Effect of applied cultivation technology and environmental conditions on lucerne farm yield in the Central Europe

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ABSTRACT

The aim of this study was to investigate the impact of used technology and environmental condition on lucerne dry matter yield in the regional conditions. During a three year period (2011–2013), the investigation was based on management survey in 27 farms in the Czech Republic. Climate conditions significantly influenced yield in some interaction with soil where only combination of dry climate and less fertile soil conditions reduced forage yield. The single soil effect was not significant for forage yield. Applied technology was influenced by both environment and farm characteristic (such as farm size and cow's milk performance) which together significantly explained about 40% of variability of used technological properties. From all investigated technological properties, only cultivation of lucerne in mixture with grasses consistently increased forage yield therefore should be considered as important factor for modelling forage farm yield in the regional conditions.

Keywords: forage; alfalfa; grass mixture; harvest management

The generation of energy from biomass has a key role in current EU strategies to enhance energy security. According to Ericsson and Nielson (2006), biomass can contribute in stabilization of carbon dioxide concentrations in the atmosphere through biomass production for fossil fuel substitution and carbon dioxide storage in vegetation and soil. Regarding to energy production from biomass of crops in the arable land, it is currently based mainly on the anaerobic digestion of maize due to the highest methane hectare yield (Amon et al. 2007), however maize growing has some negative impact on environment and maize fields are vulnerable to both water and wind erosion (Graebig et al. 2010). Lucerne or other forage legumes could be also suitable source for biogas production (Hakl et al. 2012) and it is generally accepted that their cultivation significantly improves soil fertility (Frame et al. 1997).

For optimization of energy sources utilization, regional sustainable energy policy (ReStEP) project provides a new comprehensive method for landscape management and regional planning in the field of proposing and assessing energy project in the Czech Republic. The new method uses an innovative software tool – an interactive map of conditions for renewable and alternative energy sources. In the ReStEP project, the prediction of regional crops productivity was based on the soil and climatic conditions. Applied technology is generally an important factor which should be taken into account; however the effective implementation of this factor to software tool for plant productivity prediction is not easy for wide range

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of users where only the most important points may be included. For productivity of the most crops, the nitrogen fertilization could be considered as one of the most influencing factor (Černý et al. 2010). For forage legume crops such as lucerne, this point seems not important due to potential of nitrogen fixation (Carlsson and Huss-Danell 2003). The impact of applied technology on lucerne or lucerne-based stand yield was usually investigated under field plot experiment covering large area from advantages of lucerne grass mixture (Bélanger et al. 2014), stand establishment (Norton and Koetz 2013), and population density (Lamb et al. 2003) to applied harvest management (Hakl et al. 2010, Testa et al. 2011) in relation to ethanol (Lamb et al. 2014) or biogas production (Hakl et al. 2012). However relationships among technology, environment condition and yield were not directly investigated, because these studies were usually conducted in one or few sites, under a few treatments with limited explanation power regarding to interaction with environment as well as other technological factor. For the purpose to evaluate impact of technology on lucerne yield in the regional conditions in connection to ReStEP project, the present study was based on farm management survey. The aim of this paper was therefore to analyse data from 27 farms in the Czech Republic (i) to determine the extent of applied technology for lucerne cultivation; (ii) to assess the significance of environmental and technological factors on lucerne dry matter yield, and (iii) to investigate the relationships between environment conditions, applied technology and lucerne yield. These results could be useful for understanding the impact of applied technology on lucerne yield in the real field conditions.

MATERIAL AND METHODS

In 2011–2013, lucerne was grown in 27 commercial farms (altitude 180–550 m a.s.l.) across the Czech Republic. The farms included in the investigation have a size from 58 to 6081 hectares with the total area of cultivated lucerne 4311 hectares. Cow's milk performance at farms ranged from 5500 to 11 000 kg of milk per lactation. Climate characteristic of farms was described by climatic regions (CR) in accordance to Tolazs (2007). In this study related to lucerne cultivation, the seven CR (0, 1, 2, 3, 4, 5, 7) were included within the range of average annual temperature from 6.5–9.5°C and annual sum of precipitation 500–700 mm. Soil conditions were classified into three main groups as Chernozems, Luvisols or Cambisols which presented the most spread soils in the Czech Republic. Technological properties were questioned in the farms in relation to stand establishment, treatment, fertilization, weed or harvest management and are summarized in Table 1. Dry matter yield was calculated as a long term mean based on farm's evidence.

One-way analyses of variance (ANOVA) for investigating environment or management effect on lucerne dry matter yield were performed using Statistica 9.0 (StatSoft, Tulsa, USA). Redundancy analysis (RDA) of multivariate data was used to perform two main analyses (A_{1-2}) with assessment of proportion of variability explained by explanatory variables. Dependent variables were technological properties (Table 1) whilst farm size, milk performance, climatic region, and soil were included as explanatory variables. Standardisation by parameters (dependent variables) was used because the analysed data were of various types and units. The statistical significance of the first and all constrained canonical axes was determined by the Monte Carlo permutation test (499 unrestricted permutations). All ordination analyses were performed using CANOCO for Windows 4.5 and ordination diagram was used for graphical visualisation of the results (ter Braak and Šmilauer 2002).

RESULTS

The overview of the extent of applied lucerne cultivation technology is shown in Table 1. Lucerne stand are established mainly: after ploughing, in the spring, as monoculture, without seed inoculation. Cereals are used as the most common cover crop. In the seeding year, herbicides and fertilization are used approximately on half of the area whereas the utilization of both is rapidly decreased in post-seeding years. In terms of harvest management, three or four cuts are usually realised during the three post-seeding years where the first cut is harvested mainly in bud stage. Prevailing conservation technology is silage making with using of silage additives. Conservation with hot drying air as well as irrigation of lucerne fields are not almost used.

From environment condition, the significant effect on lucerne yield was observed for climate

Table 1. The overview of extent of applied technology for lucerne cultivation in the Czech Republic (source: 27 farms, 4311 hectares of lucerne, percentage values represent ratio from total investigated area)

Stand establishment	Soil tillage	(%)	Type of stand	(%)	Seed inoculation	(%)	Type of establishment	(%)
	ploughing	66	monoculture	82	inoculated	18	cover crop	53
	loosening	34	lucerne-grass mixture	18	unused	82	pure seeding	47
Weed management	utilization of cover crop	(%)	herbicide in seeding year	(%)	herbicide in post-seeding year	(%)	cut	(%)
	forage	86	regularly	56	regularly	21	regularly	23
	grain	14	unused	44	unused	79	unused	77
Fertilization	in seeding year	(%)	in post-seeding year	(%)				
	regularly	55	regularly	17				
	unused	45	unused	83				
Treatment in post-seeding year	harrowing	(%)	pests control*					
	regularly	41	rodenticide	25				
	unused	59	unused	75				
Harvest management	number of cut per year	(%)	number of post-seeding years	(%)	maturity stage in the first cut	(%)		
	2	18	2	14	bud	92		
	3	41	3	54	bloom	8		
	4	37	4	15				
	5	5	5	17				
Conser-vation	type	(%)	silage additives	(%)				
	hay	12	regularly	90				
	silage	88	unused	10				

Microtus arvalis

region in contrast to soil or area of lucerne in the farm (Table 2). Due to low number of farms in CR 0 and 7, they were grouped with CR 1 and 5, respectively. In terms of applied technology, there was no-significant effect of almost all methods of management with exception for cultivation of lucerne-grass mixtures which significantly over-yielded monoculture. These results of ANOVA represent single effect of investigated factor across all environments or technological properties.

Multivariate analyses (A_1, Table 3) investigated the contribution of farm characteristic, climatic region and soil condition to variability of applied technology. The impact of these factors was significant and explained 43.6% of variability of technological properties (all canonical axes). The effect of explanatory variables on technological properties is presented in Figure 1. The most important first canonical axe (horizontal) represents mainly the effect of increasing farm size and milk performance where larger farms with higher milk performance prefer silage making in the bud stage and tend to higher utilization of fertilizers and herbicides under lucerne establishment without cover crop. Smaller farmers rather prefer hay making in bloom stage, stand establishment with cover crop, and higher stand longevity. This first axe also clearly separated warm and dry climatic regions (0, 1, 2) on the right side of the figure where the hay making is more often used. This first axe did not

Table 2. The impact of environment and applied technology on lucerne farm dry matter yield (DMY, t/ha) in the Czech Republic (source: 27 farms, 4311 hectares of lucerne)

	Climatic region	DMY	Soil	DMY	Size of lucerne area	DMY
Environment conditions	0, 1 (4)	8.22^{ab}	Chernozem (11)	8.15	< 100 ha (10)	8.18
	2 (4)	8.28^{ab}	Luvisol (8)	9.24	100–200 ha (9)	8.64
	3 (7)	9.33^{a}	Cambisol (8)	7.89	> 200 ha (8)	8.39
	4 (7)	6.97^{b}				
	5, 7 (5)	9.32^{ab}				
	P-value	0.025		0.179		0.828
Technology	soil tillage		type of stand		type of establishment	
	ploughing (20)	8.49	monoculture (22)	7.96^{a}	cover crop (15)	8.37
	loosening (7)	8.13	grass mixture (5)	10.31^{b}	pure seeding (12)	8.43
	P-value	0.609		0.001		0.917
	cover crop		herbicide in seeding year		fertilization in seeding year	
	cereal (7)	8.03	regularly (16)	8.68	regularly (15)	8.58
	legume (4)	9.46	unused (11)	7.99	unused (12)	8.17
	mixture (4)	7.88				
	P-value	0.441		0.268		0.521
	harrowing	DMY	number of cut	DMY	number of post-seeding years	DMY
	regularly (9)	8.45	2–3 (15)	8.05	2–3 (16)	8.41
	unused (18)	8.37	3–4 (12)	8.83	3–4 (11)	8.38
	P-value	0.899		0.208		0.961

One-way ANOVA, different letters document statistical differences for the Tukey *HSD* ($P \leq 0.05$). Values in brackets represent numbers of cases

show any clear correlation with lucerne yield. The second axe (vertical) represents the differences between colder and wet climatic region 5 and 7 where ploughing, seed inoculation and using of grass mixture are preferred. This is in contrast mainly to very dry CR 4 where loosening and lucerne monoculture is the prevailing technology.

In the second analyses for separate factor effect (A_2, Table 3), the effects of farm characteristic and climatic region were significant and explained 19.9% and 21.5% of variability of technological properties, respectively. Soil effect was no significant with the lowest contribution to investigated variability (9.4%).

Table 3. Results of redundancy analyses investigating effect of farm characteristics, climatic regions and soil on technological properties used for lucerne cultivation in the Czech Republic (source: 27 farms, 4311 hectares of lucerne)

A	Explanatory variables	% ax.1 (all)	*F* 1 (all)	*P* 1 (all)
A_1	farm characteristic climatic region, soil	17.3 (43.6)	3.76 (1.73)	0.008 (0.004)
A_2	farm characteristic	15.1 (19.9)	4.26 (2.98)	0.002 (0.002)
	climatic region	7.9 (21.5)	1.88 (1.50)	0.366 (0.032)
	soil	7.7 (9.4)	2.00 (1.25)	0.074 (0.174)

$n = 27$, % ax.1 (all) – variability of technological properties explained by canonical axis 1 or by all axes in brackets; *F* 1 (all) – *F* statistics for the test of axis 1 or all axes in brackets; *P* 1 (all) – probability value obtained by the Monte Carlo permutation test (499 permutations) for the test of axis 1 or all axes in brackets

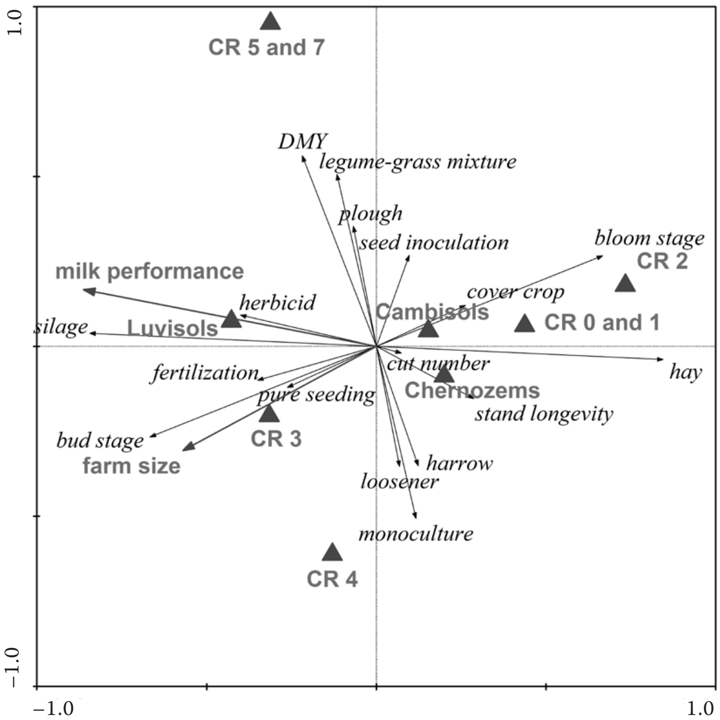

Figure 1. Ordination biplot showing relationship between farm characteristics and environment conditions (explanatory variables, labels or arrows in bold) and technological properties used for lucerne cultivation in the Czech Republic (dependent variables, solid line arrows in bold), where 43.6% of variability was explained by all canonical axes ($P = 0.002$; 499 permutations). CR – climate region

DISCUSSION

In terms of environmental condition, our results in Table 2 document that climate regions strongly impact the lucerne yield where CR 4 (8.0°C, 500 mm) provided significantly lower yield than CR 3 (8.5°C, 600 mm). The effect of growth environment on lucerne productivity is often reported (e.g. Lamb et al. 2014, Chmelíková et al. 2014), however, observed CR effect could not be simply contributed to climate and is probably also connected with soil conditions. In contrast to CR 4, the CR 0, 1, and 2 with warmer climate (8.5–9.5°C), similar precipitation (500–550 mm), and usually more fertile soils (Chernozems, Luvisols) provided yield between CR 3 and 4. In spite of it, the single effect of soil factor across CR was not significant which suggests that temperature-precipitation relationship had greater impact on lucerne yield overall in the Czech Republic.

Regarding the applied technology, harvest management is generally considered among factors with the greatest impact on both lucerne yield and quality (Lamb et al. 2003, Testa et al. 2011). In our study, number of cuts per year or number of productive years did not influence dry matter yield which supported idea that the effect of harvest management is more consistent within the each environment than across them. Similarly, almost all technological properties have no significant effect on lucerne yield. For example, positive yield effect of lucerne pure seeding in contrast to cover cropping was not observed, although this effect is often reported, mainly for arid and semiarid conditions (Norton and Koetz 2013). For the Czech Republic, using establishment without cover crop was more related to high milk performance at the farm (Figure 1). This could be explained by the fact, that cereal or cereal-legume mixture used as cover crops were previously utilized as a forage source with high fibre content (Hakl et al. 2011), which is not sufficient for high-performing cows. These farms also harvested lucerne at the bud stage which is in line with the best forage quality declared (Hakl et al. 2010, Testa et al. 2011).

From all management methods, only lucerne-grass mixture significantly increased forage yield in accordance with the positive effect of mixture to dry matter yield (Bélanger et al. 2014). Grass legume mixtures also resist weed invasion better than monocultures (Sanderson et al. 2012), however some changes in forage nutritive value could be also observed (Bélanger et al. 2014). In the Czech Republic, this technology is more applied in more humid regions (CR 5: 7.5°C, 600 mm; CR 7: 6.5°C, 700 mm) which are more favourable for grass components.

Regarding factors influencing suitable technology selection, results in Table 3 show that farm characteristics and climate condition contributed similarly (each about 20%) to variability of applied technology. These factors had a greater impact than soil condition. It could be concluded that applied technology of lucerne cultivation was related not only to environment condition but also to farm size and cow's milk performance. Regarding the forage yield-technology relationship, using of lucerne grass mixture increased dry matter yield in the Czech Republic; therefore it should be considered as an important factor for modelling forage farm yield in the regional condition.

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