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Impact of Large Ungulates on Forest Land in Terms of Soil Compaction in the Temperate Zone of Europe

A.M.A. Adam[1*], V. Pichler[2], M. Homolak[3]

[1]Dept. of Wildlife, Faculty of Forestry Sciences, University of Zalingei, Zalingei, Sudan.
[2,3]Dept. of Natural Environment, Faculty of Forestry, Technical University in Zvolen, Zvolen, Slovakia.

**Corrsponding Author: alfadil09@yahoo.com, Tel.: +249-910551166*

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Abstract- The study of impact of large ungulates on forest land with regard to soil compaction was conducted in two locations in the temperate zone of Europe. They were selected in Carpathians and eastern Poland (the Bialowieza National Park and the Bialwieza Forest). The study aimed to investigate the physical effects of large ungulates on forest soils, as produced by trampling or hoof action, with respect to soil compaction, as well as to determine the spatial pattern of influence by grazing animals. Samples for determination of soil physical properties (soil particle density, bulk density, and soil porosity) 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 samples of soil were taken from different depths (0–5cm and 5–10cm). The data used for evaluation of soil physical properties were analyzed through the analysis of variance (ANOVA) with Duncan's multiple range test $P<0.05$ and Wilcoxon matched pair test at $P<0.1$. The results indicated that all soil bulk densities of the highly disturbed areas were higher than those in medium and undisturbed sites. Thus, mean bulk density of the plot Bialowieza Bison Park in the breeding area (1.58 g cm^{-3}) was significantly higher than in the undisturbed area (1.18 g cm^{-3}), in opposite, soil porosity in the breeding area (38.5%) was significantly lower than (53.5%) in the undisturbed area. In the view of considerable forest damage caused by forest game at the present time, our study shows that beside the traditionally recognized damage (such as browsing), degradation of soil physical and hydrophysical properties should be considered when proposing sustainable game management.

Keywords- large ungulates, soil compaction, soil physical properties, soil porosity, soil bulk density.

I. INTRODUCTION

Impacts of large ungulates on soil can be physical impact of the animal such as soil damage, or biological and chemical impact of the dung and urine that deposits to soil. Soil hydroloy and mechanical properties of soil can be affected by garzing and other animal activity. Animals trampling cause soil deformation, becuase of pressures under their hooves [11]. The change in pore system and macroporosity of soil caused when soil destroyed as a result of kneading and homogenization. Besides applied stresses, the impact depends on aggregate stability and soil moisture[11]. Soil physical condition near the surface has been affected by the grazing, because of urine and dung deposition, nutrient storage and hoof action [7]. Soil is considered as one of the most important factors in any ecosystem. Rangeland and forest land quality depend primarily on soil characteristics (physical, chemical, and biological). Large ungulates may cause soil degradation especially in semi-arid ecosystems, which directly affect plants cover, vegetation changes, establishment and growth invasive plants, hydrologic functions, wildlife habitats, and etc.

The study targeted the impact of some of the most important large ungulate species in Europe, in particular red deer (*Cervus elaphus*), roe deer (*Capreolus capreolus*), wild boar (*Sus scrofa*), and european bison (*Bison bonasus*).

The objectives of the study were to investigate the physical impacts of large ungulates on soils within silvopastoral system, which caused by trampling or hoof action, with respect to soil compaction, and to determine the spatial pattern of influence by grazing animals.

II. RELATED WORKS

Reference [15] mentioned that wild ungulates such as wild boar, roe deer and red deer are forest ecosystems key drivers. Understanding the impacts which resulting from ungulate density are important changes to undesired states (e.g from forest to heathland) [15]. Ungulates can affect ecosystems through, trampling, seed dispersal, fraying, browsing, stripping and uprooting, [16], [17].

III. MATERIAL AND METHODS

A. Study areas

The study was conducted in two main locations in Central Europe. First one represented by Carpathians which itself includes four study sites distributed on most parts of

Slovakia, are: (1) (Bukovina: 48°34'08.19" N and 19°01'16.99" E) in the middle, (2) the Polava in the middle, (3) the (Iviny: 48°37'08.19" N and 19°23'50.77" E) in the middle as well, (4) Topolčianky Game Reserve (Bison Park: 48°27'50" N and 18°20'28" E) in the north, and (5) 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) and the Bialowieza Forest in eastern Poland.

B. Techniques and Tools of Samples Collection

Site selection

For samples collection processes in the field which used for determination of soil physical properties 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:

1. 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).
2. 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.
3. 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 physical properties were taken from two soil horizons (0–5 cm and 5–10 cm) by using cylinder sleeve sampler of known volume fits into metal pusher, spade or knife were used.

C. Determination of Soil Physical Properties

We used a sylinder core sampler with volume of 100 mL, for taking samples in the field. Beside sylinder core sampler other different tools were used for taking samples in the field are: shovel to remove the sampler from soil; metal pusher; knife for trimimg the end of core sampler. Then samples transfered to laboratory in samples container. Samples were dried at 105 °C in an oven until reach constant weight.

Then we calculated the bulk density as described by [13]:

$$\rho b = (Wd - Wc)/Vs \quad (1)$$

Where:

$\boldsymbol{\rho b}$ is bulk density; W_d is oven dry weight of the sample; W_c is weigh an oven proof container in grams; and V_s is volume of sample.

For determination of the soil particle density, a pycnometer (specific-gravity flask) was employed.

We calculated the particle density as follows:

$$\rho d = pw(Ws - Wa)/[Ws - Wa) - (Wsw - Ww)] \quad (2)$$

Where:

$\boldsymbol{\rho d}$ is density of water in grams per cubic centimeter at temperature observed; *Ws* is weight of the pycnometer plus soil sample corrected to oven-dry water content; *Wa* is weight of pycnometer filled with air; *Wsw* is weight of pycnometer filled with soil and water; and *Ww* is weight of pycnometer filled with water at temperature observe

$$\text{Soil porosity} = 1 - \frac{Bulk\ density}{Particle\ density} x100 \quad (3)$$

D. Data Evaluation

The data used for evaluation of soil physical properties were analyzed through the ANOVA. Refference [14] who described that the ANOVA is used to test for differences among sample means. using an ANOVA is to see wethere any difference between groups on some variable or not. We used main effects ANOVA and factorial ANOVA.

Main effects ANOVA

$$xij = \bar{x} + ai + bj + ei,j \quad (4)$$

Factorial ANOVA

$$xi,j,p = \bar{x} + ai + bj + (ab)i,j + ei,j,p \quad (5)$$

$\bar{x}$ is the overall mean; α_i is the main effect of Factor A; b_j is the main effect of Factor B; $(\alpha b)_{i,j}$ is the interaction effect between A and B; ei,j,p is referred to as a "random error term"

For determination of which means differ significantly, we used Duncan's multiple range test. Then compare the pairs of treatments by conducting *post hoc test* [2].

IV. RESULTS AND DISCUSSION

A. Bulk density

Bulk density (g cm^{-3}) values are represented in following tables (1– 4), and also as graphs (Appendix III). Analysis of variance was applied. Means were compared by using *post-hoc* Duncan's test.

Table 1: Soil bulk densities (g cm^{-3}) in two soil layers in the high, medium, and undisturbed plot sites at the plots: Bukovina, Polova, and Iviny.

Plot	Depth	Degree of disturbance		
		High	Medium	Undisturbed
Bukovina	0–5 cm	1.127	1.036	0.833
	5–10 cm	1.116	1.086	0.920
Polova	0–5 cm	1.209	1.107	1.120
	5–10 cm	1.150	1.152	1.266
	0–5 cm	1.394	1.022	0.990

Iviny	5–10 cm	1.381	1.239	1.054
Mean bulk density	**0–5 cm**	***1.243a***	***1.055ab***	***0.981b***
	5–10 cm	***1.216***	***1.159***	***1.080***
	0–10 cm	**1.229a**	**1.107ab**	**1.030b**

Note: different letters in the same row refer that means are significantly different according to Duncan's test and ANOVA (P<0.05).

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

Plot	**Plot point**	**Depth**	**Bulk density (g cm^{-3})**		
			Breeding area	Medium	Undisturbed
Bialowieza Bison Park	**1**	0–5 cm 5–10 cm	1.589 1.563	1.348 1.511	1.372 1.202
	2	0–5 cm 5–10 cm	1.461 1.541	1.351 1.389	1.147 1.278
	3	0–5 cm 5–10 cm	1.556 1.693	1.277 1.291	1.159 1.143
	4	0–5 cm 5–10 cm	1.641 1.640	1.308 1.296	1.072 1.125
Mean bulk density		**0–5 cm**	***1.562a***	***1.321b***	***1.187c***
		5–10 cm	***1.609a***	***1.372b***	***1.187c***
		0–10 cm	**1.585a**	**1.346b**	**1.187c**

Note: different letters in the same row refer that means are significantly different according to Duncan's test and ANOVA (P<0.05).

Table 3: Soil bulk densities under the breeding and undisturbed areas at the plot Topoľčianky Bison Park.

Plot	**Plot Point**	**Depth**	**Bulk density (g cm^{-3})**	
			Breeding area	Undisturbed
Topoľčianky Bison Park	**1**	0–5 cm 5–10 cm	1.395 1.067	1.217 1.355
	2	0–5 cm 5–10 cm	1.249 1.432	1.086 1.345
	3	0–5 cm 5–10 cm	1.251 1.383	1.259 1.097
Mean bulk density		**0–5 cm**	**1.298**	**1.187**
		5–10 cm	**1.294**	**1.266**
		0–10 cm	**1.296**	**1.226**

Note: different letters in the same row refer that means are significantly different according to Duncan's test and ANOVA (P<0.05).

Table 4: Soil bulk densities at the animals' track and out of the track, at the plot Kováčovské Kopce.

Plot	**Depth**	**Bulk density (g cm^{-3})**	
		At the track	Out of track
Kovačovské Kopce	0–5 cm 5–10 cm	1.205 1.271	1.112 1.021
Mean bulk density	**0–10 cm**	**1.238a**	**1.067b**

Note: different letters in the same row refer that means are significantly different (using *t-test* for indepentent variables P<0.1).

Comparison of the three degrees of disturbance (high, medium, and undisturbed plot sites) indicates that the high disturbed site generally had greater bulk density than the medium and undisturbed sites. The differences were clearer at soil depth 0–5 cm at the investigated plots (Tables 1 and 2). The total mean of bulk densities (0–10 cm) of the plots: Bukovina, Polova, and Iviny were significantly (P<0.05) higher in the high disturbed site (1.229 g cm$^{-3)}$ than undisturbed site (1.030 g cm^{-3}). Also, the mean bulk densities in the layer 0–5 cm was significantly higher in the high disturbed site than in the layer 0–5 cm of the undisturbed site, whereas in the layer 5–10 cm there are differences among the high, medium, and undisturbed sites, but the differences statistically not significant (Table 1). Comparing the medium site with the high disturbed one in terms of mean the bulk density, the difference was in the border of significance (P=0.05).

In the plot Bialowieza Bison Park, the mean bulk densities among all the plot sites (breeding area, medium disturbed, and undisturbed) showed very clear differences. All three plot sites differed significantly (*P*<0.05) with respect to soil bulk densities (Table 2). The mean bulk densities of the layer 0–5 cm were 1.562, 1.321, and 1.187 g cm^{-3} represent breeding area, medium, and undisturbed sites, respectively. Similar to these results reported by [12] who found in their study of trampled, grazed, and ungraded plots at the depth (0–5 cm) that, the differences were significant in terms of bulk density, with values 1.35, 1.22, and 1.06 g cm^{-3}, respectively. The bulk density for the breeding area (1.585 g cm^{-3}) substantially greater than (1.187 g cm^{-3}) of the undisturbed area; these findings fit with the results provided by [6] who mentioned that soil bulk density (1.478 g cm^{-3}) on the breeding area was clearly higher value than the undisturbed area (0.850 g cm^{-3}). Similarly, [3]found that in Rocky Mountain National Park, elk grazing and hoof action are compacted the soils. The bulk densities horizontally differed, but vertically did not have quite differences between the two different layers (0–5 cm and 5–10 cm), with evidence that undisturbed plot site in both layers had the same bulk densities with value of 1.187 g cm^{-3} (Table 2).

In general, the mean bulk densities of the plot Topoľčianky Bison Park in the breeding area were higher compared with the undisturbed site, but the difference was not significant. In the breeding area the bulk densities much more similar between the two layers: layer 0–5 cm (1.298 g cm^{-3}) and layer 5–10 cm (1.294 g cm^{-3}), with negligible difference (Table 3). Bulk density of soils not only can be influenced by the compaction, there are many other factors affecting bulk density of soils such as pore space, soil texture, or organic matter content. By using *t-test* for the independent variable, bulk density value (1.238 g cm^{-3}) at the animal track was significantly higher than (1.067 g cm^{-3}) out of the animal track (Table 4).

We investigated values of the bulk densities in different plot sites and diffrent depths (0–5 cm and 5–10 cm), with differnt degrees of disturbance in order to enable us to evaluate the influence of ungulates on soil in terms of bulk density. Refference [6] investigated the impacts of red deer grazing on the litter and surface soil layer (0–5 cm depth) in the breeding area, which has been used for a long time, in comparison with an adjacent undisturbed area. Refference [12] studied different plots (trampled, grazed, and ungrazed) at depths (0–5 cm and 5–10 cm) to report a variations in soil bulk density and other soil properties.

Our results revealed that the bulk densities were significantly higher in the breeding area and high disturbed site, except at the plot Topoľčianky Bison Park there was difference, but not significant. The high bulk density can be attributed to the intensity of animal trampling on soil which leads to soil compaction and increasing in bulk density. Many studdies about effects of the grazing and over grazing on soil found that, as a results of increasing animal trampling soil was compacted and bulk density was increased [4], [10], [7], [5], [11], [8], [9].

B. Particle Density

The overall mean soil particle densities for the investigated plots according to degree of disturbance did not show significant differences. The mean particle density of the plots: Bukovina, Polova, and Iviny for the high disturbed site (2.50 g cm^{-3}) was slightly higher than undisturbed (2.48 g cm^{-3}) which equal to the mean of the medium disturbed (2.48 g cm^{-3}) (Table 5). On the other hand, the difference between the total mean particle density according to the depth were differed significantly (layer 0–5 cm was lower in particle density than layer 5–10 cm).

Regardless of the differences between sites in the plot Bialowieza Bison Park, the value of mean particle density (2.58 g cm^{-3}) of the breeding area was higher than (2.54 g cm^{-3}) in the undisturbed area (Table 6). The higher value of particle density in the breeding area may occur due to low organic matter. [4], found that organic matter (56.7%) in the breeding area is significantly lower than (79.07%) in the undisturbed area. Therefore, soils low organic matter have higher particle densities than soils similar in texture that are high in organic matter. In terms of particle densities per depth, there were fluctuations in values of particle density between sites and even within the same site itself.

Table 5: Soil particle densities (g cm^{-3}) in two soil layers in the high, medium, and undisturbed plot sites at the plots: Bukovina, Polova, and Iviny.

Plot	Depth	Degree of disturbance		
		High	Medium	Undisturbed
Bukovina	0–5 cm	2.43	2.46	2.43
	5–10 cm	2.44	2.55	2.45
Polova	0–5 cm	2.44	2.41	2.51
	5–10 cm	2.58	2.57	2.6
Iviny	0–5 cm	2.55	2.43	2.47
	5–10 cm	2.57	2.49	2.5
Mean particle density	**0–5 cm**	***2.47***	***2.43***	***2.47***
	5–10 cm	***2.53***	***2.54***	***2.52***
	0–10 cm	**2.50**	**2.48**	**2.48**

Note: different letters in the same row refer that means are significantly different according to Duncan's test and ANOVA (*P*<0.05).

Table 6: Soil particle densities under breeding area where highly disturbed by the bison, medium, and undisturbed areas at the plot Bialowieza Bison Park.

Plot	Plot point	Depth	Particle density (g cm^{-3})		
			Breeding area	Medium	Undisturbed
Bialowieza Bison Park	**1**	0–5 cm	2.6	2.58	2.58
		5–10 cm	2.55	2.56	2.56
	2	0–5 cm	2.58	2.58	2.44
		5–10 cm	2.62	2.59	2.55
	3	0–5 cm	2.6	2.53	2.48
		5–10 cm	2.56	2.57	2.58
	4	0–5 cm	2.48	2.63	2.54
		5–10 cm	2.57	2.47	2.56
Mean particle density		**0–5 cm**	***2.57***	***2.58***	***2.51***
		5–10 cm	***2.58***	***2.56***	***2.54***
		0–10 cm	**2.58**	**2.56**	**2.54**

Note: different letters in the same row refer that means are significantly different according to Duncan's test and ANOVA (*P*<0.05).

Table 7: Soil particle densities under breeding and undisturbed areas at the Topoľčianky Bison Park.

Plot	Plot Point	Depth	Particle density (g cm^{-3})	
			Breeding area	Undisturbed
Topoľčianky Bison Park	**1**	0–5 cm	2.61	2.56
		5–10 cm	2.67	2.59
	2	0–5 cm	2.55	2.56
		5–10 cm	2.62	2.64
	3	0–5 cm	2.56	2.57
		5–10 cm	2.64	2.62
Mean particle density		**0–5 cm**	***2.57***	***2.56***
		5–10 cm	***2.64a***	***2.61b***
		0–10 cm	**2.60**	**2.59**

Note: different letters in the same row refer that means are significantly different according to Duncan's test and ANOVA (*P*<0.05).

C. Soil Porosity

In general, mean soil porosity (pore space) of the plots: Bukovina, Polova, and Iviny differed among the plot sites (high, medium, and undisturbed). Table 8 shows that high disturbed area (50%) lower in porosity than medium and undisturbed, with values 56% and 59%, respectively. Although these differences statistically are not significant. Similarly, the porosity on the top layer (0–5 cm) was significantly higher in undisturbed area than the high disturbed one, with values 61% and 50% respectively. The average soil porosity value was 58% in the high disturbed and 57% in the undisturbed of the layer 5–10 cm are relatively similar (Table 8).

In the two sites of the plot Topoľčianky Bison Park, the mean soil porosity (50%) relatively lower in breeding area than (53%) in undisturbed (Table 10). The proportion of porosity was significantly smaller at the animals' track compared with the proportion of porosity out of the track (Table 9). Decreasing in soil pore space in breeding area can be attributed to increasing of the bulk density becaue of compaction due to animal trampling. Results in the beeding area, showed the significant decreases in the litter in saturation capacity, which caused by deer grazing, that increases the fine soil weight in bulk density due to the soil compaction by animal trampling [6]. The water and air capacities of soils can be impacted by the degree of soil compaction.

Table 8: Soil porosity (%) in two soil layers in the high, medium, and undisturbed plot sites at the plots: Bukovina, Polova, and Iviny.

Plot	Depth	Porosity (%)		
		High	Medium	Undisturbed
Bukovina	0–5 cm	54	58	67
	5–10 cm	54	58	63
Polova	0–5 cm	50	54	55
	5–10 cm	55	55	51
Iviny	0–5 cm	45	58	60
	5–10 cm	64	50	58
Mean porosity	**0–5 cm**	***50a***	***57ab***	***61c***
	5–10 cm	***58***	***54***	***57***
	0–10 cm	**54a**	**56a**	**59a**

Note: different letters in the same row refer that means are significantly different according to Duncan's test and ANOVA (*P*<0.05).

Table 9: Soil porosity at animals' track and out of the track at the plot Kováčovské Kopce.

Plot	Depth	Porosity (%)	
		At the track	Out of track
Kovačovské Kopce	0–5 cm	49	54
	5–10 cm	47	58
Mean porosity	**0–10 cm**	**48a**	**56b**

Note: different letters in the same row refer that means are significantly different (using *t-test* for indepentent variables *P*<0.1).

Table 10: Soil porosity under breeding and undisturbed areas at the Topoľčianky Bison Park.

Plot	Plot Point	Depth	Porosity (%)	
			Breeding area	Undisturbed
Topoľčianky Bison Park	**1**	0–5 cm	47	53
		5–10 cm	60	48
	2	0–5 cm	51	58
		5–10 cm	45	49
	3	0–5 cm	51	51
		5–10 cm	48	58
Mean porosity		**0–5 cm**	***49***	***54***
		5–10 cm	***51***	***52***
		0–10 cm	**50**	**53**

Note: different letters in the same row refer that means are significantly different (using *t-test* for indepentent variables *P*<0.1).

With regard to soil porosity in the plot Bialowieza Bison Park, and according to statistical test using analysis of variance, there were significant differences between all three plot sites in terms of proportion of soil porosity (Table 8). The mean porosity (38%) in the breeding area, was significantly lower than in medium and undisturbed sites, with values 47.5 and 53.5% respectively. In the Table 11, the mean soil porosity in the breeding area at depth 0–5 cm was lower significantly in comparison with depth 0–5 cm in medium and undisturbed. On the other hand, the differences between depths (0–5cm and 5–10cm) did not show significant differences. Table 11 soil porosity with comparison to the Table 2 soil bulk density in the same plot (Bialowieza Bison Park), it is obviously that increasing in bulk density directly leads to decreasing in proportion of porosity and vice-versa. These findings we have found correspond well with results provided by [1] who reported that Soil has invers relation between the bulk density and porosity, soil with lower value for bulk density has more pore space.

Table 11: Soil porosity under breeding area where highly disturbed by the bison, medium, and undisturbed areas at the plot Bialowieza Bison Park.

Plot	Plot point	Depth	Porosity (%)		
			Breeding area	Medium	Undisturbed
Bialowieza Bison Park	**1**	0–5 cm	39	48	47
		5–10 cm	39	41	53
	2	0–5 cm	43	48	53
		5–10 cm	41	46	50
	3	0–5 cm	41	50	53
		5–10 cm	34	50	56
	4	0–5 cm	34	51	58
		5–10 cm	36	48	56
Mean porosity		**0–5 cm**	***39a***	***49b***	***53c***
		5–10 cm	***38a***	***46b***	***54c***
		0–10 cm	**38.5a**	**47.5b**	**53.5c**

Note: different letters in the same row refer that means are significantly different according to Duncan's test and ANOVA (*P*<0.05).

Taken together the results of soil porosity and the results of soil bulk density, the decreasing of porosity directly leads to increasing in bulk density. In reverse, organic matter content is know to effect positively on porosity. Clear differences were found between breeding area and undisturbed area interms of capacity of saturation, depending on soil compaction and soil organic matter [1]. They also found that the value of saturation capacity (71.47%) in the undisturbed was considerably higher than (28.83%) in the breeding area.

V. CONCLUSION

In conclusion, our findings suggested that animal impact (i.e., heavy trampling by large ungulates) was responsible for some differences. Impacts of large ungulates on soil, directly increased soil bulk density and decreased soil porosity. Bulk density of all investigated plots showed clear differences, all bulk densities in the high disturbed or breeding areas were higher than those in medium and undisturbed sites. In reverse to bulk density, the differences of particle density whether horizontally (among plot sites) or vertically (between depths 0–5cm and 5–10 cm) did not differ according to degree of disturbance. Therefore, we cannot attribute these differences to the animals' impact. Contrary to the bulk density, soil porosity decreased with increasing degree of disturbance. Proportions of porosity in the high disturbed/breeding areas were lower than in undisturbed areas.

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
Implementation of mangement strategies are important to reduce desturective impacts of large ungulates on soil, such as (short time of utilization or rotation system).
To supplement these results, more studies are suggested relative to the determination of an optimal numer of animals can be kept in breeding area or pasture (habitat).

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AUTHORS PROFILE

Dr. Alfadil Mohammed Abdelrahman Adam, pursed BSc. in Natural Resources from University of Sinnar, Sudan, MSc in Applied Zology and Game Management, and PhD in Forestry Amelioration (Soil and Water Conservation) from Faculty of Forestry,TUZVO. Currently working as assistant professor at Department of Wildlife, Faculty of Forestry Sciences, University of Zalingei. He conducted many researches in the field of wildlife.

Prof. Viliam Picher is a professor of Pedology and Forest Carbon Sequestration at Department of Natural Environment, Faculty of Forestry, TUZVO, Slovakia. He published more than 150 research papers in the field of Pedology, Forest Carbon Sequestrations and other related fields.

Dr. Marian Homolak is currently assistant professor at Department of Natural Environment, Faculty of Forestry, TUZVO, Slovakia. He teaches pedology and soil mechanics. He published many research papers in field of soil and forestry sciences.