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in

Ben Salem H. (ed.), López-Francos A. (ed.).
Feeding and management strategies to improve livestock productivity, welfare and product quality under climate change

Zaragoza : CIHEAM / INRAT / OEP / IRESA / FAO
Options Méditerranéennes : Série A. Séminaires Méditerranéens; n. 107

2013
pages 243-252

Green house gas emissions from organic and conventional systems of food production, with and without bio-energy options

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Abstract. This study uses input and output data from 8 year rotations in the Nafferton Factorial Systems Comparison experiments to model Life Cycle Assessment (LCA) to the farm gate, estimating green house gas emissions (GHG) from a range of farming systems. Six scenarios were assessed that allowed the comparison of: (i) organic *vs* conventional production; (ii) stockless arable *vs* dairy (cow) production; and/or (iii) composting of straw based manure *vs* biogass production from slurry manure in a dairy (cow) unit. Systems were compared on the basis of; gross GHG, the potential off-set from energy generation using biogas (both as CO_2 equivalents/ha; tCO_2e/ha) and the yield of human food energy, throughout the 8 year rotation. Including a dairy enterprise under both organic and conventional management substantially increased gross GHG (3.2-3.3 and 4.3-4.4 t CO_2e/ha respectively) compared with stockless scenarios (0.6 and 2.0 t CO_2e/ha respectively) due to enteric methane output, yet biogas production contributed a relatively low counter to off-set these high emissions (0.4 -0.5 t CO_2e/ha for organic and conventional systems). In all comparison conventional systems generated more GHG than organic production (differences ranged from 0.9 to 1.4 t CO_2e/ha) largely due to greater reliance on manufactured inputs including feed and fertiliser along with higher N_2O emissions resulting from fertiliser use. Food energy output was also higher under conventional management with little difference between the 3 scenarios (44-47 GJ per Ha). On the other hand, the organic stockless system yielded substantially less food energy (22 GJ/ha) with the introduction of a dairy enterprise raising this to 31-32 GJ/ha, largely due to direct utilisation of forage crops grown in 3 out of 8 years during the rotation.

Keywords. GHG – Organic – Livestock – Bio-energy.

Emissions de gaz à effet de serre à partir des systèmes organique et conventionnel de production des aliments avec ou sans options bioénergétiques

Résumé. *Cette étude utilise des données d'entrée et de sortie issues de 8 années de rotations dans le cadre des essais de comparaison des systèmes factoriels Nafferton pour l'évaluation du modèle de cycle de vie (LCA) de la ferme en estimant les émissions de gaz à effet de serre (GES) à partir d'une gamme de systèmes d'élevage. Six scénarios ont été évalués et ont permis la comparaison de : (i) la production conventionnelle* vs *la production organique ; (ii) système de production sans animaux* vs *système de production laitière ; et/ou (iii) compostage du fumier à base de paille* vs *production de biogaz à partir du lisier dans une unité de vaches laitières. Les systèmes ont été comparés sur la base de : GES, potentiel de compensation à partir de la génération d'énergie utilisant le biogaz (sous forme d'équivalent CO2/ha : tCO2e/ha) et rendement de l'énergie des aliments consommés par l'homme pendant 8 années de rotation. L'intégration d'une entreprise laitière soumise à une gestion conventionnelle et organique a considérablement augmenté les GES (3,2-3,3 et 4,3-4,4 t* CO_2*e/ha respectivement) par comparaison aux scénarios sans animaux (0,6 et 2,0 t* CO_2*e/ha respectivement) à cause de l'élimination du méthane entérique, donc la production de biogaz a faiblement contribué à compenser ces importantes émissions (0,4 -0,5 t* CO_2*e/ha); pour les systèmes organique et conventionnel). Pour toutes les comparaisons, les systèmes conventionnels ont généré plus de GES que la production organique (différence variant de 0,09 à 1,4 t* CO_2*e/ha, cela est dû en grande partie à la grande dépendance vis-à-vis des intrants fabriqués tels que les aliments et les fertilisants parallèlement aux émissions plus élevées de* N_2O *résultant de l'utilisation de fertilisants. L'énergie alimentaire en output a été aussi plus élevée avec une gestion conventionnelle avec une légère différence entre les 3 scénarios (44-47 GJ per ha). D'autre part, le système organique sans animaux a produit sensiblement moins d'énergie alimentaire (22 GJ/ha) qui est passée à 31-32 GJ/ha avec l'introduction d'une entreprise laitière, résultant de l'utilisation directe des fourrages cultivés lors de 3 années sur 8 pendant la rotation.*

Mots-clés. *GES – Organique – Bétail – Bioénergie.*

I – Introduction

The initial step in reducing the environmental cost of food production is to quantify agriculture's contribution to green house gas (GHG) emissions and climate change. The next stage might be to compare farms or production systems to identify strengths and scope to reduce their impact without penalising output or quality. (Krammer *et al.*, 1999 and Dalgaard *et al.*, 2001). To this end, it is generally considered that producing bio-energy on farm (e.g. biogas digestion, biomass burning) can partially offset GHG emissions from food production (Boodoo *et al.*, 1977 and Fredrickson *et al.*, 2006).

This paper is an extract from a wider Life Cycle Assessment (LCA) comparing GHG emissions from organic and conventional production systems (Cooper *et al.*, 2011); it considers the role of livestock and how alternative manure management might affect emissions. Two baseline systems from the Nafferton Factorial Systems Comparison trial are compared with alternative models varying end-uses of agricultural by-products, considering on-farm and upstream emissions only.

II – Materials and methods

The Nafferton Factorial Systems Comparison (NFSC) trial was established in 2003 and compares organic and conventional systems of crop rotation (see Table 1), crop protection, and fertility management in a factorial design. GHG balances were compared for 2 of the scenarios along with 4 other simulated options (all listed in Table 2). Calculations are based on recorded input and output data from the trial (with a 10% reduction in yield for crops grown after straw incorporation in stockless systems) along with published default emission factors (IPCC, 2006).

Table 1. Crop rotations in the Nafferton Factorial Systems Comparison experiments

Crop rotation	Rotation year							
	1	2	3	4	5	6	7	8
Conventional	Winter wheat	Winter wheat	Winter barley	Potatoes	Winter wheat	Winter barley	Grass/ clover	Grass/ clover
Organic	Winter wheat	Potatoes	Spring beans	Cabbages	Spring barley	Grass/ clover	Grass/ clover	Grass/ clover

Livestock numbers are based on feed energy produced relative to requirements for dairy production, assuming a 25% replacement rate for milking cows calving at 24 months in both systems. Milk yield was assumed at 8250 litres for conventional cows and 6750 litres under organic management (Anon 2008) with 65% and 80% respectively of feed energy supplied from forage (50,903 *vs* 56,205 MJ ME) (Butler *et al.*, 2008). Enteric methane production was estimate at 155 kg per cow per year in the conventional systems compared with 176 kg per cow per year for organic production with greater fermentation losses on the higher forage diet (Butler *et al.*, 2007). Additional nutrients, necessary for target milk production were supplied initially from homegrown feeds then balanced with purchased cereal and protein (based on feed composition and nutritional requirements in McDonald *et al.*, 2002), while excess cereals or beans were assumed to be sold off the farm.

Table 2. **Agricultural systems used for baseline scenarios and alternative scenarios (baseline scenarios in bold)**

Code	System
O+LS	**Organic crop rotation with organic management; forage crops fed to dairy cattle; straw for bedding; composted manure returned to the field; potatoes sold off the farm (stocked)**
O-LS	Organic crop rotation with organic management; straw and forage crops incorporated into the soil; cereals beans, potatoes and cabbages sold off the farm (stockless)
O+BG	Organic crop rotation with organic management; cereals, beans and forage crops fed to dairy cattle; straw returned to the soil; manure slurry used for biogas, then returned to the field; potatoes and cabbages sold off the farm (stocked)
C-LS	**Conventional crop rotation with conventional management; all crops (and straw) sold off the farm (stockless)**
C+LS	Conventional crop rotation with conventional management; forage crops fed to dairy cattle; straw for bedding; composted manure returned to the field; potatoes sold off the farm (stocked)
C+BG	Conventional crop rotation with conventional management; straw returned to the soil; manure slurry used for biogas, then returned to the field; potatoes sold off the farm (stocked)

On site calculations accounted for direct and indirect GHG arising from: burning of fossil fuel in farm activities (listed in Table 3), fuel extraction and transport, the energy costs of producing farm machinery and other inputs as well as IPCC default values for N_2O (from soil, fertiliser and manure) and CH_4 (from manure and enteric fermentation) (IPCC, 2006). As standard in LCA modelling, all emissions were converted to CO_2 equivalents (CO_2e) using factors of 23 for CH_4 and 310 for N_2O (Baggott *et al.*, 2007).

Calculations for GHG off-set by energy generation used published estimates of energy yield from anaerobic digestion of slurry as suggested by Balsam *et al.* (2006). The total human food energy produced over the 8 year rotation in each scenario was calculated using recorded crop yields, dairy outputs as stated earlier and food nutrition composition as published by USDA (2010).

III – Results and discussion

1. Gross emissions per hectare

Estimated gross GHG emissions per hectare for the 6 scenarios are shown in Fig. 1. Generally conventional production generated higher emission per hectare than the organic systems. Livestock systems generated considerably higher emissions than cropping only options largely due to the relatively high contribution of enteric methane from dairy cows and replacement heifers. There was little difference between both organic dairying scenarios (O+LS and O+BG); both are dominated by enteric fermentation contributing 75 to 76% of gross emissions, which in magnitude are 3 times the entire emissions from the stockless system (O-LS). Gross emission on an area basis are higher for conventional production largely explained by a combination of (a) greater dependence on manufactured inputs (including fertiliser and feed), accounting for 26-27% of total gross emissions on the livestock systems (C+LS, C+BG) and 36% on the stockless system (C-LS), in addition to (b) higher N_2O originating from mineral fertiliser application; representing 18-20% on the livestock systems and 34% of gross emission on the stockless conventional system. As with organic production, there are only slight differences in gross emissions between the 2 conventional dairy scenarios although in these cases, enteric methane contributes a lower proportion of total emissions (38%) because of higher use of manufactured inputs including fertiliser.

Table 3. Default figures used for calculating greenhouse gas emissions from field activities (direct emissions) for the Nafferton Factorial Systems Comparison experiments

Activity		Source
Emissions calculated on an area basis	kg CO_2e/ha	
Ploughing	131.6	Kramer *et al.* (1999)
Seeding	23.7	Kramer *et al.* (1999)
Rolling	23.7	Kramer *et al.* (1999)
Pesticide spray	41.2	Kramer *et al.* (1999)]
Weeding	23.7	Kramer *et al.* (1999)
Fertilizer spreading	36.2	Kramer *et al.* (1999)
Combining	91.2	Kramer *et al.* (1999)
Secondary tillage	43.1	Kramer *et al.* (1999)
Mowing	16	Dalgaard *et al.* (2001)
Ridging	19.2	
Potato harvest	54.4	
Potato planting	19.2	
Flailing	16	
Emissions calculated on a weight basis	Total CO_2e/tonne	
Baling	6.4	Dalgaard *et al.* (2001)
Compost application	1.92	Dalgaard *et al.* (2001)

Emissions for baling straw and silage were based on a figure of 2 litre diesel fuel per tonne of biomass; diesel fuel use was converted to CO_2 emissions using a factor of 3.2 kg CO_2 emitted per litre of diesel fuel burned; ridging and potato planting were assumed to be equivalent in energy use to heavy seedbed harrowing; emissions for rolling were assumed to be equivalent to sowing; potato harvesting was assumed to be equivalent to sugar beet harvest; flailing was assumed to be equivalent to mowing; compost application figures were based on the values for loading and spreading manure from Dalgaard *et al.* (2001)

Although nitrogen fertiliser manufacture is considered energy intensive and its application to crops results in significant emissions of nitrous oxide, these calculations show it does not contribute a high proportion of emissions in the wider picture, especially in options with livestock where emissions are dominated by methane. For example, in the stockless conventional scenario (C-LS), emissions from the manufacture of off-farm inputs include N fertiliser only accounted for 14% of the total. Hillier *et al.* (2009) found N application rates, whether from inorganic or farmyard manure (FYM) sources, explained 95% of the variation in the carbon footprints of different farm types in Scotland. If we exclude enteric methane emissions from our calculations, the average annual on-site emissions for our O-LS baseline scenario are 841 kg CO_2e ha^{-1}, which is similar to the carbon footprints of the farms in the Hillier *et al.* study (728 kg CO_2e ha^{-1}). Estimates of on-farm emissions for a comparable stockless conventional system in our analysis were 2019 kg CO_2e ha^{-1} (for C-LS) compared with 1541 kg CO_2e ha^{-1} for the conventional farm types in the Scottish study.

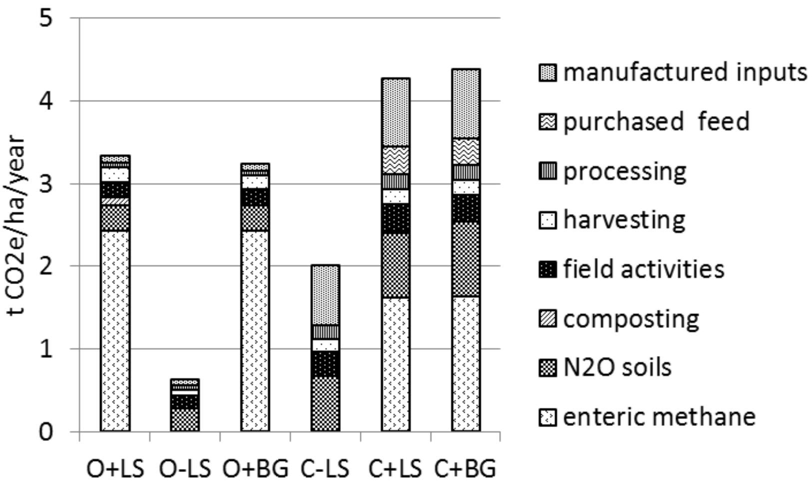

Fig. 1. Breakdown of gross Greenhouse Gas emissions from 6 scenarios detailed in Table 2.

2. Net greenhouse gas emissions including on-farm bio-energy production

In the two bio-energy scenarios (O+BG and C+BG) emissions of GHG can be offset if the energy produced on-farm displaces electricity from coal; assumed to be 410 kg CO_2e ha^{-1} in the O+BG scenario and 451 kg CO_2e ha^{-1} in the C+BG scenario in this study. The inclusion of biogas digesters on farms with ruminants is one strategy to compensate for the high emissions of methane from the rumen. However, the modest off-set of only 12% of total emissions in the O+BG scenario and 6% in the C+BG scenario are swamped by the relatively high contribution of enteric methane; 75-76% of the total emissions from the stocked organic systems and 38% from the stocked conventional systems (Fig. 2). Therefore, it is apparent that a multi-faceted approach to addressing methane emissions from ruminant systems needs to be implemented and we cannot rely solely on energy generation to reduce the overall impact. This could include a reduction in the fibre content of dairy diets, the inclusion of vegetable oil to suppress rumen protozoan activity or longer term benefits from selective breeding (of livestock, forage plants and/or rumen microbes). Effective methane output per unit of food (be it milk or meat) can also be reduced if progress is made to improve longevity and/or productivity, spreading the methane generated during the rearing phase over greater output. This whole area is complex and in its infancy; it is interesting to note that current modelling (IPPC, tier 2) lacks the sensitivity to acknowledge any progress due to such action (IPCC, 2006 and IPCC, 2007).

The offsetting of GHG emissions by soil carbon (C) sequestration is not included in this analysis but on average, organic land has higher soil C levels than conventionally farmed land. Reganold *et al.* (1987) reported that a side-by-side comparison of an organically and conventionally managed wheat field showed higher soil C levels in the organic field. This has been followed by more comprehensive paired comparisons of organic and conventional farms. In 1992 Armstrong Brown *et al.* surveyed 30 pairs of organic and conventional farms in the UK and reported a trend towards higher soil organic matter (SOM) for organic horticultural and arable farms compared with their conventional equivalents. They attributed the differences to the greater use of farm year manure, reduced tillage intensity, and more periods under temporary ley or permanent pasture.

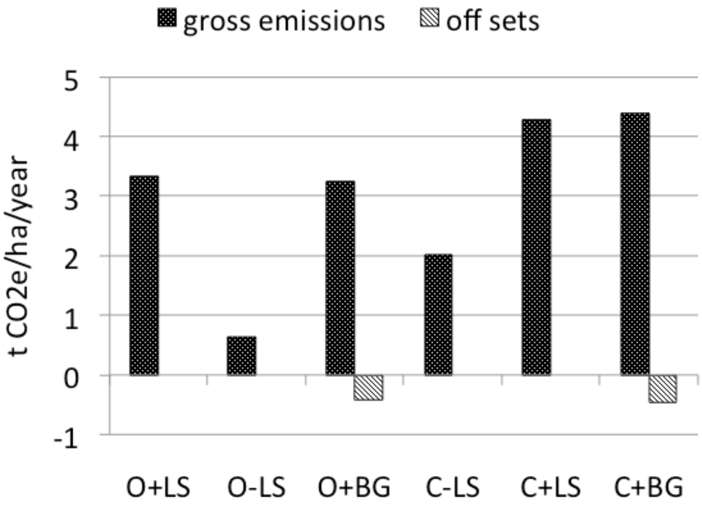

Fig. 2. Gross emissions and off set GHG from anaerobic digestions of slurry for 6 senarios detailed in Table 2.

Including soil C in GHG inventories remains a contentious issue. Changes in soil C occur gradually, and eventually reach an equilibrium value related to annual inputs of soil C balanced against losses. For some scenarios in this study, composted manure was returned to the soil (e.g. O+LS and C+LS), while in the biogas cases, C is lost from the system through conversion to CH_4 and burning of the gas for energy. The remaining C, however, may be relatively resistant to decomposition since it is stabilised by the digestion process (Moller *et al.*, 2009). Therefore it is likely that different quantities and qualities of carbon would be returned to the land in each scenario, and that this would result in variations in equilibrium soil C among the scenarios. To include changes in soil C in our GHG balance we would have needed to estimate differences in equilibrium soil C between the baseline systems and the alternative scenarios and then calculated annual losses or gains of soil C for each scenario relative to the baseline (e.g. O+LS and C-LS). The rates of gain or loss of soil C would be expected to diminish each year, so we would also have needed to arbitrarily choose a specific year since conversion from the baseline to the alternative scenario. The estimation of these values was beyond the scope of this study, and would ideally involve the use of a recognised soil C model such as CENTURY (Paustian *et al.*, 1992) or ROTH-C (Jenkinson 1990). This type of analysis is planned for future LCAs of the NFSC trial data.

3. Gross emissions per MJ human energy

Figure 3 shows average calculated yields for human food energy from each of the farming systems over the 8 years for each rotation. Actual crop yields from the Nafferton Factorial Systems Comparison experiments were used as the baseline for calculations and, typically yields were lower under organic management. However, since records used were taken in the early years after organic conversion, these represent a system in transition to organic status when it is common to experience reduced yield as the soil adjusts to a fully biological system of production (Huxham *et al.*, 2005). Entz *et al.*, (2005) reported grain yields 23-27% lower on a survey of organic farms compared to conventional; however, they also reported maximum yields on organic farms that were greater than the long-term averages for conventional farms, indicating that there is potential in organic systems to improve yields. In the Nafferton experiments, N is supplied either from the legumes in the rotation (grass/clover or beans) or applied compost. Since 95-100% of the N in the compost was in an organic form (for composts used between 2004 and 2007), it may not be readily available to the growing crop during the year of application and plant growth could have been N-limited. As reserves of soil organic N build, subsequent mineralisation will increasingly contribute to crop growth and long-term inputs of organic matter can alter the composition and activity of the soil microbial community relative to conventional management (Widmer *et al.*, 2006 and Fließbach *et al.*, 2007). This can lead to a soil microbial community that is more adapted to cycling of N in organic systems i.e. with enhanced biological N fixing capacity and more efficient pathways for mineralization of nutrients from organic matter.

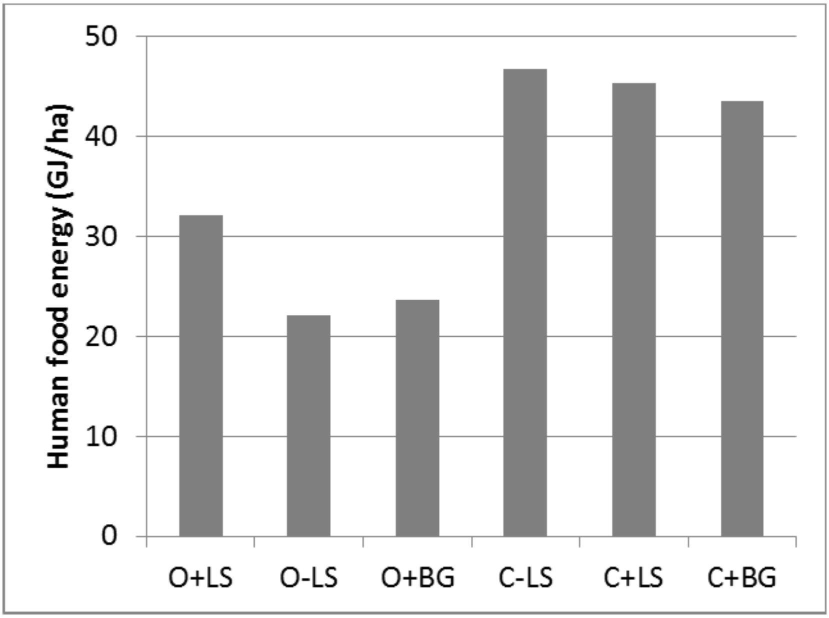

Fig. 3. Human food energy produced (GJ) per hectare of land over 8 years in each of the scenarios detailed in Table 2.

Food energy output ranged from an average of approximately 47 GJ ha^{-1} over the 8-year rotation for the conventional dairy system (C+LS) to 22.4 GJ ha^{-1} for the stockless organic scenario (O-LS) (Fig. 3). In the organic scenarios, the best way to maximise food production was to include livestock (in this case dairy cattle), which utilise the productive grass/clover swards that dominate the crop rotation, and convert forage plants into human food. Food yields for the stockless scenario under organic management (O-LS) are low since food crops/energy are only produced in five out of the eight years of the rotation, with the grass/clover grown in the remaining years left *in situ* as mulch. In the stockless system under conventional management (C-LS) this practice is unnecessary as mineral fertiliser can replenish nutrient balances and forage crops can be exported from the system, hence the higher output of food energy relative to the organic system.

4. Optimising food production and minimising GHG emissions

The ideal food production system will maximise food production, while minimising environmental damage. If we plot the net GHG emissions versus the food energy produced in each of the scenarios (Fig. 4) we can see that both stocked conventional systems (C+LS and C+BG) and the stockless conventional (C-LS) system, in which all crops are exported off the farm for livestock feed, produce the largest amounts of energy per hectare, however this food production comes at the cost of high GHG emissions. All of the organic systems produce less food, but they also are all relatively low in emissions.

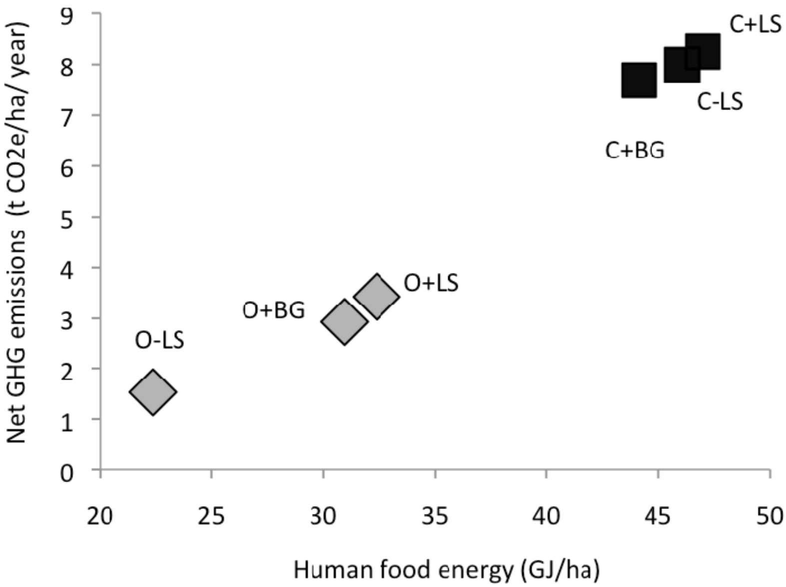

Fig. 4. Relationship between net GHG emissions and food energy production for 6 production scenarios detailed in Table 2.

This simple analysis highlights some key aspects of life cycle analysis that need to be considered if the results are to be meaningful. In this analysis a full 8 year crop production cycle has been studied. In the real world most farms follow a crop rotation and while some phases may have relatively low emissions of GHG (the ley phase of the O+LS scenario in this analysis emitted less than 100 kg CO_2e ha^{-1} y^{-1}), other phases may emit considerably more (e.g. the cabbage phase of the O+LS scenario emitted ~1400 kg CO_2e ha^{-1} y^{-1} on-site). Therefore it is necessary to consider a full cycle of the crop rotation when comparing different farming systems using LCA.

Likewise, it is important to look at the full impact of GHG emissions beyond the farm gate, to effectively compare systems. Although not fully explored in this small study, the conventional systems exported most of their emissions beyond the farm gate, although it will depend on the ultimate use of the forage and food crops sold from the farm. If subsequently fed in pig or poultry production (or forages for ruminant systems), down-stream emissions would be considerably higher than direct human consumption. These externalised environmental costs are not accounted for in this LCA that stops at the farm gate. This was particularly evident when the emissions associated with pig farming (the ultimate consumers of crops produced on many arable farms in the UK) were also included in the balance (Cooper *et al.*, 2011). It is also inconsistent to use a system boundary of the farm gate for downstream emissions, when most LCAs account for emissions from inputs well before they reach the farm (e.g. the upstream emissions associated with manufacture of farm inputs).

IV – Conclusions

Food production remains the primary goal of farming in Europe and we are facing increasing challenges globally to feed the expanding world population. Therefore any LCA of farming systems needs to place this analysis in the context of food production. The scenarios in this study demonstrate trade-offs that often exist between food production and environmental sustainability. The systems with the lowest emissions (O-LS) also produced the lowest food energy per hectare; while highest emissions were associated with the most productive systems. But the fact remains that the highly productive, conventional systems in these scenarios are dependent on imported nutrients for production. Nitrogen fertiliser is produced using energy from a non-renewable resource (fossil fuels) and P fertilizer is mined from soil reserves whose supply is finite. It has been estimated that known P-deposits may be depleted within 50 years (Fantel *et al.*, 1985). These high levels of production may therefore not be sustainable in the long-term.

The bio-energy scenarios show innovations can be adopted on farms to at least partially offset emissions from farming practices. In addition, on-farm bio-energy systems may generate additional farm income, making their implementation a “win-win” situation although the relatively low off-set suggests other measures are also necessary to reduce the environmental impact of livestock production.

Further studies are needed to clarify the uncertainties associated with LCAs of farming systems especially to monitor and reduce methane emissions from ruminants. Overall, improvements in N use efficiency at the farm level will reduce emissions from food production systems, and at the same time minimise environmental damage.

Acknowledgements

The authors gratefully acknowledge funding from the European Community financial participation under the Sixth and Seventh Framework Programme for Research, Technological Development and Demonstration Activities, for the Integrated Project QUALITYLOWINPUTFOOD,FP6-FOOD-CT-2003- 506358 and LowInputBreeds (Grant agreement No 222623).

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