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Use of Potato Peelings in Composting Techniques: A High-Priority and Low-Cost Alternative for Environmental Remediation

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ABSTRACT

Castilla y León is the leader among Spanish vegetable producers and consumers, with high cultivation and consumption of cereal and potatoes; and with an important alimentary industry based on these cultures (*Gullón* and *Siro* groups), which produces a significant volume of residues such as straw and potato peelings. This paper reports our results on a chips factory remainders composting, under three different experimental conditions: only potato peelings and shavings, potato peelings with sewage sludge composting, and potato peelings with low grade meat composting. Tanneries remainders contain utilizable nutrients, but also toxic organic compounds which might affect soil processes and plant growth, and pathogens, which might pose a threat to the local farming community. Composting processes were monitored through different assays and their respective efficiencies were determined. The composting resulting products were characterized by electrolytic conductivity, pH, C:N ratio, and germination index (based on Zucconi method). Some resulting products were rich in organic matter, free of phytotoxicity, and had a high potassium and organic nitrogen content. We believe that this kind of compost can be useful for recultivation purposes of humus-free soils from old gravels in our geographic area. Consequently, different compost mixtures are being evaluated in order to examine their suitability for the formation of stable soil organic matter.

Keywords: sawdust, sewage sludge, straw, tanneries wastes
Abbreviations: GI, germination index

INTRODUCTION

The composting process

Composting is a technique used since ancient times by farmers and gardeners in order to obtain manure from waste. This justifies the interest that this process involves for organic farming. It should be kept in mind that until the introduction and development of chemical fertilizers, organic waste was the only way of adding nitrogen and the most important manner of providing other nutrients.

Since then, different composting systems and numerous tests with diverse wastes have been designed: municipal organic wastes (Costa *et al*. 1992); co-utilization of agricultural, municipal and industrial by-products (Brown *et al*. 1998); high-quality composts for horticultural purposes (Raviv 2005a); sewage sludge as nutritional source for horticultural soils (Casado-Vela *et al*. 2006) and with vermincompost (Khwairakpam and Bhargava 2008; Martín-Gil *et al*. 2008). All this, together with the mechanization of the process, has contributed to the fact that nowadays composting can be applied in soil remediation (Vasudevan and Rajaram 2001) and be economically profitable in afforestation areas (Larchevêque *et al*. 2006) or contaminated soils (Lau *et al*. 2003). Recently, our group has made composting experiments of hydrocarbons from the Prestige oil spill (already aged and enriched in asphaltens) with different types of fertilizers and thickening agents, and the best results (evolution of the composting process) occur when cow bed and potato peelings are used (Martín Gil 2008).

Advantages of composting

Many wastes are produced from agricultural and municipal facilities that are not suitable for direct land application. Composting these wastes converts them to a humus-containing organic material advantageous for crop production. Major advantages are to stabilize the wastes, substantially reduce the carbon-to-nitrogen ratio (in the case of agricultural residues and municipal solid wastes), reduce and virtually eliminate odours, weed seeds, and pathogens and to produce a product easily handled mechanically (Kuhlman 1990).

Composting has the advantage over other waste-treatment systems that the final product or compost is of interesting agronomic value for the following purposes:

(i) *Soil amendment*: Compost is a valuable soil amendment that improves texture thus reducing the chances for erosion. The benefits of using solid waste compost as an organic soil amendment may be seen in agricultural land, but compost should only be applied to soil after it has been characterized and shown to be safe. The main widely demonstrated positive impacts of compost amendment to soil include improving soil tilth, water-holding capacity, structure, and disease suppression. Composting can be used as organic amendments by the addition of organic wastes with higher humic acid concentration for remediation of soils polluted with gasoline (Tejada *et al.* 2008). Sánchez-Arias *et al.* (2008) noted that the grain production obtained in the tests carried out dosing compost containing ferrous sulphate waste was always about a 16% higher than that obtained in the agronomic test carried out with traditional compost.

(ii) *Manure*: Composting is an aerobic process that al-

Received: 28 July, 2008. Accepted: 22 November, 2008.

Original Research Paper

lows microorganisms to decompose organic material. During this process heat, carbon dioxide (CO_2), and water vapor are released into the atmosphere thus reducing the weight and mass of the material (Rynk 1992). Manure that is excreted from dairy cattle contains 88% water and 12% solids. Composting reduces the moisture content to about 50% allowing for easier transportation. Under saturated conditions, acidic blend amended soils may also release greater concentrations of trace m*etal*s to the environment as compared to alkaline blend amended soils (Mukhtar *et al.* 2008). Moisture content has been referred to as a critical factor to optimize compost-engineering systems because decomposition of organic matters depends on the presence of water to support microbial activity. Optimum moisture requirements for successful composting of a wide variety of organic wastes range from 25 to 80%, indicating that a more fundamental and inclusive parameter is needed for understanding the physical and biological interactions controlling composting (Stentiford 1996; McCartney and Tingley 1998). Too high or too low moisture contents reduce composting process efficiencies. Therefore, moisture content control is the key for composting (Rynk 2000; Luo and Chen 2004). Increasing the volumetric mixing ratio of bulking agent to sewage sludge in the upper half zone of the pile improved the temperature rising rate, shortened composting cycles, prolonged the thermophilic temperature stage and killed most of pathogenic organisms in different layers of the pile when the initial moisture content was adjusted to suitable values (about 60%) (Luo *et al.* 2008)

(iii) *Substrate*: Composting companies, which traditionally dealt mainly with manures and green wastes, are now confronted with the need to study the characteristics of specific substrates or their mixtures as they may differ in their transformation during the composting process and in their agricultural value. The low salinity of green waste composts makes them attractive substrates for greenhouse potting media (Zmora-Nahum *et al.* 2007). Efforts are being made to reduce the use of peat as a potting substrate and to replace it with recycled materials. Using compost as a partial substitute for peat in a growing media would be economically attractive and would help to conserve finite peat resources (Siminiss and Manios 1990). A composted material obtained from forestry wastes and solid phase of pig slurry was evaluated by Ribeiro *et al.* (2007), as a substrate component for the production of tomato and lettuce seedlings. Results from the study suggest that the compost studied is a good alternative to peat-based substrates for the production of vegetable seedlings. There are, however, certain limitations on the use of some composts: increase in salt content to levels which might affect the growth of sensitive crops (Ribeiro *et al.* 2000; Castillo *et al.* 2004); heavy m*etal* toxicity; low overall porosity and a marked variation in physical/chemical properties (Vavrina 1995; Raviv 1998; Ribeiro *et al.* 1999; Spiers and Fietje 2000; Hicklenton *et al.* 2001).

(iv) *Thermal inactivation of pathogens*: Many different groups of pathogens may be found in composted raw matter (yard waste, manure, sewage sludge and municipal solid waste). Contaminations are mainly of faecal origin, therefore the group of enteric pathogens that include bacteria, viruses and parasites (protozoa and helminths) is the most prevalent (Déportes *et al.* 1998). Composting is commonly used to treat solid wastes prior to recycling or disposal. It reduces the amount of material to handle and has the potential to inactivate pathogens thermally. The use of composts to suppress soil-borne plant pathogens has been reviewed by Ryckeboer (2001). Different mechanisms have been postulated to control plant diseases by compost application (Hoitink *et al.* 1993) such as competition for nutrients, antibiotic production by beneficial micro-organisms or activation of disease-resistance genes in plants. Compost obtained from heterogeneous vegetable wastes shows important suppressive effects against diseases caused by several plant pathogens such as *Pythium* spp. (Pascual *et al.* 2000), *Phytophthora* spp. (Widmer *et al.* 1999), *Rhizoctonia* spp. (Tuiter *et al.* 1998).

The concern over pathogens has increased with the used composts derived from materials such as farmyard manure that may be infected with organisms such as *Escherichia coli O157* or *Salmonella* spp. A sufficiently high composting temperature should inactivate many common pathogens likely to be present in solid animal waste. Turner *et al.* (2005) inferred core temperatures (and hence pathogen inactivation) from the surface temperatures of compost heaps. Droffner and Brinton (1995), conducted several experiments in order to study the survival of population in aerobic thermophilic composts. Droffner and Brinton (1995) also reported that *E. coli* and *Salmonella* were inactivated in 9 days at 60–70ºC in bench scale composting of food waste with leaves.

Bacillus spp., *Enterobacter* spp., *Pseudomonas* spp., *Streptomyces* spp. and other bacterial genera, as well as *Penicillium* spp., *Aspergillus* spp., *Trichoderma* spp., *Gliocladium virens*, and other fungi have been identified as biocontrol agents in compost-amended substrates (Chung and Hoitink 1990; Hoitink *et al.* 1993).

Composting is not a sterilization process. Enteric bacteria reduced to low levels during the thermophilic process (discussed below) may re-grow to higher density, under proper conditions, in finished stockpiled compost or following land applications. *Salmonella* spp., in particular, may pose a re-growth potential problem and health hazard (Skanavis *et al.* 1994).

Composting from the microbiological process point of view

Composting is a microbiological process in which a large number of bacteria, fungi and actinomycetes are involved. It is a dynamic process, since each microorganism species requires certain environmental conditions that occur only during a relatively limited time, and each one is capable of decomposing a certain group of organic materials. The factors that influence most species of microorganisms that exist at each moment are temperature and available food. Next these aspects will be approached in detail gathering some examples of scientific literature:

(i) *Microbiological process*: Composting is a dynamic process carried out by a rapid succession of mixed microbial populations. The main groups of microorganism involved are bacteria, including actinomycetes, and fungi (Golueke 1991). Although the total number of microorganisms does not significantly change during composting, the microbial diversity can vary during the different phases of composting (Atkinson *et al.* 1996a). The precise nature of succession and the number of microorganims at each composting phase is dependent on the substrate and on the preceding microorganisms in the succession (Crawford 1983). At the beginning of composting mesophilic bacteria predominate (*Pseudomonas*, *Bacillus*, *Lactobacillus*), but after the temperature increases to over 40°C, thermophilic bacteria (*Bacillus*, *Thermus*, *Hydrogenobacter*) take over and *Streptomyces* and thermophilic fungi also appear in the compost. When the temperature exceeds 60°C, microbial activity decreases dramatically, but after compost has cooled, mesophilic bacteria and actinomycetes again dominate, in addition to fungi (*Ascomycota*, *Basidiomycota*) (McKinley and Vestal 1985; Strom 1985a). In the maduration stage, Gram (-) bacteria, actinomycetes and fungi (*Ascomycota*, *Zygomycota* and *Oomycota)* are predominant (Noble and Roberts 2003).

Composting is an aerobic process in general, but anaerobic microenvironments may develop. Atkinson *et al.* (1996b) estimated that almost 1% of all the bacteria found in municipal solid waste compost were anaerobic. All the anaerobic bacteria found were highly cellulolytic, and thus may play a significant role in the degradation of macromolecules. The majority of the mesophilic anaerobic bacteria were facultative, while under thermophilic conditions more obligate anaerobic bacteria were found.

(ii) *Stages*: Composting is a process that combines microbiological aerobic mesophilic (15-45°C) and thermophilic (45-70°C) phases for the processing of organic waste into a stable, free of pathogens and weed seeds product that may be applied to the soil as an organic fertilizer (Miller 1996). The temperature profile can be used to classify the stages of composting into pre-thermogenic (mesophilic), thermogenic (between 60 and 82°C; thermophilic or temperature ascent) and post-thermogenic phase (cooling or temperature descent), and maturation (Finstein and Morris 1975; Godden *et al.* 1983; Beffa *et al.* 1996).

As an example, we may focus on paper and boards of municipal solid waste: compostable household waste contains, together with vegetable material, varying amounts of papers and boards. Paper is made up of lignocellulose and it may contain up to 20% of lignin. Efficient degradation of papers in composting plants means that biodegradation of lignin is also needed. The elevated temperatures found during the thermophilic phase are essential for rapid degradation of lignocellulose. Complex organic compounds like lignin are mainly degraded by thermophilic microfungi and actinomycetes. The optimum temperature for thermophilic fungi is 40 ± 50°C which is also the optimum temperature for lignin degradation in compost (Tuomela *et al.* 2000).

Food available through enzyme from microorganisms

Successful conversion of organic matter into simpler units of organic carbon and nitrogen is the basic functional process of composting. Composting helps in managing large quantities of organic wastes in a sustainable manner. It is one of the technologies of integrated waste management strategies, used for the recycling of organic materials into a useful product (Giglotti *et al.* 2005). Microorganisms through different kinds of substrate based hydrolytic enzymes promote the degradation of organic materials. The enzymes released by the microorganisms during composting breakdown several organic compounds characterized by a complex structure, finally leading to the solubilisation of simple water soluble compounds (Benitez *et al.* 1999).

With regard to the types of materials that the different microorganisms are capable of assimilating, it is accepted that those low molecular weight materials which are soluble in water can quickly pass through the cell-wall and therefore can be metabolized by a wide range of non-specialized organisms. However, high molecular weight polymeric materials cannot get through the cell-wall and only a limited number of specialized organisms are able to produce their breaking. The latter occurs through the production of some extracellular enzymes which hydrolyze the long polymer chains into mono- and oligo-saccharides of short chain length.

The degradation of the labile substrates contained in organic materials can be followed by studying specific hydrolases, which are relatively easy to determine, and specific to the substrate (Ayuso *et al.* 1996). Extracellular enzymes are known to be involved in the depolymerization of different constituents of organic wastes. Some important enzymes involved in the composting process include cellulases and β-glucosidases related to C mineralization, proteases and urease involved in N cycle and phosphatases and arylsulphatases related to P and S cycles (Mondini *et al.* 2004). Some authors have reported a decrease in enzymatic activity during the composting process related to the decline in microbial activity and available substrates (García *et al.* 1993; Benitez *et al.* 1999).

In recent years, it has become clear that nutrient release from soil organic matter is not simply a function of initial nutrient concentrations, but rather a complex microecological system involving a wide range of organisms, including bacteria and their protozoan and nematode grazers (Griffiths 1994). Roper and Halsall (1986) demonstrated that the administration of high-energy substrates (carbohydrates) to soil enhanced the nitrogenase activity of a wide range of N-fixers, including *Azotobacter*, *Azospirillum* and *Pseudomonas*. What makes compost unusual as a nutrient source is that the predominant microorganisms are thermophiles, since composting takes place at between 50 and 80°C. Incorporating a fresh compost means that an unusual microbiological population will initially inoculate the soil (Keeling *et al.* 1995).

The different microbial populations and other microorganisms (such as protozoan) involved in the process may come from air, water, soil or composting materials. In the first stage of the composting process, bacteria and fungi appear. Fungal, actinomycete and mesophilic bacterial species have been reasonably well classified and enumerated in composts (Miller 1993; Strom 1985b) and are important components of both the pre-thermogenic and post-thermogenic succession profile. Then, as temperature rises, thermophilic bacteria emerge and, to a lesser extent, thermophilic fungi and actinomycetes. The most important thermophilic bacteria in the composting process are: *Bacillus stearothermophilus*, *Thermomonospora*, *Thermoactinomyces* and *Clostridium thermocellum*. Important fungi in the thermophilic process of production of compost are: *Geotrichum candidum*, *Aspergillus fumigatus*, *Mucor pusillus*, *Chaetomium thermophile*, *Thermoasscus auranticus* and *Torula thermophila* (Finstein and Morris 1975).

For instance, in one large premolecular study of composts samples in the higher temperature range of 49 to 69°C cultured strains of *B. stearothermophilus*, *B. coagulans*, *B. licheniformis*, *B. brevis*, *B. sphaericus*, *B. subtilis* (and other numerically minor unidentified *Bacillus* spp.) were found to account for 87% of the isolates obtained (Strom 1985a, 1985b).

When temperature rises more due to microbial activity, microorganisms die, but often reappear when the temperature is lower than 60°C (Peña 1992). The results presented by Zhang (2002) show that thermophilic strains of *B. thermodentrificans* apparently grow well at 70°C, and the hottest samples (at least 70°C) had higher vegetative cell counts and a lower percentage of spores compared to other samples suggesting that much of population of thermophilic *Bacillus* species existed in the hottest samples in a vegetative form, and presumably active. Thus, these might play important roles in degradation during the composting process in the thermogenic phase.

Compost parameters regarding the substrate nature

The most important parameters regarding the substrate nature are briefly mentioned below:

a) *Particle size*: Particle size is an important aspect to consider because the larger the surface exposed to microbial attack, the faster and more complete the reactions that are taking place will be. That is to say, the material flaking facilitates the attack of microorganisms and influences the process speed. The ideal particle dimensions would be microscopic, but this would require excessive energy consumption and lead to a material which would lack the necessary porosity. Most of the authors consider that the optimal size ranges from 1 to 5 cm (Gray *et al.* 1971; Haug 1993). The particle size has a great influence on the organic matter C/N and N-losses evolution. Bueno *et al.* (2008) have developed an empirical model to determine the relative influence of moisture, aeration, particle size and time to minimize nitrogen losses.

b) *Porosity*: The mass under composting must have an adequate porosity so that there are spaces for proper air circulation. For low porosity wastes composting, it is advisable to mix them with some structuring agent in order to provide the required porosity to allow for adequate ventilation, such as wood shavings, grinded bark, crushed straw, recycled compost, plant stems and reeds.

Degraded soil quality, expressed as poor surface soil aggregation, high bulk density, low porosity, and slow infiltration, limits agricultural productivity and increases nonpoint source pollution of surface water via agricultural runoff. Increasing soil organic matter content through the addition of organic amendments has proven to be a valuable practice for maintaining or restoring soil quality (Wander *et al.* 2002).

Several methods have been used to provide oxygen to composting material. In the passive aeration method, oxygen supply is achieved by means of the natural convective movement of the air through the pile (Mason *et al.* 2004). The size and porosity of the pile should be adequate to enable the aeration (Szanto *et al.* 2007). Turned composting methods are passively aerated but additional turning is used to maintain the proper porosity, to provide oxygen, to mix the material and to release excessive heat, water vapour and other gases (Haug 1993).

In order to achieve that adequate porosity in some wastes, they are mixed with other remainders capable of maintaining a rigid structure in a very humid environment or with "bulking", structuring or blowing agents. The structuring or blowing agents can be either compostable or inert. Bulking agents typically include materials such as sludge cake, spent horse bedding (a mixture of horse manure and pinewood shavings), wood chips, refused pellets, rotting hay bales, peanut shells, and tree trimmings (Mukhtar *et al.* 2004).

c) *Nutrients*: Nutrient balance is determined primarily by the ratio of carbon to nitrogen in the compost mixture. From a chemical point of view, it is necessary to keep in mind that the microorganisms that carry out the composting require certain elements for their correct development and reproduction, being essential that the material possesses a certain relationship C:N. The microorganisms require carbon and nitrogen for growth since these elements are the main components of carbohydrates and protein. Most authors state that the 20-35 range is the most recommendable for a quick and efficient composting. When the C:N ratio is higher, the process has a longer duration and the composting rate decreases, as the microorganisms have to oxidize C excess with the subsequent slowing down of the process, and a lower N content prevents the formation of enough microbiological biomass. A C:N proportion lower than 20 leads to the release of leftover nitrogen in the form of ammonia, producing bad odors, and lowers the fertilizing value of the resulting compost (Jhorar *et al.* 1991). It has been reported that during efficient composting, the C:N ratio is expected to decrease because of degradation of organic matter and mineralization (Margesin *et al.* 2006). Chanyasak *et al.* (1982) found a linear relation between the ratio of total organic carbon to total nitrogen and proposed that C:N ratio in water extracts of well matured compost should be 5–6. However, Hirari *et al.* (1983) stated that the C:N ratio cannot be used as an absolute indicator of compost maturity, since the values for well-composted materials present a great maturity variability, due to the characteristics of the waste used. In some cases, it is also necessary to ensure that nutrients such as P, Ca, Mg and other micronutrients are available for the microorganisms. Singh and Amberger (1990) discovered that the straw decomposition increases as phosphorus is added. The C:P ratio optimal for composting is between 75 and 150, and the N:P proportion should be between 5 and 20.

d) *pH*: Centrally collected household waste is often acidic, with pH normally ranging between 4.5 and 6 (Eklind *et al.* 1997). The acidity is due to the presence of shortchain organic acids, mainly lactic and acetic acid (Beck-Friis *et al.* 2001). These acids are found in the raw material, and their concentrations increase during the initial phase of composting (Nakasaki *et al.* 1993; Beck-Friis *et al.* 2003). The presence of short-chain fatty acids under acidic conditions and their absence during alkaline conditions indicate that they are a key factor regulating the pH in composts (Choi and Park 1998; Beck-Friis *et al.* 2003). During successful and fully developed composting, the pH often rises to 8–9.

The stagnation in the microbial activity has in some cases been observed to coincide with low pH in the material (Day *et al.* 1998; Beck-Friis *et al.* 2001). Beck-Friis *et al.* (2001) noted that the change from mesophilic to thermophilic conditions during the initial stage of composting coincided with a change in pH from acidic (pH = 4.5–5.5) to alkaline (pH = 8–9).While bacteria growth is better in neutral media, fungi prefer slightly acid ones. In order to lower the pH of the compost solution, one of the amendments used by Raviv *et al.* (2005b) was orange peels. Sundberg *et al*. (2004) conclude that inhibition of the microbial activity at temperatures near 46°C and pH below 6.0 is a common problem in the initial phase of food waste composting. The inhibition of thermophiles at low pH is an important key to explain the often observed lag phase in the transition from mesophilic to thermophilic conditions in the initial phase of composting. The observed decrease in pH when the temperature was 46°C and the initial pH was below 6.5 implies that in large-scale composting with limited cooling there is a risk that conditions with low degradation rates at low pH and high temperature are maintained for long periods of time.

Factors involved in the composting process

As in the composting process microorganisms are the agents of the transformations, all the factors that may limit their growth, limit the process. Many complex variables are involved in any process of biological nature, being among the most important: aeration (if it is an aerobic process), humidity and temperature (Epstein *et al.* 1997; Keener *et al.* 2001). Other variables (i.e. acidity, nutrient balance and the presence of an appropriate microbial population) have been considered previously.

(i) *Aeration*: to carry out the (aerobic) composting process, it is essential to ensure the presence of the necessary amount of oxygen. In the case of composting in dynamic conditions or turning batteries, the air is introduced by turning the pile. In other cases, oxygen is supplied by a pressure or suction air inlet, as in static batteries and some closed systems. If the ventilation is inadequate or irregular, anaerobic conditions appear and, as a consequence, the decomposition rate is reduced and the production of bad smells increases. On the other hand, an exaggerated aeration leads to a cooling of the material, to its drying up to a variable extent and to an inadequate hygiene. Despite the fact that a temperature decrease tends to be negative, sometimes some kind of cooling is required in order to maintain the temperature within the range in which the activity of microorganisms is possible. The effects of aeration rate on generated compost quality, using aerated static pile method have been thoroughly studied by Rasapoor *et al.* (2009), and the effects of a negative-pressure vacuum-type aeration composting reactor have been tested by Lin (2008) for food waste composting, proving to be an effective and environmental friendly system.

(ii) *Humidity*: microorganisms require a certain amount of water for their metabolism, as well as for food and waste materials transport. Regarding the optimal level of humidity, Pietronave *et al*. (2004) carried out experiments on the influence of biotic and abiotic factors on human pathogens in finished compost. Composting can be difficult in an open-air windrow system due to dry or wet climatic conditions. Materials with low-moisture content (below 30% of water content), deprive microorganisms of the water needed for their metabolism and the rate of decomposition decreases because nutrients must be in solution to be utilized by microorganism. However, too high humidity (60% or higher) may lead to undesirable anaerobic fermentation, holding water in the pores and thus removing the air from them. Fermentation will set in and odours will be emitted from the material. Pathogens inactivation was lower when compost was stored at 40 and 80% humidity and at 37°C (Pietronave *et al.* 2004). The major role in the pathogens suppression was played by the indigenous microflora of the finished compost, although physical factors too influenced the growth phenomenon.

(iii) *Temperature*: a sign that the composting process is taking place in a materials mixture is the temperature rise.

Since the release of heat is directly related to the microbial activity, temperature is a good process indicator. The process is usually divided into four stages: mesophilic, thermophilic, cooling and maturation. At first the mass is at room temperature, but as the mesophilic indigenous population multiplies, the temperature quickly rises. At about 40°C, mesophilic activity ceases and degradation enters in the thermophilic stage. At 60°C, the thermophilic fungi die and the reaction is carried out by both spore-forming bacteria and actinomycetes. Since microbial activity cannot take place above certain temperatures, it is advisable to control this parameter, using aeration when the temperature is above 60°C. However, one of the advantages of composting is that it is one of the few treatments capable of virtually eliminating pathogens (Ryckeboer 2001). This requires the composting temperature to be high for a while. Thus, if a sanitizing of the wastes is required, a compromise must be reached between the necessity to maintain high temperatures for a few days and an excessive decline in microbial activity.

While the first three stages of the composting cycle typically take place in a relatively short time, the maturation stage can be very long (in general, between one and two months according to Carballo *et al*. (2008)). During this final stage, humidification occurs, accompanied by a very slow process of mineralization. This step takes place at room temperature, and involves little heat production and weight loss. Despite the fact that sometimes it has not been given adequate attention, it is of extreme importance, as the compost stability (the term "stable" typically refers to a compost that is not undergoing rapid decomposition and whose nutrients are slowly released into the soil) and maturity index (an evaluation procedure to describe the degree of decomposition and completeness of a compost process, which relies on any two or more test methods performed concurrently on the same sample) are key quality parameters (Said-Pullicino *et al.* 2007). Many parameters to evaluate the maturity of compost from food wastes or city refuse, such as the change of physico-chemical properties (Jimenez and Garcia 1992), calorimetric and spectroscopic methods (de Oliveira *et al.* 2002), germination tests (Zucconi *et al.* 1981a, 1981b) enzymatic activity (Vuorinen 2000) have been reported. Current thought is that respirometric techniques are well suited for compost stability measurement (FCQAO 1994).

Influences on the variables involved in the composting process

The variables studied above are influenced by environmental conditions, the type of waste (as a carbon source) under treatment, additives and how the necessary operations are carried out. The interaction among all of them has proven to be especially important. One of the most important aims of soil study is to assess its physical, chemical and biological properties, which are the main indicators of soil quality and fertility. Nevertheless, no isolated measurement, whether physical, chemical or biological, can give a complete picture of the quality of a soil (de Sena *et al.* 2000). Assessing the agronomic and environmental effects of the application of cattle manure compost on soil by multivariate methods have been carried out by Gil *et al*. (2008). Next several examples about this sort of considerations are presented:

(i) *Environmental conditions*: Environmental conditions change during the successive stages of composting and help to determine the boundary conditions for microbial growth and diversity include the pH, the C:N ratio, oxygen concentration and moisture content (Miller 1993). In particular, respirometric determinations have been used in order to evaluate the biodegradability of polymer films as water soluble poly(vinyl alcohol) blown films in composting, soil burial and aquatic degradation tests under different environmental and test conditions (Chiellini *et al.* 1999). Methane production and emission from paddy soil in laboratory experiments were affected by sterilization, temperature, organic matter supplementation, urea application, oxygen concentration, water content, soil pH and light intensity. Anaerobic conditions and water flooding on the surface of soil favoured methane emission (Yang and Chang 1998).

(ii) *Type of waste as a carbon source and additives*: Various materials can be used as a carbon source, including materials such as sawdust, straw, corn stover (mature cured stalks of corn with the ears removed and used as feed for livestock), poultry litter, ground corn cobs, baled corn stalks, wheat straw, semi-dried screened manure, hay, shavings, paper, silage, leaves, peat, rice hulls, cotton gin trash, yard wastes, vermiculite, and a variety of waste materials like matured compost. Bulking agents or amendments also provide some nutrients for composting (Das *et al.* 2003). They usually have bigger particle sizes than carbon sources and thus maintain adequate air spaces (around 25-35% porosity) within the compost pile by preventing packing of materials (Mukhtar *et al.* 2004).

Nitrogen loss during composting of separated cow manure was minimized using high C:N (wheat straw, grape marc or a slightly acidic orange peels) additives. Plant responses suggest that N availability is the main variable affecting growth. These materials reduced the incidence of crown and root-rot disease in tomato as well as the population size of the causal pathogen, *Fusarium oxysporum f. sp. radicis-lycopersici* (Raviv *et al.* 2005b).

(iii) *Methods for composting*: Methods commonly used for composting include passive composting piles (also referred to as static pile composting), passively aerated windrow (supplying air at ambient pressure through perforated pipes embedded in the windrow), active aerated windrow (forced air through perforated pipes), turned bins, rectangular agitated beds, silos, rotating drums, and vermi-composting (using worms to degrade organic material).

Composting is gaining increased attention for treating food wastes with various agricultural by-products in different systems (Elwell *et al.* 1996; Donahue *et al.* 1998; Laos *et al.* 1998; Faucette *et al.* 2001; Seymour *et al.* 2001; Tomati *et al.* 2001; Filippi *et al.* 2002). The selection of the system is dependent on the nature of the waste to be composted, available manpower, and economic conditions. Despite the high initial costs, the in-vessel systems require less space and provide better control than windrows for uniformly handling mixtures, and for manipulating gas emissions and polluting leachates (Mohee and Mudhoo 2005).

Other advantages of in-vessel systems over windrow composting involve shortened mesophilic (25–45°C) and thermophilic (45–75°C) stages, higher process efficiency resulting in a decreased number of pathogenic microorganisms, and thus more valuable final product. Donahue *et al.* (1998) demonstrated that food waste was successfully composted with sawdust and mulch chips in an in-vessel system within 14 days, after which the product was placed in windrows for the curing stage.

However, the lower capital investments and the less need for intensive knowledge and skills during operation make windrow systems more attractive to farmers for routine use (Cekmecelioglu *et al.* 2005). The windrow technique is simple and accomplished easily with standard equipment. Specialized windrow aeration equipment has been developed for use when large amounts of waste are involved. Municipal sludge is readily composted in combination with finished sludge compost or other products in windrows aerated twice or more per week with virtually complete pathogen destruction.

Front end loaders, skid steers with buckets, conventional solid manure spreaders, tub grinders or mixing wagons are among the equipment used to mix the compost ingredients and deposit the material in windrows. The method selected depends on the type of livestock, size of the operation, climatic conditions and available capital.

Turning the windrows restores porosity to the piles and reduces the particle size increasing the surface area of bulking material like straw. During the turning process oxygen is introduced into the windrow but it normally is rapidly consumed by microorganisms often within a matter of hours.

However, restoring porosity enhances the passive movement of air into the windrow and accelerates decomposition. Excessive turning of the material can accelerate nitrogen loss, water loss and result in cooling of the compost (Buckley 2001).

Rynk (2003) evaluated ground carcasses mixed with co-composting material in a system in which the primary composting phase was carried out in a rotating vessel or drum followed by windrow composting. Results indicated that turning the mixture every 15 days reduced the composting time to 75 days. Although this system may require more capital investment, overall it is less expensive than conventional bin or windrow composting. When adequate grinding capacity is available, this system has the potential to speed up carcass composting and facilitate high capacity. According to Rynk (2003), this method has several important advantages: it diminishes the composting time and thus management cost; reduces the co-composting materials up to one fourthof the conventional system; decreases the risk of odor production and risk of scavengers; allows better control over key composting parameters such as temperature pattern, pH, particle size, and color; and produces a more uniform product.

Composting of residues as a value-increase system versus burial and incineration

There are very few alternatives for waste management, and most of them are not acceptable from an ecological point of view:

(i) *Burial or placement in a dump*, which can lead to problems of water pollution and shortage of adequate spaces to be used as landfill sites. Landfills can generate problems such as surface and subsurface fires, wind blown litter, traffic problems, and problems regarding the leachate and gas management, together with accidents and fatal injuries. An indicative example of a disaster that is related to land disposal of waste is that happened in the Leuwigajah dumpsite in Indonesia, where after 3 days of heavy rainfall 2,700,000 m^3 of waste started sliding down the valley, killing 147 people (Kölsch *et al.* 2005). Dokas *et al.* (2009) describe a novel research investigation on how to combine fault tree analysis and fuzzy expert systems for emergency response of landfill operations.

By using life cycle assessment (LCA) modeling, (Manfredi and Christensen 2008) compares the environmental performance of six landfilling technologies (open dump, conventional landfill with flares, conventional landfill with energy recovery, standard bioreactor landfill, flushing bioreactor landfill and semi-aerobic landfill) and assesses the influence of the active operations practiced on these performances. The results of the assessment show that very high environmental impacts were found for the open dump landfill and sow that it is crucially important to ensure the highest collection efficiency of landfill gas and leachate since a poor capture compromises the overall environmental performance.

(ii) *Incineration*, which entails problems such as smoke, ashes and high fuel consumption (as wastes have high moisture content). The construction of biomass combustion plants has been encouraged, to raise the proportion of renewable energy and therefore increasing amounts of wood ash are starting to accumulate. Mohapatra and Rao (2001) review some aspects related to the use and environmental effects of fly ashes in general, resulting from the burning of municipal solid waste. Reijnders (2005) discusses disposal practices, uses and treatments for combustion ashes (from coal, wood, agriculture residues...), taking into account the associated pollution, which is mainly provoked by leaching processes. Kuba *et al*. (2008) state that up to 16% ash admixture to organic wastes does not impair the composting process but is even able to improve the product quality. However, it has to be made sure that only bottom ashes of low heavymetal contents are being used and strict quality control is implemented.

In comparison with previous alternatives, composting is a recovery system. Composting is currently important as a way of avoiding the high ecological and financial cost of landfilling some types of organic wastes, and compost products supply an increasing amount of organic soil builders for the horticultural and landscaping industries (Harrison 2008).

The use of sanitary landfills to dispose of biodegradable wastes is currently restricted by the European Landfill Directive (EU 1999/31). Moreover, incineration of solid wastes produces significant amounts of polluting flue gases and toxic solid residues, so that high investments for pollution control in incineration plants are needed.

Composting may be a safe and successful strategy for accelerating the decomposition and stabilization of the biodegradable components of biowaste from municipal solid wastes, for sustainable complete recycling, thereby producing compost that can be used as soil conditioner and/or organic fertilizer. Municipal solid wastes can be composted to reduce the volume of waste and disease-causing organisms and to convert it in an organic-rich, soil-like product, through aerobic or anaerobic fermentation.

COMPOSTING OF POTATO REMAINDERS FROM AGRO-FOOD INDUSTRIES AND OTHER WASTES

A huge quantity of organic waste is produced yearly as a by-product from the agro-food industries. The management of these residues is crucial for the preservation of the environment and the valorization of these by products. In Castilla y León (Spain), agro-food industries generate significant quantities of solid waste and a large amount of wastewater which causes a lot of harm to the environment. Castilla y León is the leader among Spanish vegetable producers and consumers, with high cultivation and consumption of cereal (8.5 million tons/year of grain production) and potatoes (900.000 tons/year); and with an important alimentary industry based on these cultures (Gullón and Siro Co.), which produces a significant volume of residues such as straw and potato peelings. 2008 has been declared the international year of the potato by the United Nations, in order to raise awareness of the important paper of this tubercle in providing food security and eradicating poverty. Experts predict that its consumption will double in the two next decades in developing countries. Nowadays the annual potato production is of near 300 million tons.

The sewage sludge production is also becoming increasingly important as a source of solid waste. The European Union regulates by means of the 86/278/CEE guideline of the Council (12th June 1986) the use of sewage sludge in agriculture with the purpose of avoiding the injurious effects in the ground, the vegetation, the animals and the human being. It should not be forgotten that the organic fraction of solid wastes is responsible for the emission of greenhouse gases, requiring treatment (Flotats and Solé 2007). The Spanish National Sewage Plan 2001-2006 (MMA 2001), estimated that in the end of year 2005, the amount of sewage generated was higher than 1.3 million tons and could reach the 1.5 million tons. According to the 2007-2015 plan (MMA 2007), at least 70% of the produced sewage sludge will be used for agricultural valorization from 2009 onwards.

Another significant source of pollution results from remainders of tanneries industries. The management of the remainders of the meat industry is governed by European Regulation 1774/2002. Tanneries remainders contain utilizable nutrients, but also toxic organic compounds which might affect soil processes and plant growth, and pathogens, which might pose a threat to the local farming community.

This paper reports our results on a chips factory remainders composting, under three different experimental conditions: potato remainders alone; potato peelings and shavings with sewage sludge composting, and potato peelings and shavings with low grade meat composting. All these wastes are located nearby the chip factory.

Co-treatment, either by means of anaerobic co-digestion or by co-composting, presents the following advantages: (i) takes advantage of the complementarity of compositions; (ii) makes it possible to share facilities; (iii) unifies management methodologies; (iv) acts as a buffer for temporary variations in the composition and production of each remainder, and (v) reduces the investment and operation costs (Flotats and Solé 2007).

The composting experiences designed have as their main aim the valorization of the remainders by means of composting techniques, and also to evaluate the viability of these methods as an alternative to other elimination techniques. The resulting compost can be useful for recultivation purposes of humus-free soils from old gravels in our geographic area. Consequently, different compost mixtures have been evaluated in order to examine their suitability for the formation of stable soil organic matter. Another objective is to determine if the new products can be classified as organic fertilizer (class 2) or as organic amendment (compost, class 6.02, or vegetal compost, class 6.03) according to the Spanish law "*Real Decreto 824/2005, de 8 de julio sobre productos fertilizantes*" and "*Orden APA/863/2008 de 25 de Marzo 2008, sobre productos fertilizantes*". According to Spanish Order APA/863/2008, 'organic amendment' or 'compost' is a sanitized and stabilized product obtained by means of aerobic biological decomposition (including thermophilic stage) from biodegradable organic materials under controlled conditions; and 'organic amendment' or 'vegetal compost' is analogous to previous one, but for the starting material: only leaves, cut grass and pruning remainders, always under controlled conditions.

Composting of potato residues alone

Our composting study was conducted on the wastes from chips factories (SIRO® Group) located in Venta de Baños (Palencia, Spain). Siro® is one of the most important corporations in the Spanish national market of snacks (in which chips are included, distributed under the trademark name *Dora/Rosdor*). This company receives in average and per year the following proportions of each of the potatoes varieties: 'Hermes' 60%, 'Agria' 30%, 'Lady rosseta' 5% and 5% of other varieties mainly at the end of the season. In the manufacture of chips varieties with high content in dry matter are demanded: 'Hermes' has over 22% and 'Agria' between 20 and 22%. For industrial chips, the company requires the potato to be round-shaped and of regular size (because an abrasive system by means of centrifugal rotation is used), with superficial eyes ('Hermes' type) and with good external appearance (MAPA 2003). In chips factories there are residues which, apparently, have no utility: either potatoes in poor conditions (unriped, rotten...) or roots and remnants of potato peeling, i.e., shavings generated in the cutting or filleting of potato chips processes, and debris from the control-quality process (chips discarded due to their size or because they have been excessively fried).

Remainders can be classified on the basis of the manufacture process stage:

(a) Whole potato remainders (100 to 200 kg per day, approximately), include those potatoes which arrive at the factory in bad conditions (i.e. immature or rotten).

(b) In the peeling process, a small amount of potato and some roots are obtained along with the potato skins (60 to 125 kg per day). This is the remainder referred as "potato peelings".

(c) In the potato slice process, those slices that do not accomplish the size or thickness requirements (which depend on if either chips or ripple crisps are been produced, but which are generally between 45 and 65 mm) are rejected (150 to 300 kg per day). This is the remainder denominated "potato shavings".

(d) Finally, those fried potatoes burned or badly toasted are also rejected.

The (a) type remainders are mainly used for ovine cattle feeding and are offered to cattle dealers of the locality. The (d) type remainders are gathered by another company which produces animal chow. (b) and (c) remainders did not have any direct use, and therefore are suitable for composting.

Composting processes of some industrial residues of agro-food activity (oil exhausted olive-cake) have been thoroughly investigated by Sellami *et al.* (2008). However, information about the composting of potato remainders is very scarce: our research group has previously investigated vermicomposting of potato remainders with cow-bed and hydrocarbons (Martín-Gil *et al*. 2008).

Composting of sewage sludge with potato remainders

This composting assay has been carried out to solve two problems simultaneously: one caused by the solid waste residues from a chips factory of the SIRO® group, and another originated by the anaerobic sludges produced in the treatment of urban waste water. In addition to attempting to give an answer to these problems though composting, having in mind that the geographical context of our research is a rural region, the end product may have an important role as organic fertilizer. Composting processes of sewage sludge and factory waste have been investigated recently (Jouraiphy *et al*. 2005; Lu *et al*. 2008; Pedra *et al*. 2008; Sánchez-Arias *et al.* 2008).

Composting of potato remainders with tanneries wastes

The equine remainders come from a tannery in Villarramiel (Palencia, Spain). This organic remainders not only do not entail profits but also suppose a problem for the industry, which must eliminate them. Burial is generally used in order to avoid these problems. In our study, they have been used for composting with remainders of Siro® chips factory.

According to Spanish Environmental Ministry, in year 2006 Spain was the third meat producing country within the EU. In tanneries, one of the first operations to be performed is the so-called *"de ribera"*, which consists of washing, depilation and flesh removing. In this series of operations, a solid residue which consists of long strips of meat (sometimes 0.5 m long) is obtained, which contains traces of all chemicals used in the process: sulphides, carbonates, etc. In order to reduce the pH and eliminate some of the substances used in the process, all experiences require the strips of meat to be immersed in water for 24 hours. Composting reduces the volume of the organic waste and destroys pathogens if the process is controlled properly (Keener *et al*. 2000). Composting of dead birds, animals, slaughterhouse and hatchery wastes under temperate conditions have been reported (Murphy 1988; McCaskey 1994; Blake *et al*. 1996; Lawson and Keeling 1999; González-Hurtado 2000; Kastner *et al.* 2004).

METHODOLOGY

Typical chemical analyses are conducted for the initial and resultant materials. For the smallest product fractions, moisture, C:N, organic matter content, nitrogen, phosphorus, calcium, magnesium and some heavy metals are measured. The analysis of total N has been carried out using the Kjeldahl method, which does not include the N-nitric (nonetheless, in general this omission is insignificant). The concentration of total organic C of compost is a clear indicator of its content in organic matter and therefore an index of its quality (Sullivan and Miller 2001). The organic matter (OM) content of the compost has been analyzed by weight loss on ignition at 430°C for 24 h (Navarro *et al.* 1993). Total P has been determined by the vanadate/molybdenum blue method after microwave digestion (HNO_3/H_20_2) of dried and ground samples in triplicate. Conductance (1:25 fresh compost/water ratio, w/w), dry matter content (% formula weight, 105°C) and ash content (% dry weight, 480°C, 16 h) were all measured in triplicate. Calcium, magnesium and other heavy metals are measured by Absorption Atomic Spectrometry. pH was determined on a water extract from compost using a compost to water ratio of 1:25 by weight. Moisture has been determined in a Perkin-Elmer thermogravimetric analyzer (TGA) at 105°C.

In the composting experiments that have been conducted for some wastes, explained below, temperature has proven to be the main control and monitoring parameter. It has been monitored daily at nine different points: (a) four points at 10-15 cm above the base of the reactor, (b) four points at a similar distance from the upper surface, and (c) a point in the middle of the material under composting. Simultaneously, temperature was recorded on the outside because: (i) a temperature rise indicates initiation of the process, (ii) a temperature decrease, once the process has started, suggests a lack of oxygen or a lack of moisture, and therefore rolling and/or irrigation is required, (iii) the active stage of composting finishes when, after careful turnovers and irrigations, temperature inside the reactor does not exceed the outer one.

The turnovers, which are carried out with a shovel, are necessary in order to provide air and homogenize the material, and, at the same time, to contribute to the moisture reduction in the mixed materials under composting. The parameter which determines when it is necessary to proceed to the turnover is temperature: a temperature decrease is an indication of lack of oxygen and excess or deficit of moisture (in this latter case, the mixture should also be irrigated). In some situations, because of the nature of the waste being used, it has been tried to dispense with the turnover and rely only on the 'chimney effect' for the air supply.

In some cases, the amount of nitrogen which could have been lost by ammonia volatilization or the amount of carbon dioxide emitted has also been measured. In any composting process, a weight loss takes place: in our experience, weight has been measured before the process, once the active phase has been completed and after the resulting product has acquired the necessary moisture to be marketed as organic fertilizer (maximum humidity 30-40% allowed by Spanish law Real Decreto 824/2005).

Once the process is finished, a granulometric analysis of the final product is carried out, in order to assess the amount which can be sifted through a 10 mm and 25 mm sieve (maximum particle size allowed by Spanish law "*Real Decreto 824/2005, de 8 de julio sobre productos fertilizantes*" and "*Orden APA/863/2008"*).

As a prelude to a possible use in seedbeds and as a maturity degree measurement, the germination rate is determined using the Zucconi method (1985) and extracts obtained from different composted material/water proportions. Tests in flowerpots are also carried out, according to Juste (1987), comparing the growth of a plant in the obtained compost, in peat (as a reference) and in a mixture of compost and peat at a 50%.

In order to assess the phytotoxicity of compost, seed germination and plant growth experiments were conducted in '*in vitro*' conditions, since field tests are not advisable because sensitivity to toxic compounds can be surpassed by means of adaptation of the plants (Zucconi *et al.* 1985).

Garden cress (*Lepidium sativum* L.) is the species most commonly used, due to its ease of handling and its fast germination and growth (in few days). This species is very sensitive to salinity (FCQAO 1994), but does not seem to discriminate well between mature and immature compost (Emino and Warman 2004). Other plants seeds have also been used, such as tomato (*Solanum lycopersicum* L.), or Italian rye grass (*Lolium multiflorum Lam*.). In our assays with extracts coming from composting of potato residues and also from sewage sludge with potato remainders, we have performed the Zucconi test using seeds from *Marglobe* variety of tomatoes (*Lycopersicon lycopersium* L.), which were sown in the Petri plates. In the case of germination test of composting of potato remainders with tanneries wastes, garden cress (*Lepidium sativum* L.) and radish (*Raphanus sativus*) seeds were used for the Zucconi and the Juste tests. The extracts were obtained adding 200 mL of water to 62 g of compost, in a Petri dish.

The phytotoxicity of composting mixtures was evaluated by the seed germination index (GI). According with Emino and Warman (2004), values of germination index (GI) inferior to 50% indicate a high phytotoxicity of the material. Values of GI between 50 and 80% indicate moderate phytotoxicity, whereas when the values are superior to 80% it is considered that the material does not present phytotoxicity. In those cases in which GI surpasses the value of 100% compost can be considered like phyto-stimulant or phyto-nutrient. One of the advantages of the chosen germination tests is their easy execution, since the seeds are put in the extract in a Petri plate during several days at temperatures between 20 and 28°C. The germination index was according to the following formula (Zucconi *et al.* 1981a, 1981b).

$$GI = \frac{S_{compost}}{S_{peat}} \cdot \frac{L_{compost}}{L_{peat}} \cdot 100$$

where
$S_{compost}$: sprouts in compost extract
S_{peat}: sprouts in peat
$L_{compost}$: average length of sprouts in compost extract
L_{peat}: average length of sprouts in white (peat).

ASSAYS AND RESULTS

Three different experiments have been carried out: composting of potato remainders, potato peelings with sewage sludge composting, and potato peelings with low grade meat composting.

1. Composting of potato remainders

Our composting experiences have been conducted during the period 2005-2007 using remainders from early potatoes (those harvested from 16th April to 15th June) and mid-season potatoes (those gathered from 16th June to 30th September) from above mentioned Siro factory. The variety with which we have mainly worked has been 'Hermes' (80% approximately) and 'Agria' variety (about 20%) (**Photo 1**).

As explained above, the C:N ratio is one of the most accepted indexes used in order to study the evolution of the organic matter during the composting: it represents the loss of organic carbon as a result of the mineralización of the organic matter and measures the increase of the nitrogen concentration due to the loss of weight. As a result, a diminution of this parameter is obtained, with almost constant values at the end of the process as a result of the organic matter stabilization. The importance of this relation lies in the fact that, in order to develop the composting process in a suitable way, the starting material must have a C:N ratio between 25 and 30, since microorganisms consume 30 parts of carbon by each part of nitrogen (Roig and Sánchez 2007). For a correct composting, the most suitable C:N proportion is between 20 to 35 (Golueke 1991).

Our initial mixture of potato peelings and shavings showed an initial C:N ratio of 31.7 (a value close to that recommended by Gouleke), and the initial humidity was 84.51% (**Table 1**). Therefore, the composting process can be conducted without mixing with a drying material and a reduction in the moisture content is expected by means of lixiviation.

Photo 1 Potatoes used in our study, from Astudillo (Palencia, Spain).

Table 1 Mixture composition of potato peelings and shavings.

Initial mixture	Moisture	Ashes	Total organic matter	Total nitrogen	C:N ratio
Potatoes % dry matter	84.51	19.18	80.82	1.48	31.7

Table 2 Assays results of composting potato peelings and shavings.

	Test #1	Test #2	Test #3	Test #4	Test #5	Test #6	Test #7
Duration (days)	70	66	66	65	69	60	42
T_{max} (ºC)	52.7	58.7	65.9	71.1	70.7	71.4	68.2
Turnovers	7	7	10	11	12	11	10
Decrease in volume (%)	71.6	62.7	54.6	53.3	58.6	54.16	52
Decrease in volume (%), dry	84.6	84.8	71.8	72.1	73.8	71.0	68.4
Decrease in weight (%)	78	62.6	72.25	41.96	78.2	71.6	58.1

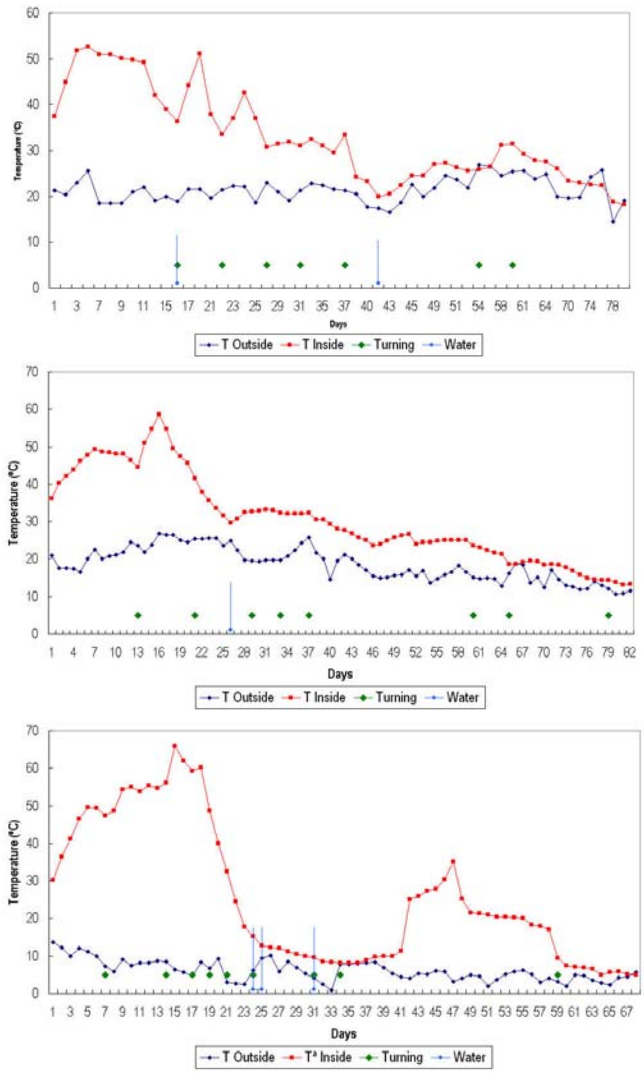

Fig. 1 Potato remainders composting. *Top*: Test #1, potato peelings + potato shavings (1.2:1); *centre*: Test #2, potato peelings + potato shavings (2:1); *bottom*: Test #3, potato peelings + potato shavings (1.9:1).

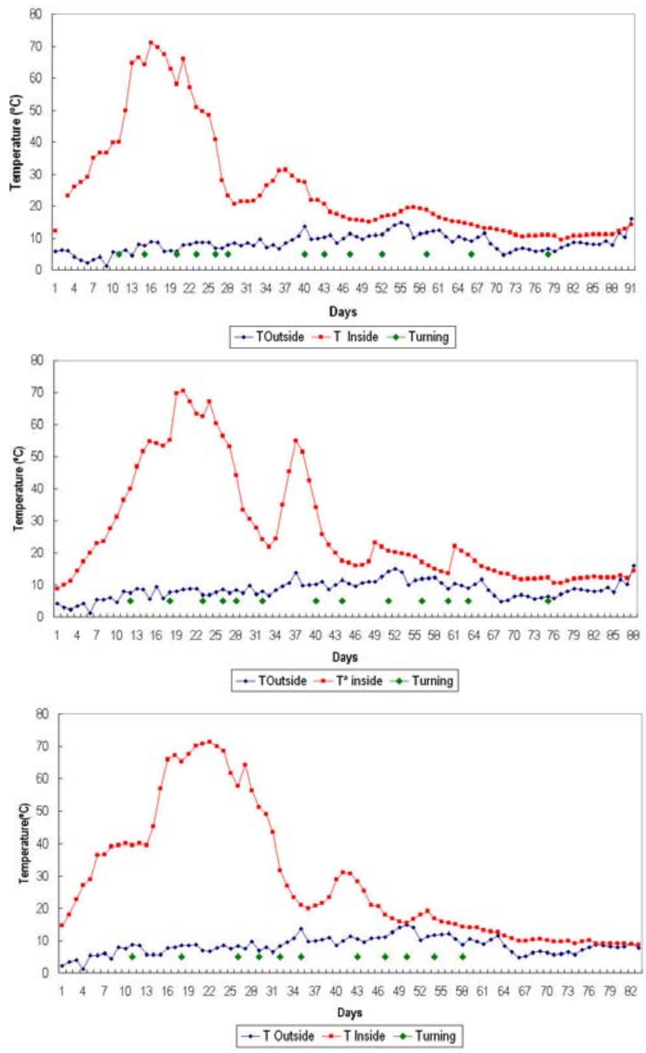

Fig. 2 Potato remainders composting. *Top*: Test #4, potato peelings + potato pieces; *centre*: Test #5, potato peelings + potato shavings (1.7:1); *bottom*: Test #6, potato peelings + potato pieces.

Due to the physical and chemical characteristics of this waste, our mixtures of materials are composted in simple structures or bins. Bins are considered a form of in-vessel composting, but they are usually not enclosed. An isothermal container of 95-100 L (test 1) and afterwards a 120 L capacity one (test 2) were used, equipped with a small hole for exit of the gases (mainly water steam) generated in the process.

The following tests have been carried out with the aim of finding the most suitable proportion of peelings and shavings mixture. Initially, the amount of peelings is slightly greater than that of shavings (test 1). The proportion was afterwards modified so that the ratio peelings to shavings was 2:1, to check if it led to appreciable variations (test 2). In test 4, greater size remainders, such as potato pieces, were also used. Previous tests were repeated in order to ensure that no important changes in the results took place (tests 3, 5 and 6). Finally, to avoid losses associated to leachates, an additional experience was conducted using a mixture of dry compost (obtained in tests 1 and 2) and approximately equal amounts of peelings and shavings (test 7).

- *Test 1*. Potato peelings + potato shavings (1.2:1). 30 kg of potato peelings and 22.5 kg of potato shavings were mixed in a 96 L container. The amount of obtained compost was 12.2 kg.
- *Test 2*. Potato peelings + potato shavings (2:1). 59 kg of potato peelings and 28.5 kg of potato shavings were mixed in a 120 L container.
- *Test 3*. Potato peelings + potato shavings (1.9:1). 62.7 kg of potato peelings and 33.5 kg of potato shavings were mixed in a 120 L container.
- *Test 4*. Peelings with some potato pieces. 96.5 kg of potatoes were mixed in a 120 L container.
- *Test 5*. Potato peelings + potato shavings (1.7:1). 61 kg of potato peelings and 36.5 kg of potato shavings have been mixed in a 120 L container.
- *Test 6*. Potato peelings with some potato pieces (similar to test 4). 97 kg of potatoes were mixed in a 120 L container.
- *Test 7*. The dry compost result of the 1st and 2nd tests

Table 3 Granulometric analysis results of composting potato peelings and shavings.

Compost particle diameter	Test #1	Test #2	Test #3	Test #4	Test #5	Test #6	Test #7
< 20 mm			7.35	10.14	15.65	9.53	10.06
< 10 mm			92.65	89.86	83.70	90.47	89.94
< 2 mm	88.06	22.99					

(7.1 kg) was mixed with 30.5 kg of potato peelings and 29.4 kg of potato shavings in a 120 L container.

Once the active phase of the composting process was finished, the fresh compost is weighted and, after a 30-day maduration, it is weighted again (when it acquires an humidity lower than 40%, which is the amount allowed by the Spanish Order APA/863/2008, *sobre productos fertilizantes*").

Table 2 shows the yields obtained in each of the tests, in terms of: % volume decrease (fresh) (in the range 52-72%), % volume decrease (dry) (between 68 and 85%), and % weight decrease (from 42 to 78%).

The composting process in terms of days and reached temperatures, for tests #1 to #6, is shown in **Figs. 1** and **2**. These figures display the three parameters that control the composting process: temperature, turning and water addition. The process duration was about 65 days for all the assays, and the maximum temperature reached was 70°C approximately. The active phase of the composting process is pretty similar in all these assays: from the 1st to the 15th day, a temperature increase took place; and from the 15th day temperature values above 50°C were reached. 7 to 12 turnovers (in green) wew conducted in order to compact and aerate the mixture, and water was added twice in test #1, once in test #2 and three-times in test #3 (in order to maintain the process active). Test #7, not included in the figures, produced lixiviates much darker that in the previous tests, and its composting active phase lasts only 42 days, since the starting material (compost) inoculates the microorganisms (**Table 2**).

Without addition of structuring agents, i.e., using exclusively potato peelings, the results can be summarized as follows: (i) the composting process duration for tests 1 to 7 is approximately 65 days and the maximum reached temperature is 70°C; (ii) the volume decreased by approximately 55%, and up to 72% after compost initially obtained was dried; (iii) the amount of dry compost obtained is 5% in weight of the initial waste (in this case, composting is more a system of waste disposal than a waste recovery process); (iv) on the basis of the conductivity study results, it was observed that compost in assay 6 shows high salts content (25.1 dS/m), which can negatively influence the soil-plant system when used as soil amendment (diminishing the germination capacity of the seeds, inhibiting the growth of the plants and even deteriorating the ground structure). According to Abad *et al*. (1999), if the substrate is going to be used for the production of horticultural seedlings, it is desirable that the electrical conductivity is in the range 0.151-0.5 dS/m. Other authors (Moral and Wall, 2007) establish that maximum values of electrical conductivity would be 2 dS/m for seedling substrates, and 3.5 dS/m for those substrates oriented to adult plants culture; (v) finally, germination tests have also been carried out, according to a slight modification of Zucconi methodology, and to Juste (1987) flowerpots germination test (which compares the growth of a plant in the obtained compost, in peat and in a mixture of both at a 50%): compost resulting from assay 6 has proved to be moderately mature, since GI values was higher than 50%; (vi) once the process is finished, a granulometric analysis of the final product has been carried out in order to assess the amount of material that passes through a 25 mm sieve (maximum size particle according to Spanish Order APA/863/2008): compost resulting from our experiments exceeded the 90% requirement stated by this law (**Table 3**).

It can be observed that when only compost is used, the vegetal root is less developed because it retains moisture (this compost by itself does not serve as a substrate and needs to be mixed with peat).

Table 4 Chemical parameters of composting potato peelings and shavings (assay #6).

	Final compost
pH	8.6
Electr. conductivity (dS/m)	25.1
Moisture %	7.69
	% dry matter
Ashes	23.59
Total organic matter	76.41
Total nitrogen	3.30
C:N ratio	13.43
Phosphorus (P_2O_5)	1.26
Potassium (K_2O)	4.41
Calcium(CaO)	1.37
Magnesium(MgO)	0.50
	mg kg^{-1} dry matter
Cu	18
Fe	1741
Mn	69
Zn	69

In agreement with Spanish Order APA/863/2008, our compost could be classified either as organic amendment or compost (class 6.02) or as vegetal compost (class 6.03), since in the analysis conducted for test 6 content of total organic matter was 76.41% (vs. 35 and 40% requirements, respectively). Humidity after the composting and maturation process was 7.69%, inferior to the maximum 40% humidity allowed by Spanish Order APA/863/2008. The C:N ratio is 13.43, below the 20 and 15 maximum ratios allowed for compost and vegetal compost, respectively (**Table 4**).

After the process of composting, the main nutrients analysis showed that the total N content was 3.30%. According to APA/863/2008, for a vegetal-origin nitrogenated organic fertilizer, a 2% of total N and a C:N ratio nongreater than 15 are required. Therefore, compost from essay 6 could be classified as a vegetal-origin nitrogenated organic fertilizer (class 2.1.02). In addition, total contents of P as P_2O_5 (1.26%) and of K as K_2O (4.41%) are superior to 1%. Nevertheless, contents of calcium and magnesium (expressed as oxides) do not reach the 2% of CaO and the 2% of MgO proportions, required in order to label it as fertilizer with secondary nutrients. Among the micronutrients, presence of Cu, Fe, Mn and Zn has been found. Since Cu and Zn present contents of 18 mg/kg dm and 69 mg/kg dm (lower than 70 mg/kg dry matter and 200 mg/kg dry matter limits, respectively), the final products could be classified as A class fertilizers. Since pH of the final compost is basic, it can be applied in acid soils.

2. Composting of sewage sludge with potato remainders

The mixture of potato peelings and shavings (**Table 5**) had initial moisture of 84.51%, and the sludge from the sewage plant which has been used originally had moisture of 68.8%. The C:N ratio was 31.7 for the potato remainders and 10.19 for the sludges. As in previous section, it is necessary to

Table 5 Mixture composition of potatoes/sludges.

Initial mixture	Moisture (%)	Ashes	Total organic matter	Total nitrogen	C:N ratio
Potatoes % dry matter	84.51	19.18	80.82	1.48	31.7
Sludges % dry matter	68.8	38.3	61.7	3.51	10.19

Table 6 Assays results of composting potatoes/sludges.

	Test #8	Test #9	Test #10	Test #11	Test #12	Test #13
Duration (days)	70	70	70	72	78	80
T_{max} (ºC)	51	69.4	58	68	57.3	57.8
Turnovers	11	10	11	9	12	11
Decrease in volume (%)	63.3	53.3	57.3	57.3	50.6	52
Decrease in volume (%), dry	77.0	75.2	77.0	76.6	70.1	72.7
Decrease in weight (%)	61.9	65.5	59.2	75.4	70.6	70.8

know the evolution the organic matter during the composting process, and therefore it is essential to initially fit the C:N ratio of the mixture of remainders subject to composting.

The final ratio depends on the mixture formed for composting: (i) relationship potato remainders/sludges = 3.0 (C:N = 21); (ii) relationship potato remainders/sludges = 1.9 (C:N = 19); (iii) relationship potato remainders/sludges = 1.11 (C:N = 16).

Two isotherm containers have been used for the composting process, one of 95-100 L (test 8) and another of 120 L (tests 9, 10, 11, 12 y 13), both equipped with a small hole for the exit of the gases (mainly water vapor) which are generated in the process.

Tests based on potato remainders mixed with sewage treatment plant sludges were also conducted with the aim of finding the proportion most appropriate for improving the resulting product. Firstly, in tests 8, 9, 10 and 11, potato remainders were mixed with smaller or equal amounts of sewage sludges (3:1, 2:1, 1:1 and 1:1). Subsequently, potato remainders were mixed with sludges in proportion 1:2 (tests 12 and 13), to see if appreciable variations were observed.

- *Test 8*. Potato remainders (peelings and shavings) + sewage treatment plant sludges. Potato-sludge (3:1). 22.5 kg of peelings + 16.75 kg of shavings + 13.25 kg of sludges were mixed in a 96 L container.
- *Test 9*. Potato remainders (peelings and shavings) + sewage treatment plant sludges. Potato-sludge (2:1). 36.5 kg of peelings + 31.75 kg of shavings + 35.5 kg of sludges were mixed in a 120 L container.
- *Test 10*. Potato remainders (peelings and shavings) + sewage treatment plant sludges. Potato-sludge (1:1). 27.5 kg of peelings + 24.75 kg of shavings + 47 kg of sludges were mixed in a 120 L container.
- *Test 11*. Potato remainders (peelings and shavings) + sewage treatment plant sludges. Potato-sludge (1:1). 33.25 kg of peelings + 25.75 kg of shavings + 58.75 kg of sludges were mixed in a 120 L container.

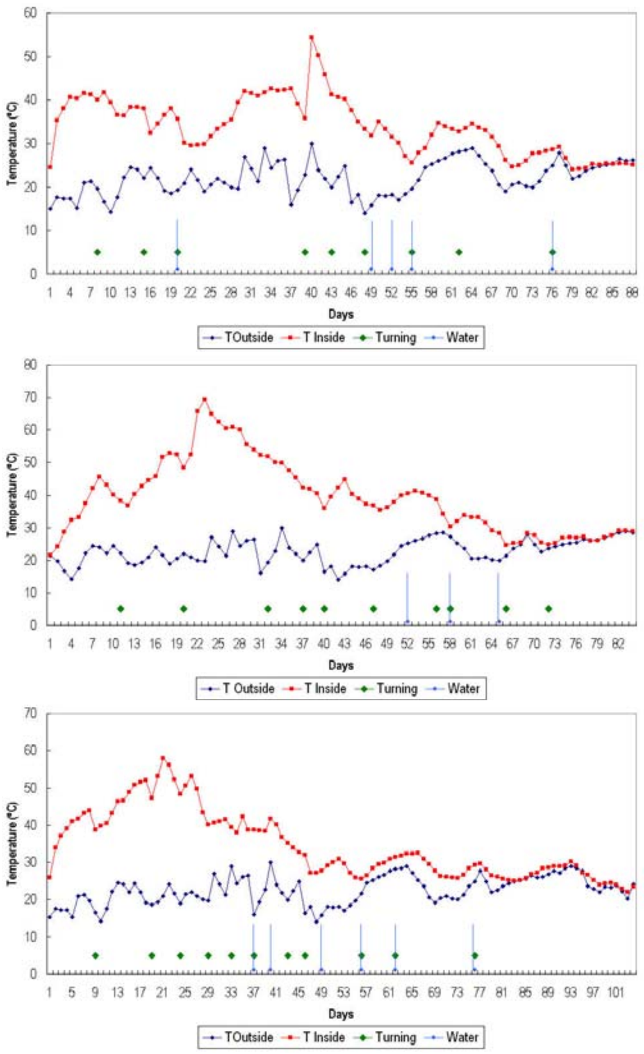

Fig. 3 Potato remainders + sewage sludges composting. *Top*: Test #8, potato peelings and shavings + sewage sludges (3:1): *centre*: Test #9, potato peelings and shavings + sewage sludges (2:1); *bottom*: Test #10, potato peelings and shavings + sewage sludges (1:1).

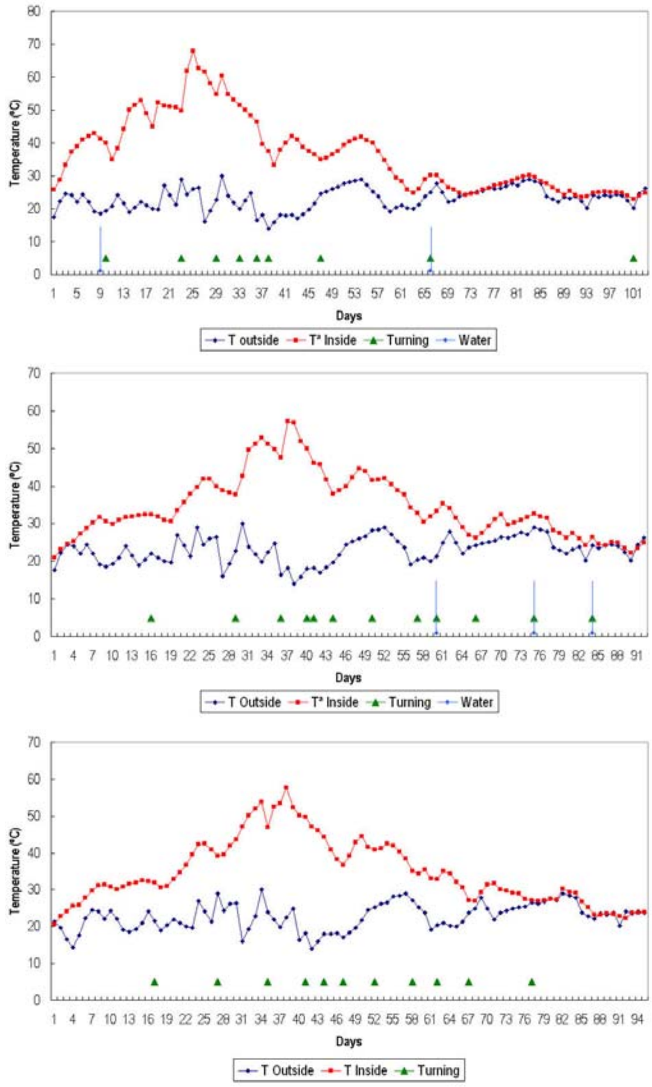

Fig. 4 Potato remainders + sewage sludges composting. *Top*: Test #11, potato peelings and shavings + sewage sludges (1:1); *centre*: Test #12, potato peelings and shavings + sewage sludges (1:2); *bottom*: Test #13, potato peelings and shavings + sewage sludges (1:2).

- *Test 12*. Potato remainders (peelings and shavings) + sewage treatment plant sludges. Potato-sludge (1:2). 20.5 kg of peelings + 20 kg of shavings + 79.25 kg of sludges were mixed in a 120 L container.
- *Test 13*. Potato remainders (peelings and shavings) + sewage treatment plant sludges. Potato-sludge (1:2). 20.75 kg of peelings + 18.5 kg of shavings + 76.5 kg of sludges were mixed in a 120 L container.

In all the conducted tests, weight is determined before the process starts, once the active phase was completed and after the compost had acquired the moisture that law determines in order to be marketed as class organic fertilizer.

Table 6 shows the yields obtained in each of these tests, in terms of: % volume decrease (fresh) (in the range 50-63%), % volume decrease (dry) (between 70 and 77%), and % weight decrease (from 59 to 76%).

The composting process in terms of days and reached temperatures, for tests #8 to #13, is shown in **Figs. 3** and **4**. In these assays more time is required in order to optimize the composting process (in comparison to the assays conducted only with potato remainders).

As the sewage sludge proportion increases in the initial mixture, the composting process takes more time (tests #12 and #13). Maximum temperatures are approximately of 70°C. 1:1 mixture used in tests #10 and #11 seems to be the most suitable, since higher temperatures are achieved before and they are maintained during longer periods. 10 turnovers (on average) were required in order to compact and aerate the mixture. Except for test #13, water was added in small proportions with the aim of slightly increasing temperature.

In the experiments carried out with potato remainders and sewage sludges, the results can be summarized as follows (**Table 6**): (i) In assays #8 to #13, maximum temperatures are reached later than in the potato-only based assays mentioned above. (ii) The yield in weight is higher than in potato-only based tests, resulting in more final compost. (iii) The most appropriate ration potato/sewage sludge is 1:1, since the process is faster and higher temperatures are achieved during longer periods, ensuring pathogen elimination.

Once the composting process has been finished, granulometric analyses, germination tests and chemical properties tests have been carried out.

Granulometic analysis results, germination tests results and chemical properties

(i) The granulometric analysis results are shown in **Table 7**. The granulometric analysis of the final products for the different assays showed that more than 90% of the compost could pass through a 20 mm sieve, meeting the requirements Spanish Order APA/863/2008 for organic amendments (class 6).

(ii) Germination tests results: It was observed that plants germinate at the same time in all three substrates, and the crop development in compost was faster than in the peat. The germination index (GI) for assay 11 was higher than 140%, and the resulting product was practically free of phytotoxic substances, so that it can be considered as phytonutrient.

(iii) **Table 8** shows the results of the chemical parameters of composting potatoes/sludges (assay #11). In agreement to Spanish Order APA/863/2008, this product can be classified as *organic amendment* or *compost* (class 6.02), since the total organic matter content is 32.29% (vs. 35% required). Humidity after the composting process is 61.39%. The end product requires a final drying process so as to reduce its moisture in order meet law requirements, i.e., 40%. Total N is 4.43% (higher than 3% minimum requirement) and C:N ratio is 4.23 (bellow the limit of 12). Total contents of P expressed as P_2O_5 (8.18%), and of K expressed as K_2O (2.3%), are both higher than 1%, and the sum of the contents of total N and P (P_2O_5) is 12,61% (vs. 6% required by law). Therefore, all this fertilizers can be classified within Groups 2.1.03 and 2.4.02 (vegetal and animal-origin nitrogenated organic fertilizers, APA/863/2008). Nonetheless, it is not possible to label the final product as fertilizer with secondary nutrients because of the contents of calcium and magnesium. Since the pH of the final compost is neutral, it can be applied to all kind of soils.

Table 8 Chemical parameters of composting potatoes/sludges (assay #11).

	Final compost
pH	7.09
Electric conductivity (dS/m)	11.8
Moisture (%)	61.39
	% dry matter
Ashes	68.2
Total organic matter	32.29
Total nitrogen	4.43
C:N ratio	4.23
Phosphorus (P_2O_5)	8.18
Potassium (K_2O)	2.3
Calcium (CaO)	2.14
Magnesium (CaO)	0.62
	mg kg^{-1} dry matter
Cu	37
Fe	1342
Mn	180
Zn	400
Cd	-
Cr	920

Sludge used in our assays comes from a sewage treatment plant located in the same municipality as the potatoes factory. These residues are the result of the sludge stabilization by biological methods (bio-discs). The heavy-metal content of the sludge must not exceed the limit allowed by Spanish law "*Real Decreto 824/2005, de 8 de julio sobre productos fertilizantes*". This law classifies the fertilizing products in A, B and C types, depending on the heavy-metals content. With regard to class A or B composting products, the dosage depends on the Spanish '*códigos de buenas prácticas*' guidelines, whereas the class C products cannot be used for agricultural soils in doses higher than 5 tons of dry matter per hectare (ha) and year. For the sewage sludge used in our experiments, the initial heavy-metal contents were: (i) chrome, 1000 mg/kg of dry matter (kg dm) (vs. 300 mg/kg dm for class C fertilizers); (ii) copper, 206 mg/kg dm (vs. 300 mg/kg dm for class B fertilizers); (iii) lead, 190 mg/kg dm (vs. 200 mg/kg dm for class C fertilizers); (iv) zinc, 674 mg/kg dm (vs. 1000 mg/kg dm for class C fertilizers); and (v) nickel, 87 mg/kg dm (vs. 90 mg/kg dm for class B fertilizers).

In the final compost, the following micronutrients have been found: Cu, Fe, Mn and Zn. Since Cu and Zn contents are 37 mg/kg dry matter (vs. 300 mg/kg dry matter allowed by law) and 400 mg/kg dry matter (vs. 500 mg/kg dry matter), respectively, the resulting compost could be classified as Class B fertilizer. On the other hand, Cr content (920 mg/

Table 7 Granulometric analysis results of composting potatoes/sludges.

Compost particle diameter	Test #8	Test #9	Test #10	Test #11	Test #12	Test #13
>20 mm	0.26	0.27	0.68	6.23	-	0.87
< 20 mm	15.06	30.14	15.31	32.53	38.66	36.34
< 10 mm	84.68	69.59	84.01	61.24	61.34	62.79

kg dry matter), surpasses the 300 mg/kg dry matter limit required in order to classify the product at least as Class C fertilizer); therefore, it would be advisable to previously control the heavy-metal levels in the sewage sludge. It is important to consider that the heavy metal content of the sewage sludge constitutes the main limitation for the compost use in agriculture due to the toxicity risks for plants, animals and people.

On the basis of the conductivity study results, it has been observed that compost in assay #11 shows high salts content (11.8 dS/m), which can negatively influence the soil-plant system when used as soil amendment. The potential risk of ground salinization derived from the agricultural application of residual sewage sludge can display problems of toxicity in cultures sensitive to chloride.

3. Composting of potato remainders with tanneries wastes

The composting has been carried out in reactors of 96 L capacity, thermally insulated. The main parameter, which has been controlled and monitored, is temperature. It has been measured in nine different points inside the reactor (as explained above) and, simultaneously, outside it.

As in both previous assays, it is necessary to know the initial C:N ratio of the mixture. Tannery wastes have a C:N = 6 (**Table 9**), very low in order to conduct a good composting process (Golueke 1975; Jhorar *et al.* 1991). When the initial C:N proportion is very low, the nitrogen excess is lost in form of ammonia and is not used by the microorganisms. In order to improve the initial C:N ratio and achieve a value near 30, carbon-rich materials are required, such as the potato remainders, straw or sawdust. These two latter products act as bulking agents and allow the obtention of higher quality and more agronomic-valuable final compost (in comparison to the mixture of only potato remainders with tanneries wastes).

Table 9 Mixture composition of potatoes/tanneries wastes

Initial mixture	Moisture (%)	Ashes	Total organic matter	Total nitrogen	C:N ratio
Potatoes % dry matter	84.51	19.18	80.82	1.48	31.7
Tanneries wastes % dry matter		-	93	3	6

Firstly, a trial test was carried out mixing 59.3 kg of tannery wastes with 5 kg of sawdust (12:1 ratio) in a 96 L and 64.3 kg container, obtaining a 63.2% decrease in volume and a 77% reduction in weight. Despite the resulting product proved to be well composted, the process took four months. Therefore, tests 14 to 17 had to be designed and carried out in order to shorten the period required for composting.

Tests 14 and 15 involve approximately the same ratio of potato shavings to tannery remainders, but the disposition in which they were arranged was different: on the one hand, in test 14 potato remainders and tannery wastes were placed in alternating layers; on the other hand, in test 15 they were mixed using a shovel. With regard to tests 16 and 17, the mixture (by means of a shovel) of potato shavings with tannery remainders is used too, because the potato shavings accelerate the process, but a structuring agent is added to improve the germination index (straw and sawdust, respectively) till the composter is full. The required quantity of sawdust is about five times bigger than that of straw.

- *Test 14*. Potato shavings mixed with tannery remainders (1:2) in layers

With the aim to activate the composting process and, mainly, to avoid the meat remainders piecing procedure, lixiviated potato shavings have been used. From previous assays it has been learnt that once these remainders loss a little of water through lixiviation, they undergo a spontaneous composting and high temperatures are reached in the process.

In our experimental conditions, potato remainders and meat remainders have been put in alternate layers. At the

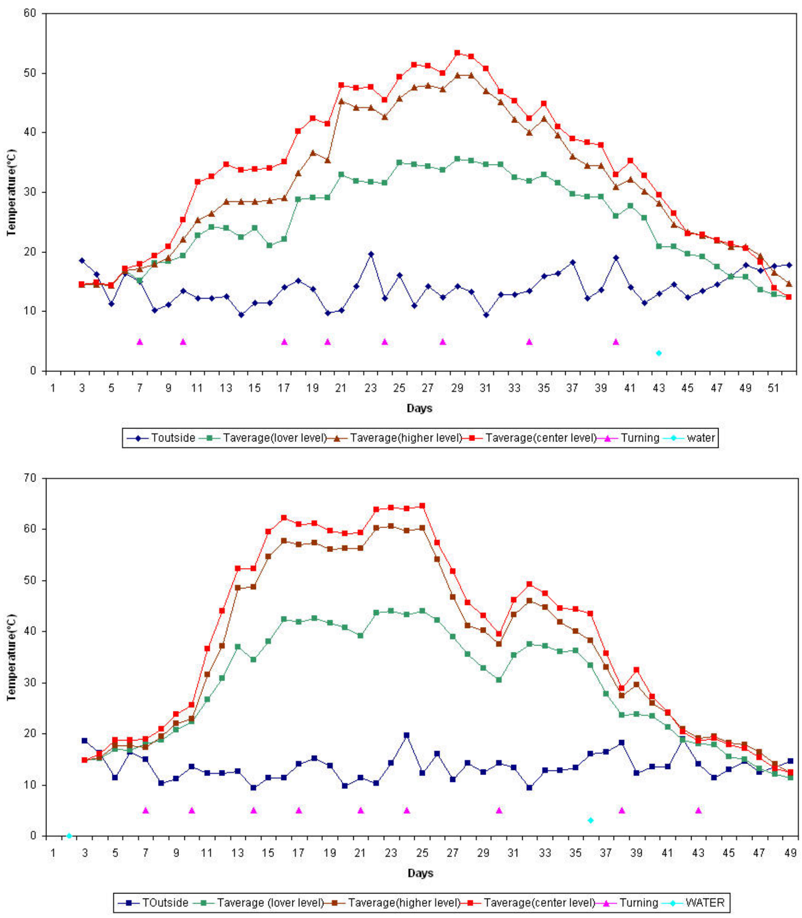

Fig. 5 Potato remainders + tanneries remainders composting. *Top*: Test #14, potato shavings + tanneries remainders (1:2) in layers, *bottom*: Test #15, potato peelings and shavings + tanneries remainders (1:2.2) mixed).

basis, a 5 cm thick potato remainders layer was deposited and above this another 10 cm thick meat remainders layer and so on, until the reactor is full. The amounts of mixture were: 20.1 kg of potato shavings with 41.1 kg of meat remainders (61.2 kg in total).

The amount of obtained compost was 12.2 kg. The yield has been 19.9% in weight and 30.1% in volume.

The composting active stage required 2 months. Since the first day, a temperature increase was observed. From the 26th day, values higher than 50°C were reached. These levels were maintained for six days. In the lower part of the reactor, the maximum temperature reached was 35°C. The difference with the superficial temperature was higher than 15°C. Along the process, aeration was carried out 8 times (**Fig. 5**).

- *Test 15*. Potato shavings mixed with tannery remainders (1:2.2)

This assay was carried out simultaneously to Test 14. The amounts of mixture were in this case: 19.8 kg of potato shavings with 43.9 kg of tannery remainders (63.7 kg in total).

The amount of resulting compost was 12.8 kg. The yields were 20.1% in weight and 31.8 % in volume.

The composting duration was 49 days. Since the first day, a temperature increase was found. From the 11th day, values above 50°C were reached, which were maintained for 15 days. After water addition, temperature raised above 60°C for six days. The difference with the superficial temperature was higher than 20°C (**Fig. 5**).

- *Test 16*. Potato shavings mixed with tannery remainders and straw (15.8:39.4:1).

For this test, 17.4 kg of potato shavings were mixed with 43.3 kg of tannery remainders and with 1.1 kg of straw (61.8 kg in total). As a result, 11.7 kg of compost were obtained. The yield was 18.9% in weight and 29.4% in volume.

The composting process duration was 50 days. Since the first day, a temperature increase was observed. From the 13th day, values of 60°C were reached, which were maintained for 13 consecutive days. After water was added, temperature raised above 65°C for six days. The difference with the surface temperature was higher than 25°C. The aeration was carried out 11 times (**Fig. 6**).

The germination assay, according to Zucconi procedure, gave a germination index (GI) higher than 50% in tests 16 and 17, which indicates that the compost is moderately phytotoxic in these tests. The product could be classified as *organic amendment* or strictly speaking *compost* because:

- 100% of particles went through a 20 mm-diameter sieve (law states as a requirement that 90% of particles should pass through a 25 mm diameter sieve) (**Table 10**).
- 92.65% of particles could be sifted through a 10 mm diameter sieve (in agreement to the law requirement that 90% of particles should pass through a 10 mm diameter sieve).
- The total organic matter content, 60.77%, was higher than that stated by law (35%), so that it can be classified as organic amendment or compost (Class 6.02 according to Spanish Order APA/863/2008).
- The end product required a final drying process to reduce its moisture in order fit to that stated by law, i.e., 40%.

The product could be used for amendment of acidic soils or as a replacement of peat.

Table 10 Granulometric analysis results of composting potatoes/tanneries wastes.

	Test #14	Test #15	Test #16	Test #17
Percentage of particles <10 mm	-	93.08	92.60	92.11

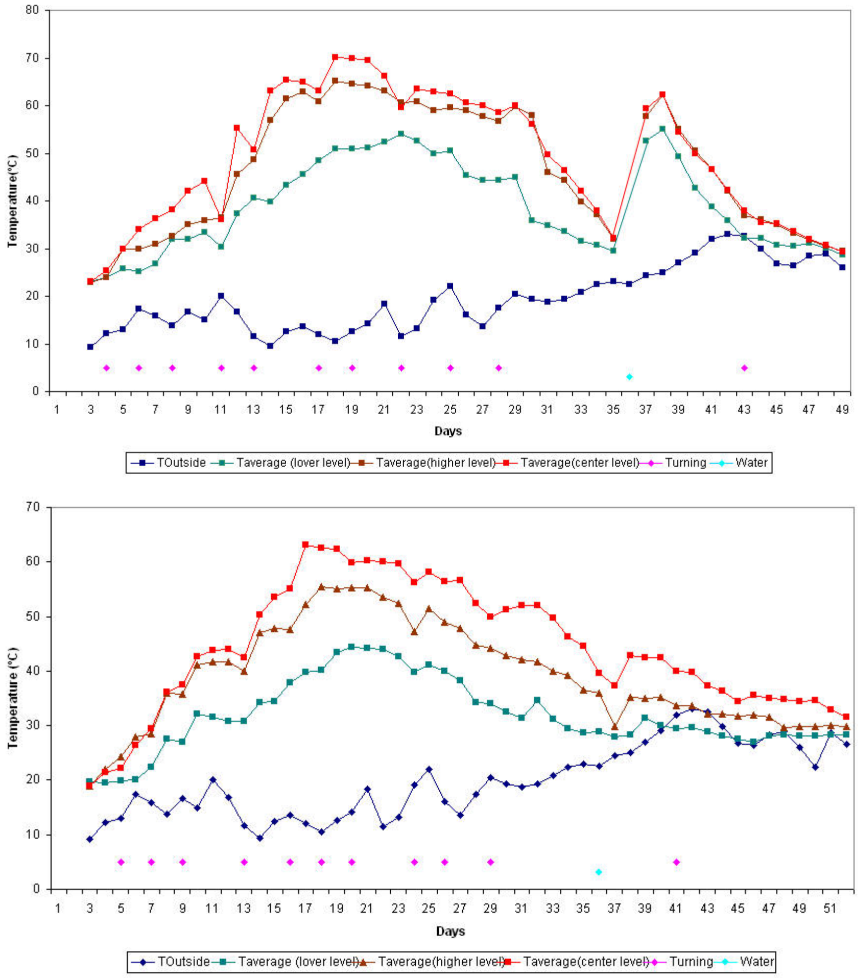

Fig. 6 Potato remainders + tanneries remainders + straw/sawdust composting. *Top*: Test #16, potato shavings + tanneries remainders + straw (15.8:39.4:1), *bottom*: Test #17, potato peelings and shavings + tanneries remainders + sawdust (3.7:7.8:1).

Table 11 Assays results of composting potatoes/tanneries wastes.

	Test #14	Test #15	Test #16	Test #17
Duration (days)	54	48	48	47
T máx (°C)	53.3	64.5	70.2	64
Turnovers	8	9	11	11
Decrease in weight (%)	81	80	81	78
Decrease in volume (%)	70	68	71	64
Water added (L)	8	10	8	8

Table 12 Chemical parameters analysis results of composting potatoes/ tanneries wastes.

			Final compost	
	Test #14	Test #15	Test #16	Test #17
pH	9.1	8.9	9.4	9.0
Electrical conductivity (dS/m)	12.1	11.5	11.9	10.3
Moisture (%)	70.7	66.2	50.16	62.40
		% dry matter		
Ashes	37.40	36.40	39.20	46.29
Organic matter	62.60	63.60	60.77	53.71
Total nitrogen	1.50	1,54	2.79	2,90
C:N ratio	24.20	23.95	12.00	10.00
Phosphorus (P_2O_5)	0.14	0.06	0.78	0.89
Potassium (K_2O)	0.05	0.05	0.88	0.95
Calcium (CaO)	18.70	17.82	15.01	16.16
Magnesium(MgO)	0.20	0.19	0.50	0.54
		mg kg^{-1} dry matter		
Cu	6.66	54.58	12.11	14.32
Fe	1645	1128	2391	4031
Mn	56.1	6.9	117.6	143.7
Zn	86.0	87.3	62.6	87.9

- *Test 17*. Potato peelings and shavings + tannery remainders + sawdust (3.7:7.8:1).

For this composting process, 19.5 kg of potato shavings were mixed with 40.6 kg of tannery remainders and with 5.2 kg of sawdust (65.3 kg in total). As a result, 14 kg of compost were obtained. The yield was 21.4% in weight and 36.0% in volume.

The composting active stage took 45 days. Since the first day, a temperature increase was observed, as in previous tests. From the 13th day, values of 50°C were reached, which were maintained for 6 successive days. After water was added, the temperature raised above 65°C for six days. The difference with the superficial temperature was higher than 20°C. The aeration was carried out 11 times (**Fig. 6**).

The period of time required is substantially reduced (about 50 days for tests 14 to 17, in comparison with the four months required in the initial trial test). The temperature of the active stage of the composting process is higher in those tests in which a shovel was used for the mixing, in comparison to test 14 (in which alternating layers were chosen). With regard to the decrease in weight and volume, as well as concerning electrical conductivity, test 17 was the most successful one (**Table 11**). The addition of the blowing agents leads to a reduction of the C:N ratio in a 50%, improves the germination index (>50%) and increases the phosphorus, potassium and magnesium content.

The resulting product requires a final drying process so as to reduce its moisture (62.40%) in order fit to that stated by Spanish law, i.e., 40%. The final product can be classified as *organic amendment* since: (i) the total organic matter content is 53.70%, higher than 35% required by Spanish Orden APA/863/2008; (ii) 100% of particles can be sifted through a 20 mm diameter sieve (**Table 10**); (iii) C:N final ratio (**Table 12**), is lower than 20 (limit stated by Spanish law "*Real Decreto 824/2005, de 8 de julio, sobre productos fertilizantes"*).

The composting of potato remainders with tanneries wastes (with the addition of blowing agents) leads to a spongy, black coloured, odorless final product characterized by: (*i*) a yield in weight close to 20%, (*ii*) a yield in volume above 35%, (*iii*) a density is the 400-420 g/L range, (*iv*) good granulometry for crop culture purposes, in addition to a good water-holding capacity (but without leading to flooding or layer-formation which could affect the crops growth), (*v*) a content in N, P, K macronutrients close to 4% (required to classify it as organic fertilizer), (*vi*) a high content of organic matter and calcium, (*vii*) the absence of heavy metals, (*viii*) the absence of pathogens, (*ix*) properties stability with time, and (*x*) basic pH.

Other advantages of the obtained compost are its ability to dramatically reduce the waste generated by tanning industries (reducing their weight in a 62.5%) and its utility from the agronomy standpoint.

CONCLUSIONS

1. Composting of potato residues

The initial C:N ratio of 30.2 is appropriate for a composting process with potato remainders. The C:N ratios at the middle (C:N=12.05) and at the end (C:N=13.43) of the composting process indicate that the main reactions occur in the early days of the process. The yield in weight of compost obtained is low and, only after a period of maturation of the compost, the seed germination tests are positive. Compared with peat (as reference), our compost is moister and vegetal roots are less developed in it.

The final product can be seen as an amendment and vegetal-origin organic fertilizer, and its application to soil improves its physical, chemical and biological properties.

Nevertheless, more interesting results can be achieved if, instead of focusing just on removing waste from the potato industry, these potato remainders are composted with materials such as sewage sludge. These wastes are difficult to compost due to their low C:N ratio and to their poor biodegradable matter content (after having undergone a biological stabilization process).

2. Composting of sewage sludge with potato remainders

The composting process of the mixture of potatoes remainder with sewage sludge from municipal wastewater has proved to be very satisfactory: it provides an excellent way to upgrade both residues, which in practice could be a source of contamination. The resultant product composition allows its sale as vegetal and animal-origin nitrogenated organic fertilizer as long as initial sewage sludge fulfills the requirements on heavy metals.

For the above mentioned reasons, this method could be defined as a good integrated waste management: using potato remainders from a chips factory and sludges from a sewage treatment plant, it is able to produce compost suitable as a substrate. The final product can be used as amendment, capable of improving the physical, chemical and biological properties of the soil.

3. Composting of potato remainders with tanneries wastes

The meat remainders are, from the physical and legal point of view, a compostable material. Therefore, the following procedure is recommended: (*i*) immerse the material in water for 24 hours to start the process, (*ii*) crush or mix the material with additives, preferably fresh vegetable remainders, (*iii*) add dried vegetables as structuring agent in order to promote aeration, achieve a more uniform temperature and reduce anaerobic reactions (so as to lose the least possible amount of nitrogen in form of ammonia), (*iv*) turnover every two or three days during the first two weeks, in order to accelerate the temperature increase. Two months are required to get a mature composted material. The compound resulting from the mix of meat remainders + potato shavings + straw shows excellent germination rates, and higher temperatures are reached during the composting process (which implies greater reduction of pathogens). The residue can be recovered as fertilizer amendment or compost y NPK fertilizer compost according to "Real Decreto 824/ 2005" and Spanish Order "APA/863/2008".

ACKNOWLEDGEMENTS

To Dr. Mrs Juliana Luisa González-Hurtado, recently retired director of our research group and emeritus professor of the University of Valladolid.

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