Agriculture, Ecosystems and Environment 139 (2010) 284–292

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

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

Dynamics of soil organic carbon in an innovative irrigated permanent bed system on sloping land in southern Spain

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ARTICLE INFO

Article history:
Received 7 April 2010
Received in revised form 25 August 2010
Accepted 26 August 2010
Available online 21 September 2010

Keywords:
Permanent beds
Residue management
Soil carbon dynamics
Zea mays
Irrigated conservation agriculture

ABSTRACT

Irrigated spring cropping systems on sloping soils require conservation agriculture (CA) to minimise soil erosion. In southern Spain, management of residues in the commonly-practiced maize–cotton rotation is a major hurdle against adoption of CA. Recently, a minimal-cultivation, irrigated permanent bed system has been developed in which, two weeks before sowing, maize or cotton residues are relocated from the seed rows on the top of beds into the furrows. This allows solar heating of the beds which accelerates seedling emergence. This paper presents the effects that the introduction of this system had on soil properties along a variably-sloping landscape in which six homogeneous zones were identified. It also discusses the system's potential for carbon sequestration and shows that a similar quantity of carbon is stored after 4 years under irrigated permanent beds to that after 11–21 years in rainfed no-tillage systems. The relocation of residues resulted on average in lower soil organic carbon concentration (SOCc) in the beds than in the furrows (1.40 and 1.51% respectively in the top 5 cm of soil). Under this system SOCc also varied among the landscape zones particularly in the top layers. SOCc was highest in the most eroded shoulder-backslope zone (Z2) though soil organic carbon storage (SOCs) there was the lowest because of the zone's high >2-mm soil fraction. The SOCs (0–30 cm) global average during the study was 35.2 Mg C ha^{-1} and ranged from 22.4 Mg C ha^{-1} in the shoulder Z2 zone to 41.4 Mg C ha^{-1} in the Z5 footslope zone. When compared to conventionally-managed fields nearby, following this management system appeared to improve soil characteristics significantly and protect against soil erosion.

1. Introduction

Soil erosion is the main environmental problem associated with agriculture in Mediterranean environments because of the heavy rains occurring in autumn or winter after the fields have been tilled in preparation for sowing. It has also become a major problem in irrigated cropping systems in hilly terrain with the expansion of sprinkler and drip irrigation during the last century. The adoption of conservation agriculture (CA), i.e. minimum or no tillage, crop residues retention on the soil surface and crops rotation (Govaerts et al., 2009), could in principle reduce the risk of soil erosion in irrigated Mediterranean agriculture, as it has for rainfed systems, but in practice it has not been adopted because of limitations associated with managing excessive crop residues and/or avoiding soil compaction (Gómez-Macpherson et al., 2009).

Harvesting cotton generally results in unacceptable soil compaction in our Mediterranean conditions as it is done in early autumn when the probability of rainfall is high. On a wet clay soil one single wheel pass can compact the soil severely (Alakukku and Elonen, 1995) and such compaction has been associated with reduced yields in CA cotton (Raper et al., 2000). The traditional remedy for soil compaction is tillage, an approach to be avoided under CA systems. So CA farmers prefer to use low pressure wheels and to restrict their traffic to specific paths by using GPS-controlled devices. When beds are used traffic can be restricted to specific furrows which can occasionally be deep-ripped. This avoids the requirement for special GPS-controlled machinery though all equipment has to be adapted to fit the distance between furrows.

In southern Spain, irrigated cropping land can have steep slopes and severe erosion problems (Calleja et al., 2008). In such hilly regions, soil organic carbon (SOC) pool dynamics are affected by erosion–deposition processes down the slopes (VandenBygaart et al., 2002). Areas where soil and organic carbon are lost can be more extensive than the depositional areas where they accumulate, with the result that the land overall becomes impoverished (Gregorich et al., 1998). This effect can be reduced under no tillage and by maintaining residues (VandenBygaart et al., 1999; Etchevers et al., 2006).

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doi:10.1016/j.agee.2010.08.015

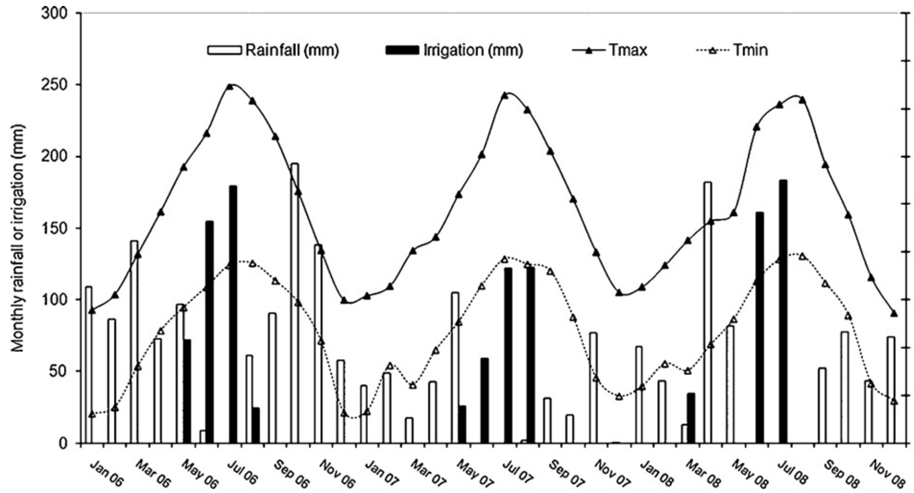

Fig. 1. Monthly weather data in Fuente Palmera, Spain, between January 2006 and December 2008. Accumulated precipitation (rainfall, open histograms; irrigation, solid histograms). Temperature (maximum (▲), minimum (△)).

A mulch of residues covering the soil is critical for reducing soil water erosion but in Mediterranean environments the residues have the negative effect of retarding establishment of crops sown at the end of the cold season in late winter or early spring (Gómez-Macpherson et al., 2009). This is because the residues prevent solar radiation from warming the soil. Farmers need to aim for the earliest possible sowing time to extend the limited growing period of spring crops like maize (*Zea mays* L.) or cotton (*Gossypium hirsutum* L.). The simplest way to avoid the delay in establishment has been to remove the residues from the row surface at sowing (Kaspar et al., 1990; Swan et al., 1994).

Removing residues from the top of the bed leaves the surface without mulch protection from March to August. This is of concern during the first two months when heavy rains may occur and the risk of soil and nutrient loss is high (Salinas-Garcia et al., 2001; Jin et al., 2009a,b), particularly in sloping hill lands. Furthermore, removing the residues may worsen physical and chemical soil properties, as occurred in an irrigated permanent bed system in north-western Mexico (Sayre and Hobbs, 2004). Their absence from the top of the beds may also impact on their usual beneficial overall effect on SOC (Govaerts et al., 2006), though it is noted that the effect of residues on SOC depends on landform (Gregorich et al., 1998), soil type (Franzluebbers and Arshad, 1997), crop rotation (Limon-Ortega et al., 2002), N fertilizer rate (Campbell et al., 2001), climate conditions (Halvorson et al., 2002), stone cover (Yang and Wander, 1999) and residues management (Wilhelm et al., 2004).

A new permanent bed system that includes removal of residues from the beds two weeks before sowing has been developed on a commercial farm in southern Spain (Calleja et al., 2008). This paper examines how the removal of residues affects SOC and other soil parameters (pH, electrical conductivity and phosphorus availability) and how these effects change down a sloping landscape 4 years after introducing the system. While other researchers have focused on the effects of removing residues from the seed row surface on plant establishment (Swan et al., 1994), we have targeted the effects on soil properties and the implications for prevention of soil erosion. Being the first study on irrigated permanent bed systems in the region, its potential for carbon sequestration is also discussed particularly in comparison to irrigated conventional tilled systems and rainfed no-tilled systems.

2. Material and methods

2.1. Location, landscape zones and farm management

This research was conducted on a commercial farm of the Fuente Palmera irrigation district (Córdoba, Spain; 37°44′N, 5°09′W). The climate is Mediterranean with a mean annual rainfall of 608 mm mostly distributed from October to May and essentially absent during the summer cropping season. The mean monthly maximum and minimum temperature and the accumulated monthly rainfall during the study are shown in Fig. 1.

In 2004, the farmer established under conservation agriculture (CA) a 20 ha field with the local common maize–cotton irrigated rotation. This field is the basis of the study described here. His choice of management for the field was based on results from a neighbouring field in which he had tested various reduced tillage options since 2001. The studied field occupies the edge of an eroded quaternary terrace of the Guadalquivir Valley. The top of the terrace is a Typic Calcixerept (Z1 in Fig. 2). During erosion the parental rolling stones have been deposited in the lower blue marls along the slope. Most of the soil in the field is a vertisol (Typic Haploxerert) with a high proportion of rolling stones in some zones (Table 1). Early in the study, a topographical survey of the field was done using a total station (Electronic Station GTS-210, TOPCON). Six homogeneous zones were identified according to landscape segmentation (Wysocki et al., 2000) and after discussion with the farmer (Table 1;

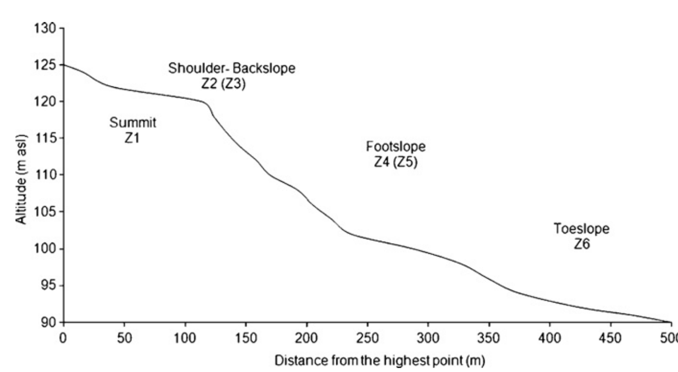

Fig. 2. Vertical cross section of the studied field in Fuente Palmera, Spain. Landscape zones Z3 and Z5, in brackets, are located in a different cross section of the studied field.