Applied Soil Ecology 103 (2016) 110–116

Contents lists available at ScienceDirect

Applied Soil Ecology

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

Crop residue retention enhances soil properties and nitrogen cycling in smallholder maize systems of Chiapas, Mexico

Ryan P. Murphy[a], Joaquín A. Montes-Molina[b], Bram Govaerts[c], Johan Six[a,d], Chris van Kessel[a], Steven J. Fonte[a,e,*]

[a] Department of Plant Sciences, University of California, Davis, CA 95616, USA
[b] Laboratory of Plant Biotechnology, Instituto Tecnológico de Tuxtla-Gutiérrez, Tuxtla-Gutiérrez, Chiapas, Mexico
[c] International Maize and Wheat Improvement Center (CIMMYT), Apdo. Postal 6-641, 06600 Mexico, D.F., Mexico
[d] Department of Environmental Systems Science, Swiss Federal Institute of Technology (ETH), ETH Zurich, Tannenstrasse 1, 8092 Zurich, Switzerland
[e] Department of Soil and Crop Sciences, Colorado State University, Fort Collins, CO 80523 USA

ARTICLE INFO

Article history:
Received 27 June 2015
Received in revised form 30 January 2016
Accepted 16 March 2016
Available online 8 April 2016

Keywords:
Soil aggregation
Conservation agriculture
Phospholipid fatty acid analysis
^{15}N
Soil quality
Zea mays

ABSTRACT

Conservation agriculture (CA) encompasses three principles: reduced tillage, residue retention, and crop rotation, and is thought to hold great potential for improving soil function and maintaining long-term productivity in agricultural systems. However, the benefits of CA likely depend on the biophysical and socioeconomic context in which CA technologies are implemented and whether or not all components of CA are in place. To better understand the effect of key CA components on soil quality and nutrient use efficiency, an on-farm field trial was conducted during the second year of an irrigated field experiment in Chiapas, Mexico. The experiment included two levels each of tillage and residue management in a full factorial design (three replicates each) with the following treatments: 1) conventional tillage with crop residue; 2) conventional tillage without crop residue; 3) zero tillage with crop residue; and 4) zero tillage without crop residue. In each replicate plot (8×20 m) a ^{15}N labeled microplot (0.95×0.93 m) was established and fertilized according to standard rates. Mid-season soil samples were analyzed for total and available (Bray) P, as well as microbial community composition using phospholipid fatty acid (PLFA) analysis. Crop yield, nutrient uptake, and aggregate-associated soil organic matter were evaluated at harvest. Crop residue retention led to small increases in aggregate stability and greater fungal PLFA. The retention of crop residues also resulted in a 110% increase in the recovery of fertilizer-derived N in vegetative biomass, leading to a marginally significant increase of 41% for total recovery of fertilizer N in the soil-crop system. Effects of tillage were less prominent, but conventional tillage was found to improve mid-season available P by roughly 60%. These results indicate that CA technologies, residue retention in particular, offer a promising set of options for farmers to improve soil functioning and reduce fertilizer-N losses, particularly for sandy soils within sub-humid tropical regions.

1. Introduction

Agricultural lands throughout the tropics are becoming increasingly degraded as per capita arable land area declines and cropping system intensity increases. Conservation Agriculture (CA) – a set of three management practices including reduced or zero tillage, crop residue retention, and crop rotation – has been proposed as a promising management option to support farm productivity, reduce soil degradation, and improve nutrient cycling in agroecosystems (Verhulst et al., 2010). While CA components have been shown to have a number of clear benefits, the overall impacts depend greatly on climatic conditions, soil type, and the unique characteristics of the agroecosystem in which CA is adopted (Giller et al., 2009; Pittelkow et al., 2015).

Adoption of CA practices can influence soil function via impacts on soil structure, soil organic matter (SOM) storage, and biological activity, all of which can affect soil-crop nutrient dynamics (Vanlauwe et al., 2001; Govaerts et al., 2009; Paul et al., 2013). Both soil structure and SOM are influenced by tillage and residue management and are considered key determinants of soil fertility (Six et al., 2002; Bronick and Lal, 2005). As organic residues and

Abbreviations: CA, conservation agriculture; CT, conventional tillage; fertN, fertilizer derived-N; MWD, mean weight diameter; NR, no crop residues; PLFA, phospholipid fatty acid; R, residues retained; SOM, soil organic matter; ZT, zero tillage.

* Corresponding author.
E-mail address: Steven.Fonte@colostate.edu (S.J. Fonte).

http://dx.doi.org/10.1016/j.apsoil.2016.03.014
0929-1393/

SOM decay, they provide binding agents that support soil aggregation. Organic matter, in turn, is phyically-protected within the soil aggregates, thus contributing to soil C stabilization (Six et al., 2002). Therefore, the reduction of organic matter inputs associated with crop residue removal can have important implications for soil structure and C storage within agricultural soils (Lichter et al., 2008). Being closely associated with SOM, soil microbial communities are important drivers of many ecosystem processes (Jackson et al., 2007). Microbes play important roles in nutrient cycling, plant-pathogen suppression, and decomposition of residues (Kaschuk et al., 2010; de Graaff et al., 2015), and are considered valuable indicators of soil quality and ecosystem functioning. The transition from conventional tillage to zero tillage with residue retention has been shown to increase microbial activity and diversity (Govaerts et al., 2007) and is likely to impact the overall functioning of soils in a number of ways.

In many small-holder farming systems, success in long-term agricultural production relies on the efficiency with which nutrients and other resources are conserved and recycled (Rufino et al., 2006). Nitrogen is of particular importance, as it is often the most limiting nutrient in agricultural systems and losses can have numerous deleterious impacts on the environment (Galloway et al., 2003). Therefore, one of the principal aims of alternative cropping systems should be to minimize the loss of N, while maximizing the uptake of N by crops (Kramer et al., 2002). In the tropics, the addition of crop residues can play a critical role in regulating nutrient availability and retention in soils (Vanlauwe et al., 2001). This is of particular importance for coarse-textured soils, where nutrient holding capacity is limited by low SOM and clay content (Feller and Beare, 1997) and a continuous supply of organic inputs may be needed to facilitate nutrient retention (e.g., via short-term immobilization) as well as provide supplemental nutrients through decomposition.

The components of CA and their potential to benefit farmers will vary depending on the climatic, biophysical and socioeconomic conditions in which they are employed. Due to this variability, each component should be evaluated separately as well as in combination, as there are farm-level trade-offs that may prevent a farmer from implementing all components (Giller et al., 2009) and each component may have different impacts if adopted individually or as one of a set of practices.

Low-input subsistence farming continues throughout much of Chiapas, Mexico. However, more intensive practices are rapidly being adopted by farmers who have flatter terrain and access to tractors, irrigation, and agrochemical inputs. Adoption of the CA components, either alone or in combination, could provide substantial benefits to this agricultural transition, yet has received little attention to date in the region. Therefore, the objective of this study was to quantify the effect of crop residue retention and reduced tillage on crop production, N cycling, and selected soil physical, biological, and chemical parameters in a recently intensified maize cultivation system in Chiapas. In this research we sought to address the following main hypotheses:

(i) Residue retention and reduced tillage enhance soil structure, biological functioning, and stabilization of SOM within soil aggregates.
(ii) Residue retention improves N cycling by increasing crop N uptake and reducing losses from the soil-plant system.

2. Materials and methods

2.1. Site description and study design

The study was conducted on an experimental farm located in the municipality of Villaflores, department of Chiapas, Mexico (16°23′ 07.23 N 93°16′ 37.36 W). The farm was situated at an elevation of 640 m in a valley where maize, sorghum, and livestock production are the primary agricultural activities. The region has a sub-humid tropical climate with annual precipitation averaging between 1400 and 2000 mm, falling mainly from May to October, and mean monthly temperatures ranging from 22 to 26 °C. Soils at the farm site studied here are Inceptisols with a sandy loam texture (66–73% sand), pH between 6.0 and 6.5, and C content of roughly 0.8% (unpublished data).

The study was conducted from September 2011 to January 2012 during the second year of an on-farm field trial to test principles of CA. The field experiment consisted of two residue and two tillage management treatments in a full-factorial design with three replicate field plots (8 × 20 m) for each treatment. The four treatments tested were: 1) conventional tillage with maize residues retained as mulch (CT R); 2) conventional tillage with no crop residues (CT NR); 3) zero tillage with crop residues retained (ZT R); and 4) zero tillage with no crop residue (ZT NR). These treatments were managed roughly the same in the first and second year of the experiment, with maize planted in both years.

Due to the high cost of ^{15}N labeled fertilizer, a single microplot (0.95 × 0.93 m; with a 1 m buffer on all sides) was established within each replicate field plot for ^{15}N fertilizer application. Microplots were implemented prior to planting (and fertilization) in all plots. Tillage in the conventional till microplots was managed using hand implements immediately before planting by disturbing the soil to approximately 15 cm in depth, so as to mimic standard tillage practices in the region. Maize was direct seeded into the plots in late September 2011. Each microplot received two applications of ^{15}N labeled ammonium nitrate (NH_4NO_3), enriched at 10 atom%, while the surrounding buffer area received no fertilizer inputs during the study period. The ^{15}N labeled fertilizer was dissolved in deionized water and spread evenly over the microplots with a watering can at a rate of 51 kg N ha^{-1} in mid-October and again at 35 kg N ha^{-1} in early November according to the rates and frequency of fertilizer application in the main field plots. Triple Super Phosphate ($Ca(H_2PO_4)_2 \cdot H_2O$) was applied at a rate of 41 kg P ha^{-1} at the time of the first N application. When fertilizer was applied to the microplots with surface residues (ZT R), the organic material was carefully removed from the soil surface and then replaced shortly after fertilization.

2.2. Field sampling

Soil samples for nutrient and isotopic N analyses as well as aggregate fractionation were collected from each microplot in September 2011, prior to fertilizer application, and at maize harvest in early January 2012. At each sampling date, two soil sub-samples were taken from within the microplots at the 0–15 cm and 15–30 cm depths by carefully removing samples with a soil sampling knife to minimize disruption of soil aggregates. For each sampling date, bulk density was measured adjacent to each sub-sample using metal cylinders (5 cm dia. and 5 cm in length) at depths of 1–6 cm and 9–14 cm.

In late November 2011 (mid-season), four sub-samples were taken from each microplot using a soil corer (5 cm dia.) and composited for analysis of mid-season soil P availability and microbial community composition. A representative sample of 100 g was frozen and shipped overnight to the University of California, Davis, USA, for phospholipid fatty acid (PLFA) analysis. Sub-samples from these same cores were also air-dried for subsequent analysis of total and available P.

In early January 2012, all maize plants within each microplot were harvested by cutting the stalks at ground level and then dried at 60 °C. Samples were separated into grain and vegetative