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Uncropped field margins to mitigate soil carbon losses in agricultural landscapes

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A B S T R A C T

Agricultural intensification is a major cause of habitat transformation. Continuous cropping alters ecosystem services, such as biodiversity and carbon sequestration. Empirical evidence from agricultural lands in Argentina has shown that permanently vegetated areas imbedded in the agricultural matrix (uncropped margins) play a critical role in plant and animal communities compared to the usual situation of crops surrounded by other crops (cultivated margins). However, the potential impact of uncropped margins on their own carbon stocks and fluxes and on those of their neighbouring cropped fields remains unknown. We investigated the impact of uncropped (herbaceous and woody) and cropped margins (cultivated fields) on their own topsoil carbon stocks and fluxes and on those of their neighbouring croplands (soybean fields). We identified soybean fields adjacent to one of three possible margin types: herbaceous or woody permanent vegetation, and field crop, which acted as control because it is the most frequent situation in the region. In each of these margin–soybean pairs, we sampled transects from the margin towards the centre of the soybean field (50 m). Woody margins showed the greatest soil carbon content, the least decomposable plant litter and the greatest influence on the neighbouring crop. Conversely, herbaceous margins had the lowest litter accumulation and the most decomposable litter. Only woody margins influenced soil properties in the first metres of the cropped neighbourhood. Centres of soybean fields were similar, irrespective of margin type. The decomposition of common substrates was not affected by margin type. These findings suggest that woody margins are the unique element of the current landscape with a potential to mitigate soil carbon loss from agroecosystems, albeit spatially limited. In contrast, the low biomass and highly decomposable litter of herbaceous margins reveal the urgent need to re-think their current management strategies.

1. Introduction

Agricultural intensification is a major cause of landscape fragmentation and losses of biodiversity and soil carbon. A large number of studies, involving different scales and approaches, confirm the negative effects of agriculture expansion and intensification (Matson et al., 1997; Burel et al., 1998; Benton et al., 2003; Tscharntke et al., 2005; Norris, 2008). Overall, increasing cultivated area, reducing crop diversity, homogenizing crop management and replacing perennial permanent and semi-permanent habitats for annual crops resulted in a reduction of spatial and temporal landscape heterogeneity (Tscharntke et al., 2005; Poggio et al., 2010). In temperate grasslands of South America (Soriano, 1991), and particularly in the Rolling Pampa region (Baldi et al., 2006), there mixed farming systems that combined extensive husbandry with annual crops have been largely replaced by continuous cropping. This replacement reduced landscape heterogeneity and altered the provision of ecosystem services such as biodiversity (de la Fuente et al., 2006; Bilenca et al., 2007) and carbon sequestration (Viglizzo et al., 2011a,b; Caride et al., 2011).

Landscape ecology has provided valuable approaches to understand the impact of agriculture expansion and intensification on ecosystem properties. Permanent or semi-permanent landscape elements imbedded in the agricultural matrix are critical for preserving ecosystem services (Klein et al., 2003; Follain et al., 2007). Corridors of uncropped permanent vegetation (margins) constitute both habitat and refuge for many species (Burel et al., 1998; Marshall and Moonen, 2002; Tscharntke et al., 2005). They also serve as connectors for metapopulations (Gonzalez et al., 1998) and as barriers that reduce wind speed and soil loss by erosion (Burel et al., 1998; Walter et al., 2003; Brandle et al., 2004; Follain et al., 2007). Moreover, in European landscapes, where corridors represent a large proportion of the landscape (Baudry et al., 2000), hedgerows tend to increase local soil carbon content (Walter et al., 2003; Follain et al., 2007). Nevertheless, the effect of margins on ecosystem functioning will depend on

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margin type, target species traits and landscape context (Aviron et al., 2005). The agro-ecosystems of the Rolling Pampa largely differ from the well studied European systems. They form an extensive and homogeneous cropland mosaic made of large arable fields and sparse, less disturbed wire-fencerow networks composed of spontaneous woody patches scattered and herbaceous fencerows that frequently receive intentional or unintentional spraying of total herbicides from the neighbouring soybean crops (Ghersa et al., 2002; de la Fuente et al., 2010). Empirical evidence suggests that, in spite of the large structural and functional differences between the Rolling Pampa and the European agricultural landscapes, Pampean uncropped margins also impact on plant and animal communities. Studies performed at detailed spatial scales revealed more diverse weed communities (Poggio et al., 2010, 2013) and a greater abundance of small mammals (Bilenca et al., 2007) in uncropped margins than in their neighbouring cropped fields. Furthermore, weed richness gradually decreased with distance from the uncropped margins (Poggio et al., 2010), which suggests that margins, despite their limited proportion in the landscape, act as a source of material and information (*e.g.* propagules), while the cropped matrix acts as a sink.

Carbon cycling in agroecosystems is largely affected by crop management and landscape context. Crop sequence, tillage techniques and fertilization levels regulate the amount of carbon fixed by plants and exported by harvest, and the quantity and quality of the residue incorporated into the soil (Follett, 2001). In turn, agricultural practices indirectly control other carbon cycling subprocesses by modifying soil temperature, moisture and fertility (Knorr et al., 2005; Luo et al., 2010). At the landscape scale, margins may also play a critical role against soil erosion, particularly in semiarid and rolling regions (Okin et al., 2006; Alvarez et al., 2012). Yet in humid and flat landscapes margins may affect carbon cycling. For instance, different vegetation types impact on decomposition and carbon storage through differences in their litter quality among other factors (Liao et al., 2008; Castro et al., 2010). In the case of soil carbon stocks and fluxes, we have no evidence at the landscape scale of the potential impact of low-disturbed margins either on their own carbon stocks and fluxes or on those from their neighbouring cropped areas.

Here we investigated this impact of low disturbed margins. We also investigated the role of decomposition as a mechanism partially responsible for the eventual effects of margins on soil carbon stocks. We identified adjacent pairs of "uncropped herbaceous margin–soybean field", "uncropped woody margin–soybean field" and "cropped margin–soybean field", as a control treatment (*i.e.* crop–crop interface). By setting sampling points along 50 m-long transects, we first sampled carbon and mass stocks in standing vegetation, litter, and topsoil inside the margin system in order to describe the three aforementioned margin types. Second, by sampling along transects from the margin towards the adjacent soybean fields we investigated the effect of each margin type on the neighbouring soybean field. Finally, by means of complementary field and greenhouse decomposition experiments, we investigated the role of decomposition as a critical carbon sub-process that may partially account for variation of carbon stocks among margin types. Our experimental design discriminated among margin effects related to *in situ* microenvironment, and biological and physicochemical features inherent to soil and litter quality. We expect (1) woody margins to have the largest carbon stocks (plant, litter and topsoil) and herbaceous margins to have intermediate values, between woody and cropped margins. The greater carbon accumulation of woody margins would partially result from a slower *in situ* decomposition rate, due to differences in litter quality rather than in the soil environment; (2) woody margins to display the greatest effect on carbon stocks of neighbouring soybean fields, with a decreasing effect as distance from the margin increases, and herbaceous margins to display intermediate values. Along uncropped margin–soybean field interface, differences in litter quality and soil microenvironmental conditions are expected to vanish as distance from margin increases.

2. Materials and methods

2.1. Study area

The study was carried out in 2010 in the central Rolling Pampa, which extends from 32° to 34° S and 60° to 61° W in the North of Buenos Aires province, eastern Argentina. Climate is temperate sub-humid, with warm summers and no marked dry season. Mean annual rainfall is 1000 mm and mean annual temperature is 17 °C. The frost period extends from mid-April to late-September. Soils are mainly Argiudolls, characterized by a clay accumulation subsurface horizon (Soriano, 1991). During the expansion of agriculture in 1880–1914, the original grassland vegetation was extensively ploughed and converted into an area of cattle and crop production, which resulted in extensive farmland mosaics fragmented by intricate networks of wire-fencerows, railroads, roads, streams and rivers (Ghersa and León, 1999). Since the 1990s, technology (no-tillage and genetically modified crops), as well as the increased international prices for soybean, led to an intensification of agriculture with the replacement of the mixed cattle and crop systems by continuous cropping. Nowadays, cropping is the dominant land use and has been accompanied by the removal of fencerows to enlarge and simplify the cropped area. Therefore, in the current landscape, native species occur only as small, scattered populations in fragments of semi-natural vegetation in grazing paddocks, wire-fencerows and roadside verges (Rapoport, 1996; Ghersa and León, 1999).

2.2. Description of field margins

We identified two representative uncropped margin types: (i) dominated by spontaneous herbaceous vegetation (hereafter herbaceous margin) and (ii) dominated by spontaneous woody vegetation (hereafter woody margin). We also considered fields cultivated with soybean and maize (hereafter cropped margin), representing the most frequent situation, and considered as control situation (Fig. 1). Herbaceous margins were dominated by annual and a few perennial species and they are vegetated most of the year, with lower cover during winter. The most abundant species are grasses (*Cynodon dactylon*, *Digitaria sanguinalis*, *Lolium multiflorum*, *Poa annua* and *Paspalum dilatatum*) and forbs (*Apium leptophyllum*, *Artemisia annua*, *Anthemis cotula*, *Bidens subalternans*, *Capsella bursa-pastoris*, *Chenopodium album*, *Hypochoeris radicata*, *Matricaria chamomilla*, *Portulaca oleracea*, *Silene gallica*, *Tagetes minuta* and *Trifolium repens*). These margins are linear environments, 5–10 m wide. Woody margins cover an average area of 1 ha, are permanently covered and the most abundant tree species of the overstory are *Broussonetia papyrifera*, *Fraxinus* spp., *Gleditsia triacanthos*, *Ligustrum* sp., *Melia azedarach* and *Morus alba*. These margins also have an herbaceous understory (*Ammi majus*, *Bromus catharticus*, *Chenopodium album* and *Tagetes minuta*), however, unlike the herbaceous margins, woody margins are not directly sprayed with herbicides. They receive drift from the neighbouring crops fields' application at a very low frequency. Cropped margins (represented by crop fields averaging 50 ha in size), cultivated with soybean and maize, are sprayed with systemic and contact insecticides during the spring and harvested in the first half of autumn; then soil remains covered with crop residue until the following crop. They are also sprayed with non-selective herbicides (*e.g.* glyphosate) to reduce weeding (Ferraro et al., 2003). Our