Agronomy Research **2**(2), 169–180, 2004

Chemical parameters of coastal grassland soils in Estonia

K. Kauer, T. Köster and R. Kõlli

Department of Soil Science and Agrochemistry, Estonian Agricultural University, Kreutzwaldi 64, 51014 Tartu, Estonia; e–mail: kauer@eau.ee, tints@eau.ee, raimo@eau.ee

Abstract. Larger areas of coastal grasslands can be found in western Estonia and in the islands of the west coast. Salt marshes of the Baltic Sea are not natural biotopes but developed by agricultural use, mainly grazing by beef cattle and horses. The main goal of the work is to discuss the properties of the investigated soils (*Hyposalic Fluvisols*), nutrient cycle in the plant-soil system and the influence of grazing on the coastal biotope. In this study, the coastal grassland soils in Hiiumaa have been investigated by using morphologic (depth of humus layer, bulk density) and chemical parameters (pH, total N and C, mineral elements P, K, Na, Ca, and Mg). The investigated soils contain high amounts of soluble salts K, Na, Ca, and Mg. The total nitrogen and humus content were high, but the content of P was low.

Key words: coastal grassland soil, chemical parameters, humus layer depth, bulk density, impact of grazing

INTRODUCTION

Estonia is located on the shore of the Baltic Sea: from 57º30´ to 59º40´ N and from 21º45´ to 28º15´E and the length of the coastline is about 3,794 km. In larger areas coastal grasslands can be found in western Estonia where landscape is flat and on the islands of the west coast. In the last 60–65 years, the total area of semi-natural grasslands and their importance as a forage resource for animal husbandry has radically changed in Estonia, depending on the management system in agriculture. The area of coastal meadows has decreased 4 to 5 times compared to the beginning of the last century (Sammul et al., 2000). The investigated soils on the island of Hiiumaa were determined as *Hyposalic Fluvisols* (World Reference Base…, 1998), and they occupy 0.7% of the Estonian territory – 29.1 thousand ha (Kokk, 1995). They are young soils with a slightly differentiated gleyic profile (Reintam, 1995). The surface horizon is thin, slightly decomposed, rich in fine roots that are matting materials together and create a felty (or fibrous) structure. The content of soluble salts in coastal soils is caused by the influence of seawater as the soil is flooded and the level of groundwater is high. The salinity of seawater in the Baltic Sea is quite low and does not exceed 7 ‰ (Astok et al., 1995).

The coastal grasslands have been traditionally grazed by cattle and horses for a long period of time. One reason for this was the relatively good quality of grass that met the requirements of livestock in extensive farming. Grazing animals affect the movement and utilisation of nutrients through the soil and plant system, and thus on the fertility of pasture soil (Haynes & Willams, 1993).

The effect of grazing on plants and soil includes plant defoliation, nutrient removal and redistribution through excrete and mechanical impact on soil and plants through trampling (Vallentine, 1990). The treading of animals can result in compaction and disruption of the soil surface leading to reduction of infiltration, development of animal trails and soil erosion. Stocking rate, duration and frequency of grazing, vegetation, soil type and soil moisture influence the degree of compaction (Broersma et al., 1998). Urination and dung are important means of returning part of the nutrients to the soil; they form local additions of fertilisers, which are unevenly spread through time and space (Peterson et al., 1956). This nutrient input depends on the type and age of livestock, quality, and weather conditions (Lowday & Wells, 1977). The content of mineral elements, formation and some aspects of classification of soils in coastal areas were already studied by R. Kask (1996) but more specific aspects on the content of nutrients in coastal soils and impact of grazing needs advanced research.

The main goal of the work is to discuss the coastal soils properties and the problems with the exploitation of coastal grasslands. Also the changes in salinity of soils in coastal area were investigated, depending on the degree of inundation.

MATERIAL AND METHODS

The investigated coastal grasslands are situated on the Kassari Peninsula in South Eastern Hiiumaa. This area (400 ha) is grazed by horses and beef cattle. The grazing intensity is quite low and has not been equal in the whole area, depending on the productivity of the grassland. In some places, the grazing has not been intensive enough to suppress the spreading of reed.

Soil samples were collected from six investigated areas (IA 1–6) in the years 2001 and 2003 (Fig. 1). In the year 2001 four soil pits to areas 1–4 were made, in 2003 one pit to area 5 was made. In 2003, soil samples from two top horizons [A, (A)CG] in IA 4, 5 and 6 were collected to investigate the changes of chemical parameters at different distances from the sea. Areas 1–3 and 5 were situated about 300–400 metres from the sea (Table 1). IA 4 about 100 m and this area was overgrazed and the productivity of plant association *Clauco-Juncetum gerardii* was low (94 g m^{-2}). In IA 6 samples were taken 30 metres from the sea.

Table 1. Distances from the sea and plant associations of the investigated areas.

Area code	Distance from the sea (m)	Plant association
1	300-400	*Festucetum rubrae*
2	300-400	*Clauco-Juncetum gerardii*
3	300-400	*Festucetum rubrae*
4	100	*Clauco-Juncetum gerardii*
5	300-400	*Clauco-Juncetum gerardii; Phragmitetum australis*
6	30	*Festucetum rubrae; Phragmitetum australis*

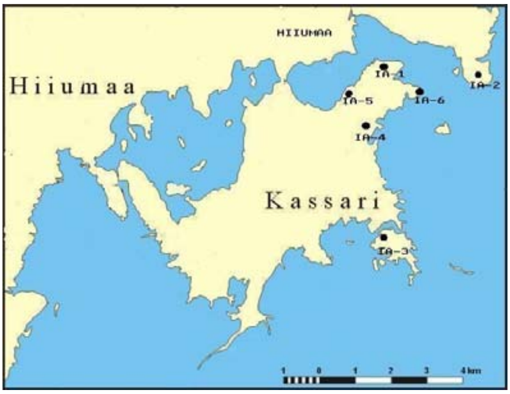

Fig. 1. Investigated areas (IA) on the Kassari Peninsula (AS Regio).

To study the productivity of the grassland, the phytomass in the research area was cut in four replications (plots of 6 m^2), weighed, and an average sample (1 kg) was taken to estimate dry matter (DM) yield.

Air-dried soil samples were sieved through a 2 mm sieve, and in this material there were determined: pH (in 1M KCl and in 0.01M $CaCl_2$; 1:2,5), organic carbon by Tjurin (Vorobyova, 1998), total-N after Kjeldahl (Procedures for …, 1995), P, K, Na, Ca and Mg according to Mehlich-3 using 0.015 M NH_4F / 0.20 M CH_3COOH/ 0.25 M NH_4NO_3/ 0.013 M HNO_3, at a weight and volume ratio of 1:5 (Handbook on …, 1992). In addition to this, P was analysed according to Olsen, using 0.5 M $NaHCO_3$ at pH 8.5 at the same weight and volume ratio (Kalra et al., 1991). Soil electrical conductivity and bulk density were determined (Methods of Soil…, 1986) and humus and nitrogen stocks in soil were calculated. In IA 1–5 soil texture was determined by pipette method (Procedures for …, 1995).

Soil samples were also collected at various distances from the sea in 2003. Soil samples were taken from two top horizons – 2, 100 and 200 metres from the sea in IA 4 and 10 and 30 metres from the sea in IA 6.

The annual mean temperature of the study area is +6.0°C, the annual mean precipitation 600–650 mm and the mean ice cover period 90 days (Jaagus, 1999). The year 2001 was quite humid and cool but the year 2003 was, on the contrary, warm and dry.

The analysis of variance was employed for data analysis and the Least Significant Difference ($LSD_{0.05}$) is presented. The relationships between total N and C and total N and P (by Olsen) were determined by regression analysis.

RESULTS AND DISCUSSION

Soil phosphorus was determined by two methods: by Mehlich-3 and by Olsen. 46 soil samples were analysed and there was correlation (R^2 = 0.69) between the total nitrogen of soil and soil phosphorus determined by Olsen. In comparison, total soil nitrogen with phosphorus was determined by Mehlich-3 and there was no correlation. There was better correlation (R^2 = 0.95) between total nitrogen and the carbon of soil (Fig. 2).

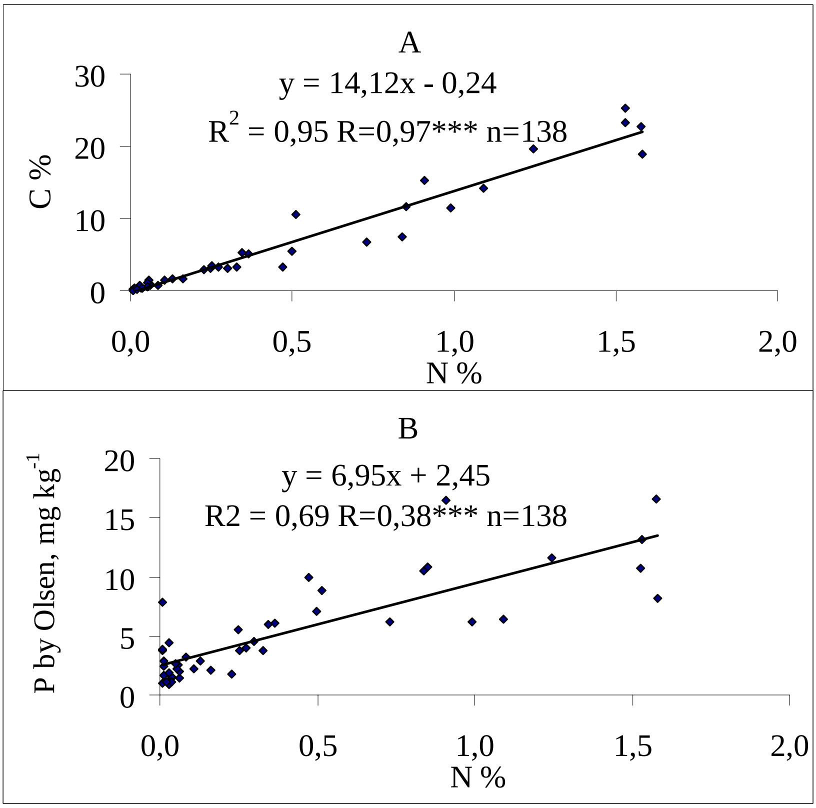

Fig 2. Correlation between total N and C of soil (A) and correlation between soil total N and phosphorus determined by Olsen (B) (Level of significance p<0,001).

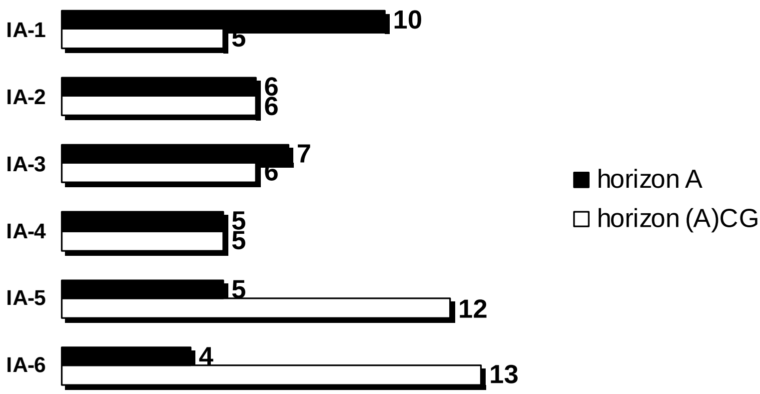

Fig. 3. Depth of horizon A and (A)CG in the investigated areas, cm.

Coastal soils have developed under *aquic* conditions and they are submitted to periodical overflow by seawater. Soils are formed in gleysation process under poor drainage conditions, which results in the reduction of iron and other elements and appears in soil profile as grey colours and mottles. They have horizon A characterised by a high content of organic material and the second horizon (A)CG altered by humus substances and elements influenced by vegetation (roots and litter).

The depth of horizon A in the investigated soils was shallow, varied 4–10 cm, and that of horizon (A)CG 5–13 cm (Fig. 3).

In the investigated areas 1–3, the dominating plant associations were *Clauco–Juncetum gerardii* and *Festucetum rubae* and the productivity extended to 330 g m^{-2}. The greater accumulation of organic matter to humus horizon was performed in the areas where grassland productivity was higher (Fig. 4).

If the content of clay (particle size < 2 µm) in coastal soils is low, the exchangeable cations are mainly absorbed by organic matter. Surface horizons (especially clay texture) are water repellent, resulting in very difficult rewetting, once they have dried out. Due to the pore size and shape of sandy soils with a particle diameter around 200 µm, the plant root penetration is frequently limited to a shallow layer of about 25 to 35 cm thick (Ampe & Langohr, 1993).

Treading by animals causes soil compaction that is probably the result of frequent trampling of livestock, especially during wet soil conditions (Dahlgren et al., 1997). The degree of compaction depends on vegetation type, soil properties such as texture, organic matter, water content and management condition such as grazing regime and density, also the species of animals (Mapfuma et al., 1999). Grazing results in an increase of bulk density of the surface horizon (Bauer et al., 1987; Van der Meulen et al., 1996). Ampe et al. (2002) showed that the treading effects on bulk density at the level of animal tracks are greater in wet than in dry sites. In wet areas, the bulk density values of the surface horizon are significantly higher for paths than control areas.

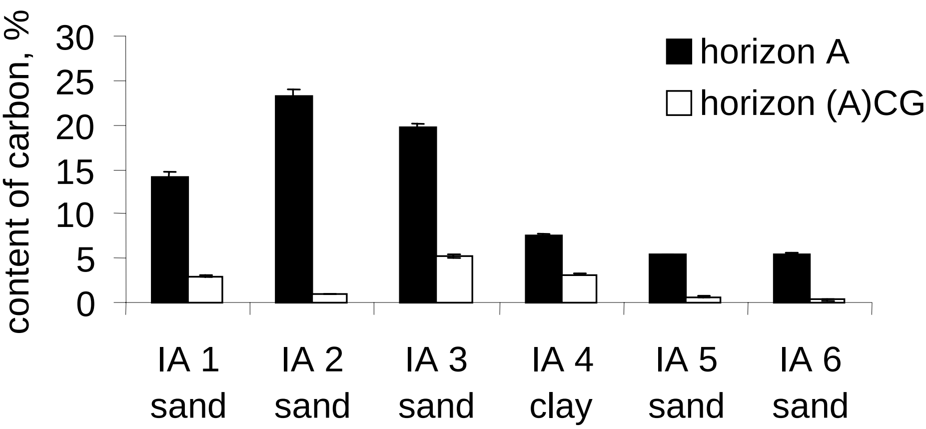

Fig. 4. Soil texture and content of organic carbon (%) in horizon A and (A)CG of the investigated areas (IA) 1–6.

Table 2. Bulk density (g cm^{-3}) and stock of N and C (Mg ha^{-1}).

Area code	Bulk density, g cm^{-3}	Stock of nitrogen, Mg ha^{-1}	Stock of humus, Mg ha^{-1}
4	1.49	0.80	17.7
5*	0.51	1.27	23.5
5**	1.41	0.55	18.3
6'	1.22	0.93	12.5
LSD $_{0.05}$	0.67	0.36	7.2

*horizon A; **horizon (A)CG
'10 m from sea

Originally, low-lying sites have lower bulk density values compared to dry areas. This is because of the higher organic matter contents in wetter areas as a result of slower decomposition and accumulation of organic matter during the frequent high groundwater levels. This increases susceptibility to compaction of the surface horizon. Also higher moisture contents in low-lying sites make these soils more vulnerable to trampling. It is known that soils covered by a dense sod are less susceptible to deep treading damage (Vallentine, 1990).

In our investigated areas, the bulk density varied 0.51–1.49 g cm^{-3} in humus horizon (Table 2).

The greater value of bulk density was in the area 4 that had clayey soil texture. This area was also overgrazed, and trampling there had been more intensive than in other investigated areas. The calculated stock of humus and nitrogen was based on bulk density. The stock of nitrogen and humus varied 0.8–1.3 Mg ha^{-1} and 12.5–23.5 Mg ha^{-1}, respectively. In the humus horizon of IA 5 with lower BD, there were higher humus and nitrogen stocks, which decreased with depth.

The grazing and trampling of domestic animals creates gaps, which can be invaded by ephemerals. All such gaps are not quickly invaded because of overly dry conditions or high salinity levels (Jutila, 1997).

In IA 5, there were two small sandy areas (approximately 10–150 m^2). One of the areas was vegetated by halophytes like *Salicornia europaea, Honckenya peploides, Cakile maritima* and *Halimione pedunculata* which had emerged in the second half of the vegetation period. The other area was without vegetation. From both areas soil samples were taken, and the distance between the two areas was 100–150 m. In comparison, chemical parameters of humus horizon of grassland have been presented (Table 3).

IA 5 was also inhabited by reed (*Phragmitetum australis*) from which a sample from horizon A and (A)CG was taken. The humus horizon was well–rooted with thick roots of reed. The habitat of reed was characterised by intensive accumulation of organic matter and slow decomposition. In ecosystems with low rates of decomposition, carbon limitation may be reached relatively early in the decomposition process and C-concentrations in the soil will remain high (Kooijman et al., 2002).

Table 3. Chemical parameters of humus horizon in IA 5.

Indicator	Area without vegetation	Area with vegetation	Grassland *Clauco–Juncetum gerardii*	Habitat of *Phragmitetum australis*	$LSD_{0.05}$
pH(KCl)	6.7	7.4	5.8	5.3	
N, %	0.04	0.03	0.50	1.53	0.13
C, %	0.3	0.8	5.4	25.3	0.46
P*, mg kg^{-1}	1.5	1.9	7.1	10.7	0.9
K, mg kg^{-1}	252	496	366	1113	102
Na, mg kg^{-1}	3227	26058	7961	44505	1458
Ca, mg kg^{-1}	1133	1637	2248	5318	119
Mg, mg kg^{-}	746	2154	943	3116	165
C/N	9	28	11	17	
Ca/Mg	1.5	0.8	2.4	1.7	
EC, dS m^{-}	10	31	n.d.**	n.d.	

* by Olsen; **not determined

Table 4. Chemical parameters of investigated areas humus horizon.

Indicator	IA 1	IA 2	IA 3	IA 4	IA 5	IA6	$LSD_{0.05}$
pH(KCl)	5.2	4.7	5.1	5.5	5.7	5.1	
N,%	1.09	1.53	1.24	0.84	0.50	0.35	0.07
C, %	14.2	23.2	19.7	7.5	5.4	5.3	0.7
C/N	13	15	16	9	11	15	
P*, mg kg^{-1}	6.4	13.1	11.6	10.5	7.1	6.0	0.5
K, mg kg^{-1}	428	571	524	532	366	136	34
Na, mg kg^{-1}	2982	3322	2836	1512	7961	3284	248
Ca, mg kg^{-1}	847	926	795	837	2248	915	77
Mg, mg kg^{-1}	313	313	262	196	943	217	29
Ca/Mg	2.7	3.0	3.0	4.3	2.4	4.2	

* by Olsen

Analyses show that chemical parameters of soil differ a lot in the habitat of reed. The content of nitrogen, carbon and nutrients was much greater than in other types of vegetation.

The content of plant available nutrients in the investigated grassland soils was relatively high by K, Na, Ca and Mg but the content of phosphorus was low (Table 4). Only in IA 6, the content of K level was relatively low. The content of organic matter was high (especially in IA 1–3) but the content of nitrogen was low and the ratio of C/N relatively variable (8–16). In arable soils, the C/N ratio is usually determined 10–12 (Stevenson, 1994).

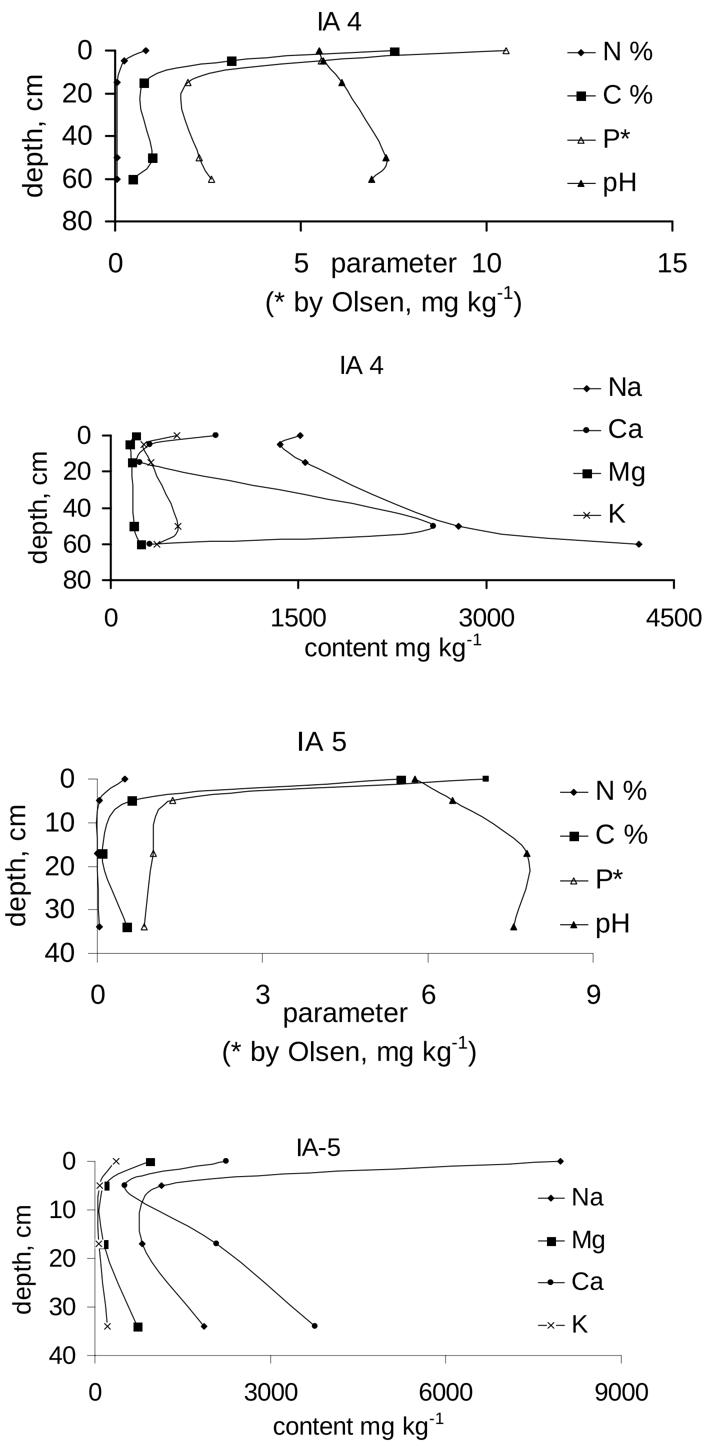

Fig. 5. Distribution curves by vertical profile in IA 4 and 5.

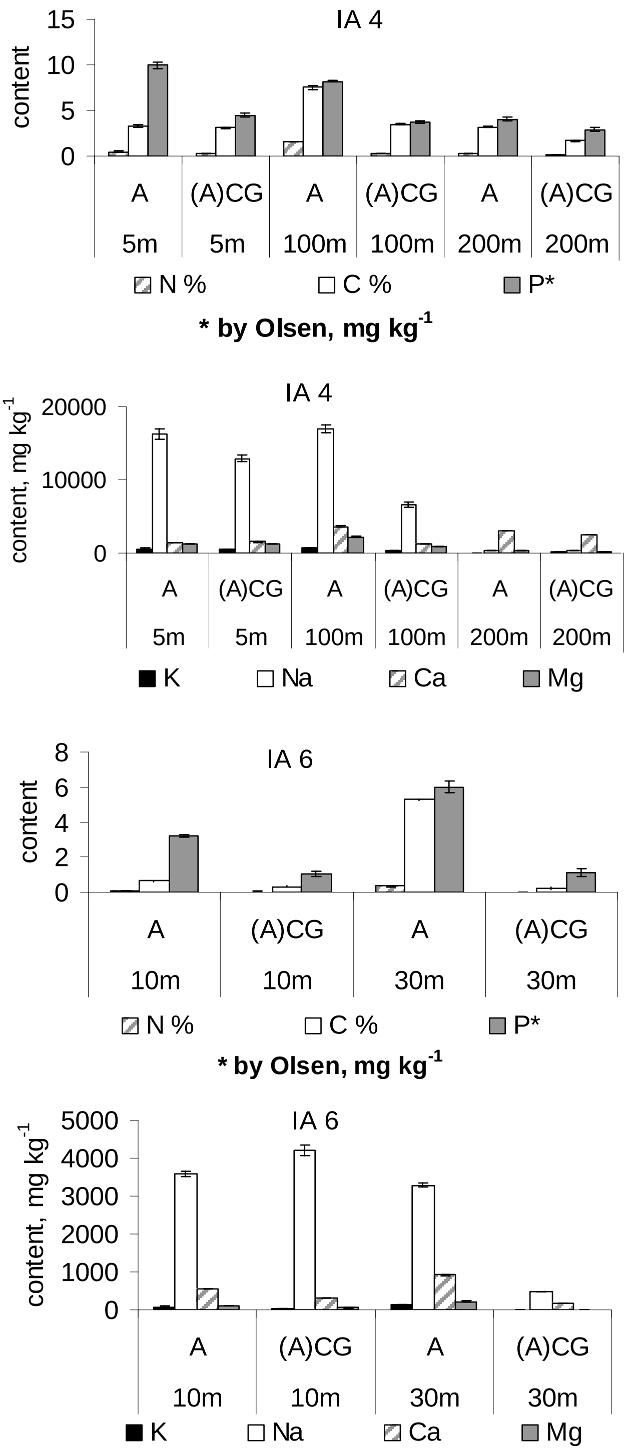

Fig. 6. Chemical parameters in humus horizon of the investigated areas.

Nutrients are consumed in living plant biomass and some of nutrients return into the soil in animal excrements. The decrease of organic matter in soil, which is a major source of nutrient mineralisation, may gradually lead to a smaller soil nutrient store and lower availability. Moderate mineralisation of excrements will enhance nutrient availability. As large herbivores tend to graze in preferential areas in their habitat and often move to other localities for resting, the habitat often becomes partly nutrient-poorer and partly nutrient-richer (Bokdam & Gleichman, 1989).

According to Kooijman & Smit (2001), stocks of organic matter and total soil N in the mineral soil overall decrease under grazed condition. Phosphorus in soil seems not to be affected by grazing. Potassium levels in soil decreased under grazing. Potassium is a highly mobile ion, which easily leaches from damaged leaf cells and litter. When biomass is only damaged by trampling, K leached from the plant may become to a large degree absorbed into soil exchange complex and remain in the plant–soil system. When K is exported in consumed biomass, this may rapidly lead to lower K levels in soil and plant.

Humus and nutrient elements were accumulated into humus horizon and their contents decreased drastically in deeper horizons (Fig. 5). Within the profile of soil, the pH tended to increase. Probably it was related to soil material accumulated by the sea at earlier stages of the profile development.

The results demonstrated that in IA 4, situated at a distance from the sea (Fig. 6), the content of Mg, Na and electrical conductivity decreased, whereas the soil pH and the ratio of Ca/Mg increased. Na content decrease after 200 metres was even 40 times smaller in the humus horizon. The ratio of C/N and the content of Ca increased a little. The electrical conductivity of soil was related to soil salinity that was caused by seawater salinity. In Estonian seawater, sodium and magnesium chloride have dissolved the most (Valing, 1973), which explains Na, Mg and EC decrease to receding from the sea in that area. In IA 6, there was little difference. The content of soil total nitrogen, humus and soluble salt, except Na, was lower than in other areas. As noted above, humus horizon depth changed after 20 m from 9 up to 4 cm. The analysis demonstrated that in the humus horizon content of N, humus, K, Ca, Mg increased, the content of Na was almost invariable. But in the next horizon, the content of N, K, Na, Ca and Mg decreased (the content of Na decreased nearly 8 times). The ratio of C/N increased in both horizons from 8 to 16.

CONCLUSIONS

The *Hyposalic Fluvisol* had a root-rich felty fabric humus horizon with a high content of organic matter (the content of carbon varied 5.5–23.2%). C/N ratios for organic material in the humus horizon of the soil reached up to 16. The content of plant available nutrients in the studied soils was relatively high by K, Na, Ca and Mg but the content of phosphorus was very low. The humus and nutrient elements were accumulated to the humus horizon and their contents decreased drastically in deeper horizons. Within the profile of soil, the pH increased. Bulk density varied 0.51–1.49 g cm^{-3} in the humus horizon and the greater value was in the area having clay texture, also the area was characterised by low productivity and overgrazing. The stock of nitrogen and humus varied 0.8–1.3 Mg ha^{-1} and 12.5–23.5 Mg ha^{-1}, respectively.

REFERENCES

Ampe, C. & Langohr, R. 1993. Distribution and dynamics of shrub roots in recent coastal dune valley ecosystems of Belgium. *Geoderma* **56**, 37–55.

Ampe, C., Ngugi, N. M. & Langohr, R. 2002. Impact of Recently Introduced Large Herbivores on Soil Properties of Coastal Dune Soils of the “Westhoek” Nature Reserve, Belgium. The Changing Coast. EUROCAST/ EUCC, Porto–Portugal, Ed. EUROCAST- Portugal, ISBN 972-8558-09-0.

AS Regio (www.saared.ee).

Astok, V. & Mardiste, H. 1995. The Baltic sea and its development. *Estonia nature* (Raukas A., ed.), pp. 228–238 (in Estonian).

Bauer, A., Cole, C. V. & Black, A. L. 1987. Soil property comparisons in virgin grasslands between grazed and non-grazed management systems, *Soil Sci. Soc. Am. J.* **51**, 176–182.

Bokdam, J., & Gleichman, J. M. 1989. De invloed van runderbegrazing op Struikheide en Bochtige smele. *Levende Nat.* **90**, 9–14.

Broersma, J. M., Krzic, M., Thompson, D. J. & Bomke, A. A. 1998. Effects of long term grazing on soil quality in southern British Columbia. In *People and rangelands: Building the future*, Proc. VI Int. rangeland congress, (Eldridge, D. & Freudenberger, D., eds.) Townsville, Australia, pp. 114–116.

Dahlgren, R. A., Singer, M. J. & Huang. X. 1997. Oak tree and grazing impacts on soil properties and nutrients in a California oak woodland. *Biogeochemistry* **39**, 45–64.

Handbook on Reference Methods for Soil Analysis. 1992. Soil and Plant Analysis Council, Inc. 202 pp.

Haynes, R. J. & Williams, P. H. 1993. Nutrient cycling and soil fertility in grazed pasture ecosystem. *Adv. in Argon*. **49**, 119–199.

Jaagus, J. 1999. New Data about the Climate of Estonia. In *Studies on Climate of Estonia* (Jaagus, J., ed.). Publicationes Institute Geographici Universitatis Tartuensis 85, Tartu, pp. 28–38 (in Estonian).

Jutila, H. 1998. Effect of grazing on the vegetation of shore meadows along the Bothnian Sea, Finland. *Plant Ecology*. Kluwer Academic Publishers. Printed in Netherlands, pp. 1–12.

Kalra, Y. P & Maynard, D. G. 1991. *Methods manual for forest soil and plant analysis*. Forestry Canada.

Kask, R. 1996. *Soil of Estonia*. Tallinn, 239 pp.

Kokk, R. 1995. The distribution and characterisation of soils in Estonia. *Estonia Nature* (Raukas, A., ed.), pp. 430–439 (in Estonian).

Kooijman, A. M. & Besse, M. 2002. The higher availability of N and P in lime- poor than in lime- rich coastal dunes in the Netherlands. *British Ecological Society, Journal of Ecology* **90,** 394–403.

Kooijman, A. M. & Smit, A. 2001. Grazing as a measure to reduce nutrient availability and plant productivity in acid dune grasslands and pine forests in the Netherlands. *Ecological Engineering* **17**, 63–77.

Lowday, J. E. & Wells, T. C. E. 1977. The management of grassland and heathland in country parks. A report to the countryside commission prepared by the institute of terrestrial ecology. ISBN 0 902590 55 3.

Mapfumo, E., Chanasyk, D. S., Naeth, M. A. & Baron, V. S. 1999. Soil compaction under grazing of annual and perennial forages. *Canadian Journal of Soil Science* **79**(1), 191–199.

Methods of Soil and Plant Analysis. 1986. Agricultural Research Centre, Department of Soil Science. Jokioinen, 45 pp.

Petersen, R. G., Lucas, H. L. & Woodhouse, Jr. W. W. 1956. The distribution of excreta by freely grazing cattle and its effect on pasture fertility: I. Excretal distribution. *Agronomy Journal* **48**, 440–449.

Procedures for Soil Analysis. 1995. (van Reeuwijk, L. P., ed.) Fifth Edition. Wageningen, 112 pp.

Reintam, L. 1995. Soils of Estonia. (Boguslawski, E. V. et al., eds.*) Boden und Düngung.* Mitteilungun der Internationalen Arbeitsgemeinshaft für Bodenfruchtbarkeit der Internationalen bodenkundlichen Gesellshaft. Tartu, pp. 122–131.

Sammul, M., Kull, K & Kukk, T. 2000. Natural grasslands in Estonia: evolution, environmental and economic roles. In *Proc. of the Int. Symp., Conventional and Ecological Grassland Management. Comparative Research and Development* (Viiralt, R., ed.), Tartu, pp. 20–26.

Stevenson, F. J. 1994. Humus Chemistry. Second Edition. John *Wiley* and Sons, Inc., 496 pp.

Valing, O. 1973. The content of mineral salts in the sea water of Estonian coastline on the assumption of using the sea water for irrigation. *EMMTUI transactions XXIX*, Tln. pp. 119–135.

Vallentine, J. F. 1990. Grazing management, Academic press, Inc. ISBN 0127100008

Van der Meulen, F., Kooijman, A. C., Veer, M. A. C. & Van Boxel, J.H. 1996. Effectgerichte maatregelen tegen verzuring en eutrofiëring in open droge duinen, Eindrapport fase 1, 1991–1995, Fys. Geogr. En bodemk. Lab., Universiteit Amsterdam. Onderzoek in opdracht van IKC Natuurbeheer, Directie Natuurbeheer, Min. van Landbouw, Natuur en Visserij.

Vorobyova, L.A. 1998. *Chemical analysis of soils*. Moscow University Press. Moscow, 272 pp.

World Reference Base for Soil Resources. 1998. FAO, ISSS, ISRIC. *World Soil Resources Reports* **84**.