Journal of Cleaner Production 73 (2014) 227–235

Contents lists available at ScienceDirect

Journal of Cleaner Production

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

Quantification of the effectiveness of greenhouse gas mitigation measures in Swiss organic milk production using a life cycle assessment approach

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ARTICLE INFO

Article history:
Received 31 March 2013
Received in revised form
22 November 2013
Accepted 29 November 2013
Available online 11 December 2013

Keywords:
Global warming potential
Greenhouse gas mitigation
Organic agriculture
Carbon footprint
Dairy production

ABSTRACT

Quantitative assessments of the effectiveness of GHG mitigation measures at farm level are scarce. Hence, the aim of this study was to quantify the GHG mitigation potential of selected measures on two typical organic farms in Switzerland. We built a single-farm model which enabled us to calculate the GHG emissions and energy consumption at farm level using a life cycle assessment approach. The model was used to calculate the effects of 13 different mitigation measures on a Swiss organic dairy and a Swiss organic mixed farm. At the dairy and mixed farm, respectively, 5.4% and 5.5% of mitigation in relation to the farms' total GHG emissions could be realized by technical means and 15.4% and 12.9% with agronomic measures. Technical measures include the use of photovoltaics and heat recovery from milk cooling devices. The agronomic measures include conversion to full-grazing systems, composting livestock manure, and the use of dual-purpose cattle breeds. The total mitigation potential of the analysed measures is 20.8% less GHG emissions for the dairy farm and 18.5% less for the mixed farm. However, some agronomic measures may result in yield decreases, which reduce the total mitigation effect of the analysed portfolio of measures from an LCA perspective.

1. Introduction

Agriculture has an important role in mitigating greenhouse gas (GHG) emissions, while at the same time needing to overcome the significant technological, social, and economic challenges posed by the expected increase in global food demand, (bio)energy production, and the impacts of climate change on agricultural production itself (European Commission, 2010).

In 2004, agriculture directly contributed about 14% of global anthropogenic GHG emissions. Land use, land use change, and forestry account for a further 17% (IPCC, 2007). Many mitigation approaches are currently under investigation and it is likely that many different strategies will be required to lower GHG emissions in agriculture significantly (BLW, 2011). Furthermore, different strategies may be suitable for different farming practices and systems (Buddle et al., 2011).

Organic farming practices are considered to have a significant potential for GHG mitigation through enhancing soil carbon stocks (Aguilera et al., 2013; Gattinger et al., 2012), reducing soil-derived N_2O emissions, and by providing various co-benefits including capacities for climate change adaptation (Müller, 2009). Nevertheless, the higher sequestration rates and the lower GHG emissions may be compensated by lower yields in organic systems (Nemecek et al., 2011). Therefore, current life cycle assessment studies show heterogeneous results on the performance of organic farming (Knudsen, 2011). A further reason for this variability between studies are different assumptions, such as with respect to allocation or system expansion (Flysjö et al., 2012).

Even though organic farming itself may be a promising GHG mitigation measure, recent studies have found a high variability between farms: even if they are of the same farm type or from the same region (Hersener et al., 2011). This implies a high potential for optimising farm management with respect to the GHG mitigation potential on organic farms.

Therefore, assessments and mitigation strategies at farm level are needed. A few farm-level approaches to defining successful GHG mitigation strategies for agricultural systems have been conducted in the past (Martin et al., 2010; Schils et al., 2007, 2005). However, assessments did not take technical measures, such as the

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http://dx.doi.org/10.1016/j.jclepro.2013.11.077

use of photovoltaics into account. While many GHG mitigation measures are applicable in both organic and conventional systems, there are some measures that are not applicable in the organic system. For instance no-till agriculture is not an option in organic systems because herbicides are required to control weeds. Thus, organic farmers are more restricted in how they mitigate greenhouse gases and specific measures may be needed. Bischofberger et al. (2011) compiled a comprehensive set of 22 GHG mitigation measures which are applicable for Swiss, and most European, organic farms. These measures include general agronomic measures, such as composting of livestock manure; measures focussing on plant production, such as reduced tillage; measures focussing on livestock production, such as optimised manure management; and technical measures such as the use of photovoltaics. The measures selected by Bischofberger et al. (2011) largely avoid trade-offs with other environmental impacts or animal welfare. Some even result in synergies between several impact categories, such as that composting is beneficial to soil fertility and that planting shade trees on pastures results in improved animal welfare.

However, the effectiveness of these measures in terms of GHG mitigation potential has not been quantitatively assessed. Therefore, the aim of this study is to identify the measures with the highest mitigation potential by quantifying the GHG mitigation potential of selected measures on two organic farms that use typical farming practices in Switzerland.

2. Methods

2.1. Farm model

We built a single-farm model based on a life cycle assessment (LCA) approach, which enabled us to calculate the GHG emissions and energy use of a farm in different conditions (Schader et al., 2012a). The main components of the model were the plant and the livestock production modules, which take into account all of the relevant processes and inputs for defining the production inventories. Inventories were based on ecoinvent (Nemecek and Kägi, 2007) and inventories of organic production processes that had been compiled in previous projects (Berner et al., 2008; Kuhn, 2012; Notz et al., 2012; Schader et al., 2013). The model was able to reflect interactions between plant and livestock production: all livestock manure is used in plant production (unless a farm sells its manure) and the sum of feedstuffs from crop and grassland production has to meet the energy and protein required for livestock production. Feeding rations were checked separately with software for feeding planning (FUPLAN, Agridea, Lausanne). For a product-related assessment, emissions from livestock manure was allocated between cash crops and livestock production by attributing the emissions from manure (including storage) to livestock production and emission during manure application to plant production. The model also included the GHG emissions of purchased inputs, according to the LCA methodology as defined in ISO14040 and 14044.

GHG emissions were calculated based on the production inventories according to the IPCC Guidelines (2006) and PAS2050 (BSI, 2008). For calculating on-farm N_2O emissions from soils, a model was employed that uses IPCC global average emission factors (IPCC, 2006) but specifically takes the mode of action of organic fertilisers into account (Meier et al., 2012). In organic fertilisers only a fraction of the total N is readily available. The rest of total N is organically bound within the C–N-pool of the soil from where it is released in the mid- and long-term by microbial degradation. The long-term (>100 years) bound N in the soil does not result in N_2O emissions within the temporal system boundary of IPCC. Therefore, it is subtracted from total N. Whether N is bound in the soil depends on soil type, climatic conditions, management practices and organic matter input. In the N_2O model, this is considered using the model to estimate annual changes in SOC from Chapter 2 of Volume 4 of the IPCC guidelines. It may also be possible that N is mineralised from the C–N-pool; mainly due to management practices. In this case, the amount of mineralized N is added to total N in the N_2O model. CH_4 emissions from enteric fermentation were modelled according to Kirchgessner et al. (1995). Carbon sequestration and carbon mineralised from soils were not considered in the GHG balance.

GHG emissions were calculated for the functional units: 'hectares of area cultivated per year[1]' and 'kilograms of fat and protein corrected milk (FPCM)'. The GHG emissions that are directly associated with cash crops were excluded when calculating the milk production-related impacts, while GHG emissions for dairy production were allocated economically between milk, meat, and live animal output. For the economic allocation, we assumed the following prices and output quantities: 0.74 CHF per kg milk, 7.15 CHF per kg carcass weight of culled cows, 3.12 CHF per kg live weight of surplus calves (Agridea, 2010), a live weight of surplus calves of 65 kg (FiBL, 2001) and a carcass weight of culled cows of 250 kg.

Changes in productivity due to GHG mitigation measures have to be determined exogenously, and were based on literature or expert opinion. GHG emissions of each farm were assessed both without implementation of the measures and with each of the measures implemented individually. The difference in GHG emissions between both states of a farm is interpreted as the effectiveness of the measure for mitigating GHG emissions on the specific farm.

2.2. Selection of model farms

Due to the dominant role of milk production for the Swiss organic sector, dairy farms were selected as the focus of this study. Two existing Swiss organic farms (Table 1) were selected based on their farm type, size, production portfolio and location, as being typical average Swiss organic dairy farms and 13 mitigation measures were quantified. The real farms were converted into model farms by adapting some farm-specific characteristics so that the results, with respect to the impacts of the measures, are more readily transferable to other farm contexts. For instance, the mixed farm had small scale processing facilities and a farm shop attached to it, but emissions from processing and selling products were excluded from the analysis because they are not readily transferrable.

One of the selected farms is a typical organic dairy farm (DF), located in the mountain areas on rather marginal land with 20 dairy cows, including offspring, kept on about 25 ha. The average milk yield (FPCM) per cow and year is 5300 kg. Organic manure; mostly slurry, is applied via pipes. The second farm is a typical organic mixed farm (MF), such as is prevalent in the Swiss lowlands, on which 40 dairy cows including offspring are kept on about 50 ha. The average milk yield (FPCM) per cow and year is 6425 kg. Slurry is applied with a slurry trailer with a drag hose.

2.3. Selection and specification of GHG mitigation measures

Based on Bischofberger et al. (2011), 13 GHG mitigation measures were selected for quantification on the two specific farms (Table 2). The measures were chosen according to their presumed mitigation potential, the absence of trade-offs with other environmental and ethological impact categories, and their applicability on Swiss organic farms. The farm specific characterisations of the measures were defined, in consultation with the farmers, according to the local conditions of the selected farms to ensure that

[1] Cultivated area includes land under arable crops, permanent crops and grasslands as well as non-crop habitats, such as hedgerows.