Soil & Tillage Research 123 (2012) 21–28

Contents lists available at SciVerse ScienceDirect

Soil & Tillage Research

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

Conservation agriculture effects on soil organic matter on a Haplic Cambisol after four years of maize–oat and maize–grazing vetch rotations in South Africa

E. Dube, C. Chiduza *, P. Muchaonyerwa

Department of Agronomy, Faculty of Science and Agriculture, University of Fort Hare, P. Bag X1314, Alice 5700, South Africa

ARTICLE INFO

Article history:
Received 17 August 2011
Received in revised form 1 February 2012
Accepted 20 February 2012

Keywords:
Fertilizer management
Soil organic matter improvement
Winter cover crops

ABSTRACT

A study was conducted to determine the effects of oat (*Avena sativa*) and grazing vetch (*Vicia dasycapa*) winter cover crops and fertilization regimes on soil organic matter (SOM) in an irrigated maize-based (*Zea mays* L.) conservation agriculture (CA) system following four years of continuous practice. Separate plots of oat and grazing vetch cover crops were grown in winter and then maize was planted in all plots in the following summer season. The four fertilization regimes used were: (i) fertilizer applied to the cover crops and the maize crop (F1), (ii) fertilizer applied to cover crops only (F2), (iii) fertilizer applied to the maize crop only (F3) and (iv) no fertilizer applied (F4). Control plots (weedy fallows) were included and the treatments were laid out in a randomized complete block design with three replications. Soil samples from 0–5, 5–20 and 20–50 cm depths were analyzed for total SOM, particulate organic matter (POM) fractions, hot water soluble C (HWC) and C-associated with water stable macro- and micro-aggregates (WSAC). While total SOM was more concentrated in the 0–5 cm soil depth across treatments, a lack of maize fertilization (F2 and F4 regimes) significantly ($P < 0.05$) reduced the stratification ratio. Oat and grazing vetch rotations produced significantly higher ($P < 0.05$) fine POM, coarse POM and HWC than weedy fallow rotations at 0–5 and 5–20 cm. When fertilized, oat was better able to support SOM sequestration in water stable aggregates at 0–20 cm while grazing vetch was more effective at 20–50 cm. The F3 regime had similar SOM levels as the F2. When no fertilizer was applied (F4-regime), there were significant ($P < 0.01$) reductions in biomass input and total SOM on the oat–maize and weedy fallow–maize rotations whereas the grazing vetch–maize rotation did not respond, both at 0–5 and 5–20 cm. The findings suggested that in the low fertilizer input CA system, targeting fertilizer to the winter cover crop as opposed to the maize crop could give similar SOM response, with less fertilizer invested and that grazing vetch cover crops may be better suited to low N input CA systems for SOM improvement.

1. Introduction

Poor soil fertility is a major problem causing low maize (*Zea mays* L.) grain yields (<3 Mg/ha) in many areas of South Africa where smallholder irrigation is practiced (Fraser, 2003; Fanadzo et al., 2010). In the Eastern Cape province, poor soil fertility is attributed to low geological reserves of essential plant nutrients, low soil organic matter (SOM) levels, continuous maize monoculture (without adequate nutrient replenishment) and tillage induced soil erosion (Mandiringana et al., 2005). Medium textured, shallow and highly erodible young soils derived from mudstones and shales, with very low SOM (<1%), are widespread in the Eastern Cape (Laker, 2004; Mandiringana et al., 2005). Improvements in SOM can result in several benefits in these soils, including improved soil nutrient storage capacity, nutrient availability, biological activity, soil structure and resistance to erosion (Brady and Weil, 2008). Meanwhile, conservation agriculture (CA) is being promoted to reduce crop production costs, conserve soil and improve its quality in low input smallholder farming systems of the Eastern Cape.

Conservation agriculture involves minimal soil disturbance, a permanent soil cover, and ecologically viable crop rotations. A permanent soil cover, through the use of cover crops and crop residue mulch retention, combined with reduced tillage could be the best management practice for SOM restoration and control of erosion (Derpsch, 2005; Hobbs, 2007). In tropical savanna regions of Brazil where the soils are of low agricultural potential, maintaining permanent soil cover with a thick layer of biomass (>6 Mg/ha) derived from cover crops and crop residues is one of

Abbreviations: ANOVA, analysis of variance; CA, conservation agriculture; g, gram; h, hour; ha, hectare; HWC, hot water soluble carbon; kg, kilogram; L, liters; LSD, least significant difference; mg, milligram; Mg, megagram; ppm, parts per million; POM, particulate organic matter; SOC, soil organic carbon; SOM, soil organic matter; WACE, weeks after crop emergence; WSAC, water stable aggregate protected carbon.

* Corresponding author. Tel.: +27 40 602 2226; fax: +27 40 602 2488.
E-mail address: cchiduza@ufh.ac.za (C. Chiduza).

0167-1987/$ – see front matter © 2012 Elsevier B.V. All rights reserved.
doi:10.1016/j.still.2012.02.008

the key factors for SOM restoration and soil fertility improvement in CA systems (Bollinger et al., 2007). Findings of recent studies carried out in irrigated maize-based smallholder CA systems of the Eastern Cape suggest that grazing vetch (*Vicia dasycarpa*) and oat (*Avena sativa*) winter cover crops can produce in excess of 6 Mg/ha dry matter annually, providing good cover, weed control, moisture conservation and maize yield benefits (Murungu et al., 2010a; Musunda, 2010).

Nitrogen fertilizer inputs are required in order to maximize cover crop biomass yields on start-up of CA (Murungu et al., 2010a). Application of N-based fertilizers is often recommended to increase SOM, particularly on lands that have already experienced a significant loss of SOM as a result of cultivation (De Maria et al., 1999). Fertilizer application to optimize grain production generally results in increased crop residue production and the lack of SOM accumulation under some no till systems of Brazil was attributed to the lack of sufficient external N input to the systems (Sisti et al., 2004). Grazing vetch appeared ideal as a winter cover crop in irrigated maize-based smallholder CA systems in the Eastern Cape because of its ability to fix N in low N soils, fast decomposition rates and rapid release of nutrients for the benefit of subsequent crops (Murungu et al., 2010b). Oat on the other hand tends to give higher biomass yields and residue persistence, and consequently better soil cover against weeds and soil erosion (Murungu et al., 2010a). There are differences in tissue chemistry (C:N ratio, lignin and polyphenol content) and thus decomposition characteristics between oat and leguminous (vetch) winter cover crops (Murungu et al., 2010b).

While the combination of reduced tillage and increased residue return through appropriate cover crop species selection and astute fertilizer application present opportunity for SOM buildup in maize-based smallholder systems of the Eastern Cape, limited studies have been carried out to systematically examine the effects of winter cover crop species and fertilizer management on SOM pools. The accumulation rate of SOM as well as its fractions depends on soil texture, precipitation and temperature (Amelung et al., 1998; Brady and Weil, 2008). On a local scale, micro-environmental conditions that depend on factors such as micro-topography, surface cover components and land management dictate spatial differences in SOM (Polyakov and Lal, 2004; Sisti et al., 2004; Ding et al., 2005)

Whereas SOM restoration can be a slow process, it is of interest to study the dynamics of SOM through its mineralizable pools which are sensitive to changes in management. Soil organic matter stabilization in soil aggregates is the principal mechanism for sequestration of C (Tisdall and Oades, 1982). Increases in SOM under continual C input are generally associated with increases in C-rich macro-aggregates (Six et al., 2002) and water stable macro-aggregates are enriched in recently deposited SOM (Angers and Giroux, 1996). Soil organic matter can be divided into a relatively inert non-mineralizable fraction associated with clay particles in soils and a second, potentially mineralizable 'active' fraction which can be expressed as hot water soluble carbon (HWC) (Körschens et al., 1990) and particulate organic matter (POM) (Cambardella and Elliott, 1992). A decline in the size of these fractions relative to total SOM is indicative of loss in inherent soil fertility (Swift and Woomer, 1993).

Vertical stratification of SOM pools is common when degraded cropland is restored with conservation tillage (Franzluebbers, 2002). It is therefore important to measure the degree of stratification as an indicator of soil ecosystem functioning (Franzluebbers, 2002). Mills and Fey (2004) used the term pedoderm to describe those first few centimeters of soil in which certain properties are often more strongly expressed than in the remainder of the soil surface horizon in undisturbed systems. The objective of this work was to evaluate the effects of oat and grazing vetch winter cover crops, including fertilizer management strategies on SOM and its pools (HWC, POM and C-associated with water stable macro- and micro-aggregates [WSAC]) in a maize-based CA system after four years of continuous practice. The hypothesis was that high biomass yielding winter cover crops and appropriate fertilizer management would improve SOM in maize-based CA systems.

2. Materials and method

Field trials were conducted at the University of Fort Hare research farm, in the Eastern Cape. The farm is located at latitude 32°46′S and longitude 26°50′E at an altitude of 535 m above sea level. It has a warm temperate climate with mean annual temperature of 18.1 °C and an average annual rainfall of 575 mm received mainly during the summer months (November–March). The soil is of alluvial origin, classified as Haplic Cambisol (IUSS Working Group WRB, 2006). It has 64.2% sand, 16.0% silt, 19.8% clay, pH 6.1 and a total elemental content of 0.35 g P/kg, 4.04 g K/kg, 4.25 g Ca/kg and <10 g SOM/kg (Mandiringana et al., 2005). The study was carried out as part of a four-year field trial, originally established to elucidate the effects of winter cover crops species and fertilizer on biomass yield and weed suppression in a maize-based CA system (Murungu et al., 2010a). The soil type and climate at the research farm closely resemble those of smallholder irrigators in the Eastern Cape.

2.1. Treatments and experimental design

This study was established on the 1st of June 2007. Oat (*A. sativa* cv. Sederbrg) and grazing vetch (*V. dasycarpa* cv. Max) winter cover crops were planted with and without fertilizer. The fertilizer was applied at 10 kg P/ha, as a compound (6.7% N; 10% P; 13.3% K) at planting. Grazing vetch was inoculated with *Rhizobium legunominosarium* biovar *viciae* at planting. Oats were top dressed using lime-ammonium nitrate (LAN–28% N) at 7 weeks after planting (WAP) at a rate of 138 kg/ha to make a total of 45 kg N/ha. Control plots with no winter cover crops and no fertilizer were included.

Table 1
Rainfall and irrigation water received during periods of summer maize and cover crops growth (2007–2011).

Month	2007/2008		2008/2009		2009/2010		2010/2011	
	Rainfall	Irrigation	Rainfall	Irrigation	Rainfall	Irrigation	Rainfall	Irrigation
June	43.6	30	14.9	30	20.5	20	48.3	30
July	16	20	2.5	40	53	10	16.8	45
August	20.6	50	68.1	20	15	40	12	60
September	5.1	40	5	50	25.3	20	9.1	0
October	56.9	0	25.2	20	56.4	30	65.7	15
November	38	20	59.5	20	50.8	20	62.3	40
December	124.7	20	99.9	20	42.5	40	122.6	15
January	104.7	0	60.6	30	103.2	0	103.2	15
February	96.5	20	112	0	40.2	40	40.2	30