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The use of compressed height to estimate the yield of a differently fertilized meadow

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ABSTRACT

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Monitoring of grassland dry matter yield (DMY) is important for the economy and ecosystem management, but it is a time-consuming process. Calculating the correlation between compressed height (CH) and DMY is a faster way to estimate DMY. The aim of our study was to use CH in order to predict DMY for a meadow with different fertilization management and plant species composition. Four fertilization treatments and one unfertilized control were established in a mesophilic meadow in the Czech Republic. Using a rising plate meter (RPM), CH was measured before the first and second cuts. In addition, the cover of individual vascular plant species was estimated. Significant correlations between CH and DMY were ranging from 0.41 to 0.79 for treatments without nitrogen fertilization in the first and second cuts; for treatments with nitrogen fertilization there was a significant correlation only in the second cut. According to our results, the RPM method seems to be suitable for a rough DMY estimate for meadows with coverage of about 60% grasses, 10% legumes and 30% forbs. However, considerable changes in the cover of tall forbs (e.g. *Urtica dioica* L.) or tall grasses (e.g. *Dactylis glomerata* L.) could be the main sources of DMY estimation inaccuracy.

Keywords: biomass production; forage; pasture; nutrient; plant diversity

Grass yield is one of the most important characteristics associated with the practical utilization, economy and also ecology of grassland management. Yield is affected by plant species composition (Honsová et al. 2007), type of management, especially cutting and fertilization (Pavlů et al. 2013), and environmental conditions, mainly light, water, and mineral nutrient availability (Cornwell and Grubb 2003).

The most accurate method to estimate forage biomass is to clip the forage from a selected area and to determine the dry matter weight (Martin et al. 2005), however this direct method takes a great effort, time and can be expensive (Sanderson et al. 2001). Due to the high demands of this method, a range of indirect methods was developed for yield estimation (Virkajärvi 1999). Some of the main indirect methods used in grasslands include the

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use of an electronic capacity meter (Vickery et al. 1980), measuring sward height with a meter stick (Sanderson et al. 2001), and determining compressed height (CH) using a rising plate meter (RPM) (e.g. Martin et al. 2005). All these indirect methods take less time, but are generally less accurate than the clipping of biomass (e.g. Sanderson et al. 2001, Martin et al. 2005).

RPM can be used for various purposes in a grassland research. Honsová et al. (2007) compared the actual CH and average height of each species from the literature on an alluvial meadow while Hejcman et al. (2005) compared CH in different management plots on a mountain meadow. Hejcman et al. (2014) also used CH as an explanatory variable for the amount of applied nutrient and plant-available concentrations of nutrients in the upper soil layer. This is also a method accepted for predicting yield in lucerne (*Medicago sativa* L.) monocultures (Hakl et al. 2012). In grasslands, RPM was mostly used for estimating yield in pastures (Virkajärvi 1999, Martin et al. 2005, Wrage et al. 2012). The observed R^2 value was in the range 0.22–0.88 for correlations between CH and the above-ground dry-matter for naturalized pastures (Martin et al. 2005, Fehmi and Stevens 2009). For special semi-natural grasslands, the observed R^2 values between CH and DMY were from 0.75 to 0.84 in prairies (Karl and Nicholson 1987) and from 0.89 to 0.96 in multi-layered savannas (Radloff and Mucina 2007).

In spite of the wide use of RPM in pastures, this method has been only very sporadically used in meadows. Honsová et al. (2007) measured the actual CH and DMY on an alluvial meadow from the first and second cuts, but they did not correlate CH and DMY. Hejcman et al. (2007) described CH and plant composition in six fertilized and unfertilized treatments in low mesophilic meadows. Only Pavlů et al. (2013) compared CH and the DMY in cut and unmanaged mountain hay meadows. They found a significant correlation (r = 0.53) between DMY and CH over seven years in a cutting treatment (one cut per year in mid-July) and an unmanaged treatment (unmanaged grassland) in a mountain hay meadow (Polygono-Trisetion alliance). The basic information about meadow DMY could be useful for farmers and scientists, although the higher heterogeneity in meadows compared to pastures could be a source of higher inaccuracy for yield prediction (Martin et al. 2005).

The aim of the study was to predict DMY on the basis of CH (measured by RPM) on a mesophilic meadow with different species composition in relation to the fertilization management and to determine the effect of the cover of functional species groups on the accuracy of the yield prediction.

MATERIAL AND METHODS

The relationship between CH and yield was tested near the village of Mšec, 45 km north-west of Prague (50°12'N; 13°51'E), at an altitude of 490 m a.s.l., where soil type is Pararendzina (syn. Calcic Leptosols), the long-term annual temperature is 8°C and precipitation 550 mm. The site was a mesophilic meadow dominated by *D. glomerata* (visually estimated cover of 45%), *Festuca arundinacea* Schreber. (12%), *Poa pratense* L. (9%) and *Taraxacum* spp. (8%) before the establishment of the fertilizer experiment. The experiment was established in the summer of 2007 and consisted of a completely randomized block design with four replicates. N, NP, NPK and P fertilizer treatments were applied and compared to an unfertilized control (in total, 20 monitored plots each of 4 m × 3 m). The application rates of N, P and K in each dosage were 150 kg N/ha, 40 kg P/ha and 100 kg K/ha, respectively. The first treatment was applied on 19 August 2007. In 2008, 2009 and 2010, the fertilizers were applied two times, at the beginning of March and then after the first cut in June. The experimental plots were cut at the beginning of June and in August. Before each cut, ten random measurements of CH were taken and the covers of each vascular plant species were estimated in each plots. CH was measured slowly putting down a rising plate meter. The RPM is a simple metal instrument with disc diameter, 0.3 m; area, 0.07 m^2 and weight, 0.2 kg (Castle 1976). In each plot, the biomass was cut 5 cm above the ground by a brushcutter and then directly weighed from the whole plot 4 × 3 m. Fresh biomass subsamples of 0.5 kg in weight were then taken from the cut material in each plot and oven-dried at 60°C for 48 h to determine their above-ground dry-matter contents and to calculate the DMY of the above-ground biomass in all plots. Vascular plant species cover was estimated visually as the total percentage cover for each species in the central 3 × 2 m of each monitored plot before each cut. The

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names of species followed local flora (Kubát et al. 2002). For more information about the described experiment and characteristics of the selected site, see Hejcman et al. (2012). The data for CH, DMY and the cover of vascular plant from the first (10/6, 4/6, 1/6) and second cuts (7/8, 20/8, 18/8) in 2008, 2010 and 2011, respectively, were used for our study.

Linear simple regression was used to determine the relationship between the stand compressed height and dry matter yield. The accuracy of the prediction was evaluated by determination coefficient (R^2) and standard error of prediction (SEP). Regression residuals of the simple linear fitting functions for predicting the dry matter yield from CH in the different cuts and treatments were used for detecting the source of prediction inaccuracy. All analyses were carried out using Statistica 12 (Statsoft, Tulsa, USA).

RESULTS AND DISCUSSION

Values of CH and DMY were higher in plots fertilized with N compared to the control and P treatments. Plots with N fertilization (treatments N, NP, NPK) reached average values of 64 cm and 4.6 t/ha for CH and DMY in the first cut, and 61 cm and 2.4 t/ha in the second cut respectively, whereas control and P plots had average CH and DMY values of 39 cm and 3.3 t/ha in the first cut and 22 cm and 1.1 t/ha in the second cut, respectively. The means and ranges of CH and DMY between cuts and all treatments are shown in Table 1. Honsová et al. (2007) obtained similar grassland yield in a fertilized two-cut alluvial meadow (6.5 t/ha for N treatment, 4.5 t/ha for PK and control treatment per year 2005) as in this study, but they obtained significantly lower values of CH (also measured by RPM), which ranged from 5 to 21 cm. Pavlů et al. (2013) measured the average range of CH from 10 to 30 cm with DMY 1.5 to 4 t/ha on the extensive mountain meadows. The differences between our results and the results of Honsová et al. (2007) were caused mainly by the date of measuring CH and DMY characteristics; on the other hand the differences of Pavlů et al. (2013) were caused by different dominant functional plant groups.

Due to the high effects of cut and N fertilization on the investigated relationship, the relation between CH and DMY in two groups of treatment were tested: (i) with nitrogen fertilization (N treatments) and (ii) plots with phosphorus fertilization and control plots (treatments without N). The predictive equations, parameters of the prediction accuracy, number of species, and cover of the functional groups are given in Table 2. For the N fertilization treatments, there was no significant relationship between CH and DMY in the first cut, however a significant relationship was observed

Table 1. Basic statistical characteristics of stand compressed height and dry matter yield under different fertilization treatments across all the evaluated years (n = 12)

Order of cut	Treatment	Compressed height (cm)				Dry matter yield (t/ha)				Linear fit	
		mean	min	max	SD	mean	min	max	SD	R^2	P
First	N	60	37	103	18	4.649	2.549	10.040	2.279	0.006	0.810
	NP	61	46	95	13	4.246	2.245	8.715	2.179	0.013	0.969
	NPK	71	47	106	19	4.990	2.247	7.910	1.842	0.075	0.390
	P	40	22	56	10	3.305	1.580	6.895	1.717	0.570	0.005
	control	38	17	56	12	3.327	1.214	5.804	1.458	0.390	0.030
Second	N	49	20	130	34	2.186	1.343	3.957	0.812	0.803	< 0.001
	NP	58	24	117	36	2.303	1.518	4.946	0.954	0.468	0.014
	NPK	77	23	153	54	2.806	1.158	5.544	1.332	0.354	0.041
	P	21	10	32	7	1.058	0.583	1.943	0.404	0.372	0.035
	control	23	11	43	10	1.217	0.634	1.773	0.428	0.450	0.017

SD – standard deviation; R^2 – determination coefficient; P – level of significance. The application rates: 150 kg N/ha, 40 kg P/ha and 100 kg K/ha

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Table 2. The relationship between compressed height (cm) and dry matter yield (t) of the vegetation for treatments with nitrogen fertilization (N, NP, NPK) and without nitrogen fertilization (P, control) across years

Treatment	*n*	Order of cut	*a*	*b*	SEP	R^2	*P*	Number of species	Grasses	Legumes	Forbs	*U. dioica* of forbs
									(%)			
N, NP, NPK	36	first	4.827	–0.003	2.1	0.001	0.883	18	54	2	78	31
	36	second	1.362	0.017	0.768	0.491	< 0.001	15	30	2	66	37
	72	both cuts	2.542	0.016	0.496	0.067	0.028	17	42	2	72	34
P a control	24	first	–0.451	0.097	1.167	0.463	< 0.001	23	79	11	46	3
	24	second	0.440	0.031	0.324	0.416	< 0.001	20	45	10	22	4
	48	both cuts	–0.761	0.098	0.371	0.623	< 0.001	22	62	11	34	4
All treatments *Urtica dioica* < 5%	56	both cuts	–1.427	0.128	0.367	0.788	< 0.001	21	68	10	39	2
All treatments height < 70 cm	99	both cuts	–0.442	0.085	0.345	0.505	< 0.001	20	57	6	49	12

a – intercept; *b* – regression coefficient; SEP – standard error of prediction; R^2 – determination coefficient; *P* – level of significance. The application rates: 150 kg N/ha, 40 kg P/ha and 100 kg K/ha

in the second cut with R^2 = 0.49. The relationship was significant in the treatments without nitrogen fertilization with R^2 values of 0.46, 0.42 and 0.62 for the first, second and combination of both cuts. The effect of fertilization on the predicted accuracy could not be widely compared with other results because non-fertilized grasslands, especially pastures, were mainly investigated (Karl and Nicholson 1987, Martin 2005, Radloff and Mucina 2007, Fehmi and Stevens 2009).

To determine the next source of the lower accuracy of the yield prediction by CH, the correlation of regression residuals of the equations of different cuts and treatments with individual characteristics of the vegetation were tested (Table 3). The highest correlation of the regression residuals was observed with forb cover, with *r* values of –0.69 and –0.76 for the N treatments and treatments without N, respectively. The range of minimum and maximum yield increased with the increasing height of plants, thus the prediction accuracy was higher in the lower-yield pastures in comparison with higher-yield cut grasslands (Radloff and Mucina 2007, Fehmi and Stevens 2009).

Table 3. The correlation coefficient *r* of the regression residuals of simple linear fitting functions of individual characteristics of vegetation across years for predicting dry matter yield from compressed height in different cuts and treatments

Treatment	Order of cut	No. of species	Grasses	Legumes	Forbs	*U. dioica* of forbs
			(%)			
N, NP, NPK	first	0.11	0.47	0.50	–0.69	–0.56
	second	–0.17	–0.01	–0.08	–0.07	–0.06
	both cuts	0.19	0.51	0.24	–0.35	–0.34
P a control	first	0.09	–0.06	0.24	–0.76	–0.01
	second	–0.43	0.18	–0.08	–0.22	–0.20
	both cuts	–0.09	0.22	0.22	–0.23	–0.26
All treatments *Urtica dioica* < 5%	both cuts	–0.19	0.01	0.03	–0.49	–0.22
All treatments height < 70 cm	both cuts	0.14	0.47	0.14	–0.36	–0.44

The application rates: 150 kg N/ha, 40 kg P/ha and 100 kg K/ha

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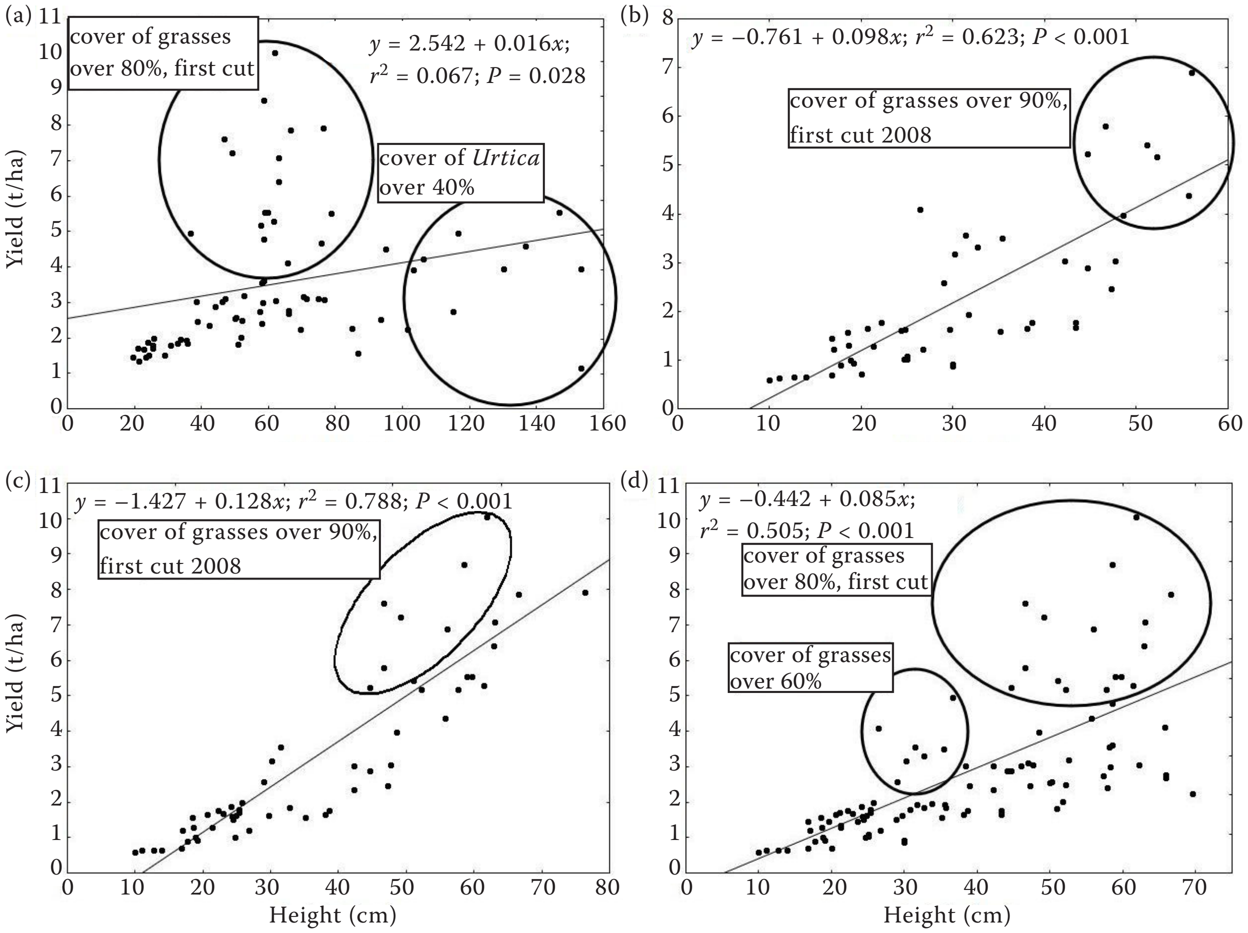

Figure 1. Regression relationship between compressed height and dry matter yield for treatments (a) with nitrogen fertilization for both cuts across years; (b) without nitrogen fertilization for both cuts across years; (c) with and without nitrogen fertilization for both cuts across years, with occurrence of *Urtica dioica* until 5%; (d) with and without nitrogen fertilization treatments for both cuts across years, limited to the compressed height of 70 cm

Analysing the impact of function groups on yield estimation, two groups were found: the first, representing plots dominated by forbs with a high occurrence of *U. dioica* in the treatment with nitrogen fertilization (Figure 1a) and the second, representing high-yield plots with high cover of grasses (Figure 1b). These values could be a source of the decreasing accuracy of yield prediction. Our results suggest that an increase in the cover of tall forbs (in our experiment mainly *U. dioica* with at least 5%, mainly 40% and maximally 99%, and also *Rumex obtusifolius* L. from 2–15%) could be partially responsible for the low accuracy of yield prediction in the N treatments. After values of DMY and CH from plots where *U. dioica* exceeded 5% cover were excluded, a good prediction of DMY by CH (R^2 = 0.79) was obtained also across all cuts, treatments and year. Also Karl and Nicholson (1987) observed a relatively low correlation in low-grazed pasture, (R^2 = 0.34) due to the presence of the dry tall plant *Kochia scoparia* (L) Schrader with low compressibility. *U. dioica* could produce the same source of inaccuracy of the yield prediction in our experiment. The cover of *U. dioica* was over 80% in N fertilization treatments with heights in the range of 100–150 cm but relatively low yields of about 2–5 t/ha in the second cut in 2010–2011 (Figure 1). This finding corresponded with the results of Šrůtek (1995). The high cover of *U. dioica* in our experiment was caused by an open sward with a high proportion of bare patches and low density of tall grass tillers in 2008 (Hejcman et al. 2012) and adequately high of nutrient (Müllerová et al. 2014). Another important source of lower accuracy was the group of high-yield plots with a high cover of grasses

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(Figure 1c). Therefore, the contribution of the CH value to the accuracy of the yield prediction when the compressed height was lower than 70 cm (Figure 1d) was also tested. Increasing grass cover led to an underestimation of yield based on CH.

According to our results, CH could be used as a rough predictor of DMY for mesophilic meadows with coverage of about 60% grasses, 10% legumes and 30% forbs; considerable changes of tall forb or grass cover on plots reduce accuracy of estimation. For generalization of the results, it is important to implement our approach on more and different types of localities.

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