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Impact of long-term organic and mineral fertilization on lucerne forage yield over an 8-year period

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ABSTRACT

Effects of direct fertilization on lucerne (*Medicago sativa* L.) forage yield have been widely investigated; however there is a lack of published studies investigating the long-term effect of indirect application of mineral and organic fertilization. The main objective of the present research was therefore to investigate differences in forage yield under different combinations of mineral (6 treatments) and organic (3 treatments) fertilization over the past 8 years of long-term experiment conducted since 1955 in Ruzyně. Long-term absence of fertilization provided average annual dry matter yield of 8.64 t/ha. Indirect application of single manure or slurry significantly increased yield to 9.68 and 9.37 t/ha, respectively. Absence of mineral fertilization provided yield of 9.23 t/ha across organic fertilization and an inconsistent effect of the increase of indirectly applied nitrogen (N) rate was observed. The highest yields over 10 t/ha were observed at treatments where combinations of organic fertilization with higher rates of N, phosphorus (P) and potassium (K) were applied. The trend for yield reduction was observed under increasing N rates within identical P and K fertilization. This research has shown that indirect effect of fertilization should be considered together with stand age when lucerne forage yield is evaluated.

Keywords: Fabaceae; alfalfa; harvest year; macronutrients; indirect organic fertilization

High forage yield and quality is a goal of lucerne (*Medicago sativa* L.) producers because these factors impact profitability of forage production (Lissbrant et al. 2009). There are many external factors affecting lucerne forage production such as climate, soil as well as applied growing management (Hakl et al. 2014). Intensive agricultural cropping system requires large quantities of plant nutrients (Lloveras et al. 2012) which highlight importance of suitable fertilization management. The impact of lucerne fertilization has been traditionally focused on effects of direct application of phosphorus (P) and/or potassium (K) in various combinations (Berg et al. 2007, Macolino et al. 2013). Direct application of nitrogen (N) or organic fertilizers for monoculture has been investigated rarely (Vasileva and Kostov 2015) because of high lucerne potential of N_2 fixation described by Carlsson and Huss-Danell (2003).

Farmers, who want to reduce their total cost, often prefer fertilization of cash crops instead of forage legumes. Contrast to very intensive lucerne fertilization described by Macolino et al. (2013), direct mineral fertilization is used approximately on half of the total lucerne area in the seeding year whereas the utilization rapidly decreased lower than 20% in harvest years in the Czech Republic (Hakl et al. 2014). In spite of the intensive previous research about lucerne fertilization, there is a lack of long-term studies investigating indirect effects of organic and N fertilization on yield within applied crop rotation. The aim of this paper was therefore

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to analyse data from long-term fertilization experiment in Ruzyně to determine the effect of (i) indirectly applied organic fertilizers; (ii) indirectly applied different rates of N and (iii) different application regime of P and K in crop rotation on lucerne forage yield over the past 8 years. These results could be unique for understanding of impact of long term applied fertilization management on lucerne forage yield.

MATERIAL AND METHODS

The Ruzyně Fertilizer Experiment (RFE) was established on a permanent arable field in 1955, on the western edge of Prague, the capital of the Czech Republic (50°05'15''N; 14°17'28''E).

At the study site, altitude is 338 m a.s.l., the mean annual temperature is 8.2°C and the mean annual sum of precipitation is 422 mm (Prague-Ruzyně Meteorological Station, 1955–2007). The soil type was classified as illimerized Luvisol. The upper 30 cm (arable layer) contains 15% sand, 58% silt and 27% clay. Total soil organic carbon content ranged from 1.36–1.69%.

The RFE is a large scale experiment consisting of five field strips. Each field strip consists of 24 fertilizer treatments replicated four times and arranged in a complete randomized block design (96 individual plots). The individual plot size is 12 m × 12 m and only the central part 3 × 12 m was used for yield assessment.

For period 2002–2014, the analysis of lucerne yield response to fertilization management was carried only in strips number II and IV with identical 9-year crop rotation system: lucerne, lucerne, winter wheat, sugar beet, spring barley, potatoes, winter wheat, sugar beet and spring barley (as cover crop). Seeding rate of lucerne (cv. Morava) was 15 kg/ha under row spacing 125 mm. Three-cut and two-cut management was applied within the first and second harvest year, respectively. Lucerne fresh matter yield was assessed in the central plot in each cut, samples were oven-dried at 103°C to constant weight and lucerne dry matter yield (DMY) was calculated. Observed annual yields, mean temperatures and cumulative precipitation in individual months of each year are given in Table 1.

Selected treatments were evaluated in the model: without organic fertilizers (CO); farmyard manure (FM) or slurry (S) application and their combination with four treatments including various rates of mineral N, P and K fertilizer and control treatment without mineral fertilization (CM). Organic fertilizers were applied each autumn before planting of beet or potatoes in particular treatments. Rates of

Table 1. The lucerne annual mean dry matter yield (DMY, t/ha), monthly mean temperature (T, °C) and sum of precipitation (P, mm) between March–September in evaluated years (Ruzyně meteorological station)

Year	DMY		Mar	Apr	May	Jun	Jul	Aug	Sep	Mar–Sep
2002	11.04	T	4.9	8.5	15.4	17.6	18.6	19.5	13.2	14.0
		P	30	28	9	53	93	147	56	416
2003	7.06	T	5.1	8.5	15.8	20.4	19.5	21.4	14.7	15.1
		P	6	31	72	28	74	31	28	270
2004	10.35	T	3.9	10.1	12.3	16.3	18.3	19.6	14.4	13.6
		P	37	16	40	110	53	65	40	361
2005	7.61	T	2.6	10.5	14.4	17.3	19.2	17.3	15.7	13.9
		P	12	12	90	68	140	66	42	430
2011	10.05	T	5.3	12.1	14.7	18.1	17.6	19.2	16.3	14.8
		P	35	19	38	86	172	88	35	473
2012	8.49	T	7.0	9.5	15.6	17.9	19.5	20.1	14.7	14.9
		P	8	48	18	50	187	79	55	445
2013	13.36	T	0.1	9.4	12.7	16.9	20.8	18.9	13.4	13.2
		P	15	27	117	153	59	138	37	546
2014	10.41	T	7.4	11.4	13.0	17.3	20.7	17.4	15.5	14.7
		P	33	23	110	14	108	54	64	406

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Table 2. The crop rotation and description of applied fertilization management

		Strip II	Strip IV
Crop rotation	lucerne	22% (2002/2003; 2011/2012)	22% (2004/2005; 2013/2014)
	cereals	45%	45%
	root-crops	33%	33%
Organic (rates over 9-year crop rotation)	control	–	–
	manure	2 × 21 t/ha*; 1 × 15 t/ha+	2 × 21 t/ha*; 1 × 15 t/ha+
	slurry	poultry 2 × 45 t/ha*; 1 × 32 t/ha+	cattle 2 × 60 t/ha*; 1 × 43 t/ha+
Mineral (average annual rates)	control	–	
	$N_1P_1K_1$	N 39 kg, P 24 kg, K 109 kg	
	$N_2P_1K_1$	N 63 kg, P 24 kg, K 109 kg	
	$N_3P_2K_2$	N 67 kg, P 31 kg, K 146 kg	
	$N_4P_2K_2$	N 91 kg, P 31 kg, K 146 kg	

*before sugar beet; + before potatoes

poultry or cattle slurry (Table 2) were equivalent to manure as to organic matter. Average annual rates of N, P and K in organic fertilizers were in the ranges of 25–30, 6–8, 17–20 kg/ha, respectively. Mineral N was not applied during the cultivation of lucerne. P and K fertilizers were applied in each autumn in particular treatments. A description of strip crop rotation and treatments as well as rates of applied fertilizers is given in Table 2. Soil pH and nutrient status for K and P in evaluated treatments are shown in Table 3.

General linear model with interactions investigating the effect of year (Y), harvest year (HY), mineral (M) and organic (O) fertilization on lucerne dry matter yield followed by post-hoc Tukey's *HSD* were performed using Statistica 12.0 (StatSoft, Tulsa, USA). In these analyses, year was considered as random factor and variance component was calculated from estimated mean square for each factor and residual mean square of the whole model.

RESULTS

The average lucerne DMY and weather characteristics over vegetation period in evaluated years are shown in Table 1. Temperature and precipitation patterns were similar all over the 8 years with exception of higher precipitations in May 2013 and 2014 which resulted in higher DMY.

Differences in DMY over harvest years, organic and mineral treatments are summarized in Table 4. All tested factors significantly influenced total annual DMY as well as yield in the first and second cut, where absence of both organic and mineral fertilization reduced DMY. In the HY2, a higher DMY was observed in the first cut in contrast to significantly lower total annual DMY. Inconsistent rise of DMY was recorded under increasing rates of NPK.

Significant interactions of HY with fertilization were observed. Under organic treatment, manure

Table 3. Mean values of soil pH_{H_2O}, potassium (K) and phosphorus (P) nutrient status in arable layer for lucerne within 2002–2014. Plant available K and P concentrations were determined by Mehlich III extraction procedure

Organic	Mineral	pH	K (mg/kg)	P (mg/kg)
Control	control	6.2	149	12
	$N_1P_1K_1$	6.3	190	45
	$N_2P_1K_1$	6.1	187	51
	$N_3P_2K_2$	6.2	220	59
	$N_4P_2K_2$	6.2	227	69
Manure	control	6.5	172	34
	$N_1P_1K_1$	6.3	249	82
	$N_2P_1K_1$	6.2	273	89
	$N_3P_2K_2$	6.2	308	103
	$N_4P_2K_2$	6.0	299	106
Slurry	control	6.4	148	61
	$N_1P_1K_1$	6.2	230	122
	$N_2P_1K_1$	6.0	229	108
	$N_3P_2K_2$	6.2	289	139
	$N_4P_2K_2$	6.2	254	127

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provided the significantly highest annual DMY in the HY1 where slurry was significantly higher than control. In the HY2, there was no significant difference between organic treatments which both provided higher DMY than the control treatment. This effect was most mostly visible in the first cut. Among mineral treatments, the more visible differences were in the HY2 where control was significantly lower than other treatments.

Interaction between organic and mineral fertilization is shown in Figure 1. CO-CM treatment reached the lowest value of DMY 8.6 t/ha. Application of manure or slurry without mineral fertilizers provided the same DMY around 9.5 t/ha as the highest rates of mineral fertilizers. The highest values of DMY over 10 t/ha were observed

Table 4. The impact of year, harvest year, organic and mineral fertilization on lucerne dry matter yield (DMY, t/ha) in Ruzyně Fertilizer Experiment (2002–2005; 2011–2014)

Factor		1 cut	2 cut	Total DMY
Year (Y, random)	*P*-value	< 0.001	< 0.001	< 0.001
	(%)*	79	86	81
Harvest year (HY)	HY 1	3.20^{a}	4.19	10.81^{a}
	HY 2	4.64^{b}	4.14	8.78^{b}
	P-value	< 0.001	0.442	< 0.001
Organic (O)	control	3.77^{a}	3.96^{a}	9.38^{a}
	slurry	3.93^{b}	4.27^{b}	9.94^{b}
	manure	4.06^{c}	4.26^{b}	10.07^{b}
	P-value	< 0.001	< 0.001	< 0.001
Mineral (M)	control	3.73^{a}	3.87^{a}	9.23^{a}
	$N_1P_1K_1$	3.99^{bc}	4.28^{b}	9.97^{c}
	$N_2P_1K_1$	3.88^{bc}	4.14^{a}	9.60^{b}
	$N_3P_2K_2$	4.08^{c}	4.30^{b}	10.17^{c}
	$N_4P_2K_2$	3.94^{bc}	4.33^{b}	10.01^{c}
	P-value	< 0.001	< 0.001	< 0.001
HY × O		< 0.001	< 0.001	< 0.001
HY × M		< 0.001	0.816	0.030
O × M		0.063	0.009	0.082

General linear model, different letters document statistical differences for Tukey's *HSD*, α = 0.05. *% estimated variance component attributed to year (random factor) in relation to harvest year

at treatments, where organic fertilizers were applied at $N_3P_2K_2$ and $N_4P_2K_2$ treatment, however the same value was also observed at application of manure under $N_1P_1K_1$ treatment. Increase of N rates within P_1K_1 treatment consistently reduced forage yield and this effect was visible also at application of manure under P_2K_2 treatment.

DISCUSSION

Year (together with HY) was the most important factor affecting about 80% of yield variability in this experiment. Higher DMY in 2013 and 2014 correspond with Raza et al. (2013) who described positive relationship between lucerne yield and soil water content with respect to root distribution over the soil profile. Higher yield of the first cut in the HY2 was in accordance with Lissbrant et al. (2009) who reported the greatest yield in the HY2. In our study, absence of third cut in the HY2 caused the significantly lower annual DMY.

Long-term absence of fertilization (CO-CM treatment) in crop rotation significantly reduced lucerne DMY to 85% in comparison with the highest rates of nutrients applied together with organic fertilizers. This decrease was very low in contrast with reduction to 41% for spring barley (Hejcman et al. 2013) or 61% for sugar beet (Hlisnikovský et al. 2014) in the RFE. Effect of indirectly applied N on DMY was inconsistent in line with results of Vasileva and Kostov (2015) about direct mineral N fertilization. Lucerne N_2 fixation can reach up to 350 kg N/ha per year (Carlsson and Huss-Danell 2003) and therefore forage yield depended less on applied N fertilization.

In contrast to it, indirect organic fertilization significantly increased DMY. Similar tendency was observed by Vasileva and Kostov (2015) for direct manure application. Both single manure and slurry application achieved 92% of maximum DMY. It was the same yield level as maximal rates of mineral fertilizers, in spite of substantially lower annual nutrient rates at single manure or slurry treatment resulting in lower soil nutrient status (Table 3). It could be explained by the impact of organic fertilization on soil properties, where long-term application of manure provided higher total organic carbon and soil microbial biomass than NPK treatment with twice higher rate of N (Šimon and Czakó 2014). It seems that indirect

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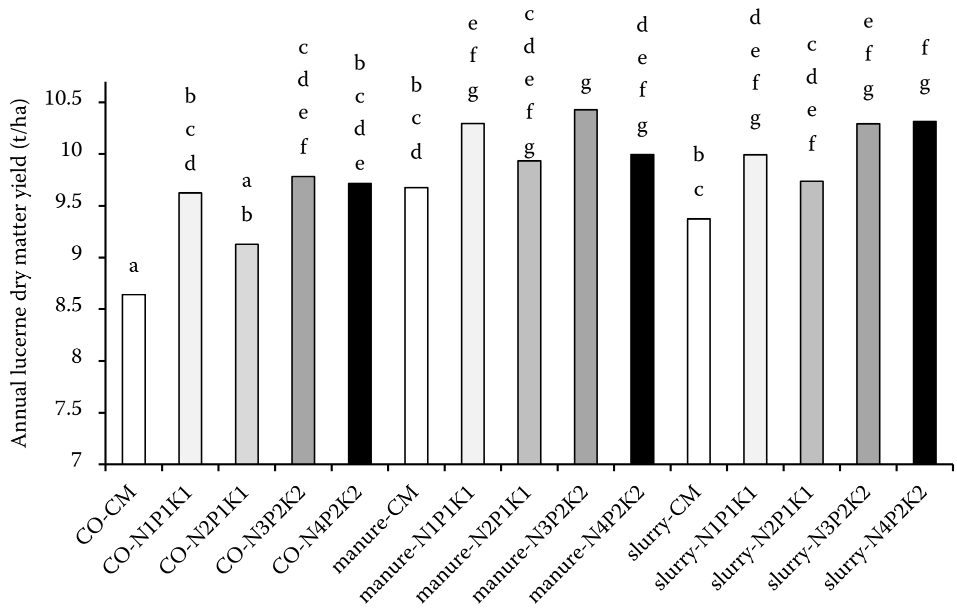

Figure1. Annual lucerne dry matter yield (t/ha) at different fertilization treatments over 8-year period (for treatments description see Table 2; different letters document statistical differences between treatments for Tukey's *HSD*, α = 0.05)

organic fertilization can increase mobilization of unavailable nutrients and improve soil physical properties which can support root development. Ilieva and Vasileva (2013) reported that dry root mass accumulated by lucerne after direct manure application was significantly higher in comparison with equivalent N rate in mineral fertilizer. It can affect lucerne DMY considering positive correlation between root mass and DMY with respect to weather conditions (Hakl et al. 2011). In the present experiment, the manure treatment achieved higher DMY than slurry application (significant in the first cut) which corresponds with a more positive effect of long-term manure application on soil properties in comparison with slurry, as was described by Šimon and Czakó (2014).

P and K fertilization generally increases lucerne yield and stand persistence (Berg et al. 2005). According to Lissbrant et al. (2009), DMY increased when 25 kg P per hectare was applied but higher rates did not further increase yield. It is in line with no significant differences between P_1K_1 and P_2K_2 treatment in present experiment. Moreover, the application of too high P and K rates need not to be effective for increasing of DMY (Lissbrant et al. 2010).

The clear (but non-significant) trend for reduction of DMY was observed under increasing N rates within P_1K_1 at each organic treatment. This effect could be related to reduction of lucerne N_2 fixation under higher N content in the soil (treatment N_1 vs. N_2). According to Houlton et al. (2008), N_2 fixation naturally enhanced phosphatase activity, which could support P uptake by lucerne under higher intensity of N_2 fixation. Within P_2K_2 treatment, this effect was less obvious except for manure treatment. Intensive N_2 fixation caused also soil acidification (Bolan et al. 1991). Rough estimation of N_2 fixation based on lucerne DMY according to Carlsson and Huss-Danell (2003) is in line with tendency to decrease soil pH in the high-yield plots within each organic treatment.

Our results reveal that not only direct but also indirect fertilization substantially influenced lucerne DMY. However, the details of this effect remain unclear. As was noted by Berg et al. (2005), direct P and K fertilization was consistently associated with greater mass of individual shoots. Low P and K soil fertility reduced fibre concentrations in the forage (Lissbrant et al. 2009) as well as persistence and productivity (Berg et al. 2007). As was highlighted by Chmelíková et al. (2015), holistic analysis including above- and belowground traits should be used for the evaluation of fodder crops. Therefore, further research is warranted to identify the influence by which long-term fertilization

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management affects lucerne yield components and also development of under-ground biomass.

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