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# LCA of cropping systems with different external input levels for energetic purposes

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ABSTRACT

Biofuels could become increasingly important for agriculture; however there is growing concern regarding the possible environmental drawbacks due to the risks of increased inputs during crop cultivation. These risks need to be evaluated in order to assess the best management practices.

In this study, a life cycle assessment (LCA) was carried out: (i) to evaluate the environmental impacts of three cropping systems characterized by different external input levels (low S1, medium S2 and high S3) applied to sunflower and maize, both in rotation with wheat, in a Mediterranean region; (ii) to estimate the environmental benefits of the optimization of cropping systems for energy management.

Output–input ratio, net energy balance, global warming potential (GWP), eutrophication potential (EP) and acidification potential (AP) were used as LCA impact categories. Data from cropping systems (external input and crop yields) were collected from a long-term experiment carried out in the coastal plain of Tuscany; data regarding fertilizers, machinery and pesticide production were taken from literature.

The results obtained showed S1 with the highest output–input ratios and the lowest impact for the selected impact categories. The other cropping systems S2 and S3 showed limited differences between them for all the impact categories evaluated. Fertilizer use and application, irrigation and machinery use caused most of the environmental impacts and energy consumption. The allocation procedure, showing residues as co-products, had a strong influence on the overall efficiency of agricultural systems.



## 1. Introduction

The need for renewable energy generation is increasing, as ambitious energy policies such as the EU target of 20% renewable energy by 2020 come into effect [1]. Agricultural biomass for energy is one such source; however at the moment it is not so extensively used as feedstock for energy generation [2]. Biomass has proved to be interesting for energy generation to rural areas when used locally [3]. This avoids problems due to biomass transport, because in general biomass feedstock has a low bulk and energy density [4,5].

On the other hand, there is increasing concern regarding possible environmental drawbacks due to crop cultivation.

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The main risk is the input level increase during cultivation, e.g. converting grassland into arable crops for biomass production, soil tillage increase or larger use of fertilizers, pesticides and irrigation [6]. This management could lead to an increase in GHG emission growth, in acidification and in nitrate leaching; a loss of soil organic carbon and biodiversity and a reduction of natural resources and landscape quality [7]. There is a need for cropping systems characterized by low external input levels in order to minimize their environmental impact and energy use during the production cycle. Such systems should be able to reduce any negative effects on the environment [3,8,9], to support technical and political decisions and to make bioenergy cropping systems more sustainable.

Life cycle assessment (LCA) has been used in many research studies to evaluate environmental impacts in agricultural production systems [10–13]. Previous research has used the LCA approach to establish the environmental impacts of wheat [10,14–17], sunflower [18,19] and maize cultivation especially for bioethanol production [8,20–22]. However only a few authors have analyzed the whole cropping system using data from long-term field experiments [15,16].

To analyze multi-output production systems, like many agricultural systems, consequential and attributional LCAs have been carried out. Consequential LCAs decrease the dependency of results on allocation assumptions by system expansion [4,21,23,24]. However other authors have carried out an attributional LCA with allocations to evaluate agricultural systems [15,16].

The objective of this research is to carry out an LCA: (i) to evaluate the environmental impacts of three cropping systems characterized by different external input levels (low, medium and high) applied to sunflower and maize, both in rotation with wheat, in a Mediterranean region and (ii) to estimate the environmental benefits from the optimization of cropping systems cultivated for energy production.

## 2. Material and methods

### 2.1. Cropping system description and input data

The studied cropping systems were based on three different approaches to agricultural production. The lower external input system (S1) aimed at obtaining adequate profitability through a significant reduction in production costs and maximum reliance upon natural resources. The aim of the intermediate system (S2) was to maximize crop profitability through the careful use of conventional cultural practices to limit production costs (S2 referred to the conventional production systems used in the study area). The aim of the third system (S3) was to ensure the highest and most stable possible yields by means of intensive cultivation with high production costs. S3 should guarantee relatively constant yields even with adverse climatic conditions [25].

These theoretical approaches to crop production were adopted with a long-term experiment carried out from 1985 to 2002 at the Interdepartmental Centre for Agro-Environmental Research of the University of Pisa located in the low valley of the Arno river, Tuscany, Central Italy. The experiment was set up on a loamy soil area with the following characteristics: 34% sand, 34% silt and 32% clay (USDA classification); 2.5% organic matter (Walkley-Black method); 8.1 pH; 0.2% total nitrogen (Kjeldahl method); 11 mg $kg^{-1}$ assimilable phosphorus (Olsen method); and 182 mg $kg^{-1}$ exchangeable potassium (Dirk-Scheffer method) [25]. The average annual precipitation in the area is 900 mm, mostly concentrated in autumn and spring, and the mean annual temperature is 12.5 °C.

**Table 1 – Cultural practices of the three cropping systems.**

| Cultural practices | Crop | S1 | S2 | S3 |
|---|---|---|---|---|
| Main tillage | Winter wheat | 25 cm ploughing | 25 cm ploughing | 25 cm ploughing |
| | Summer crops | 45 cm chiselling | 45 cm ploughing | 45 cm ploughing |
| Secondary tillage | All crops | Harrowing | Harrowing | Harrowing |
| Additional tillage | Winter wheat | No | No | No |
| | Summer crops | Hoeing | Hoeing | Hoeing |
| Fertilization | All crops | RNUMCP[a] | RNUWCB[b] | RNUWCB[b] |
| Cultivar | Winter wheat | HDR-HQ[c] | HP[d] | HP |
| | Summer crops | Short–medium cycle | Medium–long cycle | Medium–long cycle |
| Weed control | Winter wheat | Exceptional | Post-emergence | Pre + post-emergence |
| | Summer crops | Exceptional | Pre-emergence | Pre-emergence |
| Pest control | All crops | Exceptional | Curative | Preventive |
| Irrigation | Winter wheat | No | No | No |
| | Summer crops | No | 75% ETER[e] | 100% ETER[e] |
| Crop residue management | Winter wheat | Buried | Sold | Sold |
| | Summer crops | Buried | Buried | Buried |

a Reintegration of nutrient uptake by marketable crop production.
b Reintegration of nutrient uptake by whole above-ground crop biomass.
c Highly disease-resistant cultivar – high grain quality.
d High productivity.
e Reintegration of crop effective evapotranspiration.