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Linking litter production, quality and decomposition to vegetation succession following agricultural abandonment

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ABSTRACT

Agricultural land abandonment has been increasing worldwide for environmental and socio-economic reasons, and knowledge of its key ecological processes (e.g., carbon (C) and nitrogen (N) input and accumulation) in relation to vegetation succession can provide important information for ecosystem management and greenhouse gas emissions mitigation. In order to better understand the above- and belowground litter dynamics following agricultural abandonment, we simultaneously studied the litter and fine root production, quality, decomposition, C and N input in ecosystems along a secondary successional gradient (i.e., grassland, shrub-grass land, young secondary forest, and mature secondary forest) following agricultural abandonment in China's Qinling Mountains. Results showed that the significant increase of aboveground woody plant litter and decrease of grass litter during vegetation succession led little changes in total litter production and annual total C and N input in different succession stages, while the fine root production, fine root biomass, C input from fine root production increased significantly with stand age. The initial litter C concentration and fine root carbon: phosphorous ratio (C:P) were the main factors in explaining the variations of decomposition rates of litter and fine root, respectively. The increasing C concentration in litter and the increasing C:P ratio in fine root during vegetation succession had potentially driven the decreases in litter and fine root decomposition rate respectively. The accumulation of litter standing crop during vegetation succession could be attributed to the decreases in litter decomposition rate partly caused by changes in litter quality, rather than the increases in litter production. Our results imply that the changes in vegetation type have a much smaller role in the annual total litter production and the total litter C and N input than previously assumed, while the changes in quality and decomposition rate may have largely influenced C accumulation in stand floor and soil during secondary succession following agricultural abandonment.

1. Introduction

Agricultural land abandonment has been increasing worldwide for environmental and socio-economic reasons such as soil degradation, market incentives, environmental protection programs, migration and rural depopulation (Rey-Benayas et al., 2007; Cramera et al., 2008). For example, the U.S. Conservation Reserve Program (established by the Food Security Act in 1985), one of the U.S. largest environmental programs targeting land use, removes almost 13.76×10^6 ha from crop production and establishes grass or tree covers under 10–15 year contracts (Roberts and Lubowski, 2007). China's 'Grain-for-Green' project (launched in 1999), one of the world's most ambitious ecological restoration programs, has converted 9.26×10^6 ha former croplands to forests or grasslands until 2010. These abandoned agricultural lands are experiencing a change from crop to forest or other secondary vegetations, accompanied by ecosystem structure, processes and functions evolvement (Davidson et al., 2007; Zhang et al., 2010). Knowledge of key ecological processes (e.g., carbon (C) and nitrogen (N) input and accumulation) in relation to vegetation succession following agricultural abandonment can provide important information for ecosystem management and greenhouse gas emissions mitigation (Lal, 2004; Chazdon, 2008; Ohtsuka et al., 2010; Yang et al., 2011).

The production and decomposition of above- and belowground litter (mainly fine root, Steinaker and Wilson, 2005) are key processes linking plant and soil in the terrestrial ecosystem (Cusack et al., 2009; Schindler and Gessner, 2009). Most of the terrestrial net primary production (e.g., more than 85% in temperate ecosystems) enters the detritus pool as dead organic matter (Swan et al., 2009), and the subsequent recycling of C and nutrients are

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fundamentally important process which has major control over the fluxes of CO_2 from soils, buildup of soil organic matter, availability of N and other nutrients, with consequent feedbacks to vegetation growth (Hättenschwiler et al., 2005; Hättenschwiler and Gasser, 2005; Swan et al., 2009; Klotzbücher et al., 2011). The leaf litter and fine root are considered as 'fast C pools' (Meier and Leuschner, 2010). Annual C and nutrient inputs to the soil from fine roots frequently equal or exceed those from leaves (Jackson et al., 1997). In some semiarid and temperate ecosystems, belowground fine root production is even greater than aboveground production (Hibbard et al., 2001; Ruess et al., 2003; Steinaker and Wilson, 2005).

Changes in vegetation as a consequence of land-use change, e.g., agricultural abandonment, may affect litter and fine root dynamics through many potential factors and processes, including transformation of vegetation composition (Connin et al., 1997; Gill and Burke, 1999; Yang et al., 2010), improvement of soil fertility (Uselman et al., 2007), alteration of the needs in nutrient and water for plant growth (Uselman et al., 2007; Yang et al., 2010), etc. Although the litter and fine root production, decomposition and their influencing factors have been extensively investigated in various ecosystems worldwide (Bray and Gorham, 1964; Aerts, 1997; Matthews, 1997; Silver and Miya, 2001), few studies have simultaneously measured the above- and belowground litter production and decomposition in relation to vegetation succession following agricultural abandonment (Steinaker and Wilson, 2005; Yankelevich et al., 2006; Ostertag et al., 2008). Moreover, previous studies have mainly focused on the forest stage (Ruess et al., 2003; Yankelevich et al., 2006; Ostertag et al., 2008; Yang et al., 2010), and little attention has been paid to the early successional stages dominated by grass or shrub (Ostertag et al., 2008). The deficient knowledge in litter and fine root is still the main uncertainties in determining how C and N cycles respond to changes of vegetation or land-use (Matamala et al., 2003; Trumbore and Gaudinski, 2003).

In the present study, we investigated the production, quality and decomposition of litter and fine root in ecosystems along a successional gradient (i.e., grassland, shrub-grass land, young secondary forest, and mature secondary forest) following agricultural abandonment in the Qinling Mountains, China. We hypothesized that litter/fine root production had increased along with vegetation succession following agricultural abandonment, while decomposition rate decreased. We also explored the factors influencing production and decomposition of litter and fine root.

2. Materials and methods

2.1. Study site

This study was conducted in the Foping National Nature Reserve (FNNR, a member of UNESCO/MAB World Network of Biosphere Reserves), south aspect of China's Qinling Mountains. This region belongs to subtropical humid zone, and annual precipitation ranges from 950 to 1200 mm, most of which falls between July and September. Mean annual temperature is 11. 8 °C, and the mean temperatures are −0.3 °C in January and 21.9 °C in July. Frost free days average 220. Natural vegetation of the study area is deciduous broad-leaved forests. The soil is yellow brown developed from granitic gneiss (Zhang et al., 2010).

The natural successional pathway after agricultural abandonment in the region follows grassland, shrub-grass land, young secondary forest, and mature secondary forest (Zhang et al., 2010). Thus, nineteen stands including 5 grasslands, 6 shrub-grass lands, 4 young secondary forest forests, and 4 mature secondary forest (with stand age older than 50 years) were selected in this study (Table 1). We inferred that the stands were derived from croplands according to abandoned irrigation ditches and ridges (Ren et al., 1998). The years since abandonment (stand age) was sought from landowners or estimated from the tree-rings of the oldest pioneer trees. A comprehensive survey of vegetation and soil was carried

Table 1
Site characteristics and the relative proportion of the dominant litter species used in decomposition experiment.

Site	Stand age (yr)	Altitude (m)	Vegetation type	Dominant litter species	Proportion of litter used in experiment (%)
H1	1	1250	Grassland	*Artemisia lavandulaefolia*: *Polygonum alatum*: *Elsholtzia ciliata*	50:25:25
H2	4	1130	Grassland	*A. lavandulaefolia*: *Pennisetum alopecuroides*	75:25
H3	5	1233	Grassland	*A. lavandulaefolia*: *Cucubalus baccifer*	75:25
H4	5	1284	Grassland	*A. lavandulaefolia*: *Cynoglossum zeylanicum*: *P. alatum*	75:12.5:12.5
H5	8	1135	Grassland	*A. lavandulaefolia*: *P. alopecuroides*	87.5:12.5
S1	5	1098	Shrub-grass land	*A. lavandulaefolia*: *Pueraria lobata*	62.5:37.5
S2	6	1290	Shrub-grass land	*A. lavandulaefolia*	100
S3	7	1250	Shrub-grass land	*A. lavandulaefolia*: *P. lobata*: *Pteridium aquilinum*: *Rhus chinensis*	37.5:37.5:12.5:12.5
S4	7	1095	Shrub-grass land	*Populus purdomii*: *A. lavandulaefolia*	50:50
S5	11	1253	Shrub-grass land	*A. lavandulaefolia*: *P. lobata*	62.5:37.5
S6	12	1260	Shrub-grass land	*Castanea mollissima*: *Juglans regia*: *R.chinensis*: *P. lobata*: *Prunus tomentosa*	60:12.5:12.5:10:5
N1	15	1280	Young secondary forest	*Broussonetia papyrifera*: *Actinidia chinensis*: *Picrasma quassioides*	50:25:25
N2	20	1140	Young secondary forest	*C. mollissima*: *Platycarya strobilacea*	50:50
N3	≈30	1111	Young secondary forest	*Quercus variabilis*	100
N4	≈45	1301	Young secondary forest	*C. mollissima*: *Carpinus turczaninowii*: *Rhus punjabensis* var. *sinica*: *Quercus serrata* var. *brevipetiolata*: *Picrasma quassioides*	30:25:15:15:15
N5	≈50	1298	Mature secondary forest	*C. mollissima*: *Carpinus turczaninowii*: *Actinidia chinensis*: *Corylus heterophylla*: *Litsea tsinlingensis*	30:25:15:15:15
N6	≈70	1276	Mature secondary forest	*C. mollissima*: *Q. serrata* var. *brevipetiolata*: *Bashania fargesii*: *Dendrobenthamia japonica* var. *chinensis*: *Acer palmatum*	50:17.5:17.5:10:5
N7	≈80	1277	Mature secondary forest	*C. mollissima*: *Carpinus turczaninowii*: *Q. serrata* var. *brevipetiolata*: *D. japonica* var. *chinensis*: *B. fargesii*	50:17.5:17.5:7.5:7.5
N8	≈100	1257	Mature secondary forest	*C. mollissima*: *B. Fargesii*: *Juglans mandshurica*	50:25:25