Protecting Lowland Soils by Agricultural Practices

L. Mueller, U. Schindler, A. Behrendt, M. Frielinghaus

Centre for Agricultural Landscape and Land Use Research (ZALF), D-15374 Muencheberg, Germany
E-mail: lmueller@zalf.de

Keywords: river lowland, peatland, soil conservation, water management

1 Introduction

Lowland soils cover about 15%-20 % of north-eastern Germany. These sites are fertile but sensitive. Most areas do not have a nature conservancy status, but may have a landscape conservancy status. This means agriculture according to "good agricultural practice" is possible.

Based on a former study of soil indication (Mueller *et al.*, 2002) we will evaluate agricultural practices concerning their impact on soil. Main questions are:

What are the effects of agricultural practices of peatland and river lowland soils on soil status and function?

(1) The productivity function of soil for producing crop biomass

(2) The habitat function of soil

Which agricultural practices are recommendable or acceptable and which are not?

2 Material and methods

Sites:

Soil processes have been analyzed in lowland areas in the vicinity of Berlin, Germany. Alluvial clay soils have been studied in the Oderbruch area and peat soils (Histosols) in the Rhin-Havelluch and in the Uckermark landscapes. The climate is characterized by a mean annual temperature of 8.3℃, a precipitation of 470 mm/year –550 mm/year and a potential evapotranspiration of about 650 mm/year.

Table 1 shows different lowland types according to substrate, geogenesis, water regime, land use and predominant landscape and soil functions.

Table 1 Lowland types in the vicinity of Berlin

Type of lowland	Substrate of soil	Geogenesis	Water regime	Land use
Recent river floodplain (1)	Sandy with small parts of loamy and clayey layers	River banks and dunes, small backwater areas	Dependent on the dynamics of the river	Unfertilized grassland and bushland
Dam-protected floodplain (2)	Loamy and clayey with sandy parts	Large backwater areas, partly river banks	Dependent on the land drainage and sub- irrigation systems, reduced or missing river dynamics	Arable use, settlements, horticulture
Shallow Peatland (3)	Shallow peat (0.3m—0.7m) underlain by Pleistocene sand or mud	Paludification mires and terrestrialisation mires	Dependent on the land drainage drainage and sub-irrigation systems	Fertilized grassland, meadows and pastures
Humic sandy soils (4)	Pleistocene fine and medium sand	Pleistocene outwash, aeolic translocated	Dependent on the land drainage and subirrigation systems	Arable use, partly fertilized grassland, settlements
Deep Peatland (5)	Deep peat (>1.2 m)	Terrestrialisation mires and percolating mires	Dependent on the land drainage systems	Fertilized grassland, meadows and pastures

Aspects and methods of evaluation:
Three aspects of soil function have been considered,

(1) The status of soil structure
(2) The crop yield
(3) The diversity of wild plant species.

The soil hydrological and physical development status had been assessed in terms of drainage status (deep, medium-deep, shallow) which is related to typical soil parameters of water capacity and permeability of clay soils (Heim and Mueller, 1988, Mueller *et al.*, 1994). On peat soils, the topsoil status has been evaluated in terms of anthropogenic changes as earthened ("vererdet") or moorshificated ("vermulmt") (AG Boden, 1994, Schmidt, 2000). Additionally the organic matter and the unit water content (Einheitswasserzahl) according to Ohde/Schmidt (Schmidt, 1989) have been analyzed. The unit water content is a simple and appropriate measure of peat soil water holding capacity. In most agriculturally used peat topsoils, the unit water contents are lower than the threshold value of 1.8, indicating peat soil degradation (Schmidt, 1989).

The crop yield has been considered as a complex indicator of soil productivity function. The plant diversity in terms of species per area has been considered as a measure of the habitat function of soil.

Data basis:

Data come from experimental fields of Research Center for Soil Fertility (FZB) and Centre for Agricultural Landscape and Land Use Research (ZALF), Muencheberg (Heim and Mueller, 1988, Behrendt, 1995, Schindler *et al.*, 1999, Schmidt, 2000). Numerous soil profiles were dug, and associations between the water regime and the land use and management were analyzed. The data basis contains mainly physical and hydraulic properties of soil (Schindler *et al.*, 1985, Schmidt, 1989, 2000). Crop yields of several field and lysimeter studies have been included (Mueller and Tille, 1990, Sauerbrey *et al.*, 1991, Behrendt, 1995). During yield measurements the abundance of cultural and wild plants was scored (Mueller and Kalettka, 1993). Additional crop yield data come from farmers.

3 Results

3.1 Cultivation, soil status and crop yield level

Soils under study are not virgin but have a history of cultivation of about 250—300 years (Frielinghaus *et al.*, 1994). Agricultural history, current soil status and crop yield level differ between the lowland types under study (Table 2).

Table 2 Evaluation of soil structure, crop yield level and biodiversity

Type of lowland	Predominant landscape functions	Land use – induced changes of soil structure [1]	Crop yields [2]	Diversity of flora [3]
Recent river floodplain (1)	Water retention Habitat for wetland species	None to low	Low	High
Dam-protected floodplain (2)	Agriculture	Distinct	High	Very low
Shallow peatland (3)	Agriculture	Very high	Medium to high	Low
Humic sandy soils (4)	Agriculture	Low	Medium to high	Very low
Deep peatland (5)	Agriculture	Distinct	High to medium	Low to medium

[1] Heim and Mueller, Mueller *et al.*,1994, Behrendt, 1995, Schmidt, 1989
[2] Frauendorf, 1988, Mueller and Tille, 1990, Mueller and Kalettka, 1993, Schmidt, 2000
[3] Mueller and Kalettka, 1993, Succow, 1988, Sauerbrey *et al.*, 1991

Soils of recent floodplains adjacent to large rivers (Type 1 after Table 1) have the main function of providing water retention and of avoiding soil erosion during floods. Durable grassland is able to ensure these demands. The floodplains are characterized by predominant low-input grassland use without fertilization during the last two centuries. The crop yields are relatively low (2 tons—6 tons dry matter / ha) because of fluctuating water tables, prevailing sandy soils and water balance deficits. Soils and crop yields are extremely large spatially and temporally variable. This regime is correlated with a high floral and faunal biodiversity. Except some trampling pathes of cattle or some wheel tracks these soils do not show any features and indicators of degradation of soil structure induced by land use.

Within the extensive lowlands of the Elbe and Oder Rivers (Type 2 after Table 1), gley soils (FAO:Gleysols) of clayey and loamy texture are dominant. The land is relatively level and has low drainage gradients. Land drainage has intensified during the past three centuries and has caused deeper water tables and soil structural changes (Mueller *et al.*, 2000). Soil profiles show features of improved soil structure status by land drainage as well as some features of soil damage by heavy agricultural traffic like sharp–edged polyhedric and blocky aggregate without of the hierarchy of aggregates (Mueller *et al.*, 1994). Crop yields have also been increased during the latest centuries and decades and is now at about 5 tons—9 tons of cereals/ hectare. However, if water tables are deeper than 140 cm below the surface, some limitations of water supply can occur.

Shallow low moor peat soils (Type 3 after Table 1) are associated with humic sandy soils (former peat soils) and sandy soils of Type 4. They also have a history of cultivation of about 250 years. Agriculturally induced soil changes in fenland peat soils include structural changes and the mineralization of organic matter. Accelerated soil development leads to marked changes in the topsoil as reduced water holding capacity (unit water content < 1.5) and increased dry bulk density. The status of strong moorshification (“vermulmt”) is dominant. Nevertheless if they are well managed and fertilized they remain productive sites at shallow water tables of 40 cm—70 cm below the surface. Grassland yield is about 5 tons—7 tons dry matter / ha. Plant biodiversity of these grasslands is low because of frequent grassland renewing after 4 years—6 years and fertilizing,. The soil quality for high crop yields of degraded peat soils with peat thicknesses of 40 cm—60 cm, underlain by sand, can be preserved and enhanced by deep ploughing (Schindler *et al.*, 1999).

Humic sandy soils (Type 4 after Table 1) have been in arable use since at least two centuries and provide acceptable crop yields of 7 t/ha—10 t/ha dry matter of maize for silage and 4 tons/ha—6 tons/ha of cereals (rye). Fertilization and water table management (water tables of 40 cm to 90 cm below the surface) are preconditions. Water table management is often not in optimum or too expensive to realize because of microrelief- heterogeneity and lack of water. Negative effects of farming on his soil structure have seldom been observed. However, they can be expected if the tractor tyres run in the furrow at ploughing. This “offland-ploughing” causes persistent subsoil damage on all soils. High loads of agricultural traffic will also cause topsoil and subsoil compaction (Petelkau, 1984, Petelkau *et al.*, 1999). Sites have a high or excessive status of nutrients and are of low biodiversity.

Deep fenland peat soils (Type 5 after Table 1) show most obvious changes because of land use. The peat layer thickness is continuously reduced through mineralization and subsidence processes. Peat thickness losses of 1.5 cm/year—2 cm/ year under arable land use and 0.4 cm/year—0.8 cm/ year under grassland land use were typical of the north-eastern German lowlands. The soil status is earthened (“vererdet”) to moorshificated (“vermulmt”). Despite the changed state of soil structure, deep peat soils provide high yields of grass and thus remain fertile sites if the water table is not deeper than 70 cm below the surface. The crop yield is about 6 t—8 t dry matter / ha. The low or mean plant biodiversity depends on land use intensity, and fertilization in particular.

3.2 Evaluation of soil protection measures

3.2.1 Soil management

Findings of section 3.1 show the categories “Land use – induced changes of soil structure” and “Crop yields” are rather independent and not correlated. Despite the distinct indications of soil damage or even soil loss, these peat soils which are also called “degraded” by some authors, make high crop yields possible. This means, in general, current agricultural practices fulfill the “productivity function” of soils of Types 2 to 5. Diversity of flora as a measure of “habitat function” of soil is influenced by the nutrient status of soils (trophy) and is diminished by mineralization and fertilizing of grassland (Succow, 1988). On arable land it is very low because of application of herbicides.

From these findings and soil functions considered above an evaluation of soil and water management practices is possible (Table 3).

Table 3 Assessment of soil management measures

Agricultural practices	Recent river floodplain (1)	Dam-protected floodplain (2)	Shallow peatland (3)	Humic sandy soils (4)	Deep peatland (5)
Arable land use	4	1	4	1	4
Ploughing	0	2	0	2	0
Ploughing offland	0	4	0	4	0
Reduced primary tillage	0	1	0	1	0
Integrated farming	0	1	0	1	0
Biological farming	0	1	0	1	0
Grassland	1	2	1	1	1
Meadow	2	2	2	1	2
Pasture	2	2	1	1	2
Low-input grassland farming	1	1	1	1	1
Re-newing of grassland	4	2	3	2	3
Sward maintainance	2	2	1	1	1
Liming	3	1	3	1	4
Heavy agricultural traffic	3	3	3	3	3

1= Recommended, 2=Acceptable, 3= Not recommended, soil damage possible, 4= Not acceptable, soil damage probable, 0=Not relevant

On soils of recent floodplains (Type 1) any arable land use or tillage would enhance the risk of soil erosion during floods and is thus not acceptable. Low-input grassland farming is recommendable to maintain the soil and biodiversity in this area. Any mechanical impact in the soil should not be accepted.

The arable use of soils of the large dam-protected floodplain areas (Type 2) and of the humic sandy soils (Type 4) is sustainable and should be continued. However, the distinct spatial soil heterogeneity indicates the usefulness of precision farming. Preventing the damage of the soil structure tillage has to be adapted to optimum soil moisture states. “Offland ploughing” and heavy axle loads should not be accepted to avoid subsoil compaction. Fertilizing has to be restricted to the demands of plants to halt further accumulation of non- used nutrients as nitrogen or phosphate in soils and landscape. Grassland use is also soil- protecting but provides high yields only in wetter parts.

At low–moor peatland soils (Types 3 and 5) high water tables, long-lasting grassland swards and adequade soil and crop management, including fertilization of potassium, reduce the peat soil mineralization rate and are recommended. Heavy traffic should be kept away from these soft soils as it can destroy the sward and leads to deep tracks. Arable use of peat soils causes highest mineralization rates and soil losses and therefore should not be accepted.

3.2.2 Water table management

In agriculturally used lowlands of Types 2 to 5 water table control is necessary to ensure the water demand of plants and the efficiency of applied fertilizers (Table 4). It is also necessary to limit the mineralization of organic matter. Aspects of water consumption face the problems of soil conservation because the soil status depends on adequate water tables.

Table 4 Assessment of water management measures

Management measures	Recent river floodplain (1)	Dam-protected floodplain (2)	Shallow peatland (3)	Humic sandy soils (4)	Deep Peatland (5)
Ensuring wetland water supply for maintaining wetland function	1	1	1	1	1
Water table management, subirrigation	0	1	1	1	1
Sprinkler irrigation	0	2	2	2	3
Drainage without water table management	0	3	4	4	4
Temporal ponding	1	3	2	3	2

1= Recommended, 2=Acceptable, 3= Not recommended, soil damage possible, 4= Not acceptable, soil damage probable, 0=Not relevant

This objective requires high water tables even in summer and autumn and thus high subirrigation rates of more than 200 mm/year on the peat soils. The sites of Types 2 and 4 under arable use require additional water supply of 50 mm/year—200 mm/year. Drainage without water table control is not acceptable. On clay soils drainage is absolutely necessary to avoid ponding, which is detrimental for soil structure and plant growth.

Water management is not only a regional task within the lowlands. The climatic conditions, annual precipitation rates of 470 mm to 550 mm and potential evapotranspiration rates of 650 mm would lead to soil degradation by drought. Adequate groundwater recharge rates from the lowland surrounding areas, well-maintained control structures and water management practices are the main preconditions for the efficiency of soil protecting measures.

In river lowlands, flood protection is a fundamental precondition of sustainable land use and soil protection as all these areas remain flood-endangered to a certain degree. This is related to risks of soil contamination by heavy metals and other pollutants (Eulenstein *et al.*, 1998).

4 Conclusions

Any agricultural use of peat soils requires water tables below the surface and causes permanent losses of organic matter. Long-lasting grassland swards and high water tables are required to reduce the peat soil mineralization rate to a minimum. In recent floodplains being adjacent to rivers low-input grassland farming is the only acceptable agricultural practice to maintain the soil.

On cultivated mineral lowland soils arable land use is a sustainable measure. However, the run of tractor tyres in the plough furrow (offland –ploughing) causes subsoil damage and should not be accepted.

Adequate groundwater recharge rates from the lowland surrounding areas and water table control are the main preconditions for the efficiency of soil protecting measures.

References

AG Boden. 1994. Bodenkundliche Kartieranleitung. 4th ed., Hannover, 392 pp.

Behrendt, A. 1995. Moorkundliche Untersuchungen an nordostdeutschen Niedermooren unter Beruecksichtigung des Torfschwundes, ein Beitrag zur Moorerhaltung. Diss. Humboldt-Universitaet zu Berlin, 170 pp.

Eulenstein, F., L. Mueller and K. Helming. 1998. Odra 1997 flood effects on soil properties of cultivated areas in Germany. Int. Agrophysics, 1998, **12**, 241-247

Frauendorf, M. 1987. Untersuchungen ueber den Einfluss unterschiedlicher Bodenentwicklungsstufen, Grundwasserregulierung und fahrmechanischer Belastung auf einige bodenphysikalische Kennwerte tiefgruendiger Niedermoore und den Ertrag verschiedener Grasarten. Diss. Akademie der Landwirtschaftswissenschaften Berlin. 149 pp.

Frielinghaus, M., L. Mueller, F. Krueger. 1994. Landschaftsveraenderungen eines Flussniederungsgebietes waehrend der letzten 200 Jahre. Zeitschr. fuer Kulturtechnik und Landentwicklung **35** (6) 365-373.

Frielinghaus, M., L. Mueller, K. Seidel, B. Winnige. 2002. Soil indication – The basis for soil management decisions for erosion and compaction control. Proceedings of the 11th ISCO Conference Oct. 22/27 2000, Buenos Aires, Argentina, in print.

Heim, H. , L. Mueller. 1988. Field studies on the structure of alluvial clay soils as precondition for the determination of drainage situation. Archives of Agronomy and Soil Science, Berlin **32**, 3, 141- 151 (in German, Engl. summary).

Mueller, L. , P. Tille. 1990. Effects of substrate and water regime on the crop yield of an inhomogeneous alluvial soil in need of amelioration. Archives of Agronomy and Soil Science, Berlin, **34**, 2, 103-112 (in German, Engl. summary).

Mueller, L. , T. Kalettka. 1993. Soil water regime, occurrence of wild plant species and crop yield of an alluvial clay site. In: Mitteilungen der DGB, 73, 1993, (in German).

Mueller, L., U. Schindler, A. R. Dexter. 1994. Subsoil structure characteristics of river lowland clay soils with shallow water tables. Proc. of the ISTRO Conference 1994, Aalborg, Denmark, 567-572.

Mueller, L, U. Schindler, A. Behrendt, C. Schleier, M. Frielinghaus.2002. Criteria and indicators of soil quality for sustainable use of peat and river lowland soils. Proceedings of the 11th ISCO Conference Oct. 22/27 2000, Buenos Aires, Argentina, in print.

Mueller, L., M. Frielinghaus, U. Schindler, A. Behrendt, W. Schmidt. 2000. Bodenschutz auf Standorten der Flussniederungen und Niedermoore. Arch. Acker- Pflanzenbau Bodenkd., **45,** 239-262 (Engl. summary).

Petelkau, H. 1984. Auswirkungen von Schadverdichtungen auf Bodeneigenschaften und Pflanzenertrag sowie Massnahmen zu ihrer Minderung. In: Grundlagen und Verfahren der rationellen Bodenbearbeitung und Erschliessung des Unterbodens fuer Pflanzen. Akademie der Landwirtschaftswissenschaften der DDR, Tagungsbericht Nr. 227, 25 - 34.

Petelkau, H., M. Frielinghaus, K. Seidel, J. Thiere. 1999. Indikationskonzept zur Ableitung von Schadverdichtungsgefaehrdungsklassen nach der mechanischen Belastbarkeit der Boeden fuer Nordostdeutschland. In: Mitteilungen der Deutschen Bodenkundlichen Gesellschaft, Band 91, Heft 3, S. 1499-1502.

Sauerbrey, R., D. Eschner, W.-D. Lorenz, A. Titze. 1991. Oekologische Aspekte der Bodenentwicklung landwirtschaftlich genutzter flachgruendiger Niedermoore der ehemaligen DDR-Situationsbericht. Zeitschr. fuer Kulturtechnik und Landentwicklung, **32**, 300-308.

Schindler, U., K. Bohne, R. Sauerbrey. 1985. Comparison of different measuring and calculating methods to quantify the hydraulic conductivity of unsaturated soil. Z. Pflanzenernaehr. Bodenkd., **148**, 607-617.

Schindler, U., L. Mueller, W. Schaefer. 1999. Entwicklung der physikalischen und hydrologischen Eigenschaften einer Tiefpflug- Sanddeckkultur. Zeitschr. fuer Kulturtechnik und Landentwicklung. **40**. 1-7.

Schmidt, W. 1989. Untersuchungen zur Bestimmung des Verformungsverhaltens von Torfen und Mudden und der dafuer massgeblichen Bodenkennwerte. Habil-Schrift Berlin, 75 pp.

Schmidt, W. 2000. Ueber pedogene Merkmale der Niedermoorboeden und deren Ausbildungszeiten. Arch. Acker- Pflanzenbau Bodenkd., **45**, 177-186 (Engl. summary).

Succow, M. 1988. Landschaftsoekologische Moorkunde. VEB Gustav Fischer Verlag Jena, 1. Ed., 340 pp.