Science of the Total Environment 635 (2018) 551–558

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Environmental impact assessment of alfalfa (*Medicago sativa* L.) hay production

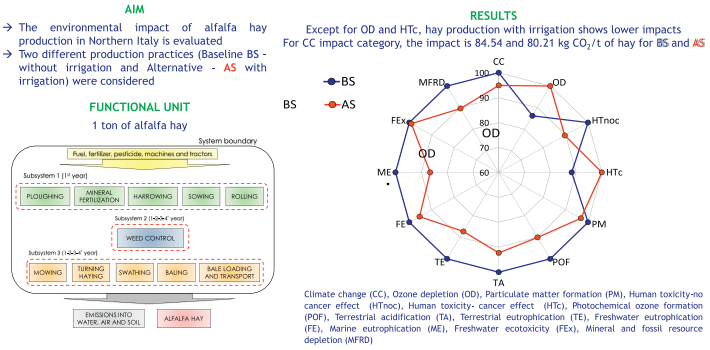
Jacopo Bacenetti [a,*], Daniela Lovarelli [b], Doriana Tedesco [a], Roberto Pretolani [a], Valentina Ferrante [a]

[a] Department of Environmental and Policy Science, Università degli Studi di Milano, Via G. Celoria 2, 20133 Milan, Italy
[b] Department of Agricultural and Environmental Science, Università degli Studi di Milano, Via G. Celoria 2, 20133 Milan, Italy

HIGHLIGHTS

- There are no studies evaluating the environmental impact of alfalfa hay production.
- The environmental impact of alfalfa hay is evaluated using the LCA approach.
- Two different production practices without and with irrigation were considered.
- Climate Change is equal to 84.54 and 80.21 kg CO_2/t for the two scenarios.
- Scenario with irrigation best results for 10 of the 12 evaluated impact categories.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 20 February 2018
Received in revised form 10 April 2018
Accepted 11 April 2018
Available online xxxx

Editor: D. Barcelo

Keywords:
Fodder
Hay
Feed
Life Cycle Assessment
Irrigation

ABSTRACT

On-farm production of hay and high-protein-content feed has several advantages such as diversification of on-farm cultivated crops, reduction of off-farm feed concentrates transported over long distances and a reduction in runoff during the winter season if grown crops are perennial. Among those crops cultivated for high-protein-content feed, alfalfa (*Medicago sativa* L.) is one of the most important in the Italian context. Nevertheless, up to now, only a few studies have assessed the environmental performance of alfalfa hay production. In this study, using the Life Cycle Assessment approach, the environmental impact of alfalfa hay production in Northern Italy was analyzed. More in detail, two production practices (without and with irrigation) were compared.
The results show that alfalfa hay production in irrigated fields has a better environmental performance compared to non-irrigated production, mainly because of the yield increase achieved with irrigation. In particular, for the Climate Change impact category, the impact is equal to 84.54 and 80.21 kg CO_2/t of hay for the scenario without and with irrigation, respectively. However, for two impact categories (Ozone Depletion and Human Toxicity–No Cancer Effect), the impact of irrigation completely offsets the yield increase, and the cultivation practice without irrigation shows the best environmental performance. For both scenarios, the mechanization of harvest is the main environmental hotspot, mostly due to fuel consumption and related combustion emissions.
Wide differences were highlighted by comparing the two scenarios with the Ecoinvent process of alfalfa hay production; these differences are mostly due to the cultivation practice and, in particular, to the more intensive fertilization in Swiss production.

* Corresponding author.
E-mail address: jacopo.bacenetti@unimi.it (J. Bacenetti).

https://doi.org/10.1016/j.scitotenv.2018.04.161
0048-9697/

1. Introduction

The environmental impact related to agricultural activities is attracting more attention from policy makers, politicians and stakeholders. Among the different agricultural activities, livestock has by far the most impact due to emissions of pollutants such as methane, ammonia and dinitrogen monoxide released by animals and their produced slurry as well as due to feed consumption (IPCC, 2006; Baldini et al., 2018). To obtain satisfactory milk production, high attention must be paid to the feed. In particular, the consumption of protein feed is often met using soybean produced in South America, which carries considerable impact in terms of greenhouse gas emissions related to land use change and indirect land use change (IPCC, 2013). The on-farm production of high-protein-content feed is highly sought by farmers. However, it is often limited because farmers mostly aim to maximize the production of fodder and silage and buy feed concentrates. Nevertheless, the on-farm production of hay and high-protein-content feed could present several advantages, among which are the diversification of crop cultivation and crop rotations, reduced consumption of feed concentrates transported over long distances and, when perennial crops are grown, the reduction of runoff during the winter season (Bretagnolle et al., 2018).

Among the crops cultivated to produce high-protein-content feed, alfalfa (*Medicago sativa* L.) is one of the most interesting in the Italian context because it is an already commonly cultivated crop adequate to the climatic conditions (Iannucci et al., 2002), it is a legume so it improves the soil quality thanks to the fixation of atmospheric nitrogen and it has a perennial crop cycle that ranges between 3 and 4 years.

For the Northern Italy context, alfalfa plays a key role in the production of one of the most important Protected Designation of Origin (PDO) (Clal, 2018) cheeses. In particular, for the production of Parmigiano Reggiano PDO cheese, only milk produced by cows fed without silages can be used. Thus, alfalfa hay is a key feed. In the last 10 years, the agricultural area dedicated to alfalfa varied from 717,000 ha in 2008 to 672,300 ha in 2018 with a total production ranging from 22.6 to 16.8 Mt. of hay (Istat - Istituto Nazionale di Statistica, 2018). With regard to price, the average yearly value of alfalfa hay was 109 and 118 €/t of hay in 2016 and 2017, respectively (ISMEA, 2018).

Nevertheless, the production of alfalfa hay presents some critical aspects. For this crop, both the timing of harvest and the harvest process are critical to obtaining hay of desired quality. In fact, high quality alfalfa hay is essential to obtain a high quality feed for cows, measured in terms of its protein and fiber content. To achieve this result, essential steps are to avoid a delayed harvest or the loss of leaves (the plant portion with the higher protein content) during the hay drying process. Finally, the weather conditions during harvesting can deeply affect the quality of the produced hay (Iannucci et al., 2002). Adequate forage quality is essential for animal feed rations and weight gain, high levels of milk production, reproduction efficiency and farm profits. The maximum yield of alfalfa is achieved at the stage of full flowering, whereas quality is the highest prior to flowering. Thus, a trade-off between quality and quantity is at the basis of alfalfa hay production (Undersander et al., 1994).

To improve the quality of hay and, in particular, to reduce product and quality losses during harvesting, over the years more adept machines have been developed. In particular, the use of a mower-conditioner with full-width conditioning rollers that crush alfalfa stems speeds up the drying process (Summers, 1998). Thanks to the conditioning, product losses (in particular of leaves) are steeply reduced, also because conditioning allows for faster hay drying—within the same weather conditions of a traditional mower—and the correct moisture content for baling can be reached with a lower number of hay turnings.

Despite the great interest in on-farm production of protein-rich feed, up to now only a few and partial studies (Gallego et al., 2007; Little et al., 2017; Parajuli et al., 2017) have been carried out with the purpose of assessing the environmental performance of alfalfa hay production. In this context, the aim of this study is to assess the environmental impact of alfalfa hay production considering primary data collected over 4 years on a farm where alfalfa hay is produced according the guidelines for Integrated Agriculture (Regione Lombardia, 2018). With regard to irrigation, two different production practices were considered: without and with irrigations.

2. Materials and methods

The Life Cycle Assessment (LCA) method was applied to perform the evaluation of the environmental impact. LCA is a holistic approach that uses a systematic set of procedures to convert the inputs and outputs of materials and energy that characterize a process into the associated environmental impact. Specifically, in this study, the ISO standard 14040/44 methodology (ISO 14044, 2006) and the Product Category Rules (PCR) guidelines developed for "Arable Crops" (Environdec, 2014) were followed, and the attributional approach was used to model the alfalfa hay production process.

According to ISO 14040/44 (ISO 14044, 2006), a LCA involves four distinct and interdependent phases:

i) goal and scope, which includes functional unit selection and system boundary definition;
ii) life cycle inventory, which involves the definition of energy and material flows between the system and the environment and through the different subsystems and operations of the evaluated system;
iii) impact assessment, during which the inventory data are converted in environmental indicators; and
iv) discussion and interpretation of the results, where the results from the inventory analysis and impact assessment are summarized, sensitivity and uncertainty analysis are carried out and recommendations are given.

2.1. Description of crop cultivation

As mentioned above, alfalfa (*Medicago sativa* L.) is one of the most widespread fodder crops in Italy; in the eastern part of the Po river valley (a plain area located in Norther Italy), besides to meadows, it represents the main crop for hay production in dairy farms.

The cultivation practice, carried out in accordance with the principles of integrated agriculture (Regione Lombardia, 2018), takes place over 4 years and includes several operations; these operations have been broken down into three subsystems:

2.1.1. Subsystem A: soil tillage and sowing

Primary tillage is performed with a moldboard plow (35 cm deep), while secondary tillage involves an intervention with a rotary harrow (10 cm deep). The sowing is performed using a mechanical universal seeder (45 kg/ha of seed). After the sowing, to help seed germination, a rolling is carried out.

2.1.2. Subsystem B: crop management

In contrast to other fodder crops or to cereal cultivation for silage production, the cultivation practice of alfalfa involves only one application of herbicide (2 kg/ha) per year. This occurs mainly to prevent the growth of other meadow plants that may affect alfalfa protein quality. During the first year of the crop cycle, fertilization with urea (30 kg of N/ha) is also performed; during the following years, in order to enhance N-fixation from the crop, no additional fertilization is performed. Moreover, no irrigation is scheduled.

2.1.3. Subsystem C: harvesting and transport operations

Harvesting takes place 5 times per year from May to October and is carried out using different machines. Each harvest is conducted by