Geoderma Regional 4 (2015) 100–107

Contents lists available at ScienceDirect

Geoderma Regional

journal homepage: www.elsevier.com/locate/geodrs

Changes in soil characteristics after six seasons of cereal–legume intercropping in the Southern Pampa

Maren Oelbermann [a,*], Alison Regehr [a], Laura Echarte [b]

[a] Department of Environment and Resource Studies, University of Waterloo, 200 University Avenue West, Waterloo, ON N2L 3G1, Canada
[b] CONICET, EEA INTA Balcarce, Ruta 226 km 73.5, C.C. 276, 7620 Balcarce, Argentina

ARTICLE INFO

Article history:
Received 20 June 2014
Received in revised form 6 January 2015
Accepted 9 January 2015
Available online 13 January 2015

Keywords:
Crop residues
Land equivalent ratio
Phaeozem
Soil light fraction
Soil microbial biomass
Soil organic carbon

ABSTRACT

The Argentine Pampa is one of the most productive agricultural regions in the world, but sole crop management practices have led to soil degradation and losses of soil organic matter. The objective of this study was to evaluate soil organic carbon (SOC) and nitrogen (N) dynamics in 2007 and in 2012 in two intercrop systems [1:2 intercrop (one row of maize (*Zea mays* L.) and two rows of soybeans (*Glycine max* L. Merr.)) and 2:3 intercrop (two rows of maize and three rows of soybean)], and in a maize and soybean sole crop. Results showed that C and N input from crop residues was significantly greater ($P < 0.05$) in the maize sole crop, followed by the intercrops and the soybean sole crop. The land equivalent ratio (LER), based on crop biomass, was significantly greater ($P < 0.05$) in the 2:3 intercrop. Soil physical and chemical characteristics (bulk density, pH, SOC and N, C/N ratio) were not significantly ($P < 0.05$) different among treatments and were significantly greater in 2012, except for pH, at all depths. Gross SOC turnover time was significantly longer ($P < 0.05$) in 2012 compared to 2007 for all treatments and depths, except in the maize sole crop. Soil microbial biomass (SMB) C and N were significantly greater ($P < 0.05$) in the 2:3 intercrop in both years. To a 40 cm depth, SMB-C turnover time (SMB-C_T) was significantly greater ($P < 0.05$) in the soybean sole crop followed by the intercrops and the maize sole crop in 2007, whereas in 2012, SMB-C_T was significantly greater ($P < 0.05$) in the intercrops followed by the soybean and the maize sole crops. The soil light fraction N (LF-N) was significantly greater ($P < 0.05$) in the maize sole crop in both years. There was no significant difference ($P < 0.05$) for LF-C. Our results demonstrated that cereal–legume intercropping is a more sustainable agroecosystem land management practice in the Argentine Pampa, with respect to soil C and N transformations, compared to sole cropping.

1. Introduction

The rapid depletion of soil organic carbon (SOC) coincides with the adoption of sole crop agroecosystem management practices in temperate biomes (Stavi and Lal, 2012). This has resulted in a 30 to 50% loss of SOC in the top 30 cm (Berhongaray et al., 2013). In temperate regions like the Pampa, the most productive agricultural land in Argentina, 90% of the land has been converted from natural grasslands to livestock and to sole crop production systems (Medan et al., 2011). These activities have reduced SOC stocks in the Argentine Pampa by 35%, to a 15 cm depth, over the past four decades (Álvarez, 2001).

Implementing agroeocsystem management practices that maintain or increase SOC stocks, while mitigating climate change via carbon (C) sequestration, and providing sufficient quantities of food, fiber and fuel for a growing population remains an agronomic challenge. Complex agroecosystems such as intercrops, where more than one crop is grown on the same land area at the same time, are currently re-gaining recognition in temperate biomes (Oelbermann and Echarte, 2011). This is because intercrops have a lower environmental impact compared to sole crops, and are more resilient to climate change due to their greater structural complexity.

Intercrops use their resources more efficiently since the mixed arrangement of crops captures resources from different parts of the soil, and/or uses resources at different times, and/or in different forms [e.g., atmospheric nitrogen (N) versus reduced forms of N] (Echarte et al., 2011). Additionally, the mixing of residues from cereal and legume crops causes complex interactions that influence the magnitude of N cycled through the intercrops compared to sole crops (Flavel and Murphy, 2006). From an agronomic perspective, the classic criterion to evaluate whether or not an intercrop is more effective than its associated sole crop is the concept of land equivalent ratio (LER) (Mead and Willey, 1980). LER, based on crop biomass or grain yield, represents the biological efficiency of growing two crops together (Mead and Willey, 1980). When LER is greater than 1, resources are used more effectively in the intercrop compared to the sole crop (Barker and Dennett, 2013).

To date, most research in temperate intercropping systems has focused on grain yield and quality, crop competition, pest management, weed and erosion control, nutrient-use efficiency, nutrient leaching, and LER (Hauggaard-Nielsen et al., 2001; Prasad and Brook, 2005;

* Corresponding author.
E-mail address: moelbermann@uwaterloo.ca (M. Oelbermann).

http://dx.doi.org/10.1016/j.geodrs.2015.01.002
2352-0094/

Waddington et al., 2007; Echarte et al., 2011; Pappa et al., 2011; Klimek-Kopyra et al., 2013). Only a few studies have investigated soil C and N dynamics, including residue decomposition (Vachon and Oelbermann, 2011) and gross N mineralization (Regehr, 2013), greenhouse gas emissions (Pappa et al., 2011; Dyer et al., 2012), and baseline changes in soil characteristics (Oelbermann and Echarte, 2011). To date no studies have investigated the short-term (2–5 years) effect of cereal–legume intercropping on SOC and N in temperate regions. Therefore, the objective of this study was to evaluate the short-term influence of intercropping on SOC and N dynamics in the Argentine Pampa. This research advances our knowledge on identifying the most effective intercrop configuration(s) to help maintain agricultural productivity, improve soil characteristics, enhance agroecosystem resilience to climate change, and encourage C sequestration.

2. Materials and methods

2.1. Experimental site

The research site was located in the southern Pampa, near the city of Balcarce (37°45′ S, 58°18′ W), Argentina. The 32-year mean annual precipitation was 860 mm, the mean annual temperature was 14.3 °C, and the site was located 130 m above sea level. The soil was classified as a Typic Agridudoll (US Soil Taxonomy) or Luvic Phaeozem (FAO Soil Taxonomy) and was part of the *Mar del Plata* series (Studdert and Echeverria, 2000). The soil texture was loam, consisting of 41.1% sand, 35.8% silt and 23.1% clay (Domínguez et al., 2009). The soil was moderately acid, had a low available phosphorus (P), and a high soil organic C (SOC) content (Fabrizzi et al., 2003). The slope was 2%, indicating little to no erosion (Domínguez et al., 2009).

The study site was established in 2007 on land previously under experimental use of alternating crop and pastures, where the most recent crop was two years of sunflower (*Helianthus annuus* L.) production, cultivated using a disk harrow followed by a spike harrow. The current study design was a randomized complete block design (RCBD) with four treatments: maize sole crop, soybean sole crop, 1:2 intercrop (one row of maize and two rows of soybeans) and 2:3 intercrop (two rows of maize and three rows of soybeans). Each treatment was replicated three times, and each treatment plot size was 8.8 × 12 m. The maize and soybean sole crops were rotated annually. For example treatment plots referred to as maize sole crop were under maize production in 2008–09, 2010–11 and 2012–13, and under soybean production in 2007–08 and 2009–10. Treatment plots referred to as soybean sole were under soybean production in 2008–09, 2010–11 and 2012–13, and under maize production in 2007–08 and 2009–10. However, the intercrops were continuous (not rotated) and soybean and maize were planted in the same rows in successive years. Plant density (plants m^{-2}) was 4.3 (1:2 intercrop), 5.3 (2:3 intercrop), 8.0 (maize sole crop) and 29 (soybean sole crop), with a 0.52 m distance between crop rows in all treatments. The site was disk harrowed three times and spike harrowed before planting. Weeds were controlled by N-phosphonomethyl glycine (Glyphosate). All crops received P fertilizer (35 kg P ha^{-1}). Maize in the sole crop and in the intercrops received N fertilizer (150 kg N ha^{-1}) in the form of urea. In the intercrops, the fertilizer was applied by hand at the bottom of the maize stems at the 6th leaf stage. Soybeans were inoculated with *Bradyrhizobium japonicum*. Maize was typically seeded in late October or early November and harvested in April; soybeans were seeded in November and harvested in May. All agronomic practices, including soil cultivation, fertilizer application rates, and intercrop configurations, were typical of those under study in this region.

2.2. Crop residues and land equivalent ratio

Aboveground biomass from crop residues was sampled at harvest, over a total of six cropping seasons from 2007–08 to 2012–13, using three randomly located areas, 1 m^2 in size, within each treatment replicate. Samples were oven dried at 65 °C for 72 h, ground to 2 mm and analyzed for C and N using an elemental analyzer (Costech 4010, Cernusco, Italy). Crop residue C and N input was determined by multiplying C and N (%) by the amount of residue produced, and expressed as g m^{-2} y^{-1}.

Land equivalent ratio (LER), on a biomass basis, was quantified according to Mead and Willey (1980):

$$LER = (MR_I/MR_{SC}) + (SR_I/SR_{SC}) \quad (1)$$

where MR_I is the quantity (g m^{-2} y^{-1}) of maize crop residue produced under intercropping, MR_{SC} is the quantity of maize crop residue produced under maize sole cropping, SR_I is the quantity of soybean crop residue produced under intercropping, and SR_{SC} is the quantity of soybean crop residue produced under soybean sole cropping.

2.3. Soil physical and chemical characteristics

Soil was sampled after the soybean harvest at 0–20 and 20–40 cm depths using a soil corer with a 7 cm inner diameter. Soil was sampled in the 2007–08 (referred to as 2007) cropping season, and again in the 2012–13 (referred to as 2012) cropping season. Three random samples per treatment replicate were extracted and composited, corresponding to depth, into one sample and air-dried. A 20 g subsample was oven-dried at 105 °C for 48 h to determine oven dry weight. Bulk density was calculated using the inner diameter of the core sampler and the oven dry weight of the soil. Bulk density was not adjusted for rock volume (mineral particles ≥ 2 mm) because these soils had minimal rock content.

All air-dried soil samples were passed through a 2 mm sieve to remove the coarse mineral fraction and large plant residue fractions. Soil pH was quantified using a 20 g subsample in a 1:1 soil:water suspension (BioKit AB 15B, Houston, TX, USA). Soil carbonates were removed by adding 150 ml of 0.5 M HCl to 2 g of air-dried and sieved soil. The mixture was stirred 3 times over 24 h, and subsequently washed by pipetting the HCl from the settled soil and adding ultrapure water to the soil. This washing procedure was repeated daily for 4 days after which the soil was dried in an oven at 40 °C for 2 days (Midwood and Boutton, 1998). The acid treated soil was ground in a ball mill (Retsch® ZM1, Haan, Germany) and analyzed for SOC and total N. Soil organic C and total N stocks were determined by multiplying SOC and total N (%) by the amount of soil per m^2, using soil bulk density and the corresponding soil depth. Gross SOC turnover time (SOC_T), defined as the amount of C in a soil system at equilibrium divided by the annual input of C into that system (Jenkinson and Rayner, 1977) was determined to a 20 and 40 cm depth.

2.4. Soil microbial biomass and soil light fraction

Chloroform fumigation extraction (CFE) was used on sieved soil at 0–10, 10–20 and 20–40 cm depths to evaluate soil microbial biomass C (SMB-C) and N (SMB-N) (Voroney et al., 2008). Prior to CFE, the soil was pre-incubated for 7 days at 25 °C and 45% water holding capacity. The extracted samples were freeze-dried, ground and analyzed for C and N, and quantified as the difference between fumigated and non-fumigated samples using a conversion factor of 0.35 for C and 0.5 for N (Voroney et al., 2008). Soil microbial biomass C turnover time ($SMB\text{-}C_T$) was quantified by:

$$SMB\text{-}C_T = SMB\text{-}C/(R_i + MY_{cf}) \quad (2)$$

where SMB-C is the soil microbial biomass C pool (g m^{-2}), R_i is the annual amount of C input from crop residues (g m^{-2} y^{-1}), and $MY_{cf} = 0.4$ is the microbial yield coefficient for biomass production (R.P. Voroney, personal communication, 2009).