ASSESSING THE ENVIRONMENTAL EXTERNALITIES OF ARABLE, FORESTRY, AND SILVOARABLE SYSTEMS: NEW DEVELOPMENTS IN FARM-SAFE

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Introduction

From the 1960s to the beginning of the twenty-first century, increased crop yields per unit area in Western Europe have occurred as a result of plant breeding, the use of external inputs such as agrochemicals and fertilizers, and the use of specialised field machinery (Burgess and Morris, 2009). However this has also led to negative environmental impacts such as nonpoint-source pollution from agrochemicals, soil degradation, and greenhouse gas (GHG) emissions.

In the SAFE project (Dupraz et al., 2005), a Microsoft Excel-based spreadsheet model called Farm-SAFE (Graves et al., 2007; 2011) was developed to evaluate the financial costs and benefits of arable, forestry and silvoarable systems in Europe (with and without grants). The model was used to determine some of the environmental impacts (Palma et al., 2007) but these were not valued. Within the AGFORWARD project (Burgess et al., 2015), the Farm-SAFE model has been developed to assess and compare the environmental externalities of carbon emissions and sequestration, soil erosion, and nonpoint-source pollution from fertilisers in arable, forestry and silvoarable systems.

Methods

The Farm-SAFE financial and economic model of arable, forestry, and silvoarable agroforestry systems has been adapted to include the following environmental externalities:

GHG emissions: In order to incorporate negative externalities of GHG emissions life-cycle based data were used. The model was adapted for the analysis of GHG emissions and sequestration in aboveground biomass. In doing so, the resources and energy used in the production system (input) and the emissions released into the environment (output) were measured and included in the economic analysis.

Soil erosion: The Revised Universal Soil Loss Equation (RUSLE) (Equation 1) was used to calculate the annual soil loss in the different production systems.

$$A = R * K * LS * C * P \qquad \text{[Equation 1]}$$

Where A is the estimated average soil loss in tons per acre per year; R is the rainfall-runoff erosivity factor; K is the soil erodibility factor; L is the slope length factor; S is the slope steepness factor; C is the cover-management factor; P is the support practice factor. When comparing soil loss in arable, forestry and silvoarable systems in the same geographical area, the factors R, K, LS and P were considered constant and only changes in the C-factor were used to assess the differences among the systems.

Nonpoint-source pollution from fertiliser use: The emissions of Nitrogen (N) and Phosphorus (P) were considered in the analysis. The differences among arable, forestry and silvoarable systems were calculated as a function of the N and P fertilizer rates and the N and P leaching rates of each system.

Results and discussion

The results presented in this paper are only for the GHG emissions. Further develop of this paper will include soil degradation and nitrogen and phosphorus loss as additional environmental externalities.

In order to include the GHG emissions in the assessment a ‘cradle-to-farm gate’ perspective was used. **Figure 1** shows the Life Cycle Assessment (LCA) system boundary for the operations of an arable system. Operations assumed to take place outside the farm gate such as cooling, drying, crop storage, and further processing of the outputs were not taken into consideration. The establishment of the farm itself, the construction of the infrastructure and transportation were also excluded from the analysis.

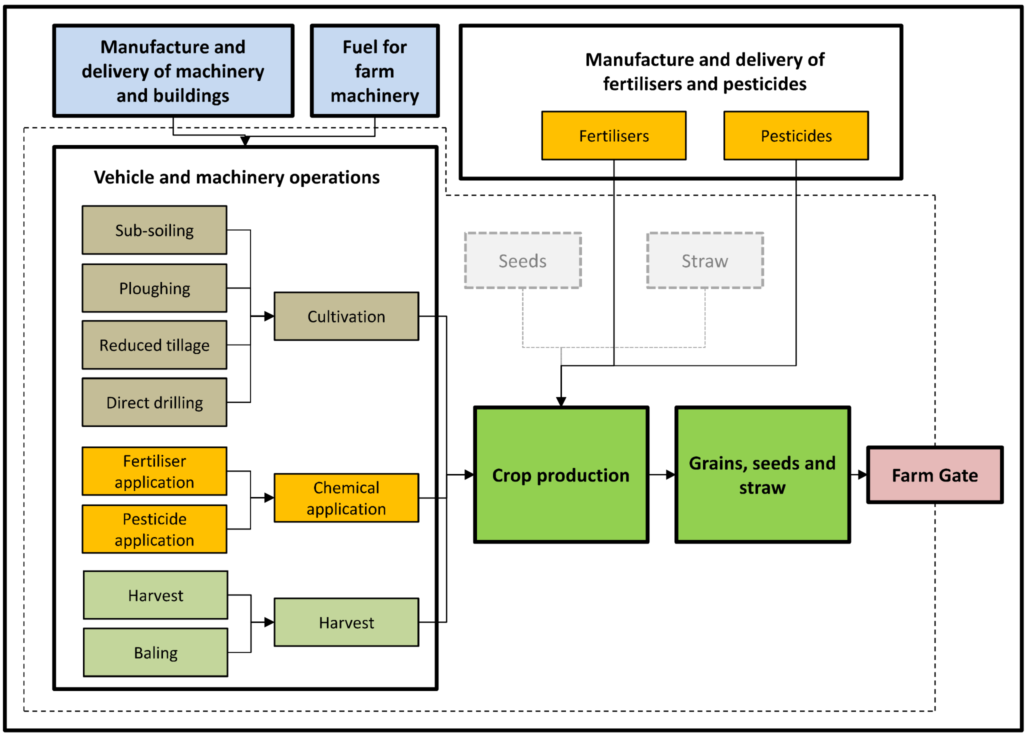

Figure 1. System diagram for the Life Cycle Assessment (LCA) of arable cropping, showing the system boundary and which inputs were included in the analysis of GHG emissions. Source: Kaske (2015).

One of the model innovations developed in this work was the flexibility for the user to change the tractor size and soil type. For some field operations, these factors are associated with the fuel consumption and work rate which affects the GHG emissions. Equations of these relationships were calculated and used to interpolate values. **Figure 2** shows an example of the equation used for the relationship between the clay content of the soil and a) fuel consumption and b) work rate. As shown, in both cases the higher the clay content percentage in the soil the higher fuel consumption and work rate. Furthermore the model allows the user to select three different cultivation methods: plough based cultivation, reduced tillage and direct drilling. The results presented in this study include the field operations for reduced tillage.

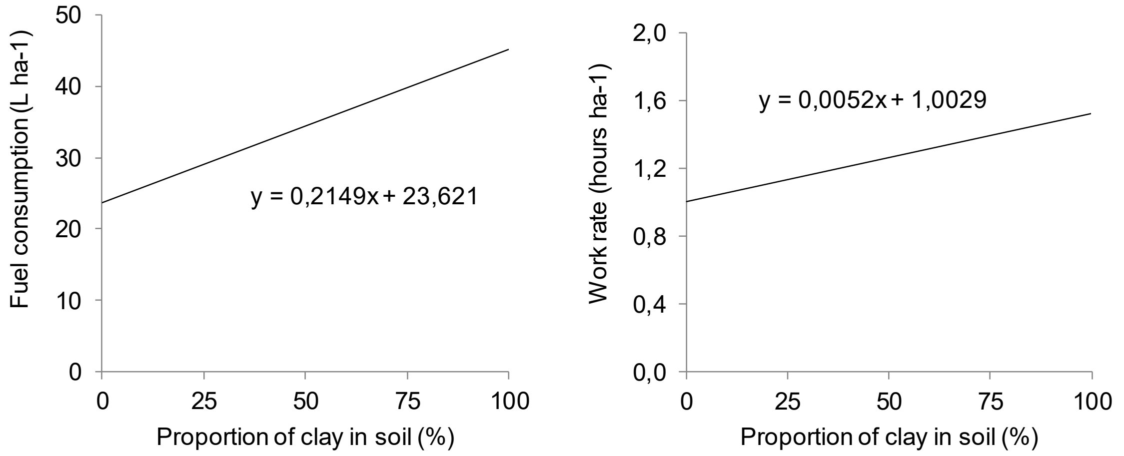
Ploughing with four furrows
b) Subsoiling of tramlines (3 leg sub-soiler)

Figure 2. Assumed relationship of the effect on the proportional clay content of the soil on a) fuel consumption for ploughing, and b) the work rate of sub-soiling.

Using such values, the equivalent annual value (EAV) of an arable, forestry and silvoarable system was calculated for a location in Bedfordshire in the United Kingdom (**Table 1**). The arable system is a four year crop rotation of wheat, wheat, barley and oilseed; the forestry system is a poplar tree plantation; and the silvoarable system is poplar tree with cropped alleys with the same rotation of the arable system. The EAV was estimated for a time horizon of 30 years at a 5% discount rate with and without grants as well as with and without including the externality of GHG emissions. The carbon price used for the calculations was 7.63 € per tonne of CO_2 which is being achieved in the UK (UK Forestry Commission, available at: www.forestry.goc.uk/carboncode).

The analysis indicated that the EAV, with grants[7], for the arable system (548 € ha^{-1}) was more profitable for the farmer than the silvoarable (342 € ha^{-1}) and forest systems (467 € ha^{-1}). Without grants, the profitability of the silvoarable system (82 € ha^{-1}) was between that for the arable (302 € ha^{-1}) and forest systems (23 € ha^{-1}). Since grants are paid by society it can be argued that the societal benefits of the system are based considered without the inclusion of grants.

Table 1. Equivalent Annual Value (EAV) of an arable, forestry and silvoarable system in Bedfordshire in the United Kingdom. Results shown for a time horizon of 30 years at a 5% discount rate.

	Arable[1]	Silvoarable[2]	Forestry[3]
EAV with grants (€ ha^{-1} year^{-1})	548	342	467
EAV without grants (€ ha^{-1} year^{-1})	302	82	23
Emissions of CO_2eq in 30 years (t CO_2eq ha^{-1})	80	42	16
EAV of CO_2eq emissions (€ ha^{-1} year^{-1})	-40	-21	-8
Sequestration of CO_2eq in 30 years (t CO_2eq ha^{-1})	0	129	177
EAV of CO_2eq sequestration (€ ha^{-1} year^{-1})	0	64	88
EAV with grants and GHG externalities (€ ha^{-1} year^{-1})	508	385	546
EAV without grants and GHG externalities (€ ha^{-1} year^{-1})	262	125	103

[1]: the arable system was a rotation of wheat, wheat, barley and oilseed rape

[2]: the silvoarable system was the same rotation as the arable system with poplar hybrids planted at 113 trees per hectare.

[3]: the forestry system was hybrid poplars planted at a density of 156 trees per hectare.

Starting from the assumption of not including the grants, the inclusion of the societal cost of GHG emissions reduced the difference between the EAV of the arable and the silvoarable system from 220 € ha^{-1} to 137 € ha^{-1} (Table 1). These results highlight how including environmental costs can change the relative societal advantage of different land uses.

Conclusions

Financial analyses can quantify the benefits and costs of different land management practices from a farmer's perspective, but this does not necessarily reflect the full benefits and costs to society. Including environmental externalities in the assessment helps highlight the most appropriate land use decisions from a societal perspective. This work presents some model improvements developed in Farm-SAFE in order to include key environmental externalities from agricultural and forestry activities. Including carbon sequestration and GHG costs in the example selected from the UK reduced the relative value of a conventional arable system compared to silvoarable agroforestry and forestry. It is anticipated that inclusion of environmental costs such as soil degradation and nitrogen and phosphorus loss would further enhance the relative societal benefit from the silvoarable or forestry system.

Acknowledgements

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[7] The grant values are based on the grant arrangements in 2013 (UK Agro Business Consultants, 2013). These are different from current grant values in 2016.

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