Organic Versus Conventional Farming: The Case of wheat Production in Wallonia (Belgium)

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Organic *versus* conventional farming: the case of wheat production in Wallonia (Belgium)

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Abstract

The environmental impact of wheat production was assessed through Life Cycle Assessment (LCA). Local data were collected to characterize Walloon conventional and organic wheat production systems. Two functional units (FU) were investigated: 1 kg of wheat grains at 15% humidity and 1 ha used for wheat cropping. An uncertainty analysis assessed the significance of differences between conventional and organic systems. Using 1 kg of grains as FU, results are not significantly different in global warming and cumulative energy demand. Very highly significant differences for soil acidification and eutrophication, and significant differences for agricultural land occupation were found to be in favor of conventional wheat production. Due to the high yield level in conventional farming (8.5 t/ha at 15% humidity against 4.5 t/ha for organic wheat), organic winter wheat has an equivalent or even, in some impact categories, a higher impact than conventional winter wheat. Using 1 ha as FU, organic production is less impacting than conventional production, except for soil acidification and eutrophication. The choice of the FU has proven to be very sensitive. This study could be improved by accounting for rotation effects, by using more specific models to calculate emissions due to organic and mineral fertilization, and by accounting for carbon storage in soil.

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*Keywords:*Life cycle assessment (LCA); organic farming; wheat; environmental impact.

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1. Introduction

There is an increasing awareness among western consumers regarding their behavior matching sustainable development, translated by a modification of some food consumption habits. The demand for organically sourced products is in constant increase in Europe, as in Wallonia (southern Belgium) where, between 2005 and 2011, the number of organic farms has risen of 49% (DGSIE, 2010) and represents up to 7% of the Utilized Agricultural Area (UAA) (Debode *et al*., 2013). Organic products are often perceived as more environmentally-friendly than their conventional counterparts. Do these prejudices reflect the truth? European consumers ask for more information on environmental impacts of food products (European Commission, 2013). This explains why European countries are eager to promote environmental labeling and sustainable food products.

It is therefore crucial to be able to determine more precisely the carbon footprint and more globally the environmental impacts of food products. The Life Cycle Assessment (LCA) methodology is appropriate to reach such a goal (Andersson, 2000).

Using the LCA standardized method (ISO 14040, 2006), the aim of this study is to assess and compare the environmental impacts of organic and conventional wheat. It aims at highlighting environmental hotspots of both production modes and identifying limitations of LCAs conducted on organic productions.

2. Methods

The system boundaries of both systems include all production steps from the field to the farm gate, including machinery production and use, inputs (fertilizers, pesticides and seeds) production, transport and use, and land occupation. Two functional units (FU) are investigated and compared: 1 kg fresh matter (FM, 85% of dry matter) of wheat and 1 hectare (ha) of wheat-cropped area.

2.1. Inventory data collection

Data on conventional wheat production in Wallonia (reference year 2010) are provided by Van Stappen *et al*., (submitted to the International Journal of Life Cycle Assessment). This conventional wheat has a grain yield of 8,350 kgFM/ha and a straw yield of 3,600 kgFM/ha. Generic data are extracted from the ecoinvent database (Nemecek and Kägi, 2007).

Table 1. Itinerary of organic and conventional wheat

Process	units	Conventional wheat	Organic wheat
Area in Wallonia	ha	139 488	584
Skim ploughing		1.5 passages, tractor 300 cv, deep skim ploughing before sowing	1 passage, tractor 100 cv, disc tiller, mounted 3.5m
Seeds	kg/ha	160	200
Organic fertilizer	kg N/ha	7	144
	kg P_2O_5/ha	3.9	64.8
	kg K_2O/ha	5.8	145.2
Mineral fertilizer	kg N/ha	182	0
	kg P_2O_5/ha	3	0
	kg K_2O/ha	5	0
Crop protection		phytosanitary treatment, 3 passages sprayer	mechanical weeding, 2 passages, spiked chain harrow, 12m
Harvesting		1 passage, tractor 350 cv, combine harvester 7m30	1 passage, combine harvester 5m
Swath drying		0.5 passage, windrower 4m , tractor 120 cv	0.5 passage, windrower 4m, tractor 120 cv
Baling		1 passage, 120*7cm, tractor 120 cv	1 passage, 120*7cm, tractor 120 cv

Production data for organic wheat are provided by local studies (Montignies *et al.*, 2011, Debode *et al.*, 2013) (Table 1). Organic wheat has a grain yield of 4,500 kgFM/ha and a straw yield of 2,500 kgFM/ha. Agricultural work processes are based on agricultural pathways defined by experts. Data from the Mecacost tool (Rabier *et al.*, 2008) are used to calculate emissions due to machinery use with the adaptation of fuel consumption, work duration, life duration, nominal and mean powers, and machinery weights. Emission factors for fuel combustion and tire abrasion come from Nemecek and Kägi (2007).

For both conventional and organic wheat production, impacts from the production of organic fertilizers are entirely attributed to animal rearing. Only fertilizers transport and use on field are considered in this study.

Field emissions due to inputs (fertilizers, pesticides, seeds) application during crop cultivation are assessed using emission models, following recommendations by Nemecek (2013). Ammonia (NH_3) emissions to air are calculated according to fertilizers nitrogen (N) content and using emissions factors from Tier 2 technology-specific models by EMEP/EEA (2013a, b). Nitrate ion (NO_3^-) emissions to groundwater are based on the model SALCA-Nitrat by Richner *et al.* (2006) adapted to local conditions with respect to cropping duration, date of N application, N mineralization potential in soils, N uptake by vegetation and risk of N leaching. Nitrogen oxides (NO_x) emissions to air are calculated from EMEP/EEA Tier 1 approach (EMEP/EEA, 2013b) and nitrous oxide (N_2O) are estimated from IPCC Tier 1 guidelines (IPCC, 2006). Phosphorous emissions to river (phosphorus (P) and phosphate ion (PO_4^{3-})) and to groundwater (PO_4^{3-}) are based on the SALCA-phosphor model by Prasuhn (2006). Trace metal (cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), mercury (Hg), nickel (Ni), zinc (Zn)) balances and related emissions to groundwater, river and agricultural soil are calculated from the SALCA-Schwermetall model by Freiermuth (2006) adapted to local conditions with respect to trace metal contents of mineral and organic fertilizers (Piazzalunga *et al.*, 2012), soil (Sonnet *et al.*, 2003), and plant material and annual deposition (Koch and Salou, 2013).

2.2. Allocation between co-products

Cereal cultivation is an indivisible multi-output product system delivering two co-products, grain and straw, both having agronomic and economic values. While cereals are generally cultivated for grain production, farmers sometimes choose to crop a few cereal hectares in order to harvest straw for animal litter or feed. Straw has no matter what an undisputable role in soil carbon and soil structure management, whether left on the field or returned to the latter as farmyard manure. For this reason the impacts of wheat production are allocated between grain and straw according to their respective prices on the Walloon market.

2.3. Life Cycle Impact Assessment

The evaluation of the environmental impacts or Life Cycle Impact Assessment (LCIA) is supported by a composite method at mid-point level constructed according to the ILCD handbook (European Commission *et al.*, 2011). The LCA software used is SimaPro 8.0.4.30 (PRé, 2015). Selected impact categories, related indicator units and reference method are listed in Table 2.

Table 2. Selected impact categories, related indicator units and reference method used for LCIA.

Abbreviation	Impact category	Indicator Unit	Reference method
GWP	Global warming potential with a timeframe of 100 years	kg CO_2 eq.	(IPCC, 2013)
HTP	Human toxicity potential	10^{-6} CTUh (Comparative Toxic Units)	USEtox (Rosenbaum *et al.*, 2008)
TAP	Terrestrial acidification potential	10^{-6} kg SO_2 eq.	(Posch *et al.*, 2008)
EUP	Eutrophication potential	10^{-6} kg PO_4^{3-} eq.	CML-IA baseline v4.2 (Guinée *et al.*, 2002)
AEP	Aquatic ecotoxicity potential	10^{-3} CTUe (Comparative Toxic Units)	USEtox (Rosenbaum *et al.*, 2008)
ALO	Agricultural land occupation	m²y (m².year)	ReCiPe v1.11 (Goedkoop *et al.*, 2009)
WDP	Water depletion potential	10^{-3} m³	ReCiPe v1.11 (Goedkoop *et al.*, 2009)
POF	Photochemical oxidant formation	10^{-3} kg NMVOC	ReCiPe v1.11 (Goedkoop *et al.*, 2009)

Abbreviation	Impact category	Indicator Unit	Reference method
CED	Cumulative Energy Demand	10^{-3} MJ	(Frischknecht *et al*., 2007)

2.4. Uncertainty analyses

Uncertainty analyses aim at determining how uncertainties in data and assumptions progress in the calculations and how they affect the reliability of the results of the LCIA (ISO, 2006b). In this work uncertainty analyses are run using Monte-Carlo (MC) simulations implemented in SimaPro 8.0.4.30 (Hedemann and König, 2003, PRé, 2015). MC simulations performed in SimaPro account for uncertainty in input and output inventory data but not for uncertainties tied to impact characterization factors. It is therefore proposed to mitigate our uncertainty results with semi-quantitative analysis based on expert judgment as recommended by Jolliet *et al*. (2010). They recommend minimum 10 % difference in order to declare results are significantly different in GWP and CED categories. For TAP and EUP, this minimum difference has to reach 30 %. Regarding HTP and AEP, one or even two orders of magnitude are necessary to declare two contributions are significantly different, considering the high uncertainty on impact characterization factors and the huge number of substances playing a role in toxicity impacts. In order to account for this uncertainty mitigation in our results, significant differences are invalidated when the above-mentioned minimum difference between compared results is not reached.

3. Results

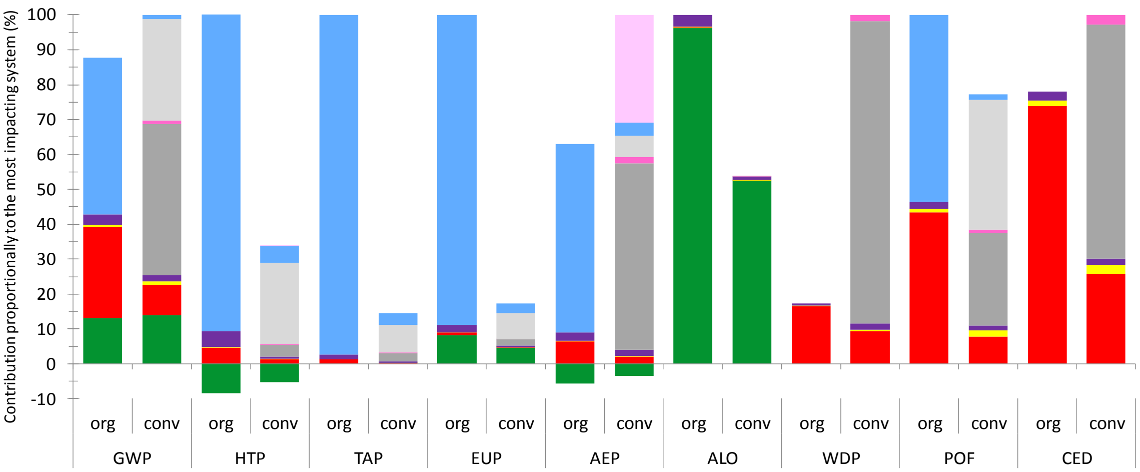

Fig. 1. LCIA results by impact category for the production of 1 kgFM of organic (org) and conventional (conv) wheat. ● Crop effect (emissions tied to land occupation), ● Mechanization, ● Transport, ● Seeds, ● Mineral fertilizers production, ● Pesticides production, ● Emissions due to mineral fertilizers use, ● Emissions due to organic fertilizers use, ● Pesticides emissions.

Environmental impacts results per kg of organic wheat (Table 3 and Fig. 1) show the major contribution of emissions due to organic fertilizer use in most impact categories. These emissions contribute to 51 %, 91%, 97%, 89%, 86% and 53% of the total impact in GWP, HTP, TAP, EUP, AEP and POF, respectively. Among these, we note that NH_3 emissions are directly responsible for 96% and 49% of the total impact in TAP and EUP, respectively, and indirectly, *via* N_2O emissions, responsible for 20% of the total GWP impact.

Regarding the conventional production of 1 kgFM of wheat, mineral fertilization is the most impacting step representing 74% of GWP, 94% of HTP, 95% of TAP, 69% of EUP, 63% of AEP, 87% of WDP, 87% of POF and

69% of CED. Mechanization has also a substantial impact in organic and conventional wheat production in the categories GWP (26 and 9%), WDP (16 and 9%), POF (43 and 8%) and CED (75 and 26%). In conventional cropping, the impact of pesticides production and application is limited to AEP (32%), WDP (1.8%) and CED (3%).

Table 3. LCIA results for organic and conventional wheat production, using 1 kgFM and 1 ha as functional unit (FU).

FU	Production mode	GWP kg CO_2 eq.	HTP 10^{-6} CTUh	TAP 10^{-6} kg SO_2 eq.	EUP 10^{-6} kg PO_4^{3-} eq.	AEP 10^{-3} CTUe	ALO m^2y	WDP 10^{-3} m^3	POF 10^{-3} kg NMVOC	CED 10^{-3} MJ
1 kgFM	Org	0.307	2.246	0.103	0.013	0.004	1.6	0.149	1.3	0.001
	Conv	0.349	0.150	0.015	0.002	0.007	0.868	0.861	0.993	0.002
1 ha	Org	1382	10109	462.7	56.6	18.6	7270	672	5793	6.7
	Conv	2991	1283	141.7	19.4	59.4	7419	7360	8489	163.6

Org: organic; Conv: conventional

MC simulations (Table 4) have been conducted to identify significant differences between organic and conventional wheat production. Using 1 kgFM as FU, MC simulations reveal very highly significant differences ($p < 0.001$) for TAP and EUP, and significant differences ($p < 0.05$) for ALO and POF. MC simulations using 1 ha as FU conclude to very highly significant differences in GWP, TAP, EUP and CED, and highly significant differences in POF. Organic production shows lower impacts than conventional production in GWP, POF and CED, but higher impacts in TAP and EUP.

Table 4. Monte-Carlo (MC) simulations comparing organic and conventional wheat production, using 1 kgFM and 1 ha as functional unit (FU).

FU	GWP	HTP	TAP	EUP	AEP	ALO	WDP	POF	CED
1 kgFM	0.133	(**)	***	***	(***)	**	0.418	*	0.054
1 ha	***	0.222	***	***	(***)	0.468	0.456	**	***

*** $p<0.001$: very highly significant differences; ** $p<0.01$: highly significant differences; * $p<0.05$: significant differences; p values for not significant differences ($p\geq0.05$) are indicated; invalidated results (see section 2.4) are displayed between brackets.

4. Discussion

When using 1 kgFM as FU, organically produced wheat has significantly higher environmental impacts than conventional wheat in TAP, EUP, ALO and POF categories. This better performance of conventional wheat production is partly explained by yield differences: 8.5 tFM/ha for conventional wheat (DGSIE, 2010) against 4.5 tMF/ha for organic wheat (Montignies *et al*., 2013).

Additionally, for an equivalent nutrient supply, organic fertilization induces more important impacts than mineral fertilization. This is explained by model emissions factors for NH_3 volatilization which are higher for organic N fertilizers than for mineral fertilizers (EMEP/EEA, 2013b, IPCC, 2006, Nemecek and Schnetzer, 2011). These factors affect NH_3 and NO_x emissions and indirect N_2O emissions, contributing to TAP, EUP and GWP. Considering the important contribution of NH_3 emissions to these impact categories, a more accurate evaluation of those emissions is crucial.

Nitrogenous and phosphorous emissions from mineral and organic fertilizers application on field are calculated from Tier 1 or Tier 2 emission models accounting partly for specific soil, practices, crop rotations or climate conditions. Even though those models are recommended by widely used databases such as ecoinvent, they introduce uncertainty in the results. More specific crop models have proven their relevance (Bessou *et al*., 2012, Godard *et al*., 2012, Williams *et al*., 2010) and may be transposed to our region in order to refine our conclusions.

When using 1 ha as FU, organic wheat is more environmentally-friendly than conventional wheat in GWP, POF and CED impact categories.

Results are highly sensitive towards the choice of the functional unit, as already observed in other studies comparing organic and conventional farming (Hayashi, 2013, Mondelaers *et al.*, 2009). Mass (kg) can be selected because this FU reflects more accurately the role of agriculture which is to provide biomass for food and non-food uses rather than to occupy land. Production is indeed the central purpose of agricultural systems, while landscape upkeep comes secondary (Charles *et al.*, 2006). The land area unit (ha) could be a suitable choice if the goal of the study is to assess which agricultural practices (organic or conventional) put less environmental pressure on land (land being seen as a finite and fragile resource) (Jolliet *et al*., 2010). The area FU brings information on the intensity in the use of agricultural inputs, while the efficiency of production systems is taken into account by a mass FU (Charles *et al.*, 2006). It is therefore essential to define the product function in a study comparing organic with conventional farming.

Results are also highly dependent on input application and on organic fertilization in particular. Any change in organic fertilization would therefore alter results substantially. In the definition of the cropping plan for organic wheat production used in this study, solid cattle manure has been considered as the sole organic fertilizer. However Abras (2014) showed that the organic fertilizer type, and its related N, P and K contents, influences wheat yields.

Furthermore, no information on nutrient and trace metal contents of organic fertilizers was available and conventional data were used. According to Cooper *et al*. (2011), it seems, however, that, in the case of wheat production among others, fertilization practices in organic production would decrease trace metal export by grains by 42% for Cd, 11% for Cu and 18% for Zn, but on the contrary increase Ni export by 23%. Trace metal contents of animal diets and manure are consequently influenced by agricultural practices (organic or conventional). Field emissions from organic fertilizer application may therefore have been overestimated. Laboratory analyses of nutrient and trace metal contents of organic fertilizers would be useful to refine those emission calculations.

Finally considering whole rotations and not only the annual wheat crop would enable to account for nutrient leftovers by preceding and for subsequent crops. It is indeed likely that subsequent crops benefit from cattle manure applied on organic wheat (van Zeijts *et al*. 1999). Besides, wheat crops do not generally come first in the rotation scheme and as such do not receive P and K nutrition. However they benefit from leftovers from preceding crops and these nutrients influence their yields. Allocating the organic fertilization at the rotation level would enable to consider the impacts attributable to the considered crop only and may reduce estimated impacts from the fertilization of organic wheat.

For lack of specific data, stock changes in soil organic carbon (SOC) were not accounted for. However, in future works, accounting for SOC stock changes using IPCC (2003) Tier 3 or other methods already tested in agricultural LCAs in Western Europe (Godard *et al*., 2012, Godard *et al*., 2013, Saffih-Hdadi and Mary, 2008) would be an asset, especially for assessing SOC changes induced by management practices such as reduced tillage or no-till (Snyder *et al*., 2009) used in conventional or organic farming.

5. Conclusion

Using the LCA methodology, this study aimed at comparing the environmental impacts of organic and conventional production of wheat.

Results are very sensitive to the choice of the functional unit. When compared on the basis of the mass (kg), organically cropped wheat seems to induce more environmental impacts than conventionally cropped wheat in terms of acidification, eutrophication, land occupation and photo-oxidants formation. Overall the most influential parameter seems to be the yield. With yields among the highest in the world, the well mastered production of conventional wheat in Wallonia shows smaller impacts than lower yielding organic wheat. However, on the basis of the land area (ha), organic wheat is more environmentally-friendly than conventional wheat in terms of global warming, photo-oxidants formation and energy demand.

Emissions from fertilizer application on field predominate in the results. Using more specific emission models would improve the quality of the results. Specific data for nutrient and trace metal contents would also enable to enhance results precision.

Accounting for the whole rotation would also help to allocate more accurately fertilizers applied for the whole rotation and benefiting to successive crops. Considering organic carbon storage from managed soils would also help refine results.

Beside environmental criteria, taking account of social and economic impacts, such as working conditions and added value distribution all along the processing chain, would allow to encompass other aspects of the sustainability of organic and conventional wheat production in Wallonia.

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