Ecological Engineering 102 (2017) 72–79

Contents lists available at ScienceDirect

Ecological Engineering

journal homepage: www.elsevier.com/locate/ecoleng

The effectiveness of Yellow lupine (*Lupinus luteus* L.) green manure cropping in sand mine cast reclamation

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ARTICLE INFO

Article history:
Received 21 November 2015
Received in revised form 13 January 2017
Accepted 29 January 2017
Available online 17 February 2017

Keywords:
Forest land reclamation
Sand mining
Excavation
Leguminous plants
Green manure cropping
Carbon
Nitrogen

ABSTRACT

Yellow lupine (*Lupinus luteus* L.) green manure (GM) cropping is an important part of the current biological reclamation treatments used in sand mining cast reclamation in the Upper Silesia Region (southern Poland) prior to reforestation. Research on this system has been limited; however, the potential benefits of using Yellow lupine in reclamation in similar climatic and site conditions may be promising. Therefore, studies were conducted in chronosequence to determine the efficacy of treatment combinations that consisted of 1 or 2 years of lupine green manure cropping and fields left to fallow, where forest humus had been added to sandy mine soils. Surface soil (0–8 cm), subsurface soil layers (8–30 cm), and aboveground plant biomass (planted lupine and successional weeds, respectively) were collected regularly along transects in the study plots. We also counted the number of vascular plant species that grew on the fields left to fallow. Soil sample controls in the 0–30 cm layer were collected on adjacent sand fields (before reclamation) and in the stockpiled forest humus (upper forest soil layers prior to mining for topsoiling). Variables of measure included: soil texture, pH, bulk density, C, N, C-to-N ratio in the soil, and plant biomass. C and N pools in developed reclamation management (soil layers + plant biomass) and changes in chronosequence were evaluated. High C and N accumulations were observed in developed ecosystems. We found up to 13.55 Mg of C ha^{-1} and 2.40 Mg of N ha^{-1} in the soil and 15.02 Mg of C ha^{-1} and 2.60 Mg N ha^{-1} in the pools of the soil + plant biomass. The C pool in the system was highest after the first year of lupine cultivation; however the differences in the N pool were not significant in the studied chronosequence. Thus, based on the results, and with consideration of the reclamation work and time involved before reforestation, 1 year of lupine GM cropping is recommended.

1.. Introduction

Organic matter (OM), carbon accumulation, and nitrogen accumulation are vital dynamics for initial soil development processes and the success of reclamation on post-mine sites (Roberts et al., 1988; Rumpel et al., 1999; Filcheva et al., 2000; Pietrzykowski and Krzaklewski, 2007a; Wick et al., 2013). At the beginning stages of reclamation, OM-enriched treatments provide the nutrients, mainly N for plants and soil biota, and energy necessary to sustain metabolism within the developed ecosystem (Bendfeldt et al., 2001; Frouz et al., 2006; Vindušková and Frouz, 2012).

OM additions during reclamation of post-industrial sites can be provided in the form of amendments such as compost, biosolids, and other high C materials (Malik and Scullion, 2006; Stuczyński et al., 2007; Kostyanovsky et al., 2011; Wick et al., 2013). Alternatively, carbon and nitrogen enrichment can also be attained through supplemental GM. Green manure crops are commonly associated with organic agricultural practices. Typically, a green manure crop is grown for a specific period of time, and then it is ploughed under and incorporated into the soil while it is green or shortly after flowering. The practice of green manuring in agriculture can be traced back to the fallow cycle of crop rotation where mainly the legume family was used to allow soils to recover. It is obtained in two ways: by growing green manure crops or by collecting green leaves (along with twigs) from plants grown in wastelands, field bunds, and forests for incorporating into topsoil (Sullivan, 2003).

Lupine, a member of the legume family (Fabaceae), operates in symbiosis with rhizobia to fix nitrogen in many systems (Hardarson, 1993). The genus, *Lupinus* L., comprises hundreds of species. They are divided into two clearly expressed groups:

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http://dx.doi.org/10.1016/j.ecoleng.2017.01.026
0925-8574/

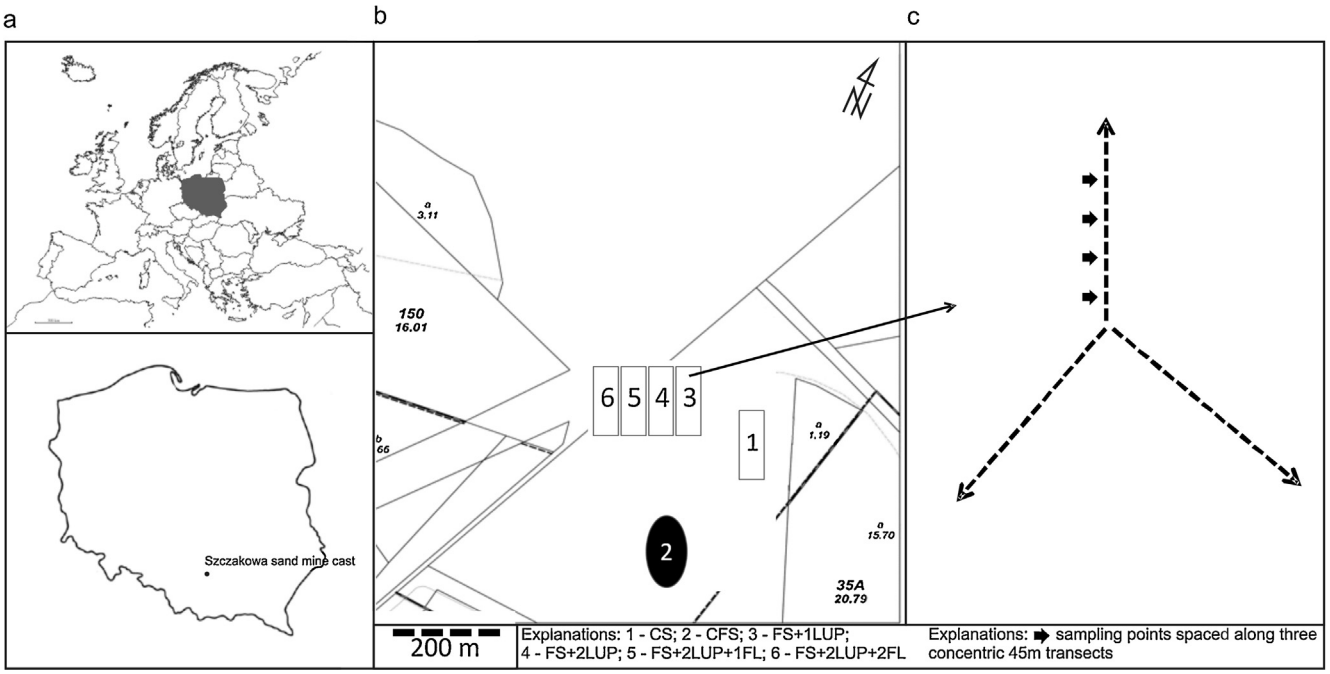

Fig. 1. (a) Localization of study area (Szczakowa sand mine cast); (b) and (c) general scheme of sampling plots in chronosequence on sand mine cast: CS - control soil (barren sand substrate); FS – forest soil additions; LUP – lupine cultivation (1 or 2-year rotation); FL – fallow fields (1 or 2-year rotation), see description in material and method section (study sites marked on the part of documentation map of Federal Forests, Chrzanów Inspectorate, Ciężkowice Forest District, Bureau of Forest Management and Forest Geodesy (BUL i GL, Krakow 2010), used with permission.

Mediterranean (Subgen. *Lupinus*) and American (Subgen. *Platycarpos*) (Kurlovich, 2002). All of these species vary in their nitrogen fixing ability.

Few studies have focused on management options that could enhance lupine growth and fix atmospheric nitrogen (Varennes et al., 2007). The role of lupine in agricultural systems, especially that of the three species native to the Mediterranean, *L. luteus and L. albus* in Europe, and *L. angustifolius* in Australia, is well documented (Brennan and Mann, 2005; Sweetingham and Kingwell, 2008). For example under North American conditions, Yellow lupine has only been used regionally, mainly in Florida (USDA PLANTS Database, 2017), and in some cases in California (Cover Crop Database, 2017). For the reclamation of post-mine sites, plants from the lupine genus can be used especially on poor sandy soils, as green manure and N-fixing species (Foy, 1997; Heinsdorf, 1999; Pietrzykowski and Krzaklewski, 2009). Lupine genus species can be used, as well, as an "in situ" phytostabilization of heavy metal polluted soils using inoculation with metal resistant plant-growth promoting rhizobacteria (Dary et al., 2010).

Forest land reclamation and reforestation is an ecologically and economically effective way to revitalize disturbed lands (Schoenholtz et al., 2000; Pietrzykowski and Krzaklewski, 2007b; Zipper et al., 2011; Pietrzykowski and Socha, 2011). Large areas (approximately 8 thousand ha) of sand mine pits in Upper Silesia (southern Poland) were reclaimed as forest over the last 40 years. Over the last 20 years several species from the lupine genus, including Large-leafed lupine (*Lupinus polyphyllus* Lindl.), Blue lupine (*Lupinus angustifolius* L.), and Yellow lupine (*Lupinus luteus* L.), are used for reclamation and GM in these areas (Pietrzykowski and Krzaklewski, 2009). However GM plays a significant role in reclamation, so far there is no detailed quantitative research that have been dedicated to application of GM with leguminous plants and its effect on SOM formation, N and C accumulation on barren sands, as a measure of effectiveness of biological reclamation management before reforestation (Pietrzykowski and Krzaklewski, 2007a; Pietrzykowski and Krzaklewski, 2009). The primary unresolved reclamation management issues concern: (1) the measurable effect of lupine green manure cropping on the initial C and N pools, (2) the optimal duration of the lupine treatments (1 or 2 years) during biological reclamation, (3) the the combined effect of lupine cropping followed by a fallow period prior to afforestation.

Thus the principal question addressed in this study was: How do C and N stocks change after forest humus enrichment + lupine treatments with respect to preparation of fields for reforestation and rehabilitation time requirements? Since this study was designed in chronosequence over a large area, we implemented a practical reclamation management that could accurately assess this question. Variables of interest were measured under similar temperate climatic conditions on barren mine sandy soils.

2.. Material and methods

2.1.1. Experimental site

The study was carried out in Upper Silesia, southern Poland (19° 26' E; 50° 16' N) on opencast sand mine sites in Szczakowa, located in the Przemsza River basin (Fig. 1). The soils in this region stem from fluvioglacial Quaternary sediment deposits (sands and gravels) surrounded by outcrops of Jurassic limestones from the Bytom basin. In general, the climate is typical for the temperate zone and is characterized by an annual average air temperature of 8 ° C with an annual average precipitation of 700 mm. Exploration in the Szczakowa opencast mine has been active since 1954. Mining creates pits 5–25 m deep, covering over 3200 ha, which have been progressively reclaimed and reforested according to reclamation technologies that have varied over time (Pietrzykowski and Krzaklewski, 2007a; Pietrzykowski et al., 2013).

Sampling sites were arranged on a sequence of areas where the current standard reclamation management had been implemented previously. This system included lupine (*L. luteus* L.) cultivation and humus enrichment (approximately 300 m^3 ha^{-1} on the surface layer) mixed with stockpiled local forest soil horizons (usually O,