Uptake of organic effluents by lignocellulosic wastes and implications for compost production.

Farinet Jean-Luc[1*], Condom Nicolas[2], Cazevieille Patrick[1], Montange Denis[1], Montes Melanie[1], Marger Jean-Luc[1]
(1) CIRAD, UR Recycling and Risk, Avenue Agropolis, 34398, Montpellier, FR
(2) Ecofilae, Campus Sup-Agro-INRA, 2 place Viala, 34060, Montpellier, FR
*Corresponding author: jean-luc.farinet@cirad.fr

Abstract
Nowadays, the biological treatment of organic waste is clearly encouraged, to limit the environmental impact of disposal and promote the recycling of organic matter in the soils. Compost production grows significantly in Europe but many agricultural or agroindustrial wastes are in liquid or semi-solid forms. To be composted, they must be mixed in specific proportions with lignocellulosic residues. In this work, we conducted a comparative study on the uptake of effluent at different concentrations on straw, hay, wood chips and sawdust. Although the sorption mechanisms differ from a lignocellulosic waste to another and for low to high effluent concentration, we obtained final products which are in the limits of moisture content and free air space for composting. Whatever the concentration of the effluent, net balances on solids suggest their affinity for wheat straw. At low concentration of the effluent, water retention is predominant for hay, wood chips, and to a lesser extent , the sawdust.

Introduction
European policy encourages the use of biological treatments to limit the amount of waste landfilled or incinerated. In addition to climate change and energy issues, the management of organic waste is also adressing agricultural issues. Indeed, soil quality declines rapidly in many parts of the world. In Africa, ca. 6.3 million hectares of degraded agricultural lands have lost their fertility and their ability to retain water [1]. The European Commission estimates that 45% of European soils, mainly in Southern Europe, have a reduced content of organic matter. The need to recover organic waste for agriculture has increased the interest in compost production. Compost is one of the categories of waste that the new EC Waste Framework Directive 2008/98/EC has recognised as candidates for "end of waste" criteria [2]. In France, composting has experienced significant growth in recent years mainly driven by the development of green waste collection and their co-composting with sewage sludge. In livestock farms or in agro-industries, organic wastes often consist on semi-solid or liquid manure and effluents containing large amounts of organic and mineral compounds. Direct composting of these wastes is not possible and they need to be mixed with solid waste as cereal straw, green or wood waste. One critical impact on subsequent composting is the uptake rate of organic effluent by the biomass. In the case of imported solid waste, their mobilization may generate costs which will be as more lower than the amount of waste required is smaller. This rate will also influence the composting parameters of the final waste-effluent mixture (moisture, free air space, C/N ratio), as well as the quality of final compost (organic and nutrient contents).

When solid wastes are soaked in liquid effluent, water uptake occurs as well as solid exchanges between the waste and the effluent. Mass transfer processes depend on temperature, on the solution concentration and on the waste composition and structure. Kinetics of moisture sorption is based on Fick's law of diffusion. Numerous models are used in food or wood sciences to predict the temporal evolution of the moisture content in the moisturizing of biological materials [3, 4]. However, few results appear on the intensity of the sorption in concentrated liquid media. Solids from waste and effluent might play an important role on the sorption process. Sugar and fat coating or solids deposit could delay moisture sorption during soaking. It should also be stressed that solids coming from waste could be lost into the effluent solution. In this work, we measured the uptake of an effluent at 6 dilution rates by 4 different lignocellulosic wastes when soaked at ambient temperature and over a time period typical of pretreatment before composting. The objective was to assess the influence of the effluent concentration on effluent uptake and water uptake, as also on solids fate and mobility.

Material and Methods

Organic effluent and lignocellulosic wastes

The organic effluent used was a concentrate issued by a yeast production plant which uses sugar beet molasses as growth substrate. This effluent was diluted with deionised water to obtain 6 solutions with various contents in total solids (TS): 3.8, 7.0, 10.8, 20.8, 40.0 and 57.6%.

Four lignocellulosic wastes were tested: wheat straw, hay, wood chips and sawdust. They came from a farm and sawmill located near the yeast production plant. The wastes were first dried at room temperature until their initial moisture level was around 10%. The sizes of the strands of hay and straw varied between 1 and 25 cm in length with a thickness of 0.05 to 0.6 cm. Wood chips sizes were between 1 and 3 cm in length with a thickness of 0.01 to 0.03 cm. The particle size of sawdust ranged between 0.1 and 0.3 cm. To obtain a similar apparent volume, individual test samples were prepared with 20 g of straw, 15 g of hay, 5 g of wood chips and 10 g of saw dust.

Lab experiments

First of all, the moisturizing capacity of the wastes has been tested to define the minimum soaking time to be applied. Waste samples exhibited typical sorption behaviour with increasing water content versus soaking time at ambient temperature. An empirical non-exponential Peleg model, suitable for modelling the sorption behaviours of many food materials, was used for water uptake description. For the four tested wastes, the calculations showed that with a soaking time of 4 hours, more than 95% of the maximum capacity of moisturizing is reached. Three test samples of each waste were selected for each run, weighed and soaked for 4 hours at a temperature of 25°C in solutions consisting with effluent at various TS contents. Triplicates were then removed from soaking and allowed to stand for 4 hours on a grid in a covered container so that excess effluent could drain without losses of water by evaporation. The volume occupied by the wet samples was measured immediately in a graduated cylinder under a weighted plate giving a uniform pressure of 44 10^3 Pa. After weighing, the wet samples were dried at 70°C to constant weight. The effluent uptake represents the effluent amount that the waste has adsorbed. It was determined by weight difference and expressed in relation to the initial mass of waste ($kg.kg^{-1}$). The water uptake was determined by weight difference before and after drying, reduced by the initial moisture of waste samples. Excess or deficiency in solids uptake is calculated by a mass balance on the basis of the weight and the water content of the samples. Free air space (in % wet waste) was calculated as the difference between the volume occupied by the wet samples and the volumes of water and dry matter, taking into account a 1600 $kg.m^{-3}$ density for dry matter [5].

Results and discussion

Effluent uptake

Effluent uptake values were significant and vary from 1.87 ± 0.10 to 5.51 ± 0.03 $kg.kg^{-1}$. The different behaviour of the lignocellulosic wastes is shown in Figure 1.

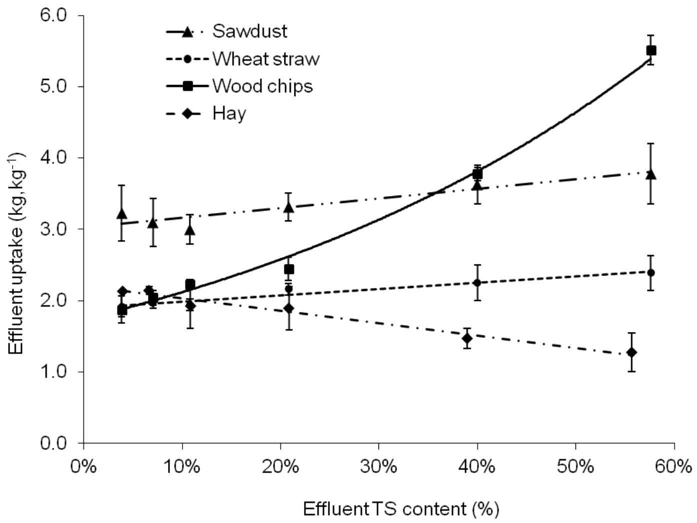

Figure 1. Effluent uptake of the lignocellulosic wastes as a function of effluent TS content

Residual heteroscedasticity was not found indicating the stability of the waste structure during soaking time. For sawdust and wheat straw, effluent uptake increases linearly with effluent TS content. For wood chips, this increase is rather exponential while for hay, the uptake decreases linearly with effluent TS content. For wheat straw, hay and wood chips, calculated free air space ratio in the final product stay always between 82 and 93%. For sawdust , this ratio is lower and decreased from 65 to 46% when the effluent TS content increases. This last value is close to the limit considered for proper aeration during composting [6].

Water uptake
As shown in Figure 2a, the water uptake was fund to decrease linearly with effluent TS content, with the exception of wood chips for which it increases. As a consequence and taking into account the previous results of effluent uptake, the solids sorption isotherms are also linear with the exception of the wood chips. The magnitude of water uptake may be correlated with the ability of the lignocellulosic matrix to take up water [7]. Sawdust has the best ability because of its small particle size. Unlike other wastes, wood chips favor water uptake when the effluent TS content increases.

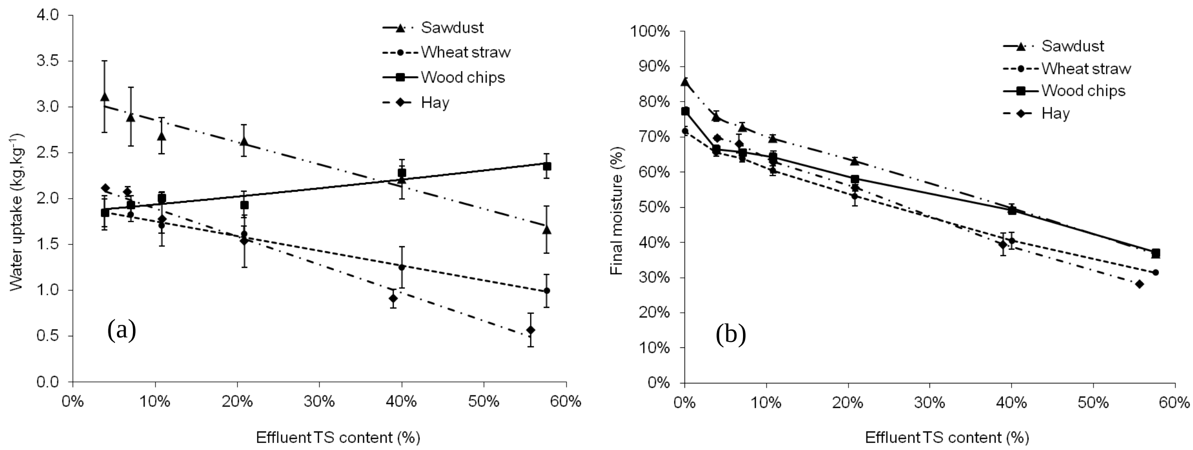

Figure 2. Water uptake (a) and final moisture (b) of the wastes as a function of effluent TS content

Figure 2b shows that the final moisture content of the wastes decreases linearly with the solids content of the effluent. This result is consistent with the precedent. For the wood chips, the water uptake increase is combined with the exponential increase of solids uptake, giving finally a moisture decrease as for the other wastes. Considering the optimum moisture content for micro-organism activity is in the range 50-70%, corresponding TS contents range from 3 to 27% for wheat straw and hay, 3 to 38% for wood chips and 10 to 38% for sawdust.

Excess or deficiency in solids uptake
As it can be seen in Figure 3, deficiencies in solids uptake are important at low TS contents in the effluent, except for wheat straw for which there is instead an excess of retained solids. The results obtained for hay and wood chips explain their performances in uptakes of effluent and water.

Solids measurement represents a net value because part of the waste could be lost in the solution and solids from effluent are simultaneously adsorbed by the waste. Taking into account the structure of lignocellulosic wastes, we can reasonably assume that the loss of solids in the solution is limited. In these conditions, the uptake of effluent seems to be homogenous for TS contents higher than 20% in the case of wood chips and sawdust. Below this threshold, the water uptake is predominant compared to solids retention. For hay, this threshold would be rather near 40% TS content. The case of wheat straw is different with a predominant solids uptake for effluent TS contents below 50 %. This material has a high specific area which may explain the solids uptake in excess compared to other solid waste.

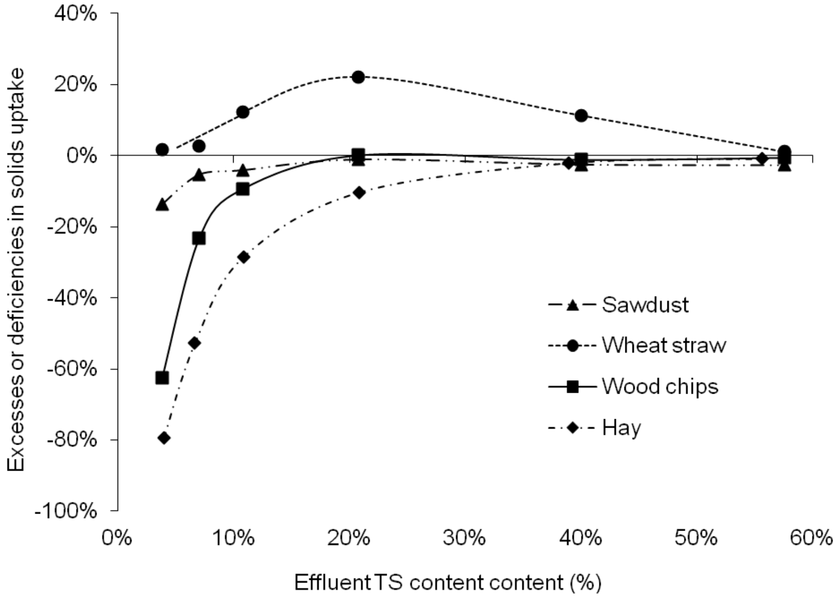

Figure 3. Excesses or deficiencies in solids uptake as a function of effluent TS content

Conclusion and perspectives

Effluent uptake on lignocellulosic wastes involves complex mass transfers and sorption phenomena, particularly when considering the complexity and variability of their structure. Water and solids uptakes occur to a significant extent at ambient temperature, but with a different rate depending on the waste and the effluent TS content. Low TS content solutions have a greater amount of “free water” which may explain the higher ability of the waste to take water up in these solutions. In concentrated solutions, effluent uptake tends to be more homogeneous. But the wheat straw is an exception because it shows an affinity for solids whatever the concentration of the effluent. For all the lignocellulosic wastes tested, a wide range of effluent concentrations is compatible with composting in terms of final moisture and porosity. Following these results, similar studies have been initiated with a crude effluent really intended to compost. Concentrations of carbon, nitrogen and other minerals are then taken into account and they act as additional limiting factors to stay within the limits permitted for composting.

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