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The potential activity of soil extracellular enzymes as an indicator for ecological restoration of rangeland soils after agricultural abandonment

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A B S T R A C T

Extracellular enzymes play an important role in soil biochemical reactions and biogeochemical cycles. However, the response of soil extracellular enzyme activities to cultivation abandonment and vegetation restoration is poorly studied for the high altitude semi-arid rangeland ecosystems in Central Iran. The objective of this study was to evaluate the influence of cultivation abandonment on soil enzyme activity as an indicator of soil quality and health along a chronosequence of abandoned agricultural fields in a semi-arid rangeland ecosystem. The potential activity of soil enzymes; including invertase, urease, alkaline phosphatase and arylsulphatase was assayed and expressed as activity per unit dry soil mass (i.e., absolute activity) and per unit microbial biomass (i.e., specific activity) along a sequence of cultivated, abandoned for 4–45 years and uncultivated rangelands. After agricultural abandonment, the absolute enzyme activities increased logarithmically. Cultivation abandonment for 45 years, on average, increased invertase activity by 44%, urease activity by 45%, alkaline phosphatase activity by 11% and arylsulfatase activity by 43% in top soil (0–30 cm). Results showed that the geometric mean of enzyme activities (GMea) increased significantly with increasing abandonment time. However, the specific activities of soil enzymes tended to decrease logarithmically, when expressed per unit microbial biomass carbon (MBC). The increases in absolute activities were largely related to changes in plant aboveground biomass, soil organic carbon (SOC), aggregate stability (AS) and MBC whereas the decreases in specific activities could be associated with alterations only in AS and SOC contents. In conclusion, enzymes produced and released by soil microbial communities after cultivation abandonment and natural vegetation restoration would interact with soil organic matter and aggregates. After cessation of rainfed cropping and the recovery of natural vegetation, the increases in soil enzyme activity can result in a higher nutrient cycling in the degraded rangeland ecosystems.

1. Introduction

Agricultural abandonment takes place worldwide and is a common land use change process in mountainous regions with unfavorable conditions for agricultural activity (Romero-Díaz et al., 2017; van der Zanden et al., 2017). Land abandonment can have both positive and negative effects on ecosystem processes and services, depending on the region, climate and scale (Osawa et al., 2016; Novara et al., 2017; Romero-Díaz et al., 2017; van der Zanden et al., 2017). Cultivation abandonment can result in a rapid re-establishment of natural vegetation with considerable changes in plant cover and community composition; and increases in biomass production (Zhao et al., 2005; Romero-Díaz et al., 2017), leading to an increase in the organic inputs as above- and below-ground plant carbon (C) over time (Shang et al., 2014; Novara et al., 2017; Yu et al., 2018). There is increasing evidence that the abandonment of agricultural activities in rangeland and grassland ecosystems is a means to restore natural plant community with a consequence for improvements of soil conditions, quality and C sequestration (Zhao et al., 2005; Raiesi, 2012; Shang et al., 2014; Novara et al., 2017; Romero-Díaz et al., 2017; Yu et al., 2018).

Changes in vegetation cover, soil organic matter (SOM), soil structure and environmental conditions after agricultural abandonment have an important impact on the recovery of soil microbiological and biochemical attributes such as microbial activity, biomass and diversity, and enzyme activities (Zhao et al., 2005; Jiang et al., 2009; Raiesi, 2012; Shang et al., 2014). Soil microbiological and biochemical properties have often been proposed as primary and sensitive indicators to detect the influence of land use changes or restoration processes on native rangeland soils and other natural ecosystems (Trasar-Cepeda et al., 2008; An et al., 2009; Wang et al., 2011). On the other hands, changes in soil microbial biomass and enzyme activities would reflect modifications in SOM stocks and other soil properties (Dick and

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Tabatabai, 1993). Both microbial biomass and enzymes play an important role in nutrient cycling, C dynamics, and development and function of the soil system, and are intimately linked to the primary productivity of an ecosystem (Jiang et al., 2009).

The activity of soil enzymes after the re-establishment of natural species was greater in the abandoned farmlands than that in the cultivated lands in the Loess Plateau of China (Wang et al., 2011). The abandonment of agricultural activity resulted in the recovery of soil hydrolase activities including ureases, proteases, β-glucosidase and phosphatases in a semiarid Mediterranean climate (Garcia et al., 1997). The underlying mechanisms by which cultivation abandonment or conversion of croplands to grasslands influences soil enzyme activity could primarily be due to the increased SOM stocks, microbial biomass pool and improved soil aggregate stability (Garcia et al., 1997; Jiang et al., 2009; Wang et al., 2011; Yu et al., 2018). The activities of most soil enzymes increased during secondary succession because of increases in SOM, microbial biomass and aggregate stability (Jiang et al., 2009). An increase in soil microbial biomass after cultivation abandonment resulted in acceleration of soil enzyme activities due to better soil conditions and aeration conditions in abandoned croplands (Wang et al., 2011). Following cessation of agricultural practices and the restoration of natural vegetation in rangelands, enzyme protection may increase, probably due to the sorption of enzymes and their substrates to mineral or organic surfaces and their entrapment and inclusion within stable aggregates (Fansler et al., 2005; Allison and Jastrow, 2006). Accordingly, enzyme activities decline with increasing soil macro-aggregates, which physically protect extracellular enzymes (Fansler et al., 2005; Allison and Jastrow, 2006). This could be an important mechanism for C accumulation and sequestration during secondary succession (Allison and Jastrow, 2006). The increased enzyme activity with plant recovery could also be due to the increased substrates produced by the newly established vegetation and their secretions by actively growing roots (Garcia et al., 1997; Zhang et al., 2012).

In a previous study (Salek-Gilani et al., 2013), significant increases in soil organic carbon (SOC), microbial biomass and aggregate stability were observed following cultivation abandonment in high altitude semi-arid rangelands of Central Iran. Nevertheless, the influence of agricultural abandonment on the potential activity of soil extracellular enzymes is still not clearly understood in these rangelands. Therefore, the objective of this study was to investigate the absolute and specific activities of four soil enzymes including urease, invertase, alkaline phosphatase and arylsulphatase, involved in N, C, P and S cycles, respectively; in a semi-arid rangeland with different times of rainfed cropping and abandonment history in Central Iran. In the semi-arid highlands of Central Iran, conventional smallholder cropping systems on native rangelands are widespread. This type of farming activity is characterized by rainfed monoculture of wheat (*Triticum aestivum* L.), and to a lesser extent of barley (*Hordeum vulgare* L.), using mechanical tillage combined with very limited returns of organic residues. Crop residues are grazed by livestock or hayed and stored for fodder. Under these conditions, bare soils are exposed to intense and inconsistent rain showers during winter and winds during summer. Intensive tillage causes the gradual loss of SOC and stable aggregates, leading to soil erosion and compaction in the long-term (Salek-Gilani et al., 2013). It was hypothesized that the abandonment of rainfed cropping systems in these native rangelands (1) would increase soil enzyme activities due to the enhanced SOC contents, aggregate stability and microbial biomass level and (2) enzyme activity expressed per unit of soil microbial biomass (i.e., specific activities) could be a suitable indicator for detecting the efficacy of rangeland restoration following agricultural abandonment. Ratios of extracellular enzyme activities to microbial biomass can be used as an index to indicate the metabolic activity of a microbial community in the soil (Waldrop et al., 2000; Katsalirou et al., 2010). Furthermore, the geometric mean of enzyme activities (GMea) was also used as a soil quality index (García-Ruiz et al., 2008; Wang et al., 2012b; Raiesi and Kabiri, 2016); deeming it is a sensitive soil property to land use changes and agricultural practices (Wang et al., 2012b).

2. Materials and methods

2.1. Description of the study area

The study area is located in semi-arid rangelands of Karsanak region (32° 31′ N and 50° 28′ E; 2570 m above sea level) in Chaharmahal and Bakhtiari province, Central Iran. The mean annual precipitation is 420 mm (mainly in winter and spring), and the annual mean temperature is 12 °C with the average minimum of 1.8 °C and the average maximum of 21 °C. In the area, landscapes are covered by mosaic of native grazing (uncultivated) rangelands consisting of three major vegetation types (i.e., *Astragalus adscendens*, *Agropyron repens* and *Bromus tomentellus–Agropyron repens*), cultivated and abandoned rangelands. Rainfed cropping systems, particularly wheat (*Triticum aestivum* L.), in these native rangelands is very common. Over the last five decades, cultivation abandonment following cessation of agricultural practices occurred in these rangeland ecosystems mainly due to the low productivity of wheat, the regular migration of local farmers and the shortage of water as a result of recent droughts and low rainfall. During the last 40 years, large areas of these rangelands have been converted to protected lands by the government, and local farmers are not allowed to cultivate. Based on data and information on land use history and current management practices gathered from local farmers and shepherds, historical records and aerial photos, all abandoned and cultivated rangelands have experienced similar tillage and cultivation practices (conventional tillage) in the years prior to abandonment time, and they were used for many decades (> 100 years) as croplands.

2.2. The experimental setting

Five different land uses were selected in a long-term chronosequence of cultivated, abandoned and uncultivated rangelands, all on similar soil type. One land use was cultivated rangelands that are currently cultivated with rainfed wheat and have never been abandoned. Three of the land uses were abandoned rangelands for 3–4, 10–12 and 30–45 years. The fifth land use was permanent rangelands uncultivated for more than 100 years, which were selected as a reference site. For simplicity, the maximum time of cultivation abandonment (i.e., 4, 12 and 45 years) was considered for each land use to analyze data. In selecting these land uses, care was made for the consistency in identical topographical features. Generally, the soil of the study area is a Typic Haploxerept with a silty loam texture for cultivated rangelands and silty loam or loam texture for abandoned and uncultivated rangelands. The experiment was a completely randomized design with five land uses; each replicated three times (i.e., three 50 m × 50 m plots for each land use). Spatially separated plots of each land use were selected within a distance of 1–3 km. The existing undecomposed, dead plant residues (including freshly fallen, intact grass leaves, twigs and stems) on the soil surface from previous growing seasons were removed before soil sampling.

2.3. Soil sampling and analysis

Six individual soil samples were taken at two soil depths (0–15 and 15–30 cm) for each land use in May 2014 and were mixed thoroughly to obtain a composite sample. In total, 30 composite samples were collected, including 5 land uses, 2 soil depths and 3 replicates. Plant fragments and visible rock fragments larger than 2 mm were removed by hand. Field-moist soil samples were passed through a 2-mm sieve and stored at 4 °C in the dark before laboratory analysis. Previous studies at the same site (Salek-Gilani et al., 2013) reported changes in soil organic carbon (SOC), soil aggregation (mean weight diameter, MWD) and soil microbial biomass C (MBC) after agricultural abandonment