Agriculture, Ecosystems and Environment 268 (2018) 103–114

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

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

The effect of a medic-wheat rotational system and contrasting degrees of soil disturbance on nematode functional groups and soil microbial communities

Johan Habig[a,c,e,*], Johan Labuschagne[b], Mariette Marais[c], Antoinette Swart[c,d], Sarina Claassens[e]

[a] MicroLife Research Centre, Agri Technovation, Louw Street, Wellington, 7655, South Africa
[b] Directorate of Plant Sciences, Western Cape Department of Agriculture, Private Bag X1, Elsenburg, 7607, South Africa
[c] Agricultural Research Council-Plant Health and Protection, Private Bag X134, Queenswood, Pretoria, 0121, South Africa
[d] Department of Zoology, University of Johannesburg, P.O. Box 524, Auckland Park, Johannesburg, 2006, South Africa
[e] Unit for Environmental Sciences and Management, North-West University, Potchefstroom 2520, South Africa

A R T I C L E I N F O

Keywords:
Nematode functional guilds
Microbial diversity indices
Microbial enzymatic activity
Cropping sequence
Tillage practices
Biological soil health indicators

A B S T R A C T

During a four-year cropping cycle, the effects of cropping sequence (wheat-medic rotation and wheat monocropping) and contrasting degrees of soil disturbance (conventional tillage and zero tillage) on nematode functional guilds and soil microbial diversity indices and enzymatic activities were quantified. Extracted and identified nematode taxa were sorted into functional guilds and assigned to a colonizer-persister (cp) scale. Soil microbial species richness and abundance were measured using the Shannon-Weaver and Evenness diversity indices, respectively, while microbial enzymatic activities (ß-glucosidase, phosphatase, urease) were assayed to evaluate ecosystem functioning over time. Crop rotation and zero tillage practices increased nematode trophic linkages, whereas plant-feeding nematodes declined over time in soils subjected to conventional tillage practices. Zero tillage practices and crop rotation over time were found to increase soil microbial richness and evenness. Carbon, phosphorous and nitrogen mineralization rates were independently influenced based on cropping sequence, but were found to have increased ($p < 0.05$) over time under zero tillage practices. Quantitative analyses of integrated biological indicators under various agricultural management practices will assist in our understanding of possible practices to ensure healthier soils with the ability to support sustainable crop production.

1. Introduction

Humanity is facing its biggest challenge yet: to provide food to an increasing global population that is estimated to reach 9 billion in 2050. It is estimated that drastic measures will be required to overcome this challenge, while declining natural resources and arable lands result in phenomena such as land degradation and loss of biodiversity and ecosystem functions (Lenné and Wood, 2011; IPES-Food, 2016). More food will have to be sustainably produced on available and diversified arable land by tweaking agricultural practices to be less detrimental to the environment and more prone to building soil resilience and lasting fertility (IPES-Food, 2016).

A large part of South Africa's total winter wheat is produced in the Western Cape Province. Dryland wheat production in the province contributed approximately 35% to the country's wheat production in 2011 and increased steadily to an approximate contribution of 51% in 2014 (Anon., 2012, 2015). Wheat farmers in the province have traditionally specialized in conventional agriculture, *i.e.* wheat monoculture in combination with conventional tillage, but gradually adopted more sustainable conservation agriculture (CA) approaches (Tilston et al., 2010). According to Karlen et al. (1992), the main aim of CA is to increase and sustain soil organic matter through crop diversification, permanent soil cover, and minimum soil disturbance – usually incorporated as a combination of the three principles. Crop diversification does not only benefit physical and chemical soil properties, but also the soil's microbial diversity and activity by depositing a more diverse composition of plant residues (*i.e.* organic matter) in various soil strata with the aid of more diverse root systems and exudates (Acosta-Martinez et al., 2007; Quio et al., 2012; Philippot et al., 2013). During zero tillage (ZT), the degree of soil disturbance is minimized, while crop residues are left on the soil surface, subsequently resulting in less CO_2 being released, creating more stable humus, increasing infiltration rates, and minimizing soil compaction and erosion (Breure, 2004; Sullivan, 2004). This beneficial effect is impeded when conventional tillage (CT) is practiced, since CT redistributes smaller crop residues throughout the ploughed layer (Six et al., 1999), resulting in the

* Corresponding author at: MicroLife Research Centre, Agri Technovation, Louw Street, Wellington, 7655, South Africa.
E-mail address: johan.habig@agritechnovation.co.za (J. Habig).

https://doi.org/10.1016/j.agee.2018.09.013
Received 1 February 2018; Received in revised form 8 September 2018; Accepted 11 September 2018

opposite effect as in the case with ZT.

Agricultural management practices such as CT, monocropping systems and residue removal management significantly influence crucial microbial processes (Coyne and Mikkelsen, 2015) and consequently, soil fertility. Due to their abundance in natural ecosystems, sensitivity to pollution and other environmental changes, terrestrial nematodes and soil microbial diversity and enzymatic activity have been used to serve as indicators of environmental disturbance (Bongers, 1990; Breure, 2004; Heininger et al., 2007; Blagodatskaya and Kuzyakov, 2013). Because of their diversity, wide feeding range and activity, beneficial nematodes and soil microbial communities contribute to the soil food web stability by facilitating critical soil biogeochemical processes in soil ecosystems such as the recycling of carbon-containing substrates, nitrogenous compounds, and transforming soil organic matter into mineral and organic nutrients. These nutrients are then taken up by the plants, influencing plant growth and crop productivity (Ingham et al., 1985; Ferris et al., 2004; Grierson et al., 2004). Due to the in-depth connection of terrestrial nematodes and microbial communities with their surroundings, they rapidly react to changes and stress in the environment (Sharma et al., 2010), making them ideal biological indicators of changes in soil quality (Dick, 1994; Pankhurst et al., 1995; Wilson and Kakouli-Duarte, 2009).

Where food production traditionally focused on nutrition and food security, the possible solution to increasing soil fertility and quality might have been left unaddressed. The impact of anthropogenic activities (which include agriculture) on essential ecosystem functioning needs to be explored to enable us in maintaining ecologically-friendly agricultural management approaches to strengthen soil biodiversity and sustainable agriculture (Andrén and Balandreau, 1999). This study presents a unique view of the influence of agricultural practices on South African soils by integrating nematode functional guilds with soil microbial diversity and activity data. The ultimate aim of this study was therefore to quantify the temporal impact of cropping sequences and degrees of soil disturbance on nematode trophic levels, soil microbial diversity indices and enzymatic activity in crop production systems in the Western Cape Province.

2. Materials and methods

2.1. Site

The long-term trial at the Tygerhoek Research Farm (GPS: -34.148100, 19.902800) near Riviersonderend in the winter rainfall sub-region of the Western Cape, South Africa, was initiated in 2007. Prior to 2000, the area was used as lucerne grazing for sheep, and as cash crop production under zero-till from 2000 to 2007. The long-term average rainfall of the region is approximately 450 mm, whereas the rainfall during the April - October growing season is approximately 315 mm. Soils on the experimental site are mainly classified as Mispah, Glenrosa and Swartland that originated mainly from residual shales of the Bokkeveld group. These soils are shallow and stony with weakly structured A horizons, making the soil prone to erosion and loss of organic carbon.

2.2. Experimental design and treatments

This study was conducted under dryland conditions over a four-year period (2011-14) during the second cropping cycle of a wheat (*Triticum aestivum* L.) monoculture (WWWW) and a medic/clover pasture and wheat rotation sequence, namely wheat-medic/clover-wheat-medic/clover (WMcWMc) and medic/clover-wheat-medic/clover-wheat (McWMcW), during every season. The three plots referred to in this study, *i.e.* McWMcW, WMcWMc, and WWWW represent the average of the triplicate treatments, each planted with its own specified cropping sequence. For the purpose of this paper the different systems will be referred to as indicated in Table 1.

Table 1
Four-year systematic cropping cycle for each of the various cropping systems.

Cropping system	Cropping Sequence			
	Year 1	Year 2	Year 3	Year 4
MW	wheat	medic	wheat	medic
WM	medic	wheat	medic	wheat
WW	wheat	wheat	wheat	wheat

Fertilization applications were standardized for each crop. Wheat received 25 kg $N.ha^{-1}$ at planting, followed by the application of 30 kg $N.ha^{-1}$ as top dressing. No fertilizer was applied to the medics. Soil fertility status was monitored and supplemented as necessary.

Each of the whole plots (gross plot size: 80 m × 15 m) were subdivided into four sub-plots (gross sub-plot size: 35 m × 7.5 m) to accommodate four degrees of soil disturbance. For the purpose of this paper, only conventional tillage and zero tillage treatments were compared and discussed to demonstrate the effect of the most contrasting degrees of soil disturbance:

1) conventional tillage (CT): soils were initially scarified to a depth of ± 150 mm, then plowed with a disc plow to a depth of 150–200 mm just before planting, and planted with a no-till tined planter that causes less than 20% soil disturbance to a depth of ± 150 mm in the planting row; and
2) zero tillage (ZT): soils were left undisturbed and planted with a star-wheel planter placing seed with minimal soil disturbance.

Crop residues were not removed from the treatments and remained on the soil surface until the commencement of the annual tillage treatments during early-autumn. In practice, the crop residues remained on the soil surface at all times in the ZT treatments. Increasing degrees of soil disturbance inevitably resulted in increased degrees of mixing of crop residues into the topsoil from zero to conventional tillage.

Each whole plot (treatment combination) was prepared in a split-plot design with rotation systems allocated to main plots and degrees of soil disturbance to sub-plots. The whole plots were prepared in triplicate and in a randomized block design.

2.3. Soil sampling and analysis

2.3.1. Soil chemical analysis

Annual composite soil samples were collected (n = 4) with the aid of a soil auger (90 mm diameter) to a depth of 150 mm from the CT and ZT sub-plots of the various treatment combinations (cropping system × tillage). Standard laboratory procedures were followed to analyze each of the composite samples. The determination of pH was performed using 1 M KCl, while electrical resistance was determined in a saturated soil-water paste. Available phosphorous (P), extractable calcium (Ca), magnesium (Mg), potassium (K) and sodium (Na) were determined by Inductively Coupled Plasma (ICP) analysis with 1% citric acid extraction. Copper (Cu), zinc (Zn) and manganese (Mn) were determined by ICP in 0.02 M di-ammonium EDTA soil extracts, whereas boron (B) was determined in hot water soil extracts, and sulphur (S) in $Ca_3(PO_4)_2$ soil extracts. The Walkley-Black and Dumas methods were used to determine soil organic carbon and total nitrogen, respectively.

2.3.2. Nematode functional groups

Soil and root samples (n = 4 per cropping sequence replicate) were collected annually before the flowering stage of the crops with the aid of a soil auger (90 mm diameter) and stored at 12 °C prior to nematode analyses. The nematodes were extracted from both soil and root samples using the sieving sugar centrifugal method (Marais et al., 2017b; Swart and Marais, 2017). The nematodes were identified and