BioConcens: Biomass and bioenergy production in organic agriculture – consequences for soil fertility, environment, spread of animal parasites and socio-economy

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Abstract
The research programme called “international research cooperation and organic integrity” was commenced for a period 2006-2010. It is coordinated by DARCOF (The Danish Research Centre for Organic Farming). The whole programme, with acronym DARCOF III, consists of 15 projects (http://www.darcof.dk/research/darcofiii/index.html). One of them is BIOCONCENS - Biomass and bioenergy production in organic farming – consequences for soil fertility, environment, spread of animal parasites and socio-economy (http://www.bioconcens.elr.dk/uk/).
The production of bioenergy in organic agriculture (OA) can reduce its dependency of fossil fuels and decrease green house gasses emission; consequently it will increase sustainability of organic farms. Biorefinery concept based on co-production of biogas, bioethanol and protein fodder in organic farming will be developed within the BIOCONCENS project and the background for the project and the different work packages will be presented in this paper.

INTRODUCTION

Energy production and use in organic agriculture (OA) should be addressed in order to reduce the reliance on non-renewable fossil fuels and greenhouse gas (GHG) emissions (Jørgensen and Dalgaard, 2004). The development of renewable energy technologies within OA has been slow. One of the reasons for this has been concern in the organic community, that soil fertility will decline if a major part of the organic residues is used for bioenergy production and only residues from anaerobic gasification are recycled (Salomonsen, 2000). Since soil fertility is the basis for OA, organic materials should be recycled to the soil to preserve fertility. Using organic sources for energy production can potentially diminish the amount of carbon and nutrients recycled to the soil (Christensen et al., 1996; 2002). However, it is possible to manage soil fertility by intelligent management of organic residues and crop rotation. It is in agreement with the precautionary principle not to implement new technologies without knowledge of their consequences (DARCOF, 2000). Principles should not be a barrier for research on sustainable energy technologies within OA, since the reduction of non-renewable fossil energy use and reduced greenhouse gas emissions agriculture are principal aims in OA. Thus, there is an obligation to find consensus between the apparently opposing aims of renewable (bio) energy production and soil fertility in OA. BIOCONCENS aims of designing and evaluating a combined concept for biomass and bioenergy production in OA, while considering soil fertility.

STATE OF THE ART

Substituting direct fossil energy use in organic agriculture with renewable energy

A thorough examination of fossil energy use and perspectives for production of energy from local resources in OA has recently been published by DARCOF (Jørgensen and Dalgaard, 2004). They estimate that the total energy use in Danish OA is close to 2.5 x 1015 J, of which 17 million L diesel and 30 million kWh power are direct energy. DARCOF have suggested that production of biogas from animal manure and grass-clover pastures can become a major renewable energy source in OA and potentially cover 72% of the energy requirements. It is estimated that 19.000 ha grass-clover pasture is required to cover 40% of the total or 77% of the direct energy use in OA (Jørgensen and

Dalgaard, 2004). This corresponds to 12% of the Danish organic area. In Sweden, the consumption of 36 million L diesel in OA can potentially be substituted from biogas deriving from all OA animal manure and grass-clover from ca. 19000 ha (6% of organic area) (Baky et al., 2002). Bernesson (2004) carried out life cycle analyses for production of fuels in OA and found that biogas production from grass-clover had the lowest land use and relatively low cultivation and soil-related emissions. Diesel engines can run on bioethanol and cleaned biogas, but large storage facilities are required for biogas, and on-farm consumption of fuel for machinery is very seasonal (Baky et al., 2002). Furthermore, compression of biogas to 200-250 bar is a prerequisite for use as fuel, accounting for ca. 10% of the biogas energy (Møller and Sommer, 2004). Co-producing biogas and bioethanol in a co-ordinated bioenergy plant might be a more optimal solution.

Co-production of biogas and bioethanol

Anaerobic digestion of manure is a well-known technology for biogas production. Apart from a significant energy production the technology results in reduced GHG emissions, improved nutrient utilisation when recycling the residue to the field and reduced odour. Since manure is poor in energy components (sugars and lipids), it is necessary to mix it with substances containing more energy e.g. waste from food industry. Grass-clover pasture can be used as an alternative energy rich waste, for biogas production using cuts taken at an early growth stage, since the most easily digestible sugars are present in the leaves before stem production in June/July (Larsen, 2004). Sommer et al. (2002) estimated that in biogas production from grass-clover pastures, >10 times more energy is produced than utilized in the energy balance, corresponding to an energy output of ca. 13000 kWh per ha. Maize silage is a resource with great potential. With a gentle pre-treatment (method to be developed within the BIOCONCENS project) using ammonia from manure for delignification, it is expected that the potential energy output from maize silage will exceed that of grass-clover pastures.

The hydrolysis of sugar polymers, proteins and lipids is the rate-limiting step in biogas production, due to lignin associated with the sugar polymers (Tong et al., 1990). However, straw is sensitive to ammonia (high pH) treatment, that opens up the lignin barrier and improves sugar hydrolysis and fermentation yields (Thomsen et al. 2003). A pretreatment process will be developed to increase sugar hydrolysis and thereby the biogas yield from maize silage and animal manure. Whey is a by-product of cheese production and whey-permeate is a liquid waste product from the production of whey-protein. Whey-permeate contains lactose (< 4.6%), minerals (0.5%) and lipids (0.05%). Whey-permeate is presently used for biogas production and pig feed. In the BIOCONCENS project we will test whey-permeate as a water resource alternative to manure for biogas and ethanol production with co-production of protein fodder. It has been shown that the content of amino acids increases by 230%, and lysine by 300% after biogas production from grass-clover pasture (Gunnarson and Stuckley, 1986).

The most well-known and easiest way to produce bioethanol is by the enzymatic hydrolysis and fermentation of starch. In this process more that 34 mill. m^3 of ethanol were produced in 2002 for transportation fuel, accounting of 60% of the total world ethanol production (Thomsen et al., 2003). The estimated production of bioethanol from wheat is 1 m^3 pr hectare. In the BIOCONCENS project, a combined ethanol and biogas production will be developed for organic farming using starch containing biomass (maize and rye) and whey-permeate as water resource with co-production of animal fodder. Natural enzymes from cereals will be used for hydrolysis of starch to glucose in accordance with technology in brewing technology (Briggs, 1981). Commercial enzymes are often produced from gene-modified organisms and will not be used in the project.

Cropping systems for biomass production

Energy crops and crop residues are renewable energy sources, which can reduce the consumption of fossil fuels. However, it is important to minimize the energy use and CO_2 emissions during the production of crops. Organic plant production is based on healthy rotations, but crops are typically sole cropped (except for pastures) in large fields. Crop diversity in time (rotation) and space (field size and intercropping of species/cultivars) can contribute to safeguarding yield stability and soil fertility, lowering nutrient emissions and reducing weeds, diseases and pests in the cropping systems (Hauggaard-Nielsen et al., 2001; 2003; Karlen et al., 1994, Willey, 1979). Intercropping was common in developed countries before the 'fossilisation' of agriculture (Cassman, 1999; Matson et al., 1997). Intercropping of plant species (planned diversity) enhances the possibility to use ecological mechanisms such as diversity, competition, facilitation and complementarity in crop production (Vandermeer, 1989) Furthermore, implementation of intercrops in agroecosystems has been shown to increase diversity of microbes, flora and fauna, which often have a positive impact on crop productivity (Vandermeer, 1995).

In the BIOCONCENS project a strip intercrop system for biomass production is developed. Strip intercropping is defined as the practice of producing two or more crops in strips wide enough that each can be managed independently, yet narrow enough that the strip components can interact. The hypothesis is that the interactions (physical, biological, ecological, management) between components of a system with greater spatial diversity will enhance biomass yield, resource use while decreasing the emissions of GHG compared to sole cropping of the same species. A perennial (2-yr) soil fertility building (SFB) strip (forage legumes, grasses) and a strip consisting of either maize or winter rye -winter vetch intercrop will be chosen to produce biomass for biogas and bioethanol. The perennial strip will enhance soil fertility, extract nutrients form deeper soil layers, fix N_2 and compensate for the effect of annual crops on soil fertility and also reduce the requirement for soil tillage. In addition all crops can alternatively be used for feed in organic milk production.

Effect of residues from biogas process on soil quality parameters

Organic agriculture depends on a high level of soil fertility to sustain crop production, while at the same time maintaining a microbiota with a high degree of diversity. The activity and catabolic capabilities/diversity of the soil microorganisms are pivotal in OA in order to drive the cycling processes (decomposition) of plant nutrients (Nannipieri et al., 2003; Wardle and Giller, 1996). Soils are amended with complex organic materials (e.g. composted plant material or animal manure) with a high C content and slow release of N. In contrast, remains from biogas production have a decreased C content and the N is more available to plants and the soil microbiota and, hence, N leaching and degradation of the soil humus content is of concern (Salomonsen, 2000). The present knowledge on this issue is sparse. Soil microbial indicators (e.g. microbial biomass, soil enzymes, qCO2, mycorrhizas) or macrofaunal (e.g. earthworms; nematodes) are considered useful and sensitive/responsive indicators of soil quality (Mäder et al., 2002; Brussard et al., 2004; Oehl et al., 2004; Johansen et al., 2005). Soil aggregate stability has shown measurable short-term response to soil management (Mäeder et al., 2002) comparable to the treatments planned in the present project. When measuring genetic and functional diversity of the entire soil microbiota the phospholipid fatty acid (PLFA) and catabolic response profiling techniques seems most useful (Zelles, 1999; Johansen and Olsson, 2005; Degens et a., 2000).

Effect of biogasification of animal manure on spread of animal parasites and survival of weed seeds.

Organic pigs and cattle are in general more parasitized than conventional indoor production (Thamsborg et al., 1999). Eggs of intestinal parasites are spread via faeces while grazing or through field application of organic manure. While infective larvae of the most prevalent cattle nematodes are relatively short-lived, the infective stages of the pig nematodes Ascaris suum (a zoonose) is common in organic pigs (Roepstorff et al., 1992; Carstensen et al., 2002) and may survive for up to 9 years (Krasnonos, 1978). The resistance of Ascaris eggs against environmental factors is generally much stronger than that of bacteria and viruses, and thus As-caris is often used as an indicator when evaluating the inactivation capabilities of sludge processing plants (e.g. Black et al., 1982; Carrington et al., 1991). The ability of weed seeds in manure to germinate may also be impaired by biogasification (Gunaseelan, 1998; Sarapatka et al., 1993). Animal manure is regarded as a major source of weed seeds that return to the soil (Jørgensen and Dalgaard, 2004.).

Emission of GHG from crop production with and without amendment with organic materials

Agricultural production is a strong source for emissions of nitrous oxide (N_2O), which has important effects on atmospheric chemistry and radiative properties (Baggs et al., 2002). Particularly high emissions are observed when manure, slurry and fertilizers are applied to the soil (Ball et al., 2004). Incorporation of plant residues has also been demonstrated to induce emissions of N_2O, the extent of which is dependent on the residue quality and quantity, and incorporation technique (Ambus et al. 2001; Baggs et al., 2002). Low-input cropping systems, with particular emphasis on legume-based systems, have therefore been suggested as a mitigation option to reduce agricultural N_2O emissions, but systematic long-term measurements in such systems are sparse. Low N_2O emissions have been observed from grass-clover pastures (Ambus 2005), but an overall N_2O budget for a grass-legume rotation is not available. Animal husbandry is also a strong source of N_2O, which is emitted in significant amounts e.g. from manure storage and compost piles (Czepiel et al., 1996; Wolter et al., 2002; Thompson et al., 2004). Biogasification of animal manure changes the chemical composition of the waste material, which may have implications for GHG emissions from subsequent field applications. Petersen (1999) found reduced N_2O emissions with anaerobic digested slurry, presumably because less C was available for microbial activity. Likewise, agricultural activities influence the emissions of methane (CH_4) that also have significant implications for atmospheric chemistry. Large CH_4 emissions are mainly associated with ruminant activity and short episodic events following applications of organic waste materials (Ball et al., 2004; Ambus et al., 2001). Manure storage piles (Wolter et al., 2004), compost piles (Thompson et al., 2004) and slurry tanks (Petersen et al., 2005) are also strong point sources of CH_4. Optimization of plant production management with reduced N-inputs and treatment of organic wastes, such as biogasification thus has a significant potential for reducing agricultural GHG emissions.

Nitrate leaching from organic systems

Nitrate leaching from organic milk production systems are generally lower than from conventional systems, due to a lower intensity of both crop and animal production and the widespread use of catch crops (Eltun et al., 2002, Kirchman and Bergstrøm, 2001). Recent Danish analyses have shown that differences are small between conventional and organic farms with plant production only (Berntsen et al., 2003). Perennial leys in the rotations contribute to reducing nitrate leaching during their growth, but the year following the breaking of the ley constitutes a high risk of enhanced nitrate leaching.

Socio-economic analysis

Biogas and bio-ethanol projects have socio-economic implications not only in the agricultural sector, but in the industrial and energy sectors as well. Amongst the environmental consequences, mitigation of pollution, GHG emission reduction and reduced eutrophication of ground water etc. are important external effects (Nielsen et al., 2002). The socio-economic analysis looks at the project or activity in question from the point of view of the society in its entirety, and takes in principle into account all so-called externalities (Lesourne, 1975). Externalities or external effects neither imply expense nor income elements for the corporate or private investor. However, externalities are important economic effects seen from the point of view of the society. A project may inflict burdens on or contribute gains to society, relative to the reference activity, which must be taken into account when evaluating a project from the point of view of the society.

OBJECTIVES

BIOCONCENS aims at developing new methods and processes for co-production of bioe-thanol, biogas and animal feed based on resources from OA and associated food processing and suggests the outline of a medium-sized plant for co-production of biogas, bioethanol, and animal feed. The project will also design and test a new cropping system for biomass production to be used for bioenergy, while at the same time safeguarding soil quality. The project will analyze the effects of remains from bioenergy production on soil fertility, greenhouse gas emissions, survival of parasites and weed seeds in the manure as affected by bioenergy production. Corporate and socio-economic analysis of the co-production of biogas and bioethanol at different scales will be carried out.

The interdisciplinary project is organized in six work packages with significant interactions between WPs. WP 6 is devoted to coordination. The objectives of the five other work packages are to:
Work package 1: Co-production of biogas, bioethanol and animal feed from organic raw materials
Work package 2: Strip intercrop system for biomass production
Work package 3: Effects of bioenergy production on soil quality and survival of parasites and weed seeds.
Work package 4: Emissions of greenhouse gases from strip intercropping and green/animal manures
Work package 5: Scenarios for bio-energy production in organic agriculture and socio-economic analysis

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