Short term effects of bioenergy by-products on soil C and N mineralization and biochemical properties

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Abstract

Bioenergy by-products largely vary in their composition and properties and they can impact soil fertility in different and unpredictable ways. We studied the effects of the application rate of bioenergy residues with contrasting properties on C and N mineralization, element availability and biochemical properties. Results underlined that the process from which the by-products originated had a great effect in determining the agronomical properties of the residues. In particular, sorghum whole stillage from bioethanol production increased biological fertility, but caused N immobilization, manure whole stillage from bioethanol production greatly increased P availability, while manure anaerobic digestate supplied significant amounts of N. A direct relationship was found between rate of application of by-products and N and P availability. Our study indicated that the reliability of the agronomical utilization of bioenergy by-products requires a thorough evaluation of their impact on soil fertility.

Introduction

Biomass plays a particular role among renewable energy sources as bioenergy is anticipated to contribute almost 54.5% to the 2020 renewable energy target [1]. The increase of bioenergy production will lead to an increased amount of the bioenergy residues. Such residues contain a significant amount of organic matter and/or nutritive elements and therefore are attractive as fertilizers and/or amendments. Soil application of bioenergy by-products appears to be a reliable strategy for their disposal, as it may increase the profitability of the bioenergy process and contribute to improve soil fertility.

However, such by-products are extremely variable in their composition and properties and may have an unpredictable impact on soil properties. To date, limited research has been performed to determine how soil application of bioenergy by-products will influence soil quality, especially when high loads of N are applied. In particular, information on the impact of bioenergy residues on soil C and N mineralization and biochemical properties is relevant for the efficient management of the residues. Soil mineralization is the main process regulating nutrient availability. The microbial pool exerts a key role in determining the degree of soil quality [2]. Enzyme activities related to the cycle of main nutritive elements could give indications on the rates of substrate turnover, soil metabolic potential and soil resilience.

Therefore, the aim of this work was to investigate the effects of the application rate of bioenergy residues with contrasting properties on C and N mineralization, element availability and microbial size and activity of amended soil.

Materials and Methods

A moist (40% WHC) Fluventic Eutrudept agricultural soil (pH 8.3, 69% sand, 3% clay, 1.1% SOC) was amended with 4 different bioenergy residues (S1: sorghum whole stillage from first generation bioethanol production; S2: sorghum whole stillage from second generation bioethanol production; M2: manure whole stillage from second generation bioethanol production; AD: liquid manure anaerobic digestate) at 3 different doses (85, 170 and 340 kg N ha^{-1}) and incubated at 20 °C in the laboratory for 21 days. During incubation soil CO_2 evolution was measured every 6 hours by chromatography. After 2, 7 and 21 days of incubation, soil samples were analysed for K_2SO_4-extractable C, N, nitrate and P, double-strand DNA and four enzymatic activities linked to C, N, P and S cycles (β-glucosidase, leucine aminopeptidase, alkaline phosphatase and arylsulfatase). K_2SO_4-extractable C and N, were determined using a TOC-VCSN analyser (Shimadzu). The content of NO_3^- in the extracts was determined by reading the absorbance at 220 nm and subtracting the absorbance at 275 nm caused by organic matter. The content of available P was determined by a colorimetric method. Soil microbial double strand DNA was determined on soil extracts by means of a fluorescence based assay. The different enzymatic activities were determined on soil extracts [3] utilizing fluorescent substrates.

Results and Discussion

Soil treated with bioenergy by-products showed significant differences in the dynamics of soil respiration as a function of the different degree of decomposability of the added exogenous organic matter. In particular, soil respiration of AD treated soil clearly indicates that the anaerobic digestion process caused a significant decomposition of organic matter of liquid manure. By contrast, S1 is the by-product characterized by the higher content of easily decomposable organic matter (Figure 1a).

a b

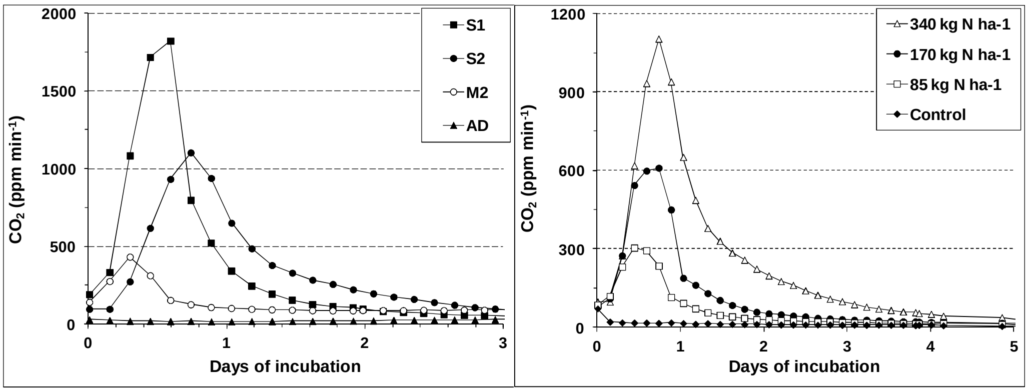

Figure 1. Dynamics of CO_2 emissions in soil treated with S1, S2, AD and M2 at a rate of 340 kg N ha^{-1} (a). Dynamics of CO_2 emissions in soil treated with S2 at a rate of 85, 170 and 340 kg N ha^{-1} (b).

Respiratory response increased linearly with application rate for S1, S2 and M2. As an example, Figure 1b reports the dynamic of soil respiration of soil treated with S2 at different doses.
Cumulative CO_2-C at the end of the incubation period was 191, 174, 110 and 15 µg g^{-1} for S1, S2, M2 and AD, respectively.
Net extractable N (control subtracted) at the end of incubation for the highest application rate was 0, 4, 27 and 39 µg g^{-1} for S1, S2, M2 and AD, respectively and was a linear function of application rate for M2 and AD. In the case of AD, net extractable N represented 11.5% of the N added with the by-product (Figure 2a).

a b

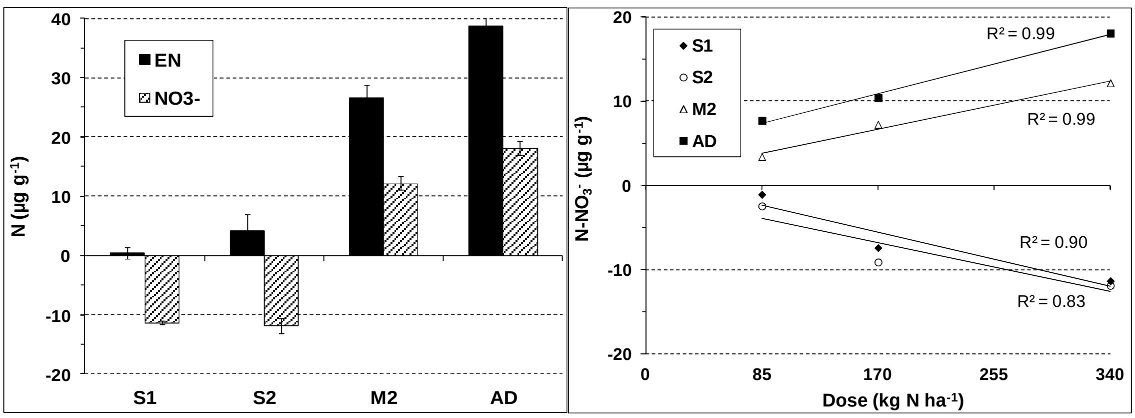

Figure 2. Net (control subtracted) extractable N (EN) and N-NO_3^- at the end of incubation in soil treated with S1, S2, AD and M2 at a rate of 340 kg N ha^{-1} (a). Relationship between rate of application and net nitrate content in soil amended with S1, S2, AD and M2 (b).

Net N-NO_3^- (control subtracted) for the highest application rate was lower than the control for S1 and S2, while it was 12 and 18 µg g^{-1} for M2 and AD, equivalent to a supply of 48 and 72 kg N ha^{-1}, respectively (Figure 2a).

The residues producing a decrease of nitrate content with respect to the control (S1, S2), are those characterized by the higher degree of organic matter degradability, as indicated by the respiratory response (Figure 1a) and the extractable organic C content (data not shown). N immobilization is likely due to the fact that soil microorganisms utilized soil soluble N in order to incorporate the high amount of available C derived from the fast degradation of the residues [2]. There was a linear relationship between rate of application and net nitrate content for each of the residues, but such relationship was negative for S1 and S2 and positive for M2 and AD (Figure 2b).
Soil amendment resulted in a significant increase in available P, with the exception of S1. Particularly relevant was the net increase of 44 µg P g^{-1}recorded at the end of the experiment in the soil amended with M2 at the higher dose, corresponding to a supply of 176 kg P ha^{-1} (Figure 3a). Available P was positively and linearly correlated with the application rate of the by-products (Figure 3b).

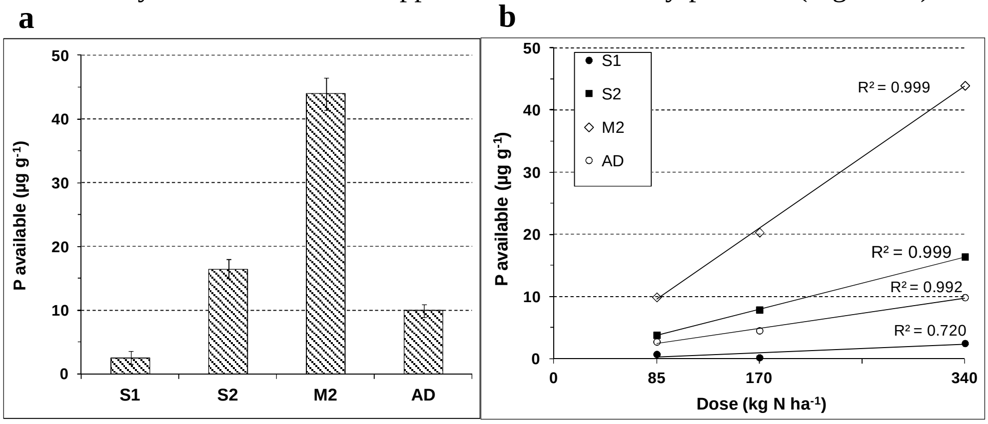

Figure 3. Net (control subtracted) available P at the end of incubation in soil treated with S1, S2, AD and M2 at a rate of 340 kg N ha^{-1} (a). Relationship between rate of application and net available P in soil amended with different bioenergy by-products (b).

Soil amendment resulted in a significant increase in double strand DNA, with the exception of AD. At the end of incubation period double-strand DNA for the highest application rate was 4.6, 2.4 and 2.1 higher than the control for S1, M2 and S2, respectively (Figure 4).

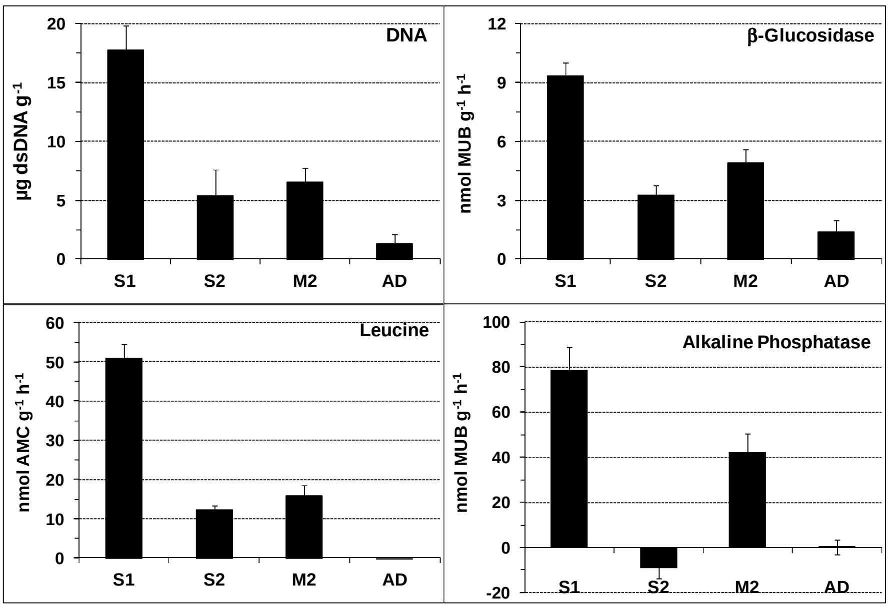

Figure 4. Net (control subtracted) double strand DNA and enzymatic activities at the end of incubation in soil treated with S1, S2, AD and M2 at a rate of 340 kg N ha^{-1}.

Similarly to DNA, the anaerobic digestate did not significantly affect enzymatic activities. This is attributable to the high degree of stabilization of organic matter of AD, as a consequence of transformations undergone during the bioenergetic process. On the contrary, S1, S2 and M2 increased

the activity of enzymes linked to C, N and P cycles (β-glucosidase, leucine aminopeptidase and alkaline phosphatase), with the only exception of alkaline phosphatase in S2 amended soil.
Soil microbial biomass plays an essential role in guaranteeing the soil capacity to develop important agronomical and environmental functions, such as the degradation and transformation of organic residues and the nutrient cycling. An increase in the content and activity of microorganisms represents an important enhancement of soil quality and health.
Overall, the different impact of the by-products on soil chemical and biochemical properties could be related to the bioenergy processes from which they originated.
S1, S2 and M2 derived from the production of bioethanol. This process is based on the hydrolysis of the biomass to release simple carbohydrates and to the fermentation of carbohydrates to alcohol. The hydrolysis process caused the degradation of complex molecules and therefore the by-products from bioethanol production were rich in low molecular weight compounds that once added to the soil increased soil respiration, nutrients availability and microbial activity. The difference between residues from first (S1) and second (S2 and M2) generation biofuels is that in the case of S1 bioethanol was produced from the sorghum juice, rich in easily degradable organic compounds, while in the case of S2 and M2 bioethanol was generated from the lignocellulosic components of sorghum and manure, respectively. This could explain the greater impact of S1with respect to S2 and M2 on respiration and biochemical properties.
Anaerobic digestion of manure is a process based on the degradation of easily degradable organic matter to produce gas. The residue utilized in this study was characterized by a stable organic matter that, when added to the soil, mineralized very slowly and consequently did not significantly increase microbial content and activity.

Conclusion and perspectives

Addition of by-products characterized by variable chemical composition caused different levels of soil respiration, elements availability and biochemical properties. This different behaviour indicated that they should be added to the soil to fulfil different aims.
Manure whole stillage from second generation bioethanol production and liquid manure anaerobic digestate are more indicated as soil fertilizers, since they supplied significant amounts of NO_3^- and available P.
Sorghum whole stillages from first and second generation bioetahnol production released significant amounts of P, but caused N immobilization which limits their validity as N fertilizers. Consequently, they are more indicated as soil amendments due to the positive effects on soil biological fertility.
The relationship between application rate and the content of nitrate (M2 and AD) and available P (S1, S2 and M2) make it possible for these residues to optimize the rate of addition in order to minimize element losses, while assuring an adequate supply of nutrients for plants.
These findings clearly indicate that a thorough evaluation of the impact of bioenergy by-products on soil fertility and biochemical properties is necessary to optimize the agronomical utilization of the residues and to increase the proficiency of bioenergy production.

References

[1] Atanasiu B, 2010. The role of bioenergy in the national renewable energy action plans: a first identification of issues and uncertainties. Institute for European Environmental Policy, 1-22, online http://www.ieep.eu/assets/753/bioenergy_in_NREAPs.pdf, accessed on 18/03/2013
[2] Stevenson FJ, Cole MA, 1999. Soil organic matter quality and characterization. In: Cycles of soil, 78-106, Wiley, New York, USA
[3] Fornasier F, Margon A, 2007. Bovine serum albumin and Triton X-100 greatly increase phosphomonoesterases and arylsulphatase extraction yield from soil. Soil Biology and Biochemistry 39, 2682-2684
[4] Cayuela ML, Oenema O, Kuikman PJ, Bakker RR, van Groenigen JW, 2010. Bioenergy by-products as soil amendments? Implications for carbon sequestration and greenhouse gas emissions. Global Change Biology Bioenergy 2, 201-213