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Self-restoration of post-agrogenic sandy soils in the southern Taiga of Russia: Soil development, nutrient status, and carbon dynamics

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ABSTRACT

The focus of this chronosequential study was on the vegetation succession, profile morphology, nutrient dynamics, and carbon stocks of post-agrogenic sandy soils under self-restoration of the southern Taiga zone in the European part of Russia. The sites investigated were comparable in climate, texture, and land-use history, but differed in the duration of agricultural abandonment, covering 3, 20, 55, 100, and 170 years of self-restoration. During self-restoration, the vegetation developed towards natural spruce forests and the soils towards natural Podzols. After 55 years of self-restoration, an initial albic horizon under a 2–3 cm thick raw humus layer had developed and after 100 years, all typical Podzol horizons (O–E–Bsh), though relicts of former land use (Ap features), were still present after 170 years. Increasing podzolisation was indicated by a pH decrease from 6.7 to 3.6 ($CaCl_2$), decrease of exchangeable Ca and Mg and decrease of base saturation from 54.0% to 4.3%, C/N ratios increasing from 15.6 to 31.2 and by the loss of pyrophosphate-soluble Fe in the top soil from 340 to 214 μg g^{-1} and accumulation in the subsoil from 162 to 896 μg g^{-1} in 170 years of self-restoration. During self-restoration, the contents of P and K in total and plant-available forms as well as total N decreased in the top mineral soil, causing a considerable nutrient depletion after 55 years and partly shifting the source of plant nutrients from the mineral part of the soil upwards to the forest floor. Despite this over-all release, the P contents stayed high (817 mg kg^{-1}) within the relictic ploughed horizons, which was also true for C. But mainly because of increasing SOC stores of the organic surface layer, carbon stocks increased from 4.5 kg C m^{-2} to 6.3 kg C m^{-2} during self-restoration, indicating a carbon sink. Because of the continued existence of C in parts of the former ploughed horizons, the carbon sink functioning is even larger in self-restorated Podzols than in natural ones.

1. Introduction

Until recently, much arable land was abandoned in many countries world-wide (Ramankutty, 2006; Lyuri et al., 2006, 2008). Most abandonment was found in Russia, reaching over 200,000 km^2 in the early 1990s (Vuichard et al., 2008) and 578,000 km^2 in the years 1961–2007 (Lyuri et al., 2008). This development was predominantly caused by economical crises. Initiated by ecological crises, wars and intensification of agriculture, the same happened in other countries (Ramankutty, 2006; Lyuri et al., 2006, 2008). As a consequence, the soils of these abandoned sites went into the process of natural restoration without direct human impact or self-restoration.

Preliminary studies of post-agrogenic sandy soils under self-restoration of the southern Taiga zone in the European part of Russia indicated that these soils are developing towards Podzols (Lyuri et al., 2006), thus to their natural configuration, as Podzols are characteristic of the sandy regions of this climatically zone; pedagogically, called Podzol–Lubrizol–Albeluvisol-zone (Schultz, 2000). The podzolisation process during self-restoration was indicated by the soil morphology and corresponding chemical properties (Lyuri et al., 2006, 2008) measured so far.

Initiated by the stop of fertilization and concurrently with acidification and podzolisation, changes in nutrition dynamics are expected to affect the biota during self-restoration. In respect of plant succession, a development towards spruce forests with dwarf-shrubs is probable, because these are natural features in the southern Taiga zone in the European part of Russia (Lyuri et al., 2008). Simultaneously, amounts and biochemical properties of litter and the organic debris, their input into the soil (above and below ground), and the number and spectrum of species of decomposing organisms will change (Chertov and Komarov, 1997), favouring the formation of raw humus forest floor and shifting the main source of plant nutrients from the mineral part of the soil upwards to the new forming organic surface layer (Chertov, 1981; Chertov et al., 2001).

In respect of climate change, the impact of self-restoration on soil organic carbon sequestration is of major concern. Enhancing soil carbon

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sink functioning is well known for afforestation of former arable sites. The most evident effect was the net sink for atmospheric CO_2 with C sequestration mainly in the growing trees and in the forest floor (Richter et al., 1999; Hooker and Compton, 2003; Post and Known, 2000; Degryze et al., 2004; Thuille and Schulze, 2006). Comparable characteristics are expected to develop during self-restoration of southern boreal sub-zone sandy soils, as preliminary studies have already indicated (Lyuri et al., 2006).

Until now, it is not clear how fast and to what extent these changes in soil and vegetation properties will occur. To fill this gap, we studied the succession of vegetation, profile morphology, and other soil properties of post-agrogenic sandy soils under self-restoration. On the basis of the available pilot study by Lyuri et al. (2006, 2008), our investigations were concentrated on the southern boreal sub-zone in the European part of Russia.

2. Materials and methods

2.1. Site of investigation

The study was done in the southern boreal sub-zone of the European part of Russia nearly 12–30 km south of the town Valday. Valday is situated at the federal highway M10, connecting Moscow with St. Petersburg, both roughly 400 km apart (Fig. 1) (http://en.wikipedia.org/wiki/Valday).

Geographically, the investigation site is a part of the Valday Hills on the east European plain. The average annual temperature is +3.2 °C, the annual precipitation is 714 mm, and the frost-free period is 128 days (http://www.valdaytravel.narod.ru/Nazparkklimat.htm). The Valday Hills' geomorphology is formed by late Weichselian end moraines, consisting of hills and many lakes in the depressions. Loamy to clayey as well as sandy sediments constitute the soil development. The latter were chosen for this study. For the chronosequential approach of this study, sites different in self-restoration time but comparable in texture, climate, and land-use history were required. Subsequent sampling sites were chosen according to appropriate information from topographic and geological maps, historical literature, and personal communications with indigenous people.

Agricultural land use started in the XIth century in Valday Hills. Until the XVth century, 15% of the areas were arable sites. With the beginning of the XVIIth century, increasing productivity was initiated by the close of the slash-and-burn land use and the introduction of the three-field technique. In 1788, forests were nearly completely cut in Valday Hills and the appropriate land was turned into arable sites. The transfer of arable land from Iverskiy Closter to the state in 1764 led to the abandonment of the study site, which has been in the process of self-restoration for nearly 170 years. Political problems coming up in 1913 and the First World War were responsible for abandonment (Tishkov, 1994) in the case of the study site that has been in the process of self-restoration for 100 years. At that time, crop production changed from rye and oats (75%), wheat and barley (4%), flax (7%) and potatoes (6%) to vegetable and forage crops (e.g. clover) (75%) and corn (15%) until today (Tishkov, 1994). Decreasing outcomes after the Second World War caused increasing abandonment (Tishkov, 1994) in the study site that has been in self-restoration for 55 years. A change in the fertilisation technique from organic manuring to additional mineral fertilisation took place early in the sixties of the XXth century (Zharikov, 1987). Thirty years later, political crises caused the abandonment in Valday Hills to proceed up to now in the sites that have been in the process of self-restoration for 20 and 3 years, respectively.

Although this preparatory work was performed very consciously, some variations could not be excluded, referring e.g. to fertility and ploughing depths, the latter being caused by ploughing depths changing from 10 cm (Pipes, 1995) 9–13.5 cm, maximally 18 cm (Milov, 1998) until the XXth century to depths of 22 cm when machine ploughing was introduced (Milov, 1998).

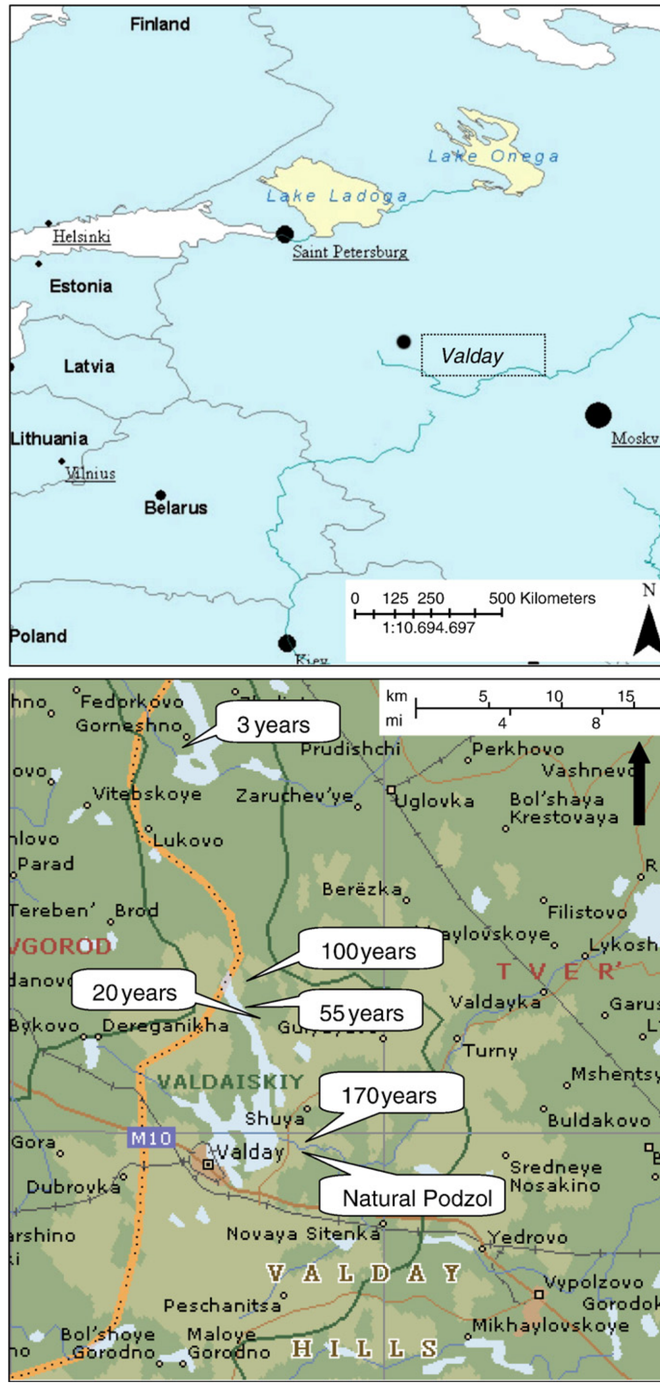

Fig. 1. Location of the investigation sites on global (top) and more exact scale (bottom).

Having found the most adequate sites, five soil profiles of different self-restoration ages were dug in September 2007. Frequent Purckhauer drilling ensured that all profiles were representative of the sites. The precise localizations of the profiles by GPS coordinates (Table 1) were generated by Garmin Etrex GPS Navigator. The chronosequential catena covered 3, 20, 55, 100, and 170 years of self-restoration. The sand percentage of all soils was >85% and the clay fraction ≤2% (Table 2), indicating their pedological affinity.

A Podzol that likely never was under agricultural use was included for comparison with natural conditions. Because of charcoal found in the natural Podzol we used data from the Russian Soil Classification in respect of C store calculation (Shishov et al., 2004). Pits were dug and then the soil morphology was described according to the Russian taxonomy (Shishov et al., 2004) and World Reference Base of Soil