Agriculture, Ecosystems and Environment 199 (2015) 382–393

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

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

Effects of contrasting catch crops on nitrogen availability and nitrous oxide emissions in an organic cropping system

Xiaoxi Li *, Søren O. Petersen, Peter Sørensen, Jørgen E. Olesen

Department of Agroecology, Aarhus University, Blichers Allé 20, Tjele, DK 8830, Denmark

ARTICLE INFO

Article history:
Received 16 July 2014
Received in revised form 11 October 2014
Accepted 16 October 2014
Available online 14 November 2014

Keywords:
Legume-based catch crop
Nitrous oxide
Crop N uptake
Organic farming
Management strategy

ABSTRACT

Legume-based catch crops (LBCCs) may act as an important source of nitrogen (N) in organic crop rotations because of biological N fixation. However, the potential risk of high nitrous oxide (N_2O) emissions needs to be taken into account when including LBCCs in crop rotations. Here, we report the results from a one-year field experiment, which investigated N availability and N_2O emissions as affected by three LBCCs, i.e., red clover (CL), red clover–ryegrass mixture (GC) and winter vetch (WV), two non-LBCCs, i.e., perennial ryegrass (GR) and fodder radish (FR), and a control (CO) without catch crops. The effect of two catch crop management strategies was also tested: autumn harvest of the catch crop *versus* incorporation of whole-crop residues by spring ploughing. LBCCs accumulated 59–67 kg N ha^{-1} in their tops, significantly more than those of the non-LBCC, 32–40 kg N ha^{-1}. Macro-roots accounted for >33% of total N in the catch crops. In accordance with this, LBCCs enhanced the performance of the succeeding unfertilised spring barley, thus obtaining a grain yield of 3.3–4.5 Mg ha^{-1} compared to 2.6–3.3 Mg ha^{-1} grain yield from non-LBCC and the fallow control treatments. Autumn harvest of catch crops, especially LBCCs, tended to reduce crop yield. The annual N_2O emissions were comparable across treatments except for fodder radish, which had the highest N_2O emission, and also the highest average yield-scaled N_2O emission, at 499 g N_2O-N Mg^{-1} grain. Although the sampling strategy employed in this study introduces uncertainty about the spatial and temporal variability, differences in seasonal emission patterns among catch crops were captured and harvest of catch crops in late autumn induced significantly higher emissions during winter, but lower emissions after residue incorporation in spring. In comparison with non-LBCC, LBCCs have the potential to partly replace the effect of manure application in organic cropping systems with greater crop production and less environmental footprint with respect to N_2O emissions. However, harvest of the catch crops may reduce crop yield unless the harvested N is recycled as fertiliser to the crops in the rotation.

1. Introduction

Organically cultivated land accounts for more than 6% of the total farmland in Denmark, and there is a political ambition to double this area by year 2020 (Ministry of Economic and Business Affairs Denmark, 2009; Norfelt, 2011). This is expected to be driven by a growing market demand for organic food, both domestically and on the global export markets. Moreover, the recent agreement of Common Agricultural Policy (CAP) by the European Commission gives positive legislative support for the development of organic farming (EU, 2013). This support is founded on trust in multiple benefits from organic production systems, although there is a need to further understand, document and improve the sustainability aspects of organic farming systems.

The productivity of organic cropping systems is often low due to lack of nitrogen (N) (Berry et al., 2002). In Danish organic farming system, the import of manure and straw from conventional sources is expected to be gradually phased out and finally abandoned by 2022 (Oelofse et al., 2013), and therefore in such systems the use of catch crops is considered an option for enhancing N recycling within the cropping system (Thorup-Kristensen et al., 2003; Müller et al., 2006; Olesen et al., 2007; Thorup-Kristensen and Dresbøll, 2010). It is well documented that catch crops can effectively retain soil mineral N in cold seasons and therefore reduce N leaching loss (Hansen and Djurhuus, 1997; Askegaard et al., 2005; Constantin et al., 2010).

* Corresponding author. Tel.: +45 87157795.
E-mail addresses: xiaoxi.li@agro.au.dk, lixiaoxi86@gmail.com (X. Li), soren.o.petersen@agro.au.dk (S.O. Petersen), ps@agro.au.dk (P. Sørensen), jorgene.olesen@agro.au.dk (J.E. Olesen).

http://dx.doi.org/10.1016/j.agee.2014.10.016
0167-8809/

Legume-based catch crops (LBCCs) are not restricted to mineralisation of soil organic matter for N supply, but can also exploit atmospheric N_2 via symbiotic N fixation. Due to their usually higher N concentrations and lower C/N ratios, legumes are expected to make N available faster after incorporation to the soil (Sainju et al., 2005; Constantin et al., 2011). After mineralisation, this N can be reused by the subsequent main crop with appropriate management strategies to ensure synchrony between N release and crop demand (Wagger, 1989; Thorup-Kristensen et al., 2003; Thorup-Kristensen and Dresbøll, 2010). Including catch crops in low-input organic cropping systems may thus contribute to improving N use efficiency.

However, during the growing period and after soil incorporation, relatively more inorganic N may accumulate in the uppermost soil layer with N_2-fixing legumes than with non-legumes (Thorup-Kristensen, 2006); this inorganic N is susceptible to nitrification and denitrification, thereby increasing the risk of nitrous oxide (N_2O) emissions (Mckenney et al., 1993; Stehfest and Bouwman, 2006; Barton et al., 2011). N_2O is a potent greenhouse gas (GHG) with a global warming potential approximately 300 times higher than that of carbon dioxide (CO_2) during a 100-year life time (IPCC, 2007), and after the phase-out of chlorofluorocarbons (CFCs) it has become the most important substance involved in ozone layer depletion (Ravishankara et al., 2009). Agricultural soils are estimated to be responsible for more than 60% of anthropogenic emissions of N_2O both globally (IPCC, 2007) and in Europe (Leip et al., 2011), mostly originating from the application of synthetic N fertilisers and manures. The uncertainty of N_2O emissions from use of catch crops is high and will depend on various climatic, soil and management factors (Vinther et al., 2004; Rochette, 2008; Petersen et al., 2011; Sanz-Cobena et al., 2014). On loamy sand soil, incorporation of catch crops and grass-clover in spring has been shown to be a significant source of N_2O in the crop rotation (Brozyna et al., 2013). Presumably the high oxygen (O_2) demand during decomposition is an important driver for N_2O emissions, whereas the importance of soil N availability is unclear (Petersen et al., 2011). There is a need to understand effects of catch crop quality and soil conditions, as well as management, on N_2O emissions during winter and spring.

Catch crops harvested for anaerobic digestion and subsequent use as a fertiliser reduced N_2O emissions by 38% compared to catch crops mulched and used as a green manure (Möller and Stinner, 2009). Nadeem et al. (2012) reported that during the green manure (grass–clover mixture) growing season, removing herbage resulted in significantly less N_2O emission ($0.37\,kg\,N_2O\text{-}N\,ha^{-1}$) than mulching of herbage. Thus, green manure management strategies may affect N_2O emissions in organic cropping systems, but consequences with respect to N availability for the subsequent main crop should also be taken into account.

In the present study, we report the findings from a one-year field experiment where organically managed spring barley followed different types of catch crop. There was no N input via manure or fertiliser application in order to emphasize the importance of the catch crops as N sources in the organic system. The objective of the study was to quantify effects of legume-based and non-legume-based catch crops on N availability for spring barley, and N_2O emissions associated with the growth of both catch crops and the subsequent main crop. The effect of autumn harvest was also investigated. We hypothesized that (1) LBCC can accumulate additional N and thus supply more N for the following crop, but with a higher potential for N_2O emissions during and after the catch crop growth period compared to non-LBCC; and (2) harvest of catch crop tops in late autumn can reduce N_2O emissions compared to incorporation of the whole plants by spring tillage.

2. Materials and methods

2.1. Experimental site

A one-year field experiment was conducted at Research Centre Foulum, Aarhus University, Denmark (56°30′N, 9°34′E). The top soil (0–0.30 m) is classified as loamy sand with 8.6% clay (<2 μm), 12.0% silt (2–20 μm), 46.6% fine sand (20–200 μm), 32.8% coarse sand (>200 μm), $18\,g\,kg^{-1}$ organic matter, $1.6\,g\,kg^{-1}$ total N, 33 mg Olsen-P kg^{-1}, 120 mg extractable K kg^{-1} and pH 6.4 ($CaCl_2$). The bulk density of the 0–0.10 m soil layer was $1.38\,g\,cm^{-3}$ at the start of the experiment in September 2012. Daily weather data were obtained from a climate station adjacent to the field experiment. The long-term mean annual precipitation at Foulum was 704 mm and the mean annual air temperature was 7.3 °C for the period of 1961–1990 (Olesen et al., 2000).

2.2. Experimental design

The factorial experimental design comprised two factors, catch crop type and harvest management. The catch crops used in this experiment included three LBCCs (red clover [CL, *Trifolium pratense* L., cv. Rajah], red clover-ryegrass [GC] and winter vetch [WV, *Vicia villosa*, cv. Villana]), two non-LBCCs (perennial ryegrass [GR, *Lolium perenne* L., cv. Foxtrot] and fodder radish [FR, *Raphanus Sativus* L., cv. Lunetta]) and a fallow control without catch crops [CO]. All treatments with catch crops were either harvested by a grass harvester on 30 October 2012 (H) or left untouched until incorporation by spring ploughing on 22 April 2013 (U). In order to maintain bare soil in control plots with minimum soil disturbance, glyphosate was applied in September 2012 instead of weed-harrowing. This treatment was abbreviated as CO_H. The experiment also included a control without catch crops, but left for voluntary weeds, which is a common way of managing fallow (CO_U). This allowed us to compare N availability and potential effect on N_2O emissions of uncontrolled weeds with the other treatments. All treatments were randomised within each of three replicated blocks (see Fig. 1), with a total of 36 plots (3 m × 20 m each). In accordance with normal practice, CL, GR and GC were

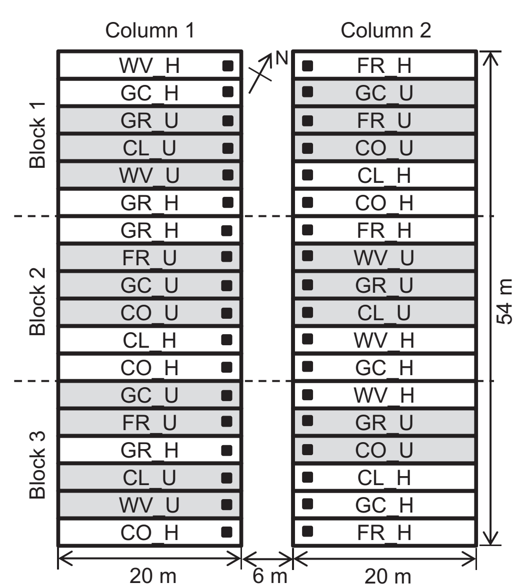

Fig. 1. Layout of the field experiment. The black square located at one end of each plot indicates the site (0.75 m × 0.75 m) for N_2O gas flux measurement. Early harvest treatments (H) are indicated by white colour, while the grey colour denotes spring incorporation treatments (U). Abbreviations: see Section 2.2.