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INTEGRATING ECONOMIC OPTIMIZATION AND LIFE CYCLE ASSESSMENT IN ITALIAN WHEAT FARMING: A WEB-BASED INTERFACE

INTERFACCIA WEB PER LE AZIENDE AGRICOLE ITALIANE CHE PRODUCONO GRANO: SOSTENIBILITÀ ECONOMICA E AMBIENTALE

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Abstract

This work presents a freely accessible web interface designed to enhance awareness among local stakeholders regarding the environmental footprint of wheat production. Users input key parameters, including province, altimetry, expected wheat selling price, and fertilizer, herbicide, and insecticide unit costs. Upon submission, the system calculates the expected yield per hectare and the required input levels that maximize profit under three distinct climatic conditions: favorable, normal, and unfavorable. The computations are based on an economic maximization framework. The parameters are estimated at the province-altimetry level using approximately 20,000 observations of durum wheat-producing farms from 2008 to 2022 taken from the Rete di Informazione Contabile Agricola (RICA). Finally, the computed input levels are integrated into a Life Cycle Assessment (LCA) to quantify key environmental sustainability indicators.

Parole chiave

Valutazione del ciclo di vita, massimizzazione vincolata, stima dei minimi quadrati, gestione dell'azienda agricola

Keywords

Life cycle assessment, constrained optimization, least square estimation, farm management

Introduction

Sustainable agriculture has gained increasing importance because of climate change, environmental degradation, and food security challenges. Adopting green agricultural practices involves methods that reduce environmental impact while maintaining productivity. However, a fundamental question arises: are farmers motivated by sustainability concerns, or do they adopt green practices primarily due to economic incentives and government policies?

Various policies have been adopted in many parts of the world to promote sustainable agriculture. Financial incentives, regulatory frameworks, and technical assistance are commonly used tools. For example, the United States Department of Agriculture (USDA) provides financial grants and research funding to encourage sustainable practices (USDA 2024). Similarly, the European Union's Common Agricultural Policy (CAP) supports agri-environmental measures by incentivizing farmers who adopt green methods. In India, the National Innovations in Climate Resilient Agriculture (NICRA) initiative supports farmers in adapting to climate change by providing knowledge and technologies for resilient agriculture (NICRA 2022).

However, while government policies play an important role, farmers' decisions are often driven by economic rationality. Studies indicate that farmers conduct a cost-benefit analysis before adopting green practices. Farmers are more likely to implement sustainability measures if they offer long-term economic benefits such as soil health, higher yields, or cost savings (Vapa Tankosic et al. 2023).

Behavioural factors also play a role in the adoption of green practices. Dessart et al. (2019) surveyed the behavioral factors affecting the choice of sustainable agriculture practices. The authors reviewed two decades of literature, providing taxonomy and reporting policy options to increase the adoption of each item.

Creemers et al. (2019) reported an example in this direction concerning Belgian sugar beet farmers, who tend to maintain green practices voluntarily because they perceive their supply chain as sustainable.

The first step in fostering the self-adoption of green practices is increasing farmers' awareness of the environmental impacts of their current practices.

To this aim, we describe a Graphical User Interface (GUI) showing such impacts for profit-maximizing farms operating in Italian provinces and at a given altimetric zone.

Materials and methods

The main idea behind the GUI is to provide a benchmark given by a farm whose objective is exclusively profit maximization.

The model is formulated considering the profit per hectare. It outputs the level of production inputs per hectare to be used to achieve the best economic result.

We start by considering that the produced quantity per hectare (the yield) can be affected by several stress factors,

such as the shortage of nutrients, weeds, insects, water availability, and so on. In the absence of stress factors, the yield is maximum. The difference between maximum yield and the realized yield is known as the yield gap (ClimaTalk, 2024; van Ittersum et al. 2013; Devkota, 2024).
The lower script i indexes stress factors. In our model, each stress factor is tamed by a specific production input: herbicide vs weeds, insecticide vs insect, and so on.
We define the conditional yield as the yield obtained when only stress factor i is binding. The conditional yield is formulated as follows:

$$y_i(x_i) = \overline{y}\left[(1 - s_i) + s_i\left(1 - e^{-\lambda_i x_i}\right)\right]$$

Where $\overline{y}$ is the highest attainable yield, x_i is the quantity of input against stress factor *i*, s_i is the yield lost if $x_i = 0$, and λ_i is the effectiveness of x_i in increasing the yield.
The calculations are based on the following formulation of the profit function:

$$\pi = p_w min_i\, y_i(x_i) - \sum_{\mathrm{i}} \mathrm{p}_{\mathrm{x}_\mathrm{i}}\, \mathrm{x}_\mathrm{i}$$

Where π is profit, p_w is the wheat price, $y_i(x_i)$ is the conditional yield defined above, and p_{x_i} is the price of a unit of input x_i.

The parameters $\overline{y}$, s_i, and λ_i are estimated at the provincial-altimetric level using data from the Agricultural Accounting Information Network (RICA), a statistical survey conducted annually by the Council for Agricultural Research and Analysis of Agricultural Economics (CREA). Our analysis focuses on durum wheat producing farms from 2008 to 2022, pooling approximately 20000 observations after data quality checks. We estimate for each Italian province-altimetric zone the maximum yield ($\overline{y}$), and the yield-fertilizer (s_1 and λ_1), the yield-herbicide (s_2 and λ_2), and the yield-insecticide (s_1 and λ_3) relationships, which are then recorded in a table. The table is queried by the GUI to obtain the parameters for the profit maximization function.
Fig. 1 shows the GUI web page faced by the user at the beginning.
The GUI, developed using HTML and PHP, allows the user to input geographic and economic parameters such as:

- province;
- terrain position (plain, hill, or mountain);
- prices for wheat, fertilizer, herbicide, and insecticide.

See Fig. 2.

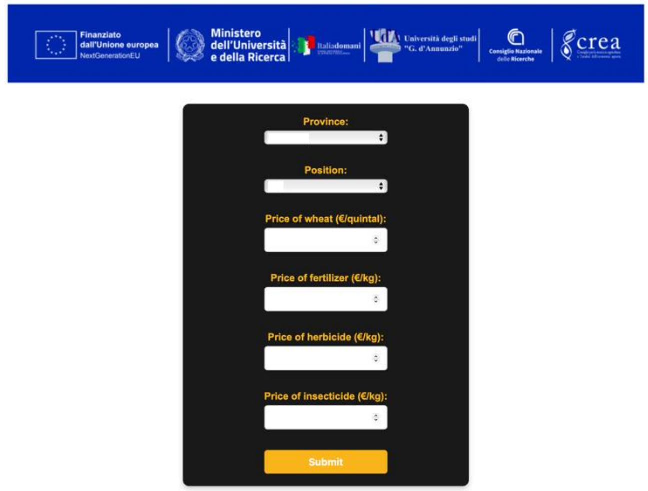

Fig.1 – The Graphical User Interface (GUI) before being filled by the user
Fig.1 – L'interfaccia grafica (GUI) prima di essere compilata dall'utilizzatore

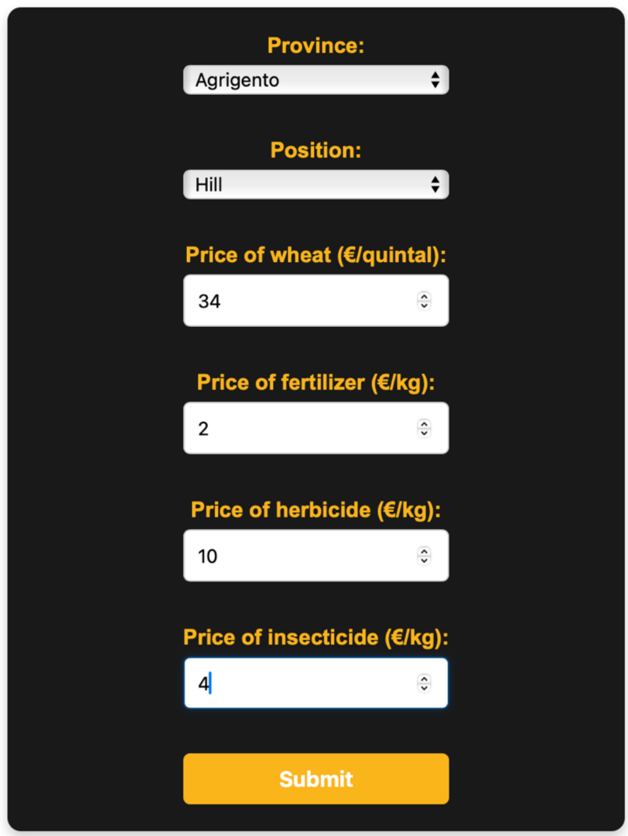

Fig.2 – The filled Graphical User Interface (GUI)
Fig.2 – L'interfaccia grafica (GUI) compilata

The PHP form retrieves the user's inputs. The geographic parameters serve to query the previously mentioned table to obtain the $\overline{y}$, s_i, and λ_i of the specified zone. These parameters, together with the prices, are sent to a backend Python script that performs the optimization. All the data submitted through the forms is stored in an SQL database for statistical purposes.

The optimization process returns the estimated yield and profit, as well as the level of production inputs needed to achieve the results. All these outputs are displayed in a new PHP page (see Fig. 3). As mentioned above, this informs the user on how to optimize production inputs in a standard profit-maximizing farm growing its durum wheat in the specified area.

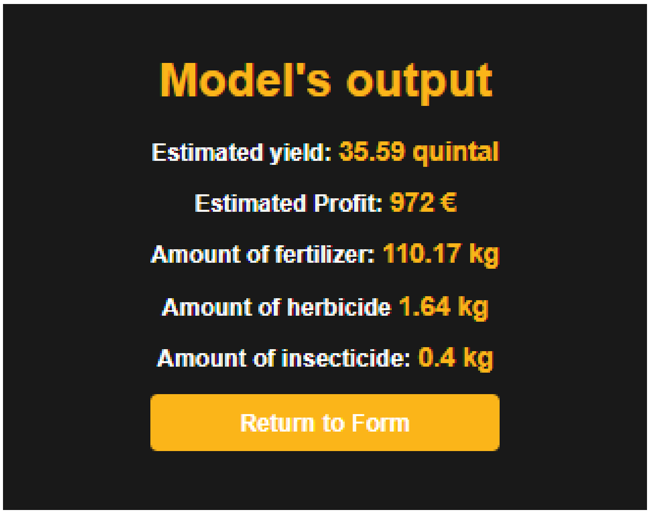

Fig. 3 – The filled Graphical User Interface (GUI)
Fig. 3 – L'interfaccia grafica (GUI) compilata

Results and discussion

The result page will be enriched with the output of a second backend Python script performing the Life Cycle Assessment (LCA) analysis. This script takes the production inputs delivered by the optimization procedure.

We use the ReCiPe 2016 methodology (Huijbregts *et al.*, 2016 and 2017) to achieve the result.

ReCiPe provides impact factors both at the Midpoint and at the Endpoint. At the midpoint level, each method delivers a physical quantity that is generally the most damaging substance for the considered category. At the Endpoint level, each method is associated with one of three considered areas of protection: human health, ecosystem quality, and resource scarcity.

The damage to each of these three areas are measured as follows:

- Damages to human health are measured by an indicator called "Disability Adjusted Life Years" (DALY) that gives the time (in years) that are lost or that a person is disabled due to a disease or accident.
- Damages to ecosystem quality are measured by the number of local species lost yearly.
- Damages to resource scarcity are computed as the extra costs for future mineral and fossil resource extraction. It is expressed in Dollars.

In Endpoint analysis, each ReCiPe method delivers a result expressed in one of these three units of measure.

This allows a nested aggregation process that identifies the damages to some identified subsystems.

Although the ReCiPe method provides tens of sustainability indicators, we decided to include the damage to humans and ecosystems in addition to the result already displayed in Fig. 3. We aim to keep the GUI understandable and straightforward to non-expert final users.

Fig. 4 reports the framework we built to perform LCA.

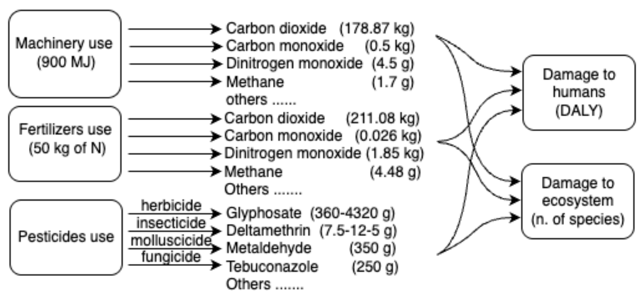

Fig. 4 – The LCA framework implemented for including results in the GUI
Fig. 4 – Analisi del Ciclo di Vita e risultati da includere nell'interfaccia grafica

In the case of Fig. 4, for example, the GUI user will be informed that his/her activity, when performed with the goal of maximizing profit, will cause the following damages:

- DALY=0.0008821667 (about 7:30 hours)
- Species lost per year = 0.000004391925.

This information will hopefully increase farmers' awareness of sustainability and draw a greater interest in sustainable production practices.

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