Agriculture, Ecosystems and Environment 183 (2014) 127–137

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

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

Reduced tillage and cover crops improve water capture and reduce erosion of fine textured soils in raised bed tomato systems

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ARTICLE INFO

Article history:
Received 13 June 2013
Received in revised form 2 November 2013
Accepted 4 November 2013
Available online 30 November 2013

Keywords:
Mulching
Organic manure
Vegetable cultivation
Infiltration
Soil water supply
Conservation agriculture

ABSTRACT

Smallholder vegetable farmers tend to specialize and intensify their production to secure income. In south Uruguay, frequent tillage and little or no inputs of organic matter have resulted in soil degradation that threatens soil productivity and systems sustainability. This study aimed to quantify the impact of tillage, crop residue management, and organic matter incorporation on runoff, soil erosion, water dynamics, and productivity of a raised bed tomato-oat rotation system. A field trial was set up in 2010 and replicated in 2011 in a temperate climate on a fine textured soil including four soil management practices: reduced tillage with a cover crop left as mulch and chicken manure incorporation (*RT*), conventional tillage with a cover crop used as green manure and chicken manure incorporation (*CGM*), conventional tillage with chicken manure incorporation (*CChM*), and conventional tillage system as control (*CT*). *RT* decreased soil erosion and runoff by more than 50% compared with the three conventional tillage systems. We proposed a non-linear model to estimate the reduction in runoff due to stubble as a function of rainfall, with locally adjusted parameters. Yields under *CChM* were the largest both years, and more than 50% greater than under *RT*. Causes of low yields under *RT* are most likely poor crop establishment under the organic cover in combination with N immobilization. Compared with *CChM* water use efficiency under *RT* was reduced by 43% during the first season, and by 35% under both *RT* and *CGM* during the second season. In a dry season, *RT* increased soil water capture by 20% (45 mm) compared with conventional tillage treatments. This is of special interest in these systems as it may result in a larger cultivated area of irrigation-dependent crops on a farm, thus building resilience to climate change. Future research on soil and water conserving practices in vegetable production systems should particularly address crop establishment and N management to avoid yield penalties under reduced tillage.

1. Introduction

Soil quality deterioration and fertility decline caused by agriculture is a problem worldwide, threatening both quality of the environment and sustainability of farmers' livelihood. This is also the case for smallholder vegetable farmers in south Uruguay, who tend to specialize and intensify their production to secure income. In the region, fine textured soils (Vertisols and vertic Argiudols) are dominant, and vegetable crops are generally grown on raised beds in order to both increase the volume of the "A" horizon that can be easily explored by roots, and to improve surface drainage after a heavy rainfall. The presence of argillic B horizons close to soil surface in combination with intense rainfall events leads to rapid saturation of the topsoil, exacerbating surface runoff. In addition, soil physicochemical quality deteriorates severely under vegetable farming due to intense tillage, poor soil cover, low organic carbon inputs, and frequent cultivation (Alliaume et al., 2013; Dogliotti, 2003). Additionally, while the frequency of extreme events such as droughts and heavy rains has increased in the region (Giménez and Lanfranco, 2012), water for irrigation is a limiting factor and most farmers in south Uruguay can only irrigate a small fraction (35% on average) of their vegetable crops (Righi et al., 2011).

The implementation of practices to improve soil quality was a key element in two projects aimed at a systemic re-design of vegetable farm systems in south Uruguay. The recommended practices included crop rotations; inclusion of a pasture phase when the farm was large enough; introduction of cover crops and incorporation of organic manures; and erosion control practices such as terracing and reducing plot sizes to avoid steep slopes (Dogliotti et al., 2013). When implemented, these practices were found to

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http://dx.doi.org/10.1016/j.agee.2013.11.001

contribute to reducing soil erosion and increasing topsoil carbon content (Alliaume et al., 2013). Particularly, the inclusion of a pasture phase reduced soil erosion estimates to levels below the threshold proposed for sustainable management of these soils, i.e. 7.0 Mg ha^{-1} year^{-1} (Hill et al., 2010; Puentes and Szogi, 1983). A pasture phase, however, is not feasible for small farms as pastures do not result insufficient financial returns in the short-term. In these cases, reduced tillage in combination with mulching on the raised beds can be a viable alternative to reduce runoff and soil erosion, and to increase infiltration. In a laboratory experiment, the use of 2–4 Mg ha^{-1}of organic mulch strongly affected the infiltration, increasing soil moisture and reducing runoff and sediment transport (Montenegro et al., 2013).

A number of studies demonstrated that the use of minimum tillage combined with cover crops and raised beds can improve soil quality (Johnson and Hoyt, 1999) and reduce erosion (Boulal et al., 2008) in vegetable production systems. Scopel et al. (2004) showed that mulching under semi-arid and humid tropical conditions increased water infiltration, reduced soil evaporation losses by ca. 52% and increase drain water storage by ca. 50%. Permanent beds with partial or complete retention of residues improved infiltration, aggregate stability and soil microbial biomass (Verhulst et al., 2011). In an arid region permanent beds and retention of residues increased water productivity by about 30% for wheat and 80% for maize, with 11–23% reduction in the amount of water applied (Devkota et al., 2013). Similar management in a Mediterranean climate did not improve water use efficiency but delayed the water use by the maize crop until later in the season without changing the yields (Boulal et al., 2012). The delay may result in a more timely and efficient use of available resources for growth (water and nitrogen) and therefore, as the authors concluded, permanent beds with mulch have potential for reducing costs and increasing profitability. However, results were not consistently positive. Poor crop establishment and lower initial LAI was observed by Boulal et al. (2012), and the impact on yield has been variable (Boulal et al., 2012; Gilsanz et al., 2004; Luna et al., 2012). Preliminary studies in Uruguay comparing minimum with conventional tillage in vegetable production showed potential benefits in terms of soil quality and soil moisture accumulation, while yields were not affected (Arboleya et al., 2012).

Conservation agriculture (CA) has been widely adopted in broad-acre arable systems in Uruguay. Vegetable cropping systems, however, which use the land much more intensively, have continued to rely on conventional tillage. For a successful adoption of CA practices, they should be adapted to local conditions and to resource availability of smallholder vegetable farmers. Accordingly, we studied the effect of combinations of reduced tillage, mulching and organic matter addition on water capture and conversion efficiencies under vegetable crops grown on raised beds on fine textured soils. We hypothesize that reduced tillage in combination with a cover crop and addition of locally sourced organic matter can substantially reduce runoff and soil erosion from raised beds as compared with current practices.

The aim of our study was to analyze the effect of reduced tillage, cover crops and organic matter addition on water runoff, soil erosion, soil moisture supply capacity and crop yield in raised bed systems on a fine-textured, moderately well-drained soil. We compared soil management practices that are readily available to local farmers, focusing on tomato as a major crop. We analyzed the first two years of transition from conventional to reduced tillage combined with organic mulching and the incorporation of cover crops and chicken manure. Runoff, soil moisture, cover and surface roughness were measured and used to calculate water-use efficiency, vulnerability to soil erosion through the Revised Universal Soil Loss Equation (RUSLE) (USDA-ARS, 2003), threshold rainfall at which runoff starts and the runoff/rainfall ratio across tillage systems.

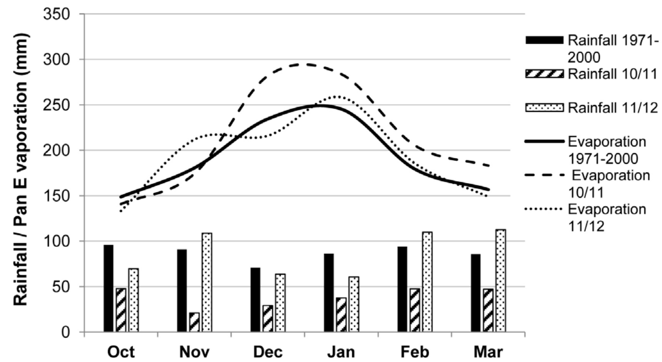

Fig. 1. Monthly pan evaporation (lines) and precipitation (bars) from October to March at INIA Las Brujas meteorological station (Lat: 34°40′ S; Lon: 56°20′ W). Bars represent climate (1971–2000; black), cropping season 2010–2011 (hatched) and cropping season 2011–2012 (gray).

2. Materials and methods

2.1. Study site, experimental design and soil management

The study was conducted at the South Regional Center Research Station, Canelones, south Uruguay. Climate is temperate with a mean annual rainfall of 975 mm (Fig. 1). Weather variables were monitored with an automatic meteorological station situated at 630 m from the experimental site and a pluviometer next to the plot.

The soil at the experimental site is a Luvic Phaeozem according to the FAO system, with particle size distribution in the upper 20 cm soil layer of 140 g kg^{-1} sand, 625 g kg^{-1} silt, 235 g kg^{-1} clay, and 15 g kg^{-1} soil organic carbon (SOC). A sequence of black oat (*Avenastrigosa* L.; winter crop) – processing tomato (*Lycopersicon esculentum* Mill.; summer crop) was established during two subsequent years (2010–2012) in a field of 50 m × 30 m as part of a rotation that also included the summer crops corn and onion. Black oat was sown in autumn and killed off with glyphosate at the end of the winter (20 August 2010 and 7 September 2011). Tomato was transplanted on 22 October 2010 and 1 December 2011 at a density of 26,667 plants ha^{-1}, and harvested weekly from 5 January to 17 February 2011, and from 8 February to 7 March 2012. Water was provided at transplanting and during the growing phase after several days of no rainfall.

Four treatments in three replicates were arranged in a complete random design in plots consisting of two contiguous raised beds, 1.5 m apart (Fig. 2). In three conventional tillage treatments, beds were re-built twice a year before each crop. The fourth treatment was based on reduced tillage where beds were re-built only before sowing black oat. The conventional tillage systems included a control system with only artificial fertilizer (*CT*), a system with a mixture of chicken manure and rice husk commonly used in the region (*CChM*), and a system with both chicken manure and green manure consisting of black oat incorporated to the soil 20–70 days before planting the tomato crop (*CGM*). In the reduced tillage treatment (*RT*) chicken manure was incorporated during the re-building of the beds, and black oat was killed with glyphosate 40–105 days before planting the tomato crop and left as mulch on the soil surface. In each treatment the soil was tilled with a tandem disk and a disk hiller was used to re-build the beds in autumn. Details of the treatments and amounts of nutrients applied are given in Table 1. *P* was not applied since it was not a limiting nutrient (*P*-Bray I status in soil surface of the plots was 75 mg kg^{-1}).