The winter wheat spelt was used as a model crop in the third year of the experiment. The application of organic fertilizers was completely omitted in this year. The highest average yield of spelt (5.5 t/ha) was observed on the variant called green manure + farm fertilizers. The average yield achieved on the unfertilized variant was lower by 0.7 t/ha. The result from this three experimental years point out the similarity between farming with and without animal husbandry in organic farming. The statistical differences between experimental stations were observed in experimental years.

Keywords: organic fertilization, organic farming, winter wheat, spelt, potatoes, crop yield

INTRODUCTION

Organic farming is a specific production system with a certain awareness to the environment. The protection of the environment in organic farming is primary possible thanks to the restriction and ban of some specific burdensome substances such as synthetic nitrogen fertilizers. Common problem of our agriculture is decreasing content of nutrients in the soils. Main reasons for this decrease are the export of production and nutrient losses (volatilization or leaching). However, fertile soil is necessary for achieving optimal yields and quality products (Dvorský and Urban, 2014). Fertilization of plants directly to the roots during the vegetation is usually not an option for organic farmers. Therefore, the content of nutrients, organic matter and humus quality before crop establishment is the point of emphasis in conditions of organic farming.

The nitrogen is still a crucial element in plant nutrition. The balance of N in terms of organic farming can be influenced by a proper crop rotation (cultivation of legumes and plants suitable as green manure) and mostly by incorporation of organic fertilizers such as manure, slurry, compost or digestate (Urban *et al.*, 2003). Organic fertilizers are vital sources of nutrients for organic farmers. Therefore, harmonic crop rotation in combination with optimal dose of organic fertilizer are essential in organic farming (Baker, 2010).

A numerous short to medium-term experiments were established to examine organic farming. a common problem of these experiment was also only one area of exploration (crop rotation or soil condition or pest/weed control). The truly long-term experiment was established in FiBL Switzerland in the 1972 (Maeder *et al.*, 2002; Fliess, 2007). There was an idea to create similar field

I: *Characteristics of experimental localities*

Experimental locality	Characteristics					
	MASL	Crop area	Reference Soil Groups	Soil texture	Average annual precipitation (mm)	Average annual temperature (°C)
Věrovany	207	Sugar beet	Black Soil	Clay	502	8.7
Čáslav	260	Sugar beet	Black Soil	Clay	555	8.9
Jaroměřice nad Rokytnou	425	Cereals	Brown Soil	Clay Loam	481	8.0
Horažďovice	475	Potatoes	Cambisol	Sandy Loam	585	7.8
Lípa	505	Potatoes	Cambisol	Sandy Loam	594	7.5

II: *The results of soil analysis performed before the start of the experiment (October of 2014)*

Experimental locality	Content of nutrients (mg/kg)						
	P	K	Ca	Mg	NO_3^-	NH_4^+	N_{min}
Věrovany	106.3	214.8	3184	135.8	35.3	0.4	35.7
Čáslav	65.6	172.2	3082	159.3	9.3	0.2	9.5
Jaroměřice nad Rokytnou	89.5	200.0	3017	210.5	8.6	0.5	9.1
Horažďovice	78.7	143.3	1711	150.6	17.6	6.4	24.0
Lípa	68.6	77.1	2261	111.6	12.8	0.8	13.6

III: *Variants of fertilization (winter wheat)*

Variants of fertilization	Organic fertilizers		BS	
	Dose and fertilizer	Date	Dose	Date
1. Unfertilized	–	–	–	–
2. Renewable external sources	14 t/ha of digestate	April 2015	–	–
3. Renewable external sources + BS	14 t/ha of digestate	April 2015	5 l/ha	2 applications in May
4. Farm fertilizers	14 t/ha of fermented urine	April 2015	–	–
5. Farm fertilizers + BS	14 t/ha of fermented urine	April 2015	5 l/ha	2 applications in May

BS: magnesium as MgO – min 4.0%, potassium as K_2O – min 1.0%, boron as B – 0.04%, manganese as Mn – 0.1%, copper as Cu – 0.05%, molybdenum as Mo – 0.001%, zinc as Zn – 0.2%, iron as Fe – 0.04%.

experiment in terms of organic farming in Czech Republic. This experiment is the first systematic attempt to examine the efffect of organic farming to the soil condition, plant nutrition and crop yields.

This work is a part of mentioned long-term experiment established in 2014 by the Central Institute for Supervising and Testing in Agriculture. This work builds on our previous article (Antosovsky *et al.,* 2017). The final goal of this research was to examine the effect of different localities and different organic fertilizers on crop yields in conditions of organic farming.

MATERIALS AND METHODS

Experimental localities

The experiment was established as a long-term and precise small-plot field research. There are 5 different experimental stations examined in this work, they are described in Tab. 1 and sorted by their soil and climate conditions. The research started in spring of 2014. The soils at each location were analyzed (Tab. II) and left as fallow as a protection against weed. The soil samples were collected by a manual soil probe in soil profile range of 0–30 cm. The content of P, K, Ca and Mg was determined by Mehlich III. The nitrate nitrogen was determined using ion-selective electrode (ISE), the ammonia nitrogen was determined in Indolphenol spectrophotometry (Zbíral et al. 2004). The content of mineral nitrogen (N_{min}) was determined according to summing nitrate and ammonia nitrogen.

Methodology of the experiment

Each variant of fertilization was repeated three times. The minimal harvested area was 10 m^2. The winter wheat was evaluated in the first year of the experiment. The average yields of potatoes were examined in the second year and the average yield of spelt was observed in the third year.

The experiment started by sowing of winter wheat (variety Bohemia) in the autumn of 2014. Green manure was not cultivated in this first

IV: *Variants of fertilizations (potatoes)*

Variants of fertilization	Application of organic fertilizers				BS
	Dose and fertilizer	Date	Dose and fertilizer	Date	Date
1. Unfertilized	–	–	–	–	–
2. Green manure (GM)	–	–	–	–	–
3. GM + renewable external sources	27 t/ha of compost	Autumn 2015	14 t/ha of digestate	April 2016	–
4. GM + renewable external sources + BS	27 t/ha of compost	Autumn 2015	14 t/ha of digestate	April 2016	5 l/ha 2 applications in May
5. GM + farm fertilizers	27 t/ha of manure	Autumn 2015	14 t/ha of fermented urine	April 2016	–
6. GM + farm fertilizers + BS	27 t/ha of manure	Autumn 2015	14 t/ha of fermented urine	April 2016	5 l/ha 2 applications in May

BS: magnesium as MgO – min 4.0%, potassium as K_2O – min 1.0%, boron as B – 0.04%, manganese as Mn – 0.1%, copper as Cu – 0.05%, molybdenum as Mo – 0.001%, zinc as Zn – 0.2%, iron as Fe – 0.04%.

V: *The content of nitrogen in organic fertilizers used in the experiment*

Date	Organic fertilizer	Content of nitrogen(%)
April of 2015 – fertilization of winter wheat	Digestate	0.75%
	Fermented urine	0.05%
Autumn in 2015 – incorporation to the soil after wheat harvest	Compost	0.43%
	Manure	0.38% Čáslav
		0.42% Horažďovice
		0.73% Věrovany
		0.86% Jaroměřice nad Rokytnou
		0.90% Lípa
April of 2016 – fertilization of potatoes	Digestate	1.37%
	Fermented urine	0.06%

year of the experiment. Tab. III is describing the fertilization of winter wheat. The application of biostimulant (BS) on leaf was performed two times in May. Biostilmulant used in this experiment year was based on the extract of seaweed *Ascophyllum nodosum* and mix of a natural, water soluble oligopeptide, amino acids, magnesium, potassium and trace elements. The winter wheat was harvested at the end of July 2015.

The fertilization with compost and manure was carried out in August of 2015. *Pisum sativum var. arvense* was used as a green manure crop and it was sown directly after the incorporation of compost and manure. The average yield of *Pisum sativum var. arvense* ranged between 0.5 to 4.7 t/ha in dry matter depending on experimental locality. Green manure crop was incorporated into the soil before winter. Tab. V is describing the fertilization of potatoes. Potatoes (variety Adéla) were planted circa two weeks after fertilization with digestate and fermented urine in early April of 2016. The biostimulant on potatoes leaf was applied two times in May. Biostimulant used in this experimental year was based only on mixture of natural, water soluble oligopeptide, amino acids, magnesium, potassium and trace elements. The potatoes were harvested at the first half of September.

Spelt (variety Alkor) was sown in autumn of 2016. Spelt was not fertilized by organic fertilizers in experimental year 2017. Only the application of biostimulant was performed in this year. The idea behind this is to simulate common praxis. If there is a good forecrop fertilized by organic fertilizers (potatoes in 2016), there is usually not necessary to fertilize in second year. The second reason for omitting fertilization of spelt was its low level of resistance to lodging. The application of biostimulant to the soil on variants 4 and 6 was performed before sowing of spelt. Bacteria fertilizer was used as a biostimulant. The winter wheat spelt was harvested at the end of July.

Tab. V is describing the nitrogen content in organic fertilizers used in the experiment. Compost, fermented urine and digestate were delivered to each experimental station from the same source. Every experimental locality produced its own manure.

Statistical analysis

The results from the experiment were evaluated by two factors analysis of variance (ANOVA) with subsequent verification based on Tukey test ($P < 0.05$). The data were processed using the STATISTICA CZ 12 software (StatSoft,Inc., USA). Results are expressed as a mean ± standard deviation.

RESULTS AND DISCUSSION

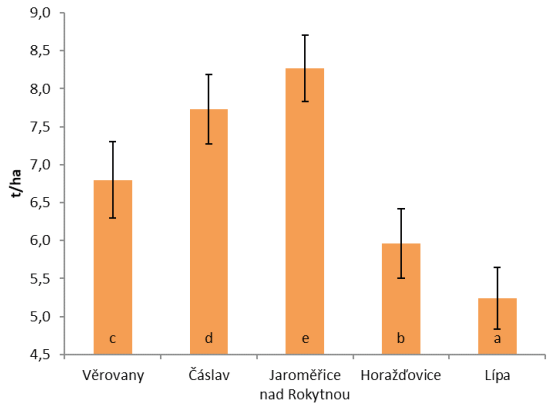
Winter wheat

The obtained results from the first year of the experiment shows statistically significant difference between every experimental station. Fig. 1 is describing the average yield of wheat grain from every station. Each station had different prerequisite for providing optimal yield of grain, as it is described before in Tab. I and Tab. II. The average yield of wheat grain in the Czech Republic was 6.36 t/ha in 2015 (CZSO, 2016a). It is evident from Fig. 1, that the average yield obtained from experimental stations Horaždovice and Lípa was lower compared to the national average. However, our results are provided from organic farming. Therefore, the average yield of winter wheat grain from every station can be evaluated as a suitable yield. For example, Rieux *et al.* (2013) are also describing usage of animal manure for production of winter wheat as an interesting alternative to the conventional mineral fertilization.

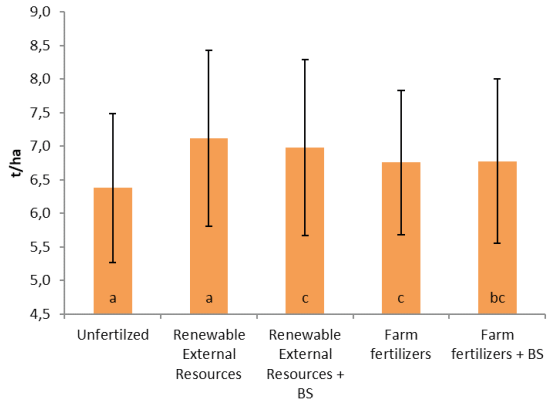
Experimental station Věrovany was determined up to 100% (reference station) in terms of grain yield due to the most fitting climate and soil conditions. The average yield obtained from experimental station Horaždovice and Lípa was lower by 12% and 24% compared to the reference station. The climate and soil conditions are the least suitable in these experimental stations. Experimental localities Čáslav and Jaroměřice nad Rokytnou provide a higher yield by 12% and 22% compared to the reference station. The soil and climate condition on these stations are very similar to the Věrovany station. The increased yield is probably a result of a more optimal weather course during the experimental year.

Fig. 2 is describing the average yields of wheat grain and their statistical significance after each variant of fertilization in the first experimental year. The average yield of each variant of fertilization was higher compared to the unfertilized variant. The statistical differences were observed between variants unfertilized (6.38 t/ha), renewable external sources (7.12 t/ha) and farm fertilizers (6.78 t/ha). a quite optimal nutrient supply in the soil was observed in each experimental station before the start of the experiment, as mentioned before in Tab. II. Also, only one application of organic fertilizers was performed in this first year of the experiment. These are probably the reasons for only a relatively small difference between achieved yield of grain in this experimental year. The highest yield at the most experimental stations were provided by variants 2 and 3 (renewable external sources with and without addition of biostimulants). The highest average yield (by 11% higher compared to the unfertilized control) was provided by variant 2, as it is evident from Fig. 2. The content of nitrogen in farm fertilizers was lower in comparison with variant based on renewable external sources (Tab. V), which is probably a reason for a lower yield observed after fertilization with farm fertilizers.

A higher statistical difference between variants was expected in the next experimental years due to the incorporation of green manure and decreasing content of nutrients in the soil on less fertilized variants.



1: *Average yield of winter wheat grain from each experimental locality (2015)*



2: *Average yield of winter wheat grain after different variants of fertilization (2015)*

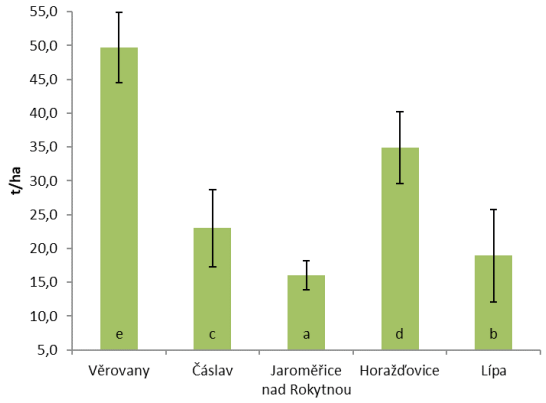
Potatoes

The effect of different experimental locality was also evaluated as a statistically significant in the second experimental year. The national average yield of potatoes was estimated about 29.43 t/ha in 2016 (CZSO, 2016b). Only two experimental localities provide higher yield compared to the national average (Věrovany and Horažďovice). However, average yield of potatoes from the experiment is suitable for organic farming. For example, El-Sayed *et al.* (2015) and Plaza *et al.* (2013) are describing organic production of potatoes as an alternative method without significant yield reduction in comparison with conventional production.

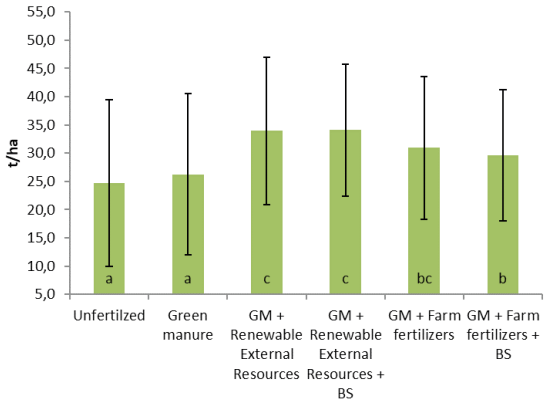
Věrovany station was again determined as a reference station (100%). The average yield of potatoes on this station is very high (circa 50 t/ha) due to the optimal course of weather during the experimental year. The yield of potatoes observed on every other experimental station were lower compared to Věrovany (Fig. 3). This result was caused primarily by drought during the year of 2016 (especially in early stages of vegetation). The lowest potatoes yield was detected in the stations Lípa and Jaroměřice nad Rokytnou (by 62% and 68% lower than reference station).

Fig. 4 is describing the average yield of potatoes and their statistical difference between variant of fertilization in the experiment. Similar yield was detected on unfertilized variant and variant with green manure. Variants with application of organic fertilizers provided a higher crop yield. Therefore, green manure itself could not fully substitute the application of some organic fertilizer. a different result is described by Makarewicz *et al.* (2015). Their experiment showed, that the green manure itself is suitable for full substitution of manure for potatoes cultivation.

Variants 3 and 4 based on GM + renewable external sources (+ AS) and then variants 5 and 6 based on GM + farm fertilizers (+ AS) provided very similar yield. The highest yield (circa 34 t/ha) of potatoes was detected again on variants based on renewable external source. It was an increase by 9.2 t/ha (37%) in comparison with unfertilized variant. Most importantly, there was also an increase of yield in comparison with the variants based on GM + farm fertilizers (+ AS) by 2.96 t/ha and 4.48 t/ha, respectively.



3: *Average yields of potatoes from each experimental locality (2016)*



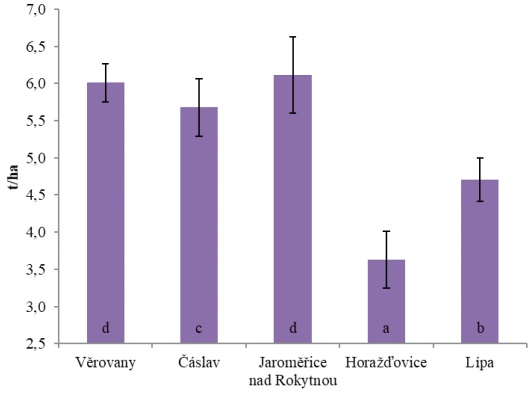
4: *Average yields of potatoes after different variants of fertilization (2016)*

The application of organic fertilizers was performed two times for potatoes cultivation. The incorporation of manure and compost were performed in the autumn of 2015, fertilization with fermented urine and digestate was carried out in the spring of 2016. Compost was delivered to every locality from the same source, manure with a moderately difference in nitrogen content (Tab. V) was produced by every station. The ratio of C/N in compost used in this experimental year was up to 9:1, which was a very thin ratio. a commonly used threshold according to Loecke *et al.* (2012) should not be less than 20 : 1. Lower ratio can cause quick net mineralization. Therefore, the thin ratio of C/N in compost lead to a very rapid decomposition, as it is also described by Gale *et al.* (2006). Miller *et al.* (2009) and Larney *et al.* (2006) are describing compost application as more efficient option in comparison with manure due to the more content of concentrated nutrients and significantly lower level of C, less content of water and reduced potential for nitrogen losses via volatilization during application.

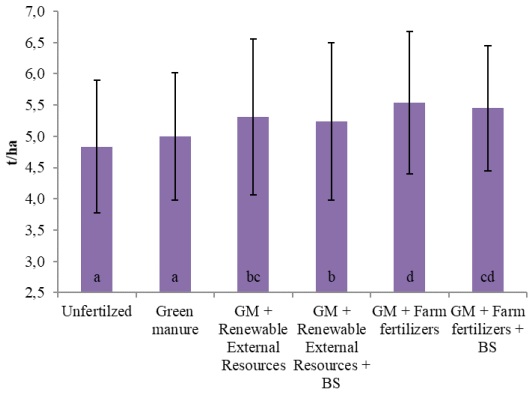
Digestate and fermented urine were also delivered to every experimental locality from the same source. The average content of nitrogen in fermented urine is circa 0.23 %. However, nitrogen content in fermented urine used in the experiment reached only up to 0.06 %. The content of N in fermented urine is highly variable and it is dependent on the strong dilution with water. Also, about 90% of N in fermented urine is in easily soluble form with the largest share of ammonia nitrogen (Urban *et al.*, 2003). The application of fermented urine can also be problematic due to the loss of ammonia via volatilization, as it is described for example by Mahimairaja *et al.* (1994). Digestate is also characteristic by a high amount of ammonia (Moller and Muller, 2012). However, the content of N in digestate used in the experiment was much higher (1.37 %) in comparison with fermented urine. Therefore, the yield of potatoes after variants based on GM + renewable external resources (+ AS) was higher in comparison with combination based on GM + farm fertilizers (+ AS) because of higher content of N in organic fertilizers (Tab. VI). An increase of potatoes yields after fertilization with compost or digestate was also observed in the experiment performed by Smatanová (2012).

Winter wheat spelt

Konvalina (2013) is describing average yield of spelt in terms of organic farming about 2.8 t/ha in



5: *Average yields of spelt from each experimental locality (2017)*



6: *Average yields of spelt after different variants of fertilization (2017)*

Czech Republic and 2.2 t/ha in Austria. Average yield of spelt achieved in this experiment was 5.2 t/ha. This result was probably caused by good forecrop (potatoes) fertilized two times by organic fertilizers (Tab. II). The concerns about lodging of spelt have not been confirmed, spelt at each experimental station endured at upright position during whole vegetation. This fact has also contributed to the reduction of harvest losses.

Fig. 5 is describing average yields of spelt grain and their statistical significance for every experimental station in year 2017. The lowest yields were observed at stations Horažďovice and Lípa. This result was caused by drought during experimental year in combination with less optimal soil conditions at these localities. The highest yield, 6.1 t/ha, was achieved at station Jaroměřice nad Rokytnou. Experimental station Věrovany, which is determined as a reference station due the best soil and climate conditions, achieved slightly lower average yield (6.0 t/ha), probably due to the high occurrence of diseases (*Blumeria graminis*) and pests (*Oulema melanopus, Oulema lichenis*).

Fig. 6 is describing average yields of spelt grain and their statistical significance for every variant of fertilization in year 2017. The lowest yield with no statistical difference was observed on Unfertilized variant and variant with Green manure alone. This result is similar to the experimental year 2016. However, the highest yields about 5.5 t/ha were provided by both variants with GM + farm fertilizers (+ AS). This result is an interesting change in comparison with the result in previous years of the experiment. Highest yield of winter wheat and potatoes provided by variants with GM + renewable external resources in year 2015 and 2016 were caused by higher content of quickly available nitrogen in compost and especially in digestate. Fertilization with organic matter was not performed in year 2017, so the spelt was only taking up rest of the nutrients from previous years. The result from this year indicates that fertilization with farm fertilizers (manure + fermented urine) provided more nutrients in second year after fertilization in comparison with renewable external resources (digestate + compost). Similar results were observed in experiment performed by Rieux *et al.* (2013), Miller *et al.* (2010), Hradil *et al.* (2007) and Gale *et al.* (2006). They have also described application of manure as preferable variant in comparison with compost. On the other hand, there are also results supporting fertilizing with compost as a superior choice (Miller *et al.*, 2009; Larney *et al.*, 2006, Sanchez *et al.*, 2004).

CONCLUSION

The results obtained from these three experimental years showed the increase of crop yield after application of organic matter regardless of the source. Green manure itself also increased crop yield in comparison with unfertilized variant, but the difference was not evaluated as statistically significant. Combination of green manure and another source of organic matter (renewable external sources or farm fertilizers) proved as a superior. Highest crop yields were each year observed on variants based on fertilization by "classic" organic fertilizers (compost + digestate or manure + fermented urine). Such result was of course expected. However, experiment was performed in terms of organic farming, where the options for crop fertilization by their actual needs during vegetation is limited. Therefore, incorporation of any sources of organic matter is necessary prerequisites for achieving optimal yield and quality products in organic farming.

Variants of fertilization were evaluated as a statistical different in every year of the experiment. The highest yield of winter wheat and potatoes from first two experimental years were detected after fertilization based on renewable external sources (compost or digestate). These organic fertilizers had higher content of quickly available nitrogen compared to variants of fertilization based on farm fertilizers (manure or fermented urine). These results are supporting the idea, that compost (in comparison with manure) is providing more nutrients for plants in the first year after incorporation. The result obtained from the year 2017 (third experimental year) showed, that the highest yield of spelt were provided by the combination of manure and fermented urine. This result supports the idea, that manure provides more nutrients for longer time after incorporation to the soil in comparison with compost. However, the ratio of C/N in compost used in this experiment was very thin. Therefore, this conclusion might be valid only for compost with similar C/N ratio.

There are many biostimulants allowed in organic farming. However, result from three experimental years showed no statistically differences in achieved crop yields after application of biostimulants (in comparison with same variant without BS).

Different experimental localities were also evaluated as a statistical different in each experimental year. Such result is a confirmation, that the adequate crop yield is heavily dependent on the optimal course of weather (especially precipitation) during the year and good soil condition with balanced content of nutrients.

Three years of the experiment may have indicated, that farming without animal husbandry may be very similar to the production based on animal husbandry. However, these results are obtained only from three experimental years. It will be interesting to observe the difference between renewable external resources and farm fertilizers in the future of this long-term experiment.

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