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Annual maize and perennial grass-clover strip cropping for increased resource use efficiency and productivity using organic farming practice as a model

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ABSTRACT

A cropping system was designed to fulfill the increasing demand for biomass for food and energy without decreasing long term soil fertility. A field experiment was carried out including alternating strips of annual maize (*Zea mays* L.) and perennial ryegrass (*Lolium perenne* L.) – clover (*Trifolium repens* + *Trifolium pretense* L.) mixture grown in the same field. In autumn an annual strip was established with green-rye (*Secale cereale* L.) after soil incorporation of a 1st year grass-clover a 6-m wide strip followed by maize sowing in May. The perennial strips were established without incorporating the same 1st year grass-clover in an equivalent 6-m wide strip, resulting in an early competitive advantage for the perennial strip toward the annual strip. Throughout the growing season maize was never able to recovery from this and yields were reduced with around 50% when grown adjacent to grass-clover (0–50 cm) compared to with >50 cm distance. There was significantly greater clover content in the sward when grown with >150 cm distance to maize (30%) compared to the 0–25 cm distance (10%) indicating more available soil mineral N in the interface between the strips related to a strong ability of the grass to compete for soil mineral N. Maize yields were clearly associated with N fertilizer application. When fertilizer N was applied through slurry or anaerobic digested slurry maize yields was increasing with up to 100% equivalent to 1200 g carbon (C) m^{-2} or 35 MJ m^{-2}. However, the same relative growth reduction was found when grown in close proximity to the grass-clover strip. If slurry is available maize secures an efficient N uptake, however, long-term effects of maize cropping and biomass removal on soil quality is of concern. The present strip cropping system did not possess the right balance of co-existence and complementarity with relative yield advantages for the whole crop cycle between 0.96 and 1.01. Thus, the total land area required under traditional cropping attaining the yields achieved when dividing the field in strips is the same. Greater complementarity between strips is needed to gain the potential strip cropping advantages.

1. Introduction

Reduced availability and increased awareness of the environmental and climatic impacts of fossil fuel use (Olesen et al., 2011; Olesen and Bindi, 2002) have stimulated interest in renewable energy sources from agricultural crops (Haberl et al., 2011). However, on the same time it is important to deliver high quality food products to a growing market (Østergård et al., 2009) including strategies to reduce the reliance on fossil fuels and decrease total greenhouse gas emissions (Carter et al., 2012). This might lead to an expansion of crop land to satisfy new demands possibly causing a significant change in present agriculture tradition and practices.

Diverse cropping systems are likely to be more resilient to externalities and less dependent on external inputs (Olesen et al., 2011; Peoples et al., 2009). A strip cropping strategy combining annuals and perennials facilitates the spatial and temporal in-field diversity by producing two or more crops within the same field in strips wide enough that each can be managed independently by existing machinery; yet narrow enough that the strip components can interact (Exner et al., 1999). It subdivides the field into strips with different crops to gain the same positive effects known from rotations (Lesoing and Francis, 1999). It can also be regarded as the adaptation of traditional intercropping systems (Willey, 1979; Ofori and Stern, 1987) to current, mechanized agricultural practices. The goal is to gain the advantage of intercropping over the more traditional sole cropping through less competition for resources between species (Bedoussac and Justes, 2010; Corre-Hellou et al., 2006; Hauggaard-Nielsen et al., 2009) and

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highest possible level of complementarity between strips (Willey, 1979).

Because of its high energy yield and the ease of mechanization and integration into the farm organization (Schittenhelm, 2008) maize is one of the globe's most widely used food staples and becoming increasingly popular as a feedstock for different bioenergy conversion technologies, currently in particular biogas in Europe (e.g. Weiland, 2006) and bioethanol in USA (e.g. Vries et al., 2010). However, increases in maize yields are closely associated with increased levels of nitrogen (N) fertilizing (Nannen et al., 2011). Residues from anaerobic digestion (AD slurry) is identified as a promising tool to improve short-term plant nutrient availability (Stinner et al., 2008; Möller, 2009; Gunnarsson et al., 2010) and strategic nutrient allocation in organic farming (Möller, 2009). Another aspect of increasing the area cultivated with maize might be shorter crop rotations (even monocultures) and conversion of permanent grassland loosing the C sequestration benefits causing a drawback for soil fertility as well as climate change mitigation in the long run (Moebius-Clune et al., 2008). This is regarded as an unsustainable development.

Grass-clover pasture increases soil organic C (SOC) pools (Conant et al., 2005; Soussana et al., 2004) and may be employed to offset the SOC decline (Müller-Stöver et al., 2012), which has been documented in many cultivated soils with negative impacts on soil fertility and biological diversity in general (Olesen et al., 2011; Sommer and de Pauw, 2011; IPCC, 2007). The use of perennials within traditionally more annual-based rotations may become more frequent in future (Reeves, 1997; Paustian et al., 1997).

In the present strip cropping system, diversity is created by alternating strips (6 m) of annual maize (*Zea mays* L.) and perennial ryegrass (*Lolium perenne* L.) – clover (*Trifolium repens* + *Trifolium pretense* L.) mixture grown in the same field. The general idea is that maize will be managed as an independent annual rotation, whereas tillage is absent in the grass-clover pasture strip for 4–6 years to enhance root biomass production and residence time of C (Conant et al., 2005; Soussana et al., 2004). When the pasture is incorporated in the soil, the two strips will change place.

The objective of this study was to determine interactions between crop rows at the strip border and associated mechanisms responsible for a potentially improved biomass productivity compared to traditional cropping. Fertilizer N supply to maize using three different organic N sources was tested as a regulatory management tool to increase maize yields and interspecific competitive ability.

2. Materials and methods

2.1. Site characteristics

The field trials were carried out from autumn 2007 until summer 2009 at the experimental farm belonging to The Faculty of Science, University of Copenhagen, Denmark (55°40′N, 12°18′E). The 25-year mean annual rainfall is 550 mm and mean annual air temperature is 8 °C with maximum and minimum daily air temperature of 16 °C (July) and −1 °C (February). For daily actual and 25-year mean temperature and accumulated precipitation during the growing season 2007–2008 (7–9 October) and 2008–2009 (12 September–8 October) see Fig. 2. The soil is a sandy loam (12% clay, 25% silt, 34% fine sand and 27% coarse sand) with pH ($CaCl_2$) of 6.8, containing 1.3% total C and 0.12% total N in the 0–30 cm soil layer. In the 0–90 cm soil profile the water content at field capacity (−33 kPa) was 26% (v/v), the wilting point (−1500 kPa) was 11% (v/v) and the soil bulk density 1.65 Mg m^{-3} (Hansen et al., 1986). Cropping history of the site was a 4-year rotation with barley (*Hordeum vulgare* L.) undersown with grass-clover, and 2 years of grass-clover pasture followed by winter wheat (*Triticum aestivum* L.). The grass-clover pasture consisted of 8% red clover (cv. Rajah), 9% white clover (cv. Klondike), 40% early rye grass (cv. Stefani), 20% late rye grass (cv. Foxtrot) and 23% hybrid rye grass (cv. Storm).

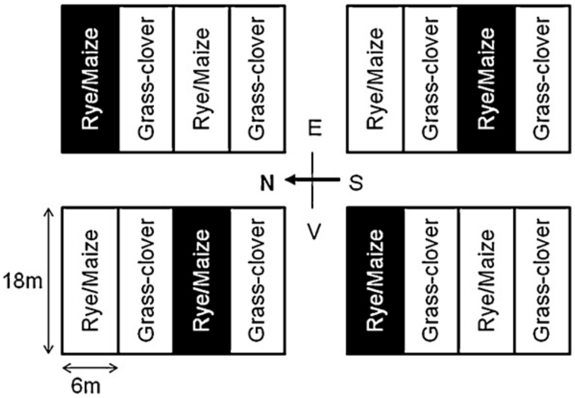

Fig. 1. Layout of the randomized strip intercropping design used in the 2007–2008 season. Black-colored strips are the "fertiliser plots" used for the N fertilizer experiments. For the 2008–2009 season a new randomization was conducted.

2.2. Experimental design and field management

Each growth cycle of the present study was initiated late August in the 1st year grass-clover field by sequential incorporation of the sward into the soil by conventional rotavation in defined 6 m × 14 m strips divided by 6 m × 14 m of the original grass-clover sward left as a soil fertility-building perennial strip (Fig. 1). No further crop management for the soil fertility-building strip was conducted. After rotavation, the soil was kept as a false seedbed and weeded mechanically twice before sowing winter rye (cv. Carotop) with 12.5 cm row distance (300 plants m^{-2}) without any further additional fertilizer applications. The function of green-rye was to act as catch crop of N mineralized from the incorporated grass-clover, but also to secure appropriate maize seedbed preparation. According to local experiences on this soil type, good seedbed preparation is necessary to avoid grass-clover re-growth in maize and to ensure sufficient seed-soil contact due to the considerable amounts of root and stubble materials often incorporated. The green-rye was then harvested early May using traditional forage harvester equipment. After rotavation and seedbed preparation, maize was sown in mid May at 50 cm row distance (12 plants m^{-2}). The actual plant densities were within 20% of the target densities (data not shown). An extra maize plot in each block was included for N fertilizer experiments.

Before sowing maize, these "fertilizer plots" was divided into four subplots (6 m × 3 m), which received (i) raw cattle slurry (Slurry), (ii) a mixture of anaerobic digested cattle slurry (85% of the N content) and digested maize silage (15% of the N content) (AD slurry), (iii) green manure consisting of fresh grass-clover cuttings (Green manure) and (iv) no fertilizer (Control). The target fertilization rate was 150 kg inorganic N ha^{-1} based on maize cultivation recommendations from the Danish Extension Service, assuming that 75%, 100% and 75% of the total N content in the three fertilizers, respectively, was plant available during the maize growing season. Right after sowing of maize, the two liquid fertilizers were applied by simulated direct injection. Briefly, furrows of about 10 cm depth and 15 cm width were made manually at 50 cm distance between the maize rows, and subsequently the liquid fertilizers were poured into the furrows using watering cans. The furrows were closed with soil after some infiltration (within 12 h). In the green manure treatment, fresh grass-clover material was placed in similar furrows that were left open.