Simple Field Methods for Measurement and Evaluation of Grassland Quality

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Abstract Grasslands and rangelands are very important ecosystems influencing natural cycles and human existence and well-being. Their functional status can be greatly affected by soil and water management. Grasslands are prone to degradation, but comprehensive frameworks and objective criteria for their monitoring are largely absent. Simple field methods of measurement and visual rating may help to detect properties and processes limiting the function of grasslands, and the results used to develop criteria and thresholds of soil and vegetation quality. Methods characterising aspects of the physical, chemical and biological status of grasslands in conjunction with soil survey data are presented here. Soil strength measured with penetrometers, sink cones and shear testers may characterise spatio-temporal alterations of soil resistance conditions best. Important attributes of the soil water status can be measured by TDR probes, field tensiometers and simplified infiltration equipment. Experience and care are necessary when interpreting field

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measurement data. A number of expert-based approaches for estimating site properties by visual-tactile methods and by bio-indicative vegetation analyses are available and should be utilized more. Some of these methods can be applied solely to study particular aspects of grassland quality like trampling effects under different animals, machinery and grazing systems or trafficability of meadows and measure the compaction status of soil, the quality of soil structure and pasture quality. In many cases a set of methods in combination with an overall assessment of soil quality (Visual Soil Assessment, VSA, and Muencheberg Soil Quality Rating, M-SQR) will provide a reliable assessment of the status of grasslands and rangelands. Methods presented here should be considered and proposed to be used as possible standard components of frameworks for assessing the functional status of grasslands by uniform methodologies over Eurasia.

Keywords Grassland ecosystems · Soil structure · Soil quality · Vegetation · Indicators · Muencheberg Soil Quality Rating

1 Introduction

Grasslands produce forage for livestock. Additionally, grasslands and rangelands provide numerous ecosystem services beneficial for humans. They play a major role for the maintenance of global biodiversity, carbon sequestration, water cycling and other functions. Improperly managed, they can be a source of significant greenhouse gas emissions (Ball et al. 2012). Pasture farming is efficient at capturing solar energy and is likely to become more important in future as fertiliser becomes more expensive and scarce e.g. Salatin (2010). Central Asia is a grassland region that differs from grasslands in temperate zones by climate, soils, vegetation and management. They are more prone to degradation and currently are already largely degraded (Saparov 2013). Overgrazing and intensive trampling are common reasons for grassland damage by erosion (Zhou et al. 2010) or initiation of degradation. Recovery of soil structure and site-specific vegetation are then difficult or impossible. Grassland monitoring is an urgent need.

Soils under grassland can be greatly affected by soil and water management. Whilst the conditions of grasslands differ between Europe and Asia, measurement and assessment methods could be based on similar, uniform frameworks and principles of measurement and assessment. Simple field methods may help to detect properties and processes limiting grassland use and functions. Assessment of overall soil quality for grassland can be done by common soil survey methods, visual methods of soil evaluation and information about climate (Shepherd 2009; Mueller et al. 2013). The framework of the Muencheberg Soil Quality Rating (M-SQR) offers some options to include more detailed information about physical, chemical and biological soil properties into rating tables and procedures. Simple but reliable field methods may provide this. This chapter gives information about simple field methods that have been successfully developed and/or applied in studies on grasslands of the temperate zone.

We have developed and tested methods characterising aspects of the physical, chemical and biological status of grasslands in conjunction with soil survey data. Some of these methods can be applied solely to study particular aspects of grassland quality like trampling effects under different animals and grazing systems or trafficability of meadows, thereby providing information on the compaction status of soil, the quality of soil structure and vegetation. In many cases a set of methods in combination with an overall assessment of soil quality will be useful for a reliable assessment of the status of soil in spatio-temporal studies.

Our hypothesis is that the majority of our methods has potential for applications in studies on grasslands in Central Asia and worldwide. Those studies could be useful for a better understanding and monitoring of degradation processes and managing soils under grasslands including rangelands more sustainably.

2 Measurement Methods Characterising the Soil Physical Status

2.1 Soil Strength

Any use and management of soil requires a minimum strength of ground and sward. Soil strength is a property of a soil to withstand external forces. It can be easily measured in the field by penetrometers, sink cones, shear testers or other devices. Figure 1 shows examples of devices used on grasslands of North–East Germany.

Fig. 1 Devices for measuring soil strength. **a** Penetrometer. **b** Sink cone. **c** Vane shear tester

Their measurement values provide fast and reliable information about relative soil strengths across and down soil profiles and soil surfaces. Typical reasons for measuring soil strength are to assess soil compaction by machinery, livestock or natural processes. Theory and principles of soil strength measurements including the application of penetrometers and shear testers are contained in textbooks in soil mechanics like (Schultze and Muhs 1967; Kezdi 1969; Terzaghi et al. 1996). Penetrometers are very common for measuring soil strength properties (Hartge and Bachmann 2004) at depths of about 0.1–1 m. It needs to be borne in mind that the size and shape of the penetrometer cone or cone cylinder affects absolute measured values inconstantly over a range of soils (Mittelstedt and Mueller 1989). Thus, information about cone properties has to be given for all measurements, and standardised devices should be applied.

In our studies on relatively wet soils we measured penetration resistance by hand held penetrometers having a 12–16 mm diameter tip. On drier soils a 10 mm tip or smaller is better. An important factor in penetrometer use is to avoid friction at the penetrometer shaft by employing a tip diameter 3-8 mm greater than the shaft diameter. Vertically operating penetrometers are commonly used (Fig. 2).

The application of penetrometers for characterising soil surface strength is sub-optimal. Measuring the sinking depth of a cone of defined weight and dimensions and calculating the cone resistance is more relevant to soil surface processes like stability against hooves of animals, sinking of tires or stability of crusts. We successfully used a large 30° sink cone combined with a penetrometer for characterising aspects of soil trafficability (Mueller et al. 1990, 2004). On grasslands, this is a good indicator of soil stability against livestock trampling. The combination of the cone with a penetrometer-like device is useful for the application of a defined load to the soil.

Vane shear tests are another option to characterise soil strength. Kraschinski et al. (2001) used them for testing the stability of very soft grassland soils. They detected the significant effects of plant root systems for increasing the resistance of

Fig. 2 Vertical penetrometer for testing soil strength on a red-deer pasture in the research station Paulinenaue, Germany

Table 1 Field measurement methods of soil strength

Method	Principle	Preferred unit	Reference*
Penetrometer resistance	Pushing a relatively small cone or cone cylinder through the soil	MPa	Mittelstedt and Mueller (1989)
Cone resistance (sink or drop cone)	Pressing a large cone on the soil surface, measuring the sinking depth	MPa	Mueller et al. (1990)
Vane shear test	Shearing a defined soil volume by turning a shear vane, reading maximum value of torque at soil disruption	MPa	Mueller et al. (2007c)

* Reference refers to tests by authors, not to the first description in literature

peatlands to agricultural traffic. We applied the Eijkelkamp light vane shear tester (Fig. 1) of vane size 16 mm diameter × 42 mm length on cropland and grassland. Vane shear testers are preferably applied on soils of low strength like in peatlands, on wet soils or on tilled soils. Under drier or stony conditions problems with damage to the shear vane may occur.

Soil strength is closely correlated with both density and moisture status of soil. Neglecting the latter aspect may lead to wrong conclusions on limiting factors. On sandy soils at field capacity, soil strength data provides good information about aspects of soil structure. On soils rich in clay, penetrometer resistance and other soil strength parameters do not provide information about soil structure (Mueller et al. 2013). The grassland sward consists of plants and soils. Their strength is largely influenced by the mechanical stability of living plants. This is a reason for the application of methods of Table 1, cone resistance and vane shear tests in particular. Ball and O'Sullivan (1982) compared cone resistance and vane shear strength with bulk density and produced limiting values for restricting plant emergence.

Though all measurements of Table 1 result in metric values of a pressure unit like MPa, the values may be very different due to the differing specific procedures. Data values obtained by all three methods are normally distributed over a number of measurements, and the number of replications at a single point can thus be relatively low. About 4–8 replications may provide reliable averages if classical statistical methods are being used.

2.2 Soil Moisture and Density Status

Water content or moisture content is the quantity of water in a soil, expressed as a ratio or percentage relative to dry soil. It can be given on a mass (gravimetric) or volumetric basis. For many practical purposes in soil hydrology, e.g. water flow through soils, the volumetric basis is of interest. For other purposes, for example, engineering behaviour of soil, the mass basis is more common.

Dry bulk density is another important soil physical parameter, related to the density or compaction status of soil. The simple formula

$$w_{vol} = w_{grav} * DBD, \tag{1}$$

combines all three parameters. Where w_{vol} is the volumetric water content in $m^3/100\ m^3$, DBD is the dry bulk density in t/m^3 and w_{grav} is the gravimetric water content in t/100 t.

Knowing the water retention curve of a soil, measured water contents can be related to the energy status of soil (e.g. the soil water content at given pressure heads or suctions), to the pore size distribution and plant ecological states of soil like water excess by lack of air (anaerobism) or drought stress by lack of soil water (Kutilek and Nielsen 1994; Schindler et al. 2010).

Volumetric water content can be measured simply by methods of time-domain reflectrometry (TDR). Hand-held field probes developed by the Institute of Agrophysics in Lublin, Poland, are examples of reliable instruments Easy Test (2012, Fig. 3).

A complication in spatio-temporal field studies is the non-availability of fast field methods for measuring DBD and gravimetric water content. This would require oven-drying of samples in a laboratory. To overcome this problem, a hand-held TDR-probe and measuring the wet bulk density (WBD) by a standard cylinder of calibrated volume and known mass, and an electronic balance can be applied. WBD is the net mass of a wet volumetric sample (wf) in gram divided by the soil volume (V) of this cylinder in cm^3.

$$WBD = wf/V \tag{2}$$

The calculation of the dry bulk density can be done by the formula

$$DBD = WBD - w_{vol}/100 \tag{3}$$

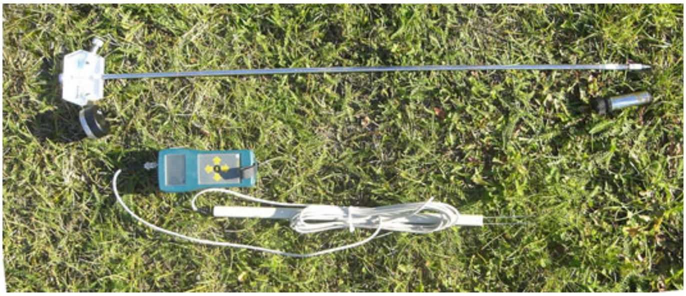


Fig. 3 Field tensiometer (Tensio 100 of UGT Muencheberg) and field TDR probe (Easy—Test, IPAN Lublin) may provide information rapidly on the soil water status

DBD is the dry bulk density in g/cm^3 (equals t/m^3), WBD is the wet bulk density (g/cm^3) and w_{vol} is the volumetric water content (g/100 g) measured by the TDR probe.

The gravimetric water content can then be calculated by using (1). This method has some potential for errors, thus well- calibrated TDR-probes and sampling cylinders no smaller than 250 cm^3 at four replications are required. An advantage of this procedure is the estimation of DBD and gravimetric moisture content in the field without laboratory equipment.

Hand-held field tensiometers may provide measurements of the energy status of the soil water, at least in a relatively moist range of about −0.01−−700 hPa suction. Measured values of suction may be related to field capacity of soils. Field capacity of soils ranges between about −60 hPa in sandy soils to −300 hPa in clayey soils. Measured values greater than −60 hPa or even positive values indicate wetness, and values outside the measurement range (less than −700 hPa) indicate drought tendencies. However, exact thresholds depend on the water retention curve and the soil depth under consideration. Modern tensiometers may provide a broader range of measurements of suction towards drier conditions (Schindler et al. 2010), but currently these high-tech devices are not yet applicable as portable field devices. Application of tensiometers in groundwater influenced soils provides information about hydrological states and processes (Fig. 4). It is particular important to know that such sites have very limited gravitational drainage. At a water table of 60 cm as shown in Fig. 4, there is no air in the subsoil of clay soils, and hydraulic gradients for seepage and salt leaching are also too low.

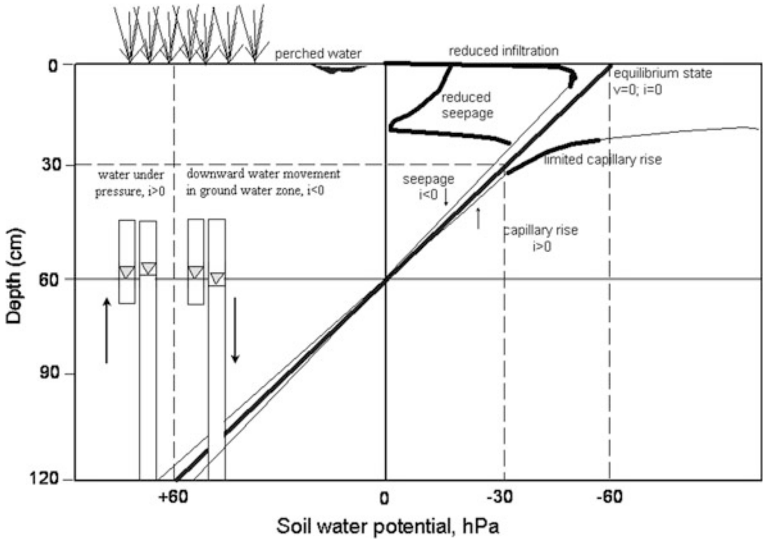


Fig. 4 Soil water potentials as indicators of hydrological processes in soils with a shallow water table (Schindler et al. 2003)

2.3 Water Infiltration

Water infiltration is an extensively studied property of soil. There is much literature about steady-state infiltration capacity of soils e.g. Jarvis et al. 2008; Moret-Fernández and González-Cebollada 2009. Sophisticated devices like the Guelph infiltrometer or disc infiltrometers provide site-specific values for soil characterisation and modelling of hydrological processes.

For more practical purposes of grassland and cropland evaluation, it is important to know the infiltration properties at different locations both between and within fields at approximately the same time, for example, after a heavy rain or snowmelt. For those spatio-temporal studies, the application of steady-state infiltration methods or the determination of a final, constant infiltration rate are not possible and do not adequately reflect natural processes. The use of rainfall simulators (Dimanche and Hoogmoed 2002; Kato et al. 2009) comes closest to real processes of infiltration during a rain but is relatively expensive in use.

We applied two simpler and faster methods for getting information on the initial infiltration rate by ponding infiltration at different field points on the same day. The initial infiltration rate was measured with simple infiltrometers. Standard thin core cylinders (common DBD-cylinders of 250 or 100 cm^3) were pushed 30–45 mm vertically into the soil (Fig. 5). The rings were then filled with 30 mm water. Differences in water levels and elapsed time were measured with a ruler and a stopwatch. As infiltration measurement values are not normally-distributed, more than six replications are necessary when comparing means with statistical methods.

Another simple ponded infiltration method can be applied to evaluate the infiltration of water beneath the soil surface (Fig. 6). This is useful in combination with an assessment of vertical biogenic pores. No infiltration rings are required. The procedure is applicable in cohesive soils. Lower parts of the sidewalls of the soil pit are sealed by soil of soft consistency to prevent lateral water flow off. The size of these pits should be about 0.1–0.2 m^2. We found clear relationships between infiltration rates, water table depth and area of biogenic macropores.

Fig. 5 Water infiltration on cattle trampling pathways as compared with adjacent parts of the paddock

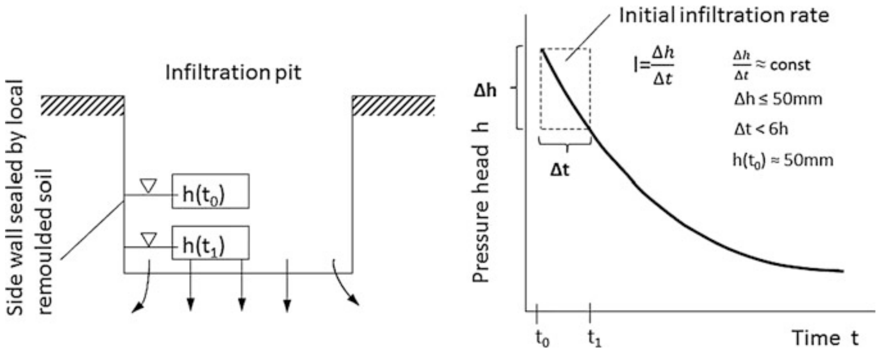


Fig. 6 Soil pit-infiltration for measuring the subsoil infiltration capacity of cohesive soils (Mueller 1988)

Table 2 Field measurement of water infiltration

Method	Principle	Unit	Reference
Initial infiltration rate at soil surface	Ponded infiltration of about 30 mm through the soil surface, sidewalls single rings (common DBD cylinders)	m/d	Mueller et al. (2009)
Infiltration rate of subsoil ("Soil pit infiltration")	Ponded infiltration of about 30-50 mm water through a soil layer beneath the surface, sidewall of sealed soil	m/d	Mueller (1988)

2.4 Detecting Soil Layering and Sampling of Soils

Root limiting layers within the upper 1.5 m of croplands and 0.8 m of grasslands may affect soil functions and crop yield potentials adversely. Those layers may be detected and evaluated by digging, augering or penetration resistance of thin steel probes. Layers within the topsoil (0–30 cm) can be detected using the Visual Evaluation of Soil Structure (Ball et al. 2007). All these methods are useful for ground-truthing of non-destructive indirect measurements for exploring the structure of soil landscapes. Rill probes of the Pürckhauer type are very common. Amongst field augers, the Edelman auger 7 cm (Fig. 7) (product of Eijkelkamp company) may be used as a standard device for detecting soil layering or a shallow water table and for any kind of soil survey. A shallow water table is a very common barrier to rooting due to anoxic conditions for valuable grassland plants. We also used the Edelman auger for soil sampling and analysing of nitrogen in soil profiles down to 5 m depth (Eulenstein et al. 2003). The third method for detecting inhomogeneities in soils, steel probe penetration, is very effective in some lowland grasslands. This method can be applied in spatio-temporal studies of grasslands on

Fig. 7 The Edelman field auger is best suited for detecting root limiting layers and for most kinds of soil survey and sampling on all soils. It can also be suitable for the installation of temporary groundwater installation tubes in lowland soils

peat soils and river lowland soils underlain by sand or gravel (Mueller et al. 2007b). Using well-constructed, thin steel probes, a physically fit person is able to detect the mineral base of peatlands down to 16 m and the thickness of lowland Holocene clay layers down to 7 m. In combination with a leveling device, those measurements permit rapid reconstruction of pre-holocene landscape structures in the field scale.

For sampling peat soils and sediments in semi-aquatic areas, the Dutch sampler, the Wardenaar sampler (Fig. 8), the Vrijwit auger and others are practicable, but every different devices suit different specific conditions. They allow taking of semi-disturbed samples. Cylinder core samples for DBD can be taken from big soil samples of the Wardenaar sampler.

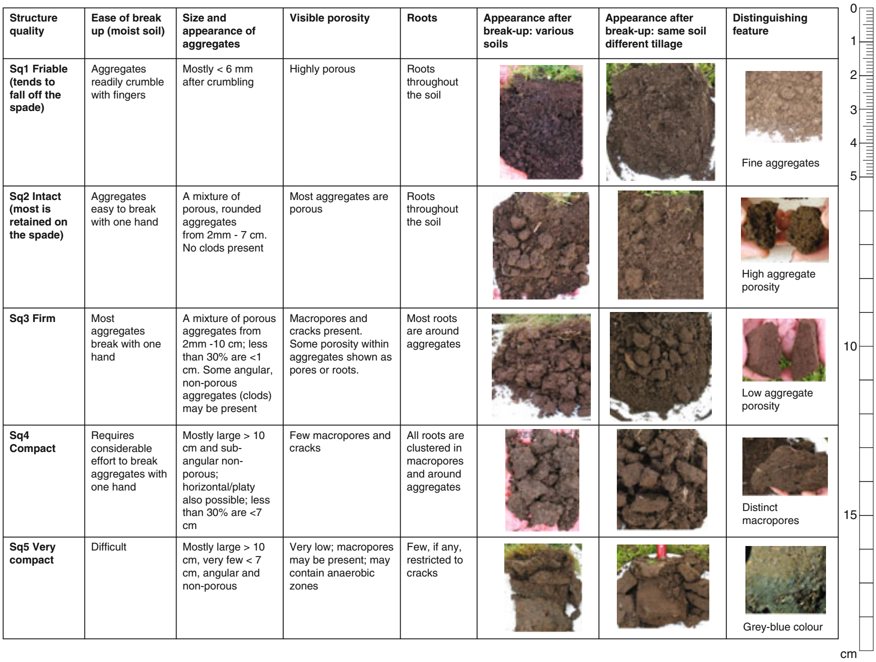
Fig. 8 Dutch sampler and Wardenaar sampler in use on peatlands and under semi-aquatic conditions. Both samplers are commercial products of the Eijkelkamp company, Giesbeek, The Netherlands

3 Visual Soil Structure Assessment Methods

Visual soil structure assessment methods may deliver much information on soil properties in the field relevant to plant growth with a minimum of equipment. Procedures provide information on the feature and function of soils from evaluation of macro-morphological characteristics of the soil structure. The procedure includes generally (1) primary recognition and description of soil structure features (2) classification, evaluation and parameterisation of visual soil structure, and sometimes (3) conclusions on the functional status of soil (Mueller 2011). Type and size of aggregates and number and size of biogenic pores are reliable criteria of assessment. Soil structural features meet the farmer's perception on soil quality (Shepherd 2000) and are correlated with measured data of physical soil quality and crop yield (Mueller et al. 2009). Over the past decades, several methods have been evolved. Most of them differ in several important ways including depth of the soil under consideration, handling the soil prior to assessment, emphasis placed on particular features of soil structure, and application of size, increments and direction of scoring scales. One of the most accepted methods is that of Peerlkamp, cited in Ball et al. (2007). It has a conjoint scale referring to type and size of aggregates and pores. The main advantages of this method are speed and minor soil disturbance, providing comparative statistical analyses both in large fields and also in small plots of long-term trials. However, the scoring scheme has potential for subjective errors. Illustrated methods like the updated Peerlkamp method, called VESS (Ball et al. 2007, Table 3, Fig. 9) and the Visual Soil Assessment (Shepherd 2009, Figs. 10 and 11) leading to ordinally scaled scores are particularly well and reliable in handling. Unfavourable visual structure scores were associated with increased dry bulk density, higher soil strength and lower infiltration rate but correlations were site-specific (Mueller et al. 2009). Visual soil structure assessment is a feasible tool for structure monitoring and management recommendations. Overall soil quality rating schemes like the Muencheberg Soil Quality Rating (Mueller et al. 2007d) include visual soil structure indicators. Techniques such as VESS also allows for the identification and assessment of limiting layers in the topsoil and may guide depth of sampling for core measurements of soil physical properties (Ball et al. 2007).

Table 3 Practicable methods of visual soil structure assessment

Method	Principle	Reference
Visual Soil Assessment (VSA)	Digging a small soil pit, taking a cube of soil and dropping it and assessing aggregates, pores, colour and smell of soil, worms and other parameters by using a manual, calculation, classification and evaluation of a soil score and a plant score	Shepherd (2000), (2009)
Visual examination of soil structure (VESS)	Digging a small pit, taking a spadeful soil, assessing shape of aggregates, pores and rooting by an illustrated conjoint scale	Ball et al. (2007)



Structure quality	Ease of break up (moist soil)	Size and appearance of aggregates	Visible porosity	Roots	Appearance after break-up: various soils	Appearance after break-up: same soil different tillage	Distinguishing feature
Sq1 Friable (tends to fall off the spade)	Aggregates readily crumble with fingers	Mostly < 6 mm after crumbling	Highly porous	Roots throughout the soil			Fine aggregates
Sq2 Intact (most is retained on the spade)	Aggregates easy to break with one hand	A mixture of porous, rounded aggregates from 2mm - 7 cm. No clods present	Most aggregates are porous	Roots throughout the soil			High aggregate porosity
Sq3 Firm	Most aggregates break with one hand	A mixture of porous aggregates from 2mm -10 cm; less than 30% are <1 cm. Some angular, non-porous aggregates (clods) may be present	Macropores and cracks present. Some porosity within aggregates shown as pores or roots.	Most roots are around aggregates			Low aggregate porosity
Sq4 Compact	Requires considerable effort to break aggregates with one hand	Mostly large > 10 cm and sub-angular non-porous; horizontal/platy also possible; less than 30% are <7 cm	Few macropores and cracks	All roots are clustered in macropores and around aggregates			Distinct macropores
Sq5 Very compact	Difficult	Mostly large > 10 cm, very few < 7 cm, angular and non-porous	Very low; macropores may be present; may contain anaerobic zones	Few, if any, restricted to cracks			Grey-blue colour

Fig. 9 Assessment scale of visual soil structure by the VESS procedure (Ball et al. 2007). Photo: Bruce C. Ball

Fig. 10 Visual scoring of soil porosity under pasture (Shepherd 2009, p. 18)

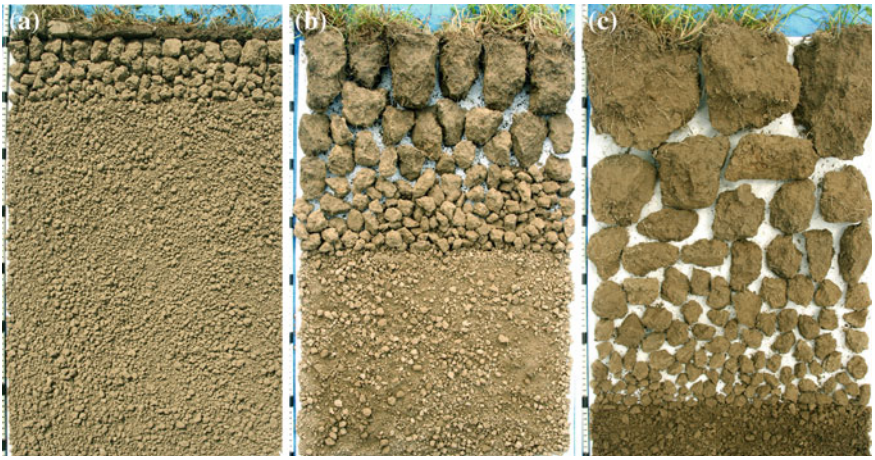


Fig. 11 Soil structure scores of VSA (Shepherd 2009). Aggregates were sorted after a drop-shatter test. **a** Good conditions, score = 2. **b** Moderate conditions, score = 1. **c** Poor conditions, score = 0. Photos: T. Graham Shepherd 2009

4 Methods Characterising Chemical Properties of Soil and Water

Lime content of soil, soil reaction (pH) and electrical conductivity are crucial properties of agricultural sites. Their estimation is part of routine soil survey and is essential for any taxonomic and functional classification of soils. Simple field test methods exist and should be part of monitoring programs to assess the status of grassland soils. Lime content can be estimated by dropping 0.1 n hydrochloric acid on a sample. The degree of effervescence is a measure of lime content and can be assessed by a scale (Boden 2005).

Electrical conductivity and pH should be measured both in soils and adjoining ground and surface waters. This is relevant to many grasslands because they are often adjacent to ponds, rivers or other water bodies or are completely located in lowlands and wetlands. Grassland is the most common land use of wetlands in Eurasia. Their possible use and land quality depends largely on their inundation or groundwater regime. Water table and salinity monitoring are important preconditions for land use optimisation and for soil and water management (Fig. 12).

For measurements of shallow water table height and water quality, a borehole is drilled down to the water table. Conductivity and pH are important parameters of salinity and sodicity classifications of soil and water (Withers et al. 1978; Mueller et al. 2007d).

Besides the ground water level, crucial properties of the soil and ground-water like pH and electric conductivity can be measured within auger holes at each sampling point by simple test kits and instruments. Those test kits are currently

Fig. 12 Soil structure deterioration and salinisation due to stock trampling. Small ponds or wetlands are prone to salinisation even in sub-humid climates. High stocking densities and livestock trampling contribute to structure deterioration and salinisation. Puddling effects decrease soil structure. Urine of cattle contributes to increasing salt concentrations. Both effects lead to adverse living conditions for earthworms and deep rooting plants, which restrict the creation of biological topsoil draining biogene macropores

accepted as reliable and effective screening tools for point-scale assessment of soil quality by providing accurate and precise data over a range of soil conditions (Liebig et al. 1996; USDA/NRCS 2001).

We used a combined pocket meter MultiLine P3 pH/LF-SET in most of our spatio-temporal grassland studies, though separate instruments for pH and conductivity can also be used (Fig. 13). pH can be measured directly by dunking the tip of the measurement electrode into the water. If the soil is too dry, a saturation extract can be created by putting the soil into a small vessel, adding de-ionised water and mixing a saturation extract. For getting reliable readings, it is important to calibrate the probes before daily use. In general, even in the driest region of Germany in the vicinity of Berlin, electric conductivity of soil and water was lower than 1 ms/cm. In some peatlands or organic clays, the common threshold of salinity (2 ms/cm) is already being exceeded locally (Mueller et al. 2007a). Measured values of topsoil electrical conductivity and pH should be assessed by evaluation of scales of salinity, sodicity or acidification. Values given in Tables 4 and 5 are crop-yield relevant and indicate reduced overall grassland soil quality which can be confirmed by performing the Muencheberg Soil Quality Rating.

The procedure for performing of the Muencheberg Soil Quality Rating will be explained in another chapter of this book.

Fig. 13 Measuring water salinity and pH by pocket devices

Table 4 Classification of measured electrical conductivity of topsoil and consequences for the Muencheberg Soil Quality Rating (Mueller et al. 2007d, mod.)

Electrical conductivity EC (mS/cm)[a]	Degree of salinisation	Score	Multiplier grassland[b]
<2	None	2	3
2–4	Low	1.5	2.6–s3
4–8	Moderate	1	2–2.6
8–16	Strong	0.5	1.5–2
>16	Very strong	0	<1.5

[a] Saturation extract of topsoil (mS/cm = mmho/cm = dS/m). If EC is measured in 1:5 solution, conversion is necessary according to Guidelines 2006

[b] Multiplier for the basic score. The final SQR score (0–100) = Basic score* active multiplier. The Basic score ranks about between 10 and 34 (Mueller et al. 2007d)

Table 5 Classification of measured pH of topsoil and consequences for the Muencheberg Soil Quality Rating (Mueller et al. 2007d, mod.)

pH	Degree of acidification or sodification	Score	Multiplier grassland
<3.3	Extreme acidification	**0**	<2.5
3.3–4	High to very high acidification	**0.5**	2.5–2.7
4–4.5	Moderate to high acidification	**1**	2.7–3
4.5–5.2	Low to moderate acidification	**1.5**	3
5.2–8.2	No acidification, no sodification	**2**	3
8.2–8.4	Low to moderate sodification	**1.5**	2.7–2.9
8.4–8.6	Moderate to high sodification	**1**	2.5–2.7
8.6–8.8	High to very high sodification	**0.5**	2–2.5
>8.8	Extreme sodification	**0**	<2

5 Assessing the Ecological Status of Sites by Vegetation

Ellenberg et al. (1991) developed a helpful system of grassland site bio-indication by vegetation. First, the plant species composition is recorded on sample plots, for example by application of a common scale (Kaiser et al. 2005). Then, ecological ranking numbers for moisture, soil reaction, nitrogen content, temperature, continentality and salt content are allocated and means can be computed for mapping units or plots. Ellenberg's ecological rank numbers are currently available for most vascular plant species of Central Europe and have already been tested in drier climates (Böhling 2004). Sometimes a local modification is necessary, but in general, the usefulness and accuracy of this system has been proven and confirmed by many authors, e.g. Schaffers and Sýkora (2000) and Pykälä (2005). Numbers are well correlated with soil properties, for example, the moisture number with watertable depth or the nitrogen number with soil nitrogen contents. Indicator values can be handled as quasi-metric data in many cases. Moisture numbers (Table 6) are particularly well studied and are reliable bio-indicators that can be also transformed to other scales of soil moisture conditions (Kaiser and Käding 2005). We used the Ellenberg system of site bio-indication in grassland studies in river lowlands, on peatlands and on sandy grasslands in Germany (Mueller et al. 2003; Kaiser et al. 2005). This system has started to be extended to other regions of Eurasia and worldwide. It should be borne in mind that all airborne methods of exploring grassland quality are very sensitive to vegetation pattern. Also, results of terrestrial soil survey and soil physical, chemical and biological measurements are closely related to vegetation. Thus, vegetation composition and its ecological value should be always assessed in all studies dealing with grassland quality. Examples are given in Figs. 14 and 15. It would be useful to test the applicability of Ellenberg's bio-indicator system over Eurasia and to consider typical species of other climate zones.

Sites of Fig. 14 are semi-natural grasslands in Northeast Germany in a sub-humid climate. Prime land use functions are nature protection/biodiversity (a,b,d) and flood protection (c). Agriculture is necessary to maintain ecosystems, but is a secondary land use function and underlies restrictions. Management intensity is low. Figure 14(a) shows steppe vegetation with *Adonis vernalis, Potentilla argentea* and *Stipa capillata* on sandy soils and southern exposure. It has a medium Ellenberg moisture number (mF) of 2.5 (dry). Biomass is 1–2 t DM/ha, and effective grassland yield without unpalatable species (EGY) is 0.5–1 t/ha. The land is used as zero-input sheep pasture for landscape maintenance. Figure 14(b) shows meadow steppe vegetation of high floral diversity with *Dactylis* spec., *Campanula* spec., *Hieracium* spec., *Plantago media, Onobrychis* spec. The Ellenberg moisture number mF is 4 (dry to moist), the biomass is 2–3 t DM/ha, and EGY is 1.8–2.5 t/ha. Land use is also zero-input sheep pasture for landscape maintenance. Figure 14(c) shows a river lowland with *Alopecurus pratensis*, *Phalaris arundenacea, Calamagrostis epigejos*

Table 6 Ellenberg's scale of moisture numbers and some examples of grassland species (Ellenberg et al. 1991, mod.)

F number	Description	Examples of species[a]
1	"Starktrockniszeiger". Indicator of extreme dryness, restricted to soils which often dry out for a certain time	
2	Intermediate between 1 and 3	*Sedum acre* *Artemisia campestris*
3	"Trockniszeiger". Dry-site indicator, more often found on dry ground than on moist places, never on damp soil	*Agropyron intermedium* *Chondrilla juncea* *Centaurea scabiosa*
4	Intermediate between 3 and 5	*Convolvulus arvensis* *Hypericum perforatum* *Medicago sativa*
5	"Frischezeiger". Moist-site indicator, mainly on fresh soils of average dampness, absent from both wet and dry ground	*Dactylis glomerata* *Plantago major* *Taraxacum officinale*
6	Intermediate between 5 and 7	*Alopecurus pratensis* *Artemisia vulgaris* *Holcus lanatus*
7	"Feuchtezeiger". Dampness indicator, mainly on constantly moist or damp, but not on wet soils	*Calamagrostis epigejos* *Cirsium oleraceum*
8	Intermediate between 7 and 9	*Polygonum lapathifolium*
9	"Nässezeiger" Wet-site indicator, often on water-saturated, badly aerated soils	*Caltha palustris* *Cicuta virosa*
10	"Wechselwasserzeiger". Indicator of sites occasionally flooded, but free from flooding for long periods	*Carex elata* *Phragmites australis* *Typha latifolia*
11	"Wasserpflanze". Plants rooting under water, but at least for a time exposed above, or plants floating on the surface	*Polygonum amphibium* *Schoenoplectus lacustris*
12	"Unterwasserpflanze". Submerged plant, permanently or almost constantly under water	

Additional symbols are:
~ "Zeiger für starken Wechsel". Indicator of a very fluctuating water regime
= "Überschwemmungszeiger". Indicator of flooding and inundation
[a] Species are part of the grassland flora of Northeast Germany and Central Asia

and invasive *Bromus hordeaceus*. Ellenberg's moisture number mF is 6.5 (damp). Biomass is 2–5 t DM/ha and EGY 1.8–4 t/ha. Haymaking and cattle grazing are common. Figure 14(d) is a peat lowland with *Carex* spec., *Polygonum bistorta*, *Caltha palustris* and *Dactylorhiza maculata*. The mF is 8.5 (wet), biomass is 6.5 t DM/ha, and EGY 1.5 t/ha. It is non grazed land used for occasional haymaking.

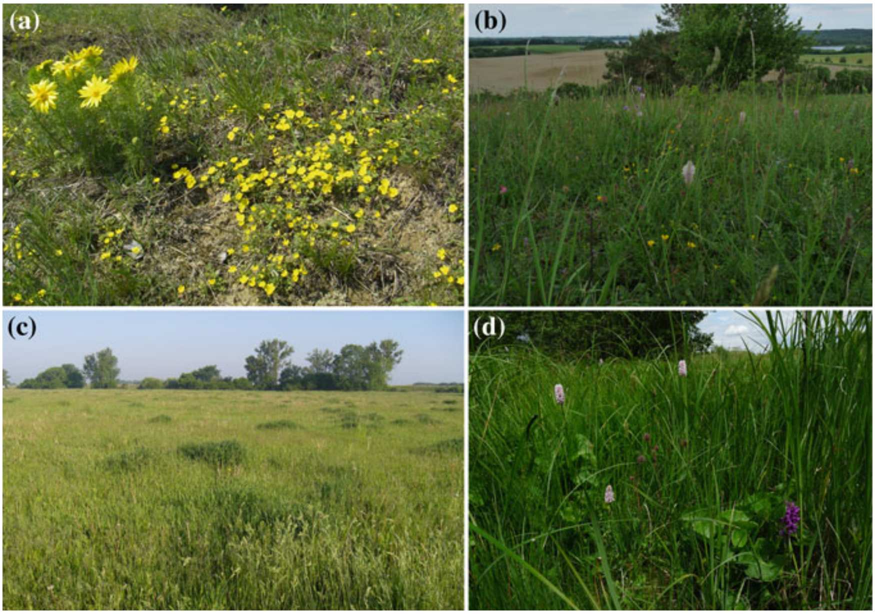


Fig. 14 Examples of grasslands, subject to functional assessment including bio-indication

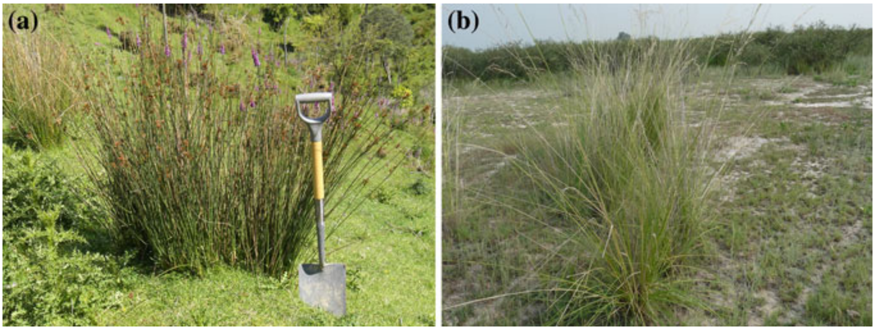


Fig. 15 Examples of potential bio-indicator plants. **a** Rushes (*Juncus spec.*) are indicators of a poor aerated soil due to compaction and/or wetness. **b** *Achnatherum splendens* is typical for some saline soils in lowlands and depressions of Asia

6 Assessing the Quantity and Quality of Vegetation

Above-ground biomass of pastures is a very good indicator of soil conditions. It can be estimated by several methods. Test cuts of random 1 m^2 samples by throwing a stable quadratic meter frame on the surface are traditional and reliable. Also, non-destructive methods ranging from visual estimation classes to complex electronic instruments are available. Examples are pasture rulers, plate discs, devices based on optical principles, and electronic capacitance meters (Lopez Diaz and Gonzalez-Rodriguez 2003). As the architecture of swards depends on the botanical composition, all these non-destructive methods require good calibration according to local conditions and do not work well on transfer to other environments. Meanwhile, a great number of remote sensing methods have been developed for estimating grass biomass consistently over large regions (Schellberg et al. 2008). These methods need accurate ground-truthing, which should be preferably done by harvesting test plots. We preferred traditional test harvests in all our grassland studies.

Sometimes, for example in wetlands, the biomass can be very high, but animals do not graze it because the plant species are of very low forage quality or even poisonous. The quality of vegetation can be assessed by separating out plant species of cut samples and estimating their proportion or weighing them separately.

Palatability values can be allocated to species. The scale of palatability values created by Klapp et al. (1953) is ten-stage: -1 = poisonous, 0 = no palatability value, 1 = very low palatability value, 2 = low palatability value, 4 = medium palatability value, 6 = high palatability value, 8 = very high palatability value. Briemle converted this scale into a common 9-stage scale, ranging from 1 = poisonous to 9 = very high (Briemle et al. 2003).

Eliminating the proportions of non-palatable species (weeds of values <2) results in an Effective Grass Yield (EGY, Mueller et al. 2008). EGY is better correlated with soil quality scores of VSA or M-SQR than the total biomass.

There is much knowledge available about ecological behaviour and palatability values of Central Asian plants, for example Gintzburger et al. (2003); Inam and Maselli (2012). A comparison of Klapp's palatability values (10-stage scale) with rank numbers of palatability given in the Herders manual edited by Inam and Maselli (2012), which has a 5-stage scale, indicate a correlation at *species* level (Table 7). Also, at *genus* level, correlations exist. However, normalised palatability rank numbers in the Herder's manual are higher indicating a definition and scaling problem of those empirical scales. A possible reason is that the available biomass per animal is higher on pastures in Europe. In well- managed grasslands, the percentage of species have very high palatability is also higher. Cattle can eat more selectively, disregarding species of medium value.

Besides climate and soil properties, the degree of grassland management is very important for determining the botanical composition and yield potentials on grasslands. In some regions of Eurasia, estimating plants and their potential biomass is difficult or practically impossible by ad-hoc methods because of permanent, excessive grazing intensity (Fig. 16). Installation of fenced test plots as practiced by researchers in Inner Mongolia of China, Mongolia (Wesche et al. 2010; Sasaki et al. 2013) and Iran (Mofidi et al. 2013) is an useful method to test the local gene pool and vegetation recovery in overgrazed areas. However, this is expensive and cannot be provided for common grassland monitoring and inventory. Knowledge of overall soil quality (M-SQR, Mueller et al. 2007d) or VSA ratings (Shepherd 2009) in combination with defined degrees and classes of

Table 7 Palatability values of some grassland species in two regions of Eurasia

Species	Palatability values	
	Northeast Germany, Klapp scale, (−1–9)	**Western Pamir**, Scale of Herders' manual, (1–5)
Alopecurus pratensis	7	5
Artemisia vulgaris	1	2
Calamagrostis epigejos	2	3
Convolvulus arvensis	3	3
Dactylis glomerata	7	5
Festuca rubra	5	5
Hypericum perforatum	1	2
Medicago sativa	7	5
Plantago lanceolata	6	4
Plantago major	2	1
Polygonum amphibium	1	4
Polygonum aviculare	1	3
Setaria viridis	3	3
Taraxacum officinale	5	4
Trifolium pratense	7	5

Fig. 16 Overgrazed semi-arid landscape in Asia. In some regions of Eurasia, permanent overgrazing is a common practise. This has altered the vegetation composition and grassland productivity. A complication is that under these conditions a status analysis is difficult. Vegetation analyses cannot be reliably performed nor grassland productivity be measured. In this case, test plots have to be fenced before management could provide estimates of grassland yields. However, worldwide acknowledged assessment scales of grassland management intensity do not exist. In subhumid to humid climates in Europe, where overgrazing is less common, the degree of management can be classified according to the criteria of Bockholt et al. (1996). Classes range from 1 = no use or extremely low intensity of use to 5 = high intensity. In our studies, it was both necessary and sufficient to introduce an additional class for damaged sward under stock and wheel tracks (Mueller et al. 2007c). Developing a common 9-stage scale of management classes for grasslands of Eurasia would by useful.

7 Conclusions

1. We offer a variety of simple field methods for measuring some crucial grassland properties and evaluating the capacity and performance of grasslands for biomass production.
2. Methods presented here have been proven in grassland studies in temperate zones but could be considered for applications to studies of Central Asian grasslands as well.
3. Some focus should be on expert-based visual or bio-indicator methods, which are feasible and reliable.
4. Procedures of Visual Soil Assessment and Muencheberg Soil Quality Rating in conjunction with physical, chemical and pasture quality field methods provide frameworks and parameters for grassland inventories over Eurasia by using uniform methodologies.
5. As there is currently no internationally acknowledged methodology, we suggest that our procedures may be adopted for the assessment of grassland and rangeland functions and the status of soil quality and degradation.

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