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Soil type mediates effects of land use on soil carbon and nitrogen in the Konya Basin, Turkey

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ABSTRACT

Objective: The goal of this study was to test for the effects of land use and soil type on soil organic carbon (SOC) and total soil nitrogen (N) stocks in an arid region with a long history of cultivation and animal husbandry. Arid to semi-arid landscapes cover a large proportion of the Earth's surface and are sensitive to agricultural intensification and projected changes in climate, yet data on landscape controls on SOC and N remain scarce.
Methods: We used a state factor approach to study the effects of soil type and land use on surface SOC and total soil N (0–25 cm) across 35 sites in a 200 km^2 area in the Konya Basin, an important agricultural region of Turkey. Using Landsat-based land cover maps, we identified three representative land uses – annual-crop agriculture, orchards and grazing lands – stratified across Aridisols formed on three different parent materials: alluvial clay-loam, lacustrine clay and terrace sandy loam soils.
Results: SOC and N stocks depended strongly on soil type with strong interactions between soil type and land use. On alluvial soils, grazing land SOC and N stocks were 37% and 23% greater, respectively, than those of agricultural sites and 63% and 50% greater than at orchard sites. In contrast, agricultural sites on lacustrine soils contained 41% more SOC and 42% more soil N. There were no land use effects on terrace soils. The vertical distribution in SOC and N within the top 25 cm, representing the plow layer in the agricultural sites, differed by soil type and land use.
Conclusions: Soil type best explained landscape-scale variability of SOC and N stocks. Interactions between soil type and land use indicate that the long-term effects of land use on SOC and N were mediated by soil type. Differences in SOC and N stocks across soil types even within the same soil order highlight the importance of identifying pedogenic differences in soil properties, such as texture and mineralogy, which can influence the response of SOC and N to land use.
Practice implications: Our study contributes baseline data on SOC and N for a semi-arid region, which can be used to aid development of landscape-scale models of SOC and N dynamics and inform land management. Our data reveal that assessments of regional land use effects on SOC and N in arid to semi-arid environments should account for landscape to regional variability in soils developing on different geomorphic surfaces and parent materials.

1. Introduction

Arid and semi-arid ecosystems cover about 41% of the global land surface, are home to 38% of the world's human population and produce regionally and globally important quantities of cereals and livestock products (Koohafkan et al., 2008; Reynolds et al., 2007). Population growth and rising demand for food and biofuels are driving intensified agricultural and livestock production, worldwide (Koohafkan et al., 2008). Expansion and intensification of agriculture and grazing in arid to semi-arid regions have contributed to increased salinization, soil erosion, and loss of soil nutrients, threatening continued productivity (Evrendilek and Ertekin, 2002; Lal, 2002a; Matson et al., 1997; Reynolds et al., 2007). Availability of data at landscape spatial scales (10 s–100 s km^2) to assess net effects of long-term land use on the current state of soil organic carbon (SOC) and soil nitrogen (N) is limited in arid to semi-arid regions. Such baseline data are necessary to understand the effects of multiple land uses across diverse regional soil types, validate landscape-scale models of SOC and soil N dynamics,

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and determine best management practices for soil conservation and the potential for C sequestration (Stockmann et al., 2013).

In arid to semi-arid ecosystems, concentrations of soil nutrients and SOC show high spatial variability, which is often attributed to patchiness of vegetation (Wiesmeier et al., 2009) and are generally lower than in more humid ecosystems (Lal, 2002a; Schlesinger et al., 1996; Vinton and Burke, 1995). At regional and landscape scales, variations in soil texture and mineralogy due to topography, geomorphology and parent material differences affect processes such as soil aggregation and organo-mineral complexation that protect soil organic matter from decomposition and lead to the accumulation of SOC and N (Bouajila and Gallali, 2010; Kölbl et al., 2011; Palm et al., 2007; Schmidt et al., 2011; Six et al., 2002).

Previous research on the effects of agriculture and animal husbandry in arid and semi-arid steppe and grassland ecosystems generally has reported reductions of SOC and N stocks in intensively used sites compared to less intensively managed soils (Conant et al., 2001; Reynolds et al., 2007; Schlesinger et al., 1990). Reductions in plant litter inputs and soil structure disruption due to overgrazing and mechanized cultivation can lead to erosion and SOC losses (Conant and Paustian, 2004; Lal, 2002b; Matson et al., 1997). On the other hand, practices such as rotational grazing and reduced tillage can lead to SOC and N recovery (Alvaro-Fuentes et al., 2009a,b; Ryan et al., 2008; Zibilske et al., 2002; Ziter and MacDougall, 2013).

Currently, there is limited understanding of the within-landscape variability of SOC, N and other biogeochemical properties and of the effects of multiple land uses on SOC and N stocks in many arid to semi-arid ecosystems (but see Wiesmeier et al., 2009, 2011, 2013). National and landscape-scale models that estimate SOC and N based on biogeoclimatic variables alone (e.g., Evrendilek et al., 2007 for Turkey) and models that quantify land use effects at the farm scale (e.g. CENTURY, Roth-C) require validation with appropriate landscape-scale environmental data (Stockmann et al., 2013). In a recent study in Tunisia, Bouajila and Gallali (2010) reported variations in SOC by nearly 50% across soil types, and by a factor of six across land use conversions from forest to grazing and agricultural lands. Such data help provide a scientific basis for land managers to structure agricultural development plans or prioritize regions for soil conservation efforts, and for ecosystem modelers to estimate the consequences of land-use change for local soil fertility or globally relevant soil greenhouse gas emissions.

The objective of our study was to examine the influence of land use and soil type on SOC and N in the Great Konya Basin of south central Turkey, an arid landscape with a long legacy of agriculture and animal husbandry. We measured soil bulk density, pH, total C, SOC and total N to a depth of 25 cm at 35 field sites stratified across three representative land uses – agriculture, grazing and orchard cultivation – and soils developed on three different parent materials. This is one of the first landscape-scale studies in the region that addresses both land use and pedogenic effects on soil properties. In Turkey, between 54 and 87% of all lands and 76% of agricultural lands are estimated to be vulnerable to erosion, with hazards for land degradation highest in marginal inland regions that are farmed and grazed intensively (Cangir et al., 2000; Lal, 2002a). The lack of spatially explicit, empirical data on soil C and N in the Konya Basin—an important region for cereal and livestock production in Turkey—limits evaluations of land use and soil conservation management.

2. Methods

2.1. Study area

We focused our research on the eastern portion of the Konya Basin, around the city of Eregli in Konya Province, located in south-central Turkey (Fig. 1). Regional climate is temperate and arid, classified as cool temperate steppe by Holdridge life zone. Mean annual temperature was 10.7 °C and precipitation was 326 mm for the 1960–1990 period (CRU, 2010). Complex geology and a long legacy of human land use make the Konya Basin an ideal natural laboratory for studying the effects of land use and soil parent material on soil carbon and nitrogen within the same climatic region.

The basin's geological history has yielded a landscape with diverse soils occurring in an area with fairly uniform modern-day climate conditions. The basin is tectonic in origin, bounded to the south by the Taurus Mountains, composed of late Cretaceous limestones, sandstones, shales and metamorphic strata, and to the north by the Pontic Mountains and Karapinar volcano fields, composed of Tertiary–Quaternary volcanic materials, and bordered by Neogene limestone terraces (De Meester, 1970). During the Pleistocene, much of the basin center was covered by a shallow lake. With weathering and sedimentation, portions of the basin have collected mixtures of geologic materials eroded from marine strata, volcanic deposits and carbonate-rich lacustrine sediments, on which a variety of soils have developed. We studied three different soils derived from alluvial, lacustrine and volcaniclastic-limestone materials on terraces, all classified as Aridisols, which differ in their soil texture, landscape position and other properties (Fig. 1; Table 1; De Meester, 1970).

The Konya Basin has a long history of human land use. One of the largest Neolithic settlements found to date in western Asia is located at Catalhuyuk between Eregli, Karapinar and Karaman, and dates back to 7500 BC (Boyer et al., 2006; Zeder, 2011). There is evidence of significant animal husbandry activities from excavations around Catalhuyuk and debated domestication of cattle (Zeder, 2011). Agriculture has been widespread in the Konya Basin at least since the Hittite period (1200 BC), but probably earlier. As of 2000, the population of the Konya Basin was over one million people (KPCC, 2012). Konya Province, of which the Konya Basin is a large part, is the largest gross producer of wheat among all provinces in Turkey and contributes 10% of Turkey's total agricultural production (KPCC, 2012). Aside from urban centers, which currently occupy a small portion of the basin area, the three dominant land-use activities in the basin are agriculture, livestock grazing or herding, and orchard cultivation (Mayes, 2011). Agriculture and grazing practices are similar throughout the study area (Table 1). Grazing occurs almost everywhere outside of the cities, except in fenced fields and orchards. On alluvial soils, often near or within towns such as Eregli, fruit orchard cultivation is an extensive and economically important activity.

2.2. Identification of field sites

Following a state factor approach (Barthold et al., 2013; Jenny, 1994), we focused on parent materials and land use as independent variables affecting soil properties, and attempted to control for the variability of the remaining state factors (relief, climate, time) in the selection of our field sites. We used a GIS to identify prospective locations where agriculture, grazing and orchard cultivation occurred on the soil parent materials of interest, and a combination of geospatial analyses, interviews and field observations to select the sites. Areas of interest were located by overlaying a digitized, 1:200,000-scale soil map of the Konya Basin (De Meester, 1970) with a new satellite-derived land cover map, based on multi-temporal classification of Landsat-TM satellite imagery for years 2006–2007 (Mayes, 2011). We restricted prospective regions for field sites by elevation (between 950 and 1100 m above sea level) and slope (between 0 and 3%) to control for relief, using digital elevation data from the Shuttle Radar Topography Mission (Mayes, 2011). These analyses made the landscape-scale problem tractable by isolating three regions where all parent material–land use combinations could be found, while relief and climate were reasonably controlled.

We collaborated with the City Engineer's Office in Eregli and interviewed farmers to identify field sites within our regions of interest whose land use practices were representative of general farming, grazing or orchard cultivation practices in the area. We restricted our criteria for field sites to control for confounding variations in land management practices as much as possible, particularly time. For agriculture sites, we