Analyse de cycle de vie de systèmes de cultures visant à réduire les émissions de gaz à effet de serre
[Thèse de Pietro Goglio, 2013]

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Outline of talk

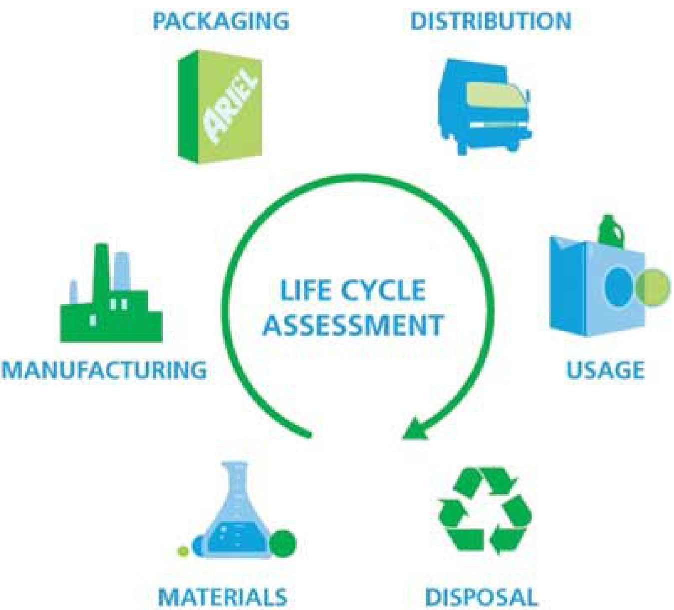
- **Introduction:**

- **Methodology:**

  LCA, Modelling set-up, field trials

- **Results & Discussion:**
  - Fields emissions in relation to climate variability
  - LCA of a long term crop management conceived to reduce GHG emissions (ICC trial crop management)
  - LCA of a real long term trial with two cropping systems established in the Mediterranean (Pisa; CIMAS trial)
- **Conclusion and perspectives**

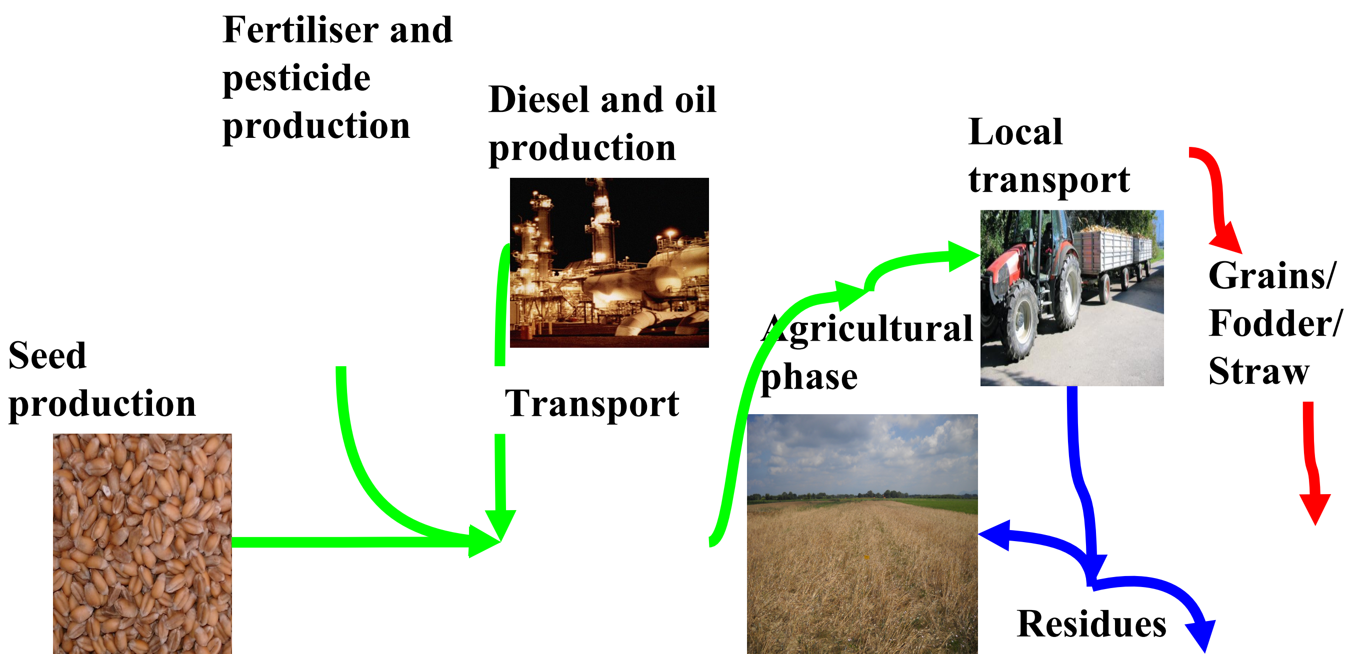
LCA approach in agriculture



LCA

Main impact categories: Energy Demand, Global warming potential, Eutrophication potential, Resource Depletion, Toxicity potentials, Ecotoxicity potentials

Agricultural LCA



Scientific issues

Reactive N species and CO_2 emissions:

- measured[1-3] ⇐ costly and time consuming
- estimated: emission factors [4], agroecosystems models [5,6]

Ignores local factors

Require large input datasets

([1] Laville et al., 2011; [2] Loubet et al., 2011; [3] Brady & Weil 2001 [4]; De Klein et al., 2006; [5] Gabrielle and Gagnaire, 2008, [6] Del Grosso et al., 2008)

Scientific issues (final):

Reactive N species and CO_2 emissions:

- measured[1-3] costly and time consuming
- estimated: emission factors [4], agroecosystems models [5,6]

ignores local factors

potentially more accurate

Several approaches were integrating agroecosystem models within the LCA [5,7,8]. However, all these studies involved:

- a limited set of crops

no carry over effect accounted

no cropping system approach

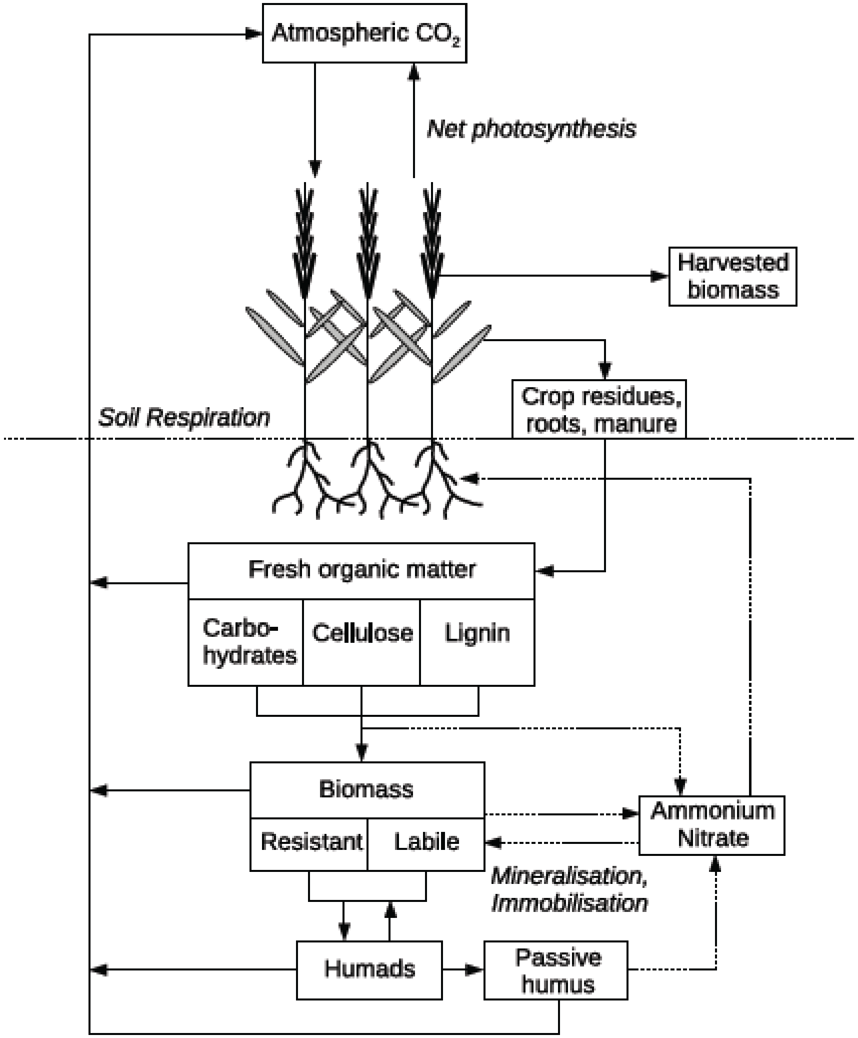
- while JRC et al., (2007) evaluated only biofuel crops with one year time frame

dependent on seasonal variability

([1] Laville et al., 2011; [2] Loubet et al., 2011; [3] Brady & Weil 2001 [4]; De Klein et al., 2006;

[5] Gabrielle and Gagnaire, 2008, [6] Del Grosso et al., 2008; [7] Adler et al., 2007; [8] JRC et al., 2007)

Schematic of an Agroecosystem model



(Lehuger et al., 2009)

Goals, scope and methodology

- **Developing a LCA approach for cropping systems**
- **Testing the approach with data coming from the field**
- **Identifying possible improvements and evaluating agricultural systems and techniques mitigating their environmental impacts**

LCA strategy:

Trial	Upstream processes for agriculture	Technical operations, fuel and material consumption during cultivation	Pesticide fate	Soil GHG emissions and other reactive N species
ICC (France)	Ecoinvent Database	Measured data	Assessed following Audsley et al., 1997	CERES based model
CIMAS (Italy)	Ecoinvent Database	Measured data	Assessed following Audsley et al., 1997	CERES based model, CO_2 with direct measurements

ICC Trial background

Objectives:

To develop, evaluate *ex ante* and *a posteriori* cropping systems with the following aims:

- respecting **specific targets** (**PHEP**, Productivity and high environemental performance and **50%GHG** cropping systems)**:**

  - Achieve a satisfactory yield
  - Diversify crops
  - Enhance biodiversity
  - Reduce soil erosion
  - Decrease energy consumption
  - Decrease depth in tillage operations
  - Reduce nitrate leaching
  - Reduce N inputs

- reaching the main **constraint** with the maximum extent (**50%GHG** cropping system)

ICC trial: Agronomical principles and technical aspects

PHEP

•**N** fertilizer application **reduction**: **legumes**

•Nitrate **leaching reduction**: **cover crop** before spring crops

•**Cover crop diversification**: more **spring crops**

•**1 deep tillage** operation every 5 years

•**No organic matter** and **compost** applied

•**Rotation (5 years):** FB-WW-Rs-WW (M)-Ba

50%GHG

-**Increasing soil C stock**: **cereals**, crop residues left in the field (+**Continous crop cover**)

-**N_2O** emission **reduction:**

Leguminous crops

Cover crop

-**Minimum tillage** (spring crops) or **no tillage** (winter crops)

-**Fertiliser application on climate basis**

Rotation (6 years): FB-Rs-(CC+LCC) WW-(CC+LCC) Ba-(CC+LCC)-Ma-XT (CC)

CIMAS trial background

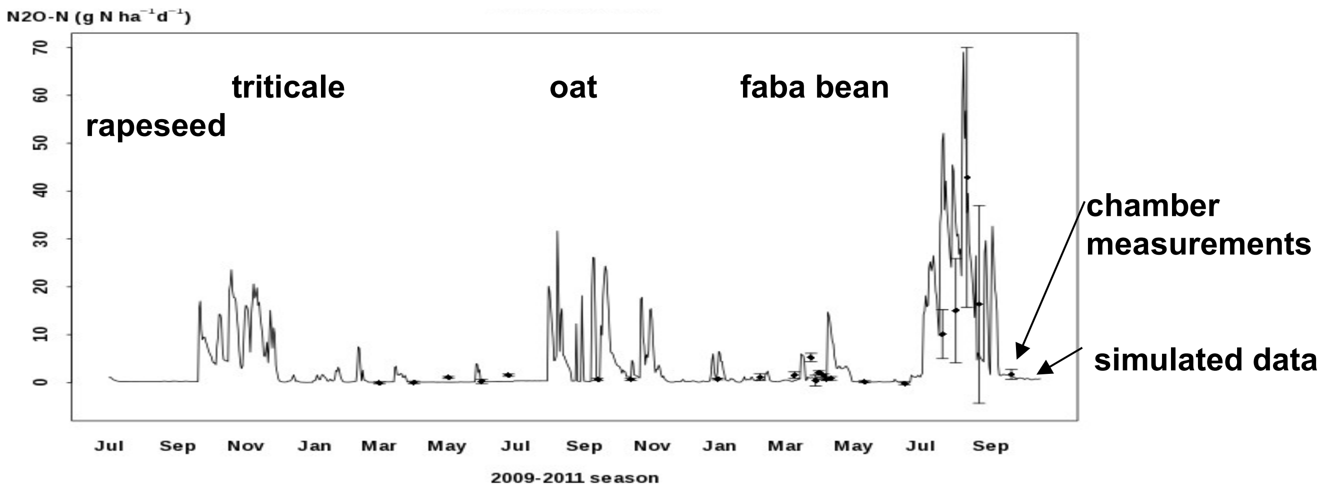
Objective: Evaluation of two cropping systems not irrigated characterized by two different levels of external inputs

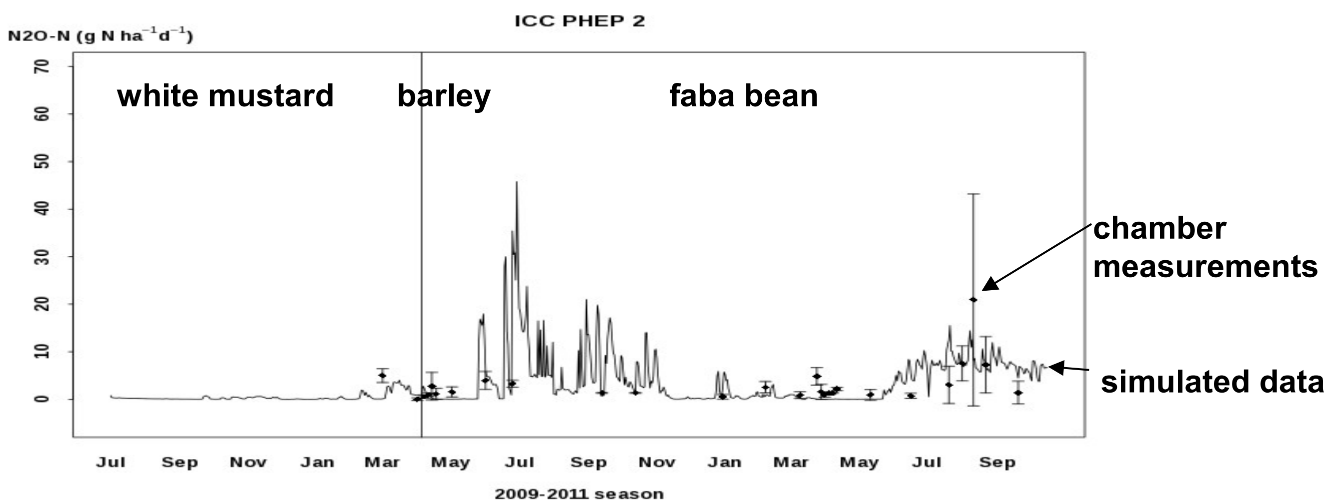
Rotation: So- Fb- Rs-Cl-WW+Cw- Sf

	Low input	High input
Tillage	Sunflower: Minimum tillage/25 cm ploughing Clover: Minimum tillage Durum wheat: No tillage/Minimum tillage Faba beans: Minimum tillage	Sunflower: subsoiling/50 cm ploughing Clover: Minimum tillage Durum Wheat: Minimum tillage/subsoiling Faba beans: Minimum tillage
Fetilisers application	Different	Different
Herbicide use	Only preemergence treatment	Premergence and postemergence
Fungicide and insecticide use	No difference	No difference

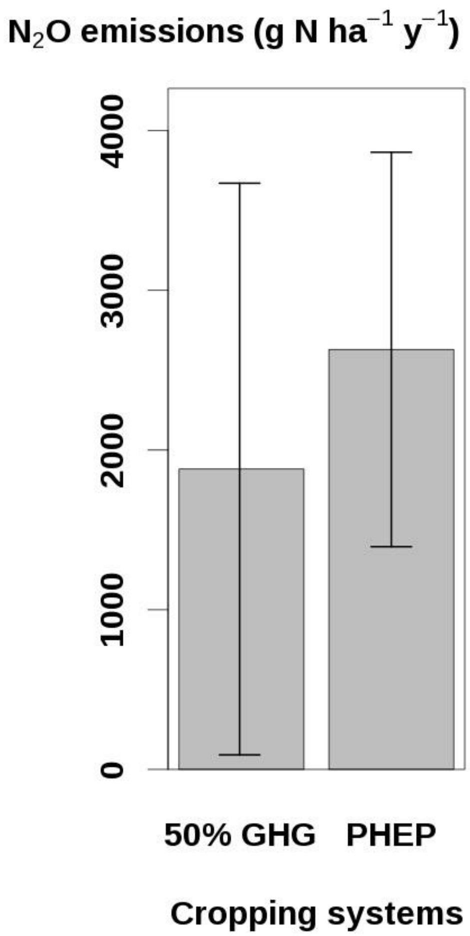
Crop management and model simulation

♦ N_2O emissions chamber measurements; Error bars: 95% confidence intervals for the observations; — Simulated N_2O emissions; | Date of N fertiliser application





Crop management simulation



Plot number	PHEP	50% GHG
1 (g N_2O-N ha^{-1})	3766	1356
2 (g N_2O-N ha^{-1})	2533	629
3 (g N_2O-N ha^{-1})	1590	3658
Mean (g N_2O-N ha^{-1})	2630	1881
Median (g N_2O-N ha^{-1})	2533	1356
CI (g N_2O-N ha^{-1})	1235	1790

Discussion

- **CERES-EGC** was succesfully **adapted to predict yield and biomass** of crops (including N fixing crops) with a **cropping system approach** contrastingly to previous studies [1]
- CERES **satisfactory predicted N_2O emissions from cereals**, especially in temperate conditions [1], considering their **high variability** [2]
- **Less good prediction** was obtained **with leguminous** crop for the following reasons:
    - **Large** emission **variability** [2]
    - Less good estimation of **residues decomposition** [3-5]
- The model **successfully evaluated** the **interactions between crop management, climate and** soil conditions **affecting reactive N** species as suggested by previous studies [3, 6]

([1] Lehuger et al., 2009; [2] Abdalla et al., 2009; [3] Saggar 2010; [4] Rochette and Janzen 2005; [5] Petersen et al., 2011; [6] Lehuger et al., 2007)

LCA impacts on ha basis (ICC) (1)

Impact category	Functional unit ($ha^{-1}\ y^{-1}$)	50%GHG Values	50%GHG *CI*	PHEP Values	PHEP *CI*
Cumulative energy demand	GJ eq	28.1	*0.00*	28.5	*0.00*
Global warming (100 year horizon)	Mg CO_2 eq	1.79	*1.03*	2.35	*1.11*
Acidification	kg SO_2 eq	16.37	*0.03*	16.14	*0.03*
Eutrophication	kg PO_4^{-3} eq	70.5	*1.4*	507.2	*2.2*
Human toxicity air	m^3	2.43E+07	*1.02E+04*	2.48E+07	*7.24E+03*
Human toxicity water	m^3	1.21E+05	*0*	1.12E+05	*0*
Human toxicity soil	m^3	2.58E+02	*0*	2.51E+02	*0*
Ecotoxicity water chronic	m^3	5.27E+06	*0*	4.42E+06	*0*
Ecotoxicity water acute	m^3	2.03E+05	*0*	1.89E+05	*0*
Ecotoxicity soil					

Impacts on ha basis (ICC) (2)

Impact category	Functional unit (ha^{-1} y^{-1})	50%GHG Values	50%GHG CI	PHEP Values	PHEP CI
Cumulative energy demand	GJ eq	28.1	0.00	28.5	0.00
Global warming (100 year horizon)	Mg CO_2 eq	1.79	1.03	2.35	1.11
Acidification	kg SO_2 eq	16.37	0.03	16.14	0.03
Eutrophication	kg PO_4^{-3} eq	70.5	1.4	507.2	2.2
Human toxicity air	m^3	2.43E+07	1.02E+04	2.48E+07	7.24E+03
Human toxicity water	m^3	1.21E+05	0	1.12E+05	0
Human toxicity soil	m^3	2.58E+02	0	2.51E+02	0
Ecotoxicity water chronic	m^3	5.27E+06	0	4.42E+06	0
Ecotoxicity water acute	m^3	2.03E+05	0	1.89E+05	0
Ecotoxicity soil					

Impacts with GJ (ICC) (1)

Impact category	Unit (GJ^{-1})	50%GHG Values	50%GHG CI	PHEP Values	PHEP CI
Cumulative energy demand	MJ eq	263	0	287	0
Global warming (100 year horizon)	kg CO_2 eq	16.7	9.7	23.7	11.2
Acidification	g SO_2 eq	153.3	0.3	162.6	0.3
Eutrophication	kg PO_4^{-3} eq	0.66	0.01	5.11	0.02
Human toxicity air	m^3	2.27E+05	9.59E+01	2.50E+05	7.29E+01
Human toxicity water	m^3	1.13E+03	0	1.13E+03	0
Human toxicity soil	m^3	2.42E+00	0	2.53E+00	0
Ecotoxicity water chronic	m^3	4.93E+04	0	4.45E+04	0
Ecotoxicity water acute	m^3	1.90E+03	0	1.90E+03	0
Ecotoxicity soil chronic	m^3	1.12E+04	0	1.24E+04	0

Impacts with GJ (ICC) (2)

Impact category	Unit (GJ^{-1})	50%GHG Values	50%GHG CI	PHEP Values	PHEP CI
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Human toxicity air	m^3	2.27E+05	9.59E+01	2.50E+05	7.29E+01
Human toxicity water	m^3	1.13E+03	0	1.13E+03	0
Human toxicity soil	m^3	2.42E+00	0	2.53E+00	0
Ecotoxicity water chronic	m^3	4.93E+04	0	4.45E+04	0
Ecotoxicity water acute	m^3	1.90E+03	0	1.90E+03	0
Ecotoxicity soil chronic	m^3	1.12E+04	0	1.24E+04	0

Impacts on ha basis (CIMAS) (1)

Impact category	Functional unit (ha^{-1} y^{-1})	LI Values	LI CI	HI Values	HI CI
Cumulative energy demand	GJ eq	26.9	2.3	33.1	3.1
Global warming (100 year horizon)	Mg CO_2 eq	2.04	0.88	4.08	0.37
Acidification	kg SO_2 eq	7.70	0.79	11.02	0.65
Eutrophication	kg PO_4^{-3} eq	30.1	17.0	49.3	26.6
Human toxicity air	m^3	1.83E+07	1.13E+06	2.43E+07	1.21E+06
Human toxicity water	m^3	1.55E+04	8.02E+03	3.70E+04	3.38E+03
Human toxicity soil	m^3	115.7	6.9	175.4	19.4
Ecotoxicity water chronic	m^3	4.56E+04	2.11E+03	7.73E+04	2.08E+04
Ecotoxicity water acute	m^3	1.08E+04	6.19E+02	2.08E+04	7.32E+03
Ecotoxicity soil chronic	m^3	5.56E+04	2.03E+04	3.00E+04	1.96E+04

Impacts on ha basis (CIMAS) (2)

		LI		HI	
Impact category	**Functional unit (ha^{-1} y^{-1})**	**Values**	**CI**	**Values**	**CI**
Cumulative energy demand	GJ eq	26.9	2.3	33.1	3.1
Global warming (100 year horizon)	Mg CO_2 eq	2.04	0.88	4.08	0.37
Acidification	kg SO_2 eq	7.70	0.79	11.02	0.65
Eutrophication	kg PO_4^{-3} eq	30.1	17.0	49.3	26.6
Human toxicity air	m^3	1.83E+07	1.13E+06	2.43E+07	1.21E+06
Human toxicity water	m^3	1.55E+04	8.02E+03	3.70E+04	3.38E+03
Human toxicity soil	m^3	115.7	6.9	175.4	19.4
Ecotoxicity water chronic	m^3	4.56E+04	2.11E+03	7.73E+04	2.08E+04
Ecotoxicity water acute	m^3	1.08E+04	6.19E+02	2.08E+04	7.32E+03
Ecotoxicity soil chronic	m^3	5.56E+04	2.03E+04	3.00E+04	1.96E+04

Impacts with GJ (CIMAS)(1)

Impact category	Unit (GJ^{-1})	LI		HI	
		Values	CI	Values	CI
Cumulative energy demand	MJ eq	264	23	251	24
Global warming (100 year horizon)	kg CO_2 eq	20.0	8.7	31.0	2.8
Acidification	g SO_2 eq	75.6	7.7	83.7	4.9
Eutrophication	kg PO_4^{-3} eq	0.296	0.167	0.375	0.202
Human toxicity air	m^3	1.79E+05	1.11E+04	1.85E+05	9.16E+03
Human toxicity water	m^3	153	79	281	26
Human toxicity soil	m^3	1.14	0.07	1.33	0.15
Ecotoxicity water chronic	m^3	448	21	587	158
Ecotoxicity water acute	m^3	106.1	6.1	158.0	55.6
Ecotoxicity soil chronic	m^3	546	200	228	149

Impacts with GJ (CIMAS)(2)

Impact category	Unit (GJ^{-1})	LI Values	LI CI	HI Values	HI CI
Cumulative energy demand	MJ eq	264	23	251	24
Global warming (100 year horizon)	kg CO_2 eq	20.0	8.7	31.0	2.8
Acidification	g SO_2 eq	75.6	7.7	83.7	4.9
Eutrophication	kg PO_4^{-3} eq	0.296	0.167	0.375	0.202
Human toxicity air	m^3	1.79E+05	1.11E+04	1.85E+05	9.16E+03
Human toxicity water	m^3	153	79	281	26
Human toxicity soil	m^3	1.14	0.07	1.33	0.15
Ecotoxicity water chronic	m^3	448	21	587	158
Ecotoxicity water acute	m^3	106.1	6.1	158.0	55.6
Ecotoxicity soil chronic	m^3	546	200	228	149

Discussion

•**50%GHG** system resulted in **lower GWP** (>24%) than the PHEP system with both functional units, however **large conficence intervals, as suggested by other research[1,2], mostly due to:**

- **Climate** variability [3]
- **Soil C dynamics** ⇐ **long term effects[4]**

•**High contribution in the halving of GWP on ha basis of the LI system (CIMAS), as suggested by previous work** [4,5]

•**Limited differences on GJ basis, due to variable and low yields**

([1] Guinée et al., 2006; [2] Guinée et al., 2009; [3] Saggar 2010; [4] Hillier et al., 2012;

Conclusions

•**Model** was **applied** successfully **to a wide range of crops** (N fixing and not N fixing) – but with clear shortcomings for legumes

•**This** LCA approach for GHG emission estimation of cropping systems **allowed to assess cropping systems with a focus on GHG** considering **interactions** between crops

•**Cropping systems resulted successful in reducing** specific environmental **impacts,** however **this involved** environmental **impact trade-offs and large variabilities**

•**Long term assessments** should be **favoured to evaluate possible GHG abatement strategies**

Perspectives

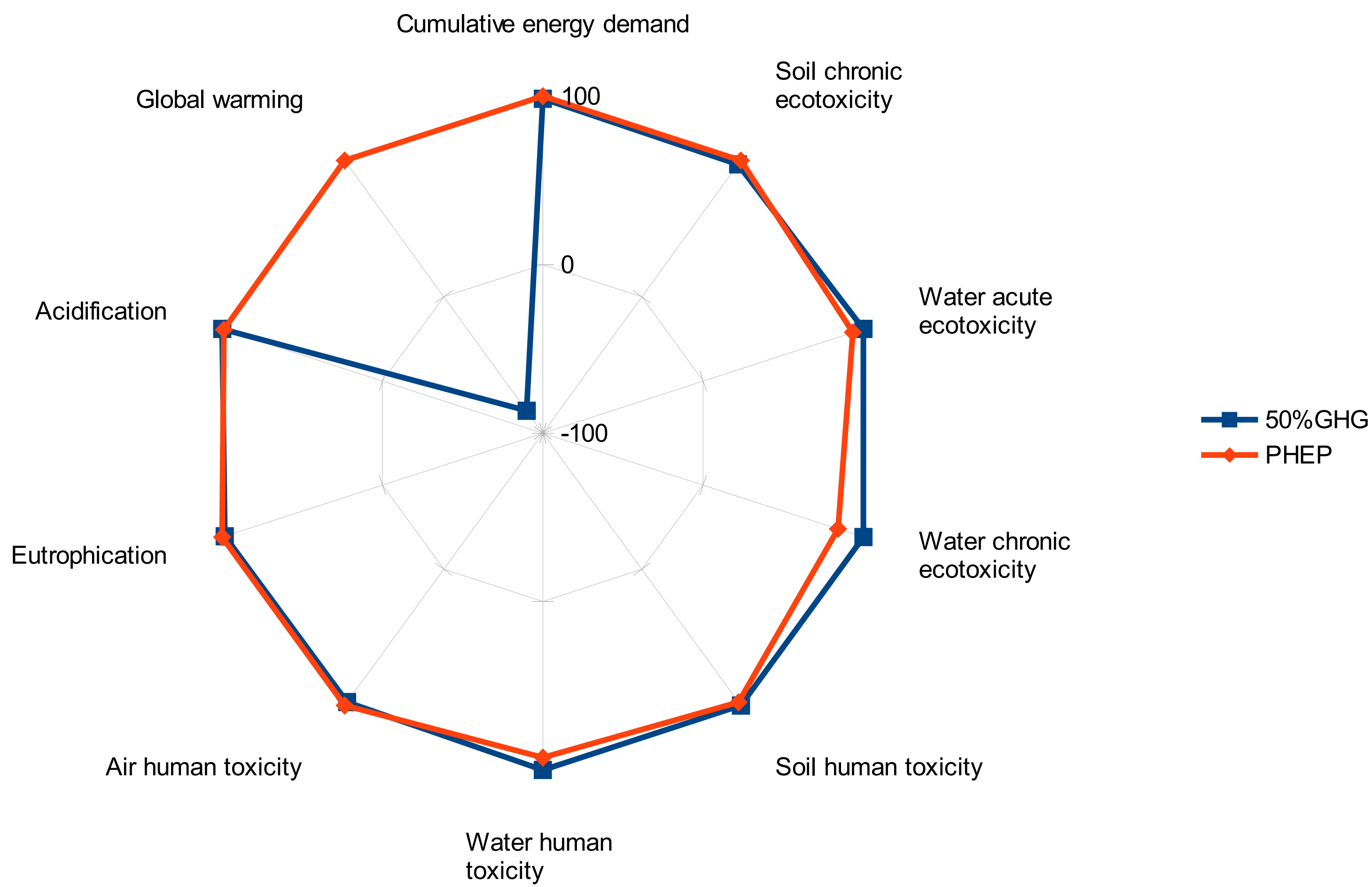
- This combined **approach** can be **extended to other cropping systems** and involve other impacts

- Further **research** is **needed to evaluate N_2O** emission dynamics **with leguminous crop** at field scale

- **Interactions between climate and** crop **management strategies to reduce GHG together with** possible side effects of the latter **on crop productivity** should be considered **in the design of cropping systems more sustainable and aimed to reduce global warming**

- **How to generalize these local results on a larger scale ?**

LCA results based on regional modelling (Ile de France)



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CERES accuracy

Automatic chambers (Courtesy of Dr Laville)

Manual chambers

Discussion (4)

- **Interactions** between **climate** and **fertiliser application timing limited** the possible **effects in N fertiliser reduction due to soil dryness,** confirming previous research **[1,2]**

- **Reduction** of **energy** consumption due to:
    - **Machinery**
    - **Fertiliser use**

Decreased GWP on ha basis but not on GJ basis in agreement with Tuomisto et al., 2012

- Substitution of **mineral N sources with organic sources** (legumes and crop residues) have the potential of **reducing GWP** (variability) [3]

([1] Pappa et al., 2011; [2] Li et al., 2012; [3] Snyder)