Review paper

# Use of agricultural and agroindustrial residues as soil amendments in Uruguay: opportunities, and challenges

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## Abstract
Recently the production of agricultural and agroindustrial residues has strongly increased in Uruguay. Although their uses is not extended environmental regulations has increased the interest in their use as soil amendments. In this work we reviewed the available information about the use of agricultural and agroindustrial residues as soil amendments, and propose guidelines for their use in different production systems of Uruguay. The agronomic evaluation of different types of residues has covered the chemical and physical characterization, evaluation under controlled conditions, and field evaluation experiments. In general the materials, although variable in characteristics present relatively low dry matter and nutrient contents. Under laboratory conditions they showed rapid decomposition, but nutrient availability depended on their composition. Field experiments were used mainly to evaluate possible application rates and frequency of application, considering crop yields and nutrient losses. The most important environmental problems related to the use of waste materials are nutrient imbalances, which led to losses and soil accumulation. However it is possible to prevent these risks through a careful selection of the application sites and using moderate application rates. On the other hand the organic amendments could be used for soil organic matter (SOM) recovery, as was found in long term experiments. One of the most important aspects of waste materials use is to establish a monitoring plan, based on soil and plant analysis to avoid excessive rates, which can cause decreases in crop yields and environmental damage.

## Introduction
The soil amendment with agricultural and agroindustrial residues has been long used in agriculture. However, in Uruguay this practice is not extended, except for a few situations, mainly involving the addition of different kinds of manure in horticultural production. This can be explained by many factors, among others the lack of environmental regulations, which led to a careless disposal of the agroindustrial residues. According to the recent regulations these options are not acceptable, and the companies must present a plan for residues disposal. On the other hand the production of agroindustrial residues, which was rather limited in area and time, has strongly increased. Recently increases have been reported in number and production capacity of dairy, meat, timber, sugar, biofuels, and cellulose factories (DIEA, 2012). But also the traditional beef and dairy production under pasture grazing, is being increasingly developed in shelters, with an important accumulation of manure and fodder residues. The application of the residues as soil amendments is the obvious response to the problems created, but many scientific, technological and environmental issues should be assessed before practical solutions are found.

In this work we reviewed the available information about the use of agricultural and agroindustrial residues as soil amendments, and propose guidelines for their use in different production systems of Uruguay.

**Agronomic evaluation of agroindustrial residues**

Although the use of agroindustrial residues as soil amendments in Uruguay is relatively new, the Soil and Water Department of the Agronomy Faculty, has produced considerable information regarding to the evaluation of different agroindustrial residues. Also the INIA Institute, belonging to the Ministry of Agriculture, has developed research in this area. The information is however dispersing, and different approaches have been used.

Given the different characteristics of the residues, one of the first steps towards the correct application is a complete characterization of the materials. According to Barbazán et al. (2011), in a survey of the most commonly used organic amendments, the materials showed a wide range of characteristics, and some of them were poorly defined. In this work the analyzed materials were collected from commercial farms, and some of them were mixed with soil, or stored in inadequate conditions. In their work the most commonly used amendments were characterized since the chemical and physical point of view. They provided tables encompassing the variability in characteristics, as a guide for users of 96 materials grouped into: i) cow and chicken manures with and without bedding (rice hull, cereal stroh, forest litter), ii) composted residues and iii) a miscellaneous group that included industrial slurry from maltery, residues of chicken slaugter, hair from tannery, wool, and ashes. The characterization showed a wide range of dry matter and nutrient contents, which make the different materials more or less valuable as soil amendments, however no one presented high levels of heavy metals, indicating that they will not produce soil contamination. Another concern in waste materials, the high Na content, was not found in the studied materials; however some of them presented moderate Na contents, which make advisable the monitoring of the exchangeable Na in the soils where the materials are applied. Although this characterization will be useful to plan the utilization of wastes generated from different activities, the final recommendation was the analysis of any given residue, previous to the land application.

Another approach to this matter was focused in the reaction of the different materials with soil, mainly through laboratory and pot studies. In laboratory experiments the mineralization patterns of different materials were determined under controlled conditions (humidity at field capacity and temperature between 20 and 25$^0$C). The studied materials were: dairy and poultry manures compared to chicken manure with rice hull bedding (del Pino et al., 2008); chicken manure, composted residues, and sheep and cattle manure mixed with forest litter (Barbazán et al., 2008), biogas sludge originated by anaerobic incubation of residues from meat and tannery industries (del Pino et al., 2012). In these studies the C mineralization of the materials mixed with the soil was rather fast, but $C_2O$ losses reached a plateau after less than half of the materials were decomposed, which indicates that in the long term they can contribute to maintaining the soil organic matter. The N mineralization on the other hand was in general related to the C:N ratio, with large amounts of N released from materials with C:N ratios around 20. When C:N was higher than 30, the mineral N release was limited, or even lower than the control soil at the beginning of the incubation. However, after a relatively short period of immobilization (10 to 15 weeks) the mineral N release was higher than the control soil. An example of the trends in C mineralization patterns is presented in Figure 1.

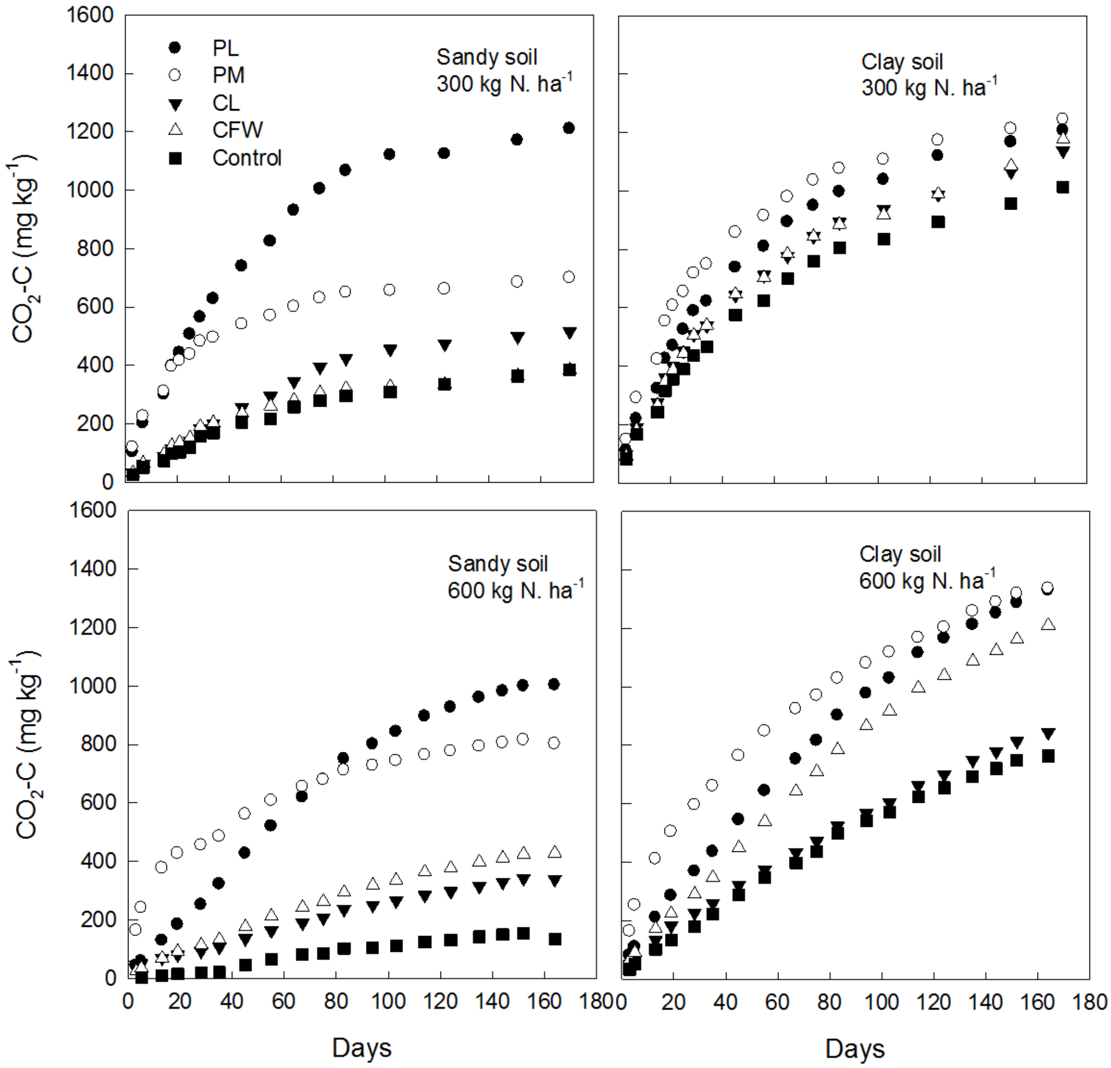


Figure 1. Carbon evolved from soils receiving poultry manure litter (PL), poultry manure (PM), cow manure litter (CL), composted waste (CFW), and control at two rates of nitrogen in two soils representative of the horticultural soils of Uruguay (Barbazan et al, 2008).

The third group of studies was related to field evaluations, involving different materials and crops, and analyzing the nutrient release from the amendments. These experiments were valuable to test different application rates and frequencies. Casanova et al. (2004) investigated the effect of dairy effluents on a pasture and crop rotation. They also examined different treatments for the effluents (anaerobic lagoon vs. direct application). Barbazán et al. (2011) studied the effect of chicken manure, and sheep and cattle manure mixed with forest litter on greenhouse tomatoes. In this work the best treatments for tomato production were moderate application rates, while the highest rates applied produced decreases in yield, probably due to excessive N availability, which promotes shoot growth, decreasing fruit production. Barbazán et al. (2012) studied the effect of a single application of maltery slurry broadcasted on a *Festuca arundinacea* sward, reporting increases in nutrient absorption and forage yield in the treated plots. The effect of a single application of biogas slurry broadcasted on a *Festuca arundinacea* sward was examined by del

Pino et al. (2012). Díaz (2012) studied the application of composted and fresh ckicken manures on a rotation of horticultural crops. All these studies based the application rates in N content of the slurries, finding that the N availability was in many of them, especially chicken manure, maltery and biogas slurries, comparable to the synthetic N sources. They also reported substantial increases in other nutrients availability (P, Ca, Mg, and micronutrients), which could contribute to the crop nutrition. Interestingly in most of the evaluations the effect of the amendments was extended in time beyond the effect of the synthetic fertilizers. Also the nutrient absorption by the crops exceeded in some cases the applied rates, indicating that the increase in biological activity produced by the organic amendments, made available other nutrient sources. An example of the trends in response of pastures to slurries application is presented in Figure 2.

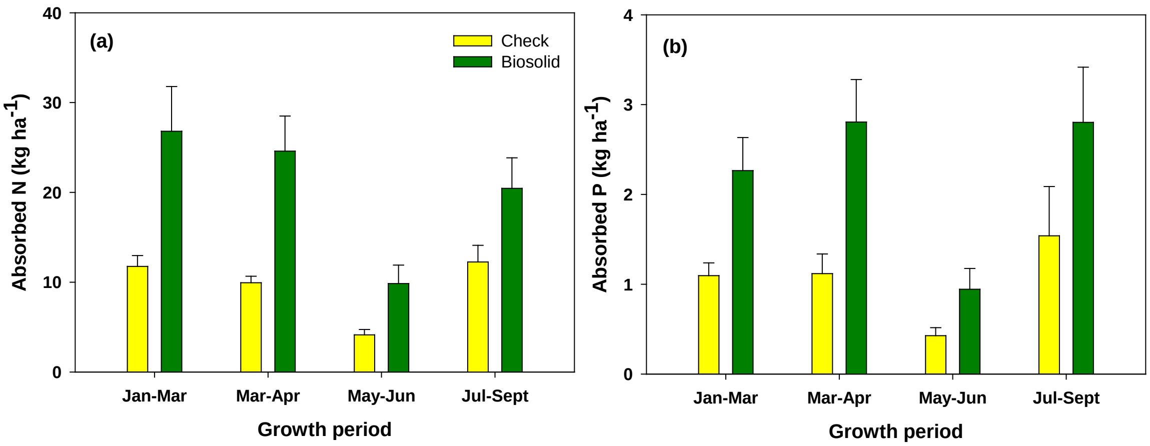


Figure 2. Absorption of N and P by *Festuca arundinacea* pasture, after a single application of 100000 L $ha^{-1}$ of biogas slurry (del Pino et al., 2012)

Regarding to positive effects of organic amendments on soil quality, Coscia et al. (2010) studied the long term effect of different combinations of cow manures and green manures in a degraded soil. After 7 years al the treatments produced improvements in SOC compared to the control, and the best combination was a 100 $m^3$ $ha^{-1}$ cow manure application with summer and winter green manures.

## Environmental challenges

The application of fertilizers and soil amendments present environmental risks. One of the first challenges is to maximize the nutrient utilization by crops, and to lessen the nutrient losses to the environment. For soil amendments this adequation is more difficult than for synthetic fertilizers, because it is not always possible to predict the extent and timing of the nutrient release. Therefore, the farmers tend to apply larger amounts of amendments than the requirements of the crops. This fact was corroborated by Barbazán et al. (2010) in a survey of 30 commercial greenhouses for lettuce and tomato production, using different organic amendments. Most of the sites presented mineral N levels many times higher than the requirements of the crops, which could led to leaching and denitrification losses (Figure 3). The mineralization process depends in a great extent on temperature and water availability. Hence, to predict the nutrient release from organic amendments not only C:N ratios must be considered but also the climatic conditions, which can accelerate the process. The use of organic matter mineralization models would be a valuable tool for this purpose, and some attempts have been made, although with a limited extent (García de Souza et al., 2011).

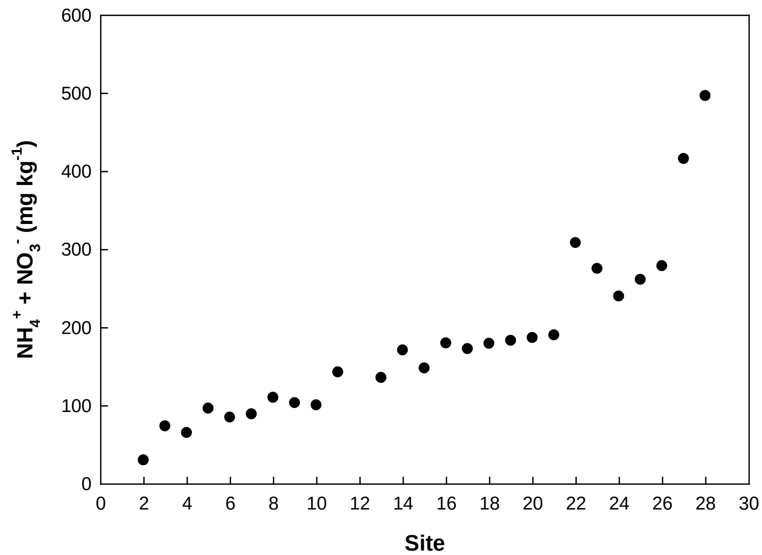


Figure 3. Mineral N in 0-20 cm soils from greenhouses, before crop planting (Barbazán et al., 2010).

Other possible negative environmental effects of residues as soil amendments, heavy metal accumulation, were not observed, probably due to the fact that the agricultural and agroindustrial wastes did not present high contents of heavy metals (Barbazán et al, 2011; del Pino et al., 2012).

**Practical implications**

The use of the agroindustrial residues is necessarily local. Most of the materials present a relatively low content of dry matter and nutrients, which makes the transportation cost an important component of the technological solutions. However, the characteristics of Uruguayan landscape with large availability of agricultural land in the majority of the country will facilitate the disposal of the residues.

The horticultural production, which makes at present the larger reception of amendments, has the advantage to incorporate the materials during the soil preparation. Therefore, the risk of runoff is minimized. On the other hand the pasture and cereal crop production utilize no till methodologies, which imply the broadcast of fertilizers and amendments without incorporation. This practice will represent a challenge, considering the large application rates required, due to the low nutrient contents of the amendments. In this context the selection of the application sites will require, a careful landscape evaluation, avoiding high slopes and the vicinity of water streams.

In any of the production systems the amendment rates should be selected considering the nutrient concentration. In general N and P rates can be used as a guide to recommend the amendment rates, but in parallel the other nutrient application rates should be calculated, in order to be aware of any unbalances produced.

The use of amendments, due to the uncertainty of the nutrient release, requires a monitoring program. Soils should be sampled and analyzed in order to detect undesirable accumulation of P and heavy metals and to prevent losses. The plant analysis can be also a tool in the monitoring program in order to detect any excess or nutrient imbalances.

**Guidelines for the use of residues in production systems of Uruguay**

1) Physical and chemical characterization of the residues, including dry matter content, bulk density, C, N, P, Ca, Mg, Na, Cu, Fe, Mn, and Zn contents, and other particular elements that are possible to be found in the residues according to the bibliography.
2) When the residues are generated during long periods the variability en characteristics and composition should also be evaluated, and the ranges in composition taken into account for planning their use.
3) Bioassays of the materials under controlled conditions in order to assess their ad equation for plant growth, and nutrient availability.
4) Careful selection of the application site, preventing possible nutrient losses (gaseous, leaching, runoff).
5) Selection of amendments rates, taking into consideration the nutrient concentrations and variation, avoiding excessive or frequent applications, which can produce losses or accumulation of nutrients or heavy metals.
6) Monitoring plan to assess the effects of the amendments in the long term.

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