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Comparison of Two Different Management Practices under Organic Farming System

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Abstract: Organic farmers usually do not have the opportunity to address the actual symptoms of deficiency through the foliar application of synthetic fertilization, therefore, the main treatment is realized by green manure crop cultivation and application of organic fertilizers. The aim of this long-term experiment was to compare two different production systems with and without livestock in terms of organic farming, and a control variant with no fertilization was also included (treatment 1). The production system without animal husbandry was based on solely the application of renewable external resources (compost or digestate) (treatment 2) and the same fertilization with the addition of auxiliary substances (AS) (treatment 3). The production system with animal husbandry included utilization of fertilizers produced on the farm (fermented urine or manure) using solely farm fertilizers (treatment 4) and in addition with AS (treatment 5). Each treatment had three replications. This work describes the average yields from four experimental years and five experimental localities. Winter wheat, potatoes, winter wheat spelt and legume-cereal mix with corn were used and examined as model crops during the first four years of this long-term research. The highest average yield of winter wheat grain and potato tubers during the first two years of the experiment were obtained after the treatments 2 (7.1 t/ha grain, 33.9 t/ha tubers) and 3 (7.0 t/ha grain, 34.1 t/ha tubers). The several times higher nitrogen content in applied digestate and compost in comparison with fermented urine and manure was probably the reason for such results. On the contrary, the results obtained from the third (spelt) and fourth (LCM and corn) experimental years favored treatment 4 (5.5 t/ha grain, 4.6 cereal unit/ha) and 5 (5.4 t/ha grain, 4.7 cereal unit/ha) from the long-term point of view. After four experimental years, the presented results supported the application of farm fertilizers as a preferable option. The treatments with additional application of AS did not provide a higher yield, therefore, such an application seems unnecessary.

Keywords: organic fertilization; wheat; potatoes; legume-cereal mix; corn; yield

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1. Introduction

The origins of organic farming date back to the first half of the 20th century, although the first law describing organic farming was not published until 1985 in Austria. Organic farming is a precisely defined type of farming with increased emphasis on the environment and its individual components. The main objectives of organic farming are to maintain and improve soil fertility and to utilize as many closed nutrients cycles as possible. The protection of the natural sources in organic farming is possible by prohibiting of mineral nitrogen fertilizers, chemical pesticides, etc. [1]. Organic farmers should minimize the use of non-renewable resources and fossil energy, while preserving biodiversity, natural ecosystems and animal welfare. These measures should ensure sustainable farming. However, the emphasis on animal husbandry is significantly lower in comparison with the past in the Czech Republic, although there has been a partial increase in recent years, especially in cattle breeding [2]. The decrease recorded in animal production can be explained by high acquisition costs of modern equipment suited for today's high standard (stables, milking parlors). Another important reason is the low interest of people working with animals, or in agriculture in general (additional costs for possible robotization). Unfortunately, it is also necessary to mention the low purchase prices of products from animal production competing with cheaper imports, usually with lower quality. Therefore, farmers are looking for another way to earn money. This situation has resulted in narrow crop rotation of economic crops (wheat, barley, oilseed rape, corn) with a declining percentage of improving and fodder crops. Another possibility of economic boost was the construction of biogas stations (more than 500 hundred in CZ, [3]), which resulted in the increase in silage corn production. Corn, with other fodder crops, is used in biogas production instead of animal husbandry. Therefore, the content of quality organic matter in our soils is decreasing, as the 4.5–5 t/ha of organic matter undergoes mineralization during the year. The organic matter in the soil is necessary for optimal soil structure, water-holding capacity, perquisition of humus and nutrient supply. As the numbers of livestock is decreasing, the organic matter is delivered to the soil from biogas stations (digestate) or from compost, as society begins to have higher demands in terms of the sorting and recovery of waste. Therefore, farming without the animal husbandry seems like a possible direction for sustainable farming and it should be examined in comparison with classic organic fertilized produced on farms, especially in conditions of organic farming.

The content of soil nutrients in the Czech Republic is decreasing, especially due to the production export (harvest of main products) and nutrient losses (nutrients leaching or volatilization). On top of that, the basics of a balanced principle are often not respected, as the fertilization with essential macronutrient such as P, K, S are omitted, probably because of the high price of fertilizers. This leads to depleted soil and decreases in crop yields. Fertile soil with an optimal supply of nutrients is, however, necessary for reaching optimal yields [4]. The supply of nutrients in the soil, the content and the quality of organic matter and humus before sowing should be the point of emphasis for organic farmers since it is usually not possible to perform fertilization with mineral fertilizers (especially nitrogen) during vegetation as in conventional agriculture. The balance of n (and other nutrients) in conditions of organic farming is possible to influence by the inclusion of nitrogen-fixing and green manure crops to the crop rotation and by application of organic fertilizers, for example manure, slurry or fermented urine in systems with animal husbandry, compost and digestate in systems without livestock [5]. The correct proportion of crops in the crop ration is enhanced with application of any organic fertilizers are necessary for optimal yield in term of organic farming [6].

A significant amount of short- to medium-term observations were performed to evaluate organic farming. A common issue of these observations was usually only a one-sided focus, for example on soil fertility, crop yield or plant protection. One of the first long-term complex experiments was established by The Research Institute of Organic Agriculture in Switzerland [7,8]. A similar field experiment was founded in the Czech Republic in 2014 by the Central Institute for Supervising and Testing in Agriculture as a result of the situation with animal husbandry listed before. The aim of this long-term experiment is to observe the effect of different systems of production in conditions of organic farming to the soil fertility, plant protection, yield of crops and quality of products. The aforementioned experiment includes seven crops in crop rotation with the idea to repeat the crop rotation at least three times and it was established on five different experimental stations. The presented article is a part of this complex experiment and it describes the average crop yields from the first four experimental years. The aim of this work is to compare two different systems of organic farming—farming based on animal husbandry and farming based on renewable resources without livestock. The basic hypothesis was to confirm that addition of organic matter regardless of the source will increase the crop yields. Another hypothesis worked with the idea, that the application of farm fertilizers results in a higher yield in comparison with renewable external resources. Treatments examined in the experiment also include auxiliary substances as the possible method of influencing yield. Therefore, the last hypothesis for this work was to confirm that the crop yield after this additional application is going to be higher in comparison with the respective variant without this fertilization.

2. Materials and Methods

2.1. Experimental Localities

The experiment was founded as a long-term small-plot field observation using RCBD. The experiment was established on five different experimental stations, therefore in different climate-soil conditions. The main characteristics of each locality are described in Table 1. The presented research started early in 2014 with soil analysis of each experimental location (Table 2). The samples of soil were manually collected by soil sampler from the profile 0–30 cm. The macronutrients content was determined according to the Mehlich III [9]. The content of N_{min} (mineral nitrogen) was determined as a sum of nitrate *n* (ion-selective electrode—ISE method) and ammonium *n* (Indolphenol spectrophotometry). After the soil samples were collected, the experimental localities at each station were left as fallow until Autumn. This period serves as a protection against weed. The soil samples were collected from the soil profile 0–30 cm each experimental year after the harvest of model crops to evaluate the content of mineral nitrogen.

Table 1. The description of main climate-soil conditions in the experimental localities.

Experimental Area	Characteristics					
	Meters Above Sea Level	Main Crop	Soil Groups	Soil Texture	Avg. Precipitation (mm)	Avg. Temperature (°C)
Věrovany Čáslav	207 260	sugar beet	Chernozems	clay	502 555	8.7 8.9
Jaroměřice nad Rokytnou	425	cereals	Haplic luvisols	clay loam	481	8.0
Horažd'ovice Lípa	475 505	potatoes	Cambisols	sandy loam	585 594	7.8 7.5

Table 2. The soil content of macronutrients before sowing (October of 2014).

Experimental Area	Content (mg/kg)						
	P	K	Ca	Mg	NO_3^-	NH_4^+	N_{min}
Věrovany	106	215	3184	136	35.3	0.4	35.7
Čáslav	66	172	3082	160	9.3	0.2	9.5
Jaroměřice nad Rokytnou	90	200	3017	211	8.6	0.5	9.1
Horažd'ovice	79	143	1711	151	17.6	6.4	24.0
Lípa	69	77	2261	112	12.8	0.8	13.6

2.2. Methodology of the Experiment

The main goal of the presented experiment was to compare the production systems with and without animal husbandry based on the application of different organic fertilizers. There were five different treatments included in the experiment: 1. Unfertilized, 2. Renewable external sources, 3. Renewable external sources + Auxiliary substances (AS), 4. Farm fertilizers and 5. Farm fertilizers + AS. Each treatment was established in three repetitions. Green manure (GM) crops (*Pisum sativum* var. arvense, *Phacelia tanacetifolia*) are also included in the crop rotation. Fertilization during the experimental years is described in Tables 3–5. The doses of farm fertilizers (manure and fermented urine) correspond to their production on a farm with a stock density of 0.8 livestock unit per hectare. Doses of renewable fertilizers (compost and digestate) were adjusted to the same level. The harvested area of each plot was 10 m^2, and respective fertilization was always performed on the 50 m^2 area (protective plot and border-line). The crop rotation examined in the presented study included winter wheat–potatoes–winter wheat spelt–legume-cereal mix/silage corn.

Table 3. Fertilization of winter wheat (2014–2015).

<table>
<tr><th>Variant</th><th colspan="2">Fertilization
(Dose and Date)</th><th colspan="2">Auxiliary substances [1]
(Dose and Date)</th></tr>
<tr><td>1. Unfertilized</td><td></td><td></td><td></td><td></td></tr>
<tr><td>2. Renewable external sources</td><td rowspan="2">Digestate—14 t/ha</td><td rowspan="4">April of 2015</td><td></td><td></td></tr>
<tr><td>3. Renewable external sources + AS</td><td>5 l/ha</td><td>May (2x)</td></tr>
<tr><td>4. Farm fertilizers</td><td rowspan="2">Fermented urine—14 t/ha</td><td></td><td></td></tr>
<tr><td>5. Farm fertilizers + AS</td><td>5 l/ha</td><td>May (2x)</td></tr>
</table>

[1] AS: Mg (MgO)—min 4.0%; K (K_2O)—min 1.0%; Z—0.2%; Mn—0.1%; Cu—0.05%; B—0.04%; Fe—0.04%; Mo—0.001% + *Ascophyllum nodosum.*

Table 4. Fertilization of potatoes (2016).

<table>
<tr><th>Variant</th><th colspan="4">Fertilization
(Dose and Date)</th><th>AS [1]
(Dose and Date)</th></tr>
<tr><td>1. Unfertilized</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>2. Green manure + renewable external sources</td><td rowspan="2">Compost—27 t/ha</td><td rowspan="4">August of 2015</td><td rowspan="2">Digestate—14 t/ha</td><td rowspan="4">April of 2016</td><td rowspan="2">5 L/ha May (2×)</td></tr>
<tr><td>3. Green manure + renewable external sources + AS</td></tr>
<tr><td>4. Green manure + farm fertilizers</td><td rowspan="2">Manure—27 t/ha</td><td rowspan="2">Fermented urine—14 t/ha</td><td></td></tr>
<tr><td>5. Green manure + farm fertilizers + AS</td><td>5 L/ha May (2×)</td></tr>
</table>

[1] AS: Mg (MgO)—min 4.0%; K (K_2O)—min 1.0%; Z—0.2%; Mn—0.1%; Cu—0.05%; B—0.04%; Fe—0.04%; M—0.001%.

Table 5. Fertilization of legume-cereal mix and silage corn (2018).

<table>
<tr><th>Variant</th><th colspan="4">Fertilization
(Dose and Date)</th><th>AS [1]
(Dose and Date)</th></tr>
<tr><td>1. Unfertilized</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>2. Green manure + renewable external sources</td><td rowspan="2">Compost—27 t/ha</td><td rowspan="4">August of 2017</td><td rowspan="2" colspan="2"></td><td rowspan="2">0.5 L/ha June</td></tr>
<tr><td>3. Green manure + renewable external sources + AS</td></tr>
<tr><td>4. Green manure + farm fertilizers</td><td rowspan="2">Manure—27 t/ha</td><td rowspan="2">Fermented urine—14 t/ha</td><td rowspan="2">May of 2018</td><td rowspan="2">0.5 L/ha June</td></tr>
<tr><td>5. Green manure + farm fertilizers + AS</td></tr>
</table>

[1] AS: Mg (MgO)—min 4.0%; K (K_2O)—min 1.0%; Z—0.2%; Mn—0.1%; Cu—0.05%; B—0.04%; Fe—0.04%; M—0.001%.

The winter wheat (*Triticum aestivum*, cultivar Bohemia) was selected as a first model crop. The sowing of winter wheat was performed in the October of 2014 in the standard sowing rate of 200 kg per hectare. Table 3 describes the organic fertilization during the first experimental year. The two applications of auxiliary substance on leaves were carried out in May. AS was based on mix of natural water-soluble oligopeptide, amino acids, Mg, K, microelements, and extract of seaweed *Ascophyllum nodosum*. The harvest of wheat was carried out at the turn of July and August of 2015. The focal occurrence of weeds was eliminated by the mechanical weeder or by hand (*Galium aparine*). The sporadic occurrence of *Oulema melanopus* and *Puccinia striiformis* was observed without any protection realized. The harvest of spelt was performed by the classic plot harvester.

Potatoes (*Solanum tuberosum*, cultivar Adéla) were cultivated as a followed crop during the second experimental year. The experimental area was fertilized with compost and manure during the August of 2015, after the harvest of winter wheat. The organic fertilizers were incorporated to the soil by stubble cultivator. This operation was followed by sowing of green manure crop (*Pisum sativum* var. arvense). Green manure crop provided an average yield of 2.6 t/ha in dry matter. The cultivated biomass was mulched during the November of 2015, the soil was then prepared by ploughing. The application of organic fertilizers and auxiliary substances during this experimental year is described in Table 4. The spring fertilization of potatoes with organic fertilizers (digestate, fermented urine) was performed early in April of 2016 and it was shortly followed by potatoes planting (3000 kg/ha). The AS was applied on leaves in two separate doses during the May of 2016. The occurrence of *Leptinotarsa decemlineata* and *Phytophthora infestans* was observed during vegetation. The plant protection was realized by the application of allowed products in organic farming (active substance Spinosad and copper oxychloride).

Auxiliary substance applied in the second year was based on mix of natural water-soluble oligopeptide, amino acids, Mg, K, and microelements. The two-phase harvest of potato tubers (mechanically removed from ground and gathered by hands) was carried out in September 2016.

Spelt (*Triticum spelta* L., cultivar Alkor) was chosen as a subsequent crop in the crop rotation after the harvest of potatoes. Sowing of winter wheat spelt was carried out in October 2016 at the standard sowing rate of 200 kg/ha. The organic fertilization of spelt was omitted in this year with the idea to mimic the practices of classic crop production. Therefore, crop rotation with an improving organically fertilized forecrop (potatoes) is usually allowed to omit application of organic fertilizers in the following year (spelt). Another argument to skip the fertilization during this year was a higher habitus and lower resistance level of winter wheat spelt to lodging. The auxiliary substance (bacteria fertilizer for improving non-symbiotic nitrogen fixation) was applied to the soil on variants 3 and 5 before sowing of spelt in the dose of 10 L/ha. Weed control was realized two times during the vegetation by mechanical weeder. The occurrence of *Oulema gallaeciana* and *Blumeria graminis* f. sp. *tritici* was observed during the vegetation. The plant protection was realized by application of sulphur-based fungicide in combination with orange-oil based insecticide. The harvest of spelt was carried out in July of 2017 by classis plot harvester.

The spelt straw with the organic fertilizers were incorporated to the soil by ploughing in August 2017. *Phacelia tanacetifolia* was chosen as a GM crop and it was sown immediately after the organic fertilization (Table 5). The mulching and ploughing were performed in November 2017. The average yield of *Phacelia tanacetifolia* was 3.0 t/ha in dry matter. Crop rotation in the fourth experimental year was divided to meet the specific requirements of the compared production systems. Farming based on animal husbandry has to ensure a sufficient supply of feed, therefore, silage corn (*Zea mays*, cultivar KXB7342) was chosen as a model crop on variants 4 and 5 based on farm fertilizers. Corn was sown at the beginning of April (55 kg/ha) and it was also fertilized by the fermented urine approximately a month after sowing. The legume-cereal mix of spring barley (*Hordeum vulgare*, cultivar Azit) and field pea (*Pisum sativum*, cultivar Eso) harvested for grain was chosen as a model crop for variants 2 and 3 based on farming without animal husbandry. These variants were not fertilized by digestate in spring, because the utilization of digestate by a cultivated mixture would be poor (fertilization by digestate was performed in the next year and fertilization by fermented urine was omitted). The legume-cereal mix was sown at the beginning of April (250 kg/ha 1:1). The application of AS (bacteria fertilizer for improving non-symbiotic nitrogen fixation) was performed in June. The weed control was realized by mechanical weeder in the legume-cereal mix and by hand weeder on corn. The plant protection of legume-cereal mix (*Blumeria graminis*) was realized by the application of sulphur-based fungicide, the protection of corn (*Ostrinia Nubilalis*) was realized by *Trichogramma.* The mixture of barley and pea was harvested at the start of August 2018 by a plot harvester with the additional separation of grain, and silage corn was harvested approximately 14 days later by plot harvester. The yields of legume-cereal mix and corn have been recalculated into the cereal units per hectare for better comparison (cereal unit of field pea = 1 t/h of grain × 1.20; cereal unit of barley = 1 t/ha of grain × 1; cereal unit of silage corn = 1 t/ha of fresh silage × 0.15).

The average content of nitrogen in the applied organic fertilizers during the experimental years is described in Table 6. Every fertilizer was delivered to each experimental area from the same source, except for cattle manure, which was produced individually at each experimental area. The source of digestate, compost and fermented manure differs each year, as it was difficult to obtain organic fertilizers with similar quality.

Table 6. The average *n* content in applied organic fertilizers during the experiment.

Date	Fertilizer	Content of *n* (%)
April of 2015—fertilization of winter wheat	Digestate Fermented urine	0.75 0.05
August of 2015—fertilization after harvest of wheat	Compost Manure	1.30 0.67
April of 2016—spring fertilization of potatoes	Digestate Fermented urine	1.37 0.06
August in 2017—fertilization after harvest of spelt	Compost Manure	1.47 0.69
May of 2018—fertilization of corn	Fermented urine	0.07%

2.3. Statistical Data Analysis

Statistical evaluation of the monitored parameters was performed by the Statistica 12 CZ program [10]. A two-way analysis of variance (ANOVA, variant of fertilization, experimental locality) and follow-up tests according to Fisher (the LSD test) were conducted. The average crop yield recalculated to cereal unit per hectare over 4 experimental year was analyzed by three-way ANOVA (year, variants of fertilization, locality). The results were expressed as the mean ± standard deviation (SD).

3. Results and Discussion

3.1. First Experimental Year—Winter Wheat

The average grain yield of winter wheat observed after the first experimental year is described in Figure 1. Every treatment provided higher yield compared with the control variant with no fertilization. The highest grain yield (7.1 t/ha) was provided after the sole fertilization with renewable external resources (i.e., digestate). The average grain yield detected on unfertilized control (6.4 t/ha) was lower by almost 11%. Figure 1 also describes the statistical differences between examined variants of fertilization. It is evident from this figure that there were differences between the three main examined treatments—unfertilized, renewable resources and farm fertilizers (both without additional AS). The nitrogen content in farm fertilizers (fermented urine) was significantly lower compared with fertilization based on application of renewable external resources (digestate), as shown in Table 6. This could be possibly the reason for lower yields obtained after the application of farm fertilizers, which is also supported by the content of mineral nitrogen in the soil after winter wheat harvest (Figure 2). It is evident from Figure 2 that the average content of nitrogen in the soil after the harvest was lower (5.18 mg/kg) in the production system based on farm fertilizers in comparison with renewable external resources (6.92 mg/kg). Also, the supply of nutrients (P, K, Ca, Mg) in the soil before the start of the experiment was quite good at each experimental station (Table 2). In addition, the examined fertilization was performed only one time at this point, as this was only the start of the experiment.

Therefore, the differences between examined variants in terms of crop yield were relatively low. A more significant difference in crop yield was expected later in the experiment due to the repeating fertilization, additional cultivation of green manure crops and probably decreased content of soil nutrients. The increase of grain yield after different organic fertilization is also described for example by Šimon et al. [11], and the positive effect of digestate application on wheat is also mentioned by Abubaker et al. [12].

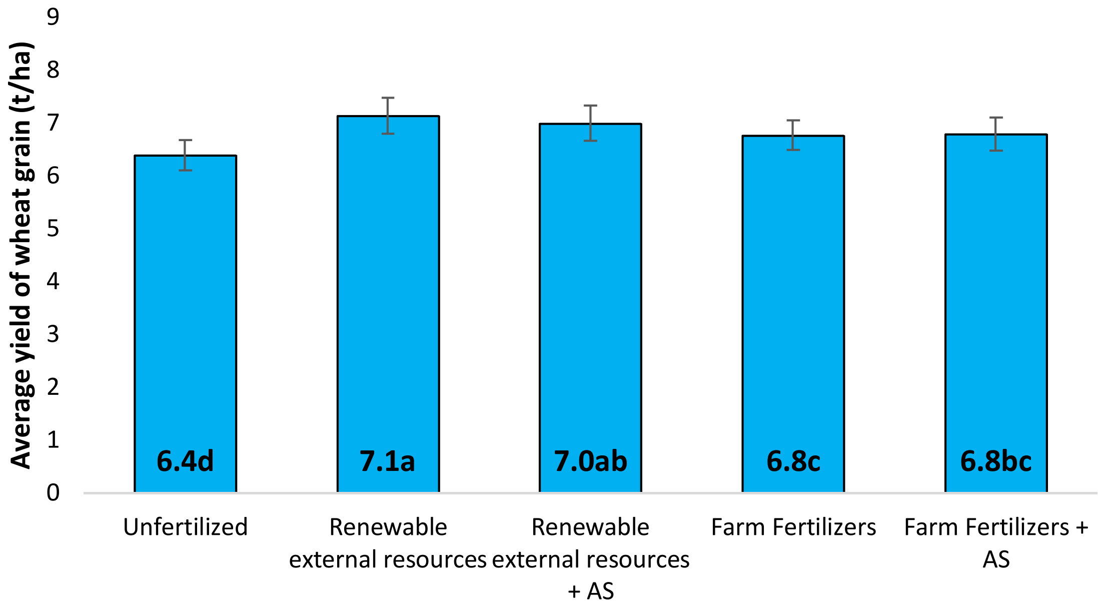

Figure 1. Grain yield of winter wheat (observed treatments, 2015). Error bars represent the standard error (SE). Different letters mean statistical difference ($p \leq 0.5$).

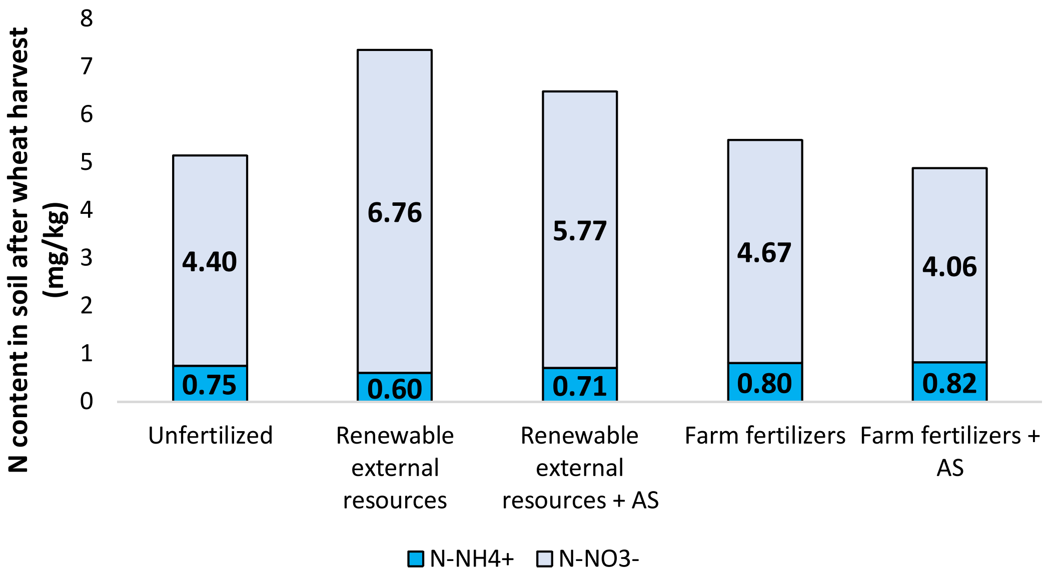

Figure 2. Content of mineral nitrogen in the soil after the harvest of winter wheat (observed treatments, 2015).

The average grain yield of winter wheat in CZ was 6.4 t/ha in the experimental year of 2015 [13]. Each treatment with organic fertilization provided higher yield in comparison with the national average, as described in Figure 1. It necessary to point out that this result is obtained from organic farming, i.e., without application of mineral nitrogen. Therefore, such a result only confirms the importance of organic fertilization to the soil. Rieux et al. [14] are for example also suggesting the utilization of manure for cultivation of cereals as a possible interesting alternative without economic losses to the mineral nitrogen fertilization.

3.2. Second Experimental Year—Potato Tubers

The average yields of potato tubers and the statistical differences between variants of fertilization are described in Figure 3.

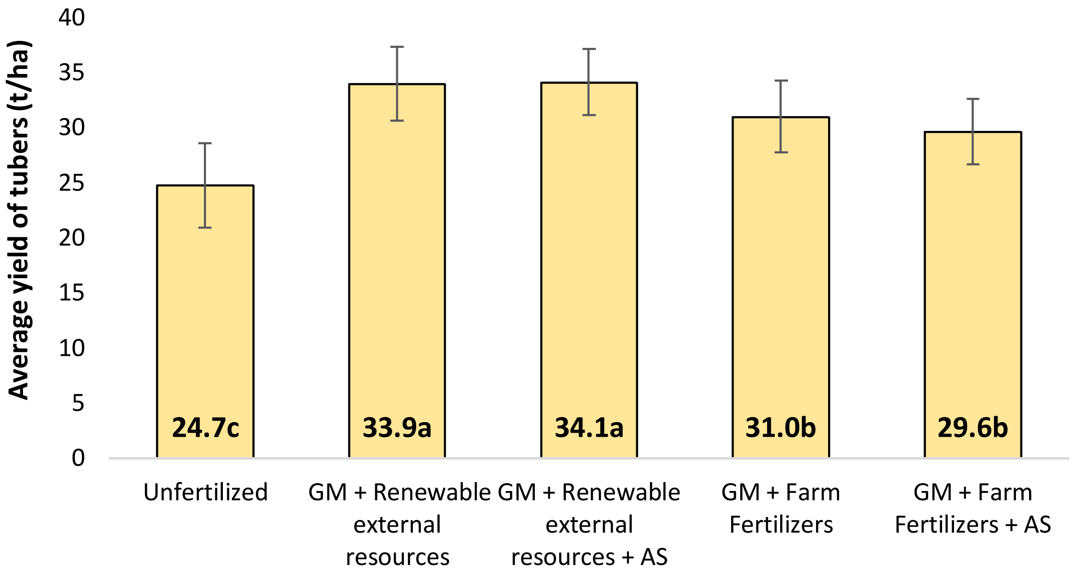

Figure 3. Potato tubers yield (observed treatments, 2016). Error bars represent the standard error (SE). Different letters mean statistical difference ($p \leq 0.5$).

The results are very similar to the result in the first year of the experiment, although the differences between obtained yield were higher. Almost identical yields of tuber were detected on variants based on same production system (with and without animal husbandry). The application of additional auxiliary substances did not provide significantly different yield, which corresponds with the result from previous year with winter wheat. The highest average yield of potato tubers was observed after utilization of renewable external resources (compost + digestate) enhanced with incorporation of green manure crop. The obtained yield (34.1 t/ha) was higher by 38% (9.4 t/ha) compared to the control variant without fertilization and by 9% (3.1 t/ha) in comparison with incorporation of farm fertilizers (manure + fermented urine) enhanced with green manure crop.

The fertilization with manure and, respectively, compost on the soil were carried out in August 2015, and application of fermented urine, respectively digestate was performed in April 2016. Manure was independently produced at each area with a moderate difference in the content of nitrogen (Table 6), while compost was distributed to each area from the same external source. The compost applied in this year of the experiment was characteristic with a very narrow ratio of C/N (9:1). For example, the threshold for commonly used compost described by Loecke et al. [15] should not be lower than 20:1, as a lesser ratio could lead to quick mineralization of organic matter. Therefore, such a low ratio of carbon to nitrogen probably caused a rapid decomposition and nutrient release from compost, as is for example also indicated by Gale et al. [16]. This could be one of the reasons for a higher yield of tubers detected after the treatment with renewable external resources and, therefore, without animal husbandry. For example, Larney et al. [17] and Miller et al. [18] are also recommending fertilization with compost as a preferable option compared to the application of manure, mostly because of the higher content of concentrated nutrients and lower content of carbon, water, and also a lower possibility of nitrogen loss through volatilization. Digestate, respectively fermented urine, were distributed to each area from other external sources as well. Fermented urine characteristically has average content of *n* of about 0.23% [19]. The content of nitrogen in this fertilizer is heavily dependent on the dilution with water, so it can be very variable. In addition, the majority of nitrogen contained in this fertilizer can be characterized as an easily soluble with the highest part in the ammonia *n* form. However, fermented urine applied as fertilizer before potato planting was evaluated as very poor, as the content of nitrogen was only up to 0.06%. Mahimairaja et al. [20] also describe the possible problem with volatilization, e.g., losses of ammonia nitrogen after application of fermented urine. Digestate is also characteristic as a fertilizer with a higher content of mineral nitrogen [21] with a majority in ammonium form [22] and with as much 10 times lower C/N ratio in comparison with farmyard manure [23]. Unfortunately, the digestate applied in this experimental year was characteristic with very high content of nitrogen (1.37%). This could probably be the second reason for achieving a higher yield of potato tuber after treatment without animal husbandry (renewable external resources) in comparison with farm fertilizers. An increase in yield of tubers after the incorporation of digestate or compost as an organic fertilizer was also detected in the research performed by Smatanová [24]. The comparable yields of tubers were also detected in three-year experiment with potatoes based on a comparison of digestate and classic mineral fertilization with UREA [25].

Figure 4 presents the content of mineral nitrogen in the soil after the harvest of potato tubers. It is evident from this figure, that the average content of nitrogen is higher after utilization of farm fertilizers (6.47 mg/kg). This situation supports the previous claim that farming without animal husbandry (application of digestate and compost) positively influenced the crop yield, however, farm fertilizers for crop production are more suitable from the long-term point of view, which was proved next experimental year with the winter wheat spelt without organic fertilization.

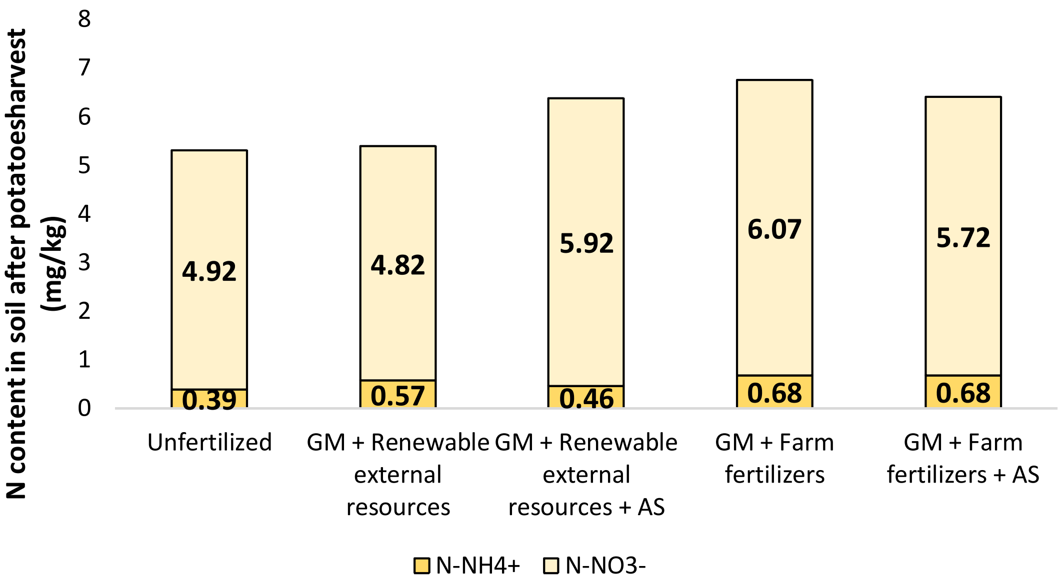

Figure 4. Content of mineral nitrogen in the soil after the harvest of potato tubers (observed treatments, 2016).

The nationwide average yield of potato tubers has reached about 29.4 t/ha in year 2016 [26]. In our research, only the unfertilized control variant provided lower yield. Nevertheless, the average yield of potato tubers detected from this experiment could be again evaluated as very suitable in terms of organic farming as the nationwide average yield of potatoes produced only by organic farmers in the Czech Republic was circa 15 t/ha [2]. El-Sayed et al. [27] or Plaza et al. [28] are recommending organic cultivation of potato tubers as a suitable alternative option in comparison with conventional production without significant reduction of average yield.

3.3. Third Experimental Year—Spelt

The average grain yield of winter wheat spelt and the statistical differences between variants of fertilization are described in Figure 5. Again, the lowest yield of grain (4.6 t/ha) was detected on the control variant without fertilization. By contrast, the highest yield (5.5 t/ha) was provided by fertilization with a farm fertilizer enhanced with a green manure crop. Such result is in contrast in previous experimental years (highest yield of crop after fertilization with renewable resources), which is an interesting development. The highest yield of winter wheat and potatoes detected after the treatment without animal husbandry (renewable external resources) in experimental years 2015–2016 were presumably caused by higher nitrogen content in applied fertilizers (compost, digestate) and narrow C/N ratio. As mentioned in the methodology of the experiment, spelt was not organically fertilized, therefore, the plants were only able to uptake the nutrients from the soil and from the rest of the organic fertilizers applied in previous experimental years. Our result indicates that production systems with animal husbandry, e.g., farm fertilizers (manure, fermented urine), could possibly provide more nutrients to the plants in the following years after application compared to the production systems without livestock, e.g., renewable external resources (compost, digestate). This hypothesis is also confirmed by the content of mineral nitrogen in the soil after the harvest of winter wheat (Figure 6). The average *n* content in system with farm fertilizers was 4.07 mg/kg, which represents an increase by 0.59 mg/kg in comparison with production systems without animal husbandry (3.48 mg/kg). Comparable result in terms of crop yield was described by several authors [14,16,29,30]. These authors are promoting the fertilization with manure as a preferable option in comparison with compost application. However, it is also possible to find the results describing the application of compost as a more suitable option [17,18,31]. The application of additional auxiliary substances did not provide any significant change in grain yield.

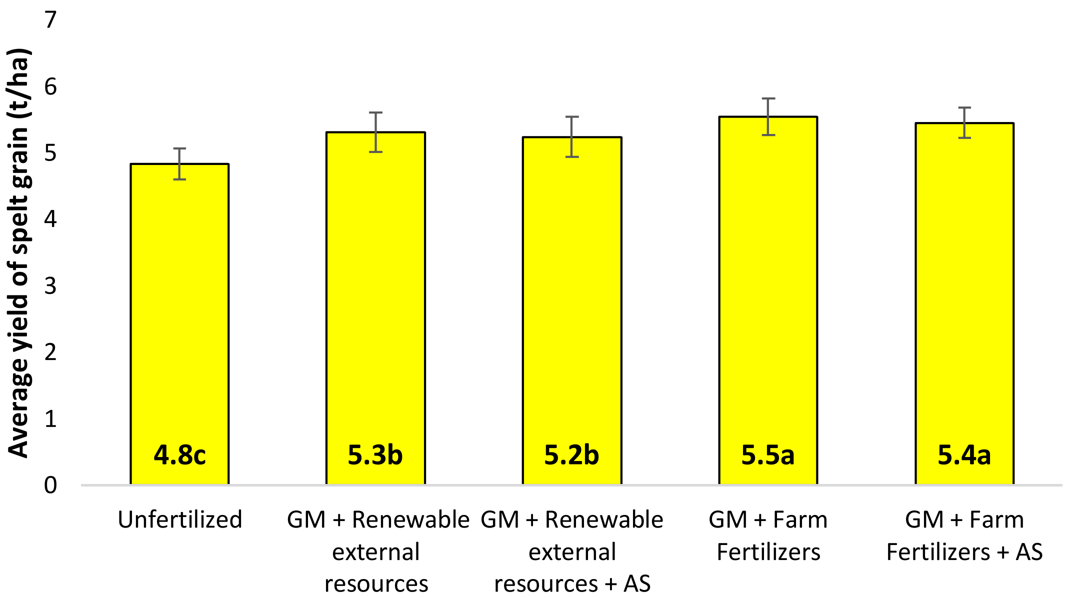

Figure 5. Grain yield of spelt (observed treatments, 2017). Error bars represent the standard error (SE). Different letters mean statistical difference ($p \leq 0.5$).

The average grain yield of winter wheat spelt produced only by organic farming was about 2.7 t/ha in Czech Republic [2,32]. However, the average grain yield of winter wheat spelt detected in this experimental year was about 5.3 t/ha. A result with such a difference could be possibly influenced by crop rotation that improves forecrop two times fertilized by organic fertilizers (potatoes in 2016) and it is again a very good argument for performing any type of organic fertilization and rotating crops. The spelt is also characteristic with possible lodging during vegetation. However, no lodging of plants was observed during the experimental year, which also contributed to the minimum of grain loss during harvest. The spelt also managed to resist disease and pest pressure, which also reduced the possible losses.

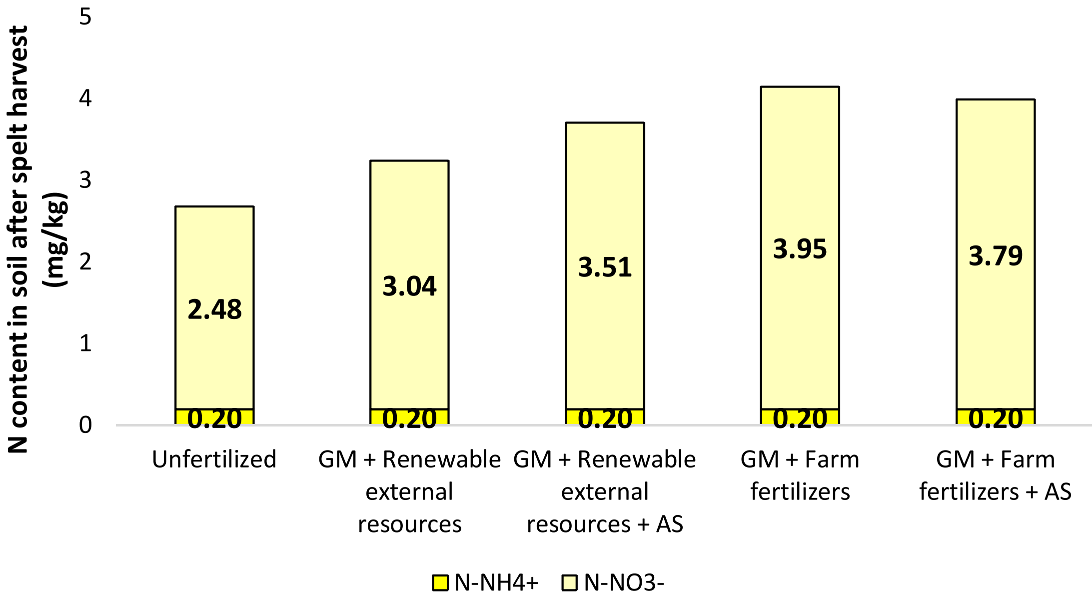

Figure 6. Content of mineral nitrogen in the soil after the harvest of spelt (observed treatments, 2017).

3.4. Fourth Experimental Year—Legume-Cereal Mix and Silage Corn

The average yields of silage corn and legume-cereal mix harvested for grain and their statistical differences are described in the Figure 7. Yields have been recalculated to the cereal units for better comparison. It is evident from these results that the highest yield was provided by the production system with animal husbandry, therefore application of farm fertilizers (manure and fermented urine). There are several possible explanations for this result. Firstly, as this was the fourth experimental year, these results can simply indicate that agriculture based on animal husbandry and therefore application of farm fertilizers could be more suitable in the long-run in terms of slower decomposition and more balanced release of nutrients in comparison with quickly available nutrients (especially *n*) from fertilizers based on renewable external resources. This result is partially supported by two experimental years described by Alburquarque et al. [23], Their results also show that the application of digestate is very beneficial only in the short-term. However, the long-term positive effect of manure fertilization was not proved, as this experiment was performed in horticulture (two crops in one year). Secondly, variants based on farm fertilizers was fertilized two times in this experimental year in comparison with only one application for variants based on renewable external resources (Table 5). This difference in fertilization is caused by different crop rotation and it is explained in the methodology. The final factor to consider is the different crop yield obtained from cultivating of legume-cereal mix and average yield of silage corn (Figure 7). As mentioned before, these yields were recalculated in the cereal units according to corresponding coefficients, but higher average yield of corn in fresh silage (31.5 t/ha) was simply higher in comparison with average grain yield of legume cereal mix (2.2 t/ha of barley + 0.4 t/ha of field pea). An increase in yield of corn or sunflower after organic fertilization is described, for example, by Ahmad et Jabeen [33], Somasundaram et al. [34] or Lehrsch et Kincaid [35]. The yield of spring barley and field pea was also reduced by more pests and diseases in comparison with silage corn.

The content of mineral nitrogen after the harvest is described in Figure 8. The average contents of nitrogen are very similar for both production systems, which may be possibly caused by the difference in crop rotation, as silage corn uptake much more nitrogen to produce adequate biomass in comparison with legume-cereal mix characteristic with lower crop yield.

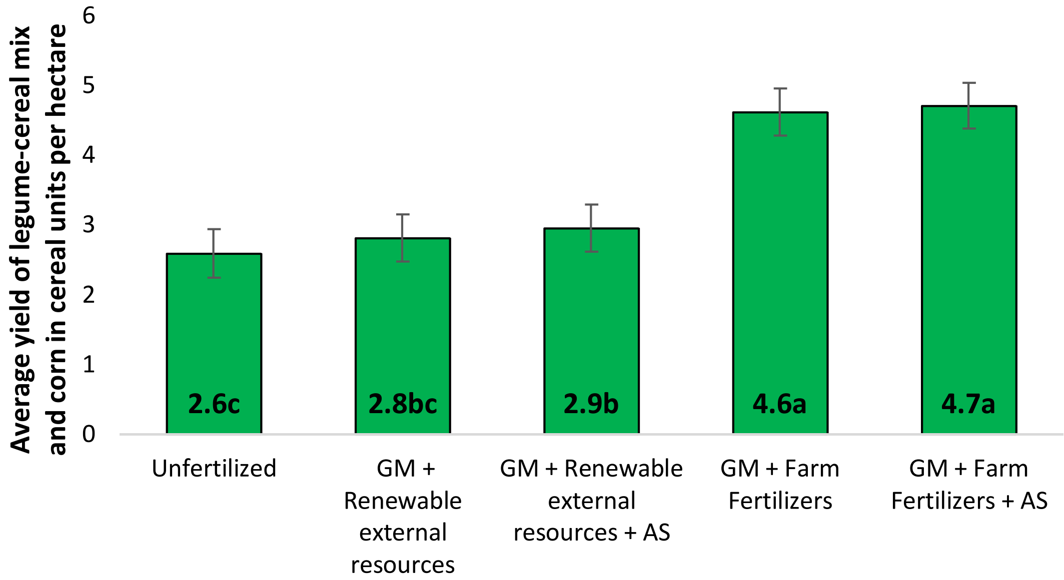

Figure 7. Average yield of legume-cereal mix and silage corn recalculated to the cereal units per hectare (observed treatments, 2018). Error bars represent the standard error (SE). Different letters mean statistical difference ($p \leq 0.5$).

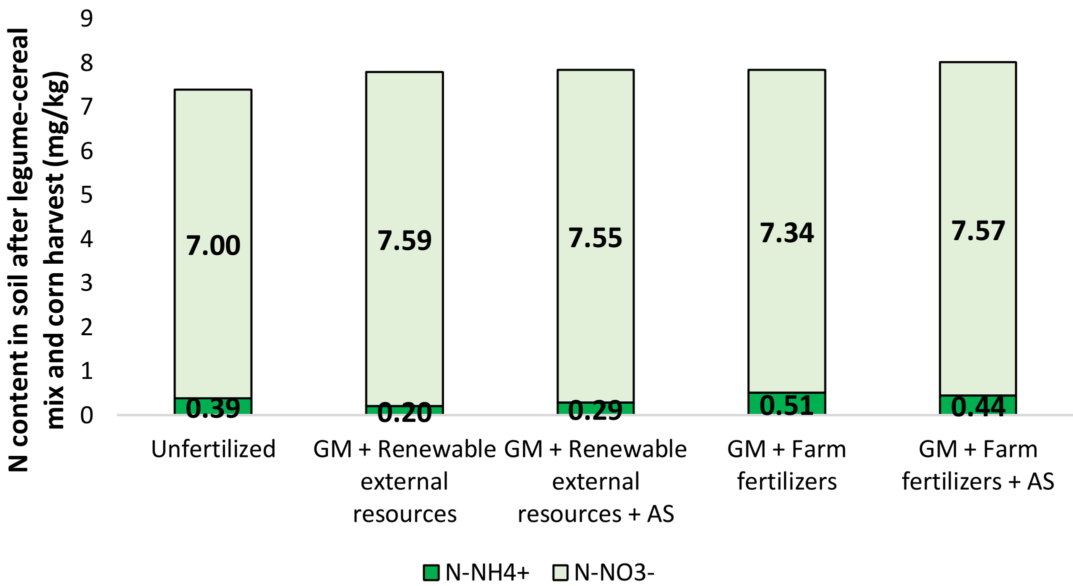

Figure 8. Content of mineral nitrogen after the harvest of legume-cereal mix and corn (observed treatments, 2018).

3.5. Average Yield over Four Experimental Years—Summary

The average yields of crop grain expressed in cereal units per hectare and their statistical differences are described in Figure 9. The highest average yield (6.2 cereal unit per hectare) over four experimental years was observed on the variant with sole application of farm fertilizers. This variant of fertilization provided 24% higher yield compared to the unfertilized control. On a four-year average, both treatments with farm fertilizers achieved slightly higher crop yield compared with both treatments based on production system without animal husbandry. The application of compost and digestate proved to have a short-term positive effect, especially thanks to the significant difference in nitrogen content in applied digestate and fermented urine. Nitrogen rich digestate in combination with compost characteristic with narrow C/N ratio were probably the reason for higher and statistically different yields obtained from first two years of the experiment. Digestate is also a characteristic of an organic fertilizer, but the quality of organic matter, however, is poor as the labile organic matter is used during the fermentation process. This results in narrowing the C/N ratio and high content of organic matter with problematic decomposition [36,37]. By contrast, the crop yield detected in the third and fourth experimental years was in favour for application of farm fertilizers. A possible explanation could be gradual release of nutrients from farm fertilizers (manure and fermented urine) in comparison with quickly available nutrients (especially nitrogen) from renewable external resources (nitrogen rich digestate and compost with narrow C/N ratio). Another possible explanation could be the difference in crop rotation and fertilization in the fourth experimental year, as mentioned before.

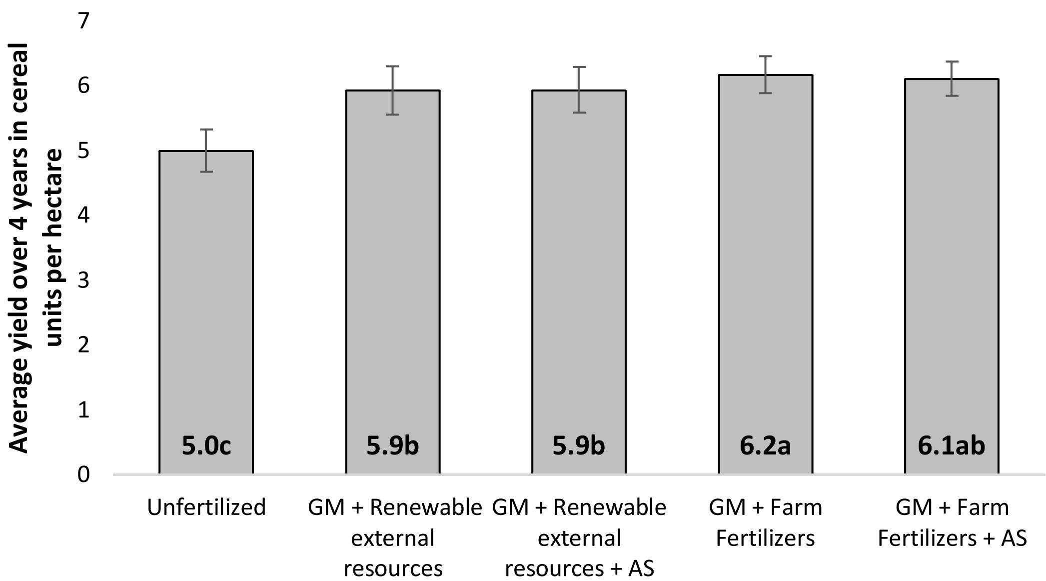

Figure 9. Average crop yield over four experimental years recalculated to the cereal units per hectare units (observed treatments). Error bars represent the standard error (SE). Different letters mean statistical difference. Cereal unit of winter wheat = 1 t/ha of winter wheat grain × 1; cereal unit of potatoes = 1 t/ha of potato tubers × 0.25; cereal unit of winter wheat spelt = 1 t/ha of spelt grain × 1; cereal unit of field pea = 1 t/h of field pea grain × 1.20; cereal unit of spring barley = 1 t/ha of barley grain × 1; cereal unit of silage corn = 1 t/ha of fresh silage × 0.15.

Overall, the average yield achieved during the examined period of the experiment was very high, in some cases even higher in comparison with conventional agriculture. Such results are very promising, and they are only supporting the importance of organic fertilization for maintaining and improving soil fertility, therefore improving possible crop yields. However, it is necessary to point out that the results were obtained from a small plot field experiment with a harvesting area of 10 m^2. The average yield from this area (in kg) was then recalculated to represent the standard agriculture unit of 1 ton per hectare. In common practice, the harvesting area (whole field) is much bigger, which opens a lot of possibilities for biotic and abiotic factors to reduce the crop yield, such as higher occurrence of pest, diseases or weed, higher heterogeneity of the cultivated field, drought and more. It is relatively easier to maintain the small experimental area in comparison with common practice and, therefore, the obtained yield may be influenced by this factor. On the top of that, the cultivated crops were not really damaged by diseases and fungi, probably because of very hot and drought periods during vegetation. The occurrence of insect and weeds were higher, but insects were dealt with the application of allowed products, and weed was removed mechanically or by hand. Before the start of the experiment with organic farming, the examined areas were used for conventional experiments, therefore with intensive agriculture. Overall, the nutrient supply and climate-soil conditions can be evaluated as a very good, which is also a possible explanation for high yields. Another hypothesis behind very high crop yield could be the organic fertilization itself, as the dosage and quality of organic matter in common practice is problematic in our country. Organic fertilization is usually performed mostly by incorporation of straw or green manure crop only. The utilization of digestate has also been rising in recent years, mostly near biogas stations. However, farm fertilizers or compost are being used rather locally, the dosage per hectare can be lower, as the farmers have to distribute their organic fertilizers to more fields.

The application of additional auxiliary substances, therefore fertilizers allowed in organic farming, proved to have statistically insignificant influence on the crop yield in comparison with the same variants without AS. The achieved yield of crop in most of the experimental years was even lower in comparison with same variant without AS, however, the differences were insignificant. Similar results are described by or De Olivera et al. [38]. There is a hypothesis formulated by Holečková [39] that positive results of similar experiments based on application of AS, sometimes referred also as "bioeffectors", are often published only from pot experiments with fully or semi controlled conditions. Several authors [40–42] illustrate a positive effect of similar AS examined in controlled conditions. The inconclusive effect observed in field experiments through the four experimental years could be possibly affected by a much greater competitive relationship between the AS and climate soil conditions in the field in the comparison with pot experiments.

Figure 10 describes the average crop yield detected on five experimental localities over four experimental years. The average yield was recalculated and expressed to the cereal units per hectare. The result corresponds with Tables 1 and 2 respectively (climate-soil and nutrients characteristic of each experimental station). The order in the aforementioned tables is from most optimal to least suitable conditions and it corresponds almost perfectly with the order of each locality in terms of crop yield provided during the experimental period. It is evident, that the average crop yield is decreasing in correlation with increased altitude. The experimental localities Věrovany and Čáslav are also characteristic with the Chernozems soil group with the soil texture clay, which is often considered as the most fertile soil. On the contrary, Horažd'ovice and Lípa can be described as a Cambisols soil group with sandy loam texture.

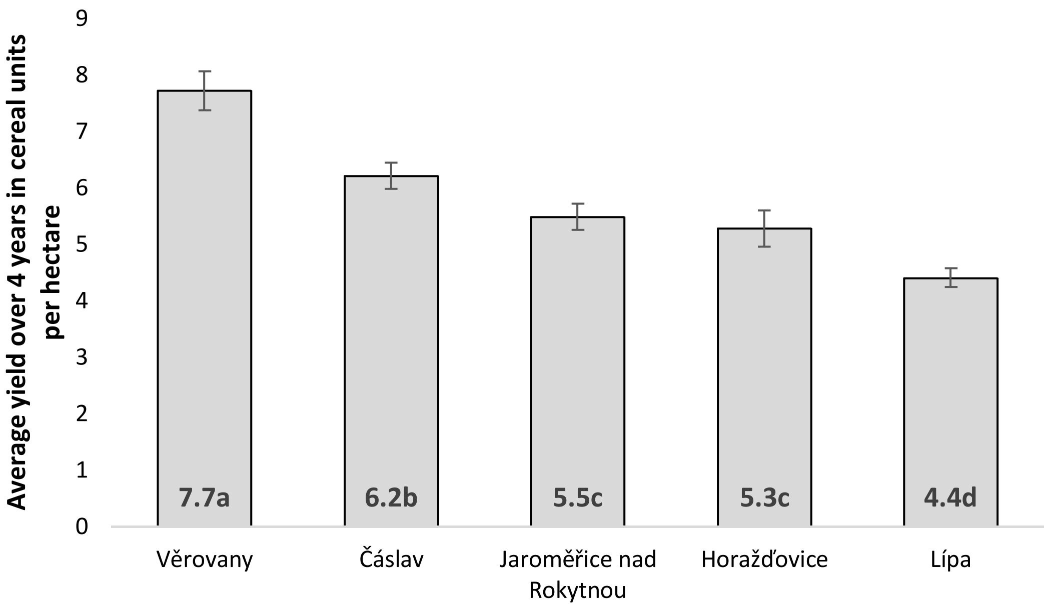

Figure 10. Average crop yield over four experimental years recalculated to the cereal units per hectare (observed experimental localities). Error bars represent the standard error (SE). Different letters mean statistical difference ($p \leq 0.5$).

4. Conclusions

The average crop yields examined over four experimental years indicate the increase in yield of crops after organic fertilization regardless of the production system (with or without animal husbandry) compared to the control variant without fertilization. This result confirms the basic hypothesis given before the start of the experiment, that the addition of organic matter regardless of its source is going to improve the crop yields.

The highest average yields of winter wheat and potato tubers observed after the first and second years of the experiment were provided by the production system without animal husbandry (renewable resources = compost, digestate). The content of quickly available *n* was higher in these fertilizers compared to the fertilizers with the origin on farms with animal husbandry (manure, fermented urine). Therefore, the observed result is related to the hypothesis, that compost could possibly provide more nutrients to the crops during the first year after application. The average yields observed from the third experimental year with winter wheat spelt was highest in the variant based on farming with animal husbandry, therefore through application of manure or fermented urine. On the contrary, such a result supports the hypothesis that manure in comparison with compost can provide more nutrients to the plants for longer period after fertilization. The result acquired from the last experimental year after recalculating different crop yields (spring barley + field pea and corn) to the cereal units per hectare are also in favour of a production system with animal husbandry. The average crop yields over four experimental years suggest the application of farm fertilizers as the preferable option from the long-term point of view. This was also confirmed by the content of mineral nitrogen in the soil after each experimental year.

Auxiliary substances, fertilizers allowed in organic farming, could possibly enhance the crop yield in organic farming. However, our result obtained over four years did not show statistically differences in average yields of crops observed after addition of auxiliary substance in comparison with the identic variants of fertilization without auxiliary substances. On the contrary, the achieved yield on these variants was insignificantly lower. This result contrasts with the original hypothesis, that the additional fertilization in organic farming is going to result in a higher crop yield.

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