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CHRISTIAN STOLZ*, UWE DEPPE**, GERD KÄMMER***, MICHAEL KUHWALD****, DANIEL NASS*****, LEIF SÖNNICHSEN******

THE DEVELOPMENT OF NUTRIENT CONTENTS ON A NEW CONSERVATION AREA IN THE FAR NORTH OF GERMANY CONCERNING DIFFERENT TYPES OF USE. A PROPOSAL FOR A SUSTAINABLE DEVELOPMENT IN NATURE CONSERVATION PRACTICE

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Abstract. The present study analyzes a short-term observation of a newly created nature conservation area. The aim was to investigate different effects of grazing by cattle and, otherwise, the frequent mowing on the development of nutrient contents of soils. The results are typical for the strong sandy Weichselian outwash plain in the north of Central Europe (Schleswig-Holstein, Germany). Two neighboring testing areas of different use and sowed with an agricultural grass were observed for more than two years. The first area had been grazed intensively by cattle and the other one had been mowed twice a year. During this time, several nutrients and other soil parameters have been analyzed at regular intervals. Furthermore, we made observations about soil compaction and the succession of vegetation.

The results show a stronger reduction especially of nitrogenous nutrients on the mowing area (-25%). In contrast, on the grazing area, the contents of nitrogen doubled during two growing

* Europe University of Flensburg and Johannes Gutenberg University of Mainz, Auf dem Campus 1, 24943 Flensburg, Germany; corresponding author: christian.stolz@uni-flensburg.de

** University of Applied Sciences, Kanzleistraße 91-93, 24943 Flensburg, Germany.

*** Bunde Wischen e.V., Königswiller Weg 13, 24837 Schleswig, Germany.

**** CAU Kiel, Ludewig-Meyn-Straße 14, 24098 Kiel, Germany.

***** CAU Kiel, Olshausenstraße 75, 24118 Kiel, Germany.

****** Nature Conservation Authority, Kreis Schleswig-Flensburg, Flensburger Straße 7, 24837 Schleswig, Germany.

seasons (+125%). However, a high atmospheric input of nitrogen strengthened the result. Less conclusive were the results about the contents of potassium, phosphorus and SOM.
Therefore, mowing could be advised, if quick results are required concerning the impoverishment of soils. Furthermore, the development of succession vegetation was quite different on both areas with the number of plant species 12% higher on the grazing area. However, long-term but non-intensive cattle-grazing must still be rated as an excellent method of maintenance for this type of cultural landscape. It corresponds with the centuries-old land-use practice in this type of landscape and promotes high level of biodiversity. Therefore, there is nothing that speaks against non-intensive grazing from the beginning on a newly created nature-protection area within a long-term conception of nature conservation. The removal of A horizons should be avoided as it damages Holocene soil profiles and has only short-term effects.

Keywords: nature conservation, nutrient contents, grazing, mowing, impoverishment

1. INTRODUCTION

In many cases, the soils on newly designed nature conservation areas are quite nutritious. This is also the case in regions with comparatively poor soils developed in sands or debris-rich material. The reason for this is the high supply of inorganic fertilizers and manure over decades on arable land. Nutrient-poor sandy soils are characterized by high biodiversity (cf. Oelmann *et al*. 2009) and the proportion of species-rich permanent grassland shrunk dramatically in the last decades in Northern Germany (Krause 2014). Hence, an impoverishment of grassland is a frequent aim of conservation acts.

On the Weichselian outwash plains of the northern part of Schleswig-Holstein (Schleswigsche Geest) containing poor podzols and gley soils, there have been different possibilities for soil restoration by nature conservationists and farmers. However, studies monitoring these processes on newly sown grassland are missing in this part of Germany.

For renaturation, in most cases, a reforestation is not required. Mostly, such areas should be grazed by hardy cattle to create a half-open pasture landscape (cf. Bunzel-Drüke *et al*. 2008, Zoller and Haas 1995, Riedel and Heintze 1987), similar to the type of landscape that was distributed in large sections of historical Schleswig Duchy during the Early Modern Period or already earlier. Quite poor soils frequently get transformed in heath conditions, mostly by using sheep (cf. Bakker *et al.* 1983, Bakker and de Vries 1985). The main reason for this is the conservation of different plant and animal species and the typical landscape scenery of the region. Another possibility to keep an open landscape is the mowing of grass twice a year and removing the grass cuttings. Sometimes, even nutritious topsoils have been removed for acceleration the impoverishment of soils and for a fast resettlement by different plant species. This practice is not considered appropriate due to the irreversible destruction of natural soil profiles and the local natural environment (cf. Stolz and Riedel 2014). Another method to impoverish soils is to plant cereals for a short time after regular agricultural management, sometimes with the application of inorganic fertilizers to increase nutrient uptake. On a testing field in England, it needed more than 7 years to have an effect (Marrs *et al*. 1998). For meeting the demands of agriculture and nature conservation equally, Oelmann *et al*. (2009) recommend a cautious PK fertilization and mowing twice a year on wet soils. However, frequent grazing or mowing could be having a similar effect on impoverished fertilized soils (cf. Bakker 1987). This can quite often only reduce nutrients but not biomass production (Mládková *et al*. 2015). Since it was uncertain which method would be better for the aimed impoverishment of the sandy Geest soils, we made an observation on the development of chemical soil parameters, soil organic matter (SOM), NH_4, NO_3, K_2O, P_2O_5 (plant available), carbon-to-nitrogen ratio (for the method cf. Bakker 1987). Furthermore, a specific analysis of the effects on physical parameters, like soil compaction, and the influences on the succession of vegetation was necessary.

2. STATE OF RESEARCH

The process of conversion for (over-) fertilized species-rich grasslands into species-poor communities has been well known for decades, especially in the Netherlands (Bakker 1987). The absence of N fertilizers especially has this effect. A sharp decrease in species-diversity of experimental plots after a long period of N fertilization was shown, for example, in the Netherlands (Elberse *et al*. 1983, cf. Vermeer and Berendse 1983), in different parts of Germany (Klapp 1965) and over 100 years of observations in England (Williams 1978). However, there are few results concerning investigations on sandy soils. Generally, observations are for longer periods than we could provide in the present study. In the Netherlands, Oomes (1990) measured dry matter yield and NPK concentration on sandy grassland for 14 years after the withdrawn of agriculture use. They needed 9–10 years to get rough natural conditions. Mládková *et al*. (2015), in the Czech Republic, needed 7 years to reach “the lowest plant-available P under grazing and the lowest plant-available K under mowing”. Most of the other studies deal with riverside or fen locations and primarily wet soils (e.g. Oelmann *et al*. 2009). Thus, a comparison is difficult.

3. MATERIALS AND METHODS

We made a study for 2 years (2013 and 2014) on a 1.7 ha area with a largely homogenous soil structure (eroded podzols, developed in glacio-fluvial sands) next to Tüdal, in the South of the City of Flensburg (Kreis Schleswig-Flensburg) in Schleswig-Holstein (54°37’59.65”N; 9°23’15.94”E; Fig. 1). In 2012, the former field was sown with agricultural grass (*Lolium perenne*) and fenced off into a larger and a smaller area. The smaller part (0.6 ha; 168 × 12 m) was mowed two times every year. In contrast, the other part (1.1 ha; 168 × 101 m) was grazed by cattle with a high grazing pressure for two vegetation periods. During this time, in 10 locations on both parts of the testing area we took samples regularly and measured different soil parameters, nutrient contents, soil compaction and penetration resistance. Additionally, we made an observation on vegetation. The objective was to evaluate the effects of grazing vs. mowing concerning the desired impoverishment of soils.

Fig. 1. The location of the investigation area in northern Germany, close to the border with Denmark

3.1. Regional Setting and Experimental Setup

The relief on the Weichselian outwash plains is quite low (cf. Schott 1956: 14ff, Strehl 1999). The local sediments are homogeneous and are strong sandy which is attributable to the outwash plain. Typical soils are podzols, mostly degraded by wind. In lower parts, there is a podzolic transitional layer over the suspected gley conditions close to the groundwater level. The surrounding of the testing area is subjected to intensive agriculture as typical in Schleswig-Holstein.

In the south and in the east, the testing area is framed by deciduous forests, partly with some spruces. In the north, there is a small mount with a hedgerow and behind it is newly sown grassland. At the western edge, there is an unpaved road with a hedgerow and a maize field beside it. The last crop on the testing area up until 2011 was maize. This situation is quite typical for the Schleswig area with small forests, the landscape is forested (9%), with traditional hedge mounds between the fields (in some locations, only parts of this former, quite densely network, exist; Riedel and Polensky 1987). The main crops are winter wheat and, circa 2002, more maize for animal feed and the production of biogas (Statistikamt Nord 2016, Riedel and Stolz 2015). The whole sampling area has been in conventional agricultural use over the last several decades until 2011, primarily with maize cultivation. In 2012, it was sown with *Lolium perenne*.

From 2013, the mowing area was mowed twice a year. For mowing we used a Deutz Agrotron tractor, Type TT2, empty weight 4,440 kg, with a Krone easy-cut 320 mower, weight 995 kg, with tree-point linkage. Goodyear 540/65 R38 Optitrac DT 818 High Speed tyres were used on the back and BTK 540/65R24 Agrimax RT657 tyres on the front. Tedder and swader were used by the same tractor; a baling press by a similar model. The grazing area was grazed during 2013 by five three-year old Galloway heifers and one five-year old Galloway bull during the time of the study. The grazing period regularly started at the end of May and lasted until the middle of December. The cattle avoided tough grass and showed a grazing preference for the south-eastern part of the study area with a species-rich grass community. During July, the heifers gave birth to five calves, which stayed with their mothers till the end of the grazing season. At the end of May and a second time at the end of July, the mowing area was mowed. The grazing regime was similar in 2014 except for the fact that the heifers did not have calves and two Galloways were exchanged for two White Park cattle.

Samplings took place on May 8, 2013, November 8, 2013, November 16, 2014 and May 31, 2015. In 10 locations (4 on the mowing area and 6 on the grazing area) we opened and closed small pits 4 times in the same locations, while grazing and mowing took place. From these small sites of about 40 × 40 cm we took soil samples for analysis of nutrients in different depths, respectively from the Ap horizon (between 0 and 16 cm), from the Bh horizon (between 12 and 32 cm) and from the Bs horizon (between 24 and 66 cm). For this purpose, the locations were precisely marked so that each new sampling took place no more than 20 cm from the old sampling site. The determination of the sampling depths happened in the context of the local soil formation. At each site, the sampling depths stayed the same during the complete sampling cycle. For measuring bulk density we used sampling rings (in 5–15 cm depth). We did the same at 2 locations in the adjacent forest and in one location on the neighboring maize field in the west (Fig. 2), for comparing and classifying the values from the testing ground. Additionally, we measured soil penetrating resistance using a penetrologger (more than 100 measurements in 20 locations). Furthermore, we made 10 drillings up to a 3 m depth to explore the subsoil material and we observed the upcoming succession vegetation. Special attention was paid to the floristic differentiation in relation to land use and under the influence of the loss of phytomass by grazing and mowing. Unfortunately, the testing area had to be used in a different manner since spring 2015 by establishing a perennial garden for local wild plants. Therefore, the testing series had to be stopped. Nevertheless, the results from 2 vegetation periods are quite significant, although the final result of impoverishment could not be reached during this short period.

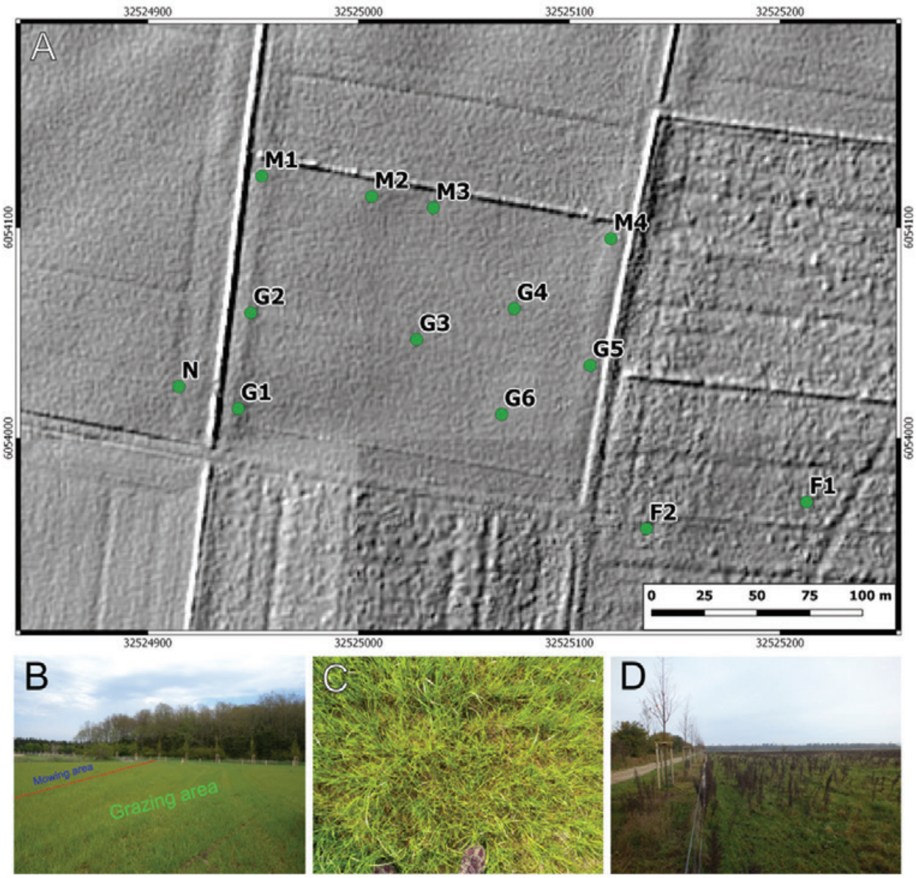

Fig. 2. (A) Site plan of the testing area next to Tüdal (District of Schleswig-Flensburg). M: Sites on the mowing area; G: Sites on the grazing area; F: Sites in the adjacent forest; N: Site on the neighboring field (Data source: DGM 1, LVermGeo SH 2015; coordinate system: UTM, WGS 84). (B) Section of the both testing areas in spring 2013, sown with *Lolium perenne*. (C) Growth density of *Lolium perenne* in detail, sown using a seed drill. (D) The grazing area with mass development of *Conyza canadensis* in autumn 2014

3.2. Regional Climate and the Weather Conditions in 2013 and 2014

Climatically, Schleswig-Holstein is dominated by mild winters and cool summers with an annual temperature of 8.2°C and oceanic weather conditions due to westerly winds. The annual precipitation is about 918.9 mm/a (meteorological station of Flensburg, 1961–1990) (DWD 2012). During the investigations in 2013 and 2014, the weather conditions were not consistent. Both years were characterized by less rain and above-average temperatures in summer (except August 2014). In 2013, the summer was quite dry and the plant growth was strongly restricted due to continuous periods without any rainfall. In 2014, it was even warmer, especially in the middle of July. In August 2014, there were partially strong rainfall events in the north of Schleswig-Holstein. The winter 2013/2014 was quite mild with average rainfalls and hardly any snow. The temperatures in winter 2014/2015 were also mostly warm, except in January. December was very wet, with partly excessive rainfalls (DWD 2015).

3.3. Sedimentology and Soil Analysis

The pits were opened and closed at the exact same place every time using a spade. After removing the old refilling material, the pit was slightly enlarged to get undisturbed samples. Drilling profiles were performed alongside, using a Pürckhauer auger. All profiles were described after Ad-hoc-AG Boden (2005) and IUSS Working Group WRB (2006) using a standardized form sheet. All samples were analyzed by using the following methods: Grain size (method after Koehn; cf. Gee *et al*. 1986), debris content (by mass), soil color (Munsell), soil organic matter and carbon (loss of ignition, 480°C), pH value (electrometric in *Aqua dest.* and in CaCl solution, 0.01 M), cations K, anions NH_4, NO_2, NO_3, PO_4 (photometric, GBC, Australia, and using ion chromatographic method, Dionex, USA), CNS (elemental analyzer, Elementar, Germany; combustion analysis, Analytic Jena, Germany, with determination of the total nitrogen content organic and inorganic). Using 100 ml sampling rings, the pore volume and the dry bulk density were determined in g/cm³, additionally indicated according to the SI system in kg/m³ (all methods after Schaller 2008, Blume 2000, and Rowell 1997).

3.4. Soil Penetration Resistance

Measuring penetration resistance is widely used to investigate the effects of different kind of land use and soil management on soil properties (e.g. Afzalinia and Zabihi 2014, Salem *et al*. 2015). Depending on soil moisture, soil texture and carbon content, soil compaction affects penetration resistance; penetration resistance increases with higher soil compaction. Hence, several studies used penetration resistance data to investigate the effects of wheeling and field traffic (e.g. Barik *et al*. 2014, Braunack and Johnston 2014, Usowicz and Lipiec 2009), while other studies used penetration resistance as an indicator for trampling effects on soil physical properties (Donkor *et al*. 2002, Ludvíková *et al*. 2014). Additionally, the fast and minimal-invasive method enables a spatial analysis of soil characteristics and the derivation of spatial patterns resulting from various land use and soil management (Kuhwald *et al*. 2016, Veronesi *et* *al*. 2012). Therefore, penetration resistance was used as an additional indicator to characterize the effects of mowing and animal trampling.

In October 2014, soil penetration resistance was recorded at 20 sites distributed over the entire field (Fig. 7). 12 sites were located in the grazing area and 8 sites in the mowing area. Additionally, two sites were measured in the forest to compare the cultivated area with more or less natural vegetation. A penetrologger with automatic data storage (Eijkelkamp, Penetrologger 06.15.31) was used to measure the penetration resistance in 1 cm intervals from surface to a depth of 25 cm. A cone with an angle of 60° and a cone base area of 1 cm^2 was selected and was pressed into the soil by hand with a mean velocity of approximately 2 cm/s.

At each site, five measurements were performed; the arithmetic means were calculated out of these parallels for each centimeter for further analysis. The actual soil moisture content was recorded by a TDR-device (ThetaProbe ML2x) with five replications at the measurement sites. Coordinates (WGS 84 UTM 32 N) of each site were determined with a handheld GPS (Trimble Juno Sc).

The software environment 'R' (R Core Team, 2014) with the packages 'gstat' and 'sp' (Bivand *et al*. 2013, Pebesma 2004, Pebesma and Bivand 2005) was used for spatially analyzing penetration resistance. Due to the limited amount of measuring sites (20 in total), the spatial prediction was performed by inverse distance weighting with a power-value of 2 and a raster cell size of 1 m^2.

3.5. Botanical Investigations

The aim of the botanical part of the investigation was to find out differences in species number and community structure in both parts of the testing ground (grazed/mowed). All vascular plants were determined according to Jäger (2011). Some mosses were also recorded according to Frahm and Frey (2004). Vegetation data was analyzed according to Braun-Blanquet (1964), Barkman *et al.* (1964) (see Fig. 8). The study plots were taken at random in both parts of the investigation area in May/July and September/October 2013 and 2014. Plot sizes varied from 1 to 4 m^2. The classification of plant communities follows the methods of Dierßen (1990), Pott (1995) and Wilmanns (1998).

3.6. Statistics

The statistical evaluation was performed and differentiated regarding the two testing grounds and their different use. For each testing ground, each sampling cycle and each variable, we took the arithmetic mean. This allowed a good comparison to illustrate the development of the values over time. Peak values have not been left off. For calculation of average values about the development of nutrient contents we took all values from all sampled depths. Descriptions about the differences between various horizons are marked separately.

4. RESULTS

4.1. The Development of Nutrient Contents and other Parameters

4.1.1. Local soil formation and subsoil

The profiles on the testing areas have a fairly homogenous structure. The subsoils consist of coarse and middle sands with low debris content (coarse sand 5–35%; medium sand 35–60%; sand in total 90–98%) The topsoils are a few more silty. It is the sediment of the regional Weichselian outwash plain. Its base could not be reached, because these glacio-fluvial sands in the south-west of Flensburg are regularly 25–30 m thick (Strehl 1999). The content of silt and clay was in all cases less than 10%. Thus, the quality of the local soils for agricultural use is quite low (regular German yield index unit <33). The unweathered sands are a light yellow to strong brown color (for example, 7.5 YR 5/8).

Within the sands, a Holocene podzol developed, which is nearly in all locations eroded in its upper part. Only the rest of the sesquioxide B horizon and in places the humic B horizon (7.5 YR 5/6) were partly visible. In the lower parts of some profiles (lower than 120 cm) there are initial traces of agley soil oxidation horizon. However, the local ground water level was always significantly lower than 150 cm. The upper parts of most profiles with a thick, dark brown horizon (7.5 YR 2.5/1) were noticeable, which was in some cases too thick for a typical ploughing horizon. A former anthropogenic influence with the application of plaggen or peat from bogs in the surrounding area is probable. However, the P values were not noticeably enhanced, and light, sandy streaks in the horizon could be an indication for that. Moreover, the presence of former swampy channels when there were higher ground water levels on the outwash plain is a possibility.

Nearly in all locations, there was residue of the former maize plants in the ploughing horizon. In the western part, 3 profiles were disturbed by an underground gas pipeline (M1, G1 and G2, cf. Fig. 2). All the samples were carbonate free. The pH values were generally acidic (4.29 to 6.14).

4.1.2. Ammonium (NH_4)

Ammonium mostly stems from dung and feces, but also from atmospheric inputs originating from emissions by manure and fermentation residues from biogas production. At first, ammonium becomes nitrified to nitrite, later to plant available nitrate.

In spring 2013, the content of ammonium in almost all profiles was quite high (Table 1). Especially in the upper 10 cm we measured peak values up to 24 mg/kg. The values decreased continuously (minimum: 0.5 mg/kg) down to the lower horizons. At the edges of the testing area a tendency to higher values was visible.

Already within the first year, there was significant shrinking of values ($p<0.00$) at nearly all sites, except at locations on the grazing area, due to the fresh dung of the animals. The average shrinking of NH_4 contents of all sampled horizons on the mowing area is -54% in average, in contrast to only -14% on the grazing area. Within the second year (2014), the shrinking was somewhat stronger and the grazing area caught up to the reduction on the neighboring area (Fig. 3). On both grounds, the average NH_4 reduction between spring 2013 and autumn 2015 was approximately -87%. There was a noticeable rise in NH_4 content in the winter 2014/2015 at nearly all locations.

Surprisingly, in the adjacent forest and on the neighboring farmland there was another development: some of the values on these sites were still higher than from the first measurement in the spring 2013, especially in the two upper samples. In total, the values on the mowing area shrunk at a more continuous rate than on the grazing area with the typical dung deposits of the animals. In the end, after 2.5 years, the total shrinking of NH_4 on the mowing area was in average -34%. In contrast, on the grazing area it increased by 62%. In particular, this was measured in the two upper samples, but not in the samples from the Bs horizon, where most of the measured values shrunk.

Due to the high values of ammonium we tested some samples for N emissions (analysis by Thomas Behrendt, Max Planck Institute of Geochemistry Jena). However, we could not detect any strong emissions (<1 nmol/m^2 NO). This suggests a quite low activity of N processing microorganisms in the profile.

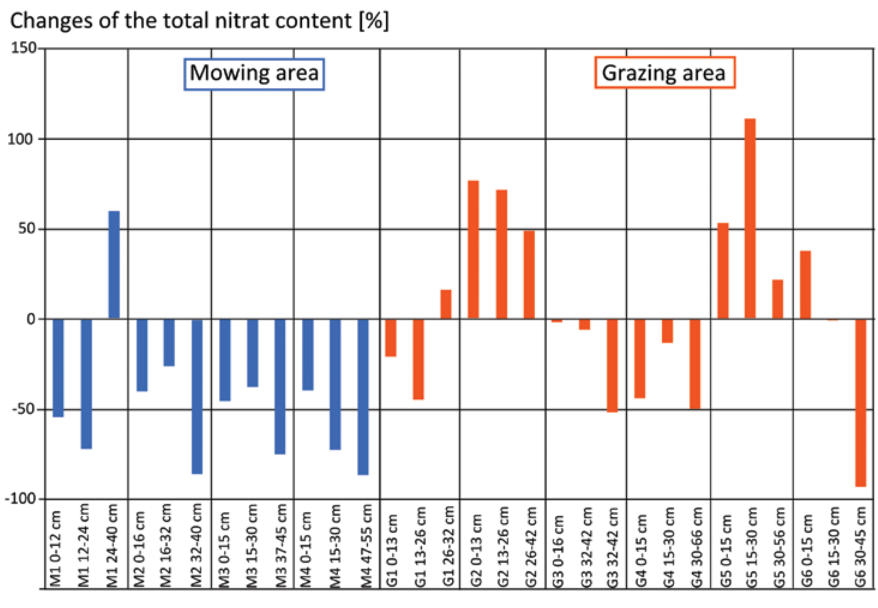

Fig. 3. Changes of the total nitrate content (%) in the single sites (see Fig. 2) and in different depths between autumn 2013 and autumn 2014. M: Sites on the mowing area; G: Sites on the grazing area

4.1.3. Nitrate (NO_3)

In spring 2013, all locations had been well supplied with nitrate (up to 9 mg/kg in the topsoil; Table 1). Down to the middle samples from the Bh horizon, the values shrunk continuously. This also concerns the lowest samples from the Bs horizon with 1–2.4 mg/kg nitrate. The values in the east side of the mowing area close to the forest were slightly lower. During the vegetation period of 2013, on both sampling areas the values rose again (in average 10% on the mowing area and 144% on the grazing area). In 2014, the values on the mowing area shrunk again (-46% in comparison to the first measurement 2 years earlier); meanwhile on the grazing area, the values did not show a homogenous tendency. However, there was still an increase of 71% compared to spring 2013. During the whole sampling period, the nitrate values on the mowing area shrunk approximately 20% in average. In contrast, the values on the grazing area rose about 196%. In most cases, this also concerned the subsoils and, consequently, the complete profile. To sum up, the tendency of shrinking and rising of the nitrate values was not consistent, but more unique on the mowing area (Fig. 4).

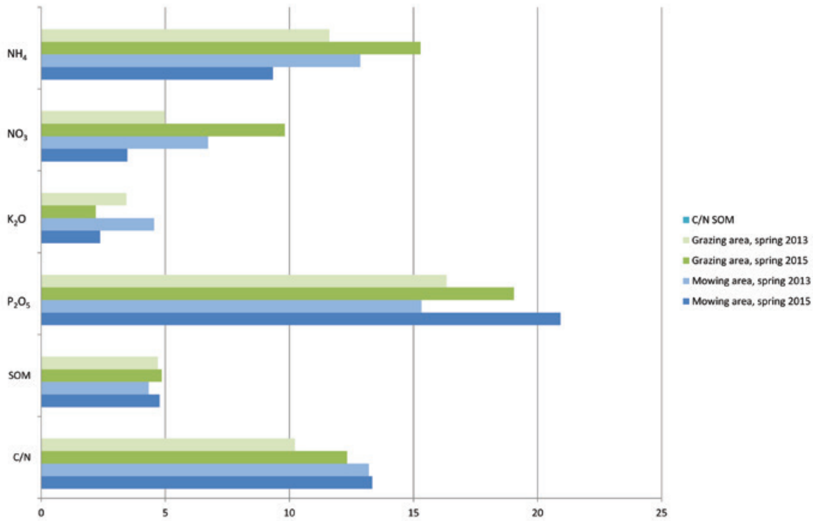

Fig. 4. Measured values of several parameters in the upper soils in spring 2013 and in spring 2015 (in mg/kg; without the forest locations)

4.1.4. Potassium (K_2O)

At the beginning of the measurement, the potassium values had been also quite high (up to 6 mg/kg). The values ranged between these of the adjacent area (higher: 8–9 mg/kg) and these of the forest location (lower: 0.3–1.6 mg/kg). In the following 2 years, at nearly all sites on both testing areas, they shrunk only slightly in a similar way and there were only a few outliners (in average -4.8% on the mowing area and -17.4% on the grazing area). In many cases, a strong decrease of potassium in the subsoils was quite conspicuous (Table 1).

4.1.5. Phosphorus (P_2O_5)

The spreading of the phosphorus contents in the investigated soil profiles (in the beginning, 13–20 mg/kg in the topsoil (Table 1)) is similar to the nitrogen compounds. However, most of the values rose continuously since the beginning of the measurements in nearly all locations (in spring 2015, 18–21 mg/kg in the topsoil – a rise of -100% on the mowing area, probably in consequence of mineralization of dung, and -45% on the grazing area).

4.1.6. Soil organic matter (loss of ignition)

The values of the soil organic matter (Table 1) shrunk moderately between the first two measurements; especially on the grazing area. In the upper part of the subsoils (the intermediate samples of the investigated profiles; 12–32 depth), a small increase was partly visible; maybe in consequence of a stronger root penetration. The last comparison of the spring values between spring 2013 und spring 2015 was unspecific again. The values of the topsoil fluctuated between 3.6% and 5%.

4.1.7. Carbon-to-nitrogen ratio

The carbon-to-nitro ratio is the ratio between nitrogen and carbon in soils and it is a measure for the nitrogen availability of plants. The smaller the C/N value, the more nitrogen is available and the better the soil is supplied. On an area that should be impoverished, the C/N ratio should get higher.

At the beginning of the measurement, it was noticeable that the values on both testing areas were quite homogeneous (9–13 in the topsoil). In general, the autumn values were higher than the spring values. In the forest it was conversely. Most of the values increased during the investigation period. Between autumn 2013 and autumn 2014, there was an average decrease from 19 to 13 (-31%) on the mowing area and from 18 to 13 (-28%) on the grazing area. Just only from spring 2015, it rose again, but not in all locations.

4.2. Soil Compaction

4.2.1. Bulk density (using sampling rings)

At first, we measured the pore volume and bulk density using sampling rings in 5–15 cm depth. The results were not clear and fluctuated quite strongly. However, we could notice a visible tendency (Fig. 5).

Table 1. All measured chemical values for all location and all sampling cycles (NH_4, NO_3, K_2O, P_2O_5, carbon-to-nitrogen ratio, loss of ignition)

Sample	NH_4-N				NO_3-N				K_2O				P_2O_5				SOM				C/N ratio			
	May 13	Nov. 13	Oct. 14	May 15	May 13	Nov. 13	Oct. 14	May 15	May 13	Nov. 13	Oct. 14	May 15	May 13	Nov. 13	Oct. 14	May 15	May 13	Nov. 13	Oct. 14	May 15	May 13	Nov. 13	Oct. 14	May 15
	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	%	%	%	%				
M1 0-12	11.15	7.37	0.81	n.a.	7.54	5.96	2.73	n.a.	4.00	3.07	2.77	n.a.	15.83	31.49	39.91	n.a.	4.51	4.37	4.19	n.a.	13.30	13.73	12.90	n.a.
M1 12-24	7.32	4.90	1.84	n.a.	5.56	9.03	2.53	n.a.	3.61	3.51	3.58	n.a.	17.23	19.12	42.46	n.a.	4.88	4.24	4.04	n.a.	14.03	14.59	12.68	n.a.
M1 24-40	2.88	1.44	0.00	n.a.	2.36	1.23	1.97	n.a.	1.51	2.29	1.86	n.a.	2.40	12.06	17.07	n.a.	1.40	1.54	2.29	n.a.	14.48	28.34	19.35	n.a.
M2 0-16	14.42	11.67	1.08	n.a.	4.69	8.68	5.25	n.a.	6.05	1.61	2.81	n.a.	13.38	5.12	37.55	n.a.	3.62	3.96	3.63	n.a.	11.34	15.21	12.01	n.a.
M2 16-32	20.88	2.65	0.00	n.a.	4.91	4.52	3.37	n.a.	1.95	1.77	1.18	n.a.	13.71	20.14	35.26	n.a.	3.45	3.47	3.16	n.a.	12.44	10.76	11.19	n.a.
M2 32-40	2.59	1.46	1.48	n.a.	1.86	1.40	0.20	n.a.	1.83	2.17	1.71	n.a.	0.97	1.89	1.82	n.a.	1.21	1.69	1.30	n.a.	12.57	26.34	11.90	n.a.
M3 0-15	16.87	8.81	1.11	7.08	8.08	5.82	3.20	1.81	3.99	1.63	1.45	n.a.	14.26	9.76	33.05	20.03	4.95	4.48	4.61	4.72	16.18	18.32	12.43	13.03
M3 15-30	7.16	2.81	1.99	6.29	3.00	5.17	3.21	1.62	1.91	0.96	0.91	n.a.	9.17	12.24	37.17	19.67	3.86	3.79	3.97	4.30	13.12	15.51	11.59	n.a.
M3 37-45	4.48	1.04	0.00	2.10	1.48	1.58	0.40	1.73	1.16	1.30	0.82	n.a.	1.54	17.35	6.02	8.07	2.14	2.83	2.14	3.40	17.54	23.64	13.67	n.a.
M4 0-15	8.95	4.09	1.85	11.60	6.58	7.15	4.33	5.12	4.18	2.05	2.44	n.a.	17.79	28.80	42.27	21.81	4.24	4.17	4.36	4.81	11.98	15.59	11.96	13.64
M4 15-30	16.41	5.53	0.00	7.28	3.37	4.44	1.24	4.47	1.08	0.98	1.27	n.a.	18.97	1.55	49.64	21.07	3.79	4.07	4.04	4.75	11.63	20.53	13.96	n.a.
M4 47-55	4.32	1.05	0.00	2.04	1.31	1.15	0.16	0.99	0.72	0.90	0.51	n.a.	5.93	4.75	4.71	5.15	2.38	2.63	2.22	2.84	18.33	31.41	15.19	n.a.
G1 0-13	23.93	7.11	0.71	n.a.	3.90	5.52	4.37	n.a.	4.63	3.94	3.17	n.a.	18.44	24.35	45.73	n.a.	4.45	4.38	3.96	n.a.	9.00	15.60	11.02	n.a.
G1 13-26	17.47	3.18	0.20	n.a.	4.11	10.14	5.58	n.a.	6.12	3.13	2.39	n.a.	14.64	23.38	40.66	n.a.	4.37	4.23	4.09	n.a.	9.66	14.57	12.05	n.a.
G1 26-32	2.51	1.30	0.00	n.a.	1.49	1.67	1.95	n.a.	2.08	2.03	2.15	n.a.	3.91	12.38	17.50	n.a.	1.21	1.84	1.90	n.a.	6.10	25.09	16.72	n.a.
G2 0-13	6.77	9.22	1.29	n.a.	4.36	4.90	8.67	n.a.	4.82	3.18	3.44	n.a.	13.08	20.03	39.93	n.a.	5.03	4.58	4.43	n.a.	9.17	13.60	11.00	n.a.
G2 13-26	5.04	4.02	1.09	n.a.	4.60	6.76	11.63	n.a.	3.69	2.70	2.97	n.a.	14.68	14.21	47.59	n.a.	5.08	4.09	4.52	n.a.	9.07	13.86	10.73	n.a.
G2 26-42	0.48	0.27	0.00	n.a.	1.33	1.30	1.93	n.a.	1.72	1.04	1.75	n.a.	5.83	3.86	8.43	n.a.	1.67	1.19	1.06	n.a.	12.25	28.33	7.77	n.a.
G3 0-16	7.72	7.56	1.72	21.62	5.70	9.56	9.44	17.76	2.93	1.95	2.17	n.a.	13.23	12.99	30.34	18.77	5.10	4.85	4.82	5.28	12.23	16.79	11.51	11.69
G3 16-32	3.43	5.05	0.46	4.43	2.15	4.83	4.55	12.36	1.04	1.18	0.73	n.a.	13.84	13.41	33.06	17.35	4.13	4.17	4.09	4.28	9.04	16.05	15.18	n.a.
G3 32-42	2.05	0.69	1.51	2.08	0.98	1.82	0.88	7.64	0.88	1.10	0.24	n.a.	2.46	2.19	3.49	7.94	1.53	1.80	2.18	3.03	6.32	19.45	11.13	n.a.
G4 0-15	5.30	13.45	0.92	16.01	9.24	5.82	3.28	6.75	2.32	2.25	1.18	n.a.	15.56	49.95	36.77	18.40	5.04	5.31	4.75	4.95	10.08	15.39	12.00	12.99
G4 15-30	2.39	5.14	0.00	8.15	1.71	4.38	3.81	6.61	1.05	1.23	1.02	n.a.	12.63	14.04	37.30	18.73	4.61	5.02	4.91	4.89	10.52	16.79	13.30	n.a.
G4 30-66	2.79	0.75	0.00	1.79	0.86	1.23	0.62	0.92	0.47	0.83	0.48	n.a.	4.63	6.36	9.51	9.07	2.17	2.12	0.99	2.43	11.26	22.02	12.32	n.a.
G5 0-15	4.33	1.34	1.24	14.84	3.90	5.84	8.96	4.34	3.74	2.35	1.70	n.a.	18.02	30.13	40.41	18.89	3.86	4.26	4.18	4.44	10.48	15.95	11.70	11.89
G5 15-30	2.54	4.80	0.65	6.06	2.13	2.91	6.15	8.65	1.57	1.15	1.17	n.a.	17.10	23.47	52.88	20.64	3.51	3.92	3.87	4.03	9.73	17.81	12.77	n.a.
G5 30-56	4.34	1.13	0.00	1.50	1.58	1.50	1.83	2.38	2.08	1.48	0.88	n.a.	8.66	2.92	4.38	13.00	3.99	3.98	1.98	3.08	12.17	24.47	16.50	n.a.
G6 0-15	21.59	10.89	1.44	8.69	2.82	6.06	8.37	7.87	2.12	1.99	1.54	n.a.	19.63	18.51	40.56	20.13	4.71	4.19	4.46	4.71	10.33	16.11	16.00	12.37
G6 15-30	15.31	11.44	0.73	7.33	2.24	5.43	5.42	5.12	1.44	1.03	0.92	n.a.	18.88	16.85	41.19	19.85	4.03	3.74	4.24	4.69	9.82	14.98	12.35	n.a.
G6 30-45	4.78	1.79	0.00	1.31	1.01	16.75	1.24	1.47	0.95	0.86	0.43	n.a.	10.00	20.04	7.93	10.84	3.54	4.39	2.65	2.25	15.63	23.01	24.50	n.a.
Forest 1 0-15	n.a.	n.a.	3.32	n.a.	n.a.	n.a.	16.69	n.a.	n.a.	n.a.	1.32	n.a.	n.a.	n.a.	6.56	8.63	n.a.	n.a.	3.93	n.a.	n.a.	n.a.	10.97	13.67
Forest 1 15-22	n.a.	n.a.	0.86	4.77	n.a.	n.a.	6.99	5.80	n.a.	n.a.	0.37	n.a.	n.a.	n.a.	9.18	9.37	n.a.	n.a.	1.86	3.53	n.a.	n.a.	12.98	n.a.
Forest 2 0-15	n.a.	n.a.	1.56	7.13	n.a.	n.a.	13.45	9.56	n.a.	n.a.	1.59	n.a.	n.a.	n.a.	6.90	14.54	n.a.	n.a.	3.83	5.32	n.a.	n.a.	10.85	12.89
Forest 2 15-25	n.a.	n.a.	0.00	2.48	n.a.	n.a.	14.93	3.76	n.a.	n.a.	0.26	n.a.	n.a.	n.a.	4.70	15.46	n.a.	n.a.	2.60	3.59	n.a.	n.a.	14.19	n.a.
Neighb. field 0-15	n.a.	n.a.	0.92	5.60	n.a.	n.a.	8.19	11.56	n.a.	n.a.	7.92	n.a.	n.a.	n.a.	32.16	17.97	n.a.	n.a.	4.61	4.34	n.a.	n.a.	11.83	13.70
Neighb. field 15-25	n.a.	n.a.	1.26	6.62	n.a.	n.a.	10.41	7.42	n.a.	n.a.	9.03	n.a.	n.a.	n.a.	32.93	17.64	n.a.	n.a.	4.73	4.65	n.a.	n.a.	12.06	n.a.

After the change of the former maize field into grassland (between September 2012 and May 2013), the pore volume shrunk everywhere (first measurement: 1.21–1.60 g/cm³, 1,210–1,600 kg/m³, respectively 40–55%). Later, a further shrinking was well visible, in consequence of compression by the animals on the grazing area. Particularly, this was well visible in the resting locations of the cattle. In spring, some values rose up again. But in consequence, there is a tendency to a predominant higher density of the soils on the grazing area.

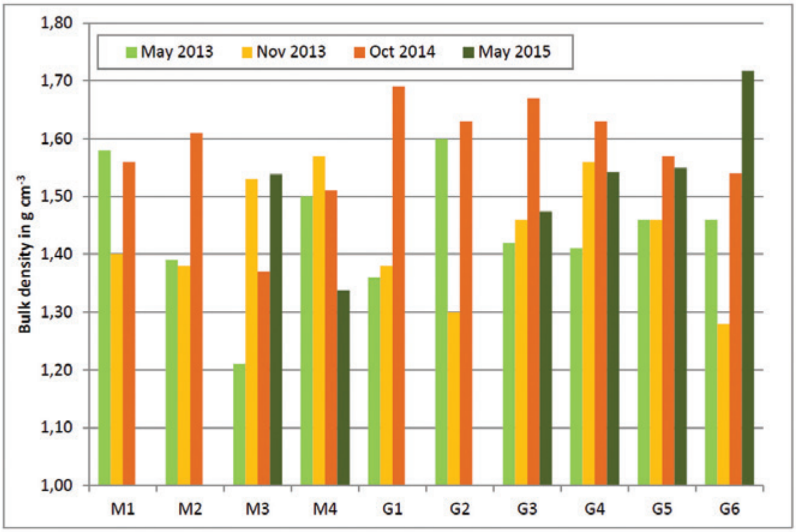

Fig. 5. Average bulk density for all sites on the mowing and on the grazing area, determined using sampling rings in g/cm³ (1 g/cm³ = 1,000 kg/m³)

4.2.2. Soil penetration resistance

Fig. 6 shows the effect of different types of land use on soil penetration resistance. The graph illustrates the arithmetic mean of all measurements separated by land use into grazing area, mowing area and forest. For all three categories the penetration resistance increased from surface to the depth of 25 cm. The grazing area consistently revealed the highest values. Compared to the mowing area, the penetration resistance in the grazing area was up to 33% higher, while it was up to 220% higher compared to the forest.

Fig. 7 illustrates the spatial distribution of penetration resistance at the depth between 5–15 cm. The applied interpolation technique (inverse distance weighing) resulted in sharp transitions between points. However, clear spatial patterns of different penetration resistance are visible. On the east and west site, close to the field borders (points 1, 5, 7, 12, 13 and 20), the penetration resistance with a maximum of 3.8 MPa was significantly higher compared to the inner field. Additionally, the inner field of the mowing area (points 14–19) revealed lower values (max. 2.3 MPa) compared to the inner field of the grazing area (max. 2.9 MPa).

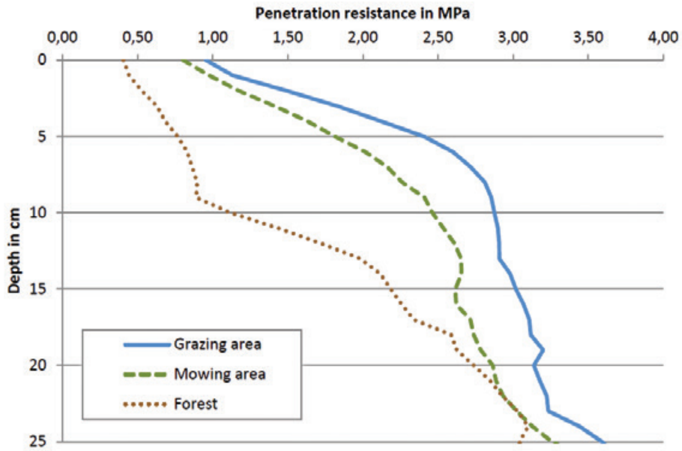

Fig. 6. Penetration resistance profiles comparing the grazing area, mowing area and the forest

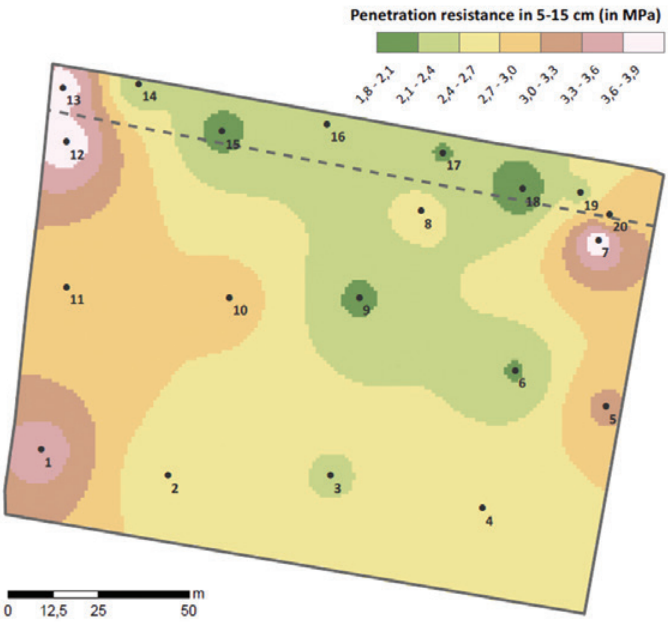

Fig. 7. Spatial distribution of predicted penetration resistance at a depth between 5–15 cm. Point numbers 1–12 are in the grazing area, 13–20 – in the mowing area. The dashed line shows the border between the grazing and mowing area

Fig. 8. Botanical plot in the mowing area (05.07.2013)

4.3. Botanical Observations

In 2013, there was a dominance of the sown *Lolium perenne*. This species dominated most of the investigation area by its narrow planting rows and its good condition. Considering that, the appearing plant society is belonging to the *Lolium multi florum* society, due to the name giving species. It is part of the class *Molinio-Arrhenatheretea*, the class of typical agricultural meadows. The coverage of sown *Lolium perenne* in both parts of the investigation area was rather high, often about 50% and more. Uncovered soil surface of 10 to 25% appeared in the 2013 investigation in every plot. Initial species are often mosses like *Bryum spec*. (in 2013) and *Funaria hygrometrica* (in 2014). They appear as an indicator of a disturbed vegetation layer. The moderately species richness beneath has a certain influence on the area. The immigration of *Rubus caesius* from a hedge mound beside into the mowing area is a typical example. Table 2 shows the species numbers in both parts of the area; Table 3 shows a typical vegetation assessment; Table 4 shows the species names of both testing areas. In 2013, in both parts of the area, the vegetation was quite still similar. In 2014, the vegetation structure changed to a small degree, but not significant.

In 2014, the level of *Lolium* coverage decreases to a rate of generally under 50%. A few new species appeared, and in the end of summer a remarkable appearance of *Conyza canadensis* was noticed (Fig. 2, B).

To sum up, in 2013, we detected the same 33 species on both parts of the testing area. In 2014, there were 50 species in the mowed part and 67 (+12%) in the grazing area (Table 2).

Table 2. Number of species during the observation period

Year	Total no.	Mowing area	Grazing area
No. of species 2013	33	33	33
No. of species 2014	67	59	67

Table 3. Typical vegetation assessment in 2013 and 2014 (mowing area, method after Braun-Blanquet):

r = rare (single individual, clear <1% coverage); + = less (2–5 individuals, <1% coverage); 1 = many (6–50 individuals, <5% coverage); 2 = a great many (>50 individuals, <5% coverage), 3 = 26–50% coverage; 4 = 51–75% coverage; 5 = 76–100% coverage

05.07.2013		18.05.2014	
Total coverage: 75%		Total coverage: 80%	
Plot size: 4 m^2		Plot size: 4 m^2	
Species number: 5		Species number: 13	
Lolium perenne	4	*Lolium perenne*	3
Viola arvensis	1	*Capsella bursa-pastoris*	1
Veronica persica	1	*Geranium molle*	1
Achillea millefolium	+	*Veronica arvensis*	1
Conyza canadensis	+	*Cerastium glomeratum*	1
Seedlings, dryed	+	*Cerastium semidecandrum*	1
		Poa annua	1
		Ornitopus perpusillus	+
		Taraxacum officinale agg	+
		Viola arvensis	+
		Artemisia vulgare	+
		Sonchus spec.	r
		Vicia lathyroides	r

Table 4. Overview of plant species on the testing area (05.10.2014)

	Mowing area	**Grazing area**
	Coverage 95%; moss layer 10%, 10–15 cm; partly deer feces (?)	Only additional species
1	*Acer pseudoplatanus (juvenil)*	*Agropyron spec.*
2	*Achillea millefolium*	*Alchemilla vulgaris*
3	*Alopecurus spec.*	*Hypericum perforatum*
4	*Artemisia vulgare*	*Melilotus spec.*
5	*Bellis perennis*	*Sonchus oleraceus*
6	*Campanula rotundifolia*	*Stellaria media*
7	*Capsella bursa-pastoris*	*Festuca gigantea*
8	*Cerastium arvense*	*Vicia angustifolia*
9	*Cerastium glomeratum*	
10	*Cerastium pumilum (vel semidecandrum)*	
11	*Cirsium arvense*	
12	*Cirsium vulgare*	

		Mowing area	Grazing area
13	*Conyza canadensis*		
14	*Deschampsia flexuosa*		
15	*Erodium cicutarium*		
16	*Erophila verna*		
17	*Festuca rubra*		
18	*Filago pyramidata*		
19	*Filago vulagaris*		
20	*Fragaria cf. moschata*		
21	*Galinsoga parviflora*		
22	*Geranium molle*		
23	*Geum urbanum*		
24	*Holcus lanatus*		
25	*Hypochoeris radicata*		
26	*Knautia arvensis*		
27	*Leontodon autumnale*		
28	*Leucanthemum vulgare*		
29	*Linaria vulgaris*		
30	*Lolium multiflorum*		
31	*Lupinus polyphyllos*		
32	*Matricaria discoidea*		
33	*Ornithopus perpusillus*		
34	*Plantago lanceolata*		
35	*Plantago major*		
36	*Poa annua*		
37	*Poa trivialis*		
38	*Polygonum aviculare*		
39	*Potentilla spec.*		
40	*Ranunculus repens*		
41	*Rosa spec.*		
42	*Rumex acetosa*		
43	*Rumex acetosella*		
44	*Rumex crispus*		
45	*Rumex obtusifolius*		
46	*Senecio jacobaea*		
47	*Senecio vernalis*		
48	*Senecio vulgaris*		
49	*Sonchus arvensis*		
50	*Stellaria holostea*		
51	*Tanacetum vulgare*		
52	*Taraxacum officinale agg*		
53	*Trifolium dubium*		
54	*Trifolium hybridum*		
55	*Trifolium repens*		
56	*Veronica arvensis*		
57	*Vicia cf. sativa*		
58	*Viola arvensis*		
59	*Viola tricolor*		

5. DISCUSSION

Most of the measured values were similar as expected. A special significance have the high ammonium values, which must be explained by corresponding inputs in the region (about 5 kg/ha*a in Schleswig-Holstein; LLUR 2006). In some parts of Schleswig-Holstein, the atmospheric ammonium values are the highest in Germany. Thus, similar values could be measured at all locations, also in the adjacent forest. The source of the inputs is unknown. But in the surroundings, 300 m in the north-west and 600 m in the south-west, there are two farms with big slurry tanks. However, the shrinkage on the mowing area was more continuously due to the absence of fresh dung. Therefore, mowing with concurrent removing of the grass is the better method for the reduction of high ammonium values.

The interpretation of the nitrate values is similar. The values partly rose up again during the measuring period in consequence of nitrification and the new input of atmospheric N. This is also demonstrated by the comparatively high nitrate values in the forest. However, the situation concerning the desired shrinking of nitrate contents seems better on the mowing area, especially during the first year (Fig. 4).

Due to the nitrification process it is interesting to take a look at the total N content of the samples. Total N was calculated with help of the ammonium and nitrate values. Nitrite has not been taken into the calculation. The results are useful for a better comparison of these different N compounds.

Especially a comparison between autumn 2013 and autumn 2014 shows a clear impoverishment for the topsoil samples: on the mowing area, -62.7% N and on the grazing area, -35.5% N. However, this process slowed down in the time after, due to increased dung inputs on the grazing area and the presumed input of atmospheric nitrogen. Furthermore, on the grazing area, a typical mosaic structure concerning the spreading of dung deposits and resting places of the animals got well visible. In consequence, the situation after 2 vegetation periods (comparison between spring 2013 and spring 2015) is quite another: for the mowing area still a decrease of the N content can be calculated: -29.9%. But in consequence of the dung inputs, on the grazing area, the values rose up in the same period by 124.7%. Therefore, concerning the development of the N content, the frequent mowing is more suitable for impoverishment of former cropland.

More unique and as expected is the shrinking of the potassium values at nearly all sites. Surprising was the unique rising of the phosphorus contents at the most sites and on both testing areas. Primary, phosphorus is contained in feces. But on the mowing area has not been any visible input of dung or similar. Therefore, the rising can only be explained by the progressive mineralization of existing dung components originating by the former land use. Generally, it is visible that the values from autumn are a bit higher as the spring values, because the mineralization processes primary take place during the growing season. Otherwise, phosphorus is quite robust in soils and remains detectable for centuries (cf. Schaller 2008).

A proper indicator for the desired effect of impoverishment and nutrient depletion is the C/N ratio. At first, it shrunk immediately in consequence of the ongoing mineralization and nitrification processes. The first signs of a rising C/N value at few locations appear in spring 2015 on the grazing area, during the last test series. That shows that the total measuring period is quite short for the experiment of soils impoverishment (cf. Oomes 1990).

Interesting are the results about the soil compaction as a consequence of livestock farming. Both, by the measurement using sampling rings, and by using the penetrologger, the soils on the grazing area have been more compacted as those on the mowing area, although this area was at least frequented by a heavy tractor twice a year. By means of the penetration resistance, it becomes clear that the most compacted parts of the grazing areas are located of its edges, in consequence, of the preferred resting places of the cattle. This factor is a further argument for the preference of a frequent mowing process.

Measured soil penetration resistance showed significantly higher values in the grazing area compared to the mowing area (Fig. 6 and 7). Lowest values were recorded in the forest as it is not affected by human activity (cf. Martínez and Zinck 2004).

In the grazing area, the increased penetration resistance was caused by trampling of the animals, which resulted in homogenization, shearing and compaction of the soil (Dec *et al.* 2012, Krümmelbein *et al.* 2008). Donkor *et al.* (2002) and Martínez and Zinck (2004) found similar results. They proved that penetration resistance increases with increasing trampling intensity, in particular in the topsoil. Animals have certain preferred areas, e.g. entrance area, where the trampling intensity is much higher (Dec *et al*. 2011). Thus, recording maximum values at the border of the field was reasonable. Further preferred areas are camping or resting areas, resulting in higher penetration resistance also in the inner field (e.g. point number 10). Consequently, areas with low penetration resistance indicate a reduced trampling intensity.

The spatial distribution of penetration resistance in the mowing area was different. The penetration resistance in this area depends on field traffic activities and machine settings as has been reported above (Głąb 2013, Głąb and Gondek 2014). The field was harvested two times a year by using the described machines; hence, the traffic intensity was low. Thus, penetration resistance was lower in the inner field compared to the grazing area. Except the east and west border, there was revealed high penetration resistance in the same magnitude as in the grazing area. More intense field traffic in the turning zone for the harvester may be a reason for increased values in this area (points 13 and 20) (Duttmann *et al*. 2013).

Also other studies discovered the effect of intense grazing affecting soil physical properties negatively (Dec *et al*. 2012, Krümmelbein *et al.* 2009, Zhao *et al*. 2007) which led to structure deformation (Krümmelbein *et al*. 2008). Furthermore, freezing and thawing may change and recover functions (Dec *et al*. 2012, Donkor *et al*. 2002).

Additionally, the comparison with the results of the measurement of soil penetration resistance is quite difficult, for example, Dec *et al.* (2011) could not detect any dependencies.

A change of land use will induce a change in species number and species composition (Wilmanns 1998: 227). Grazing supported dominance of grasses while mowing that of non-leguminous forbs (Mládková *et al*. 2015). After two years, there are no significant differences between the mowed and the grazed part. The investigation period may be too short to show differences. Two reasons may be responsible for low differences too, namely extreme dry weather conditions in 2013 on the one hand, and the amount of livestock on the other hand. In 2013, many seedlings were dried out on both parts of the testing ground. Strong damage obviously caused by livestock had taken place in the same year. The number of vascular plants will increase as long as open soil gives seedlings the opportunity. Effects of mowing and grazing seem to have less impact on vascular plants than climate conditions in this case. Livestock influence on vegetation and soil like rolling, cow droppings, hoof beat, embedding and grazing in general will have greater effect in the future.

To classify the two investigation areas in a system of vegetation may be difficult because of the lack of many exclusive species. Fresh sown meadows are often fragments, so only a generalized estimation will make sense. The vegetation on both parts of the investigation area belongs obviously to the class *Molinio-Arrhenatheretea*, the agricultural grassland. Situated on a sandy soil without any wetness we can state the order *Arrhenatheretalia* and the two possible alliances *Cynosurion* and *Arrhenatherion elatioris* (Pott 1995). Schubert *et al.* (2010) describe a society without taxonomical status. Their agricultural plant community is called Seedland. This community will develop into associations of the alliances mentioned above. In a part of the *Arrhenatherion elatioris* in the year 2014 we recognized a basal form of *Tanaceto vulgaris-Arrhenatheretum elatioris* (according to Fischer 1985). Furthermore, in a part of the *Cynosurion* we recognized a *Lolio perennis-Cynosurion cristati* (according to Braun-Blanquet 1964). Further investigations would help to decide exactly and show a more characteristic combination of species.

6. CONCLUSIONS

Relating to the results of this study, we can give the advice for a frequent mowing of former cropland areas for the fast impoverishment of soils. Obviously, it is important to remove the mowed grass. Probably, grazing by cattle could have a similar effect over a longer time span, especially if the related area is part of a bigger one. However, this effect could not be evidenced in this study, because of the quite short observation period. Therefore, frequent mowing is the better method at any rate, if results are required in a short-time period.

Particularly obvious was the decreasing of ammonium and nitrate on the mowing area (-25%), whereas the values on the grazing area even rose up (+125%) due to dung input. Less conclusive were the results about the contents of potassium, phosphorus and SOM. A positive result for the grazing method is the slight rise of the C/N ratio at the end of the observation period. On the mowing area, this effect was quite weak. The high atmospheric inputs of nitrogen have been noticeable, probably in consequence of the regional agriculture and maybe also due to the production of biogas in the surrounding.

Furthermore, a problem of strong grazed areas is the soil compaction caused by the animals. In addition, the selective grazing behavior of cattle promotes certain plant species; in case of this study, the neophyte *Conyza canadensis* (Canadian Horseweed) and partly the native plant *Senecio jacobaea* (Common Ragwort). This can have a stronger influence of succession processes than mowing two times a year. Otherwise, due to the formation of a mosaic structure after two years on the grazing area, there could be evidenced 67 plant species (in contrast to 59 on the mowing area, -12%).

For further results in terms of the development of nutrients and vegetation, a longer observation would be recommended. Unfortunately, in this case, this was not possible due to short-term conversions of the testing area.

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