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Treball Final de Grau

Skewer method validation for moisture estimation in home composting.
Validació del mètode de la broqueta per a l'estimació de la humitat en autocompostatge.

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Qui dubta i no investiga, es torna no només infeliç, sinó també injust.

Blaise Pascal

Aquest treball no s'hauria pogut fer sense la inestimable ajuda del Ricard, per guiar-me en el treball i ajudar-me a trobar solucions a petits problemes que anaven sorgint.

Gràcies al Xavi pels seus consells, recomanacions i ajuda en les parts estadístiques del treball.

Cal també agrair a tots aquells que m'han ajudat posant en pràctica el mètode i permetent que un anàlisi estadístic fos possible, així com als que m'han ajudat en algun moment en temes fotogràfics. Agraeixo, doncs, als alumnes del màster en Enginyeria Ambiental, als amics, companys i professors que van participar d'alguna manera o altra facilitant la feina a fer, reservant un agraïment especial per als companys del laboratori, per ajudar-me en el que he pogut necessitar i fer més amenes les hores passades allà.

REPORT

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1. SUMMARY

Compost is a product obtained from the degradation of organic matter that can be used as a soil fertilizer or amendment. The process to obtain it is an important way of recycling all the organic matter that is produced every day, basically from food leftovers.

The process of composting can be carried out either at an industrial scale or at home. In the first case, there are big infrastructures to help the degradation of the organic matter, and exhaustive control of the process and the properties of the composting material. When it is done at home, though, the budget is not the same, and the process is smaller in production. Nevertheless, it is vital to control all the properties of the compost, such as its temperature and moisture, during the process so that it develops correctly.

In the case of the moisture level, it is necessary to consider than when it's too low, the reaction rate of the degradation is very low too. On the other hand, if it's too high, anaerobic conditions may appear. It is important, then, to place the process in the suitable moisture range. Nevertheless, it is necessary a cheap and reliable method to measure the moisture in home composting. Thus, the aim of this project is to develop a method that allows to know the moisture of this composting material.

The proposed system is to introduce a skewer into the composting material and, from its appearance once it's been pulled out, knowing if its moisture is right or not. Three moisture levels have been differentiated: too dry, correct and too wet. This way, this simple, clean, cheap and reliable method can help composters to control their process.

To establish the method, different factors that could affect it were studied: the contact time of the material, the kind of skewers to be used, the compression level of the material and the presence of a dry material layer in the composter. Then, samples of compost at different moisture levels were prepared, and the skewer obtained in each sample was photographed. Once these photos were analyzed, they were used as a pattern to validate the method with other people. The outcome was generally positive, with a high percentage of correct answers, which proved the well-functioning of the proposed method.

Keywords: Moisture, Skewer, Home Composting.

2. RESUM

El compost és un producte obtingut de la degradació de matèria orgànica que pot ser utilitzat com a fertilitzant o condicionador del sòl. El procés per a obtenir-lo és una manera important de reciclar tota la matèria orgànica que es produeix a diari, principalment de restes de menjar.

El procés de compostatge es pot dur a terme tant a escala industrial com a casa. En el primer cas, hi ha grans infraestructures per a ajudar a la degradació de la matèria orgànica, així com controls exhaustius del procés i de les propietats del material que està compostant. No obstant, quan es fa a casa el pressupost no és el mateix, i el procés és menor en producció. Tot i així, és vital controlar totes les propietats del compost, com la seva temperatura i humitat, durant el procés, per tal que aquest es desenvolupi correctament.

En el cas concret del nivell d'humitat, cal considerar que quan és massa baix, la velocitat de degradació de la matèria orgànica és molt baixa. Per altra banda, si és massa elevat, es poden produir condicions anaeròbiques. És important, doncs, situar el procés en el rang d'humitat adequat. Ara bé, cal un mètode barat i fiable per a mesurar la humitat en el compostatge domèstic. Per això, la intenció d'aquest treball és desenvolupar un mètode que permeti conèixer la humitat d'aquest material que està compostant.

El sistema proposat es basa en introduir una broqueta en el material que està compostant i, a partir de l'aspecte que presenta en treure-la, saber si la seva humitat és correcta o no. S'ha diferenciat entre tres nivells d'humitat: massa sec, correcte i massa humit. Així, aquest mètode simple, net, barat i eficaç pot ajudar als compostaires a controlar el seu procés.

Per a establir el mètode, es van estudiar diferents factors que podrien afectar-lo: temps de contacte del material, tipus de broquetes a utilitzar, nivell de compressió del material i existència d'una capa de material sec en el compostador. A continuació es van preparar mostres de compost a diferents nivells d'humitat, i es va fotografiar la broqueta que s'obtenia en cadascuna de les mostres. Analitzades aquestes fotografies, es van emprar com a patró per a validar el mètode amb altres persones. El resultat va ser generalment positiu, amb un alt percentatge de respostes correctes, cosa que va provar el bon funcionament del mètode proposat.

Paraules clau: Humitat, Broqueta, Autocompostatge.

3. INTRODUCTION

"Recycling" is becoming a more and more common word to see in almost every scientific project. Being able to take profit from the waste that we produce is an appealing idea not only for many enterprises, but also for many people at their home. That's why new ways of recycling are being researched every day, making it easier and cheaper than it was a few years ago, up to the point that nowadays almost everything can be recycled in some way.

The most common recycling system for ordinary people may be the municipal waste management one, in which every different product is disposed into a different color trash can. Blue, yellow and green (for paper, bottles and glass, respectively) are the most popular ones, but there is another one which is as important or more: the brown one, used to dispose organic matter. Recycling of organic matter is carried out through a process called composting, in which the final product is a fertilizing substance that enhances the soil properties called compost. This way, a cycle as the one shown in Figure 1 is stablished, and the same product that was disposed in order to produce this compost can help grow other products of the same kind.

Figure 1. Recycling cycle for organic matter (Agència de Residus de Catalunya, 2016).

3.1. THE PROCESS OF COMPOSTING

Composting is the biological decomposition and stabilization of organic substrates, under conditions that allow development of thermophilic temperatures as a result of biologically produced heat, to produce a final product that is stable, free of pathogens and plant seeds, and can be beneficially applied to land (Haug, R.T., 1993). It is important to remark, as said before, that these organic substrates usually come from waste, so the process of composting is also a recycling method.

This process can take place either at an industrial scale or at home, with smaller production. Although the basics are the same, there are certain differences between these two ways of composting.

3.1.1. Industrial composting

Industrial composting is usually done by batches. That is, a certain amount of compost enters the process, goes though the different phases and gets out. When this batch is finished, another one starts the process again. It is important, then, to have the entering amount of compost conditioned before the reaction takes place, in order that it occurs at the optimal conditions.

The different phases of the industrial composting process, from the raw materials to the final outcome, which would be the compost ready to be used or sold, are included in the Figure 2.

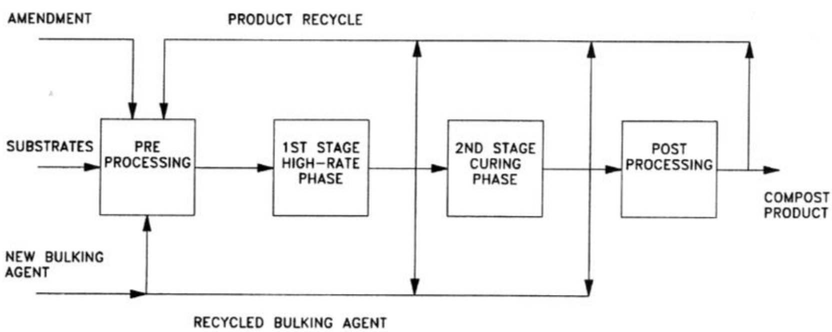

Figure 2. Phases of the composting process (Haug, R.T., 1993).

3.1.1.1. Pre-processing stage

The organic matter to be composted may not have the right properties for a right development of the process. Its moisture or pH can cause problems if they aren't in a certain range at the start of composting. Therefore, a pre-treatment is needed to correct these properties. Depending on the state of the initial organic matter, two main materials can be added (Haug, R.T., 1993):

-An amendment, which can be used either to dry the organic matter or to increase the amount of biodegradable organics. These amendments can be materials such as sawdust, straw or even rice hulls.

-A bulking agent, which provides structure to the organic waste and maintains air spaces within the composting mixture. Little wood sticks or nut shells, among others, are usually used as bulking agents.

Of course, if the initial organic matter is too dry, water can also be added to obtain a correct moisture level.

3.1.1.2. Process stage

Once the initial organic matter is conditioned, the degradation of the organic matter starts. As R.T. Haug explains in his book "Practical Handbook of Composting Engineering", this degradation is usually divided into two stages:

-The high-rate phase, which takes place at thermophilic temperatures and provides a great reduction of biodegradable volatile solids. The basic change in this stage is the rupture of organic structures. This stage might present some odor problems in some cases.

-The curing phase, which takes place at lower temperatures and is used to ensure the transformation of the non-degraded organics from the high-rate phase. Therefore, macro-molecules are formed, which will provide the compost with many beneficial properties, such as the ability to retain moisture in a better way or to liberate nutrients at a slower rate. This stage also provides the conditions for some microorganisms to develop and help the compost to stabilize.

3.1.1.3. Post-processing stage

After the degradation, the last step is to adjust the moisture to the selling one. It is by law defined as a maximum of 40 % (Real Decreto 506/2013, de 28 de junio, sobre productos fertilizantes), in order that the product won't be water in its majority. To adjust this moisture, amendments are once again used if it's too wet, as well as water in case that it's too dry. After this stage, the compost is ready to be sold or used.

3.1.2. Home composting

Although the composting process is normally carried out in an industrial way, lately the idea of doing it at home is becoming more and more popular. The base of the process is the same, but there are some characteristics which make each of them a little bit different from the other. The main difference is that at home the different stages take place simultaneously. That is, the pre-processing sometimes takes place at the same time as the process itself, having to add water or remove it when necessary. Furthermore, the budget is not the same, so there might be some more deviations during the process which need to be corrected. For that reason, regular controls of the compost properties are needed during the process (Sanz, N., 2008).

It is worth mentioning that in Catalonia there are great efforts to promote home composting in order to reduce the amount of organic matter to be recycled in an industrial way, being it cheaper to do it at home. As an example of this, there are over 20.000 composters (number given by the Agència de Residus de Catalunya) in different homes, and this number is expected to rise.

3.2. IMPORTANCE OF MOISTURE IN COMPOSTING

Moisture plays an important role in the process of composting. Depending on its level, the process can be seriously affected, both if it's lower or higher than the optimum. The recommended moisture for a good development of the compost is set to be from 50 % to 60 % w/w, and out of this range, there may appear some problems.

If the moisture level is too low (lower than 35-40 %), the biological activity lowers drastically. The microorganisms responsible for the degradation of the organic matter can't obtain everything they need to develop correctly, and the degradation doesn't take place at a normal rate (Rynk, R., 2000).

On the other hand, if the moisture level surpasses 70 %, the water will cover the empty spaces inside the compost, preventing oxygen to reach the deeps parts and reaction gases to go to the environment. As a consequence, the degradation will take place in anaerobic conditions, causing the reaction to take place slower and generating annoying odors.

It is vital, then, to check if the compost moisture is right in order that the process develops correctly. Not being in the right range of moisture (both if it's too high or too low), can seriously affect the final outcome of the process, making the compost not to have the expected quality and probably making worthless months of work to obtain it.

3.3. EXISTING METHODS OF COMPOST MOISTURE ESTIMATION

Having in mind the possible results of composting at the wrong moisture, people have always wanted to estimate it in order to know if the process is developing correctly. Both in industries and at home, there have been many methods to estimate the moisture of the compost they're producing, all of them with their upsides and downsides.

3.3.1. Calculation of the compost moisture in industries

Measures of compost properties in industries need to be quick and accurate, in order to correct it as soon as possible and not letting the process go on at the wrong conditions. As a consequence, one of the most common methods to check the compost moisture in industries is the use of moisture sensors. These sensors measure properties like electrical conductivity by applying a voltage to the compost and relate it directly to the moisture level. This way, the moisture in any point of the compost pile can easily be estimated, although there are some factors that can affect this measure. The salt content of the compost, for example, makes the electrical conductivity vary, even if the moisture content is the same. Thus, depending on the initial organic matter used to make the compost, it will have a different salt level and, consequently, the outcome of the moisture sensor will be slightly different (Rynk, R., 2000).

Another broadly used method to calculate the compost measure is the gravimetric method. It consists on weighing a quantity of compost and heating it at a temperature slightly over to the water boiling point in order to eliminate as much water as possible. After a few hours (depending on the sample size), when the compost is totally dry, it is weighed again, and the moisture can be calculated by dividing the difference between the initial weight and the weight of the dry compost for the initial weight. This provides an accurate value of the compost moisture, but it takes some time to be done. Furthermore, it requires samples of different parts of the compost pile in order to check that the moisture remains constant, which means a loss of a little part of the final product (Test Methods for the Examination of Composting and Compost, 03.09-3).

3.3.2. Estimation of the compost moisture at home

The main difference between almost every process done at home and at an industrial scale remains in the budget, being significantly lower in the first case. As a consequence, simpler methods which don't require any special sensors are more common, although the previously explained ones can also be used.

The main moisture estimation method when doing it at home is the squeeze-test. The process is described by the following recipe:

Take a sample of compost in your hand. Make sure there are no sharp objects in the sample. Squeeze tightly. If water flows freely out of your hand, the moisture content is 65 percent or higher – too wet. If a few drops of water are visible between your fingers, you are right at 60 percent – the upper limit.

If you don't see any water, open up your hand and if a sheen is clearly visible, moisture content will be at 55 to 60 percent. If no sheen is visible and a ball remains in your hand, tap the ball gently. If the ball stays intact, moisture content is 50 to 55 percent. If a ball forms but breaks apart during tapping, moisture content will be 45 to 50 percent. When opening your hand and the compost does not remain in a ball, moisture content is likely below 40 percent, which slows down composting process (Rynk, R., 2000).

This method provides an easy and quick estimation of the moisture content of the compost, but it requires to get your hands dirty when it's done, not to mention the potential risk of cutting your hand. It may not be a problem for some, but it leaves a door open for some cleaner and safer methods to appear.

4. OBJECTIVES

The main objective of this project is to develop a simple, cheap, clean and reliable method to estimate the moisture of a compost sample. However, to achieve this objective, it is necessary to establish other intermediate ones. In order to establish the method in a proper way, it has been set as an objective to evaluate of different variables that can affect the process. Three variables will be studied before doing the main experiments: the kind of skewers to use, the way to introduce them in the composters and the minimum required contact time. After the method is developed, the influence of the compression that may suffer the compost in a composter and the dry compost layer that can be in it will be studied. All these experiments will establish this desired method to help home composters know the moisture level of their compost. Once this method is completed, the project’s aim will be to check if this method really works by trying it with composters, evaluating its success rate.

5. MATERIALS AND METHODS

The experiments made during this project were intended to have compost samples at 5 different moistures, starting from 30% and up to 80%. As a consequence, many materials and methods have been used to obtain them. An explanation on how these processes have been carried out and which materials have been used is done in this section.

5.1. SKEWERS

One of the most important materials to do this project is the skewer. It will be used to introduce it into the composting material and estimate its moisture by analyzing its appearance once it's been pulled out.

The used skewers need to be made of wood, in order that they can absorb part of the water in the compost and make it easier to distinguish the look of the skewers at different moisture levels. The inability of other materials such as plastic or steel to do that causes their rejection.

To do this experiment, three kinds of skewers have been used: bamboo skewers and natural wood skewers of two different brands: Don Palillo and Maxi Madera. The bamboo skewers can be seen in Figure 3, and the two brands of natural wood skewers in Figure 4.

Figure 3. Bamboo skewers.

Figure 4. Natural wood skewers.

5.2. Initial compost

All the compost used in this work came from home composting. A sample big enough to complete all the predicted experiments was provided by the tutor, saving the time of having to produce a compost specifically for this project. This compost will be called Compost A. However, the moisture of Compost A impeded its use in experiments with low moisture, and the initial compost for the experiments was changed to another one produced by the Master's degree in Environmental Engineering students one year ago, being it drier and allowing to achieve any desired moisture to make the experiments. This compost will be called Compost B.

It is important to know the properties of the initial compost used to prepare all the samples, since it's the starting point for all the experiments. Thus, some experiments have been carried out in order to know its moisture, density, amount of volatile solids and stability.

5.2.1. Moisture

To calculate the moisture of the initial compost in the laboratory, the most accurate and reliable way is the gravimetric method. The steps followed to do it (Test Methods for the Examination of Composting and Compost, 03.09-3), are:

- Weigh an empty bowl with a scale. Its weigh will be defined as W_0.
- Fill the bowl with a sample of the compost (as full as possible) and weigh it again, being this weight W_1.
- Put the bowl in the heater at a temperature of 105 ºC for 48 h.
- Pull the bowl out and leave it for about 20 minutes in the desiccator.
- Weigh the bowl again. This weight will be W_2.

Once this process is completed, there is enough data to calculate the moisture (H). It is defined as:

$$H\ [\%] = \frac{Amount\ of\ water\ in\ the\ sample}{Total\ weight\ of\ the\ sample} \cdot 100 \qquad (1)$$

The total weight of the sample can be calculated by doing $W_1 - W_0$, and the amount of water in the sample as $W_2 - W_1$, since the difference in weight will be the vaporized water. As a result, the expression used to calculate the moisture in % is:

$$H\ [\%] = \frac{W_2 - W_1}{W_1 - W_0} \cdot 100 \qquad (2)$$

The materials used to do this process are:

- An empty, clean bowl.
- A compost sample (as much as the bowl can contain).
- A scale with 4-digit precision.
- A heater at 105 ± 2 ºC.
- Plastic gloves.
- A desiccator.

For the initial moisture of the compost, this method has been done three times in order to check that the moisture in different points of the total amount was similar. For the Compost A, the one chosen at first, all the three values were very similar to each other, being the average moisture 51.5 %. The project aimed to produce compost samples starting from 30 % moisture. Since the initial moisture of the Compost A was higher than the lowest desired for the experiments and taking into account that reducing this moisture can alter the properties, it was decided to use a different compost as the initial one.

For this new compost, the Compost B, the three values obtained from the moisture calculation were also very similar between them, and the average moisture was 18.5 %. This new value allows to reach any range of moisture simply by adding water and letting the compost absorb it.

5.2.2. Density

The density of the initial compost was also measured. To estimate it, a certain amount of compost was weighed and then added to a beaker, where the approximated volume was checked. The beaker needs to be graduated in order to see the approximate volume occupied by the compost. To calculate the density, the operation was quite simple:

$$\rho = \frac{weight\ of\ the\ compost\ sample}{volume\ of\ the\ compost\ sample} \tag{3}$$

In order to do this, the following materials were needed:

- A compost sample
- A scale with 4-digit precision.

- A plastic bottle cut across to help the weighing of the compost. The beaker wasn't used to weigh because it surpassed the scale limit.
- Plastic gloves.
- A graduated beaker.

This process was carried out five times for each compost in order to have a reliable average density. For the Compost A, the result was 0.35 g/cm^3, and for the Compost B it was 0.28 g/cm^3. The Compost A, whose moisture was higher, has also a higher density, due to the extra water that contains the material. The Compost B, which has a lower moisture level, has consequently a lower density.

5.2.3. Volatile solids

The volatile solids are a good indicator of organic matter present in the compost and it provides information about the quality of the compost. The process followed to calculate the volatile solids (Test Methods for the Examination of Composting and Compost, 05.01-1) is the following:

- Put a certain amount of compost in a bowl in the heater at 105 ºC for about 48 h (the dry compost from the moisture calculation can be used, letting this step to be skipped).
- Weigh a crucible. The obtained weight will be $W_{c,0}$.
- Add a sample of the dry compost to the crucible and weigh it again. The result will be defined as $W_{c,1}$.
- Put the crucible in the oven at a temperature of 550 ºC for about 4 h.
- Pull the crucible out and leave it in a desiccator for about 1h.
- Weigh the crucible again. The obtained value will be $W_{c,2}$.

When the process is finished, the calculation of the volatile solids (VS) can be done.

$$VS\ [\%] = \frac{Volatilized\ solids}{Initial\ dry\ sample\ weight} \cdot 100 \qquad (4)$$

Volatilized solids can be calculated as the difference of weight before and after the oven, being it $W_{c,1}$ - $W_{c,2}$, and the initial dry sample weight is $W_{c,1}$ - $W_{c,0}$. This leads to the following expression:

$$VS\ [\%] = \frac{W_{C,2} - W_{C,1}}{W_{C,1} - W_{C,0}} \cdot 100 \quad (5)$$

To do this experiment, the following materials were needed:

- Dry compost or initial compost heated at 105 ºC for 48 h (with a heater)
- Crucibles
- A scale with 4-digit precision.
- An oven able to reach at least 550 ºC.
- Heat protection (gloves and tongs)
- A desiccator.
- Plastic gloves.

After following the previous steps (as before, three times for each compost) and having done the required calculations, it has been found that the Compost A has a volatile solids content of 57.6 %, and the Compost B of 65.3 %. These results seem logical, since the Compost A was composted for a longer time, making it riper than the compost B and, therefore, with less volatile solids.

5.2.4. Stability

Stability is another important feature to take into account when talking about the compost properties. If the compost is "stable", the degradation rate is so low that the process can be considered finished; the biological activity is very low. Thus, to check the stability, the biological activity will be studied by measuring the temperature of the compost during 10 days. If there is no substantial variation in this temperature, there will be no important biological activity, and the compost will be considered as stable. On the other hand, a rising temperature will be a sign of biological activity, which means that the compost is not stable.

The process followed to check the stability of the compost is:

- Take a sample of compost and sieve it to 1 cm.
- Check its moisture using the same method as described in 5.1.1.
- If the compost moisture is 50 %, go on to the next step. If it's higher than 50 %, dry it with air until it reaches this percentage. If it's lower, add water carefully, calculating the amount of water to add with the following expression:

$$\frac{W_S \cdot H + W_A}{W_S + W_A} = 0{,}5 \quad (6)$$

Where W_S is the weight of the compost sample, H its moisture and W_A the amount of water to add.

- Once the sample moisture is 50 %, it is introduced in a Dewar flask, where the temperature is controlled with a thermometric probe. Leave it there for 10 days.
- After that time, download the results and check if the temperature has varied a lot. Depending on its variation, it will have a certain level of stability or another one (Brinton Jr, W. F., 19995), as shown in Table 1.

Table 1. Levels of compost stability.

Class	Maximum Net Temperature [ºC]	Stability Degree
I	40-50 (or higher)	Unstable
II	30-40	Active
III	20-30	Active
IV	10-20	Stable
V	0-10	Stable

After doing this process for the two initial composts, the results were treated in order to reach a conclusion. The best way to see if the temperature variates or not is to represent the net temperature (which is the result of subtracting the room temperature, 18 ºC, to the one indicated by the probe) in front of the time, to see how the system evolves. The representation was done for each compost twice, since the experiment was repeated, and they can be seen in Figures 5 and 6.

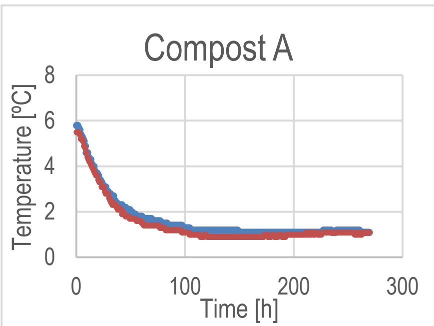

Figure 5. Temperature evolution for Compost A.

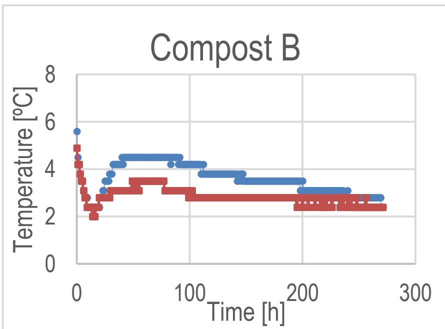

Figure 6. Temperature evolution for Compost B.

As it can be seen in the previous graphics, the net temperatures don't surpass the top value of the class V, which is 10 ºC. Therefore, even if the Compost B shows a little growth of the temperature with time, it's not enough to consider it active or unstable, and the two Composts will be catalogued as Stable in Class V.

5.2.5. Summary of all the initial properties

In order to have a clearer idea of all the characteristics of the initial compost, the Table 2 sums up all the measured properties of the two initial composts.

Table 2. Properties of the initial composts.

Compost	Moisture [%]	Density [g/cm^3]	Volatile Solids [%]	Stability
A	51.5	0.35	57.6	Class V
B	18.5	0.28	65.3	Class V

5.3. COMPOST CONDITIONING

In order to do the experiments, the compost needs to reach certain properties, some of them different from the ones of the initial compost. That's why some measures to condition the compost have to be applied.

5.3.1. Moisture samples preparation

Once knowing the characteristics of the initial compost and the conditions in which the experiment will take place, it's time to prepare the samples that will be used for the experiment. These samples consist on compost at different moisture levels, and are prepared simply by adding water to the initial compost and letting it settle, mixing it from time to time to make sure that the water is well distributed.

The main difficulty of preparing these compost samples is knowing the necessary water to reach the desired moisture level. To calculate it, the first thing to do is taking into account the moisture of the initial compost, which, as calculated in 5.1.1, is 18.5 %. Having this value in mind, the process used to calculate the necessary water is the following:

- Weigh some compost and put it in a beaker. To do so, a plastic bottle cut across so that it resembles a glass has been used to measure it, weighing first the bottle with the compost inside ($W_{e,1}$), transferring the compost to the beaker and weighing the empty bottle ($W_{e,0}$). The quantity of compost (W_e) will be the difference between these two weights ($W_{e,1}$ - $W_{e,0}$).

- From the previous weight, it is interesting to know how much of this compost is water and how much is dry. Here is where the moisture of the initial compost appears, since the water contained by the compost is calculated simply by multiplying the moisture expressed as so much per one for the quantity of compost. The amount of dry compost will be the difference between the weighed quantity and the calculated water content, as shown in the following expressions:

$$W_{e,water} = \frac{H\,[\%]}{100} \cdot W_e \quad (7)$$

$$W_{e,dry} = W_e - W_{e,water} \quad (8)$$

- After having calculated the amount of dry compost, the total amount of water which is necessary to take the sample to a certain level of moisture can be calculated. Being the desired moisture H_d, the amount of water of the compost for a given dry compost weight will be:

$$W_{water} = \frac{\frac{H_d\,[\%]}{100} \cdot W_{e,dry}}{1 - \frac{H_d\,[\%]}{100}} \quad (9)$$

- However, the initial compost isn't totally dry, and has already some water. The amount of water that needs to be added to the initial compost for a desired level of moisture is:

$$W_{water\ to\ add} = W_{water} - W_{e,water} \quad (10)$$

The added water was then calculated in volume, since the measuring is way faster. This can be done just by multiplying it by its density. After adding the necessary water, the beaker was covered with plastic film in order that the water doesn't evaporate. Then, the compost was left for 48 h, so that the compost could absorb the water, mixing it every 12-24 h to ensure that the water was well distributed. Once this time was past, the samples were ready to use.

5.3.2. Pressure applied to the compost

When the compost is in the composter, it suffers a pressure from the compost above it. That is, the compost in the bottom will be more compacted than the one in the surface. This compacting was also simulated in the lab in a simple way: pressing the surface of the compost with an equivalent pressure to the one suffered in the composter. Based on the project titled *Generació de FORM i evolució de la massa en el compostatge casolà*, by Gemma Arroyo in

2007, an average weight of 50 kg of compost is produced in a composter during the process. Thus, this weight was taken as a reference in order to apply a pressure. The used composters are square shaped, with each side measuring 60 cm. Taking this into account, the area of the base can be calculated by the following expression:

$$A_C = s \cdot s = 60\ cm \cdot 60\ cm = 3{,}600\ cm^2 = 0.36\ m^2 \quad (11)$$

Being *s* the length of each side. The equivalent pressure that the compost in the bottom will receive will be the force that the 50 kg does by its weight divided by the area of the base (A_c):

$$P = \frac{F}{A_C} = \frac{50\ kg \cdot 9.8\ m/s^2}{0.36\ m^2} = 1{,}361\ Pa \quad (12)$$

Once this pressure is found, it is necessary to know the surface of the beaker in which the experiment will be carried out. Its diameter is 8 cm, so the area (A_{Beaker}) will be:

$$A_{Beaker} = \pi \cdot \frac{d^2}{4} = \pi \cdot \frac{(8\ cm)^2}{4} = 50\ cm^2 = 0.005\ m^2 \quad (13)$$

Given the area of the beaker and the pressure that the compost must suffer, the equivalent weight can be easily calculated:

$$W_{eq} = \frac{P \cdot A_{Beaker}}{g} = \frac{1{,}361\ Pa \cdot 0.005\ m^2}{9.8\ m/s^2} = 0.698\ kg \quad (14)$$

This weight will be applied in form of water contained in a plastic bottle. Since the density of the water is approximately 1 kg/L, the required volume of water will be 0.698 L.

As this water will be contained in a bottle, it is easier for later experiments to calculate the height of the bottle that would reach this volume of water. To do so, the area of the section of the bottle has to be calculated. The diameter of the bottle is approximately the same as the beaker, so the section will also be the same. Thus, the height of water in the bottle will be:

$$h = \frac{V}{A_{Bottle}} = \frac{0.698\ L \cdot \frac{1\ m^3}{1.000\ L}}{0.005\ m^2} = 0.139\ m = 13.9\ cm \quad (15)$$

This way, a line will be drawn at this height, so that any time that the bottle must be filled the only necessary step would be to add water until the line.

It is important to remark that when the pressure is applied, there shouldn't be any extra forces, such as pushing down the bottle or adding other things inside it. Otherwise, the pressure will vary, and the conditions wouldn't be the same in all the experiments.

5.4. PHOTOGRAPHY CONDITIONS

This project focuses on taking pictures of different skewers which have been introduced into the compost. As a consequence, a good photography preparation will be ideal to ensure that all the photos taken have the same characteristics, from the quality of the picture to the luminosity or the background. In order that all the photographs can be comparable, it's been used a system as shown in Figure 7.

Figure 7. Illumination system.

This system is formed by the following elements:

- A desktop lamp, in order that the light keeps the same. The decision of using the lamp was taken after several considerations. First, the experiment couldn't be done with natural light. A simple change of the weather, doing it at a different hour of the day or even at the same hour but with some weeks of difference can affect the natural light of the lab, making the photographs look darker or brighter. The option of using the camera flash was also taken into account, but it was discarded after seeing that, since the photos need to be taken at a short distance, it caused reflections, making it harder to appreciate the totality of the skewer.
- A box as an elevation, in order that the light doesn't reflect as much.
- A white plastic to leave the skewers on. Although the first idea was to do it with paper, it was dismissed after realizing some disadvantages. The main one was the bad quality of the background that it provided, being the plastic of a much

brighter white than the paper and allowing a better contrast between it and the skewer. In addition, for the high moisture samples, the paper absorbed some of the water in the skewer, making the skewer look drier and leaving some stains in the paper. The plastic, on the other hand, didn't absorb the water and was easily cleanable. A comparison of the quality of the pictures with paper and plastic as background is shown in Figures 8a and 8b.

Figure 8a. Skewer photo with paper background.

Figure 8b. Skewer photo with plastic background.

It is also worth mentioning that the first tests, which were photographed with the mobile phone, were discarded because of the difficulty of having the skewer well focused, which caused a lack of definition in the pictures. To solve this problem, all the photos were taken with a reflex camera (Canon EOS 350D, 8 MP, 50 mm objective), keeping the photo conditions the same during all the experiment.

5.5. COMPOST RECYCLING

In every experiment made, the different samples were prepared from the same initial compost. To ensure that, it is important not to return the used compost to the original container, as the moisture could be affected. As a solution, all the used compost was thrown in a "special" bin designed just for that purpose. The used skewers were also thrown there, since they can act as a bulking agent without modifying the compost properties. This bin can be seen in Figure 9.

Figure 9. Bin designed for the compost recycling.

When the bin was full, the content was used as compost in the Camps Experimentals de la Universitat de Barcelona. This way, the compost was not only separated from the initial one, but also recycled.

6. Results and Discussion

After preparing the samples and having all the required materials set for the experiment, it's time to carry it out. The obtained results will be discussed in order to reach some conclusions about the experiment.

6.1. Experiments made

In order to fulfill the proposed objectives, many experiments were required. They can be separated into three different categories: the preliminary experiments, the method establishers and the method checkers. The preliminary experiments were made in order to know the best way of doing the experiments or, in other words, the way in which the results would be more clearly visible. The method establishers were meant to help designing the moisture estimation method, taking into account some variables that could affect the process. Finally, the method was checked in order to know its effectiveness, with the help of people who followed the method in order to estimate the moisture of some samples. Table 3 shows a summary of the different tests carried out during the project.

Table 3. Experiments made during the project.

Category	Experiment
Preliminary	Minimum contact time
	Kind of skewers
	Way of introducing the skewer
Method Establishers	Different moistures
	Pressure influence
	Dry layer influence
Method Checkers	Statistical study of the method success
	Method checked in a composter

6.2. PRELIMINARY EXPERIMENTS

Some experiments prior to the ones to establish the method were made in order to know the best conditions to carry out the experiments. These preliminary experiments basically involve the skewers, checking some aspects that could influence in the final outcome of the experiments.

6.2.1. Minimum contact time

One of the first aspects to observe was the minimum time required for the skewer to have a good measure of the compost moisture. To do so, it has been studied the looking of the skewer after being introduced in the same sample for a different amount of time, leaving the skewer stuck for 5, 10, 20, 40 and 60 seconds, as it can be seen in Figure 10. The studied sample was at a moisture of 53.1 %, being it correct.

Figure 10. Skewers stuck into the compost for the minimum contact time experiment.

A lower time than 5 seconds was discarded because of the difficulty of its exact calculation. The results of the experiment are displayed in Table 4.

Table 4. Appearance of the skewers for different contact times.

Contact time [s]	Skewer appearance
5	
10	
20	
40	
60	

The results of the experiment show no difference between the skewers. In all the times studied, the outcome is the same: the tip of the skewer has a darker color, with the rest of the skewer slightly stained. Therefore, it can be concluded that 5 seconds in enough contact time for the skewer to obtain reliable results, being it the minimum contact time.

6.2.2. Kind of skewers

The skewers used in the experiment play an important role in its final outcome, so it is vital to know if the kind of skewer that will be used has any influence on the final appearance of the skewer. The material of the skewer (kind of wood) or the brand are two aspects that need to be considered in order to discard this influence.

6.2.2.1. Influence of the skewer material

Depending on the material that the skewer is made of, it will absorb in a different way the moisture of the compost. A simple test has been made to prove that, and to decide which kind is the best option. It has been compared a natural wood skewer with another one made of bamboo, which can be seen in Figure 3.

Each kind of skewer was tested with three different moistures (30 %, 55 % and 65 %), in order to see the effect of the material in every range of moisture. Table 5 shows the results of this experiment.

Table 5. Comparison between natural wood and bamboo skewers.

Moisture [%]	Natural Wood	Bamboo
30		
55		
70		

Analyzing the results, it can be seen that the two kinds of skewers seem to work well, clearly differentiating between three moisture levels and looking alike between the different materials. However, it has been carried out another experiment to check if this was really true. This experiment consisted in making people stick both skewers in a certain composter, and see which moisture level they think the compost had from the appearance of the two different skewers. The compost moisture level was measured twice following the method described in 5.1.1., obtaining that it was correct, with an average moisture of 55.6 %. The correct answers obtained with each kind of skewer are displayed in Table 6 and Table 7.

Table 6. Correct answers for each skewer material.

Material	Correct answers	Correct answers [%]
Natural Wood	9	60
Bamboo	12	80

From these values, it can be proven that the success of the method is the same for the two materials. A statistical study is necessary to do so, making a hypothesis contrast in which

$$H_0: p_W - p_B = 0$$

$$H_1: p_W - p_B \neq 0$$

Being p_W the probability of getting a correct answer with a natural wood skewer and p_B the probability of getting it with a bamboo skewer. The parameter p_0 can be calculated by the following expression:

$$p_0 = \frac{n_W \cdot p_W + n_B \cdot p_B}{n_W + n_B} \tag{16}$$

In which n_W is the number of experiments made with the wood skewers and n_B with the bamboo skewers. In both cases, it's 15. Substituting the values of $p_W = 0.6$ and $p_B = 0.8$ obtained from the number of correct answers, p_0 takes a value of 0.7. From p_0, q_0 can be calculated by doing

$$q_0 = 1 - p_0 \tag{17}$$

From these results, the critical value can be calculated with the following expression:

$$CV = \frac{p_W - p_B - d_0}{\sqrt{p_0 \cdot q_0 \left(\frac{1}{n_W} + \frac{1}{n_B}\right)}} \tag{18}$$

Having all the values of the different variables and taking into account that d_0 is 0 in this case, the critical value is -1.19. This critical value has to be compared with the normal distribution N (0,1). For a $\alpha = 5$ % and considering a bilateral distribution, the normal deviation is in a range from -1.96 to 1.96. These results have been obtained by consulting tables of values for the normal distribution in Schaum's Outline of Statistics, by Spiegel, M. (2014). Since the critical value is inside the defined range, it can be stated that the result for the different samples is the same. This proves that the skewer material has no influence in the method, since the probability of getting a right answer is the same for the two different materials.

6.2.2.2. Influence of the skewer brand

Once checked that the material has no influence, it is also important to know if the brand has any kind of effect in the result of the experiment. In order to prove it, two brands were compared for the different moisture levels: Don Palillo and Maxi Madera. Figure 4 shows a picture of the two brands of skewers.

The same experiments were made for the two brands to compare the outcome. They were tested at a 30 %, 55 % and 70 % moisture to see the appearance of each one of them and check if there is any influence in the brand of the skewers. The results are displayed in Table 7.

Table 7. Comparison between skewer brands.

Moisture [%]	Don Palillo	Maxi Madera
30		
55		
70		

As it can be seen, there is no substantial difference between the two brands. For all the moisture levels, the looking of the skewers remains similar between the two brands, which leads to the conclusion that it is only important the material the skewers are made of, and not the brand itself. Of course, it has to be taken into account as well if the brand adds any kind of varnish or paint, which may affect the results if it's waterproof.

6.2.3. Way of introducing the skewer

Although it might seem at first unrelated, the way in which the skewer is introduced into the compost may affect their appearance once they are out. As a consequence, an experiment was required to prove this. In this experiment, two ways of introducing the skewer into the compost were studied: to introduce it straight or to make the skewer spin slowly once it's inside. This comparison was made with compost at two different moisture levels: 55 % and 70 %, and the experiments for each moisture was repeated three times. All the photos can be seen in the Appendices, and Table 8 shows a comparison of the obtained results.

Table 8. Comparison between two different ways of introducing the skewer.

Moisture [%]	Introduced straight	Introduced spinning
55		
70		

It can be appreciated that the skewers that have been spun have a more homogeneous color than the ones that have been just introduced straight, without any kind of spin. A more homogeneous appearance makes the comparison easier, because a global look already gives an idea of the moisture level. On the other hand, if the compost attached to the skewer is distributed in a heterogeneous way, the comparison might be confusing, and it may be hard to decide which side of the compost is more relevant.

Evaluating the results, the following conclusion was reached: the skewer indicates better the moisture level when it's spun inside of the compost. It has to be slowly spun, though, making two or three turns. This way, its appearance will be more homogeneous and, consequently, the comparison will be easier.

It is also worth mentioning that when the method has been tested with people, they also agreed with the better results obtained when the skewer is spun. Although there were no experiments focusing just on this part, the conclusions seem pretty clear: the spinning helps to improve the method, but doing it without spinning the skewer may also lead to good results.

6.3. METHOD ESTABLISHMENT

After all the preliminary experiments and taking into account the necessary materials and the methods to be followed, the experiments that would be used to establish the moisture estimation method could start. In order to make the method as reliable as possible, it is important not only to do all the required experiments to relate each moisture level to a photo, but also to take into account the different variables that could affect the method. It is also vital to contrast the method with people to see its success rate.

6.3.1. Estimated moistures

Before starting the experiment, it is necessary to know which moistures will be the chosen ones to relate with the different moisture levels. To make that choice, it has to be considered the effect that moisture has in the composting process, which is explained in 3.2.

Since the correct level of moisture covers a range of 50 to 60 % w/w, seems obvious that an intermediate value will be chosen to experiment with. In this case, the chosen value was 55 %. From this correct range, if a 10 % is added to the maximum value for a correct moisture, the result will be a 70 %, which would be a compost with more water than the optimal. On the other hand, a 10 % less than the minimum value for a correct moisture will lead to a 40 % moisture, which means that the compost is slightly drier than the optimal. If an additional 10 % is added or reduced in each side, the results will be a dry compost with 30 % w/w moisture and a wet compost with 80 % w/w moisture. These five levels will be the studied ones, with every moisture representing a different level. Table 9 sums up all these moistures with their equivalent levels.

Table 9. Estimated moistures for the experiment.

Moisture [%]	Moisture level
30	Very dry
40	Dry
55	Correct
70	Wet
80	Very Wet

Although these levels seem ideal, when the experiment were made, not all the moistures worked properly. When the different compost samples were prepared following the method in 5.2.1., it was observed that the one at 80 % contained too much water, up to the point that the compost was completely surrounded by water, as seen in Figure 11.

Figure 11. Compost sample with 80 % w/w moisture.

It was left more time to see if the compost could absorb more water, but the situation didn’t improve. Since there was so much water, when the skewer was introduced no compost was attached, it just got wet, with a visible water film surrounding the skewer, just as in Figure 12.

Figure 12. Skewer introduced in the 80 % compost sample.

As a consequence, this moisture level was discarded, leaving only four different levels. The experiments for each moisture were repeated three times. The general appearance of the skewers can be seen in Table 10, and all the pictures are included in the Appendices.

Table 10. Skewers introduced in the different compost samples.

Moisture [%]	Skewer appearance
30	
40	
55	
70	

These results show the relation between a certain moisture percentage and the looking of the skewers. However, it can be seen that the 40 % moisture can cause confusion, since it’s just slightly stained, and it may not be always possible to distinguish from the 30 % one. Taking this into account, for the final method only three different moistures were considered: 30 %, which means that the compost is too dry; 55 %, meaning that the compost moisture is correct, and 70 %, which indicates that the compost is too wet. This way, the method will result easier for starter composters, who will only have to compare the skewer with three images and follow the instructions given in each case.

6.3.2. Skewer method: compost moisture estimation

After picking the desired moistures that would be used as a reference, the method could be fully designed. It also takes into account other important parameters discussed in previous sections.

The process followed to estimate the moisture of a composting material sample, called the “Skewer method”, is the following:

1. Grab a clean wood skewer. It has to be made of wood, otherwise the method might not work properly.
2. Introduce the skewer in the composter, sticking in into the composting material. Make sure that at least ¼ of the skewer reaches the zone in which the moisture wants to be estimated.
3. Slowly spin the skewer, making 2-3 turns while it is inside of the compost.
4. Keep the skewer stuck for at least 5 seconds, and then pull it out.
5. Look at the appearance of the skewer and compare it with the reference pictures. The picture that looks more alike to the skewer will indicate the moisture level of the compost.

The given pictures in order to compare with the skewer appearance are shown in Figures 13, 14 and 15.

Figure 13. Skewer indicating that the compost is too dry.

Figure 14. Skewer indicating that the compost moisture is correct.

Figure 15. Skewer indicating that the compost is too wet.

Taking these pictures as reference, and after the observation of the skewer's looking, the results can be the following:

- If the skewer looks more similar to the picture in Figure 13, the composting material is too dry. When this happens, add water to the composter in a homogeneous way, pouring it little by little.
- If the skewer looks more similar to the picture in Figure 14, the compost moisture is correct. In this case, there is no need of doing anything.
- If the skewer looks more similar to the picture in Figure 15, the compost is too wet. When this happens, mix the compost or add an amendment (such as sawdust, straw or rice hulls) or a bulking agent.

This way, this simple process can help to know the moisture level in a simple, cheap and clean way, which will be very useful for the composters. It is important to remark that the controls need to be done periodically (every day/ every two days) so that any possible correction to a wrong moisture level can be done as quick as possible.

The established method was then tested with people in order to know if it works well. To do so, 30 people from the Master's degree in Environmental Engineering were asked to do a simple survey, in which they had to try the method with four different samples and deciding at which moisture level they were. The moisture of the compost samples used for this experiment are displayed in Table 10.

Table 10. Moistures of compost samples used for checking the method.

Sample	Moisture [%]	Moisture level
1	52.8	Correct
2	25.6	Too dry
3	53.1	Correct
4	63.2	Too wet

After following the different steps of the method, the results obtained for each sample were evaluated. The number of correct answers in each can be seen in Table 11.

Table 11. Correct answers for each compost sample.

Sample	Correct answers	Correct answers [%]
1	17	56.7
2	29	96.7
3	23	76.7
4	30	100

Just by looking at these results, it can be clearly seen that both for a low and a high moisture (samples 2 and 4) the method succeeds, with a high percentage of right guesses. For the correct moistures, the percentage is a little bit lower, but more than half of the answers were correct. The results were treated statistically to check if the method really worked, making a hypothesis contrast for each sample in which

$$H_0: p = 0.75$$

$$H_1: p > 0.75$$

Being p the probability of guessing right each moisture level. The theoretical probability, p_0, will be then 0.75. Having the probabilities of each sample and p_0, taking into account that q_0 can be calculated with equation 12 and that the total number of experiments (n) for each sample is 30, it can be checked if the images taken as reference really correspond to the moisture levels that they represent. To do so, it is necessary to calculate the critic value (CV) with the following expression:

$$CV = \frac{p - p_0}{\sqrt{\frac{p_0 \cdot q_0}{n}}} \tag{19}$$

This critic value will be calculated for samples 2, 3 and 4, discarding the first one, since the moisture level is the same as the third. The results of the calculations are displayed in Table 12.

Table 12. Critical values for each moisture level.

Sample	Moisture level	p [%]	CV
2	Too dry	0.967	2.74
3	Correct	0.767	0.21
4	Too wet	1	3.16

These values have to be compared with the ones of the normal distribution N (0,1). For α = 5 %, the normal deviation is 1.65. It can be seen that, for the dry and wet levels, the critical value is higher than the normal deviation, which indicates that the success rate is higher than 75 %. For the correct level, though, the value is lower. However, the previous experiment done in the composter for the testing of the skewer materials shows that the success rate is quite high. Further experiments were carried out in order to check other aspects of the method.

First of all, it was proven that the two correct samples had the same success rate. To ensure that, another hypothesis contrast was made, in which

$$H_0: p_1 - p_3 = 0$$

$$H_1: p_1 - p_3 \neq 0$$

Where p_1 is the probability of guessing the sample 1 right and p_3 the same for sample 3. From here, the equations 11, 12 and 13 were used to obtain the critical value, which in this case is –1.64. Once again, it is inside the normal deviation range for α = 5 %, which goes from -1.96 to 1.96. The success rate is, consequently, the same for the two samples at the correct moisture level.

It was then thought that the fact of doing the experiment in beakers, having just a small sample inside of them, could make the sample drier at the end of the experiment, even though the periodical mixing of the sample during the test. That's why an experiment in real composters was carried out. In this experiment, different people were asked to introduce a skewer in a composter, following the method to estimate its moisture level. Unluckily, the moisture of the composting material (calculated as explained in 5.1.1.) was 62 %, a value which is in the boundary between the "correct" and the "too wet" moisture levels. As a consequence, the obtained results from the 18 people who did the experiment were 55.6 % of "correct" moisture level and a 44.4 % of "too wet". The fact that there is such a division of opinions in the border seems positive, since the not well defined moisture level of the composting material implies a not well defined result. Nevertheless, as the controls are done periodically, a moisture value in the border can change from one day to another, allowing to see then in which moisture level the composting material is and to make, if necessary, the required corrections.

Finally, it was demonstrated that the three success rate was homogeneous for all the moisture levels (taking samples 2, 3 and 4 for the analysis). To do so, another hypothesis contrast was made, in which

H_0: The success rate is not homogeneous

H_1: The success rate is homogeneous

Having calculated the probability to obtain each moisture level, it has to be checked the importance that each value has in the global results. With a total amount of 82 correct answers and 8 wrong ones, the percentage of right answers is 91.1 %, with an 8.9 % of wrong answers. Since there are 30 answers for each moisture level, the number of correct answers from these 30 will be 27.33, with 2.67 wrong ones. These last values will be e_{ij}, defining I as the moisture level and j if the answer is correct or not. The critical value can be calculated with the following expression:

$$CV = \sum_i \sum_j \frac{n_{ij}^2}{e_{ij}} - n \quad (20)$$

The result obtained is 21.79. This value has to be compared with the one in the χ^2 function. Since the experiment has 2 degrees of freedom, and $\alpha = 5$ %, the limit value will be 5.99. Since 21.79 is higher, it means that H_1 is correct, and the success rate for all the experiments is homogeneous. This ensures that no moisture level has higher chances of being chosen than the others, and the results of the experiment will be trustworthy.

The survey also included a question about the difficulty of the method. On a scale from 1 to 10, being 1 the easiest and 10 the most difficult, the method got an average mark of 2.17, which means that it is in fact a very easy method to carry out.

6.3.3. Pressure influence

The pressure that the compost suffers in the composter is a variable that can potentially affect the outcome of the experiment. To prove if it affects or not, some tests were carried out, comparing the looking of the skewers when the method was followed with a normal compost sample and with a compressed one, prepared as explained in 5.2.2. Three different experiments were made to analyze the influence of the compost pressure level, doing it for four different moistures in each case. All the photos are displayed in the Appendices, and the results are summed up in Table 13.

Table 13. Influence of the compression of the compost.

Moisture [%]	Without Compression	Compressed
30		
40		
55		
70		

Looking at the obtained results, it seems that the skewers introduced into the compressed compost are slightly more stained than the ones introduced in the uncompressed compost. Nevertheless, the levels are in both cases well differentiated, and the appearance is very similar between the skewers stuck in the samples of the same moisture level, disregarding the compression level. Taking this into account, it can be concluded that the method works well for both compressed and uncompressed compost samples, since there is a clear differentiation in the moisture levels and for each level the results look similar.

6.3.4. Dry layer influence

When the compost is in the composter, there are some open spaces that let air come in. This air can dry the more external layer of compost, causing that its moisture would be different than the one in the center of the composter. It has been studied if this dry layer can affect the method, even if the skewer reaches the part of the composter in which the moisture wants to be measured.

To simulate this situation, a layer of dry compost has been added to the compressed sample. This dry compost came from the initial one, which moisture was 18.5 %, so that the difference in moisture would be higher. An example of this sample is the beaker shown in Figure 16.

Figure 16. Compressed compost sample with a dry compost layer.

After preparing these samples, the method was tested, and a comparison was made between the compressed compost and the one with a dry compost layer on top. This experiment was made for four different moistures, and repeated three times with each of them. All the photos taken can be found in the Appendices, and Table 14 shows a summary of the obtained results.

Table 14. Skewers introduced in compressed compost with and without a dry compost layer.

Moisture [%]	Compressed	Compressed with dry layer
30		
40		
55		
70		

As the results show, there is no substantial difference between the different skewers. It is worth mentioning, though, that for the highest moisture level some drier particles get attached to the skewer, making it look not so wet. Nevertheless, the general appearance is very similar, with the only difference that some particles can be a little bit smaller. After the experiment, then, it has been concluded that there is no great influence from the possible dry layer that can be in the composter.

7. CONCLUSIONS

After all the experiments made, the following conclusions were reached:

- The skewer kind of wood and the skewer brands do not affect the outcome of the experiment, obtaining the same results for the two tested ones.
- At the work conditions, especially because of the kind of compost, it was not possible to work in the lab with samples at very high moistures (over 70 %), since the beaker got totally flooded. As a consequence, the planned experiments for an 80 % moisture were discarded.
- The difference between the 40 % and the 30 % moistures is too low to consider doing different moisture levels for them. Thus, the final method only had three different moisture levels.
- The defined method works well, having positive results in the experiments made to check its success rate.
- For moisture values which are in the border of the different moisture levels, there is a division of results.
- The level of compression has little influence in the well-functioning of the method, as well as the presence of a dry compost layer.
- The attached *Carta d'Humitats* shows the result of all the work done, with the method explained and ready to be given to the composters so that it can be followed.

8. RECOMMENDATIONS

This project has taken into account a wide range of variables to ensure that they don’t affect the outcome of the experiment. However, there are some aspects than couldn’t be treated, and they are proposed as recommendations for further studies.

The main recommendation, in order to dissipate any possible doubt, is a study of the borders of the different moisture levels. Since there is a division of opinions in the results when the moisture is close to the border (as seen in the experiments, where at around 60 % moisture the results were diverse), it is convenient to do a further study of these limit values, stablishing more moisture levels in these ranges.

Other recommendations are the study of other possible variables that haven’t been taken into account: to do more experiments studying the different moistures directly from the composters at the different moisture levels, and analyzing the appearance of the skewers then, taking photos of them; making an analysis on how the method works with expert composters; test the method with less ripe compost and study other materials which could do the same function as the wood in order that the skewer could be used more than once.

9. REFERENCES AND NOTES

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10. ACRONYMS

A_i: Area.

CV: Critical value

d: Diameter

e_{ij}: Theoretical number of results in a sample based on the results of the total population.

F: Force.

FORM: Fracció Orgànica de Residus Municipals.

g: gravity acceleration.

H: Compost moisture.

h: Height.

n: Number of experiments.

n_i: Number of cases favorable to i.

P: Pressure.

p_i: Probability of getting i.

q_i: Probability of not getting i.

s: Side of a square.

V: Volume.

VS: Volatile solids.

W_i: Weight.

ρ: Density.

APPENDICES

APPENDIX 1: EXPERIMENT PHOTOGRAPHS

During this project, many photos were taken. The following tables collect the ones that aren't shown in the different sections of the project because of its volume. They also include the real moisture of the samples that were used, since there is always a little deviation from the desired value.

Table a. Way of introducing the skewer.

Theoretical Moisture [%]	Real Moisture [%]	Way of introduction	Skewer appearance
55	53.1	Without spinning	
55	53.1	Without spinning	
55	53.1	Without spinning	
55	53.1	Spinning	
55	53.1	Spinning	
55	53.1	Spinning	
70	63.2	Without spinning	
70	63.2	Without spinning	
70	63.2	Without spinning	
70	63.2	Spinning	
70	63.2	Spinning	
70	63.2	Spinning	

Table b. Results for a 30 % moisture.

Real Moisture [%]	Sample	Skewer appearance
25.6	Uncompressed	
27.3	Uncompressed	
26.8	Uncompressed	
25.6	Compressed	
27.3	Compressed	
26.8	Compressed	
25.6	Compressed with dry compost layer	
27.3	Compressed with dry compost layer	
26.8	Compressed with dry compost layer	

Table c. Results for a 40 % moisture.

Real Moisture [%]	Sample	Skewer appearance
38.7	Uncompressed	
40.7	Uncompressed	
37.5	Uncompressed	
38.7	Compressed	
40.7	Compressed	
37.5	Compressed	
38.7	Compressed with dry compost layer	
40.7	Compressed with dry compost layer	
37.5	Compressed with dry compost layer	

Table d. Results for a 55 % moisture.

Real Moisture [%]	Sample	Skewer appearance
53.2	Uncompressed	
51.0	Uncompressed	
56.7	Uncompressed	
53.2	Compressed	
51.0	Compressed	
56.7	Compressed	
53.2	Compressed with dry compost layer	
51.0	Compressed with dry compost layer	
56.7	Compressed with dry compost layer	

Table e. Results for a 70 % moisture.

Real Moisture [%]	Sample	Skewer appearance
66.5	Uncompressed	
66.8	Uncompressed	
68.6	Uncompressed	
66.5	Compressed	
66.8	Compressed	
68.6	Compressed	
66.5	Compressed with dry compost layer	
66.8	Compressed with dry compost layer	
68.6	Compressed with dry compost layer