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Improving bioenergy sustainability evaluations by using soil nitrogen balance coupled with life cycle assessment: a case study for electricity generated from rye biomass

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Abstract— The use of Life Cycle Assessment (LCA) as an environmental tool to evaluate the sustainability of different bioenergy pathways has become a common practice since the European Renewable Energy Directive was published in 2009. In the evaluation of bioenergy produced out from dedicated energy crops, nitrogen fertilizer production and use are commonly identified as the most important contributors to fossil energy consumption and to several environmental impacts categories including Global Warming Potential. In considering the impacts produced by the nitrogen fertilization of energy crops and in addition to the effects of fertilization schemes on the biomass yield, more attention should be paid to the changes in soil nitrogen to know if fertilization doses and application schemes are sufficient enough to maintain soil nitrogen stocks and ensure that soil quality is preserved for future years. To this aim, in this work soil nitrogen balance is used as an indicator to estimate the evolution of soil nitrogen stocks and complement LCA calculations. In this paper, the effects of three nitrogen top fertilization doses (null, 30 and 80 kg N/(ha y)) used for rye cultivation are compared when ry is grown as a dedicated energy crop for electricity generation under the Spanish province of Soria conditions. A LCA was carried out using experimental crop testing results and a centralised (25 MWe) straw power plant data in combination with soil nitrogen balance obtained in each of the experimental crop trials. After that, the LCA results were compared with those obtained when electricity is generated from natural gas in Spanish power plants. According to the average calculations, each additional kg N/(ha y) applied in top fertilization produces a reduction of 0.18% on GHG savings with respect to natural gas electricity, as well as a worsening in the energy balance of 0.00084 TJ fossil energy per TJ of electricity generated but reduces soil nitrogen deficit in 0.43 kg N/(ha y). For top fertilization doses of 80 kg N/(ha y) the average GHG savings with respect to natural gas were 63.7% and the average non-renewable energy consumption was 6, 4 times less for the bioenergy system than for natural gas. Fossil energy accounted for more than 95% of total non-renewable energy in this calculation. This work evidences that determinate biomass growing conditions associated to high GHG savings and improved energy balances may cause detrimental effects for soil fertility due to considerable associated negative soil nitrogen balances. This finding suggests the convenience to include the soil nitrogen balance as a complementary indicator for bioenergy LCA calculations.

Index Terms— Bioenergy; Sustainability; Life cycle assessment (LCA); Soil nitrogen balance; Fertilizers; Energy crops

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