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Investigate the Impact of Large Ungulates on Forest Land with Regard to Soil Hydrology in Central and Eastern Europe

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Abstract:

The study of impact of large ungulates on forest land with regard to soil hydrology was conducted in two locations in central and eastern Europe. The study aimed to investigate the impact of large ungulates on forest soils, as produced by trampling or hoof action, with respect to soil hydrology. Samples for determination of water retention were taken from three kinds of plots representing different sites with different degrees of animal disturbnace (high disturbance, intermediate, and undisturbed conditions). From each plot, several soil samples were taken from two depths (0–5 cm and 5–10 cm). Water infiltration measurements were conducted for determining soil hydraulic conductivity. The data used for evaluating soil water retention and soil hydraulic conductivity were analyzed through the ANOVAwith Duncan's multiple range test and Wilcoxon matched pair test at P<0.05 and P<0.1, respectively. The mean hydraulic conductivity (2, 77.10^{-2} cm day^{-1}) in the high disturbed area was significantly lower than (3,88.10^{-2} cm day^{-1}) in the undisturbed area. Water retention significantly lower in the disturbed sites than undisturbed, except in the plot Topoľčianky Bison Park, it is higher in the disturbed site.

Key words:large ungulates, water retention, hydraulic conductivity

1. INTRODUCTION

Hydrologic function has been defined as the ability of rangelands to capture, store, and release water [15], it is difficult to accurately measure and monitor the inputs and outputs in the field. Instead, several indicators have been developed to characterize hydrologic function with percent bare ground exposure and soil moisture being some of the most commonly applied and accepted indicators [4],[18]. Indeed, [19] argue that soil moisture is the principal determinant of productivity and the primary driver of rangeland condition in semi-arid ecosystems.

Soil moisture is an important environmental indicator of both the soil-water balance and a soil's ability to regulate the hydrologic cycle. Soil water content (expressed as either percent water by weight, percent water by volume or cm of water per cm of soil) can range from 0.05 g/g (5.0%) in xeric regions to 0.50 g/g (50%) or above [21],[9] in more mesic areas. Regardless of the methodology used to estimate soil moisture, site specific calibration curves must be developed [9]. The depth at which soil moisture instruments are placed is important if results are to be meaningful. For most rangeland applications, instruments should be located within the root zone of the site-specific plant community. It has been established that soil water content is dependent upon soil type, structure, porosity, and organic matter [21]. In addition, soil water content can be affected by changes in vegetation, runoff from adjacent roads, as well as other factors.

The study targeted the impact of some of the most important large ungulate species in Europe, in particular European bison (*Bisonbonasus*), red deer (*Cervuselaphus*), roe deer (*Capreoluscapreolus*), and wild boar (*Sus scrofa*).

The objective of this study was to investigate the hydrophysical effects of large ungulates on soils within silvopastoral system, which caused by trampling or hoof action, with respect to soil compaction.

II. MATERIAL AND METHODS

A. *Study areas*

The study was conducted on two main locations in central and eastern Europe. First one represented by Carpathians which itself includes four study sites distributed on most parts of Slovakia, are: (1) Bukovina (Budča-Boky: 48°34'08.19" N and 19°01'16.99" E) in the middle, (2) the Poľana Region (Iviny: 48°37'08.19" N and 19°23'50.77" E) in the middle as well, (3) Topolčianky Game Reserve (Bison Park: 48°27'50" N and 18°20'28" E) in the north, and (4) Kováčovské Kopce (47°51'10" N and 18°47'17" E) located extremely in the south part near to the State border with Hungary. The second location represented by the Bialowieza National Park (Bialowieza Bison Park) in Poland.

B. *Techniques and Tools of Samples Collection*

1)Site selection

For samples collection processes in the field which used for determination soil water retention were taken from three kinds of plots represent different sites, which all of them under heavy animals traffic and intensively used by large ungulates, these plots are as follows:

- Animal feeder places (salt and grain feeders) or mud pits (where animals cooling): from this kind of plots 3 sample points located at each plot according to the degree of animal disturbance (high disturbed, medium disturbed, and undisturbed).
- Fenced reserves where European bison are bred (Bison Parks): three sample points located inside the fence where intensively used by the animals during most time of year which considered as highly disturbed, three from medium disturbed area, and three others sample points located outside of the fence which considered as undisturbed point.
- Animals' paths: in this kind of plots two sample points located at each plot, one at the animals path and another away from the path (undisturbed by the animals).

From each sample point two undisturbed soil samples for determination of soil water retention were taken from two different soil horizons (0–5 cm and 5–10 cm) by using cylinder sleeve sampler with volume 100 mL fits into metal pusher, spade or knife were used for trimming the soil extending beyond each end of the sample holder and hammer sometimes used in hard soil.

C. *Determination of soil hydrology*

We determined water retention of soil from samples of natural sturcture. In laboratory, samples wetted and placed into apparatus for determing water retention. Three matric pressure range systems were used (low-range, mid-range, and high-range). Pressure ranges from 0–10000 cm of water. Samples removed from apparatus, and we determined the wet weight of the soil plus can, W_w. Then we dried the sample at 105 °C and determined the oven dry weight of of the soil plus can, W_d.

We calculated the volumetric water content, θ, of each sample from:

$$\theta = (W_w - W_d)/(dV_s) \quad (1)$$

We also conducted soil hydraulic conductiviy by using the mini disc infiltrometer, which is ideal for field measurements; due to its compact size, the water needed to operate it can easily be carried in a personal water bottle.

We prepared the infiltrometer for water infiltration measurement according to the following steps which described in [8]:

1. Fill the bubble chamber three quarters full by running water down the suction control tube or removing the upper stopper (do not use distilled water. Soil water has solutes and clays have salts on the exchange sites. Using distilled water changes the ionic balance and may flocculate or disperse the clay in the soil).
2. Once the upper chamber is full, slide the suction control tube all the way down, invert the infiltrometer, remove the bottom elastomer with the porous disk, and fill the water reservoir.
3. Replace the bottom elastomer, making sure the porous disk is firmly in place.
4. If the infiltrometer is held vertically, no water should leak out.

To make the hydraulic conductivity measurement, make sure you have first prepared the instrument as described above. Then data can be collected by doing the following steps as [8]:

1. Record the starting water volume.
2. At time zero, place the infiltrometer on the surface, assuring that it makes solid contact with the soil surface.
3. Record volume at regular time intervals as the water infiltrates. The time interval you choose is based on both the suction rate you select and the soil type being measured. For example, sand will typically be 2–5 seconds between readings, silt loam every 30 seconds, and a tight clay 30 to 60 minutes. For the calculation of hydraulic conductivity to be accurate at least 15–20 mL of water needs to be infiltrated into the soil during each measurement.

We conducted a measurement of the water infiltration into the soil by using Mini Disk Infiltrometer [Decagon Devices Inc. 2365 NE Hopkins Court Pullman, WA 99163] in three plots: Bukovina, Topoľčianky Bison Park (TBP), and Bialowieza Bison Park (BBP) which include different plot sites (high, medium, and undisturbed in Bukovina; inside and outside in Topoľčiankyand Bialowieza Bison Parks). Each plot site 15 mL of water needed to be infiltrated into the soil. Excel Spreadsheet was used for calculating the slope of the curve (y).

We used mini disk infiltrometer not a cylinder infiltrometer to measure water infiltration, because mini disk infiltrometer is more appropriate and gives more accurate results than clylinder infiltrometer. Reference[5] found that infiltration rates based on cylinder infiltrometer measures are fraught with errors and uncertainties. Measurement errors can occur due to soil disturbance by the insertion of the cylinder into the soil [6].

D.Data Evaluation

The data used for evaluating soil water retention were analyzed through the analysis of variance (ANOVA) which is a statistical method used to test differences between two or more means.For hyraulic conductivity analysis Wilcoxon matched pair test at $P = 0.1$ was used.

III. RESULTS AND DISCUSSION

E. Water retention

Overall, we investigated the water retention of top soils at different plots. Included two layers (0–5 cm and 5–10 cm) under two ranges of the water pressure (0–200 cm and 200–10^{-4} cm). As indicated in before, we used the analysis of variance as the principal tool for the statisticaltreatment of our data. We used parametric ANOVA test, because central data disturibtion did not deviate from the normal disturibution, according to the Kolmogorov-Smirnov test.

.**Table1:** Soil water retention in two soil layers in the high, medium, and undisturbed plot sites at the plots: Bukovina, Polova, and Iviny.

Plot	**Depth**	**Pressure**	**Water retentioncm^3 cm^{-3}**		
			High	Medium	Undisturbed
Bukovina	0–5 cm	0–200	0.40a	0.49b	0.47b
		200–10^4	0.37a	0.40b	0.43c
	5–10 cm	0–200	0.44	0.43	0.44
		200–10^4	0.32a	0.42b	0.40c
Polova	0–5 cm	0–200	0.43a	0.45a	0.47c
		200–10^4	0.39a	0.41b	0.43b
	5–10 cm	0–200	0.39a	0.44b	0.47c
		200–10^4	0.36a	0.38b	0.43c
Iviny	0–5 cm	0–200	0.38a	0.42b	0.46c
		200–10^4	0.34a	0.38b	0.42c
	5–10 cm	0–200	0.39a	0.42b	0.44b
		200–10^4	0.34a	0.40b	0.42c

Note: Means in the same row followed by different letters are significantly different ($P<0.05$) according to ANOVA and Duncan's significant difference test (*post-hoc* Duncan's test).

Table 2: Soil water retention under breeding area where highly disturbed by the bison, medium, and undisturbed areas at the plot Bialowieza Bison Park.

Plot	**Depth**	**Pressure** (cm)	**Water retentioncm^3 cm^{-3}**		
			Breeding area	Medium	Undisturbed
	0–5 cm	0–200	0.38ab	0.43bc	0.46c
		200–10^4	0.27	0.29	0.31

Bialowieza Bison Park	5–10 cm	0–200	0.39	0.43	0.40
		200–10^4	0.29	0.27	0.27

Table3: Soil water retention under breeding and undisturbed areas at the Topoľčianky Bison Park.

Plot	**Depth**	**Pressure**(cm)	**Water retentioncm^3 cm^{-3}**	
			Breeding area	Undisturbed
Topoľčianky Bison Park	0–5 cm	0–200	0.39a	0.37a
		200–10^4	0.32a	0.22b
	5–10 cm	0–200	0.42a	0.36b
		200–10^4	0.30a	0.21b

Note: Means in the same row followed by different letters are significantly different ($P<0.05$) according to ANOVA and Duncan's significant difference test (*post-hoc* Duncan's test).

Comparison of the results of highly disturbed sites with undisturbed one at the plots (Bukovina, Polova, and Iviny), it is clearly show that water retention in both depths (0–5 cm and 5–10 cm) of the high disturbed sites, significantly lower than in the undisturbed (Table 1). In the plot Bialowieza Bison Park, the differences were significant on the top layer (0–5 cm) under water pressure (0–200 cm). Water retention at the breeding area (0.38 cm^3 cm^{-3}) was significantly lower than (0.46 cm^3 cm^{-3}) in the undisturbed (Table 2). Soil physical properties (in particular bulk density and porosity) can be impacted by large ungulates activities, due to compaction. Therefore, soil water retention impacted as well. Reference[16] reported that soil compaction causes a significant deterioration of the structure of the top-soil which, in turn, affects the availability of water to plant roots. The latter can be estimated from a soil moisture retention curve. The soil physical properties that are required to estimate the model parameters are: bulk density, organic matter content, liquid limit and level of compaction.

In reverse to the above mentioned plots, water retention at both depths (0–5 cm and 5–10 cm) of the plot Topoľčianky Bison Park in the breeding area, significanlly higher compared with the undisturbed sites (Table 3). This findings show the disturbed plot as undisturbed and undisturbed as disturbed. May other factors influence water retention, such as period of animals changing plots. Also soil type may affects water retention. Similar to this results reported by [17] who reported that for water potentials <-20 kPa, the compacted layer retained more water than did the uncompacted layer.Reference [1] found that volumetric water content at -5 kPa increased with increasing compaction until a critical bulk density was, reached and then declined rapidly. Volumetric water content at field capacity, which for all soils was taken as -5 kPa, was found to decrease with increasing compaction for all soils except loams and clays where field capacity increased with increasing bulk density[17].

F. Hydraulic conductivity

On the other hand, we conducted hydraulic conductivity measurements on different sites. In the following section the hydraulic conductivity values are represented.

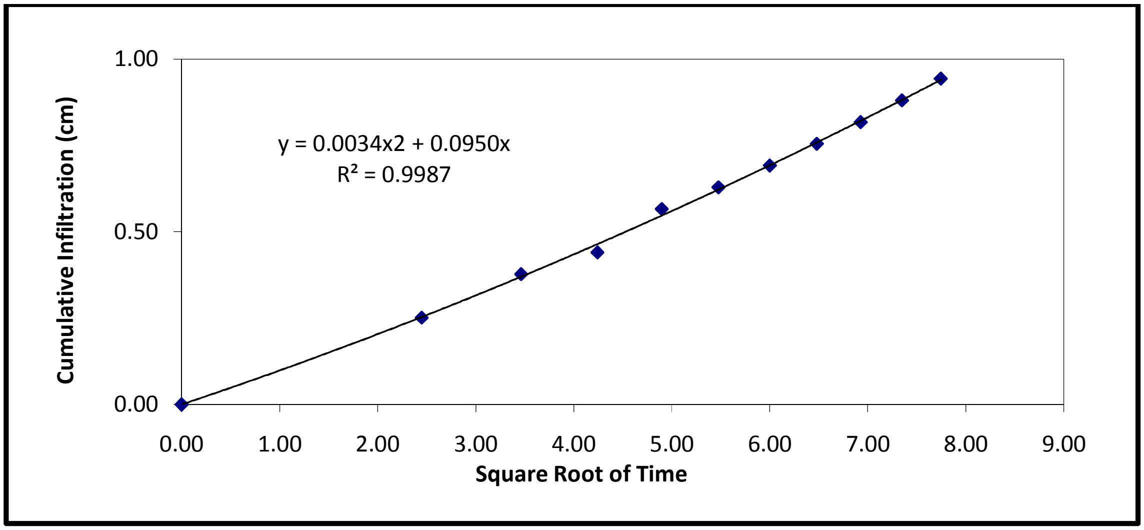

Fig. 2: Cumulative infiltration vs. square root of time at plot Bukovina high disturbed.

$K = 0.0034/7.10 = 0.00048$ cm.min^{-1} (0.006912 m.day^{-1})

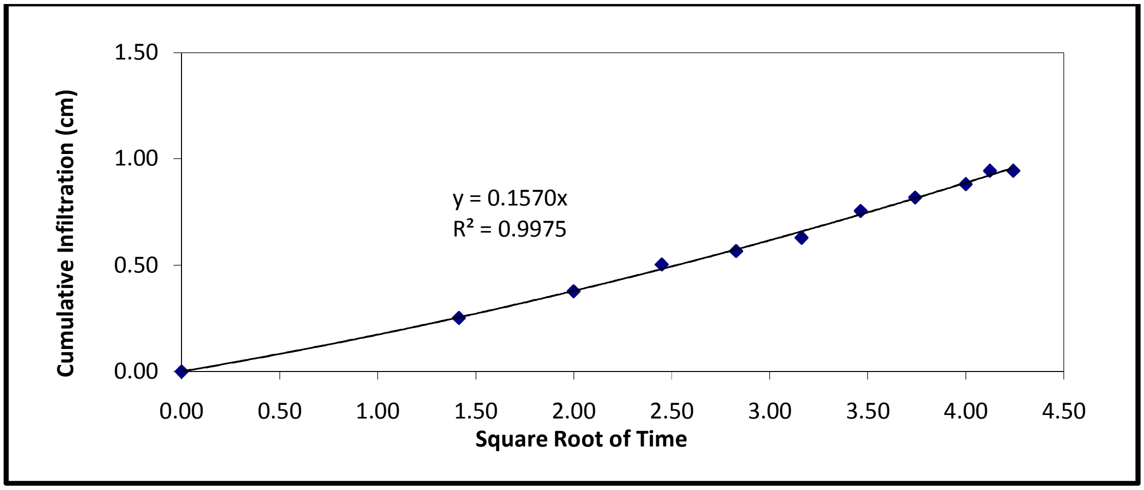

Fig. 3: Cumulative infiltration vs. square root of time at plot Bukovina undisturbed.

$K = 0.0162/7.10 = 0.00228$ cm.min^{-1} (0.032832 m.day^{-1})

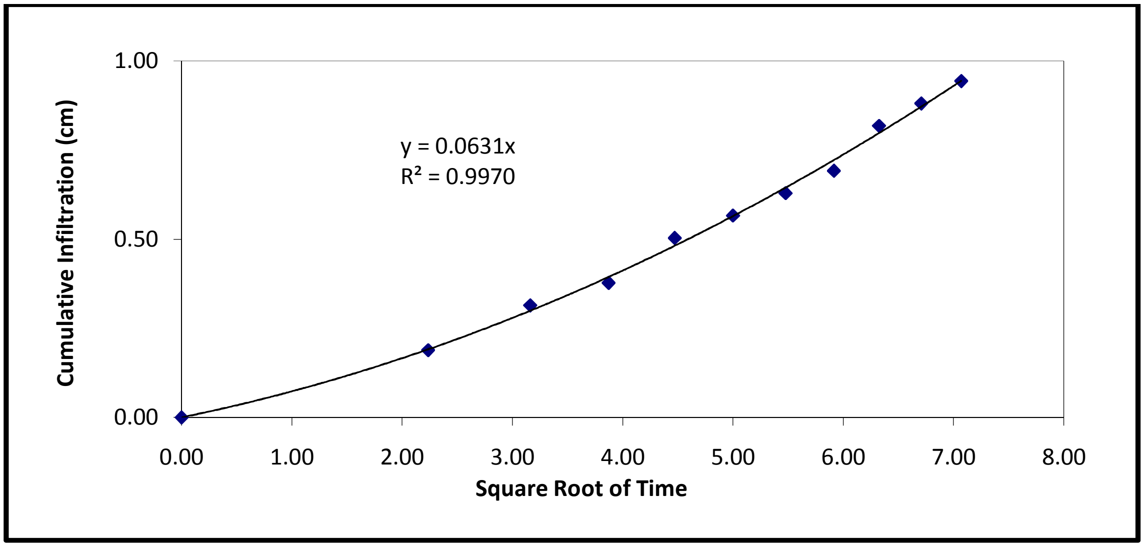

Fig 4: Cumulative infiltration vs. square root of time at inside Topoľčianky Bison Park.

$K = 0.0100/7.10 = 0.00140$ cm.min^{-1} (0.02016 m.day^{-1})

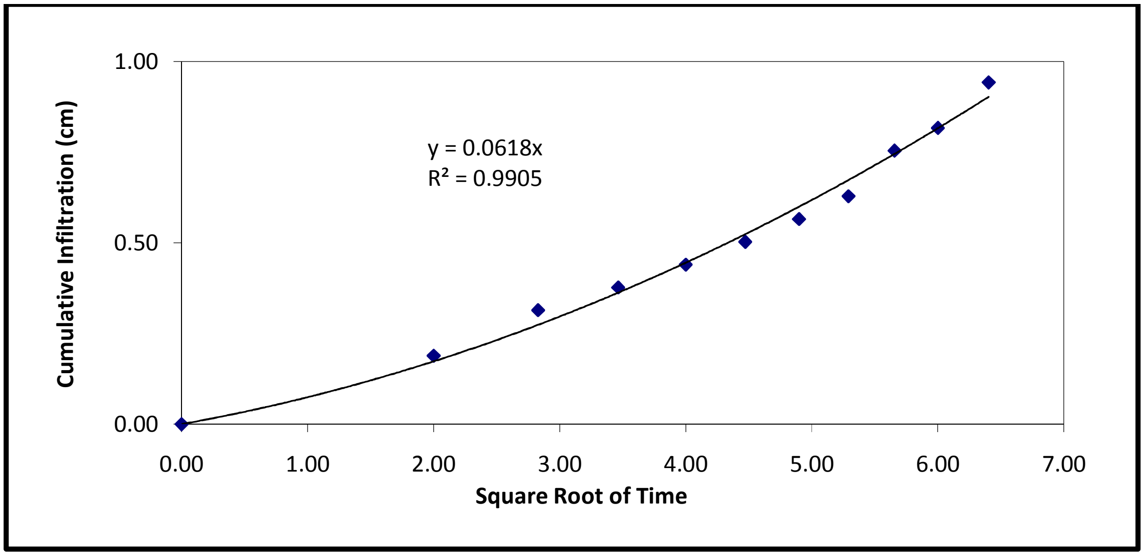

Fig 5: Cumulative infiltration vs. square root of time at outside Topoľčianky Bison Park.

$K = 0.0124/7.10 = 0.00174$ cm.min^{-1} (0.025056 m.day^{-1})

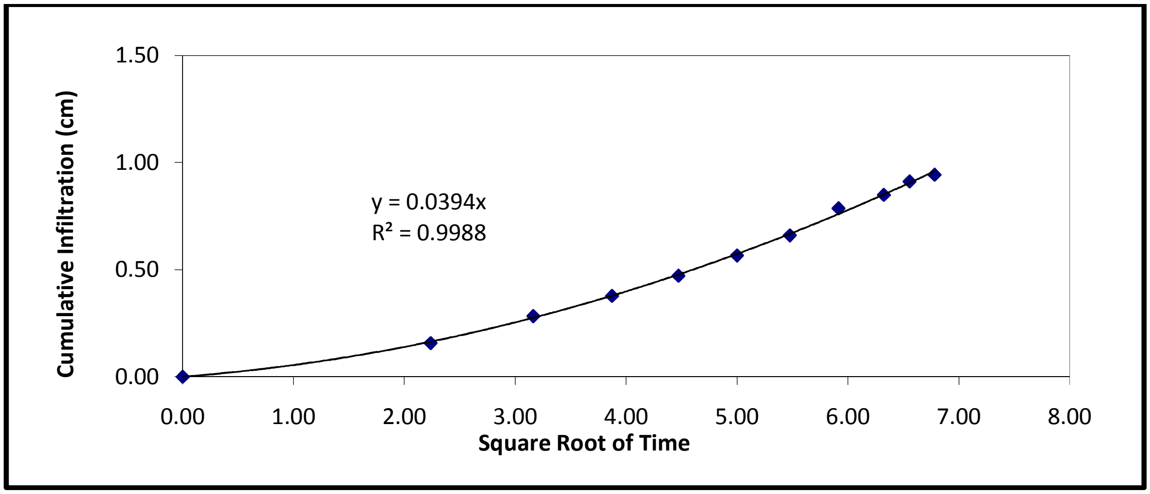

Fig. 6: Cumulative infiltration vs. square root of time at inside Bialowieza Bison Park.

$K = 0.0150/3.88 = 0.00388$ cm.min^{-1} (0.055873 m.day^{-1})

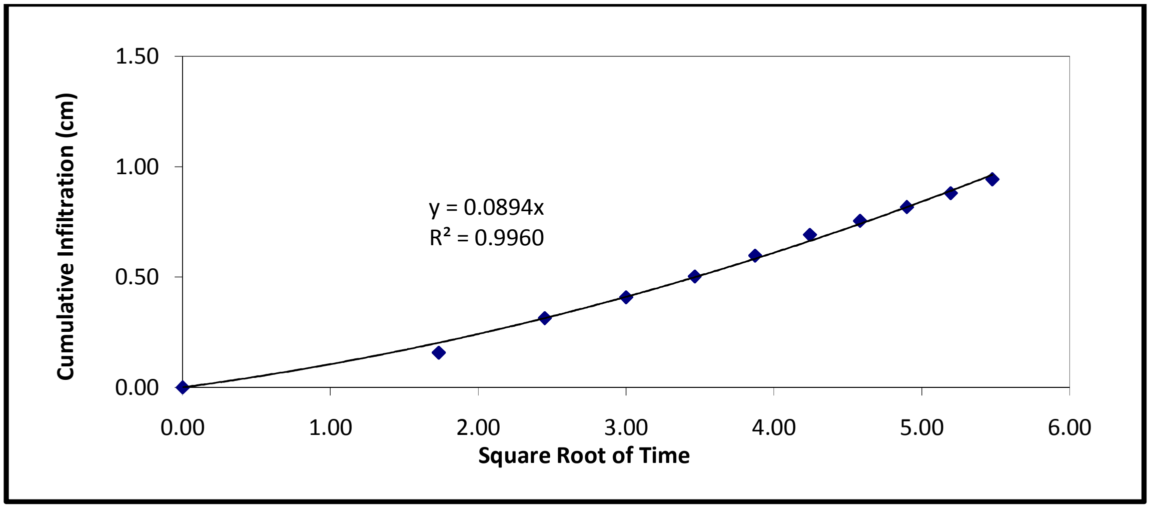

Fig. 7: Cumulative infiltration vs. square root of time at outside Bialowieza Bison Park.

$K = 0.0158/3.88 = 0.00407$ cm.min^{-1}; (0.058608 m.day^{-1})

Table 4: Hydraulic conductivity (K) under breeding /high and undisturbed areas at different plots.

Plot	**Hydraulic Conductivity** (m.day^{-1})	
	Breeding area/high disturbed	Undisturbed
Topoľčianky BP	0.02016	0.025056
Bialowieza BP	0.055872	0.058608
Bukovina	0.006912	0.032832
Mean of K	**0.0277a**	**0.0388b**

Note: Means in the same row followed by the different letters are significantly different (*P*<0.10) according to Wilcoxon Matched Pairs Test.

In terms of hydraulic conductivity, the total mean of hydraulic conductivity in the breeding/high disturbed area was significantly higher ($P<0.10$) than undisturbed area, with values 0.0277 $m.day^{-1}$ ($2,77.10^{-2}$ cm day^{-1}) and 0.0388 $m.day^{-1}$ ($3,88.10^{-2}$ cm day^{-1}), respectively (Table 4). In the breeding areas soil can be higher in bulk density and lower porosity than in those undisturbed, that occurred due to compaction. Soil compaction is know to decrease hydraulic conductivity of the soils whether saturated or unsaturated. Soil compaction decreases saturated hydraulic conductivity by increasing soil bulk density [2],[13] and reducing total soil porosity. When soil become compacted, changes in total porosity, micro porosity, macro porosity and pore-size distribution cause the hydraulic conductivity to decrease, and penetration resistance and bulk density to increase [12].

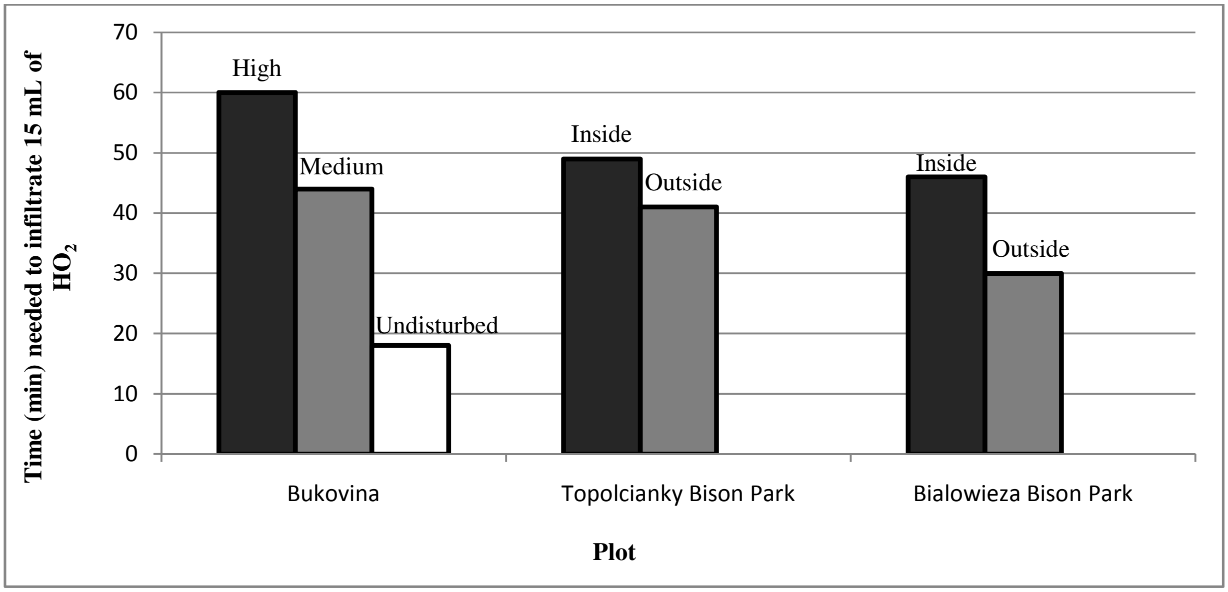

Fig.8: Time needed to infiltrate 15 mL of water in different plot sites (high, medium, and undisturbed in Bukovina; inside and outside of Topoľčianky Bison Park as well as Bialowieza Bison Park.

For determining hydraulic conductivity, preliminarily we highlighted about specific amount of water (15 mL) infiltrated into soils with different degrees of disturbance. Therefore, time needed to infiltrate 15 mL of water into soil, in all three plots differed substantially among the plot sites (Fig.8). The infiltration time in the plot Bukovina which includes: high, medium, and undisturbed plot sites, with total time spent 60, 44, and 18 min/15 mL, respectively. The infiltration in TopoľčiankyBison Park inside the Bison Park was 50 min/15 mL and outside 41 min/15 mL, whereas in Bialowieza Bison Park inside and outside the Bison Park was 46 and 30 min/15 mL, respectively (Fig.8). Preliminarily, our findings showed that the infiltration of water into the high disturbed site at the plot Bukovina was lower compared with the other sites (medium and undisturbed). These differences can be attributed to the high bulk density and low porosity, because soil compaction. This can be documented by the results of [20] who reported that the infiltration rates on the heavy continuous grazed pastures were significantly lower than other two grazing treatments (short duration and grazed exclusion). In addition, they mentioned that the rested short duration treatment infiltration rates were significantly higher than the heavy continuous and the grazed short duration. Also, it can be confirmed by the [10] who found that grazing and trampling both had severe effects on soil compaction, as a result of mechanical stresses imposed on the soil. Higher bulk densities and a lower water content, proportion of stable aggregates, and infiltration rate, as a result of increased animal trampling, have been observed for different grazing animals in different grassland ecosystems [7],[3],[11].The measuremet of water infiltration revealed that the time spent for infiltrate 15 mL among medium disturbed and non-disturbed sites of the plot Bukovina was different (medium is lower). [16] found that the most striking observation of the study was the significant difference in water infiltration between trampled and non-trampled soils, although the grazing intensity had been low. They also added that, when the trampling occurred for longer periods in a soil with a high clay content (Typic Cryaquept) the infiltration rate of drinking site was only 10–15% of that in non-trampled pastures.

IV. CONCLUSION

In conclusion, these results suggest that animal impact (i.e., heavy trampling by large ungulates) was responsible for most of the observed differences. With regard to the hydraulic conductivity, the sites with high disturbed were lower in water infiltration due to small pore space, and consequently were lower in hydraulic conductivity. Water retention of the investigated plots show significant differences among disturbed and undisturbed sites, in all plots, disturbed sites are lower than undisturbed except in the plot Topoľčianky Bison Park was opposit.

Practical use of the obtained results, is considered to be very important for regulating an optimal distribution of animals in rangelands and hibitats which vulnerable to erosion or has less soil aggregate stability, in order to avoid acceleration of the erosion process and destruction of pasture. With regard to breeding areas, suitable management strategies should be implemented in order to mitigate such negative impacts of large ungulates on soil. Among these strategies can be setting shorter time periods of utilization of breeding areas. Another strategy can be rehabilitation or rotation in breeding areas to protect the ecosystem sustainability. To supplement these findings, additional studies are suggested relative to the determination of an optimal numer of animals can be kept in breeding area, pasture orhabitat.

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