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Environmental analysis of sunflower production with different forms of mineral nitrogen fertilizers

D. Spinelli [a], L. Bardi [b], A. Fierro [c], S. Jez [a], R. Basosi [a,*]

[a] Department of Biotechnology, Chemistry and Pharmacy, University of Siena, Via Alcide de Gasperi 2, 53100 Siena, Italy
[b] Agricultural Research Council, Research Centre for the Soil–Plant System, Turin Research Group, Via Livorno 60 (A2lab), 10144 Turin, Italy
[c] Department of Biology, University of Naples Federico II, Via Cinthia, 80126 Naples, Italy

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ABSTRACT

Environmental profiles of mineral nitrogen fertilizers were used to evaluate the environmental disturbances related to their use in cultivation systems in Europe. Since the production of mineral fertilizers requires a large amount of energy, the present study of bioenergy systems is relevant in order to achieve crop yields less dependent on fossil fuels and to reduce the environmental impact due to fertilization.

In this study, the suitability of the LCA methodology to analyze the environmental impact of sunflower cultivation systems with different forms of mineral nitrogen fertilizers urea and ammonium nitrate was investigated. Effects on climate change were estimated by the use of Ecoinvent 2.2 database default value for soil N_2O emission factor (1%) and local emission data (0.8%) of mineral nitrogen applied to soils.

LCA analysis showed a higher impact on environmental categories (human health and ecosystem quality) for the system in which urea was used as a nitrogen source. Use of urea fertilizer showed a higher impact on resource consumption due to fossil fuel consumption. Use of mineral nitrogen fertilizers showed a higher environmental burden than other inputs required for sunflower cultivation systems under study. Urea and ammonium nitrate showed, respectively, a 7.8% and 4.9% reduced impact of N_2O as greenhouse gas by using direct field data of soil N_2O emission factor compared to the default soil emission factor of 2006 IPCC Guidelines.

Use of ammonium nitrate as mineral nitrogen fertilizer in sunflower cultivation would have a lower impact on environmental categories considered. Further environmental analysis of available technologies for fertilizer production might be also evaluated in order to reduce the environmental impacts of each fertilizer.

1. Introduction

During the past few years, there has been an increasing interest on the contribution of agricultural biomass for bioenergy production. Net primary production (NPP) of the global croplands has been estimated at 15% of global terrestrial NPP (Field et al., 1998). Today, the increased productivity is due to greater use of fossil fuels and technologies, giving life to the so-called industrialized agro-ecosystems. The large input of subsidiary fossil energy towards the agricultural systems improves the primary productivity, but mobilizing matter from other systems and speeding up the cycle matter inside the system, results in pollution and environmental degradation. In fact, one of the main effects of the industrialized agro-ecosystem is the alteration of biogeochemical cycles, mainly carbon and nitrogen cycle. Input of resources including nitrogen fertilizers to the industrialized agro-ecosystem can be substantial, resulting in a large nitrogen surplus. Rotz et al. (2005) reported a nitrogen surplus of 150–250 kg N ha^{-1} yr^{-1} in highly productive dairy farm systems in the Netherlands and northern Germany. The large part of the surplus nitrogen is usually lost through leaching of nitrate or emitted as gaseous nitrogen (ammonia, NH_3; nitric oxide, NO; nitrous oxide, N_2O; and dinitrogen, N_2), leading to economic and environmental impacts.

Nitrogen is the main macro-nutrient affecting plant growth and crop yields, since nitrogen is an important component in plant cells of several structural, genetic and metabolic compounds such as proteins and nucleic acids. It is also a component of energy-transfer compounds, such as ATP (CFF, 2010). Nitrogen can be taken up by plant roots in inorganic forms (also called mineral nitrogen) such as ammonium ion (NH_4^+) and nitrate ion (NO_3^-) (CFF, 2010). The most

* Corresponding author. Tel.: +39 0577234240; fax: +39 0577234239.
E-mail addresses: basosi@unisi.it, riccardo.basosi@unisi.it (R. Basosi).

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widespread mineral nitrogen fertilizers are ammonium nitrate (NH_4NO_3) and urea $CO(NH_2)_2$. Urea is characterized by a high nitrogen content (46%) which contributes to a reduction in transport costs, and its production requires the use of CO_2. Urea fertilizer added to the soils leads to a loss of CO_2 that was fixed in the industrial production process. Urea is converted into ammonium ion (NH_4^+), hydroxide ion (OH^-), and bicarbonate ion (HCO_3^-), in the presence of water and urease enzymes. The increase in soil inorganic carbon from urea fertilization do not represent a net removal of CO_2 from the atmosphere. Urea is preferred in warm-temperate climate zones, because to make nitrogen available in soils, this compound needs a hydrolytic decomposition that is slow in cold environments. For these reason, in cold-temperate climate zones ammonium nitrate is preferred, even though its nitrogen content is lower (about 26–30%) and its storage is problematic due to hygroscopicity. Moreover, its transportation poses a danger due to its explosiveness and flammability. Ammonium nitrate provides nitrogen in a form immediately available to plants, but also it is more easily lost due to its leaching from the soil. Other mineral nitrogen fertilizers, such as anhydrous ammonia (NH_3), urea–ammonium nitrate (UAN, a liquid fertilizer), ammonium sulphate ($(NH_4)_2SO_4$), calcium nitrate ($Ca(NO_3)_2$), and calcium cyanamide ($CaCN_2$) are less commonly used. It should be noted that 97% of nitrogen fertilizers are derived from ammonia (European Commission, 2006).

During the life cycle of mineral nitrogen fertilizers, greenhouse gas emissions may arise through the extraction of resources, the transport of raw materials and products, in fertilizer production processes and during an agronomic phase as N_2O produced by soil microbial processes of nitrification and denitrification (Kramer et al., 1999; West and Marland, 2002; Patyk, 1996; Fierro and Forte, 2012). In particular, estimates of the International Fertilizer Industry Association (IFA) indicate 0.93% of global greenhouse gas emissions are due to fertilizer production, 0.07% to the fertilizer distribution and 1.50% to fertilizer use (International Fertilizer Industry Association, 2009). Therefore, due to the environmental relevance of the production phase of fertilizers, the evaluation of this contribution to GHGs emissions of agricultural processes must be considered (Wood and Cowie, 2004).

Environmental profiles analysis of mineral nitrogen fertilizers is particularly relevant for bioenergy systems. Our previous studies have shown that the agricultural phase, in first generation biofuel production line from sunflower, is the least environmentally friendly stage due to the use of mineral nitrogen fertilizers (Spinelli et al., 2012). Hence, in order to reduce the overall impact of the biofuel production lines, a comparison among the applications of different mineral nitrogen fertilizers allows the evaluation of possible differences in the indirect environmental burden of agricultural processes (Spångberg et al., 2011; Linderholm et al., 2012). In this study, Life Cycle Assessment methodology was used to analyze the environmental impact of the production of sunflower crops with two different forms of mineral nitrogen fertilizers to reveal differences between the two alternatives. Finally, the importance of local field emission data for a precise assessment of N_2O contribution to net GHG emissions by means of LCA applied to agricultural system was demonstrated.

2. Methodology

2.1. Goal and scope definition

In this paper, the goal of the analysis was to evaluate the impact of different mineral nitrogen fertilizers on the environmental burden associated with sunflower production system in the Province of Siena. In this predominantly agricultural area in the Tuscany region of Italy, a pilot production chain of biodiesel from sunflower represents an opportunity to reduce dependence on petroleum (Spinelli et al., 2013).

The analysis was performed on average field data for 2010 from four farms of the Province of Siena (Table 1). The utilization of arable land was 5 ha yr^{-1}. The variety of sunflower crop used was high oleic. Sunflower seeds are produced with intensive use of mineral fertilizers and pesticides, a common practice in conventional farming. The sunflower production systems analyzed differed in the form of mineral nitrogen fertilizers applied after sowing with both ammonium nitrate (NH_4NO_3) and urea ($CO(NH_2)_2$). Ammonium nitrate and urea contain nitrogen in different forms. Plants cannot use the nitrogen content in either fertilizers until it has been converted to the nitrate form. The use of ammonium nitrate allows a faster absorption of nitrogen from the plants than urea (particularly for low temperatures soils). The same yield for the cultivation systems was assumed. The analysis focused on the agricultural phase of the sunflower seed production.

The straw from the agricultural phase was not considered in the analysis, assuming that it left on fields increased the soil organic matter content. The analysis did not take into account Direct/Indirect Land-Use Change because sunflower crops are usually cultivated on the lands under study.

In addition to the tillage, all the relevant up-stream activities involved to mineral nitrogen fertilizers were taken into account in this LCA. European average data from the fertilizers' production plants (for year 2003) were used. Transport of the intermediate products to the fertilizer plant as well as the transport of the fertilizer product from the factory to the regional storehouse were included. Production and waste treatment of coating and packaging

Table 1
Material and energy fluxes for the production of sunflower seeds from conventional farming on a surface of 5 ha yr^{-1} in the province of Siena (year 2010).

Flow and unit	Farm 1 (intensive farming)	Farm 2 (extensive farming)	Farm 3	Farm 4	Average amount per ha per year	Standard deviation
Input						
Nitrogen fertilizer (g)[a]	1.39E+05	6.90E+04	8.10E+04	7.80E+04	1.14E+05	3.19E+04
Phosphate fertilizer (g)	10.1E+04	8.00E+04	9.50E+04	9.20E+04	9.20E+04	4.88E+04
Insecticide, pesticide, herbicide (g)	1.00E+03	9.20E+02	9.60E+02	9.60E+02	9.60E+02	3.26E+01
Diesel (l)	1.71E+02	1.47E+02	1.08E+02	1.39E+02	1.41E+02	2.60E+01
Steel for agricultural machine (g)	2.64E+02	2.59E+02	1.85E+02	2.10E+02	2.29E+02	3.84E+01
Lubricants (l)	4.30E−01	4.30E−01	4.30E−01	4.30E−01	4.30E−01	0.00E+00
Seeds (g)	4.10E+03	4.10E+03	3.60E+03	2.90E+03	3.67E+03	5.68E+02
Output						
Yield seeds (g)	2.20E+06	2.20E+06	1.40E+06	2.50E+06	2.01E+06	4.72E+05
Crop residues (g)	4.95E+06	4.95E+06	3.15E+06	5.62E+06	4.50E+06	9.21E+05

[a] In spite of the different nitrogen content of the two mineral nitrogen fertilizers (NH_4NO_3 35% and $CO(NH_2)_2$ 46%) the same amount of ammonium nitrate and urea was considered for LCA in order to compare the environmental performance of the two different fertilizers.