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Impact of land use on water properties of rendzinas

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A b s t r a c t. The human agricultural activity leads to very strong changes in the soil – even the period of several decades of fallowing as well as the restitution of potential vegetation communities are not able to level those transformations. The climatic changes and agricultural use discontinuation from calcareous soils are caused to coming into existence the climax forest communications on these areas. Rendzinas that were agriculturally used in the past, despite the development of secondary xerothermic swards differ in their hydrophysical properties from the soils occupied by the primary swards. In this work the impact of the way of land use and the natural successive transformations of vegetation on the hydrophysical properties of rendzinas were shown. The surface horizons of cultivated and fallow rendzinas (in comparison with the respective horizons of soils overgrown by primary xerothermic vegetation) are characterized by greater bulk density, lower water retention in the full range of the studied soil water potentials, smaller number of pores, especially of the large pores (dia > 18.5 μm). Water retention and conductivity for soil water potential >1 hPa of surface horizons of fallow rendzinas are close to the values that are characteristic for soils overgrown by shrubs, this being a possible cause of the instability of secondary xerothermic swards as well as of the fast rate of succession in the direction of shrub and forest communities.

K e y w o r d s: rendzinas, land use, plant succession, water retention, water conductivity

INTRODUCTION

Rendzinas, which are formed by the weathering of the carbonate rocks of various geological formations, are interzonal soils developed in the subboreal, boreal, as well as in some regions of the subtropical zones. Their characteristic features are the occurrence of the fragments of the parent material in the surface level and neutral or a basic reaction of the soil in a solution with a high content of calcium carbonate (Dobrzański *et al*., 1987; FAO/UNESCO, 1997; ISSS-ISRIC-FAO, 1998; Pranagal *et al*., 2005; Zawadzki, 1999). Various natural vegetation communities can grow on rendzinas *ie* forest, forest-pasture, forest-steppe, and pasture-steppe. In Central Europe, in the specific ecological conditions (on slopes facing south or west or on hill tops with high sun exposure) rendzinas are a potential habitat of extra-zonal and non-climax xerothermic phytocenoses (pasture-steppe) (Alard *et al*., 2005; Dodd *et al*., 1998; Ellenberg *et al*., 1991).

In contemporary climatic conditions in Europe, the xerothermic communities are not stable phytocenoses but they create a chain link succession, which makes its way to creating the climax forest communities. Their occurrence is connected with varying relief and calciferous or loess bedrock predominantly made up of calcium carbonate. These communities are extremely important for maintaining the gene resources of flora and fauna (Hurst and John, 1999; Janisova, 2005; Michalik and Zarzycki, 1995; WCS, 1980).

The development of agriculture needs to be accompanied by care for the agro-ecosystems. The term ‘sustainable agriculture’, introduced at the end of the 20th century, signifies a system of farming which ensures the maintenance of biological and soil diversities. As such, the system of farming requires among others, an in depth knowledge of natural properties of its components. One of components is the soil. An exact knowledge of soil properties is fundamental meaning to creating an optimal environment for the growth and development of plants, spatial planning of the structure of farming system – and finally, decisions about the exclusion of certain areas from agricultural production (including the means of restoration) (Dębicki and Skłodowski, 1999; Gliński and Walczak, 1998; Gough and Marrs, 1990; Parrish and Bazzaz, 1982; Paschke *et al*., 2000; Włodarczyk *et al*., 2005).

The problems of the vegetation succession after cultivation appear in the agricultural and ecological literature relatively rarely. A few studies have been devoted to changes in

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the climate and soil environment together in relation to vegetation changes (Bobbink and Willems, 1987; Janssens *et al*., 1998; Kalicka, 2006; Kalicka *et al*., 2004; Rizand *et al*., 1989). However the creators of the succession theory (Clements, 1916, 1928; Odum, 1969) emphasized that the succession process is a result of the transformations occurring in the abiotic environment (Fig. 1).

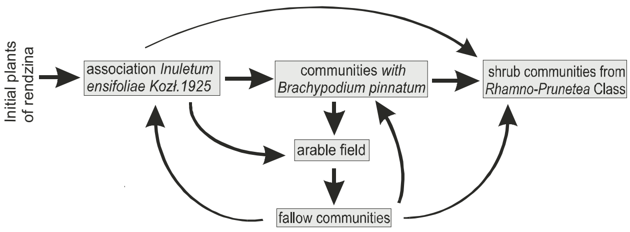

Fig. 1. Succession scheme of xerothermic phytocenoses overgrown cretaceous rendzinas (Clements, 1928).

The hydrophysical properties of soils *ie* the water retention and the water permeability in the saturated and unsaturated zone, not only affect the water balance but also have a dominant influence on the conditions of growth and development of plants. They determine the availability of water to plants and leaching of nutrients dissolved to the deeper layers of the soil (Coquet *et al*., 2005; Hillel, 1998, Kutilek and Nielsen, 1994; Witkowska-Walczak *et al*., 2000). The knowledge of the hydrophysical properties of the soil is therefore essential in the interpretation and prediction of changes of the vegetation cover, which occur as a result of a natural succession.

The aim of this work was to determine the impact of the way of land use and the natural successive transformations of vegetation on the hydrophysical properties of rendzinas.

MATERIALS AND METHODS

The study area is located in the Lublin Upland region of southeast Poland. It consists predominantly rendzinas formed from the carboniferous rocks of the Daan and Upper Maastricht periods. The spatial distribution of the soil profiles in relation to the vegetation communities being the consequent succession stages, allows for objective evaluation of the variability of their hydrophysical properties.

The fieldwork design is:

I – arable rendzinas (3 profiles);

II – rendzinas under fallow for several years, which are overgrown by fallow communities, a mixture of vegetal and meadow species, which forms an initial stage of xerothermic swards (3 profiles);

III – rendzinas currently overgrown by well developed secondary xerothermic swards (these sites are the most typical for rendzinas vegetation group *Inuletum ensifoliae* Kozł. or the community with *Brachypodium pinnatum* occurred, being consecutive stage of the natural succession (5 profiles);

IV – rendzinas overgrown by primary xerothermic swards (vegetation canopy *Inuletum ensifoliae* Kozł.), these sites due because of their steep slopes, were never cultivated, and they have been under strict preservation protection for several decades (4 profiles);

V – rendzinas on which there occur communities of thermophilic shrubs from the *Rhamno-Prunetea* class in the primary habitats (these phytocenozes constitute successive stages of the succession series of xerothermic swards leading to the development of climax climatic conditions in the forest communities of Central Europe) (4 profiles).

Undisturbed soil samples were taken in three replications from the upper layer of the rendzinas (5-15 cm) into the cylinders of 5 cm in diameter and with 100 cm^3 volume. Their chosen properties were determined using standard soil laboratory methods (Cassagrande's method, ISO 14 235, ISO 10 693 and ISO 10 390), and bulk density – gravimetrically, after drying at 105°C (Table 1).

T a b l e 1. Chosen properties of the investigated rendzinas (mean data)

Type of plant communities*	Grain size distribution (%, dia in mm)				pH_{H2O}	pH_{KCl}	$CaCO_3$ (%)	$C_{org.}$ (%)	Bulk density (g cm^{-3})
	>1	1-0.1	0.1-0.02	<0.02					
I	5	35	20	45	7.8	6.9	18.1	1.0	1.21
II	6	10	31	59	7.5	7.0	40.5	2.0	1.19
III	8	9	34	57	7.4	7.1	41.4	2.2	1.16
IV	17	12	31	58	7.2	6.9	20.1	4.2	0.90
V	17	9	38	53	7.3	7.0	31.1	4.0	0.85

*Type of plant communities: I – arable fields; II – fallow communities, initial stages of xerothermic swards; III – secondary xerothermic swards; IV – primary xerothermic swards; V – shrub communities.

Static hydrophysical characteristics, that is the water retention curves, introducing the dependence between the soil water potential and the water content (moisture) were measured in the process of drying using a laboratory set LAB 012 from Soil Moisture Equipment Corp., Santa Barbara, California, USA (Instruction, 1995) for the 8 values of soil water potentials in the range of 0.1 – 1 500 kJ m^{-3}, *ie* 0.1 kJ m^{-3} (0.1 hPa); 1 kJ m^{-3} (1 hPa); 6.3 kJ m^{-3} (63 hPa); 16 kJ m^{-3} (156 hPa); 31 kJ m^{-3} (310 hPa); 100 kJ m^{-3} (1 000 hPa); 500 kJ m^{-3} (5 000 hPa), and 1 500 kJ m^{-3} (15 000 hPa).

Values of the coefficient of water conductivity in the saturated soil zone (soil water permeability) were measured using an apparatus for measuring of water permeability from Eijkelkamp, Agrisearch Equipment, The Netherlands (Instruction, 1998). The coefficient of water conductivity in the unsaturated zone was determined using the method of moment profiles, based on the measurement of moisture and soil water potential in the selected layers of the soil samples by using a laboratory TDR (Time Domain Reflectometry) set in the drying process (Malicki *et al*., 1992; Porębska *et al*., 2006; Sławiński *et al*., 2006; Walczak *et al*., 1993).

The amount of water useful for the plants (WU) was calculated as the difference between the water content at 156 hPa (field water capacity for soil profiles without the ground water table) and 15 000 hPa (the permanent wilting point of plants). At the description of the forms of the soil water at various degrees of its accessibility for plants the following boundary values of potential were accepted: 156-1 000 hPa for capillary water easily accessible for plants (WEA); 1 000-15 000 hPa for capillary water accessible for plants with difficulty (WDA), and above 15 000 hPa – water not useful for plants (WN). The soil water potential of 6.3 kJ m^{-3} corresponding to 63 hPa was accepted as limit for gravitational water quickly and slowly permeating. As bordering values of diameters of pores 18.5 μm (156 hPa) was accepted between large and medium pores and 0.2 μm (15 000 hPa) between medium and small ones (Zawadzki, 1999). The all statistical calculations were performed with the use of Excel and Statistica programs.

RESULTS AND DISCUSSION

The bulk density of the surface horizons of the rendzinas indicates a very strong dependence on the way of land use (Table 1). The clearly higher values were exhibited by rendzinas that are currently, or were recently cultivated. The lowest density was exhibited by the profiles, where for a long period of time there was no direct human interference (occupied by the shrub communities, under the protection of preservation for many years) or situated on steep slopes, in places with unfavourable conditions for agricultural activity. Together with the succession of the natural xerothermic vegetation the density of rendzinas decreases from 1.21 g cm^{-3} on the cultivated fields (I) to 0.85 g cm^{-3} under the shrubs (V).

The curves of the water retention for the rendzinas are presented in Fig. 2. It can be seen that the total water capacity (at 0.1 hPa) assumes the highest values – 67% vol. – under the primary xerothermic swards (IV) and a shrub communities (V), the lowest – in the cultivated rendzinas (I) – 51% vol. In the range of potential corresponding to 0.1-1 000 hPa the highest amounts of water were retained by the rendzinas overgrown with primary swards (IV), the smallest – on the cultivated fields (I). For the potentials higher that 1 000 hPa the fallow rendzinas (II) and those under the secondary swards (III) retained less water that those which were used agriculturally (I). The amounts of water retained at 15x10^3 hPa fluctuated from 32% vol. in the rendzinas under the primary swards (IV) to 27% vol. under the secondary swards (III). The shape of the course of the curves of retention of the studied rendzinas, regardless of the type of the occurring community, is similar. In the range of 0.1-63 hPa, including the quickly permeating gravitational water, its amount rapidly decreases, which is especially clear for the shrub communities (V) and those of primary swards (IV). The decrease of moisture in this range is from 10% for the cultivated fields (I) to 24% for the shrubs (V). Between the values of 63 and 1 000 hPa that is in the section that includes the very slowly permeating gravitational water as well as water in the large capillaries, a gentle decrease in moisture was noted. In none of the studied cases did it exceed 7.5%. Above 1 000 hPa again a rapid decrease of the amounts of retained water is marked – at approximately 7-8.5% vol. for the formation II-V, for the cultivated rendzinas (I) – of 4.5% vol.

The content of the pores of various sizes in the surface levels of the studied rendzinas is presented in Fig. 3. Based on the results obtained it was noted that the amount of micropores (dia <0.2 μm) is 26.9-33.7 % and it exceeds the amount of macropores (dia >18.5μm) (14.1-25.4%), as well

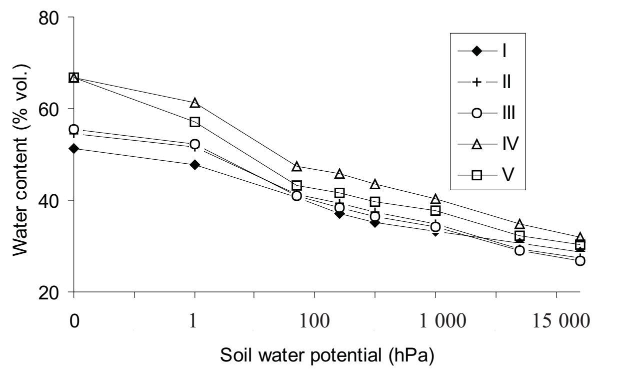

Fig. 2. Soil water potential (hPa) – water content (% vol.) characteristics for surface layers of the investigated rendzinas overgrown by the different types of plant communities (mean data). Explanations: I – arable fields; II – fallow communities, initial stages of xerothermic swards; III – secondary xerothermic swards; IV – primary xerothermic swards; V – shrub communities.

as of mezopores (18.5<dia<0.2 μm) (8.6-13.9%). The soil surface levels, on which occur the primary xerothermic swards (IV) occur are distinguished by the highest percent participation in the volume unit of medium pores storing the water that is available for plants.

The amount of plant available water was calculated, including easy and difficult to access for plants as well as the amount of water inaccessible for plants (Fig. 4). The data presented shows that the resources of water available for plants fluctuate from 8.6 to 13.9% and are the highest in the rendzinas occupied by the primary swards (IV). The amounts of easily accessible water in the surface horizons of the studied rendzinas are not large and they fall within the range of 3.7-5.6% vol. Similarly to the case of the available water, they are the highest for the formations for the primary swards (IV). The amounts of water that is difficult to access range from 7.1 to 8.4% vol., with the exception of the rendzinas which were under cultivation (I) - 4.5% vol.

Analysis of the values of the coefficient of water conductivity of the studied rendzinas (Fig. 5) showed that they are clearly different for various forms of land use. The cultivated rendzinas (I) in the saturated zone (at 0.1 hPa) conduct water at the rate of 10 cm day^{-1}, that is two orders of magnitude slower than the rendzinas occupied by the communities of shrubs (V) and swards (IV), 1200 and 1350 cm day^{-1}, respectively, and one order of magnitude slower than the fallow rendzinas (II) and those under the secondary swards (III), 200 and 360 cm day^{-1}, respectively. The values of the coefficient of the water conductivity decrease rapidly together with the increase of the soil water potential, for the cultivated rendzinas (I) to 1 hPa – 0.35 cm day^{-1}, for the remaining ones (II-V) to 156 hPa – reaching the extremes of 0.012 and 0.034 cm day^{-1} for the primary swards (IV) and the secondary swards (III), respectively. Further on, to 1 000 hPa, the decrease of the values of the coefficient of conductivity is considerably gentler for all the studied formations. And so in the cultivated fields it decreases to 0.02 cm day^{-1} and for the fallows, swards and shrubs in fluctuates from 0.4x10^3 to 1.4 x10^3 cm day^{-1}. In the range of 1 000-15 000 hPa again a ra- pid decrease of the values of the coefficient was noted, and they finally were 5 x10^{-4} cm day^{-1} for the cultivated fields and for the remaining formations from 2 to 8x10^{-6} cm day^{-1}. It should be emphasized that the differences between the values of the coefficient of the water conductivity for the rendzinas under the communities II-V are minor, only the cultivated rendzinas (I) have up to 63 hPa (substantially lower) and after crossing 156 hPa – substantially higher values of the coefficient of water conductivity.

The soil tillage has as its goal a decrease of volume density and increase of porosity. In the soils with high content of fine particles it can lead also to the destruction of

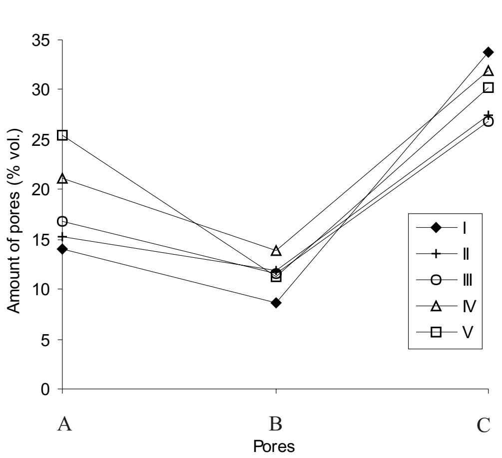

Fig. 3. Pore size distribution in surface layer of the investigated rendzinas (mean data). Explanations: Pores: A – dia >18.5 μm; B – 18.5< dia <0.2 μm; C – dia <0.2 μm. Type of plant communities as in Fig. 2.

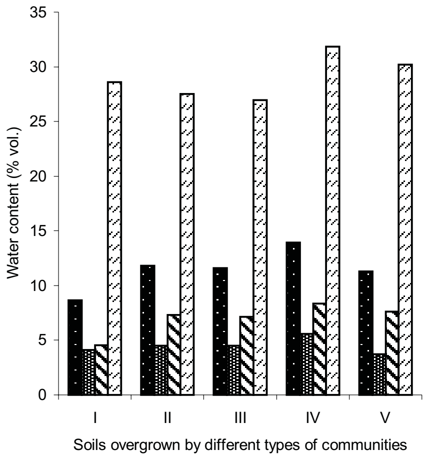

Fig. 4. Availability of soil water for plants in surface layer of the investigated rendzinas (mean data). Explanations: Soil water availability: WU – water useful for plants; WEA – water easy available for plants; WDA – water difficult available for plants; WN – water not useful for plants. Type of plant communities as in Fig. 2.

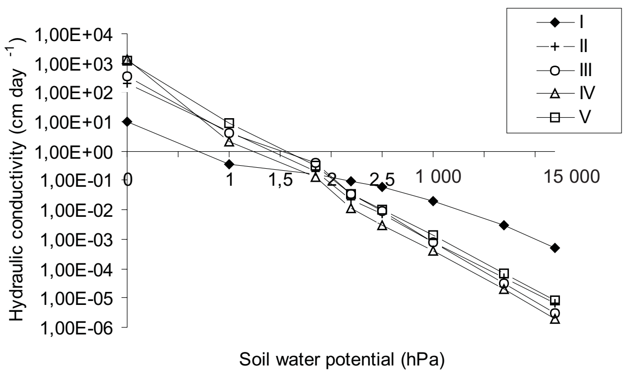

Fig. 5. Water conductivity as a function of water potential (hPa) for surface layer of the investigated rendzinas (mean data). Type of plant communities as in Fig. 2.

structural aggregates, which in consequence has a reverse effect. After ceasing of cultivation (the soil profiles of formations II and III) an increase of the amount of large pores (dia >0.2 μm) follows, especially of organic origins (plant roots, soil fauna activity) which results in an increase of total water capacity of soils. At the same time an increase of the content of water available for plants is noted, including that which is hard to access for plants, and a small decrease of the amount of water which is inaccessible for plants, which is stored in the small pores. In the further order, the process of automatic gravitational compacting strengthened. This is caused by the soil moisture changes (wetting – drying) and temperature changes (freezing – thawing). This leads to an increase in the amount of micropores rather than mezopores, and a decrease in the amount of water which is easily accessible for plants. Destruction of soil aggregate structure by human activity intensifies the settling (compacting) process so that even the long-term effects of flora and edaphon cannot bring about a decrease of the density of soils on the fallow fields.

In the extent of natural habitats (formations IV and V) a decrease of the volume density of the surface levels of the rendzinas together with the length of the period of occurrence of swards, as well as due to the plant succession was observed. The stronger and more developed root system of shrubs (formation V) causes an increase in the amount of macropores per unit of volume of soils, and at the same time the consolidation of the neighbouring soil material and a decrease in amount of mezopores. This contributes to the worsening of the ability of available water retention of the surface horizons of soils, and especially of that easily accessible for plants in comparison with the rendzinas of formation IV.

The values of the water conductivity coefficient of the cultivated soils differ from those observed in the soils on which no tillage measures are conducted, even if the period without human interference is short (as is the case with formation II). The range of changes of the water conductivity coefficient, depending on the type of the overgrowing vegetation is not large, but in the range between 63 and 15000 hPa (including gravitational water which permeates very slowly as well as capillary water) the lowest values were noted on the habitats of primary swards (IV), which has a close relation with the good retention abilities for water which is usable for plants of the rendzinas occurring here.

The dynamic as well as static hydrophysical characteristics of the soil water potential >1hPa of the surface levels of the fallow rendzinas (II and III) are close to the values which are characteristic for soils which are overgrown with shrubs – it is possible that from this results the instability of the secondary xerothermic swards as well as the fast rate of succession in the direction of the shrub and forest plant associations. According to Kalicka (2006) and Römermann *et al*. (2005) also the physicochemical properties, that is the pH, the nitrogen and organic carbon content, nutrients, and sorption capacity of the habitats of primary and secondary swards change substantially.

CONCLUSIONS

1. The rendzinas which used to be utilized in agriculture, regardless of the development on them secondary xerothermic swards (III) differ in bulk density and total porosity from soils occupied by the primary swards (IV).

2. Rendzinas which are currently, or were in the past, utilized agriculturally (I-III) differ substantially from those overgrown by primary xerothermic vegetation (formations IV and V); they exhibit lower water retention in the full range of studied soil water potentials, and smaller amount of large pores (dia > 18.5 μm).

3. The largest amounts of water available for plants, including that which is easily accessible, are retained by the rendzinas which are overgrown by natural habitats of swards (IV). In those rendzinas it was also noticed, that there was the highest amount of water inaccessible for plants. The increase of the participation of bushes and shrubs on a given habitat (V) leads to the decrease of the amount of all categories of water.

4. Tillage greatly modifies the water permeability of soils. The values of the water conductivity coefficient of the cultivated rendzinas (I) in the range 0-63 hPa are substantially lower, and after crossing 63 hPa – substantially higher (2-3 orders of magnitude) than the values observed for the other formations (II – V).

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