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Analysis of Organic Resource Quality for Parameterisation of Simulation Models

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Abstract

Updating of simulation models to incorporate new thinking on parameters that influence decomposition and hence nutrient release in the soil has been slow, with most models relying on N and lignin contents as determinants of decompositions. In addition, these analyses are expensive and time-consuming. This paper summarises the papers on analysis of the standard sample set of 32 different quality organic materials and how this can be linked to parameterisation and improvement of simulation models.

From this cross-method analysis, the minimum data set to assess organic resource quality consists of N, lignin and soluble polyphenol content, which is consistent with conclusions from earlier efforts. When considerations of cost and speed are included in the analysis, aerobic incubation is one of the cheapest, but also it's the slowest method. NIR, on the other hand, is the fastest method, but also most expensive until it is used for routine assessments.

Class III resources needed solely N content measured, whereas for Classes I and II there were no single quality indices. For Class III resources that show positive mineralisation with time, including polyphenol content in the decomposition routines of simulation models would increase the accuracy of prediction.

During the 1990s, the formulation of research hypotheses related to residue quality and N release led to a vast amount of projects aiming at validation of these hypotheses. Based on all this information, Palm et al. (2001) compiled the 'organic resource database' (ORD), which contains information on organic resource quality parameters including macronutrients, lignin and polyphenol contents of fresh leaves, litter, stems and/or roots from almost 300 species found in tropical agroecosystems. In addition, it contains many records of animal manures and livestock feed species. The database is available for downloading from the Internet at
<http://www.ciat.cgiar.org/catalogo/producto.jsp?codigo=P0215>.

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Following careful analysis of a large number of N-mineralisation studies using a wide range of organic resources, Palm et al. (2001) proposed a conceptual decision-support system (DSS) for organic N management. The DSS proposes four classes of organic resources, each having specific management options. Class I contains materials with high N (> 2.5%), low soluble polyphenol (< 4%), and low lignin (< 15%) content, and it is proposed that they be applied directly to a growing crop. The proposal for classes II and III is that they be mixed with either fertiliser or class I materials, as they have either a high N and high polyphenol content (class II) or a low N, low polyphenol and low lignin content (class III). Class IV materials have a low N and high lignin content and the recommendation is that they be applied as surface mulch.

Over the years, the range of organic resource quality characteristics found to affect the decomposition and mineralisation process has broadened.

Originally, the C/N ratio was seen to relate well with N availability. Mellilo et al. (1982) showed that the N and lignin content of hardwood leaf litter residues significantly affected their decomposition. Palm et al. (1997) introduced the soluble polyphenol content in organic resource quality–N-mineralisation relationships, while Handayanto et al. (1994) showed that the content of soluble polyphenols that were actively binding proteins was better related to decomposition than the total soluble polyphenol content itself. One of the 'traditional' assessments for C and N mineralisation is an aerobic incubation under controlled conditions for a number of weeks. Recently, some efforts have been made to short-cut this procedure by adapting in vitro approaches used by animal nutritionists (Tian et al. 1996; Cobo et al. 2002).

Description of a standard method(s) to establish resource quality characteristics that can be used to parameterise simulation models is needed. Therefore, the objectives of this work were to use a large and well-chosen range of organic resources covering the complete organic resource quality spectrum (Class I to Class IV) to measure resource quality and decomposition, in order to: (i) explore relationships between aerobic incubation, in vitro digestibility and near-infrared reflectance spectrometry approaches for assessing short-term organic resource decomposition; (ii) to evaluate relationships between short-term decomposition dynamics and organic resource characteristics; and (iii) to reflect on the minimum data set needed to predict short-term N mineralisation dynamics.

Materials and Methods

Organic materials were collected from different parts of Kenya (Gachengo et al. 2004b), and their resource quality was determined using a variety of standard and less commonly used characteristics. The C and N mineralisation of all organic resources was measured in an aerobic incubation experiment (Gachengo et al. 2004a) and through an in vitro dry matter digestibility (IVDMD) method (Barrios 2004). Near infrared reflectance spectroscopy (NIRS) (wavelengths from 1.0 to 2.5 µm) was used for rapid prediction of C and N mineralisation rates and IVDMD (Shepherd 2004).

Data analysis

Simple and multiple regression (STEPWISE method) techniques (SAS 1985) were used to relate decomposition dynamics with various organic resource characteristics. For C mineralisation and IVDMD data, a single multiple-regression model was used, while for the N mineralisation data, separate models were run for the treatments with negative and positive percentages of applied N mineralised. This was done because the 'traditionally' used calculation procedure results in a discontinuity when the percentage N mineralised is zero.

Results

Simple linear regression analysis shows that cumulative C release after 28 days is linearly related to especially the lignin content, the polyphenol/N ratio and the PBC/N ratio of the organic resources, where PBC is the protein-binding capacity (Table 1). Cumulative N release after 28 days is highly significantly related to the N content, soluble C content, and soluble C/N ratio of the organic materials. For the IVDMD, the resource quality parameters yielding the most significant relationships are the N content, the lignin content, and the PBC:N ratio.

NIRS first calibrated the organic resource attributes to first derivative reflectance using partial least squares regression. Cross-validated r^2 values for actual versus predicted values were 0.84 for percentage of added C mineralised, 0.84 for percentage of added N mineralised, and 0.88 for IVDMD (Shepherd 2004).

Multiple regression analysis shows that soluble C, polyphenol, and lignin content of the organic resources explain 86% of the variation in cumulative C mineralisation (Table 2). When using IVDMD data, soluble C and lignin content and PBC explain 89% of its variation. For residues with positive N-mineralisation values, the N and polyphenol content of the organic resources explain 60% of the variation in N mineralisation at day 28. For all other residues, 90% of the variation was explained by their N content (Table 2).

Figure 1 showed three classes of organic resources: one class with N-mineralisation values significantly above 0 (Class I), one class with values not different from 0 (Class II), and a third class with values significantly below 0 (Class III). When considering only Class III data, a highly significant linear relationship was observed between N mineralisation and the N content of the organic resources (Figure 2a). For Class I data, no significant relationships between N mineralisation and any specific organic resources quality parameter were observed. Excluding the *Gliricidia* samples, however, N mineralisation was linearly related with the lignin/N ratio of the organic resource (Figure 2b).

For organic resources with high polyphenol or lignin content, the IVDMD assay-based assessment of decomposition correlated well with the aerobic incubation assay (Figure 3). This was, however, not true for organic resources with low polyphenol and lignin content. This may not be surprising, as the IVDMD assay is based on an anaerobic microbial decomposition phase and an enzyme digestion phase. Both phases are unlikely to be affected by lack of N for optimal decomposition of the organic resources with low biochemical resistance against decomposition. In the aerobic decomposition process, however, lack of mineral N may hamper the decomposition of organic resources with low N. For organic resources with either high polyphenol or lignin content, the organic resources themselves show some biochemical protection against decomposition, independent of the availability of N.

Table 1. R^2 values of the simple linear regressions between selected decomposition parameters and commonly used organic resource characteristics.

Organic resource characteristic	Cumulative C release after 28 days (%)	Cumulative N release after 28 days (%)	In vitro dry matter digestibility (%)
N content (% DM[a])	0.21^{**b}	0.82^{***}	0.45^{***}
C:N ratio	0.21^{**}	0.38^{***}	0.24^{**}
Polyphenol content (%DM)	0.21^{**}	0.01	0.06
Lignin content (% DM)	0.48^{***}	0.15^{*}	0.59^{***}
Soluble C content (% DM)	0.18^{*}	0.46^{***}	0.32^{***}
Protein-binding capacity (mg BSA g^{-1} DM)	0.29^{**}	0.00	0.19^{*}
Soluble C:N ratio	0.12	0.56^{***}	0.15^{*}
Polyphenol:N ratio	0.45^{***}	0.25^{**}	0.35^{***}
Lignin:N ratio	0.24^{**}	0.25^{**}	0.25^{**}
(Lignin+Polyphenol):N ratio	0.26^{**}	0.26^{**}	0.26^{**}
Protein binding capacity:N ratio	0.50^{***}	0.19^{*}	0.46^{***}

[a] DM = dry matter.
[b] *, **, and *** indicate significance at the 5, 1, and 0.1% level, respectively.

Table 2. Multiple regression analysis using selected decomposition parameters as dependent variables and C, N, P, polyphenol, lignin, and soluble C content and protein-binding capacity as independent variables.

Dependent variable	Multiple regression equation[b]	R^2
Cumulative C mineralisation at day 28 (%)	$37^{***} - 1.84 \times$ (polyphenol content)*** $- 0.92 \times$ (lignin content)*** + 1.80 x (soluble C content)***	0.86
In vitro dry matter digestibility (% DM[a])	49*** – 1.51 × (lignin content)*** + 2.69 × (soluble C content)*** – 0.10 × (protein binding capacity)***	0.89
Cumulative N mineralisation at day 28 (%) for treatments with positive values	–11 + 9.84 × (N content)*** – 1.59 × (polyphenol content)*	0.60
Cumulative N mineralisation at day 28 (%) for treatments with negative values	–100*** + 34.1 × (N content)***	0.90

[a] DM = dry matter.
[b] *, **, and *** indicate significance of coefficients of regression at the 5, 1, and 0.1% level, respectively.

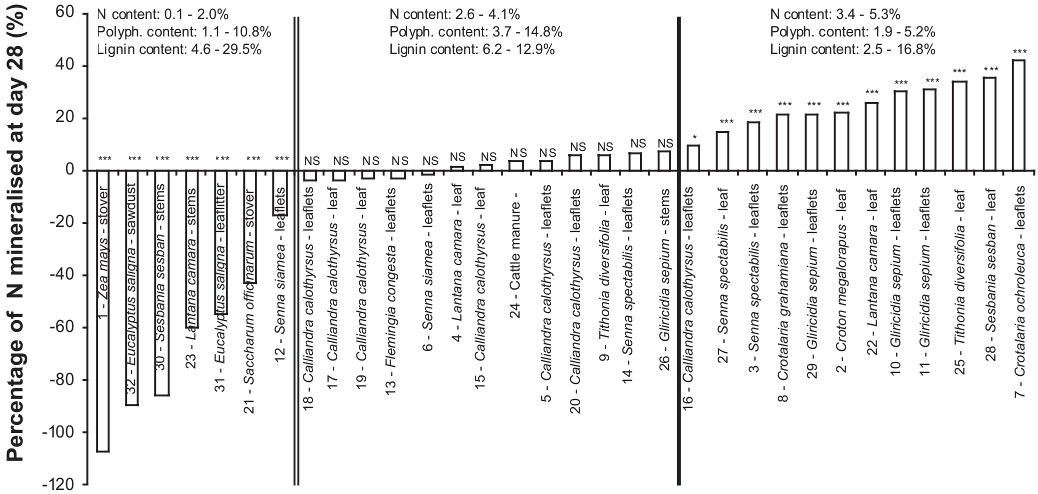

Figure 1. The percentage of added organic resource N mineralised after 28 days. '***', '*' and 'NS' signify significance at the 0.1%, the 5% level and not significant, respectively, as calculated with the LSMEANS option of the MIXED procedure (SAS 1992). The vertical bars delineate three groups of organic resources: a first group that has values significantly less than 0, a second group with values not different from 0, and a third group with values significantly larger than 0. The range of N, polyphenol, and lignin contents presented for the middle group excludes sample numbers 24 (cattle manure: 2.5% N, 1.1% polyphenols and 17.3% lignin) and 26 (*Gliricidia* stems: 1.6% N, 1.3% polyphenols and 20.4% lignin).

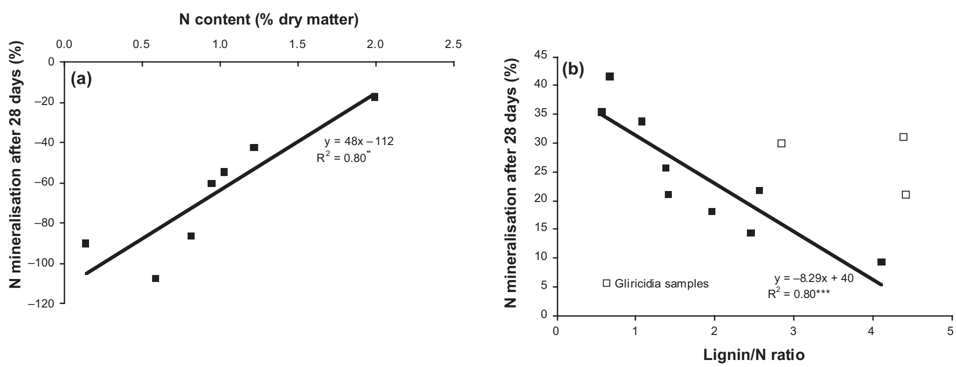

Figure 2. Relationship between the percentage of added N mineralised after 28 days and (a) the N content for organic materials with values significantly below 0, and (b) the lignin/N ratio for the organic materials with values significantly above 0. In Figure 2b, the *Gliricidia* leaves (samples 10, 11, and 29) were excluded from the regression.

Discussion

From the different methods used in this cross-method analysis, the minimum data set to assess organic resource quality appears to consist of N, lignin, and soluble polyphenol content, a finding that is consistent with conclusions from earlier efforts. The various methods used to assess short-term mineralisation produced significant correlations to N and C mineralised after 28 days, with at least one of the three aforementioned characteristics.

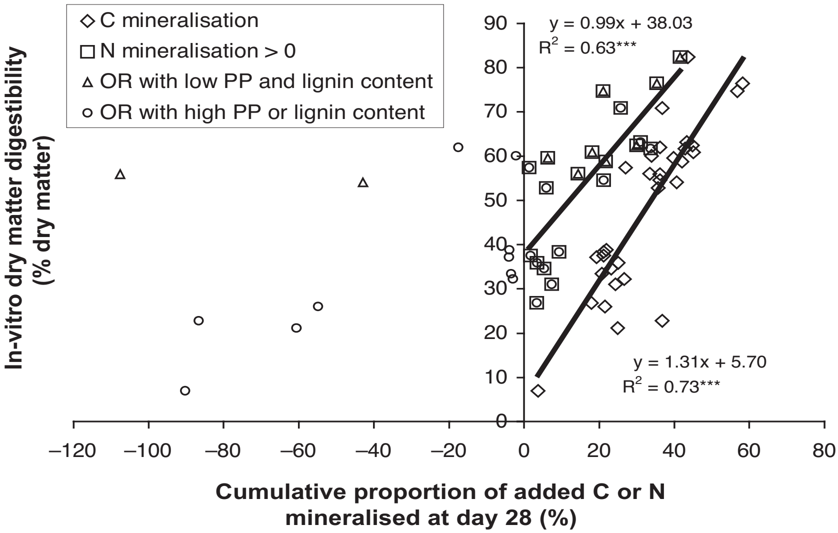

Figure 3. Relationships between C and N mineralisation as assessed using the aerobic incubation technique and the in vitro dry matter digestibility assay.

Cost and speed also need to be compared where more than one method is available. Aerobic incubations are one of the cheapest but slowest methods, compared with NIR, which is the fastest. Although NIR is expensive to purchase, for routine analysis of many samples it would be cost effective. Construction of spectral calibration libraries in central laboratory facilities would greatly increase the efficiency of NIRS use for routine organic resource characterisation in laboratories and dramatically reduce the costs of this analysis.

An issue that this analysis has raised is the inclusion of other parameters that should be included in simulation models to enhance their predictions of decomposition. This applies to only certain classes of resource quality. Only N content needs to be measured for Class III resources, whereas for Classes I and II there were no single quality indices.

For Class III resources that show positive mineralisation with time, including polyphenol content in the decomposition routines would increase the accuracy of prediction. Whitmore and Handayanto (1997) developed algorithms to include the polyphenol effect in decomposition and hypothesised the direct transfer of C and N to the stable soil organic matter, without any decomposition and loss of C.

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