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The use of life cycle assessment to compare the environmental impact of production and feeding of conventional and genetically modified maize for broiler production in Argentina

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ABSTRACT

The paper presents the methods and results of a life-cycle assessment (LCA) applied to the production of maize grain from a conventional variety compared with maize grain from a variety genetically modified to be herbicide tolerant and insect protected and to contain an enhanced oil and lysine content, and its impact when fed to broiler chickens. The findings show that there are both environmental and human health benefits of growing GM maize including lower impacts on global warming, ozone depletion, freshwater ecotoxicity and human toxicity. However, when considered in terms of the use of maize as a feed input to broiler chicken production, the benefits of the GM alternative become negligible compared to the use of conventional maize.

KEY WORDS: life-cycle assessment, GM maize, environmental effects, poultry

INTRODUCTION

Between 1996 and 2004 the area of genetically modified (GM) crops grown globally increased from 2 to 80 million ha (James, 2004). The principal GM crops are soyabean, maize, cotton, and canola modified for agronomic input traits such as herbicide tolerance (Ht) and/or insect protection (Bt) all of which are used in monogastric and ruminant livestock production rations as either energy and/or protein feeds.

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There are now several reports in the scientific literature showing that the use of GM crops can markedly reduce pesticide use and the environmental footprint of agriculture on the environment (Carpenter et al., 2002; Phipps and Park, 2002; Gianessi et al., 2003). While the recently published results of the four-year Farm Scale Evaluation have assessed the effects of introducing GM crops on the abundance and diversity of farmland wildlife (The Royal Society, 2003), to-date little attempt has been made to consider the effect on the whole system, using an environmental impact assessment tool such as life-cycle assessment (LCA) (Audsley et al., 1997; Bennett et al., 2004). SETAC (1993) define LCA as a method for "evaluating the environmental burdens associated with a product, process or activity by identifying and quantifying the energy and materials used and wastes released to the environment". In this respect it is often termed a "cradle to grave" technique.

This paper presents the methodology used and the results obtained from a LCA for the production of maize grain from an Ht and Bt GM variety with enhanced oil and lysine content compared with a conventional maize variety and when these feed ingredients are used in broiler chickens.

MATERIAL AND METHODS

The LCA methodology used in the current study followed the guidelines set by SETAC (1993). There are four interrelated phases and a brief outline of each stage is presented below:

Goal definition and scoping

Goal definition and scoping defines the aims, objectives and the scope of the study and establishes a functional unit. The aim of the current study is to undertake a partial LCA which concentrates on those aspects that differ between conventional production systems for maize grain and those that use GM maize modified for Ht and Bt and also when these feed ingredients are used in poultry production. The functional unit must reflect the product's utility. In this study the functional unit was defined as "1 kg (body weight) of broiler chicken at the processing plant door".

Inventory analysis

The inventory analysis compiles all resources required and all emissions released by the system under investigation and relates them to the defined functional unit (ISO, 1998). Production systems for both the conventional and GM maize crops and poultry production were modelled using data from Ecoinvent (2004). Each system was represented as a simple form of a process diagram. Sub-process diagrams were also prepared which were then incorporated into the whole LCA. These diagrams enabled energy flows, inputs and outputs to be defined for the entire LCA. The model includes the manufacture, packaging and transport to the farm of each pesticide and includes the field operations; manufacturing, repairs and maintenance of farm machinery; production and use of fuels for tractors, and transport costs; construction, maintenance and ultimate demolition of buildings for machinery storage. It also takes account of emissions to air from combustion and emissions to soil from tyre abrasion during the work process. The model also includes the manufacture, packaging and transport to the chicken processing unit of each of the dietary supplements.

The growth time for the maize was taken as being between a typical spring sowing to autumn harvest. Environmental conditions were assumed to be a clay-loam soil with no fewer than 3 days without precipitation after pesticide spray application on a typical Argentinean farm with a crop yield of 8 t DM/ha (Adreani, personal communication) Four different possible spray regimes were evaluated and are shown in Table 1; these were a conventional system and three systems that might be used with the GM variety.

Table 1. Herbicide and insecticide spray regimes used for maize grain production from a conventional maize variety and three alternative spray programmes (GM1, GM2 and GM3) used in the production maize grain from herbicide tolerant and insect protected genetically modified maize variety grown in Argentina

Programme	Formulation (F)	Number of applications	Product, kg or l/ha	Active ingredient (a.i)	kg a.i /kg product	kg a.i/ha
Conventional	Roundup	2 × 2 l/ha	4 l/ha	Glyphosate	0.36	1.44
	Semevin	1 × 1 l/100 kg	0.2 l/ha	Tiodicarb	0.35	0.07
	Gesaprim 50	2 × 2 l/ha	4 l/ha	Atrazine	0.50	2
	Guardian	1 × 2 l/ha	2 l/ha	Acetochlor	0.84	1.68
	Esteron	2 × 0.5 l/ha	1 l/ha	2,4-D	0.797	0.797
	Challenger	1 × 0.07 kg /ha	0.07 kg/ha	Nicosulfuron	0.75	0.0525
	Arrivo	2 × 0.1 l/ha	0.2 l/ha	Cypermethrine	0.25	0.05
Biotech: GM1	Roundup	2 × 2 l/ha	4 l/ha	Glyphosate	0.36	1.44
	Gesaprim 50	1 × 2 l/ha	2 l/ha	Atrazine	0.50	1
	Esteron	1 × 0.5 l/ha	0.5 kg/ha	2,4-D	0.797	0.3985
	Semevin	1 × 1 l/100kg	0.2 l/ha	Tiodicarb	0.35	0.07
	Roundup max	2 × 1.5 l/ha	2.3 kg/ha	Glyphosate	0.68	1.564
GM2	Roundup	2 × 2 l/ha	4 l/ha	Glyphosate	0.36	1.44
	Semevin	1 × 1 l/100kg	0.2 l/ha	Tiodicarb	0.35	0.07
	Roundup max	2 × 1.5 l/ha	2.3 kg/ha	Glyphosate	0.68	1.564
	Arrivo	2 × 0.1 l/ha	0.2 l/ha	Cypermethrine	0.25	0.05
GM3	Roundup	2 × 2 l/ha	4 l/ha	Glyphosate	0.36	1.44
	Semevin	1 × 1 l/100kg	0.2 l/ha	Tiodicarb	0.35	0.07
	Roundup max	2 × 1.5 l/ha	2.3 kg/ha	Glyphosate	0.68	1.564

The growth time for broilers was taken as 42 days during which time each bird was assumed to have consumed 4.32 kg feed (Nix, 2004) and gained 2.65 liveweight. The chickens were fed three diets (starter, grower, and finisher rations), with differing proportions of feed ingredients. In order to simplify the LCA a mean dietary composition was calculated based on the ingredient composition of each diet, based on work by Kebreab et al. (2005). As high-oil maize has been shown to reduce the amount of nitrogen excreted by 1.5% and phosphorus by 4% per bird (Kebreab et al., 2005), this was also included in the model. Figures 1 and 2 show the process diagrams for conventional maize production and that for the production of Ht and Bt maize, which shows an overall simplified production process.

Impact assessment

The impact assessment stage characterises and assesses the effects of the environmental burdens identified and quantified in the inventory. The inventory data are multiplied by characterization factors (CF) to give indicators for the environmental impact categories (Equation 1):

$$\text{Impact category indicator}_{i} = \textstyle\sum_{j} (E_{j} \text{ or } R_{j}) \times CF_{i,j}$$

where: impact category $_i$ = indicator value per functional unit for impact category $_i$; E_j or R_j = release of emission *j* or consumption of resource *j* per functional unit; $CF_{i,j}$ = characterization factor for emission *j* or resource *j* contributing to impact category *i*.

The characterization factors represent the potential of a single emission or resource consumption to contribute to the respective impact category (ISO, 2000). Such categories include Global Warming Potential; Acidification Potential; Eutrophication; Human Toxicity; Freshwater and Marine Ecotoxicity. A variety of different substances can contribute to each impact category and one substance can contribute to more than one impact category.

In this LCA two baseline characterization methods developed by Guinée (2002) were used for the main impact categories, these are characterizations of the Intergovernmental Panel on Climate Change (IPCC, 2001) and the Centre of Environmental Science of Leiden known as CML 2001 (Guinée, 2002).

IPCC characterizations

The IPCC describe how the potential for global warming (GWP) for different gaseous emissions are characterized according to their global warming potential

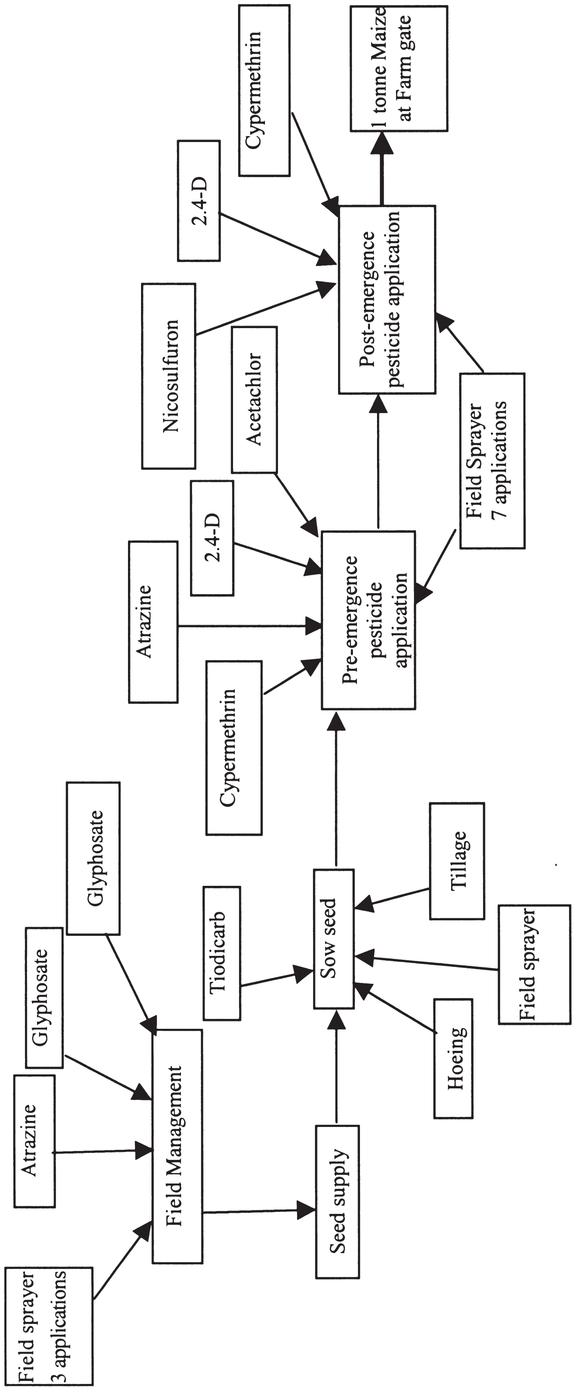


Figure 1. Conventional production system for maize grain in Argentina

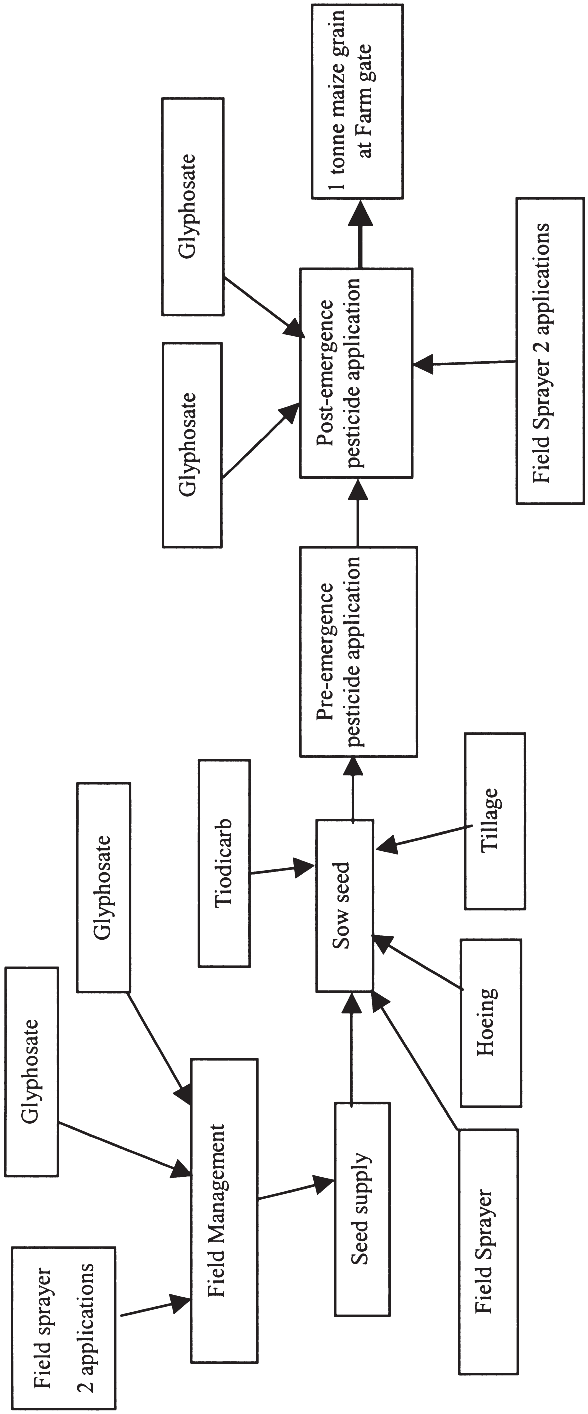


Figure 2. Production system for maize grain in Argentina when using a variety genetically modified to be herbicide tolerant (H*t*) and insect protected *(Bt)*

and then aggregated in to the impact category, climate change. GWP is an index for estimating the relative global warming contribution due to atmospheric emission of a kg of a particular greenhouse gas in comparison to the emission of a kg of carbon dioxide. GWP is meant to compare emissions of long-lived, well-mixed gases such as CO_2, CH_4, N_2O and hydrofluorocarbons (HFC),

CML 2001 characterizations

CML 2001 describes a "problem orientated approach" which is a definition of category indicators close to the environmental interventions (Guinée, 2002). This is a quantifiable representation of an impact category, such as infra-red radiative forcing for climate change that is close to a human intervention in the environment, such as resource extraction, emissions and land use.

Ecotoxicities refer to the impact of toxic substances on ecosystems or on human health. They have been characterized as a standard measurement where the ecotoxicity potential is calculated for each emission of a toxic substance to air, water and soil in kg of 1, 4- dichlorobenzene equivalent (eq.)/kg emission.

RESULTS

The LCA was conducted in two phases, where Phase 1 covered maize production and Phase 2 covered the maize and chicken production, in which the maize was used as a feed component, as a whole process.

The total emissions from growing one tonne of maize grain from four different management regimes were characterized and classified to show the potential effects on a number of environmental and human health impact factors. Figures 3 and 4 show the impacts on GWP, stratospheric ozone depletion, and fresh water toxicity levels on freshwater and human health.

All the GM systems showed a positive advantage when compared to the conventional system with the biggest benefit achieved with the GM3 system. The results show that when comparing the GM3 system of maize grain production with the conventional system there was a potential benefit of 13.5% in the case of GWP (kg CO_2 eq.) and 16.7% for stratospheric ozone depletion (kg CFC-11 eq.). Further important differences of 12.6% for freshwater ecotoxicity (kg 1, 4-DCB eq.) and the reduction of potential impact on human health of 13.6% (kg 1,4-DCB eq.) were noted in favour of the GM3 system compared with the conventional system of maize grain production. Other impact categories that were considered, such as potential for summer smog, marine ecotoxicity and terrestrial ecotoxicity, all showed similar differences to those outlined above.

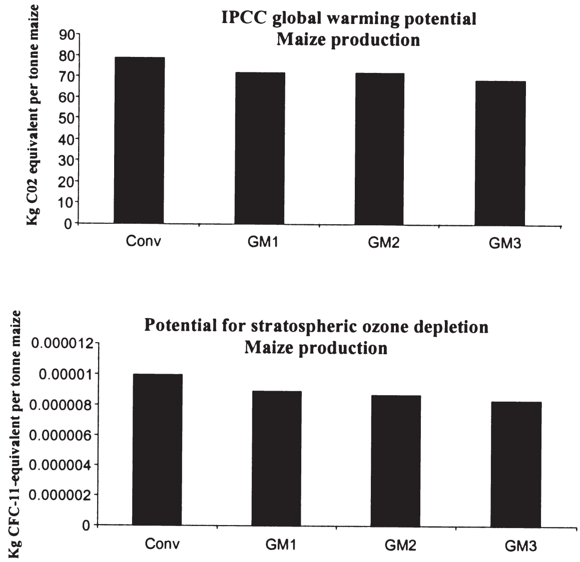


Figure 3. Global warming potential (kg C02-eq.) and stratospheric ozone depletion (kg CFC-11-eq.) associated with maize grain production in Argentina when using the conventional system compared with the use of variety genetically modified for herbicide tolerance and insect protection

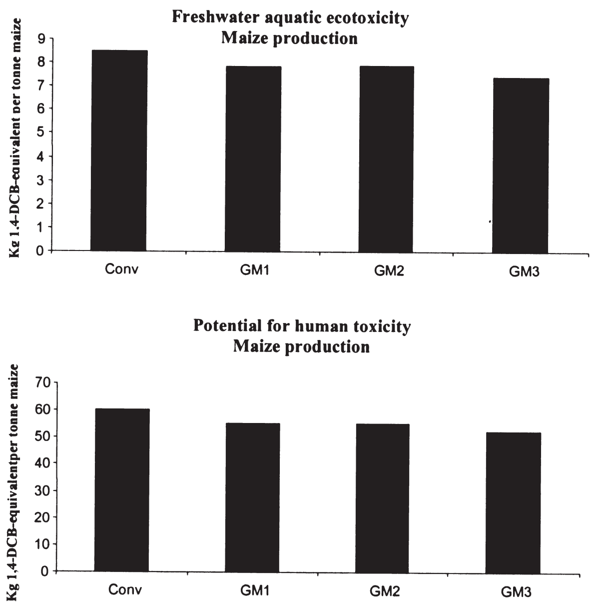
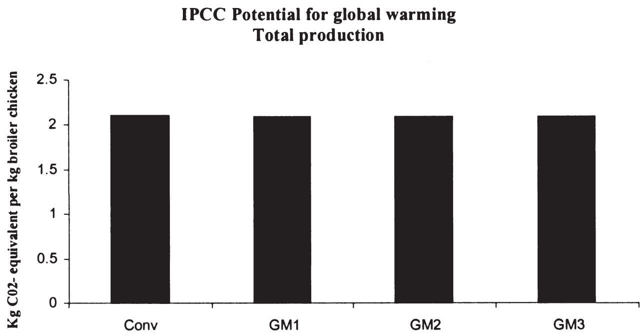


Figure 4. Freshwater and human toxicity (kg 1,4-DCB-eq.) associated with maize grain production in Argentina when using the conventional system compared with the use of variety genetically modified for herbicide tolerance and insect protection

The second phase of the work considered the environmental costs associated with the whole process of production of 1 kg (body weight) of broiler chicken and is characterized and classified across the four different maize growing regimes to show the potential impacts on a number of environmental and human health impact categories. The results for global warming, stratospheric ozone depletion, the potential toxicity levels on freshwater, and toxicity for human health are shown in Figures 5 and 6.



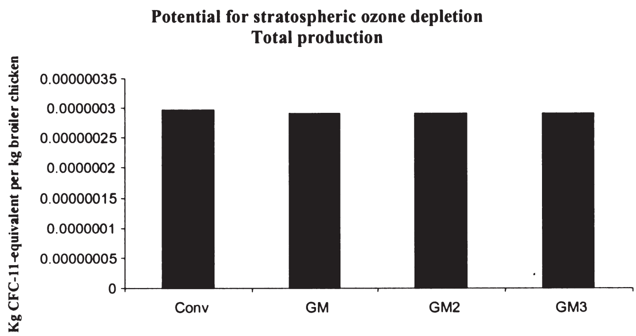
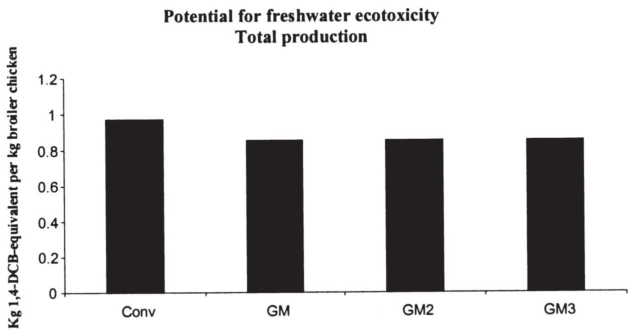


Figure 5. Global warming potential (kg C02-eq.) and stratospheric ozone depletion (kg CFC-11-eq.) associated with the whole production system (maize grain + broiler production) in Argentina when using the conventional system compared with the use of variety genetically modified for herbicide tolerance and insect protection

As maize grain is only one component used in the poultry rations its effect on the environmental impacts (per kg of body weight) is consequently reduced when compared with the production of maize grain. Thus the results for the difference between the use of conventional and GM maize in a poultry production system for GWP, stratospheric ozone depletion, freshwater ecotoxicity, and human toxicity are relatively small and there was little difference between the four GM crop regimes.



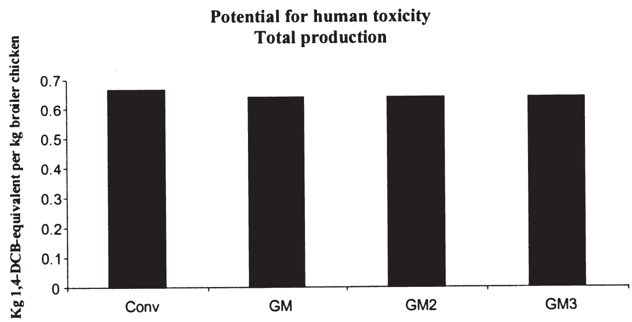


Figure 6. Freshwater and human toxicity (kg 1, 4-DCB-eq.) associated with the whole system (maize grain + broiler production) in Argentina when using the conventional system compared with the use of variety genetically modified for herbicide tolerance and insect protection

DISCUSSION

Figures 3 and 4 show that the herbicide spray regimes implemented in Phase 1 and their associated husbandry methods are important variables within the different maize production scenarios. The results support the earlier LCA conducted by Bennett and colleagues who showed positive benefits associated with the use of GM varieties of sugar beet modified for herbicide tolerance when compared with conventional varieties (Bennett et al., 2004).

In this respect, the difference between the conventional spray regime currently being used in Argentina and feasible GM spray regimes could result in a reduction in total emissions and would reduce the impact of agriculture on the environmental and human health. However, while this may be important at a local/regional level the contribution to reducing emissions at a national level requires further investigation as the introduction of the GM variety is also likely to result in a significant change in cultivation practise with an increase in minimal tillage. This potential change has not been taken into account in the present paper, but a recent publication by Brookes and Barfoot (2005) has confirmed that the introduction of minimal tillage resulting from the use of GM varieties offers major environmental benefits through reduced diesel use and CO_2 emissions. However, when considering the use of maize as a feed input to poultry production the environmental and health benefits associated with the use of the GM crop is diluted as it only forms a relatively small part of the overall system.

De Smet (1993) notes that there are a number of limitations to LCA as they will never eliminate subjectivity, and will always involve judgements based on "societal values". Also, any LCA involves a number of technical assumptions as well as "value choices" which are inclined to be subjective groupings. It is important that any assumptions and groupings are transparent and that their use can be easily justified. In this respect, the results for the impact categories included in this paper are indicative of results found for key environmental and human health impact categories that could reasonably be considered as part of an LCA. The authors recognize that the quality of an LCA is dependant on the quality of the available inventory data used to produce the environmental impact effect. In the current LCA the best data available were used and while some were relatively old they were largely comparable between herbicide ingredients, other data had been widely used in other LCA studies. The basic data used in this study are available on request from the authors.

CONCLUSIONS

The LCA showed that growing GM maize modified for herbicide tolerance, insect protection and with enhanced oil and lysine content rather than conventional maize is likely to be better for the environment and human health, with lower levels of emissions into the environment. However, when considered in terms of the use of maize grain as a feed input to broiler chicken production, the benefits of using the GM alternative becomes negligible compared to the use of conventional maize.

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