Grassland Soils – properties and functions

Soils of permanent grassland are widely distributed in Europe. They are commonly humus-rich in the topsoil. Soil organic carbon content and carbon stock are controlled mainly by soil moisture. The humus accumulation in the topsoil is associated with a high water holding capacity, a markedly pH-dependent cation exchange capacity and a high content of total nitrogen. Grassland soils are also characterized by a high aggregate stability in the A horizon. Suitable indicators for the intensity of grassland management are lactate soluble phosphorus content, ratio of carbon to nitrogen and soil structure in the topsoil. Soils of permanent grassland contribute considerably to the protection of groundwater and surface waters and they play an important role for organic carbon storage.

Dr. Andreas Bohner, Agricultural Research and Education Centre Raumberg-Gumpenstein, Irdning (A)

Agricultural land use is determined by soil quality, climate (temperature, amount and distribution of precipitation, duration of vegetation period) and topography. In many regions of Europe, large areas are covered with permanent grassland (meadows, mown pastures, pastures) due to topographical, edaphic and/or climate reasons. Thus, soils of permanent grassland are widely distributed in Europe.

Grassland soils are a major component of grassland ecosystems, providing the habitat for plants and soil organisms. Soils of permanent grassland are characterized by specific properties and functions. They differ with respect to fertility, species composition of the vegetation, yield and forage quality, sensitivity to weed infestation and animal trampling, compactibility, trafficability and suitability for a variety of utilizations. In this paper, primarily soil physical and chemical properties will be considered.

Fig. 1: Grassland soil profile. Photo: Andreas Bohner.

Soil type, soil thickness and soil texture

Nearly all soil types that are widespread in Europe can be found beneath permanent grassland. In contrast to arable soils, the thickness of grassland soils varies from very shallow to deep. All soil textural classes can be found and the soil gravel content varies considerably. Silty grassland soils are very sensitive to soil compaction. Consequently, they are less suitable for an intensive utilization. The grassland vegetation on clayey soils is often rich in herbs, especially in regions with a cool and humid climate. Under these climatic conditions, the sensitivity to weed infestation and the damages caused by animal trampling and/or tractor traffic are usually higher than on sandy soils. On the other hand, clayey grassland soils are less sensitive to soil compaction due to self-loosening of compacted soil layers by swelling and shrinking.

Humus form, soil organic carbon content and soil organic carbon stock

Most of the soil physical, chemical and biological properties are influenced by soil organic matter (Gisi 1990). Consequently, it is of great importance for fertility and soil quality in agricultural soils. Generally, plant residues from grassland vegetation are easily decomposable. Because of their rapid decomposition, mineralization and incorporation into the grassland soil, only small quantities of litter at the soil surface can be observed throughout the year. Thus, in contrast to forest soils and in dependence on soil moisture status, typical humus forms in soils of regularly used grassland are mull, hydromull, half-bog humus and fen peat.

Soils of permanent grassland usually have a high organic carbon content in the A horizon (Table 1) in comparison with arable soils. In grassland soils, living and dead roots are of utmost importance with respect to carbon input into the soil. Thus, the humus accumulation in the A horizon is mainly the result of a high below-ground phytomass which is concentrated in the uppermost 10 cm of the soil.

	Corg (%)				Corg (kg ha^{-1})			
	semi-dry	balanced	moist	wet	semi-dry*	balanced	moist*	wet**
n	32	463	146	138	32	463	146	138
minimum	2.7	2.1	2.0	3.8	27 200	21 324	19 800	19 200
maximum	10.1	18.4	44.1	53.3	101 200	184 400	441 000	266 350
arithmetic mean	6.8	6.6	9.7	32.5	67 700	65 800	97 400	162 550
median	6.6	6.2	8.2	36.2	66 300	62 209	81 700	181 200

n = number of soil analyses; soil bulk densities: * = 1,0 g cm^{-3}, ** = 0,5 g cm^{-3} (assumptions)
Corg = organic carbon content

Tab. 1: Organic carbon content and organic carbon stock in soils of permanent grassland (A horizon, 0-10 cm depth) in Styria (Steiermark) Austria as a function of soil moisture status. Source: A. Bohner, 2012.

Soils of permanent grassland play an important role for organic carbon storage (Gerzabek et al. 2005). In the uppermost 10 cm, about 60.000 to more than 100.000 kg Corg per hectare can be found (Table 1). Soil organic carbon content and carbon stock are controlled by many environmental and management factors. In soils of permanent grassland, moisture is of paramount importance. Consequently, organic carbon content and carbon stock vary widely between different sites. In general, grassland soils on moist and wet sites are characterized by particularly high organic carbon contents and carbon stocks (Table 1). Under comparable conditions, sandy grassland soils generally have lower organic carbon contents than clayey soils. An intensification of grassland management (earlier and more frequent mowing or grazing, increased stocking rate) reduces the below-ground phytomass (Klapp 1971) and increases the mean temperature in the topsoil, leading to an insignificant decrease in soil organic carbon content in the long term. On the other hand, the quantity and quality of soil organic matter can be slightly increased in case of a regular and long-term fertilization with farmyard manure. Also abandonment gradually leads to an insignificant increase in the soil organic carbon content.

Soils of agricultural grassland contain in the top 10 cm about 6.000 to 11.000 kg total nitrogen per hectare. Assuming a mineralization rate of 1 or 2 %, 60 to 220 kg nitrogen per hectare will be delivered annually from the total nitrogen stock. The ratio of organic carbon to total nitrogen (C:N ratio) is a measure of humus quality, with high values indicating poor quality. In the A horizon of agriculturally used grassland soils, the C:N ratio varies from 9 to 12:1. In the topsoil of extensively used grassland soils, this ratio is usually wider than 12:1.

In coarse-textured grassland soils, the water holding capacity is determined mainly by soil organic matter. Furthermore, the clear relationship between organic carbon content and effective cation exchange capacity in the A horizon indicates that soil organic matter accounts for a major portion of the cation exchange capacity of grassland soils low in clay (Figure 2). However, the cation exchange capacity of humus-rich grassland soils is markedly pH-dependent, even at low pH values. Very acid grassland soils (pH $CaCl_2$: <5.0) have low effective cation exchange capacities compared to less acid soils (pH $CaCl_2$: >5.0). Thus, soil acidification considerably decreases the cation holding capacity of grassland soils low in clay. *A high aggregate stability in the A horizon is typical of grassland soils. This can be attributed to a high amount of organic matter, a high root density and a high activity of soil organisms.*

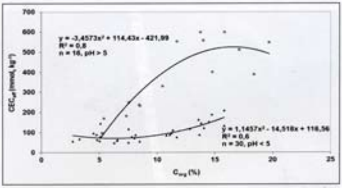

Fig. 2: Relationship between organic carbon content (Corg %) and effective cation exchange capacity.

Soil structure

Soil structure in the topsoil is markedly affected by grassland management. Consequently, soil structure is a suitable indicator for the intensity of grassland management. In the topsoil of extensively used grassland soils, the structure is in general crumbly and quite loose. This favourable soil structure and the looseness result from a high content of organic matter, a high root density and a high activity of soil organisms (particularly earthworms).

A crumb structure indicates no soil compaction caused by grazing livestock or frequent agricultural vehicle traffic. An intensification of grassland management as well as increasingly heavier tractors and machinery lead to soil compaction mainly at the 5 to 10 cm depth, to an alteration of the soil structure and to a change in the soil water regime (Bohner et al. 2006). Usually, soil bulk density increases, whereas total pore volume and saturated hydraulic conductivity decrease. The loose crumb structure will be gradually replaced by a compact platy structure. Especially in regions with a cool and humid climate, soil compaction causes stagnating moisture. Periodical wetness in the topsoil results from an inhibited infiltration of water from rainfall or snowmelt. Plant species such as *Ranunculus repens, Agrostis stolonifera* and *Poa annua* are bioindicators of such compacted grassland soils. During heavy rainfall events, soil compaction enhances surface runoff on slopes, increasing the danger of flooding. Furthermore, soil compaction increases N_2O emissions to the atmosphere (Sitaula et al. 2000), especially from nutrient-rich grassland soils with periodical wetness in the topsoil. Consequently, a severe soil compaction is more detrimental in humid regions. *In soils of permanent grassland, the compaction effects are usually long-lasting, especially in dry regions and in soils with low clay content.*

Soil moisture status

Numerous soil properties and functions depend very strongly upon soil moisture. In permanent grassland, soil moisture status varies from dry to wet. Both dry, semi-dry and wet grassland soils are unsuitable for an intensive utilization. These sites are priority areas for nature conservation. On wet grassland soils, grazing should be avoided primarily due to damages by trampling. According to a sustainable, site-adapted grassland management, only sites with a balanced or moderately moist soil water regime can be used more intensively. Under favourable topographical and climatic conditions, these sites are priority areas for an intensive utilization.

Soil nutrient status and nutrient losses by leaching and surface runoff

In permanent grassland, the lactate-soluble phosphorus content in the topsoil is a good indicator for the intensity of grassland management. Higher levels indicate a long-term high fertilizer application and an intensive grassland utilization at present and/or in the past (Bohner 2005). On the other hand, grassland soils formed from consolidated rocks or unconsolidated sediments, which contain predominantly clay minerals, micas and/or feldspars (e.g. mica schist, gneiss, granite, claystone), are frequently inherently rich in potassium. In addition, a high potassium content in the topsoil can also be the result of a long-term high farmyard manure application, especially with cattle slurry. *Under comparable conditions, intensively used pasture soils generally have higher potassium contents in the surface layer than soils of permanent meadows due to a largely closed potassium cycle.*

In general, from soils of permanent grassland the annual nutrient leaching losses are rather low, if the grassland is used in a sustainable, site-adapted way (Bohner et al. 2007). Under this condition, the risk of soil erosion is, compared with arable soils, very low, primarily because of a constant dense and closed sward. *Thus, soils of permanent grassland contribute considerably to the protection of groundwater and surface waters.* However, a compacted topsoil on slopes favours nutrient losses by surface runoff, especially in regions with high amounts of annual precipitation and/or numerous heavy rainfall events (Prasuhn & Lazzarotto 2005). ■

References

- Bohner A. (2005): Soil chemical properties as indicators of plant species richness in grassland communities. Grassland Science in Europe 10: 48-51.
- Bohner A., Öhlinger R. und Tomanova O. (2006): Auswirkungen der Grünlandbewirtschaftung und Flächenstilllegung auf Vegetation, Boden, mikrobielle Biomasse und Futterqualität. Die Bodenkultur 57: 33-45.
- Bohner A., Eder G. und Schink M. (2007): Nährstoffkreislauf und Stoffflüsse in einem Grünland-Ökosystem. 12. Gumpensteiner Lysimetertagung: 91-99.
- Gerzabek M.H., Strebl F., Tulipan M. and Schwarz S. (2005): Quantification of organic carbon pools for Austria's agricultural soils using a soil information system. Can. J. Soil Sci. 85: 491-498.
- Gisi U. (1990): Bodenökologie. Thieme Verlag. 304 S.
- Klapp E. (1971): Wiesen und Weiden. 4. Auflage. Parey Verlag. 620 S.
- Prasuhn V. und Lazzarotto P. (2005): Abschwemmung von Phosphor aus Grasland im Einzugsgebiet des Sempachersees. Schriftenreihe der FAL Reckenholz 57: 95-107.
- Sitaula B.K., Hansen S., Sitaula J.I.B. and Bakken L.R. (2000): Effects of soil compaction on N_2O emission in agricultural soil. Chemosphere - Global Change Science 2: 367-371.

Contact

Dr. Andreas Bohner – andreas.bohner@raumberg-gumpenstein.at
Agricultural Research and Education Centre Raumberg-Gumpenstein, Raumberg 38, A-8952 Irdning, Austria