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Effects of green manure herbage management and its digestate from biogas production on barley yield, N recovery, soil structure and earthworm populations

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ABSTRACT

In repeatedly mown and mulched green manure leys, the mulched herbage contains substantial amounts of nitrogen (N), which may only slightly contribute to the following crops' nutrient demand. The objective of the present work was to evaluate the effect of alternative strategies for green manure management on the yield and N recovery of a subsequent spring barley crop, and their short term effects on soil structure and earthworm populations. A field trial was run from 2008 to 2011 at four sites with contrasting soils under cold climate conditions. We compared several options for on-site herbage management and the application of anaerobically digested green manure herbage. Depending on the site, removal of green manure herbage reduced the barley grain yield by 0% to 33% compared to leaving it on-site. Applying digestate, containing 45% of the N in harvested herbage, as fertilizer for barley gave the same yields as when all herbage was mulched the preceding season. Overall, the apparent N recovery was enhanced from 7% when all herbage was mulched, to 16% when returned as digestate. A positive effect on earthworm density and biomass was seen after one season of retaining mulch material, rather than removing it. Digestate did not affect the earthworm population, but contributed to higher soil aggregate stability. In conclusion, for spring barley production after green manure ley, the digestate strategy increased N recovery and reduced the risk of N losses. The yield of the succeeding barley crop yield was reduced when N in herbage was not returned as mulch or digestate.

1. Introduction

Green manure leys are commonly used in organic cereal crop rotations to maintain soil fertility on stockless farms. Such full season grass-clover leys may increase yields through improved nitrogen (N) supply and through non-nutritional benefits such as improved soil structure, suppression of diseases and weeds, more earthworms and increased mycorrhizal activity (Cherr et al., 2006; Janzen and Schaalje, 1992; Riley et al., 2008). The green manure leys are generally grown as set-aside; managed by leaving the chopped herbage as mulch after frequent mowing during the growing season (Cormack et al., 2003; Stopes et al., 1996). The mowing is done as a means to control weeds and to keep the clover in a vegetative state and thus sustain high N_2 fixating activity and low C/N ratio (Dahlin and Stenberg, 2010).

Due to the accumulation of easily degradable N in green manure crops, current practice with repeatedly mowing and mulching means that substantial amounts of N in the herbage are at risk of being lost from the cropping system, both as gaseous emissions (NH_3, N_2O, NO and N_2) and through surface runoff or leaching of nitrate (NO_3^-) and soluble organic N (Askegaard et al., 2005; Korsaeth, 2012; Larsson et al., 1998; Möller and Stinner, 2009). Further, it is an expensive practice, using the land, establishing and managing the green manure for a whole season with no direct income, only the expectance of higher income from future crops on the field.

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That on-site mulched herbage contributes only slightly to the fulfilment of the following crops' nutrient demand has been demonstrated in several Scandinavian field trials (Engström et al., 2007; Frøseth et al., 2008; Solberg, 1995). As a consequence of herbage removal, one might expect decreased soil inorganic N availability for the green manure crop, which could enhance clover and N_2 fixation and thereby compensate for the lack of mulching in N pre crop effect. Hatch et al. (2007) found that removing cuttings from a grass-clover ley increased fixation, compared with mulching, but Dahlin and Stenberg (2010) found no differences. Neither of these studies included the N effect of these strategies on subsequent crops.

In spring barley, availability of inorganic N at the early tillering stage is a key factor for N uptake and dry matter (DM) yield (Hauggaard-Nielsen et al., 1998). Growing spring barley, based on the nutrients from a preceding green manure crop and without any additional nutrient input, is challenging under the cold Nordic climatic conditions with a short growing season. Borgen et al. (2012) concluded that there is a limited potential for improving N-use efficiency by management changes, in for example the time of ploughing and/or crop rotation, in stockless organic cereal production systems in Norway. For more substantial improvements, alternative strategies appear to be necessary. Application of digestate from green manure foliage digested anaerobically in a biogas plant may be a promising option for improving yields and N recovery instead of mulching (Möller and Müller, 2012; Stinner et al., 2008). In biogas plants, the easily degradable organic matter is digested, releasing methane for heating or fuel and residues (digestate). The latter contain plant available nutrients that may be applied as fertilizer in the subsequent season. To our knowledge, this strategy has not been compared previously with other strategies for green manure management under Nordic conditions.

Soil structure is important for the development of the barley crop (Arvidsson, 1999), both to create good conditions for root growth and for the turnover of soil organic matter (Breland and Hansen, 1996). The processes and mechanisms involved in soil aggregation is complex and can be affected through management practices (Bronick and Lal, 2005). Earthworm activity influences and normally improves soil structure and aggregate stability (Bronick and Lal, 2005; Edwards and Lofty, 1977; Marinissen, 1994). Although earthworm species have different feeding strategies, their excrements (casts) contain more plant available nutrients than does bulk soil (e.g. Buck et al., 1999; Haynes et al., 2003; Pommeresche and Løes, 2009). This finding supports the idea that one intensive year of "feeding" the soil with mulch material may improve soil structure and soil nutrient status.

The effects on earthworms when green manure herbage is removed and subsequently returned as digestate, instead of being mulched, have been little studied. Because the easiest available carbohydrates are converted to methane and removed, less energy and organic carbon (C) will be available for earthworms and other soil fauna. Ammonium and sulphide, which are toxic to earthworms (Curry, 1976) are formed by anaerobic digestion. Thus mulched green manure herbage may be more favourable to earthworms than anaerobically digested herbage.

The objective of the present work was to evaluate the effect of various strategies for green manure management on the yield and N recovery of a subsequent spring barley crop, and its short term effects on soil structure and earthworm populations in contrasting soils under cold climate conditions. The strategies involved different options for on-site herbage management and the application of anaerobically digested green manure herbage. The following hypotheses were tested:

- Removal of herbage, compared with mulching, will not affect the yield of a subsequent spring barley crop.
- Digestate applied as fertilizer for spring barley, compared with mulching the preceding season, will increase the crop yield and the proportion of N input by the green manure herbage that is recovered.
- Compared to herbage removal, mulching will not increase the amount of soil N available for a subsequent spring barley crop. On the contrary, digestate application will increase plant available N.
- Soil structure and earthworm populations will be negatively affected by removing the green manure herbage or by one application of digestate.

2. Materials and methods

2.1. Experimental sites, soil and weather conditions

Four field trials were established in 2008 at sites differing in soil characteristics and climatic conditions.

2.1.1. Weather and climate

The two neighbouring sites Kvithamar (63°29′ N, 10°52′ E) and Værnes (63°27′ N, 10°57′ E) share the same humid coastal climate in central Norway. Apelsvoll (60°42′ N, 10°51′ E) is situated inland, in eastern Norway with a drier climate and lower winter temperature. Ås (59°39′ N, 10°46′ E), in southeast Norway, represents an intermediate climate with respect to precipitation and winter temperature, but has the highest summer temperature of the sites. The normal values (1961–1990) for annual precipitation at Kvithamar/Værnes, Apelsvoll and Ås are 896, 600 and 785 mm, respectively, of which respectively 465, 319 and 382 mm occur during the growing season (May–September). The amounts of rainfall during the growing seasons of 2008/2009/2010 were 351/624/401 at Kvithamar/Værnes, 376/404/421 at Apelsvoll and 463/433/489 mm at Ås. The mean corresponding growing season temperatures in 2008/2009/2010 were 12.5/12.8/11.7, 12.8/13.1/12.4 and 13.4/13.8/13.1 °C, which are close to or above the normal values. During the winter prior to the barley crop (October 2009 – April 2010), the mean temperatures were −1.4, −3.2 and −1.7 at Kvithamar/Værnes, Apelsvoll and Ås. The corresponding amounts of precipitation were 534, 461 and 324 mm.

2.1.2. Soil properties

The soil at the sites is classified as a Mollic Gleysol, Arenic Fluvisol, Endostagnic Cambisol and Typic endoaqualf (IUSS Working Group WRB, 2006) for Kvithamar, Værnes, Apelsvoll and Ås. The soils at Ås and Kvithamar are derived from marine clay with relatively high silt contents, whilst that at Værnes overlies a coarse freshwater alluvium and that at Apelsvoll is developed from glacial till. The silty clay loam topsoil at Kvithamar is highly drought-resistant, but it overlies a very compact plough pan layer and compact subsoil with gley spots, both of which have low air and available water capacities. The clay loam topsoil at Ås is relatively drought-resistant and has a moderate air capacity, whereas the deeper soil layers are more compact, with low air and available moisture-holding capacities. At Værnes the soil is sandy loam and reasonably drought-resistant and well-aerated down to 0.5 m, but deeper layers have very low water-holding capacity and support little root growth. The soil at Apelsvoll is well-aerated sandy loam and relatively drought-resistant at all depths, and has few physical limitations to plant growth. The deeper subsoil (>0.6 m) is very compact. Information on the basic physical properties within soil profiles at the trial sites was obtained from previous studies performed at or close to the present locations (Table 1).

The topsoil at Kvithamar has a high C content, whereas the content is moderate at Apelsvoll and Ås and low at Værnes (Table 2). The C content in deeper horizons is very low, especially at Værnes and Ås. The level of total N is considerably higher at Kvithamar than