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Research article

Fast accrual of C and N in soil organic matter fractions following post-mining reclamation across the USA

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ABSTRACT

Reclamation of post-mining sites commonly results in rapid accrual of carbon (C) and nitrogen (N) contents due to increasing plant inputs over time. However, little information is available on the distribution of C and N contents with respect to differently stabilized soil organic matter (SOM) fractions during succession or as a result of different reclamation practice. Hence, it remains widely unknown how stable or labile these newly formed C and N pools are. Gaining a deeper understanding of the state of these pools may provide important implications for reclamation practices with respect to C sequestration.

We thus investigated C, N, and plant-derived compounds in bulk soil and SOM fractions during succession in post-mining chronosequences (reclaimed with overburden or salvaged topsoil) located along a northwest to southeast transect across the USA. Our results indicate that current reclamation practices perform well with respect to rapid recovery of soil aggregates and the partitioning of C and N to different SOM fractions, these measures being similar to those of natural climax vegetation sites already 2–5 years after reclamation. A general applicability of our results to other post-mining sites with similar reclamation practices may be inferred from the fact that the observed patterns were consistent along the investigated transect, covering different climates and vegetation across the USA. However, regarding SOM stability, the use of salvaged topsoil may be beneficial as compared to that of overburden material because C and N in the fraction regarded as most stable was by 26 and 35% lower at sites restored with overburden as compared to those restored with salvaged topsoil. Plant-derived compounds appeared to be mainly related to bio-available particulate organic matter and particulate organic matter partly stabilized within aggregates, challenging the long-term persistence of plant input C in post-mining soils.

1. Introduction

Surface mines occupy a comparatively small area of the total landscape (for instance, ~9000 km^2 in the US in 2006; Soulard et al., 2016) but are considered important due to their continuously growing spatial extent and their radical ecological impacts. Surface mining causes severe disturbances to whole ecosystems by damage and removal of vegetation and soil, or disruption of hydrological regimes (Ahirwal and Maiti, 2017; Hangen-Brodersen et al., 2005; Sheoran et al., 2010). Besides the establishment of a new plant cover, commonly a mixture of grasses/herbs and trees (Koch and Ward, 1994; Tropek et al., 2012), soil recovery is essential for the remediation of a functional ecosystem at post-mining sites (Frouz et al., 2013; Hüttl and Weber, 2001). Current restoration practices often involve the application of salvaged topsoil (Moreno-de las Heras et al., 2008), where soil structure and aggregation, microbial biomass and activity, and soil organic matter (SOM) and nutrient contents are usually declined as a consequence of stripping and

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stockpiling (Anderson et al., 2008; Frouz et al., 2013; Roberts et al., 2015; Wick et al., 2009). However, characteristics of salvaged topsoil (e.g., nutrient supply or soil structure) are commonly superior to overburden material, a mixture of parent material and overlying soil (Daniels and Amos, 1985), which is used as substitute material when suitable topsoil is lacking (Frouz et al., 2013). These two reclamation techniques have become common practice in the USA since the enactment of the Surface Mining Control and Reclamation Act of 1977 (SMCRA). Mining and reclamation of disturbed areas thus create sites of different ages and similar history (chronosequence) over time, which many studies have taken advantage of to investigate ecological succession (e.g., Moreno-de las Heras et al., 2008; Mudrák et al., 2016; Norman et al., 2006; Wiegleb and Felinks, 2001). However, potential effects of succession on the corresponding newly applied soils and SOM dynamics have received less attention (Courtney et al., 2010; Frouz et al., 2013). While it is generally accepted that carbon (C) and nitrogen (N) contents increase at reclaimed post-mining sites due to the re-establishment of a plant-cover and corresponding organic matter inputs (Banning et al., 2008; Šourková et al., 2005; Zipper et al., 2011), information on the allocation of C and N to differently stabilized SOM fractions over time, such as to stable aggregates or relatively easily decomposable particulate organic matter (POM), is scarce (e.g., Lorenz and Lal, 2007; Wick et al., 2009). Consequently, it remains widely unresolved to what extent C and N pools within post-mining soils are bio-accessible or decomposition-resistant and how they will react upon new disturbances or reduced input of organic matter (due to e.g. canopy closure after the climax vegetation stage has been reached; Šourková et al., 2005). Similarly, it is unknown whether rapid plant biomass accrual, incorporation of organic matter, and simultaneous aggradation of SOM after reclamation (Feldpausch et al., 2004; Wick et al., 2009) is reflected in an increasing amount of stabilized plant-derived SOM compounds (e.g., in organo-mineral associations) or whether most of these compounds accumulate in the form of POM that may be relatively easily decomposed and is not stable in the long-term (e.g., Marschner et al., 2008). Solving these open questions is crucial for enabling insights into the stabilization of SOM at post-mining sites and may provide implications for reclamation practices with respect to C sequestration (cf. Tibbett, 2010).

We thus investigated changes in chemical composition (C, N, and plant-derived lipids) of bulk soil and different SOM fractions at four post-mining areas differing in climate, vegetation (forest, tallgrass and shortgrass prairie), and reclamation practice (salvaged and stockpiled topsoil and overburden), each area including chronosequences of recently reclaimed sites (2–5 years old), old reclamation sites (15–20 years old) and natural sites featuring climax vegetation typical for the respective region. We hypothesized that the allocation of C and N to different SOM fractions and the amount of plant-derived SOM would approach similarity to the climax sites with increasing age after reclamation. We particularly expected that the amount of plant-derived SOM and the degree of aggregation and corresponding C and N contents would increase during succession, especially at sites with developed bioturbation (forest and tallgrass prairie; Frouz et al. (2013)), which either directly influences aggregation (Š. Angst et al., 2017; Frouz et al., 2009) or by which plant material is mixed with mineral soil and may subsequently act as nucleus for new aggregates (Oades, 1984; Six et al., 2004).

2. Materials and methods

2.1. Study sites and soil sampling

Field work was conducted at four post-mining sites in the US federal states of Tennessee (forest on overburden), Indiana (forest), Illinois (tallgrass prairie), and Wyoming (shortgrass prairie), the sites being termed according to their respective dominant vegetation cover in the following text (Table 1). The sites were located along a southeast to northwest axis, where annual mean temperature and precipitation ranged from 14.1 °C/1092 mm in the southeast to 6.7 °C/380 mm in the northwest (Arguez et al., 2010; Frouz et al., 2013). All studied sites were established on salvaged topsoil except for the forest on overburden sites, where a mixture of shale and weathered sandstone (rock overburden) was used as topsoil substitute. Two chronosequences were established at each study site, each consisting of a young post-mining site 2–5 years after restoration (young), an old post-mining site 15–20 years after restoration (old), and a climax site (climax), featuring natural vegetation characteristic for the respective area. We did not

Table 1
Overview of general characteristics of the investigated post-mining sites (data taken from Frouz et al. (2013)).

Characteristic	Study site			
	forest on overburden	forest	tallgrass prairie	shortgrass prairie
Location				
Soil texture	Loam to silty loam	Silty loam	Silty loam	Loam
Mean annual temperature (°C)	14.1	14.0	12.7	6.7
Mean annual precipitation (mm)	1092	1155	1118	380
Altitude (m asl.)	540–840	135–143	125–140	1360–1410
Herb layer cover %	young-100/old-100/climax-30	young-100/old-70/climax-60	young-100/old-100/climax-100	young-95/old-100/climax-80
Tree and shrub cover %	young-10/old-40/climax-90	young-5/old-60/climax-90	No trees or shrubs	No trees or shrubs
Climax vegetation (biome)	Hardwood forest	Hardwood forest	Tallgrass prairie	Shortgrass prairie
Dominant climax plant species	*Carya ovata*	*Carya ovata*	*Schizachyrium scoparium*	*Artemisia tridentata*
	Quercus rubra	*Quercus rubra*	*Sorghastrum nutans*	*Bouteloua gracilis*
	Acer saccharum	*Acer saccharum*	*Helianthus divaricatus*	*Pascopyrum smithii*
Reclamation practice	Topsoil substitute application, seeding of grass mixture, planting of *Robinia pseudoacacia*	Topsoil application, seeding of grass mixture, planting of hardwood *Liriodendron tulipifera*, *Quercus rubra*	Topsoil application, seeding of warm-season grasses	Topsoil application, seeding of local grass mixture (*Pascopyrum smithii*, *Nassella viridula*, *Hesperostipa comata*)