Atti del XXVI Convegno Nazionale di Agrometeorologia

Approcci innovativi a supporto delle produzioni agrarie in un contesto climatico in evoluzione

L'AQUILA, 5 - 7 Giugno 2024

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UNIVERSITÀ DEGLI STUDI DELL'AQUILA

CLIMA e TERRITORIO

AIAM

REGIONE ABRUZZO

sata

ISBN 9788854971509
https://doi.org/10.6092/unibo/amsacta/7718

Bologna, 2024

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AN ASSESSMENT OF FERTILIZER AND PESTICIDE TRANSITION TO A SUSTAINABLE USE PART OF THE ECOWHEATALY PROJECT

UNA VALUTAZIONE DELLA TRANSIZIONE VERSO L'USO SOSTENIBILE DI FERTILIZZANTI E PESTICIDI PARTE DEL PROGETTO ECOWHEATALY

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Abstract
In this paper, we will outline the planned activities for the next two years under the research project "Evaluation of policies for enhancing sustainable wheat production in Italy" (ECOWHEATALY). The goal of ECOWHEATALY is to evaluate the sustainability of wheat farms in Italy that are operating under the National and/or EU green policies. To this end, ECOWHEATALY plans to develop an open-source dynamic model that integrates social, economic, and environmental dimensions. The model will be a tool for Italian policymakers to evaluate sustainability indicators in wheat production under different policies. In this paper, we will explain the methodology, known as Life Cycle Assessment, that we will use to evaluate the effectiveness of these green policies on the production process of Italian farms. The paper focuses on the choices made concerning the assessment of the environmental impact of fertilizers and pesticides.

Parole chiave
Valutazione del ciclo di vita, analisi dell'inventario, processo produttivo del grano, contributo alle emissioni.
Keywords
Life cycle assessment, inventory analysis, wheat production process, emission contribution.

Introduction

The PRIN 2022 ECOWHEATALY project aims to assess the efficacy of policies in promoting sustainable wheat production techniques in Italy. The study will analyze the impact of offering financial incentives to farms that adopt sustainable practices and move towards more sustainable use of fertilizers and pesticides. To accomplish this, the ECOWHEATALY adopts a circular modeling framework that includes:

1) clustering the Italian farms based on critical resource uses (fertilizers, pesticides, and fossil fuel) to profile the actual management of the Italian wheat sector. The identification of farm types will be used to initialize the Agent-Based Model (ABM) in the next step.
2) The ABM will explore possible switching in the resource uses and farm management driven by the green policies and global wheat prices by looking at the whole farms' revenues and costs.
3) Evaluation of the actual and expected environmental impacts by means of a Life Cycle Assessment (LCA) for single farms (i.e., the Agents).
4) Aggregate the wheat production quantity output from the ABM at the national scale to supply the Global Economic Model, updating wheat prices and allowing for the inclusion of global shocks.

The present paper focuses on item 3) and it will give details on the evaluation of the environmental impact of fertilizers and pesticides.

Materials and Methods

Life Cycle Assessment (LCA)
The environmental impact of wheat production in the ECOWHEATALY project is performed through the LCA analysis. The International Organization for Standardization (ISO) set up a standard for this methodology (ISO 14040:2006). It recommends the analysis go through 4 phases: 1) goal and scope definition, 2) inventory analysis, 3) impact assessment, and 4) results interpretation. Phases 2) and 3) deserve particular attention and are briefly discussed hereafter.
The life cycle *inventory analysis (LCI)* consists of recording all the inputs and outputs involved in the production of the considered items. Inputs are distinguished into those coming from the environment and those coming from other production processes. In the same manner, outputs are distinguished between those used in other production processes, and those entering the environment (emissions). Inputs and outputs from and to other production processes are said to be techno-sphere items, while inputs and outputs from and to the environment are said to be bio-sphere items. Consider that the same input/output analysis can be done for the techno-spere inputs and outputs of the item we are considering, and in turn to the inputs of the inputs and to the

outputs of the outputs. Iterations go on until covering a part or the whole life cycle of the considered item. At each iteration, the set of bio-sphere items grows and their quantities gradually cumulate. The *impact assessment* phase makes use of one or more assessment methods developed by the scientific community. An assessment method is a function taking as inputs the quantities of selected bio-sphere items, i.e. some of the outputs of the inventory analysis, and transforming them into an indicator or damaging substance directly linked to an environmental aspect. The transformation is made via coefficients studied and provided by the researchers who developed the method. In LCA, these coefficients are better known as characterization factors (CFs).

Datasets
The data on which we build the analysis are collected by the Council for Agricultural Research and Agricultural Economy Analysis (CREA) and recorded in the RICA dataset. The RICA acronym comes from the French expression "Réseau d'Information Comptable Agricole", better known as "Farm Accountancy Data Network" (FADN). We distinguish the Italian and the European versions of RICA-FADN. The Italian version includes more variables than those contributed to the European version on a harmonized base.
After inspecting the Italian RICA contents, the following variables were selected for the wheat cultivation of each farm:

- Cultivated hectares (ha);
- hours of tractor use per ha;
- fertilizers (kilograms of Nitrogen, Phosphorus, and Potassium per ha);
- pesticides (toxicity level and quantity of herbicides, insecticides, fungicides).

Note that the hectare of cultivated wheat (1st bullet) is used mainly to obtain quantities per hectare and perform the LCA analysis on tractor, fertilizer, and pesticide use (2nd, 3rd, 4th bullets).
At the present stage, the ECOWHEATALY project is performing the LCI of tractor use, fertilizers, and pesticide use. After reporting briefly on the tractors use LCI, this paper delves into fertilizers and pesticides use LCI.

LCI of tractors use
Because the ECOWHEATALY projects aim to rely on open-source resources, the analysis is based on an adaptation of the LCI data provided by the Federal LCA Commons. Browsing the available databases, we find the "University of Washington Design for Environment Laboratory/Field Crop Production" database, where there are several processes concerning the work of agriculture tractors for several cultures in several US states. Among them, there is, for example, a process named "work; ag. tractors for growing win wheat, 2014 fleet, all fuels; 100-175HP - US-AR" gathering inputs and outputs of an agriculture tractor producing 1 megajoule of work employed in winter wheat production in Arizona. We take advantage of this LCI in the ECOWHEATALY project.

LCI of fertilizers
RICA includes detailed information on fertilizers. It has one record for each different composition of applied fertilizers. Therefore, given a farm, a year, and a culture, several records can be found (one for each different fertilizer). Among many other variables, each record includes: i) the quantity of nitrogen per hectare, ii) the quantity of phosphor per hectare, iii) the quantity of potassium per hectare. We report in the ECOWHEATALY database the sum of these three variables taken across all the records for each farm, in each year, but taking hard and soft wheat one by one. The inventory of fertilizers used in the LCA is reported in Table 1.

Tab.1 – Analisi dell'inventario dei fertilizzanti azotati dall'appendice A di Brentrup et al. (2004).
Tab.1 – Inventory analysis of Nitrate fertilizers from appendix A of Brentrup et al. (2004).

Emission/resource	Unit	N3 (144)	
		per ha	per t
Resources			
Phosphate rock	kg	202.9	23.79
Potash salt	kg	889.8	104.3
Hard coal	kg	47.12	5.524
Lignite	kg	2.285	0.268
Heavy oil	kg	10.13	1.188
Light oil/diesel	kg	76.89	9.014
Natural gas	kg	127.7	14.97
Total energy	MJ	10967	1286
Land	$m^2 \times$ year	10 000	1172
Emissions to air			
CH_4	kg	0.0129	0.0015
CO	kg	0.074	0.009
CO_2	kg	607.9	71.26
N_2O	kg	5.332	0.625
NH_3	kg	3.534	0.414
Nox	kg	4.63	0.543
Particles/dust	kg	0.553	0.065
SO_2	kg	2.58	0.303
NMVOC	kg	0.041	0.005
Emissions to water			
NO_3–N	kg	1.483	0.174
Ntot	kg	0.016	0.002
Ptot	kg	0.104	0.012
Emissions to soil			
Cd	kg	0.0052	0.0006

We look to the literature to set up an LCI analysis using these variables. The environmental effects of mineral fertilizers are analyzed in Isherwood (1998). Another interesting document concerning fertilizers is IFA and Systemiq (2022). The report points out that Nitrogen is the main responsible for emissions (see in particular chapter 1, paragraphs 6-11).

To integrate Nitrogen fertilization in our LCA we build a process based on Brentrup et al. (2004) taking as reference the median case in Appendix A.

LCI of Pesticides

RICA provides the following data on pesticides: toxicity classification, type, and applied quantity per hectare.

Toxicity classification is:

- "0" for products marked with "caution handle with care";
- "1" for products in the class "very toxic (T+)";
- "2" for products in the class "Toxic (T)";
- "3" for products in the class "harmful (Xn)";
- "4" for products in the class "Irritating (Xi)".

Pesticide types in RICA are Acaricide, Fungicide, Wetting agent, Adjuvant, Adjuvant, Herbicide, Plant growth regulator, Geodisinfestant, Insecticide; Molluscicide, Nematicide, and Rodenticide.

Unfortunately, the RICA dataset does not specify the active ingredients in each pesticide. Therefore, we do have not enough information for a standard LCA analysis of pesticides. In an attempt to trace the active ingredients, we use the Fitogest®+ where detailed information on pesticides available in Italy is recorded and can be accessed at: https://fitogest.imagelinenetwork.com/it/.

However, there is a mismatch between the RICA and the Fitogest classifications since a European directive, which implies changes in pesticide classification, came into force in June 2015. For coherence with previously recorded data, RICA reports the old classification, while Fitogest®+, being a picture of the current market, reports the newer one.

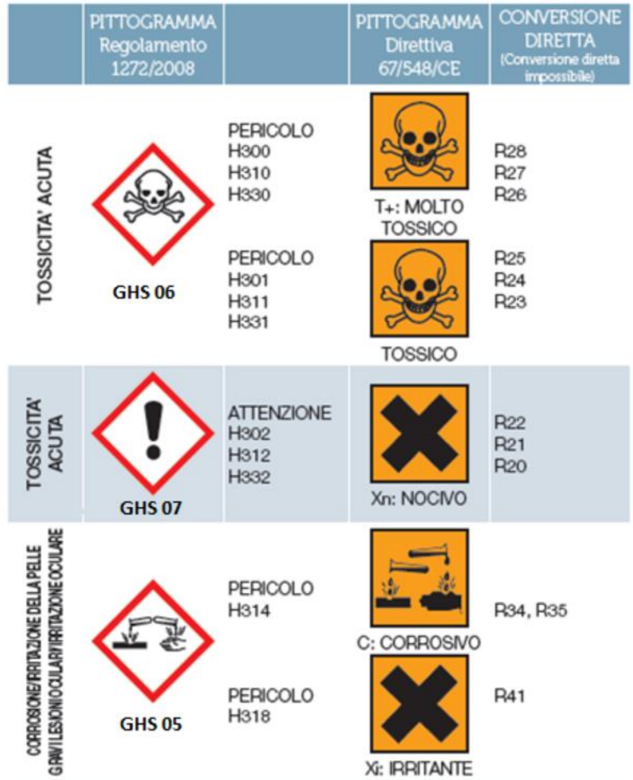
We use Table 2 from Camisa (2015) to match the two data sources, more specifically, our strategy is directed to:

- select products with the GHS06 pictogram in Fitogest, evaluate their active ingredients and use them for RICA classes T+ and T;
- select products with the GHS07 pictogram in Fitogest, evaluate their active ingredients and use them for RICA class Xn;
- select products with the GHS05 pictogram in Fitogest, evaluate their active ingredients and use them for RICA class Xi;
- select products marked with "caution handle with care" in Fitogest, evaluate their active ingredients and use them for the corresponding RICA class.

In Fitogest, we selected products with specific characteristics in RICA, such as those containing "harmful herbicides". We analyzed the most found composition of these products and then examined the concentrations and recommended quantities of the most frequently used ingredient. By assuming that farmers in RICA use these most common active ingredients, we can conduct a pesticide Life Cycle Inventory (LCI) analysis.

Tab.2 – Corrispondenze tra la classificazione di tossicità derivante dalla direttiva CE n. 1272/2008 e quella precedente. Immagine ripresa da Camisa (2015).

Tab.2 – Correspondence between the old and the toxicity classification introduced with regulation CE n. 1272/2008. Picture from Camisa (2015).



	PITTOGRAMMA Regolamento 1272/2008		PITTOGRAMMA Direttiva 67/548/CE	CONVERSIONE DIRETTA (Conversione diretta impossibile)
TOSSICITA' ACUTA	GHS 06	PERICOLO H300 H310 H330	T+: MOLTO TOSSICO	R28 R27 R26
		PERICOLO H301 H311 H331	TOSSICO	R25 R24 R23
TOSSICITA' ACUTA	GHS 07	ATTENZIONE H302 H312 H332	Xn: NOCIVO	R22 R21 R20
CORROSIONE/IRRITAZIONE DELLA PELLE GRAVI LESIONI OCULARI/IRRITAZIONE OCULARE	GHS 05	PERICOLO H314	C: CORROSIVO	R34, R35
		PERICOLO H318	Xi: IRRITANTE	R41

We report in Table 3 the results of this process. The table is split into two sub-tables for space convenience. The *id* variable can be used to match the information in the two sub-tables.

Tab.3 – Principi attivi e quantità per ettaro degli stessi ottenute confrontando il tipo e il livello di tossicità da RICA e i corrispondenti tipi e livelli in Fitogest ®+.

Tab.3 – Active ingredients and their quantity per hectare obtained by combining type and toxicity levels from RICA and the corresponding in Fitogest ®+.

id	type	tox level	active ingredient	product
1	Acaricide	irritationg	potassium salts of fatty acids	flipper
2	Fungicide	caution	sulfur	cosavet df edge
3		irritatig	prothioconazole	pecari 300
4		harmful	Tebuconazole	ares 430 sc
5	Herbicide	caution	Glyphosate	clean-up
6		irritating	2,4-D	pimiento 600
7		harmful	MCPA	erbitox m pro
8	Plant growth	irritating	chlormequat chloride	stabilan
9	regulator	harmful	Trinexapac-ethil	moddus
10	Insecticide	irritating	Deltamethrin	antal
11		harmful	Deltamethrin	antal
12		toxic	Pirimicarb	aphox 50
13	Molluscicide	caution	ferric phosphate	ferrex
14		irritating	metaldehyde	luma-kl

id	quantity	concentration	active ing per ha
1	4-10l/ha	479,8g/l	1920-4800g/ha
2	3-8 kg/ha	80%	2400-6400g/ha
3	0.65l/ha	300g/l	195g/ha
4	0.58l/ha	430g/l	250g/ha
5	1-4-6-12l/ha	360g/l	360-4320g/ha
6	0.6-1.2l/ha	600g/l	360-720g/ha
7	1.6-2l/ha	500g/l	800-1000g/ha
8	2-3.5l/ha	461g/l	922-1613.5g/ha
9	0.5l/ha	250g/l	125g/ha
10	0.3-0.5l/ha	25g/l	7.5-12.5g/ha
11	0.3-0.5l/ha	25g/l	7.5-12.5g/ha
12	260g/ha	50%	130g/ha
13	6kg/ha	25g/kg	150g/ha
14	7kg/ha	50g/kg	350g/ha

Results and Discussion

Using the LCA methodology, the ECOWHEATALY project intends to assess the environmental impact of policies. The focus is on the impact of fertilizers and pesticides, although agriculture machinery will also be modeled. The process of applying fertilizers involves various stages such as the production of fertilizers, transportation to farms, application through tractors, and direct emissions to air, soil, and water resulting from fertilizer application.
Among various LCA software options, we decided to use Brightway because it is based on Python's freely available open-source software (Mutel, 2017). As with any other LCA software, it provides access to a Biosphere database, the available set of impact assessment methods, and tools to conduct LCA analysis.
To test the LCI analysis presented above, we conducted an LCA on a hypothetical farm that used 900 megajoules of tractor power and 50kg of nitrogen fertilizers for each hectare under wheat cultivation. The goal of our LCA is to evaluate the impact of this production process on climate. Among the available assessment methods, we choose the IPCC 2013-climate change-global warming potential GWP100. This assessment method outputs the kilograms of CO2 equivalent. The result delivered by the Brightway software is 883.66 kg CO2-Eq subdivided into categories of process and emission contribution (Table 4).

Conclusion

The LCA methodology requires careful consideration in selecting the inputs used in each production phase. This becomes even more challenging when the project's goal is to produce and release open-source software that also uses open-source databases. Therefore, during the initial phase of the ECOWHEATALY project, the primary focus is on three key areas: 1) integrating pesticide active ingredients with the Brightway biosphere database to apply the "usetox" package; 2) exploring the possibility of utilizing databases created by the OLCA-pest project; and 3) identifying suitable third-party LCI processes. By the end of this phase, we will have the ability to select the impact categories and their corresponding assessment methods. We will also organize the set of impact indicators into clusters. Finally, we will develop a web application that allows wheat farmers to input the amounts of machinery usage, fertilizer and pesticide to receive environmental impact indicators.

Tab.4 – Risultati dell'LCA ottenuti dal software Brightway per un'impresa agricola che impiega 900 megajoule di potenza di trattori agricoli e fertilizzanti contenenti 50kg di azoto per ogni ettaro di grano coltivato.
Tab.4 – LCA results delivered by Brightway software for a farm that uses 900 megajoules of tractor power and 50kg of nitrogen fertilizers for each hectare under wheat cultivation.

Process contribution	Kg of CO2-Eq.
application of N fertilizer (kg)	701.51
work; tractors (MJ)	182.14
Emission contribution	
Dinitrogen monoxide (kg)	490.24
Carbon dioxide (kg)	389.94
Carbon monoxide (kg)	2.028
Methane (kg)	0.1276

Acknowledgment

This research was conducted as part of the project "ECOWHEATALY: Evaluation of policies for enhancing sustainable wheat production in Italy" (202288L9YN) funded by the European Union-Next Generation EU under the call issued by the Minister of University and Research for the funding of research projects of relevant national interest (PRIN) - "PRIN 2022".

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