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Effects of tree species on topsoil properties and nitrogen cycling in natural forest and tree plantations of northern Iran

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ABSTRACT

After 15 years, the effects of *Alnus subcordata* (AS), *Populus deltoides* (PD), *Taxodium distichum* (TD) plantations and a mixed natural forest dominated by *Quercus castaneifolia*, *Carpinus betulus* and *Parrotia persica* (QC-CB-PP) on litter quality and soil fertility were assessed in northern Iran. Sixteen samples per stand were taken from the forest floor and top 10 cm of soil. Litter quality differed among the tree species, showing the highest N concentration (1.85%) and lowest C (39.43%) in the AS stand. Sand, clay and water content did not differ for the tree species, but soil bulk density were highest in AS (1.59 g cm^{-3}) ≈ PD (1.56 g cm^{-3}) and silt content peaked in QC-CB-PP (47%). Soil pH (7.16), EC (0.29 dS m^{-1}), total N (0.34%), available P (24.6 mg kg^{-1}), available K (337.4 mg kg^{-1}), available Ca (256.3 mg kg^{-1}), available Mg (57.4 mg kg^{-1}), earthworm density (3.5 individuals m^{-2}), earthworm biomass (42 mg m^{-2}) and microbial respiration (0.48 mg CO_2-C g $soil^{-1}$ day^{-1}) were significantly higher in the AS stand. In contrast, higher contents of soil organic C (2.58%) and C/N ratio (28.70) were found in the TD stand. The fine root biomass varied among the study sites in the ranked order of QC-CB-PP (94.2 g m^{-2}) > PD (65.1 g m^{-2}) ≈ AS (64.6 g m^{-2}) > TD (36.9 g m^{-2}). Negative nitrification rates were observed in all forest types. Net soil ammonification and N mineralization rates were significantly higher in the AS (0.46 and 0.31 mg kg^{-1} d^{-1}, respectively) than in the PD (0.22 and 0.08 mg kg^{-1} d^{-1}, respectively), QC-CB-PP (−0.07 and −0.24 mg kg^{-1} d^{-1}, respectively), and the TD (−0.07 and −0.26 mg kg^{-1} d^{-1}, respectively) sites. Our study reveals the differential impacts of tree species on the physical, chemical, and biological properties of the topsoil. In particular, planting N_2-fixing *Alnus subcordata* can help increase soil fertility in northern Iran.

1. Introduction

Forest plantations have become common in landscapes all over the world (Kooch et al., 2012). For instance, in 2000, forest plantations occupied 116 million hectares in Asia, 32 in Europe, 28 in America, and 8 in Africa (Nsabimana et al., 2008). In addition to timber and non-timber (e.g. fruit and latex) production, tree plantations can provide other important ecosystem services, such as regulation of water flow, improvement in soil fertility, and carbon sequestration (Humpenoder et al., 2014). In this respect, differences between N-fixing and non-N-fixing species, between gymnosperms and angiosperms, and between native and exotic species are often highlighted (Hoogmoed et al., 2014). The litter on forest floor acts as a sink and source of nutrients, and the rate at which forest litter falls and decays, regulates the energy flow, primary production, and nutrient cycling in forest ecosystems (Scheibe et al., 2015). The quality of the litter layer determines its decomposition rates (Zhang et al., 2015), the amount of nutrient absorption by the plant's root system, the degree of interception of atmospheric depositions, and the interaction between the arboreal layer and the rainfall (Levia and Herwitz, 2005). The consequent impacts of these processes on soil properties differ depending on quality of litter produced by different tree species (Hagen-Thorn et al., 2004).

The physical properties of forest soils develop under natural conditions by the influence of permanent vegetation over a long period of time. These properties may be almost permanent characteristics unless modified by harvesting operations, forest fires and changes in tree species composition (Osman, 2013). Additionally, there is evidence that plantation leads to significant changes in the chemical properties and biochemical cycles of soils (Hoogmoed et al., 2014). According to Binkley and Valentine (1991), the influence of various tree species on soil pH is significantly relevant to the first 10 cm beneath the layer of litter. Studies have shown that soil pH and the amount of exchangeable cations can be positively influenced by the type of tree species (Mohr et al., 2005). Oulehle et al. (2007) observed a stronger acidification of the soil in coniferous than in broad-leaved tree stands due to their differences in litter quality. A higher C/N ratio, lower pH and lower nutrient content in the soil as well as an increase in toxic Al^{3+} content in soil water were also observed in coniferous rather than in hardwood forests (Barbier et al., 2008).

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Earthworm biomass is an appropriate biological indicator of litter quality, soil fertility and habitat productivity (Nachtergale et al., 2002). According to Tian et al. (2000), tree plantations may influence earthworm abundance by altering the physicochemical properties of soils, such as the temperature, moisture regime, pH, soil organic content (SOC) and litter inputs. Similarly, soil microbial respiration (SMR) has also been described to be influenced by tree species and site fertility (Butnor et al., 2003). Fine roots exert an important impact on carbon allocation and nutrient cycling of below-ground ecosystems (Sah et al., 2011). Thus, fine root production and turnover have a direct impact on biogeochemical cycles in terrestrial ecosystems (Jha and Mohapatra, 2010). Vogt et al. (1996) have suggested differences in fine root biomass between evergreen and deciduous forests, but these differences may not be so clear. Also, higher fine root biomass were recorded in needle leaf and broad leaf forests according to the cited works by Jackson et al. (1997) and Noguchi et al. (2007), respectively.

Afforestation has been reported to either cause significant alteration in soil N mineralization (Li et al., 2014) or to have a negligible effect on soil N mineralization (Zeng et al., 2009). Soil N transformation (i.e., mineralization, ammonification and nitrification) is a microbial process regulated by SOM contents and changes in SOM inputs resulting from afforestation; therefore, these potentially lead to differences in soil N mineralization (Templer et al., 2005). Abiotic factors (e.g., soil temperature, moisture and pH) exert important influences on soil N dynamics following reforestation (Li et al., 2007; Shan et al., 2011; Yao et al., 2011). The use of N-fixing tree species in forest restoration greatly affects the rates of N mineralization and other N transformations (Knops et al., 2002).

The quality and quantity of forest litter would indirectly control the transformations of soil N (Li et al., 2014). The differential influence of broad-leaved and coniferous tree species on N mineralization rate has been revealed by Xiong et al. (2014). Soil N mineralization also affects the production of trace gases in natural ecosystems (Davidson et al., 1993), and alters N cycling routes. For example, by enhancing net soil N nitrification, soil N mineralization can result in increased nitrate losses (Wright and Rasmussen, 1998). The temporal pattern of soil N mineralization should be documented to gain a better understanding of the mechanisms underlying the role of N in the function of a particular ecosystem. Based on a closer examination of changes in soil properties over time, following the establishment of different tree species is necessary to understand the mechanisms responsible for changes in SOC and nutrient availability, which, in turn, will assist in the development of effective, long-term strategies to maintain soil quality and fertility. Our case study aimed to investigate the effects of broad-leaved and coniferous tree species on the physical, chemical, and biological properties of the topsoil in the natural forest and tree plantation systems, under the temperate climate of northern Iran.

2. Materials and methods

2.1. Site characteristics

Investigations on forest plantation projects in northern Iran have shown that about 200,000 ha of degraded forests have been reforested; of which 40,000 ha consist of needle-leaved species of plants (Kooch and Zoghi, 2014). Forest plantation is the main method for rehabilitation of degraded forests in Caspian region, requiring a comparative evaluation of planted and natural forests. The study area is located at the Mahmudabad experiment station in Mazandaran Province of northern Iran (36° 38′ N, 52° 16′ E; Fig. 1). The experimental plots were located at an altitude of 30 m above sea level. The area is on a flat and uniform terrain with low slope (0–3%). Annual mean rainfall is 803 mm with wet months between September and February and a dry season from April to August. Typical average monthly rainfall is <40 mm. Average daily temperatures vary from 11.7 °C in February to 29.5 °C in August. The soils are deep, moderately well-drained, and stone-free with organic matter of 1–3% prior to planting. They have silty clay loam and clay loam textures with a pH of 6.0–7.5 and $CaCO_3$ of 0–15%. The soil order name is Alfisols. Approximately 50 years ago, this area was dominated by natural forests containing native tree species such as oak (*Quercus castaneifolia* C. A. M. *macranthera* F. & M.), hornbeam (*Carpinus betulus* L.), ironwood (*Parrotia persica* C. A. Meyer), and some individual trees of Caspian zelkova (*Zelkova carpinifolia* (Pall.) Dipp.) and Caspian locust (*Gleditschia caspica* Desf.). The surrounding area is dominated by agricultural fields and commercial buildings. In 1999, the dominant forest types, planted at a spacing of 4 × 4 m, included alder (*Alnus subcordata* C. A. M.) (AS), eastern cottonwood (*Populus deltoides* L.) (PD), and bald cypress (*Taxodium distichum* L. Rich.) (TD) stands. The stands were never fertilized. The study areas show very similar climatic conditions and management practices. Table 1 summarizes the detailed vegetation information of the forest types (Soleimany, 2014).

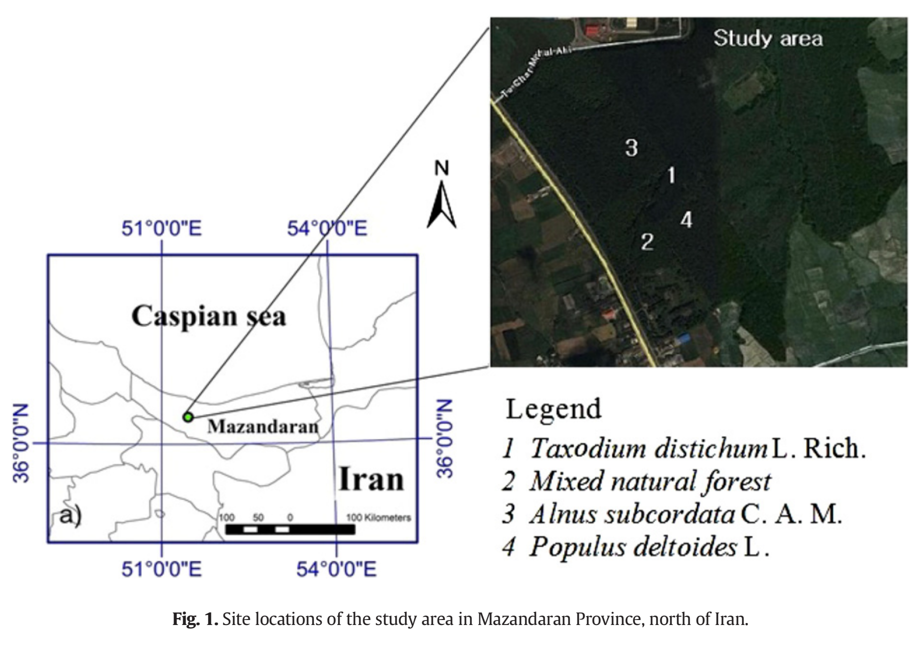

Fig. 1. Site locations of the study area in Mazandaran Province, north of Iran.