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2. Measuring "green" - does Life Cycle Analysis make sense for food?

The environmental footprint: A method to determine the environmental impact of agricultural production

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Summary

The environmental impact of producing agricultural commodities is an increasingly important topic at a time when climate change, an increasing population and competing demands for food, fibre and fuel are placing heavy demands upon the environment. There are already various methods available for quantifying environmental impact; however, none of them are flexible enough to account for multiple indicators while producing a simple, easy to comprehend result. Life cycle assessment (LCA) can be used to quantify every aspect of a production process and in agriculture has proved valuable in quantifying the inputs and outputs of resources and pollutants that are associated with the production of food commodities. However, the amount of detail that makes the LCA such a valuable tool can also make the results difficult to interpret. Carbon dioxide equivalents (carbon footprints) can be used to quantify the greenhouse gases emitted during a production process and have the advantage, in comparison to the LCA, of presenting the results as a single figure. This approach, as used in the forthcoming PAS 2050, is ideally suited to the retail market but is too simplistic to account for all the environmental burdens that agricultural production entails. This paper introduces a hybrid method, the environmental footprint, which incorporates four environmental indicators (pesticides, greenhouse gas emissions, eutrophication and acidification, and water use) and presents the result as a single figure on a per hectare basis.

Key words: Environment, footprint, carbon, greenhouse gas, pesticide, water, eutrophication, acidification

Introduction

Environmental accounting, in one of its many guises, is finding favour as a method of informing a wide audience of the environmental impact of producing agricultural commodities. There are multiple methods, both in use and under development, which use different inputs and which report their results in different ways.

An established scientific approach is life cycle assessment (LCA; BS 14040:2006), which quantifies all the inputs, outputs and wastes that are part of the life cycle of the product; this is often referred to as the "cradle to grave" approach. LCA is based on an inventory which accounts for every stage within a production process which is subsequently used to produce a detailed analysis. Unfortunately, the complex nature of food production results in the inventory holding large and discrete amounts of data which make distilling the output into a manageable form a difficult task. LCA's are an excellent tool for investigating a production process or for comparing products which use the same functional unit, but they can be unwieldy when comparing different products and the outputs can sometimes be difficult to understand. LCA's contain other environmental information that may be attributable to the product, such as: eutrophication potential, acidification potential, pesticide use and water use.

The first products bearing a carbon label have already appeared in the UK. These have been developed with the help of The Carbon Trust and measure the embedded carbon dioxide (CO_2) or carbon dioxide equivalent (CO_2e) associated with a product. The Carbon Trust is also developing a Publicly Available Specification (PAS 2050:2008) for the embodied CO_2e of all products. Both approaches result in a single figure which reports all the greenhouse gas emissions associated with a product. This approach is ideally suited to the retail market but does not account for the other environmental burdens associated with agricultural production.

Recent publicity regarding food miles has suggested that overseas production can potentially be environmentally better than domestic production, but that the boundary of the analysis is critical in understanding the answer. Kenyan roses (Williams, 2007) and Spanish lettuce (Milà i Canals *et al*., 2007) may be more energy efficient and have lower carbon footprints because they are grown at ambient temperatures but any accompanying reduction in water quality and quantity, in countries with scarce resources, is not taken into consideration.

It is probable that no single method, analysis or label can convey the environmental burden associated with a single product, in a easy to understand way, which would satisfy everyone. However, we suggest that there is room for a hybrid method, the environmental footprint, which uses a similar inventory to a LCA. This uses four aggregated environmental indicators: pesticide use, greenhouse gases (CO_2, CH_4 & N_2O), eutrophication (PO_4, NO_3 & NH_3) and acidification potential (SO_2, NO_x & NH_4), and water use and combines them into a single figure which can be reported by either product unit or by area.

This approach does not possess the breadth of the LCA but does allow easy comparison between commodities. It may require less data than a LCA but contains more environmental information than a carbon label. It can be viewed as complimentary to a LCA or as an extension to a carbon label. Whether it finds a home in an overcrowded market of different accounting methods and labelling schemes will depend on whether it can convey the environmental impact of food production to a wider audience in an easy to understand way. This paper explores the methodology employed in environmental footprinting and presents example results from a Defra project WQ0101 'Environmental footprint and sustainability of horticulture – A comparison with other agricultural sectors' (Lillywhite *et al*., 2007).

Materials and Methods

Environmental footprints were prepared for three arable crops, seven horticultural crops and two livestock sectors. Data was drawn from the 2006 Defra June Survey and standard texts on farm management (Nix, 2005; Beaton, 2006) and was designed to represent an average UK crop.

The environmental footprint is a collection of four existing indicators, combined to present an overall assessment of environmental impact. The boundary for this environmental footprint is the farm gate, which includes the energy required to store, dry and cool the commodity, but excludes all transport and point of sale packaging. The indicators are pesticides, greenhouse gas emissions, eutrophication and acidification potential and water use. These are considered in more detail in the following sections.

Pesticides

The EIQ method (Kovach *et al*., 1992) is used to quantify the environmental impact of all pesticide applications. This method aggregates the environmental impact information for an active ingredient to a single value by combining the three principal components of agricultural production systems: a farm worker component (spray operator and manual labourer), a consumer component (health and leaching) and an ecological component (fish, birds, bees and consumer). Each component is given equal weight in the final analysis, but within each component, individual factors are weighted differently. Coefficients are used to give additional weight to individual factors on a one to five scale. Factors carrying the most weight are multiplied by five (spray operator and consumer), medium-impact factors (bees and birds) are multiplied by three, and those factors considered to have the least impact are multiplied by one. A consistent rule throughout is that the impact potential of a specific pesticide on an individual environmental factor is equal to the toxicity of the chemical multiplied by the potential for exposure. Stated simply, environmental impact is equal to toxicity multiplied by exposure. For example, fish toxicity is calculated by determining the inherent toxicity of the compound to fish multiplied by the likelihood of the fish encountering the pesticide. In this manner, compounds that are toxic to fish but short-lived have lower impact values than compounds that are toxic and long-lived. A field rating for each pesticide is achieved by multiplying the EIQ value by the amount of the active ingredient that is applied. For example:

EIQ value * % rate of active ingredient * application rate = EIQ Field Use Rating

Hence for Makhteshim's Alpha Linuron in potato

EIQ 40.3 * 0.5 * 4.2 L ha^{-1} = 84.63 ha^{-1}

Greenhouse gas emissions

Although the full IPCC basket of greenhouses gases includes hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulphur hexafluoride (SF6), nitrogen trifluoride (NF3), trifluoromethyl sulphur pentafluoride (SF5CF3), halogenated ethers and some other halocarbons not covered by the Montreal Protocol (1987), this analysis concentrates on the main three gases associated with agriculture, i.e. carbon dioxide, methane and nitrous oxide.

Global warming potential is used to assess the ability of the different greenhouse gases to trap heat in the atmosphere and is based on the radiative efficiency (heat-absorbing ability) and decay rate of each gas (the amount removed from the atmosphere over a given number of years) relative to that of CO_2. Carbon dioxide equivalents (CO_2e) are calculated by multiplying the emissions of the greenhouse gas by its global warming potential to provide a common basis for comparing the amounts of the various gases and summation provides an overall assessment of the greenhouse gases associated with one product (Table 1).

Table 1. *Greenhouse gases and their warming potential*

Greenhouse gas	Global warming potential
CO_2 (carbon dioxide)	1
CH_4 (methane)	23
N_2O (nitrous oxide)	296

Eutrophication and acidification potential

Eutrophication Potential (EP) is defined as an increase in nutrients in water and soil which can result in increased primary production. It is quantified in terms of phosphate equivalents using the factors in Table 2. Within agriculture, eutrophication is mainly the result of fertilizer use and animal manures and the impacts are directly related to the amounts applied to land, especially phosphorus and to a lesser extent nitrogen. Nitrate leachate is assumed to be 15% of applied nitrogen (Silgram *et al*. 2001). Phosphate losses are assumed to be 6.5% of applied phosphorus fertilizer based on

Johnes *et al*. (1996). Within the livestock sectors, ammonia released from manures is an additional burden and is responsible for eutrophication associated with milk production.

Table 2. *The eutrophication potential of selected nutrients*

Burden	Eutrophication potential (PO_4e)
PO_4 (phosphate)	1.00
NO_3 (nitrate)	0.42
NH_3 (ammonia)	0.33
NO_x (oxides of nitrogen)	0.13

Acidification is a consequence of acids (and other compounds which can be transformed into acids) being released to the atmosphere and subsequently deposited in surface soils and water. Increased acidity of these environments can lead to forest dieback and the death of fish in addition to increased corrosion of manmade structures (buildings, vehicles etc.). Acidification Potential (AP) is based on the contributions of SO_2, NO_x and NH_3 and is quantified in terms of sulphate equivalents using the factors in Table 3.

Table 3. *The acidification potential of selected nutrients*

Burden	Acidification potential (as SO_2e)
SO_2 (sulphur dioxide)	1.00
NO_x (oxides of nitrogen)	0.70
NH_3 (ammonia)	1.88

The eutrophication and acidification factors developed from the calculated eutrophication and acidification potentials are based on the work of Azapagic (2003; 2004) and are reported as kg ha^{-1}.

Water

Water use in agriculture used to be taken for granted but climate change, competing industries and increasing demand from consumers have brought it to the fore and the environmental impact of its use is under scrutiny, especially in countries with limited resources. All agricultural commodities require additional water to that which is supplied as rain. Even totally rain fed crops such as wheat, require water for crop spraying while at the other end of the scale, protected crops require all of the water for growth to be supplied. Livestock require water for drinking, washing and dipping. We report the use of non-rainfall water in litres per hectare per year although there exists a strong argument that all water required for crop production should be accounted for.

Calculation of the overall environmental footprint

The four indicators use the same base unit, the hectare, however, the value that the individual indicators can take varies. The minimum value is always zero but the maximum value is not fixed. The theoretical maximum (Table 4) is set approximately 25% above the highest result found in the study; this level is slightly arbitrary but should ensure that all possible crops and circumstances can be accommodated in the future and allows the relative effects of the different indicators to be compared. For example, our study found that highest level of pesticide use was 205, so the maximum was set at 250.

Using these ranges, the value taken by each individual indicator was then scaled to take a value between 0 and 100. This allows the individual indicators, within the environmental footprint, to be compared and their influence to be assessed. In all cases, the greater the value calculated, the greater the negative environmental impact. The final stage was to take the mean of the four scaled indicators; this is the environmental footprint, which is expressed on a per hectare basis but has no other units.

Table 4. *The indicators used in the environmental footprint*

Indicator	Unit	Minimum value	Maximum value
Pesticide EIQ rating	kg ha^{-1}	0	250
Carbon dioxide equivalents	kg ha^{-1}	0	75,000
Eutrophication & acidification potential	kg ha^{-1}	0	250
Water	L ha^{-1}	0	3,000,000

Results

The environmental footprints of the twelve selected commodities ranged from 10.5 for winter wheat up to 58.4 for protected lettuce (Table 5). The plant based commodities fall into two discrete groups: the arable and field grown vegetable crops had footprints in the range 10 to 30 while the protected crops had footprints above 45. The two livestock commodities did not group together.

Pesticide EIQ rating

The average EIQ field rating for arable, horticultural and livestock commodities was 114, 152 and 90 EIQ ha^{-1}, respectively. The results successfully reflect the higher amounts of pesticides applied to horticultural crops and the lower amounts used in the arable and livestock sectors (Table 5) and indicates that the EIQ method has the sensitivity to differentiate between the various horticultural crops. Apples and strawberries receive the greatest amounts of pesticides while and carrots and cauliflowers the least. The use of soil fumigants in strawberries under polythene, and especially in protected lettuce, has a major environmental impact and if included, increases both the EIQ field rating and the energy input into the production system. This increased energy consumption is reflected in higher CO_2 emissions and therefore a higher environmental footprint. However, since the inclusion of soil fumigants would have disguised the impact of pesticide use of the other ten commodities and is not used in all protected crops, the decision was taken to exclude them from these calculations.

Carbon dioxide equivalents

There are a number of sources of greenhouse gases associated with agriculture. Carbon dioxide is emitted at almost every stage of the farming cycle although there are two areas that stand out: (1) CO_2 embodied within nitrogen fertilizer and (2) CO_2 embodied within glasshouses and polytunnels within the protected crops sector. Electricity and diesel use accounts for the remainder.

Methane is primarily a by product of enteric fermentation in ruminants, so unsurprisingly only the two livestock based commodities, milk and lamb, contribute in this category. Production of milk has doubled the effect of lamb production in relation to this category. Where methane is produced, it makes a large contribution to the overall CO_2e.

Emissions of nitrous oxide are dominantly associated with three sources: application of nitrogen fertilizers, tillage of agricultural land and emission from manures. The production of nitrous oxide from field crops is proportional to the amount of nitrogen fertilizer applied, so crops like winter

Table 5. *The EIQ rating, Carbon dioxide equivalents (CO_2e), eutrophication and acidification potentials (EAP), water use and environmental footprint of selected commodities*

Commodity	Data	EIQ rating	CO_2e	EAP	Water	Environmental footprint (ha)
Apple	Calculated	205	2,735	8.0	413,200	
	Scaled	82.0	3.6	3	14	25.7
Carrot	Calculated	109	3,431	23.8	518,600	
	Scaled	43.6	4.6	10	17	18.7
Onion	Calculated	140	3,271	27.4	503,800	
	Scaled	56.0	4.4	11	17	22.0
Cauliflower	Calculated	111	3,853	31.1	501,700	
	Scaled	44.4	5.1	12	17	19.7
Lettuce	Calculated	165	57,298	36.0	2,300,500	
(Protected)	Scaled	66.0	76.4	14	77	58.4
Strawberry	Calculated	178	21,511	10.1	2,303,200	
(Protected)	Scaled	71.2	28.7	4	77	45.2
Narcissi	Calculated	154	6,065	15.7	107,000	
	Scaled	61.6	8.1	6	4	19.9
Potato	Calculated	134	7,041	47.2	1,203,000	
	Scaled	53.6	9.4	19	40	30.5
Sugar beat	Calculated	124	2,960	22.0	503,800	
	Scaled	49.6	3.9	9	17	19.8
Wheat	Calculated	83	2,782	12.3	2,000	
	Scaled	33.2	3.7	5	0	10.5
Lamb	Calculated	106	8,190	45.5	23,609	
	Scaled	42.4	10.9	18		18.1
Milk	Calculated	74	19,481	192.9	95,580	
	Scaled	29.6	26.0	77	3	34.0

wheat, potato and cauliflower which have large nitrogen requirements tend to emit more nitrous oxide in comparison to crops like carrot and onion with a smaller requirement. Manures are also responsible for emitting nitrous oxide which accounts for the large amounts of nitrous oxide from the livestock commodities.

Eutrophication and acidification potentials

Within the field grown commodities, eutrophication and acidification are mainly products of fertilizer use and amounts are directly related to amounts of applied fertilizer, especially phosphorus and to a lesser extent nitrogen. Potato ranks highly since it requires high levels of phosphorus, nitrogen and irrigation water, which results in increased leaching of the nutrients into surface waters. Within the livestock sectors, ammonia released from manures is the biggest burden and is responsible for the large acidification associated with milk production.

Water

The quantity of water used per hectare varies greatly. Rain fed winter wheat uses the smallest amount, just 2000 L ha^{-1} for crop spraying, while the two protected crops, which rely entirely on irrigation, use more than 2,000,000 L ha^{-1} . The volume of water applied as irrigation attributed to the field grown horticultural crops plus sugar beet and potato in this study is based on a UK average under 'normal' climatic conditions. Longer and drier growing seasons could result in greater amounts of water being applied as irrigation which would increase the impact of water use within the environmental footprint. The production of milk requires four times more water than lamb but even so the two livestock commodities rank tenth and eleventh, respectively, out of the twelve commodities studied.

Discussion

The environmental footprint method was developed to see whether aggregated indicators could be used to differentiate between agricultural commodities, and if so, whether the method had sufficient sensitivity to make a useful contribution to understanding the environmental impact of agriculture production. The examples presented here, which were based on easily obtainable data seems to show that it has. The method provides a single figure result and allows easy comparison of different commodities and also the ability to further explore how individual indicators influence the result.

The indicators presented here cover the majority of environmental impacts within agriculture, however, for future use the environmental footprint could include others, such as biodiversity indicators like farmland bird numbers and social indicators like the requirement for labour. The advantage of the aggregated indicator approach is that any amount can be included as long as a comparable base unit, product weight (kg) or crop production area (hectare) is maintained.

However, this approach does not always work. Soil sterilants were excluded from the pesticide indicator because the resulting very high values masked the effect of the remaining pesticides and made comparisons across commodities impossible. If chemical soil sterilants continue to be used, this is an area where further refinement of the method will be required.

This study attempts to treat each indicator as having the same rank, relative to one another, however, the level at which the individual maximum value is set obviously influences the relative ranking. Lowering the maximum allowable value will increase the influence of a individual indicator at the expense of the remaining three. This is an unavoidable consequence of using multiple indicators but could be used beneficially to reflect individual circumstances, policy or requirements. For example, if production occurs in an area with scarce water resources, it might be prudent to attach greater value to water use than to pesticide use.

The environmental footprint allows the environmental burden associated with agricultural production on a per hectare basis to be compared and using publicly available land use statistics can be scaled up to provide an analysis of the environmental burden of agriculture at regional or country scale.

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