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Soil specific enzyme activity shows more clearly soil responses to paddy rice cultivation than absolute enzyme activity in primary forests of northwest Iran

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ABSTRACT

Land use changes are recognized to affect soil organic carbon (OC) and other soil properties with a consequence for microbial biomass and enzyme activities. The activities of five soil enzymes (i.e., urease, invertase, alkaline phosphatase, acid phosphatase and arylsulfatase) and soil microbial biomass carbon (MBC) contents were measured in croplands (lowland rice fields) and adjacent natural forestlands with similar soil type in Paresar area located in northwest Iran. Results showed that the quantity of MBC decreased (44%) with land use changes only at the 0–20 cm depth, but without a significant change in the microbial quotient (MBC/OC). The decreased MBC was the result of a significant decline in soil OC contents and aggregate stability in cultivated fields derived from forestlands. The absolute activities of all soil enzymes (i.e., activity per dry soil mass) remained unaffected by land use changes. However, the soil specific enzyme activities expressed either per unit of OC or MBC tended to increase (24–32% per OC unit and 22–32% per MBC unit) consistently with conversion of forestlands to croplands. Higher enzyme activities per unit of OC may reflect the release of immobilized enzymes following land use conversion. The greater enzyme activities per unit of MBC in croplands than in forestlands may imply metabolically more active microorganisms in cropland soils or increased enzyme efficiency (i.e., greater enzyme synthesis by the soil microflora). This study demonstrates that the enzyme activity per unit of OC or MBC may be a suitable indicator for detecting the effect of land use changes on soil microbial community and even losses of soil organic matter (SOM) in these humid forest ecosystems. When forestlands are cultivated with rice crop, the concurrent release of both the organic substrates and enzymes entrapped within soil aggregates may be an important mechanism for SOM losses. In conclusion, the specific enzyme activity reveals more evidently soil responses to land use changes than the absolute enzyme activity, and changes in the specific enzyme activities should therefore provide a practical means to detect modifications in soil biochemical processes, when native forests are converted to paddy rice fields in this environment.

1. Introduction

Conversion of forests to croplands is an important human intervention in natural ecosystems worldwide, since it is commonly accompanied by significant changes in ecosystem processes and functions such as net primary production and carbon (C) sequestration (Guo and Gifford, 2002; Khormali et al., 2009; Beheshti et al., 2012). This type of land use changes frequently results in changes in plant cover, composition and biomass (Solomon et al., 2002), decreased soil organic matter (SOM) inputs and organic carbon (OC) pools (Golchin and Asgari, 2008; Beheshti et al., 2012) with subsequent modifications in soil physiochemical properties (Chaer et al., 2009; Khormali et al., 2009; Beheshti et al., 2012). All these effects can be reflected by alterations in most microbiological and biochemical soil properties (Raiesi, 2006; An et al., 2008; Chaer et al., 2009).

Soil enzyme activities (EA) are important indicators of microbiological and biochemical processes because they are often involved in SOM decomposition and synthesis, nutrient cycling and availability, and biodegradation of toxic organic pollutants (Dick, 1997; Nannipieri et al., 2002). The activities of soil enzymes are regularly used as indicators of soil fertility and quality (Dick, 1994; Bastida et al., 2008; Trasar-Cepeda et al., 2008), and provide integrative information on the biochemical processes in the soil (Dick, 1997). In particular, enzyme activities are significant because of their rapid response to changes in the soil environment, and because their

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assay is easy, rapid and inexpensive to determine (Dick, 1997). Soil enzyme activities were assayed for their potential to reflect the effects of tillage, land use changes and cultivation on soil quality (Salam et al., 1999; Acosta-Martinez et al., 2003; An et al., 2008), and there has been growing evidence that enzyme activities are potential early and sensitive indicators of changes in soil conditions and properties after deforestation (Chaer et al., 2009; Gamboa and Galicia, 2011). However, the activities of soil enzymes have been reported to be greatly and differently affected by land use changes and agricultural practices (Salam et al., 1999; Acosta-Martinez et al., 2003; An et al., 2008; Trasar-Cepeda et al., 2008; Chaer et al., 2009; Lagomarsino et al., 2011; Wang et al., 2012).

The assay of soil enzyme activities can be used as a suitable indicator for quantifying and monitoring changes in microbial community structure and activity as well as SOM dynamics in response to anthropogenic disturbances (Bandick and Dick, 1999; Trasar-Cepeda et al., 2008). The microbial community composition and biomass size determine directly or indirectly the potential for enzyme synthesis and production, and thus any alteration in soil microbial community due to human intervention and disturbances should be reflected in the level of soil enzymatic activities (Dick and Tabatabai, 1993; Dick, 1994; Waldrop et al., 2000; Nannipieri et al., 2002). However, considering the link between soil microbial community and enzyme production, the total enzyme activities in the soil are due to the contribution of both extracellular and intracellular enzyme activities (Dick, 1997; Nannipieri et al., 2002). Extracellular enzymes are immobilized by clay and humic particles (Benitez et al., 2005) and can thus be protected against proteolysis, maintaining their activity even when soil microorganisms do not exist or environmental conditions are unfavourable for soil microorganisms (Nannipieri et al., 2002). Nevertheless, the complex functioning of soil enzymes raises some doubts about the use of enzyme activities as indicators of soil degradation resulted from land use changes and agricultural practices (Trasar-Cepeda et al., 2008; An et al., 2008).

Generally, the activity, persistence and stability of soil enzymes are often affected by vegetation composition, management practices, soil pH, microbial biomass, SOM, soil moisture content and temperature, aggregate stability and compaction (Acosta-Martinez et al., 2007; Sinsabaugh et al., 2008; Song et al., 2012). These factors are all influenced by land use changes, especially conversion of forestlands to croplands (An et al., 2008; Chaer et al., 2009; Beheshti et al., 2012). However, the effect of forest conversion to agricultural systems on soil enzyme activities much depends upon soil and climatic conditions of the environment, plant community type, the time frame one considers and the type of land use replacing forests. In addition, all soil enzymes are not affected by land use type and changes in the same direction; one could be more affected than others (Trasar-Cepeda et al., 2008; Wang et al., 2012).

In general, soil enzyme activities can be expressed as either absolute activity; i.e., per unit of oven-dry soil mass or specific activity; i.e., per OC (Acosta-Martinez et al., 2003; Trasar-Cepeda et al., 2008; Lagomarsino et al., 2011; Wang et al., 2012) and MBC (Landi et al., 2000; Allison et al., 2007; Lagomarsino et al., 2011) units. Many authors have reported positive correlations between the absolute activities of soil enzymes and the microbial biomass and organic matter contents (Acosta-Martinez et al., 2003; Nsabimana et al., 2004; Wang et al., 2011). The link between the absolute activities of enzymes and microbial biomass in the soil profile reveals that the enzymes are of microbial origin (Acosta-Martinez et al., 2003; Nsabimana et al., 2004), while its link with SOM shows that extracellular enzymes can be bound on clay minerals and be stabilized by SOM via the formation of enzyme-clay or enzyme–humus complexes (Nannipieri et al., 2002; Benitez et al., 2005; Bastida et al., 2012). In addition, the microbial biomass is highly inter- or auto-correlated with organic matter contents (Nsabimana et al., 2004; Wang et al., 2011). This may mask the individual effect of either microbial biomass or SOM on enzyme activity. Consequently, with absolute activity, it is not possible to ascertain whether the observed differences in the soil enzyme activities are a result of the difference in microbial biomass and organic matter contents in the soils or the actual difference in enzyme activity (Trasar-Cepeda et al., 2008; Wang et al., 2012). One way to reconcile this issue is to express enzyme activities per either OC or MBC units (i.e., EA/OC and EA/MBC ratios, the so-called specific activity), to decouple the changes in soil enzyme activities from the changes in OC or MBC contents. On the other hand, specific activities of soil enzymes can be useful to eliminate their strong covariance with SOM and MBC. Expressing activity on an organic matter basis shows a microbial property, as it expresses the nutritional status of the organic matter with regard to soil microorganisms (Wang et al., 2012). This expression could be used to account for differences in soil OC contents, allowing a reliable comparison of soils under different types of use (Trasar-Cepeda et al., 2008). Cultivated soils showed greater values of soil enzyme activities per unit of OC than the native forest soils affected by human activities (Trasar-Cepeda et al., 2008; Wang et al., 2012). Enzyme activity per unit of OC was high in the soil of low organic matter content (Wang et al., 2012). The enzyme activities expressed per unit of MBC represent the metabolic status of the microbial community, fluctuations in the stabilized extracellular enzyme activity (Landi et al., 2000; Nsabimana et al., 2004) or may correlate with microbial community composition (Waldrop et al., 2000). Greater enzyme activities per unit of MBC size may result from the increased enzyme synthesis and production by soil microorganisms, the release of enzymes immobilized by clay and humic particles, the release of enzymes entrapped within soil aggregates, or an increase in the amount of organic substrate available for enzymatic action (Bastida et al., 2008). Waldrop et al. (2000) reported that the specific activities (per unit of MBC) of some enzymes were correlated with soil community composition, while some enzymes did no show a relationship with community composition. In fact, specific activity can reflect whether changes in soil enzyme activity can occur independently of changes in OC or MBC contents. However, in the literature much less is known of the influence of land use changes on the specific activities of soil enzymes.

Our previous study has indicated the effects of forest conversion to croplands on OC contents and mineralization in northwest Iran, with substantial decreases in soil OC (Beheshti et al., 2012). They reported significant losses in soil OC and structure following land use conversion, with subsequent increases in the CO_2 emission from soil. These losses occurred largely in the labile C pool from the sand-size fraction. However, very little is known about the influence of these land use changes on soil microbial biomass and enzyme activities in this region. Specifically, soil MBC and enzyme responses are not well-known in natural forest ecosystems exposed to long-lasting land use changes in northwest Iran. The main aim of the current study was to study and report the response of soil MBC and the activity of soil enzymes including urease, invertase, phosphatases, and arylsulfatase involved in N, C, P and S cycles, respectively, to land use changes from forests to croplands at a site in northwest Iran. We hypothesized that forest conversion to cultivated lands in natural forest ecosystems would primarily decrease soil OC contents, aggregate stability and MBC levels with a consequence for declines in activities of soil enzymes. The second hypothesis was that the direction and magnitude of changes in soil enzyme activities would depend on the enzyme involved, and the way of expressing activity, based on either absolute or specific values.