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INFLUENCE OF DIFFERENT GRASSLAND MANAGEMENT ON WATER INFILTRATION AND SOIL PHYSICAL PROPERTIES

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Abstract

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The aim of this paper was to evaluate the effect of animal trampling and heavy machinery used for forage harvest on soil physical properties and infiltration rate in grasslands. Soil physical properties under grasslands are expected to be modified by stocking density at the pastures and at the meadows by silage harvest machinery. These physical properties of soil can affect hydrologic processes that have important implications for water runoff (or balance). Trial was conducted during the period 2011 – 2013 in three sward types: meadow (ME), cattle pasture (PA), and unutilized grassland (PN) which was control variant. Measurements were made at the beginning of the vegetation period (April) after the first cut (July) and at the end of growing season (October). Infiltration rate, bulk density and porosity were evaluated. For measurement of water infiltration double ring in filtrometer method was used. For determination of soil physical properties undisturbed soil samples were taken from depth of 20 – 70 mm, 120 – 170 mm and 220 – 270 mm along with infiltration attempt. Harvest machinery and cattle grazing significantly ($p \leq 0.05$) decreased infiltration rate. It reached in the first minute value 34.5 mm/min in PN treatment compared to 7.0 mm/min in PA and 12.6 mm/min in ME. Significant differences ($p \leq 0.05$) were found in soil physics at followed order in bulk density: PA (1.57g/cm^3) □ ME (1.42g/cm^3) □ PN (1.17g/cm^3), in porosity: PA (40.2% vol.) □ ME (45.9% vol.) □ PN (55.6% vol.) in average of all years and depths. These results demonstrate that intensive grassland exploitation causes soil compaction, degradation of soil physical properties and leads ultimately to reduce infiltration rate.

Key words: infiltration rate, meadow, pasture, soil compaction, soil physical properties, stocking density

Introduction

Grasslands form 23% of the area of agricultural land in the Czech Republic. If the grasslands are managed correctly, they fulfil a range of positive functions in the environment. In addition to the production of forage, many non-productive functions are often pointed out such as enhancement of soil fertility, improvement of groundwater quality, prevention of water and wind erosion, reduction of nutrients leaching and surface runoff. By their all-year-round vegetation cover, grasslands protect the soil surface from falling raindrops, disperse their energy, slowing down the surface runoff and increasing infiltration (Barnes et al., 2007). However, if managed inadequately, grasslands may contribute to the degradation of soils and the environment (Billota et al., 2007; Franzluebbers, 2011).

In pastures, surplus loading at high soil moisture results in the destruction of soil and in its compaction (Drewry et al., 2001). The reduced infiltration rate leads to the surface runoff following intensive rains. The excessive trampling denudates the soil surface and exposes the soil to erosion (Evans, 1997). The increased surface runoff from disturbed localities may release and subsequently transport a great amount of earth, plant residues and animal excrements into surface waters (Billota et al., 2007). The material may settle in the surface waters (Walling et al., 2003), the waters may become eutrophic (Hubbard et al., 2004) or contaminated by pathogens (Trevisan et al., 2010; Muirhead et al., 2005).

In meadows where forage is harvested for conservation or for feeding as green fodder, the process usually includes cutting, forage handling, collection and removal. These op-

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erations have to be done within a short time under favourable weather conditions, often with no regard of soil moisture. The pressure on increasing labour productivity calls for the ever larger and heavier machines. Although the direction of proceeding machines is usually the same each year, the location of wheel tracks is as a rule incidental. Plants are disturbed by tractor wheels, soil structure and physical characteristics of the soil become destructed (Baker, 1991). Consequently, topsoil as well as subsoil layers become compacted by tractor wheels and the compaction may become of permanent character because regeneration measures are too costly (Håkansson and Reeder, 1994). Subsoil compaction shows in the gradually decreasing forage production not only directly in the tractor tracks but also near the tyres (Jorajuria et al., 1997). Another manifestation of compaction is premature drying of plants in dry years and excessive water logging of fields in wet years (Jorajuria et al., 1997; Akker and Schjønning, 2004). Hrabě and Knot (2011) inform that dry matter yields from grasslands in conditions of the Bohemian-Moravian Upland range from 4.4 to 9.8 $t.ha^{-1}$ in dependence on the treatment. Hansen (1995) describes the effect of soil compaction by tractor wheels, which led in Norway to the reduced DM yield of grasslands from 9.0 to 6.6 $t.ha^{-1}$. There, soil compaction had a greater impact on forage yield than the dose of mineral fertilizers and the date of their application.

On one side utilization of meadows and pastures affects soil surface and physical properties. On the other side in connection with recent climate change was observed increase in frequency and intensity of heavy rains following long periods of drought (Dufkova and Toman, 2004), so the hydrology of the stand is disturbed. Result of this is clear relationship between rainfall intensity, runoff and infiltration capacity of the soil, which is important for determination the amount of total catchment runoff.

The aim of this paper was to quantify animal trampling and heavy machinery impact on the soil physical properties and infiltration capacity compared to unmanaged stand.

Material and Methods

Our experiment was conducted in 2011-2013 in the cadastre of Jimramovské Pavlovice (49°36'42."N, 16°12'19."E) in the area of the Bohemian-Moravian Upland. The site is situated at an altitude of 600 m a.s.l., mean annual temperature is 5.9°C, and total annual precipitation amount is 751 mm. A soil texture analysis made on individual sites in 2011 indicated the texture class (using USDA soil texture triangle) of loam (sites PN, PA) and sandy-loam (site ME). Table 1 show the particle size distribution taken from the depth of 50-150 mm. Pursuant to the soil texture classification by Novák used in the Czech Republic (Jandák et al., 2003), all three experimental sites feature medium, sandy-loam soil. Reference soil group: Haplic Cambisol (IUSS-ISRIC-FAO, 2006).

Infiltration was measured in three grasslands under different management types:

- without compaction, i.e. under the pasture fencing (PN), with the dominant species being *Elytrigia repens* and *Lolium perenne*;
- on an intensively burdened pastureland (PA) grazed by the beef cattle of Blonde d'Aquitaine breed – dominant species *Lolium perenne*, *Poa annua*, *Poa pratensis*, *Trifolium repens*, *Plantago major*. Thirty beef cows with their calves grazed on the area of 6 ha from the early April to the end of October;
- on a meadow under large-scale production system with heavy machinery (ME); forage was harvested by tractor with total weight of 7 000 kg with front tire size 480/70 R28 and rear tire size 580/70 R38; for ensiling three times a year and the dominant species were *Dactylis glomerata*, *Festuca pratensis*, *Trisetum flavescens*, *Arrhenantherum elatius*, *Heracleum sphondylium*;

Soil infiltration capacity was ascertained by using the double ring infiltrometer method (ASTM D 5093, 2008), with the inner and outer circle diameter being 170 mm and 310 mm, respectively. The method is based on adding water to the inner circle where the time required for the added water absorption is measured. The experiment ended upon the infiltration rate stabilization or after max. 2 hours of the measurement. The measurements were taken before the first cut (April), after the first cut (July) and at the end of the vegetation period (October), at all times in three repetitions. In meadow stand first infiltration was measured under tire part, second on near part of tire and third between the tires. At pasture and control variant was measuring taken randomly. The measured data were evaluated by using the equation according to KOSTJA-

Table 1
Particle size distribution under different treatments (%)

Treatment	Particle size								
	2.00 -0.25	0.25 -0.05	0.05 -0.01	0.01 -0.001	< 0.001	< 0.01	2.00 -0.05	0.05 -0.002	< 0.002
PN	27.1	28.2	20.1	18.4	6.2	24.6	55.3	34	10.6
PA	24.9	22.8	26.8	19	6.5	25.5	47.7	42.2	10.1
ME	32.6	24.2	21.6	16.5	5	21.5	56.9	34.6	8.5

KOV (1951). For the graphical expression of the infiltration course in a linear form, the equation was converted by using the method of logarithmic anamorphosis.

Stainless steel cylinders method was used to take undisturbed soil samples for the evaluation of physical soil properties – bulk density (BD) and porosity (P). The soil samples were taken at terms of measuring infiltration in the vicinity of individual experimental treatments. Sampling depths were 20-70 mm, 120-170 mm and 230-270 mm, at all times in three repetitions. Significance was tested by ANOVA (Statistica, Version 8.0) and by the subsequent post hoc Tukey HSD test ($p \leq 0.05$).

Results and Discussion

Average infiltration rate in the first minute of measuring the experimental grass stands in the individual months is presented in Table 2. Results show that as compared with the stand without burden (PN), the trampled pasture (PA) as well as the meadow (ME) exhibited a significantly ($p \leq 0.05$) reduced infiltration at all measured dates. In PA, the infiltration was lower in April, July and October by 81.0%, 80.8% and 76.2%, respectively. In ME, it was lower in April, July and October by 70.2%, 56.1% and 64.4%, respectively. In both experimental treatments, the infiltration rate decreased due to the soil surface loading with heavy machines and animals through which changes occur in physical soil characteristics.

Infiltration lines on selected sites for individual periods are presented in Figures 1, 2 and 3. The diagrams show a gradually decreasing infiltration rate on PA and ME sites due to the loading of grasslands. A higher infiltration rate before the first cut is given both by the absence of soil cultivation in winter, and also by the cycles of soil drying out and saturation, thawing and freezing, rooting and biological activity within the soil (Akker and Schjønning, 2004; Van Eekeren et al., 2010). The rate of infiltration was gradually decreasing during the year.

Table 2
Experimental variants

Factor	Level
1. Season	1.1. April 1.2. July 1.3. October
2. Type of management	2.1. Non-compacted grassland (PN) 2.2. Pasture (PA) 2.3. Meadow (ME)

Table 3
Infiltration rate in the first minute of measurement ($V_{i(1)}$) for each variant of treatment - average of three years (mm/min)

Treatment	Season					
	April		July		October	
	x	σ	x	σ	x	σ
PN (control)	38.9 b	13.93	38.5 b	18.40	26.1 b	6.50
PA (pasture)	7.4 a	4.51	7.4 a	3.29	6.2 a	2.45
ME (meadow)	11.6 a	4.54	16.9 a	8.45	9.3 a	2.64

σ Standard deviation
* Values characterised by the same letter in column are not significantly different ($p \leq 0.05$)

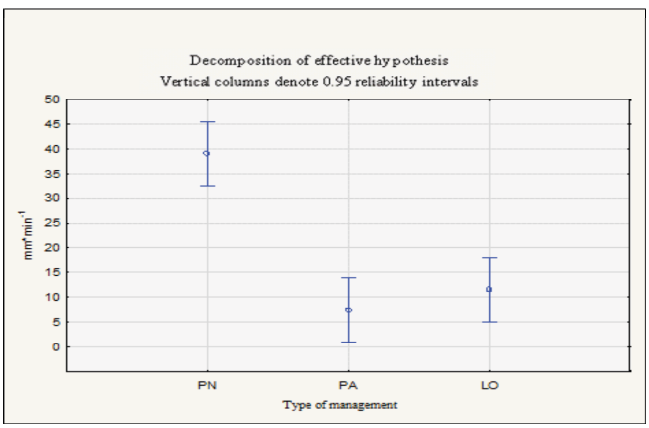

Fig. 1. April infiltration rates in the first minute of measuring in dependence on type of grassland management (the average of three years)

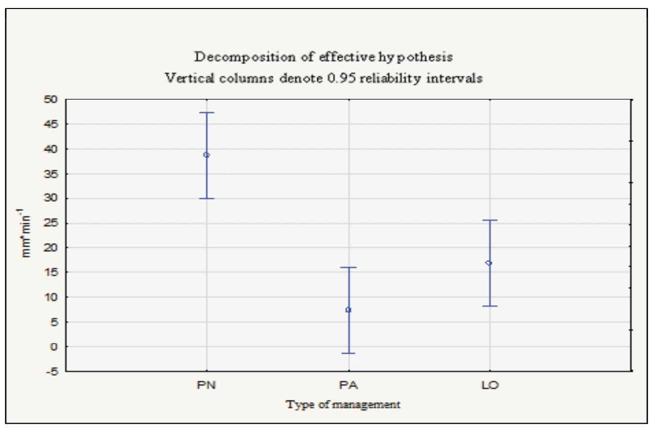

Fig. 2. July infiltration rates in the first minute of measuring in dependence on type of grassland management (the average of three years)

Cutting and subsequent forage handling in the ME stands entailed repeated drives of machines across the treated plots and resulted in soil compaction under machinery wheels. Braun et al. (1996) compared the rate of infiltration in the tractor wheel track in the first minute of work at harvesting alfalfa with the stand of wheat and concluded that the difference was nearly 50-times (wheat 28 mm/min; alfalfa 0.5 mm/min). According to Kasprzak (1990), grass stands under large-scale production system exhibited infiltration rate by an order lower than grass stands harvested by using lightweight mechanization means. On the other hand, Jorajuria et al. (1997) inform that a lightweight tractor with a higher number of travels can caused the same or even more severe damage in the topsoil layer than a heavier tractor with a lower number of passes. However, surveying the impact of the number of drives on grassland yields the authors demonstrated that at the same number of passes, the yield recorded with using the heavier tractor was lower than with using the lightweight tractor.

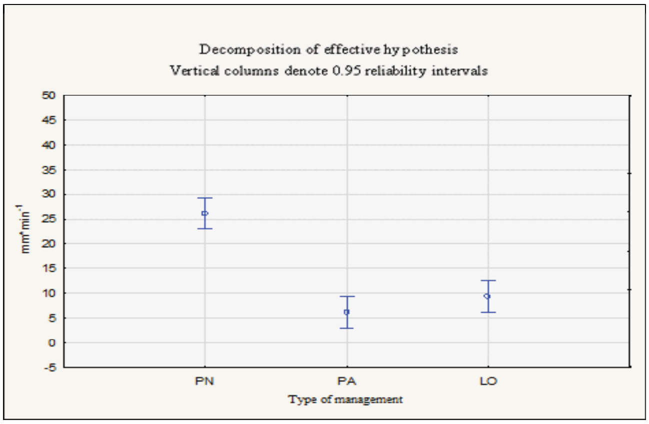

Fig. 3. October infiltration rates in the first minute of measuring in dependence on type of grassland management (the average of three years)

Values of bulk density and porosity from the respective depths are presented in Tables 4, 5 and 6. The measured data have been processed as a mean from the three depths and in-

Table 4
Bulk density (g/cm³) and porosity (% vol.) in depth 20 – 70 mm for each variant of treatment (2011 - 2013)

Treatment	Season					
	April		July		October	
	Bulk density	Porosity	Bulk density	Porosity	Bulk density	Porosity
PN (control)	1.05 a	60.1 c	1.06 a	59.2 c	1.14 a	56.0 c
PA (pasture)	1.54 c	41.1 a	1.52 c	41.7 a	1.56 c	39.5 a
ME (meadow)	1.33 b	48.8 b	1.31 b	49.5 b	1.34 b	48.3 b

Means within column followed by the same letter in column are not significantly different ($p \leq 0.05$)

Table 5
Bulk density (g/cm³) and porosity (% vol.) in depth 120 – 170 mm for each variant of treatment (2011 - 2013)

Treatment	Season					
	April		July		October	
	Bulk density	Porosity	Bulk density	Porosity	Bulk density	Porosity
PN (control)	1.11 a	57.7 c	1.15 a	56.5 c	1.26 a	51.6 c
PA (pasture)	1.60 c	39.1 a	1.57 c	40.4 a	1.57 c	40.5 a
ME (meadow)	1.45 b	44.3 b	1.45 b	44.9 b	1.44 b	44.3 b

Means within column followed by the same letter in column are not significantly different ($p \leq 0.05$)

Table 6
Bulk density (g/cm³) and porosity (% vol.) in depth 220 – 270 mm for each variant of treatment (2011 - 2013)

Treatment	Season					
	April		July		October	
	Bulk density	Porosity	Bulk density	Porosity	Bulk density	Porosity
PN (control)	1.22 a	54.0 c	1.20 a	54.6 c	1.31 a	50.5 c
PA (pasture)	1.62 c	38.8 a	1.58 c	40.2 a	1.56 c	40.8 a
ME (meadow)	1.50 b	43.4 b	1.45 b	44.9 b	1.46 b	44.3 b

Means within column followed by the same letter in column are not significantly different ($p \leq 0.05$)

dividual years. Grazing of grass stands increased significantly bulk density in PA (1.57 g/cm^3) and porosity (40.2% vol.). This site exhibited the highest soil compaction, which resulted from the enormous burden on the soil in the vicinity of winter stalling of animals. Evans (1998) informs that the intensity of load on the pasture affects not only the amount of consumed forage but also the total number of hoof prints on the unit area.

Bulk density and porosity values in the ME stands were 1.42 g/cm^3 and 45.9% vol., resp. Gaisler and Mládek (Mládek et al., 2006) reported similar results. During their study of the impact of machinery on the retention capacity of soils in a stand exploited by two cuts per year, they recorded bulk density and porosity values at a depth of 50-100 mm, which amounted to 1.39 g/cm^{3}and 49.0% vol., respectively. At comparing the impact of machinery on grasslands, Kasprzak (1987) recorded bulk density and porosity of 1.28 g/cm^3 and 51.6% vol., resp. As shown, heavy machines cause the compaction of subsoil, too – as it follows from Tables 5 and 6, where a considerable increase of bulk density was observed with the increasing depth.

Figure 4 shows a correlation between the bulk density measured at a depth of 20-70 mm and the infiltration rate in the first minute. The rate of infiltration was significantly ($p \leq 0.01$) decreasing with the increasing bulk density, with the correlation coefficient being $r = -0.6964$, $r^2 = 0.4850$ (Snedecor and Cochran, 2012). Low value of determination coefficient is probably caused by inaccurate place of soil sampling and the influence of random macroporesor local compaction.

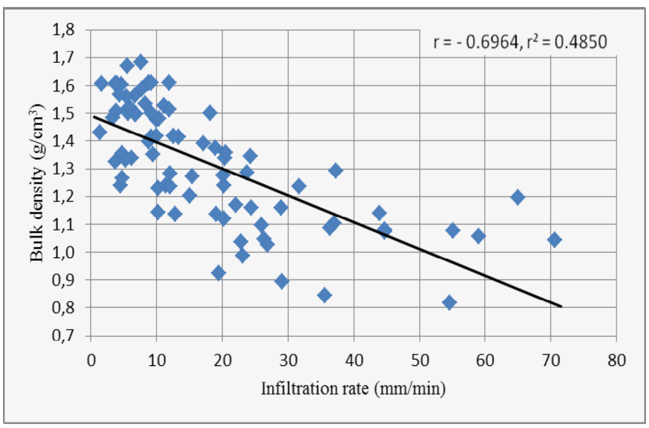

Fig. 4. Correlation between infiltration rate (mm.min^{-1}) and bulk density (g.cm^{-3})

Threshold values for the physical characteristics of compacted soils in the conditions of the Czech Republic specified by Lhotský (2000) are presented in Table 5. In the experimental treatment PA, the bulk density values were exceeded at the depth of 20-70 mm in October and at the depths of 120-170 mm and 220-270 mm at the all measurement terms. Similarly, the limit values of porosity were exceeded at all the depths at the all terms of measurement (Table 7). In ME, the recorded values neared the limit values at the depths of 120-170 mm and 220-270 mm but were not exceeded. The more the measured values get nearer to the limit values, the more disturbed becomes the soil physical properties due to compaction. Thus, the soil capacity of absorbing rainwater or developing surface runoff depends on the degree of compaction (Braun et al., 1996).

Table 7
Limit values of selected physical properties of compacted soil (Lhotský, 2000)

Soil physics	Sandy loam soil
Bulk density (g/cm^3)	> 1.55
Porosity (%)	< 42

Conclusions

The results of our experiment clearly demonstrate a significant influence of grassland management systems on the soil characteristics. Comparing the rate of infiltration with non compacted treatment (34.5 mm/min), the pasture and the meadow stand exhibited infiltration rates lower by 79.3% (7.0 mm/min) and 63.6% (12.6 mm/min), respectively. The decisive factor determining soil permeability for water was bulk density and porosity. The measured values of bulk density and porosity in the control treatment (without compaction) were 1.17 g/cm^3 and 55.6% vol., respectively. Trampling of pasturelands by the hoofs of grazing animals increased the bulk density by 34.2% and decreased the porosity by 27.7%. The limit values of physical characteristics established for the compacted soils were exceeded due to the extreme loading of the pastureland by the vicinity of winter stalling of animals. The high compaction will be difficult to regenerate under the given conditions. A follow-up research should be focused on the capacity of soil regeneration in the intensively burdened pasturelands. In meadow managed in large scale agriculture system, we recorded the soil bulk density increased by 21.4% and the porosity decreased by 17.4% under the impact of heavy machinery.

As was mentioned it is infiltration capacity the part of hydrological balance which can be more or less affected by man. This can be impacted by reduction of load of grasslands or technical conservation by use the aerators or subsoilers on most devastated parts. Those topics could be part of further research.

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