# Agricultural and urban waste in tropical area: The help of Near Infrared Spectroscopy to better orientate their valorization between soil fertilization and energy production

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**Abstract**
For a safe utilisation of organic waste as valuable supply for agricultural soils or for energy production, an in-depth scientific knowledge of their nature and impacts on the environment is required. Near Infrared (NIR) Spectroscopy was chosen as an alternative to classical methods for laboratory characterisations of the so-called Exogenous Organic Matter (EOM). This study reported EOM characterization in terms of their agronomic and/or energetic potential, the help of NIR for predicting those characteristics and a scoring method allowed to choose the best recycling-way for EOM. As results, we noticed that diversified EOM induced different potential, and NIR was helpful for characteristics prediction. Also, classification elaboration of EOM and a scoring system were appropriate to orientate the reuse of tropical EOM.

## Introduction

As observed in northern/rich countries, there is an increase in the production of organic wastes in southern/less advanced countries. So called, Exogenous Organic Matter (EOM), they can be a valuable fertilizer or amendment for agricultural soils or a new supply for energy production. In agriculture, the practice of using EOM as a crop fertilizer can be ecologically sound, both solving a waste management problem and reducing the cost of chemical fertilizer. In energy production, the use of alternative fuel sources such as organic wastes can provide inexpensive auxiliary fuel or small scale combustion or thermo-chemical conversion. The safe utilisation of EOM requires an in-depth scientific knowledge of their nature and impacts on the environment. Laboratory analysis and experiments have to be carried out in order to know their complex structure related to their physical, chemical and biochemical properties. These techniques represent a relatively high cost and are time consuming. More recently, there is emerging awareness of the value of near infrared spectroscopy (NIRS) as a tool for environmental and biological analyses. Near infrared spectra contain a wide variety of information that can be inferred through statistical treatments rather than physical and chemical treatments of samples. Several studies of EOM using NIRS have shown that NIRS could be a valuable method for assessment of EOM characteristics. It has already been used to determine the total C and nitrogen (N) contents of poultry manure [1], to assess the elemental and biochemical composition of plant materials [2-4], composted materials [5, 6] and animal manures [7-10]. In this study, Near Infrared (NIR) Spectroscopy was chosen as an alternative to classical methods for laboratory characterisations of tropical EOM. The objectives of this study are (1) to characterize EOM in terms of their agronomic potential and/or energetic potential, (2) to test the suitability of NIR for predicting EOM characteristics and (3) to elaborate a typology, build with measured or predicted parameters by NIR, taking into account some environmental impacts of the different utilisations of EOM.

## Material and Methods

*EOM characterisation and NIR spectroscopy*

The dataset included 2199 EOM samples collected and analyzed in the context of different research programs and covering a broad range of fresh and transformed organic materials. In term of EOM origin, these included 50% of poultry effluents, 19% of bovine effluents, 17% of porcine effluents, 9% of urban effluents, 3% of agroindustrial effluents, 1% of ovine effluents and 1% of other EOM. 1199 EOM have been collected in Reunion Island and 1000 EOM came from Madagascar.

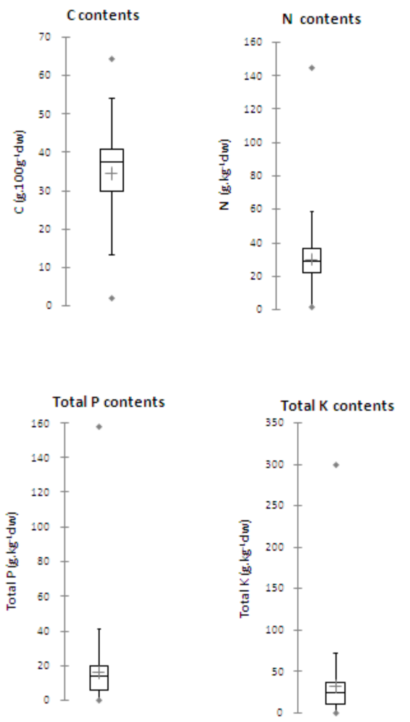
Each EOM was scanned using a NIR spectrometer from 1100nm to 2500nm. Calibration were performed with the WINISI Software (Infrasoft International).The ratio "performance to deviation" (RPD=SD/SE), was used as an indicator of model quality [11].
In addition to the classical laboratory characterisations (dosages of total C, N, P, K), other experiments have been conducted (i) for "positive" potentials: C and N mineralization measured in controlled conditions (for an agronomic use) [12], determination of High Heating Value and Biochemical Methane Potential (for an energetic use); (ii) for "negative" potential or risk: phytotoxicity assessment due to trace elements [13], and the determination of potential nitrous oxide emission.

*Typology methodology*
To elaborate the typology, the SIRIS method (System of integration of Risk with Interaction of Scores) was carried out. The SIRIS method is a decision-making tool designed to formalize the steps of a logical procedure, leading to a decision [14]. Two very important preparatory steps must be carried out before its implementation: selection of the variables to be taken into account and hierarchical classification of the criteria according to the objectives of the study. The criteria to be retained were carefully selected and assigned one of the levels: favorable, intermediate and unfavorable. As not all the criteria are of equal importance in the definitive decision, it was necessary to organize the criteria into a hierarchy of various classes, from the least to the most important. This hierarchical organization of criteria is the most difficult step and should take into account a maximum of considerations with respect to the final decision. The SIRIS method can then be applied to calculate scores for each EOM, to give an objective classification according to the aim of the recycling orientation (for agronomic and/or energetic reuse).

**Results**
*EOM characterization*
Diversity of EOM is illustrated (Figure 1) by the variability of (i) C contents (from 2 to 64 gC.100g$^{-1}$DM); (ii) N contents (from 0.2 to 14gN.100g$^{-1}$DM); (iii) total P contents (from 0.01 to 16gP.100g$^{-1}$DM),(iv) total K contents (from 0.04 to 30 gK.100g$^{-1}$DM).
"Positive" potential assessment provided information on (i) the quantity of remaining organic carbon that might be stocked into soil after applying EOM (from 102 to 955 kg.t$^{-1}$TOM), (ii) High Heating Value of EOM when recycling as a supply of small scale combustion or thermo chemical conversion (from 7 to 28 MJ.kg$^{-1}$DM), and (iii) Biochemical Methane Potential after EOM anaerobic digestion (from 69 to 488 NmlCH$_4$.g$^{-1}$TOM).
Both "negative" potential which took into account phytotoxicity due to trace elements or nitrous oxide emissions were highly dependent on the soil properties (pH, texture).

*NIR prediction of EOM characteristics*
When taking into account all EOM without regarding their nature: (i) excellent predictive models were obtained with NIR calibration for estimating N and C contents (RPD>3); (ii) approximate quantitative predictions were possible for total P or K contents (2 < RPD < 2.5). Figure 2 represented the measured vs predicted characteristics of EOM. The excellence of prediction by NIR of N and C contents can be explained by the strong absorbance of C-N, N-H and C=O groups in NIR [15] and these are the main characteristics of OM. The poor prediction results for total P and K contents could be explained by the fact that there was a lack of spectral absorption for minerals in the NIR region and that calibrations were generally not good because they depended on the relationships between organic components and the minerals, which are indirect or surrogate calibrations [16].

*Classification of EOM according to agronomic criteria*
The most important criteria selected were (i) the fertilizer value (N, P, and K contents), (ii) the capacity to restore C stock in soil (IROC) and (iii) the spreading constraints (dry weight of EOM). Three thresholds were defined for each criterion. Score varied from 0 (minimum score corresponding to EOM can be used easily as fertilizer) to 21 (maximum score corresponding to EOM can be used as soil amendment with a difficult spreading conditions.



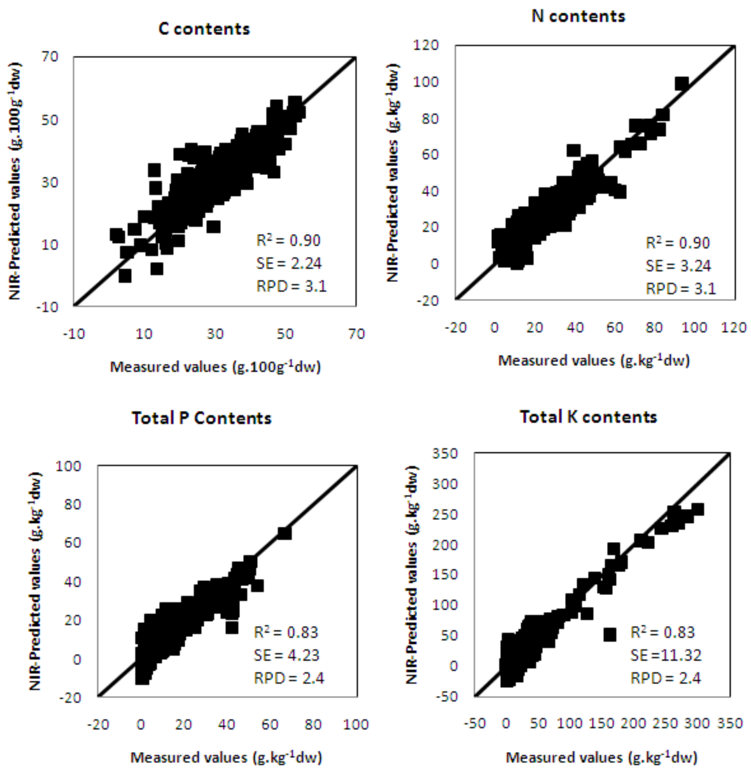




**Figure 1: Boxplots representing the variability of EOM contents (Carbon, Nitrogen, Phosphorus and Potassium)**

**Figure 2: NIR prediction of EOM characteristics (Carbon, Nitrogen, Phosphorus and Potassium)**

*Classification of EOM according to energetic criteria*

The most important criteria selected were (i) the dry matter contents of EOM, (ii) the degradability of EOM (biochemical fractions) and (iii) the available energy for microorganisms (CtoN ratio). Two thresholds were defined for each criterion. Score varied from 0 (minimum score corresponding to interested EOM for anaerobic digestion) to 12 (maximum score corresponding to EOM for bio-combustion process).

*Typology elaboration*

The SIRIS method appeared to be an efficient decision-making tool in this study. It made it possible to classify the EOM according to a simple process based on the ranking of criteria and a self-penalization scoring system. Weighting coefficients for the valorization criteria were determined automatically by a logical process that attributed a criterion penalty that increased in magnitude if the score for the previous criterion was unfavorable. Several factors are subject to debate, including the choice of criteria, their organization into a hierarchy, the thresholds for the levels and the validity of the data. However, this method has two potential advantages. Firstly, the classification can be based on several criteria, with no limits to the number of criteria that may be considered. In this study, we used only three criteria according to each scenario, but other relevant criteria could also have been used. The greater the number of criteria taken into account, the better the final scoring used for decision-making is likely to be. The second great advantage of this method arises from the selection system based on only three levels, with thresholds. Thus, this approach can be used in the absence of accurate, reliable data, which are often difficult to obtain.

Due to the size of our database (> 2000 spectra), numerous EOM had only spectra as available information for their classification. Thanks to the help of NIR prediction, scoring method was useful for better orientate their valorization between soil fertilization and energy production.

An orthogonal graph was built to plot the scores, expressed as a percentage of the maximum score, for all EOM (results not shown).The *x*-axis corresponded to the agronomic potential and the *y*-axis corresponded to the energetic potential.

## Conclusion and perspectives

An adapted typology of EOM from Madagascar and Reunion Island provides a good tool to orientate their potential use as a source of fertilizer or a valuable biomass for energy production. NIR spectroscopy allowed a rapid and non-expensive determination of several parameters that were used for classification. A visualization of relative positions of the EOM in an orthogonal graph, coordinates defined by scoring methods, distinguished EOM that should better used as fertilizers (agronomic utilization) from those that should better used for energetic purposes.

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