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Biomass yield of silage maize, fertilizers efficiency, and soil properties under different soil-climate conditions and fertilizer treatments

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Abstract. We evaluated the efficiency (the netto agronomic efficiency – NAE, the physiological efficiency – PE, and the apparent recovery efficiency – ARE) of farmyard manure (FYM) applied alone, and together with mineral N (FYM+N), and NPK (FYM+NPK), on the biomass production of silage maize at three localities (Caslav, Ivanovice, Lukavec) in the Czech Republic, characterised by different soil-climate conditions. The effect of fertilizer treatment on soil chemical properties was also analyzed. After four years of evaluation, the application of FYM resulted in comparable biomass production as in the FYM+N, and FYM+NPK treatments, showing the good ability of the mineralized FYM to provide enough nutrients during the growing season. Increasing doses of applied nutrients were connected with higher biomass production. However, no significant differences were recorded between fertilizer treatments. The efficiency of applied nutrients was higher on soils of worst quality (sandy loamy Cambisol – Lukavec), while lower on naturally fertile loamy degraded Chernozem (Ivanovice). But again, no significant differences between the selected parameters were recorded. Although the application of mineral fertilizers has not increased maize biomass yield significantly, they positively affected soil chemical properties, mainly the soil concentration of P, K, Mg, and soil organic carbon content. This shows the beneficial effect of the application of mineral fertilizers, especially in the Czech Republic, where the application of mineral P and K decreased drastically during the last thirty years.

Key words: *Zea mays* L., organic manure, NPK, soil–climate conditions, fertilizer efficiency.

INTRODUCTION

The silage maize represents one of the most important strengthening feed for ruminant livestock. Maize is widely used and popular among livestock farmers due to its positive characteristics, such as high yields, palatability, high energy content, and low labour and machinery inputs. Maize also serves as a base material for agricultural biogas stations and source material for ethanol production (Klopfenstein et al., 2013; Yu et al., 2016; Kuglarz et al., 2019).

Every farmer tries to achieve high yields of cultivated crops. For that reason, farmers select suitable cultivars (Mandić et al., 2017), environmental conditions (Peichl et al., 2019), planting techniques (Novák et al., 2019), and fertilizers (Fageria, 2001; Hirzel et al., 2007; Černý et al., 2012; Kuglarz et al., 2019). The selection of fertilizers and their doses represents a crucial step in the farm's management. The choice of fertilizer type and the dose is influenced by the availability of funds and fertilizers in order to optimize yields, maintain soil fertility, and minimize negative environmental impacts. This leads to a specific situation in the Czech Republic because many farmers have literally abandoned the application of mineral P and K fertilizers due to their high prices, and the entire conventional agricultural sector is dependent on mineral nitrogen (Fig. 1).

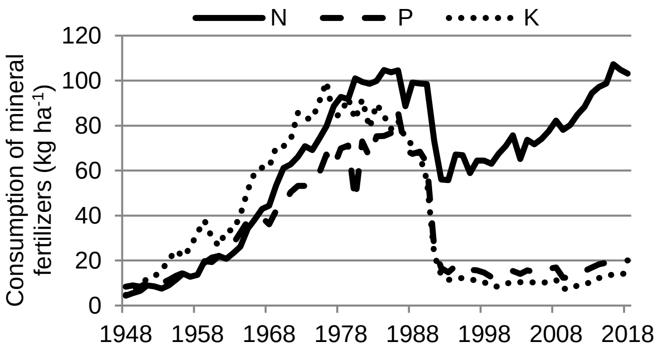

Figure 1. The mean consumption of mineral N, P, and K in the Czech Republic since 1948.

Silage maize is usually fertilized with organic manures. According to Lamptey et al. (2017), application of organic manure applied together with chemical fertilizers positively affects the leaf area index and leaf chlorophyll content, which results in higher dry matter accumulation and nitrogen content. The recommended dose of farmyard manure applied in autumn is approximately up to 40 t ha^{-1} in the Czech Republic. Application of slurries in the spring is even more efficient way of delivering the nutrients, because the mineralization process of manures with low C:N ratio is quicker, the amount of released nitrogen is higher, and the timing of nitrogen release meets the increased requirements of maize for that element. Maize is also considered as a plant requiring high doses of phosphorus and potassium. If no organic manures were applied, the application of mineral NPK in autumn and NP during the planting is recommended.

The efficiency of fertilizers varies significantly depending on soil type and season's weather conditions. According to Berenguer et al. (2008), the minimum rates for achieving maximum yields in northeast Spain (Petrocalcic Calcixerept soil type) are 30 m^3 ha^{-1} of pig slurries (PS) applied together with 100 kg N ha^{-1}, or 60 m^3 of PS per ha without any addition of mineral fertilizers. In Belgium, where sandy loam soil occurs, is the recommended dose of cattle slurry 180 kg ha^{-1}, applied together with 90 kg of inorganic N ha^{-1} (Nevens & Reheul, 2005). Higher nitrogen inputs are associated not only with unnecessary financial costs, but also closely affect the environment and long-term sustainability. According to several papers, many farmers in China apply high doses of fertilizers, mainly nitrogen and phosphorus, to obtain high yields due to rising maize prices. This leads to nutrient accumulation in the soil, causing environmental problems if concentrations exceed critical limits (Zhao et al., 2006; Xu et al., 2014). The situation is particularly sensitive in the case of maize because slow growth and occurrence of yellow whirls in spring can be misinterpreted as nitrogen deficiency, which is followed by the application of further dressings (Nevens & Reheul, 2005). Another risk of over-fertilization raises from the fact, that maize is predetermined for slurry application due to its late sowing date. Many farmers think about manures as a waste product and don't reduce the amount of mineral nutrients applied on the field together with manures (Schröder et al., 2000; Berenguer et al., 2008).

According to Černý et al. (2012) the amount of nutrients uptake in the Czech Republic is higher than their inputs to the soil via the applied fertilizers. As shown in Figure 1, most companies in the Czech Republic apply only mineral nitrogen and the application of mineral phosphorus, potassium, and organic manures is significantly restricted, which may negatively affect the soil properties in the long term. The aim of this work is to find out whether the application of manure can provide comparable conditions to maize as mineral fertilizers and what the farmer will benefit from, or will bear the consequences of the application of individual types of fertilizers. For that reason, we evaluated the maize biomass yield (BY), nutrients uptake (N, P, K), netto agronomic efficiency (NAE), physiological efficiency (PE), apparent recovery efficiency (ARE), and soil chemical properties at three localities with different soil-climate conditions and over four years (2012–2015).

MATERIAL AND METHODS

Site description

Three long-term experiments were established in three locations with different soil-climate conditions in the Czech Republic in 1955. The long-term experiments aim is to analyze the effect of different fertilizer treatments and soil-climate conditions on the yield of arable crops and soil chemical parameters. The experiments are located in Caslav, Ivanovice na Hané, and Lukavec. The basic description of the experimental sites is given in Table 1.

Table 1. The basic description of the experimental localities between 2012 and 2015

Experimental station	Caslav	Ivanovice	Lukavec
Altitude (m a.s.l.)	263	225	620
Mean temperature 1956–2006 (°C)	8.9	8.4	6.8
Mean temperature 2012 (°C)	9.8	9.6	8.1
Mean temperature 2013 (°C)	9.4	9.2	7.3
Mean temperature 2014 (°C)	11.4	10.5	8.8
Mean temperature 2015 (°C)	11.0	10.4	8.7
Mean precipitation 1956–2006 (mm)	556	555	686
Mean precipitation 2012 (mm)	637	482	747
Mean precipitation 2013 (mm)	621	551	876
Mean precipitation 2014 (mm)	618	520	936
Mean precipitation 2015 (mm)	442	387	576
Soil type	Greyic Phaeozem	Loamy degraded Chernozem	Sandy loamy Cambisol

Experiment methodology

The long-term experiments in Caslav, Ivanovice, and Lukavec have the same standardized design. The experiment consists of four fields in each location. Together twelve different fertilizer treatments with four replications are evaluated on each field, arranged in a completely randomized block design (12×4 = 48 experimental plots per field). The size of the experimental plot is 8×8 m^2, but to eliminate the edge effect only the 5×5 m central area is used to get the samples for analysis.

Out of twelve fertilizer treatments, we evaluated four treatments in this paper: 1) Control (unfertilized since 1955), 2) cattle farmyard manure (FYM), 3) cattle farmyard manure combined with mineral nitrogen (FYM+N), and 4) cattle farmyard manure combined with mineral NPK (FYM+NPK). The cattle farmyard manure was each year plowed into the soil in the autumn at a dose of 40 t ha^{-1} (typical dose of manure applied to maize by farmers in the Czech Republic). The content of N, P, and K in the FYM was approximately 200, 56, and 236 kg ha^{-1}, respectively. Mineral nitrogen was applied as ammonium nitrate with lime. Mineral phosphorus was applied as triple superphosphate. Mineral potassium was applied as potassium chloride. Mineral N was applied in two dressings (½ of the dose was applied before planting, ½ was applied at BBCH 16 – 6 leaves unfolded). Mineral P and K were applied in the autumn. The dose of mineral N, applied in the FYM+N and FYM+NPK treatments, was 80 and 120 kg ha^{-1}, respectively. The dose of mineral P, and K, applied in the FYM+NPK treatment, was 80 and 100 kg ha^{-1}, respectively. The total amount of clear nutrients, applied in the analyzed fertilizer treatments, shows Table 2. The influence of fertilizer treatment on the pH value, and concentration of N, P, K, Mg, Ca, $C_{org.}$, and $N_{tot.}$ over the evaluated period is shown in Table 3.

Table 2. The doses of N, P, and K applied in experimental fertilizer treatments

Fertilizer treatment	Nutrient (kg ha^{-1})		
	N	P	K
Control	0	0	0
FYM	200	56	236
FYM+N	280	56	236
FYM+NPK	320	136	336

Table 3. Soil chemical properties in the Control, FYM, FYM+N, and FYM+NPK treatments in Caslav, Ivanovice, and Lukavec in 2012–2015. Assessment of the P, K, and Mg (mg kg^{-1}) soil concentrations were made according to Budňáková et al. (2004)

Treatment	pH	P	P assess.	K	K assess.	Mg	Mg assess.	Ca	$C_{org.}$ (%)	$N_{tot.}$ (%)
Caslav										
Control	7.47a	44a	Low	97a	Low	110a	Suitable	3610a	1.26a	0.13a
FYM	7.48a	64a	Suitable	131a	Suitable	130b	Suitable	3497a	1.38ab	0.14a
FYM+N	7.35a	54a	Suitable	124a	Suitable	145c	Suitable	3083a	1.47bc	0.15b
FYM+NPK	7.29a	138b	High	195b	Good	148c	Suitable	3085a	1.53c	0.17c
Ivanovice										
Control	7.55a	97a	Good	199a	GSuitable	195a	GSuitable	4409a	1.87a	0.19a
FYM	7.50a	144b	High	280b	Good	216ab	GSuitable	4466a	1.97a	0.20ab
FYM+N	7.56a	136b	High	293b	Good	235bc	Good	4435a	2.17b	0.22c
FYM+NPK	7.43a	192c	Very high	364c	High	244c	Good	4342a	2.14b	0.21bc
Lukavec										
Control	6.45b	37a	Low	111a	Suitable	104a	Low	2016a	1.61a	0.17a
FYM	6.43b	72b	Suitable	148bc	Suitable	116a	Suitable	2114a	1.84b	0.20b
FYM+N	6.28ab	39a	Low	125ab	Suitable	104a	Low	2038a	1.90b	0.21b
FYM+NPK	6.20a	176c	High	156c	Suitable	103a	Low	2114a	1.93b	0.21b

The crop rotation of the long-term experiments consists of eight crops: *Hordeum vulgare* L., *Trifolium pratense* L., *Triticum aestivum* L., *Zea mays* L., *Hordeum vulgare* L., *Brassica napus* L., *Tritticosecale* W., *Solanum tuberosum* L. Maize was each year planted during the April (Caslav, Ivanovice), and up to May, 10th (Lukavec). The maize cultivar used in the experiment was LG 32.58. The planting rate was 95–100 thousand seeds ha^{-1}, the row spacing was 0.70×0.15 m.

Nitrogen efficiency of applied fertilizers

The efficiency of applied fertilizers was calculated according to Fageria et al. (2010). The netto agronomic efficiency (NAE, kg) was calculated as:

$$\left(\frac{Y_T - Y_C}{N_T}\right) \quad (1)$$

where Y_T is the biomass yield of fertilized treatment; Y_C is the biomass yield of the Control treatment; N_T represents the dose of applied nitrogen.

The physiological efficiency (PE, kg) was calculated as:

$$\left(\frac{Y_T - Y_C}{N_{TU} - N_{CU}}\right) \quad (2)$$

where N_{TU} represents N uptake of the fertilizer treatment; N_{CU} represents N uptake of the Control treatment.

The apparent recovery efficiency (ARE, %) was calculated as:

$$\left(\frac{N_{TU} - N_{CU}}{N_T}\right) \cdot 100 \quad (3)$$

Soil properties

Soil samples were collected at two depths (0.3 and 0.3–0.6 m) in spring, before N application. The pH of the soil was measured after shaking for 2 h in the suspension of 0.2 M KCl_2 (soil/solution ratio 2.5:1; w/v). The $C_{org.}$ was determined by combustion analysis using a Vario Max analyzer (Elementar Analysensysteme GmbH, Hanau, Germany). Content of plant-available forms of phosphorus, potassium, magnesium, and calcium was established by the extraction in Mehlich 3 reagent (Mehlich, 1984), followed by ICP-OES analysis (Thermo Jarrell Ash, Trace Scan, Franklin, USA). Mineral nitrogen ($N_{tot.}$) was determined in field-fresh soil samples by using 1% K_2SO_4 (soil/solution ratio 5:1; w/v). Concentrations of NH_4-N and NO_3-N were determined by the colorimetric method using the flow injection analyses (SAN plus SYSTEM, SKALAR, De Breda, The Netherlands).

Statistical analysis

The biomass yield (BY – t ha^{-1}) was analyzed by one-way ANOVA and factorial ANOVA (MANOVA). All statistical analyses were performed using Statistica 13.3 (Tibco Software, Inc.).

RESULTS AND DISCUSSION

The BY was significantly affected by locality ($p < 0.001$, 11%), fertilizer treatment ($p < 0.001$, 25%), weather conditions during the year ($p < 0.001$, 37%), and by the interaction between all analyzed factors, mainly by locality and year ($p < 0.001$, 25%).

Ivanovice was the most productive area with the average BY 19.62 t ha^{-1}, followed by Caslav (17.71 t ha^{-1}), and Lukavec (17.51 t ha^{-1}). Ivanovice has the best combination of conditions for growing the maize, including the soil type and climate. These conditions (fertile Chernozem, lower altitude, higher mean temperature, decent precipitation) are optimal for C4 plants and create a beneficial natural background for maize production in this area. Čáslav has climatic conditions comparable with Ivanovice, but has a different soil type. Both Phaeozems and Chernozems, represent the most fertile soil types in the Czech Republic (Kozák et al., 2003), and are almost comparable, but Phaeozems are more prone to leaching during the wet seasons and do not contain carbonates in the topsoil layer (European Commission, 2005). Finally, Cambisols in Lukavec are characteristic of low natural fertility and high nutrient depletion (Hejcman & Kunzová, 2010), with the climate conditions more suitable for growing the C3 plants.

The highest yields were recorded in the FYM+NPK treatment at all sites (Table 4). Generally, the increasing dose of nutrients is connected with increasing biomass production (Fig. 2). This is supported by other studies (Kunzová & Hejcman, 2009; Wei et al., 2016; Xin et al., 2017). However, in comparison with the FYM, the application of FYM+N and FYM+NPK was not connected with higher yields (Table 4, the last column). In this respect, the application of mineral P and K fertilizers to farmers is unnecessarily expensive and does not outweigh the resources invested in the purchase and application of fertilizers. A comparison of the uptake of N, P, and K from one hectare (kg ha^{-1}), and the uptake of N, P, and K, for the production of one tone of the BY (kg t^{-1}), as affected by locality and fertilizer treatment, is shown in Table 5. These data were used for calculation of the NAE, the PE, and the ARE (Table 6). The mean BY as affected by locality, fertilizer treatment, and year are shown in Table 4.

Table 4. Biomass yield (t ha^{-1}) as affected by locality, fertilizer treatment, and year

		BY (t ha^{-1})				
Locality	Fertilizer treatment	2012	2013	2014	2015	
Caslav	Control	17.4 ± 0.4^{Ab}	13.0 ± 0.2^{Aa}	13.8 ± 0.8^{Aa}	12.6 ± 0.3^{Aa}	14.2 ± 0.5^{A}
	FYM	22.6 ± 0.3^{Bc}	17.9 ± 0.3^{Bb}	17.8 ± 0.7^{Bb}	13.5 ± 0.3^{ABa}	18.0 ± 0.9^{B}
	FYM+N	23.5 ± 0.2^{Bd}	17.4 ± 0.4^{Bb}	20.8 ± 0.6^{Cc}	14.0 ± 0.3^{BCa}	18.9 ± 0.9^{B}
	FYM+NPK	24.9 ± 0.3^{Cc}	18.9 ± 1.6^{Bb}	20.4 ± 0.3^{Cb}	15.0 ± 0.3^{Ca}	19.8 ± 1.0^{B}
		22.1 ± 0.7^{c}	16.8 ± 0.7^{b}	18.2 ± 0.8^{b}	13.8 ± 0.3^{a}	
Ivanovice	Control	18.0 ± 0.4^{Aa}	21.2 ± 0.5^{Ab}	16.0 ± 0.3^{Aa}	17.0 ± 0.9^{Aa}	18.0 ± 0.6^{A}
	FYM	19.7 ± 0.4^{Bb}	22.5 ± 0.4^{Ac}	15.9 ± 0.5^{Aa}	17.3 ± 0.2^{Aa}	18.8 ± 0.7^{AB}
	FYM+N	20.1 ± 0.3^{Bb}	24.7 ± 0.3^{Bc}	18.3 ± 0.4^{Ba}	18.2 ± 0.3^{Aa}	20.3 ± 0.7^{AB}
	FYM+NPK	20.8 ± 0.4^{Ba}	26.3 ± 0.6^{Bb}	19.0 ± 0.2^{Ba}	19.1 ± 0.5^{Aa}	21.3 ± 0.8^{B}
		19.6 ± 0.3^{c}	23.7 ± 0.5^{d}	17.3 ± 0.4^{a}	17.9 ± 0.3^{b}	
Lukavec	Control	18.0 ± 0.4^{Ac}	10.2 ± 0.4^{Aa}	18.6 ± 0.1^{Ac}	12.2 ± 0.4^{Ab}	14.7 ± 1.0^{A}
	FYM	21.7 ± 1.7^{ABb}	11.9 ± 0.9^{ABa}	20.3 ± 1.4^{Ab}	12.7 ± 0.7^{Aa}	16.7 ± 1.3^{AB}
	FYM+N	25.1 ± 0.5^{Bc}	12.9 ± 1.2^{ABa}	19.1 ± 0.3^{Ab}	16.3 ± 0.5^{Bb}	18.4 ± 1.2^{AB}
	FYM+NPK	25.6 ± 0.9^{Bb}	14.2 ± 0.7^{Ba}	24.8 ± 1.1^{Bb}	16.6 ± 1.0^{Ba}	20.3 ± 1.4^{B}
		22.6 ± 0.9^{b}	12.3 ± 0.5^{a}	20.7 ± 0.7^{b}	14.4 ± 0.6^{a}	

Mean values with the standard error of the mean followed by the same letter (A vertically, a horizontally) are not statistically significantly different ($\alpha < 0.05$).

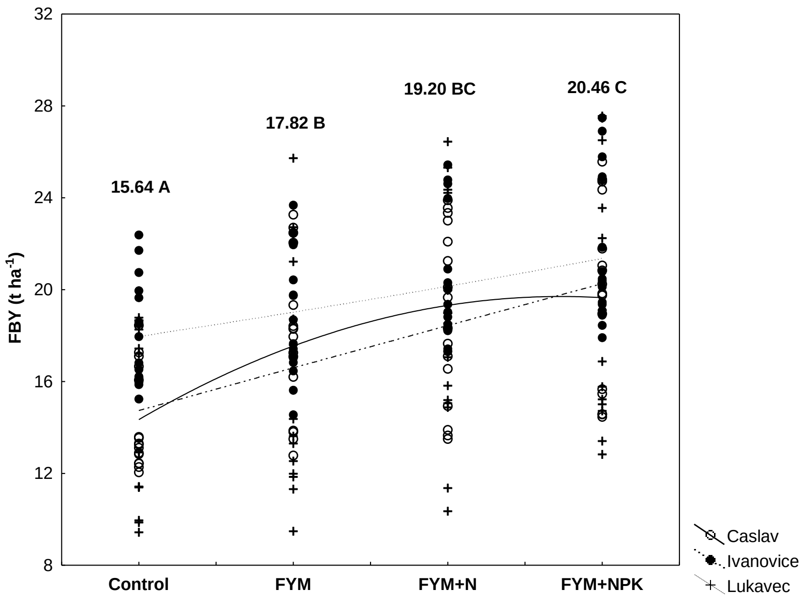

Figure 2. The mean BY (t ha^{-1}) as affected by the locality and fertilizer treatment.

Table 5. The uptake of N, P, and K from 1 ha (kg ha^{-1}), and the uptake of N, P, and K (kg t^{-1}) per production of 1 t of BY

		N (kg ha^{-1})	N (kg t^{-1})	P (kg ha^{-1})	P (kg t^{-1})	K (kg ha^{-1})	K (kg t^{-1})
Caslav	Control	160	10.8	23	1.6	79 a	5.4 a
	FYM	215	12.0	31	1.7	127 b	7.1 ab
	FYM+N	252	12.1	34	1.6	137 b	6.7 ab
	FYM+NPK	259	12.3	41	1.9	157 b	7.4 b
Ivanovice	Control	156	8.6	19	1.0	131	7.4
	FYM	176	9.3	23	1.1	191	10.3
	FYM+N	222	10.8	22	1.2	201	10.1
	FYM+NPK	242	11.9	33	1.7	195	9.4
Lukavec	Control	150	10.3	25	1.7	101	7.0
	FYM	190	11.4	29	1.8	123	7.7
	FYM+N	236	12.9	33	1.8	151	8.5
	FYM+NPK	253	12.8	40	2.0	199	9.8

The NAE is defined as the economic production obtained per unit of nutrient applied (Fageria et al., 2010). In other words, it represents the kg yield increase per kg N applied (Černý et al., 2012). The NAE values were highest at Caslav experimental station (Table 6), ranging from 24 kg in 2012 to 6 kg in 2015. This shows that agronomic efficiency, the use of nitrogen from nitrogen fertilizers, is strongly influenced by the season's conditions (Černý et al., 2012). The year 2015 was the first year characterized by the starting wave of droughts, which continues up today. During the dry years, the mineralization process of manures is significantly inhibited, and the use of mineral fertilizers is also negatively affected. It was very well documented by Hlisnikovsky et al. (2014), when warm weather front from east Europe strongly affected the South Moravian Region in the Czech Republic in 2012, significantly reducing the yields of winter wheat, no matter what kind of fertilizers and doses were applied. The lowest NAE values were recorded at Ivanovice, ranging from 4 kg (2015) to 12 kg (2013) per 1 kg of applied N. These values are very low, but relatively stable during the evaluated period. For example, Černý et al. (2012) recorded values ranging from 26.7 to 27.5 kg in treatments where 60 and 120 kg of N were applied to maize before sowing. In our case, these values were recorded at Caslav (2012, 2013, 2014), and Lukavec (2012). Comparable NAE values as in Ivanovice were recorded at Lukavec experimental station (except 2012). This is interesting because these two localities stand on two opposite poles in terms of soil-climate conditions. It shows that both localities have comparable N utilization efficiency, but soil-climate conditions represent natural borders limiting the BY production. In other words, the same N utilization can provide different BY, as the mean BY was higher at Ivanovice. It also shows that growing maize plants extracted N from other sources at Ivanovice, because the highest yields were obtained here together with the lowest NAE values. The source was naturally highly fertile Chernozem, which means that the amount of applied fertilizers could be lowered here below the doses applied in our experiment, saving farmer's financial and material inputs. A more detailed analysis will be the subject of further work.

Table 6. Netto agronomic efficiency (NAE, kg) per production of BY as affected by fertilizer treatment and year

		NAE				
Locality	Fertilizer treatment	2012	2013	2014	2015	
Caslav	FYM	26 ± 2Ab	25 ± 1Ab	20 ± 7Ab	4 ± 3Aa	19 ± 3A
	FYM+N	22 ± 2Abc	16 ± 2Ab	25 ± 2Ac	5 ± 2Aa	17 ± 2A
	FYM+NPK	23 ± 1Ab	18 ± 5Ab	20 ± 2Ab	8 ± 2Aa	17 ± 2A
		24 ± 1b	20 ± 2b	22 ± 2b	6 ± 1a	
Ivanovice	FYM	8 ± 3Aa	7 ± 2Aa	1 ± 3Aa	2 ± 4Aa	4 ± 2A
	FYM+N	8 ± 2Aa	13 ± 1Ba	8 ± 2Ba	4 ± 3Aa	8 ± 1AB
	FYM+NPK	9 ± 1Aab	16 ± 1Bb	10 ± 1Bab	7 ± 3Aa	10 ± 1B
		8 ± 1ab	12 ± 1b	6 ± 2a	4 ± 2a	
Lukavec	FYM	19 ± 10Aa	9 ± 6Aa	9 ± 7ABa	3 ± 6Aa	10 ± 4A
	FYM+N	25 ± 1Ac	10 ± 3Aab	2 ± 1Aa	15 ± 2Ab	13 ± 2A
	FYM+NPK	24 ± 3Aa	13 ± 3Aa	19 ± 4Ba	14 ± 2Aa	17 ± 2A
		23 ± 3b	10 ± 2a	10 ± 3a	10 ± 3a	

Mean values with the standard error of the mean followed by the same letter (A vertically, a horizontally) are not statistically significantly different ($\alpha < 0.05$).

The physiological efficiency (PE) is defined as the biological yield obtained per unit of nutrient uptake (Fageria et al., 2010). In other words, it represents a kg yield increase per kg increase in N uptake from fertilizer (Černý et al., 2012). The apparent recovery efficiency (ARE) represents the quantity of nutrient uptake per unit of nutrient uptake (Fageria et al., 2010). The PE values varied from 51 to 84 at Caslav, from 46 to 60 at Lukavec, and from 34 to 41 at Ivanovice (Table 7). Not any statistical differences were recorded between the treatments at all localities. These results show that the efficiency of all treatments was comparable, slightly higher at Caslav (FYM treatment). The ARE values ranged between 28–33% in Caslav, from 10–27% in Ivanovice, and 20–32% in Lukavec (Table 7). The lowest values were recorded in the FYM treatment, which means that plant N demands were worse satisfied by N released from the mineralized manure. But again, the results were not statistically different. Comparing all localities, both indicators were not statistically different, but the lowest values were recorded at Ivanovice experimental station, indicating a strong effect of the soil-climate conditions, recorded as well as in the case of the BY and NAE.

Table 7. Physiological efficiency (PE), and apparent recovery efficiency (ARE) as affected by locality and fertilizer treatment over the whole time of the experiment

Locality	Fertilizer treatment	PE (kg)	ARE (%)
Caslav	FYM	84 ± 36A	28 ± 5A
	FYM+N	51 ± 12A	33 ± 3A
	FYM+NPK	58 ± 12A	31 ± 3A
		64 ± 10a	31 ± 1a
Ivanovice	FYM	-	10 ± 6A
	FYM+N	34 ± 5A	23 ± 3A
	FYM+NPK	41 ± 8A	27 ± 6A
		38 ± 4a	20 ± 5a
Lukavec	FYM	53 ± 11A	20 ± 7A
	FYM+N	46 ± 18A	31 ± 12A
	FYM+NPK	60 ± 9A	32 ± 9A
		53 ± 4a	28 ± 4a

Mean values with the standard error of the mean followed by the same letter (A vertically for a particular locality, a for comparison of mean values between localities) were not significantly different ($\alpha < 0.05$).

The application of all fertilizer treatments significantly affected soil chemical composition (Table 3). The lowest value of pH was recorded at Lukavec, which is the only locality, where the application of mineral fertilizers significantly decreased the pH. No effect of treatment on the value of pH was recorded at Caslav and Ivanovice, although the decreasing pattern of pH with an increasing dose of mineral nutrients was recorded. The lower pH at Lukavec is generally a natural property of the soil type. The significant effect of mineral fertilizers on decreasing pH at Lukavec is caused by lighter soil and lower sorption capacity (Vašák et al., 2015). On the other hand, the high buffering capacity of Chernozems against the soil acidification helps the soil to resists the negative effects of mineral fertilizers (Vašák et al., 2015), such as at Ivanovice.

Phosphorus concentration in the soil was positively affected by the application of all fertilizers (Table 3). The higher concentration of soil P was recorded in FYM and FYM+NPK treatments, showing higher utilization of P in the FYM+N treatment for the production of higher BY (in comparison with the FYM treatment). According to our results, the application of FYM with mineral N only can lead to a higher biomass yield (in comparison with the FYM applied without mineral N), but also the one-way soil P depletion can occur. The decrease of the soil P concentration at FYM+N treatment was significant only at Lukavec, but the pattern is visible at all stations and could become significantly evident in a longer period. A similar situation was recorded in the case of potassium (Tables 3).

Concentration of Mg and Ca exhibited a reciprocal relationship at Caslav ($r = -0.9$) and Ivanovice ($r = -0.4$), while a strong and positive relationship at Lukavec ($r = 0.8$). The concentration of Mg significantly increased with the application of mineral N and NPK, showing the enhancing effect of mineral nitrogen on availability of Mg. Similar results of a positive effect of N on other nutrients availability were published by Adeniyan et al. (2011). The concentration of Ca was not affected by the application of any fertilizer at all localities.

The $C_{org.}$ was positively influenced by the application of all fertilizer treatments (Table 3). The highest concentrations were recorded in FYM+N and FYM+NPK treatments. The lowest C_{org}. content was recorded in the unfertilized Control treatment at all localities. As the aboveground biomass of the preceding was not incorporated back to the soil, the increase of $C_{org.}$ is presumably caused by a positive effect of applied organic manures via its content of organic matter, increased proliferation in the upper soil layers, improved soil physical properties (Macholdt et al., 2019), and increased nutrient and water availability (Mosaddeghi et al., 2009). Application of mineral fertilizers also increases the root biomass and crop productivity, especially in wheat (Hirte et al., 2018), which was the preceding crop to maize in our experiment. The same positive effect of fertilizer treatment on the soil content of $C_{org.}$ was published by Kanchikerimath & Singh (2001), Cai & Qin (2006), Zhao et al. (2013), and Xin et al. (2016). The $N_{tot.}$ content was significantly affected by fertilizer application, and locality (Table 3). The application of mineral fertilizers positively affected the $N_{tot.}$ at Caslav (Control, FYM < FYM+N < FYM+NPK), but the different pattern was recorded at Ivanovice (the highest content was recorded in FYM+N treatment), and no differences were recorded between the fertilizer treatments, except the Control, at Lukavec (Table 3). Our results show that the response of the soil on the applied fertilizers is not uniform, strongly depending on the soil type and climate conditions of the locality.

CONCLUSIONS

The BY of silage maize strongly depends on the soil type and climate conditions of the site, where maize is grown. In our case, the most productive site was Ivanovice, offering naturally fertile Chernozem and the most suiTable climate conditions for growing the maize. In comparison with Lukavec, offering higher altitude, lower temperature, higher precipitation, and sandy loamy Cambisol soil type, the BY was 11% higher at Ivanovice. By comparing the effect of fertilization on the BY, we have found that the application of the FYM+NPK achieved the highest yields. With the decreasing quality of soil (Chernozem<Phaeozem<Cambisol) the efficiency of applied fertilizers increased. However, the application of mineral fertilizers together with manure did not bring a statistically significant increase in yield. This shows the good ability of manure to provide maize with sufficient nutrients during the growing season, and additional application of mineral fertilizers can save farmer's finance. This is confirmed by the results of the analyzed fertilizer effectiveness (NAE, PE, ARE), which was not significantly influenced by the fertilization variant but by the locality. However, the application of mineral fertilizers affected soil properties. Application of mineral fertilizers slightly decreased the soil pH value at Caslav, and Ivanovice, and increased the concentrations of P, and K, in the soil. The soil $C_{org.}$ content was also positively affected by the application of manure together with mineral fertilizers. This is very important for the future sustainability of conventional farming, especially under conditions of the Czech Republic, where the application of mineral phosphorus and potassium is very low since 1990.

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