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Variations in soil microbial biomass and crop roots due to differing resource quality inputs in a tropical dryland agroecosystem

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Abstract

The influence of exogenous organic inputs on soil microbial biomass dynamics and crop root biomass was studied through two annual cycles in rice–barley rotation in a tropical dryland agroecosystem. The treatments involved addition of equivalent amount of N ($80\,kg\,N\,ha^{-1}$) through chemical fertilizer and three organic inputs at the beginning of each annual cycle: *Sesbania* shoot (high-quality resource, C:N 16, lignin:N 3.2, polyphenol + lignin:N 4.2), wheat straw (low-quality resource, C:N 82, lignin:N 34.8, polyphenol + lignin:N 36.8) and *Sesbania* + wheat straw (high-and low-quality resources combined), besides control. The decomposition rates of various inputs and crop roots were determined in field conditions by mass loss method. *Sesbania* (decay constant, $k = 0.028$) decomposed much faster than wheat straw ($k = 0.0025$); decomposition rate of *Sesbania* + wheat straw was twice as fast compared to wheat straw. On average, soil microbial biomass levels were: rice period, *Sesbania* ⩾ *Sesbania* + wheat straw > wheat straw ⩾ fertilizer; barley period, *Sesbania* + wheat straw > *Sesbania* ⩾ wheat straw ⩾ fertilizer; summer fallow, *Sesbania* + wheat straw > *Sesbania* > wheat straw ⩾ fertilizer. Soil microbial biomass increased through rice and barley crop periods to summer fallow; however, in *Sesbania* shoot application a strong peak was obtained during rice crop period. In both crops soil microbial biomass C and N decreased distinctly from seedling to grain-forming stages, and then increased to the maximum at crop maturity. Crop roots, however, showed reverse trend through the cropping period, suggesting strong competition between microbial biomass and crop roots for available nutrients. It is concluded that both resource quality and crop roots had distinct effect on soil microbial biomass and combined application of *Sesbania* shoot and wheat straw was most effective in sustained build up of microbial biomass through the annual cycle.

Keywords: Soil microbial biomass; Root biomass; Rice; Barley; *Sesbania*; Wheat straw; Decomposition rate; Dryland agroecosystem.

1. Introduction

Soil organic matter is the main nutrient source available through microbial transformation which improves soil quality and optimizes crop production. Dynamics of soil organic matter and its labile component (microbial biomass) reflects the properties and biological activities of soil and the quantity and quality of plant residues returned to the soil (Gregorich et al., 2000). The microbial biomass has been used as an index of soil fertility, which depends primarily on rates of nutrient fluxes. An increase in the size of soil microbial biomass is considered essential for the improvement of soil fertility. Due to its highly dynamic character the microbial biomass responds more rapidly than soil organic matter as a whole to changes in management that alter the annual organic input to the soil (Powlson et al., 1987). Manipulation of the microbial community by varying organic inputs to soil has great potential for the management of organic matter in tropical dryland agroecosystems (Singh and Singh, 1993; Kushwaha and Singh, 2005). In India about 68% of total arable land is under rainfed dryland farming conditions having no access to irrigation (http://faostat.fao.org). In dryland soils addition of chemical fertilizer is not very effective because soil is not only poor in available nutrients or carbon but also limited by soil moisture. In tropics addition of organic resources holds promise as it can ameliorate soil fertility (Palm et al., 2001) as well as enhance soil moisture content.

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Seasonal crop growth regulates the temporal and spatial distribution of organic inputs in form of crop roots, rhizodeposition, and residues which in turn influence the dynamics of soil microbial biomass (Franzluebbers et al., 1995). Crop roots have been shown to affect the microbial growth negatively or positively by reducing soil available N or soil moisture, or by providing C substrates for microbial growth (Fogel, 1985; Jackson et al., 1989). In agroecosystems the main sources of organic inputs to soil are soil amendments and crop roots. While the crop shoot biomass is harvested in croplands, substantial portions of root biomass are left in the soil. However, the role of root as source of organic matter is often neglected (Spedding et al., 2004). Information is scanty on changes in root biomass through the crop cycle and the root detritus left in soil after harvest in dryland agroecosystems (Ghoshal and Singh, 1995a). After crop harvest the decomposition and prolonged nutrient release from the decomposing dead root mass affects the nutrient availability of the subsequent crops (Singh and Shekhar, 1989a). Nevertheless, the influence of plant growth on microbial dynamics is complex and poorly understood in the rice soils (Lu et al., 2002). The rate at which nutrients are released by decomposition of organic inputs by microbes is related to the chemical composition of the input and prevailing environmental conditions. Decomposition of organic inputs and nutrient release are influenced by roots and its competition with microbes (Bottner et al., 1999).

Reports on the effects of organic residues and fertilization on the dynamics, build-up and turnover of labile component of soil organic matter are often conflicting. Due to fertilizer application microbial biomass has been reported to increase (Kanchikerimath and Singh, 2001; Graham et al., 2002; Raiesi, 2004), decrease (Mahmood et al., 1997) or show no effect/change (Biederbeck et al., 1984; Moore et al., 2000). The available studies on microbial biomass dynamics are mostly related to the effect of low quality (e.g. wheat straw, Singh and Singh, 1993; Azmal et al., 1996) and/or high-quality resources (e.g. *Sesbania,* Chander et al., 1997). Few studies have evaluated the effect of combined application of high-quality and low-quality inputs on decomposition and N-mineralization (e.g. Handayanto et al., 1997; Sakala et al., 2000); however, soil microbial biomass dynamics under such input has been least studied in agroecosystems (e.g. Ehaliotis et al., 1998).

The increase in carbon input to soil generally enhances soil microbial biomass, but the quality of input determines its accumulation and mortality (Nilsson et al., 2005). This experiment was designed to supply equivalent amount of N but variable amount of C through different exogenous soil inputs. We evaluated chemical fertilizer and three organic inputs, having contrasting chemical composition, for their impact on soil microbial biomass dynamics in a dryland agroecosystem. These organic inputs included a high-quality resource (*Sesbania* shoot), a low-quality resource (wheat straw), and a combination of these (*Sesbania* + wheat straw) to manipulate the rate of nutrient release through decomposition. The objectives of the present study, carried out in a tropical rainfed dryland agroecosystem supporting rice–barley crop sequence, were: (1) to evaluate the effect of application of varying chemical quality organic inputs on soil microbial biomass, (2) to examine the influence of crop roots on seasonal variations of microbial biomass, and (3) to document the decomposition rate of organic inputs and crop roots.

2. Materials and methods

2.1. Study site

The experiment was conducted in the cultivated fields of the Botanical Garden of Department of Botany, Banaras Hindu University at Varanasi (25°18′ N lat. and 83°1′ E long., 76 m above the mean sea level). The fields have been cultivated for decades with intermittent fallows; before the commencement of the present study in June 2002, barley was grown for two consecutive years. The pale brown, sandy loam, neutral (pH ca. 7) soil of the site belongs to the order inceptisol and suborder orchrepts. The dry tropical climate of the region is characterized by strong seasonal variations with respect to temperature and precipitation. The year is divisible into a warm wet rainy season (July–September), a cool dry winter (November–February), and a hot dry summer (April–June); October and March constitute transitional months between seasons. The average annual rainfall is 1100 mm, of which ca. 80% is received during the rainy season. High temperature (24–34 °C) and relative humidity (70–80%) prevail during the rainy season. In the winter season the temperature range is 4–25 °C. The summer is dry and hot with a temperature range of 30–45 °C during the day. In Indian dryland regions the annual cropping cycle generally consists of a rotation of rainy and winter season crops followed by fallow during hot summer.

2.2. Experimental design

The experimental plots (3 × 3 m) were laid down in a randomized block design using three replicate plots per treatment; a 1 m strip was left to separate each block. The experimental design included following five treatments: (1) Control (no inputs), (2) Chemical fertilizer (containing 80 kg N ha^{-1} from urea), (3) Wheat straw (80 kg N ha^{-1}), (4) *Sesbania* shoot (80 kg N ha^{-1}), (5) *Sesbania* shoot (40 kg N ha^{-1}) + wheat straw (40 kg N ha^{-1}). Rice (*Oryza sativa* var. NDR 97) was grown as rainy season crop and barley (*Hordeum vulgare* var. Lakhan) as winter season crop. Crop period for rice was from 0 (day of sowing of first rice crop) to 115 day in the first annual cycle and 367 to 475 day in second annual cycle. Barley cropping extended from 130 to 265 day and 490 to 645 day. Summer fallow ranged from 266 to 335 day and 646 to 700 day. No irrigation was applied and the experiment was maintained under rainfed dryland conditions. Manual hoeing was