

# Effects of application of crop residues with different chemical composition on soil N and N<sub>2</sub>O/CO<sub>2</sub> emissions

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# 1. Summary

Crop residues contribute to sustaining or enhancing soil carbon (C) stocks, thus promoting soil health and potentially mitigating climate change. Emissions of  $\text{N}_2\text{O}$  can to some degree offset C sequestration after residue addition to soil, but the effects of crop type and residue chemical composition on  $\text{N}_2\text{O}$  emissions are not well quantified. To assess the effects of residue chemical properties on  $\text{N}_2\text{O}$  emissions and soil respiration, we incubated a wide range of residues, including cover crop, ley, intercrop and root residues, using four different soils, under controlled laboratory conditions. We demonstrated that the amount of residue N per area or the residue C:N ratio are not sufficient to explain the variation in  $\text{N}_2\text{O}$  emissions. At C:N ratios below 25, the soluble C content of the residue was an important driver for  $\text{N}_2\text{O}$  emissions. The emissions induced by belowground residues were only studied for grassland species and should be studied further, but the results indicated a very low impact on the total  $\text{N}_2\text{O}$  emission, regardless of the chemical composition of the residues. We concluded that the crop species and its physiological maturity at the time of incorporation or addition to the soil could be used as a proxy for short-term  $\text{N}_2\text{O}$  emissions - at least when fertilizer is not added, which is generally the case in autumn. Aboveground residues with C:N ratios above 25 could be assumed to induce low  $\text{N}_2\text{O}$  emissions, at least during the first two months. For residues that have C:N ratios below 25, which is often the case for fresh green residues and cover crops, a high concentration of easily degradable C should be regarded as a risk factor for  $\text{N}_2\text{O}$  emissions. Degradable C is not a commonly measured variable, but crop species and crop maturity stage may be good enough indicators. The very low emissions from the belowground residues of ley, regardless of their chemical composition, suggest that the current inventory methodology may be overestimating the contribution of belowground residues to total  $\text{N}_2\text{O}$  emissions.

## 2. Introduction

Crop residues contribute to sustaining or enhancing soil carbon (C) stocks, thus promoting soil health and potentially mitigating climate change. They are, however, also potentially important sources of nitrous oxide (N<sub>2</sub>O) and may significantly affect the greenhouse gas (GHG) balance of a cropping system. The degree to which N<sub>2</sub>O emissions offset C sequestration after residue addition to soil is not well known, partly because effects of crop type and residue chemical composition on N<sub>2</sub>O emissions are not well quantified. In the IPCC methodology (IPCC, 2019), a single emission factor is provided for calculating N<sub>2</sub>O emissions from crop residues, assuming a direct proportionality between N<sub>2</sub>O emissions and residue N input. Emissions have, however, shown to be very variable and factors such as C/N ratio and residue degradability have been suggested as important factors affecting the magnitude of N<sub>2</sub>O emissions. To assess the effects of residue chemical properties on N<sub>2</sub>O emissions and soil respiration, we incubated a wide range of residues, including cover crop, ley, intercrop and root residues, using four different soils, under controlled laboratory conditions.

### 3. Materials and methods

A total of 16 aboveground crop residues and crop residue combinations were used: (field pea (PEA), maize (MAZ), mustard cover crop (MUS), oilseed rape (RAS), potato (POT), red clover (RC), ryegrass (RYE), sugar beet (SUB), winter wheat (WHT), miscanthus (MIS), alfalfa in immature stage (ALF), barley (BAR), lupine (LUP), oat (OAT), carrot (CAR), PEA+BAR, LUP+BAR and RYE+RC. These residues were incubated with one or more of the following soils: a calcareous silty clay loam (GRI), a sandy loam (SLU) and a clay loam (KIT). Control treatments without residues were included for each soil and there were at least three replicates of each treatment combination. This experimental work was divided between three laboratories (SLU, INRAE, KIT) that used different gas measurement techniques but a common experimental protocol: residues were always applied at a rate of 4 t DM ha<sup>-1</sup> and mixed into the upper 4 cm of 8 cm deep soil cores and the incubations were carried out at 15°C and 60% WFPS, in the dark, for 60 days, with no mineral N addition. One of the treatment combinations (RC\_SLU) was included at all three laboratories, in five replicates, and was used to compare results between laboratories. In a separate incubation, in a fourth laboratory (NMBU), combinations of stubble and herbage, from grass and clover, were incubated with freshly sampled clay loam soil from either a fallow treatment (containing no roots) or from grass or clover ley (containing fresh roots). The treatment soil (with roots and/or stubble and herbage) was filled in glass jars to 4 cm height, topped with fallow soil to a total of 8 cm height and incubated at 15°C for 107 days. Nitrate was added to some treatments in this incubation, and four replicates were used.

For each residue type, total C and N contents were determined by elemental analysis. Water soluble C, N, NH<sub>4</sub><sup>+</sup> and NO<sub>3</sub><sup>-</sup> contents were determined by dry combustion and colorimetric methods after water extraction at 20°C. Fractions of soluble compounds, hemicellulose, cellulose and lignin+ash were estimated by the Van Soest method. Soil cores incubated in parallel to the main cores, with identical residue additions and incubation conditions, were extracted at 0, 4, 7, 14, 28, and 60 days after crop residue incorporation, for analysis of NH<sub>4</sub><sup>+</sup> and NO<sub>3</sub><sup>-</sup> contents. Emissions of N<sub>2</sub>O and CO<sub>2</sub> were measured using steady-state or non-steady state enclosures, with continuous gas analysis or repeated sampling and subsequent analysis by gas chromatography. In the INRAE laboratory, the soda trap method was used for CO<sub>2</sub> measurements. Emission factors were calculated by subtracting the cumulative emission of a corresponding control treatment from that of a residue treatment and dividing by the total N in the added residues.

## 4. Results and discussion

For most treatments, incorporation of residues resulted in an immediate sharp increase in N<sub>2</sub>O emissions. The peaks usually declined to background levels within 10 days, but for SUB, POT, RC and RYE treatments, emissions remained above those of the control treatment for up to 40 days. The sharp and early peaks show the importance of monitoring N<sub>2</sub>O emissions with a high temporal resolution during the first days after residue addition. The N<sub>2</sub>O emission values obtained for the RC\_SLU treatment were similar at the SLU, INRAE and KIT laboratories, with cumulative values of  $2.3 \pm 0.76$ ,  $2.9 \pm 0.14$  and  $2.5 \pm 1.4$  kg N<sub>2</sub>O-N ha<sup>-1</sup> over 60 days, respectively. We therefore deemed it appropriate to calculate mean emissions across laboratories. There was, on the other hand, considerable variation in cumulative N<sub>2</sub>O emissions between residue types and soils.

N<sub>2</sub>O emissions were significantly higher with SLU soil than with KIT or GRI soil. Across soils, there was a negative exponential relationship between mean cumulative N<sub>2</sub>O emissions over 60 d and residue C:N ratio, that clearly divided the residue treatments into a high-emitting (C/N<25) and a low-emitting (C/N>25) group. These two groups largely coincided with the maturity of the residues at the time of crop harvest, with the C/N<25 group including only “immature” residues, that were green and fresh at harvest, and the C/N>25 group including all “mature” residues, that were yellow and dry at harvest, but also the two “immature” residues CAR and ALF. Cumulative N<sub>2</sub>O emissions, across laboratories, ranged between 0.2-0.7 and 1.0-4.3 kg N<sub>2</sub>O-N ha<sup>-1</sup>, for “mature” (WHT, RAS, MAZ, PEA, PEA+BAR, OAT, MIS, LUP+BAR) and “immature” (RYE, MUS, SUB, POT, RC, RYE+RC, ALF and CAR) residues, respectively. Emissions of N<sub>2</sub>O from ley roots, for both red clover and grass, were very low and could not be explained by the chemical composition.

Soil respiration was highest immediately after residue incorporation, but the subsequent decline was slower than for the N<sub>2</sub>O emissions. The cumulative soil respiration was higher for the KIT and SLU soil treatments than for the GRI soil treatments, when control fluxes were not subtracted. When control values were subtracted, soil respiration was larger for the SLU soil treatments than for the other two. The KIT soil had a high basal soil respiration, presumably due to its high organic carbon content. The dynamics of ammonium and nitrate in the soil were not straightforward to interpret and link to N<sub>2</sub>O emissions, since the concentrations depend on several factors – mineralisation, immobilisation and gaseous losses. The total gaseous losses were not well quantified in this study, since NO and NH<sub>3</sub> were measured only in the KIT laboratory and N<sub>2</sub> was not measured.

The emission factors derived from the cumulative N<sub>2</sub>O emission values varied widely (-0.5% to 5.6%), in stark contrast to the single IPCC default emission factor of 0.6%. The values from our studies are not directly comparable to the default value, since we measured over only 60 d, but the variation in itself indicates that the emissions were affected by factors other than the total N applied. For the whole set of emission factors derived from the incubations at SLU, INRAE and KIT, water soluble C explained 26% of the variation and other parameters included in the analysis (C:N ratio, soil respiration and contents of N<sub>min</sub>, water soluble N, water soluble C, soluble C as extracted according to the Van Soest method, hemicellulose and cellulose) did not add any explanatory value. When analysing the C/N<25 and C/N>25 treatment groups separately, however, the results were more informative. In the low C/N group, water soluble C explained 53 % of the variation in total net N<sub>2</sub>O emissions, with no other parameters contributing. For the high C/N group, none of the variation was explained by any of the parameters. We concluded, in accordance with

observations from other studies, that residue C:N ratio and availability of degradable C are important drivers of N<sub>2</sub>O emissions. The emissions from soil with high C/N residues seemed to be N limited and could have been higher had fertilizer been applied with the residues. For the low C/N residues, the N<sub>2</sub>O emissions seemed to be C limited. Interestingly, the emissions associated with belowground residues deviated from these patterns and were low regardless of C:N ratio, soluble C content or other measured properties.



## 5. Conclusions

We demonstrated experimentally that the amount of residue N per area or the residue C:N ratio are insufficient to explain the variation in N<sub>2</sub>O emissions. At C:N ratios below 25, the soluble C content of the residues was an important driver for N<sub>2</sub>O emissions. The emissions induced by belowground residues were only studied for grassland species and should be studied further, but the results indicated a very low impact on the total N<sub>2</sub>O emission, regardless of the chemical composition of the residues. This suggests that the current inventory methodology may be overestimating the contribution of belowground residues to total N<sub>2</sub>O emissions.

We conclude that the crop species and its physiological maturity at the time of incorporation or addition to the soil could be used as a proxy for short-term N<sub>2</sub>O emissions, under Northern European climatic conditions - at least when fertilizer is not added, which is generally the case in autumn. Aboveground residues with C:N ratios above 25 could be assumed to induce low N<sub>2</sub>O emissions, at least during the first two months. For residues that have C:N ratios below 25, which is often the case for fresh green residues and cover crops, a high concentration of easily degradable C should be regarded as a risk factor for N<sub>2</sub>O emissions. Degradable C is not a commonly measured variable, but crop species and crop maturity stage may be good enough indicators.

## 6. References

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