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Valorization of Household Anaerobic Processed Digestate: A case study of Morocco

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- ✓ Household waste;
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- ✓ Soil amendment

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Abstract

Organic wastes, through biotechnology, are valued by the production of renewable energy and fertilizer for soil fertilization. In this study, we will present an assessment of the potential value of organic household waste. Namely, the assessment of physical, chemical and biological parameters of biogas slurry or processed digestate was conducted in order to use it as a soil amendment. The assessment and study of digestate quality are directly related to the concept of compost maturity criteria and methods of evaluation. The results obtained allowed us to conclude that methane fermentation of household waste followed by an aerobic stage of maturation of digestate have several advantages: (1) obtaining processed digestate as a valuable fertilizer by-product whose nutrient content and phytotoxic effect are satisfying; (2) reduction of the maturation period to 35 days compared to 90 days in the case of the conventional composting. On the other hand, this reduction is accompanied with over 50 % of raw material in the studied digestate; (3) production of a renewable energy of retrievable biogas, therefore avoiding the greenhouse gas unlike another methods (conventional composting) and escaping from bad odors, thanks to the use of digesters.

1. Introduction

With ever greater and more diverse consumption throughout the world, the production of waste is increasing in quantity and diversity, thus generating huge risks on the environment and consequently the health of populations [1,2]. This situation is much worse in developing countries (DCs) because of the considerable delay in the field of management and development due to lack of resources and difficulty to approach the issue with an approach adapted to the local context, in order to establish an effective and sustainable policy of good management and recovery of organic waste in DCs [3]. The multiple challenges that Morocco faces range from waste management, intense soil organic matter mineralization, the renewed interest in organic farming, and prohibitive price of chemical fertilizer. On the other hand, in Morocco, the overall solid waste generation is 6.852 million metric tons. Urban waste generation is now approximately 0.76 kilos per day per capita, whereas rural waste generation per capita is about 0.3 kilos per day [2]. The Department of Environment of Morocco reported in 2001 that MSW organic matter content is in the range of 50-70% [4]. Most of these organic urban wastes are landfilled and thus their organic matter is lost forever while the majority of Moroccan soils are poor in organic matter [5][6]. Taking into consideration all of these issues, using biogas digestate organic wastes as a bio fertilizer would be of great interest. A waste is defined as an object or a material whose economic value is zero or negative, at a time and in a given place. The definition in relation to the economic value, however, is relative. Most of research on methanisation of organic wastes has been carried out purely based on its value as a source of renewable energy, while the under-standing of agronomic and physicochemical properties of digestate has not been widely reported [7]. Actually, thanks to anaerobic digestion, organic waste can be valued by the production of renewable energy and fertilizer for soils. Returning digestate to soils offers the opportunity for true recycling of plant nutrients [8]. Actually many studies reported that the digestate could be used as potential substitute to chemical fertilizers in agriculture [9-13]. Nevertheless, it is recommended to stabilize the digested material through a post treatment, by composting [10] or liquid-solid separation [13] prior to the application of soil amendment. Therefore, the aim of this study was to assess the agronomic potential value of two household wastes (HHW) after anaerobic digestion (AD) resulting in nutrient-rich humus like material (i.e., solid fraction of mechanically separated) called processed digestate. This work was carried out at Agadir city in south Morocco.

2. Experimental details

2.1. *Sampling of organic waste*

This study focused on the anaerobic treatment of organic HHW, as follows:

HHW1: household waste 1: it consists notably of remains and preparation of meals and vegetables with a large proportion of waste legumes (beans and peas), collected at three different homes;

HHW2: household waste 2: it has the same origin of HHW1. The HHW2 contains the last constituents of HHW1 and a little quantity of bread, lemons and chicken leftovers.

2.2. *Physical and chemical characteristics*

2.2.1.*Determination of density*

A graduated test-tube of 1 liter volume is filled with organic substrates without compaction and weighed on balance. The density is calculated by the following formula:

$$\rho = m/v$$

ρ: density ($kg.m^{-3}$)
m: weight (kg)
v: volume of the container (m^3)

2.2.2. *Moisture (% M), dry matter (%DM), mineral matter (%MM) and organic matter (%OM)*

The percentage of the different fractions of the HHW is determined by the sample weight difference before and after AD [3] as follows:

$$\%M = (W_0 - W_1).\ 100/W_0$$
$$\%DM = 100 - \%\ M$$
$$\%MM = W_2\ .100\ /W_1$$
$$\%OM = (W_1 - W_2).100\ /W_1$$

W_0: Initial sample weight before drying
W_1: final weight of the sample after drying at 105 °C
W_2: the final weight of waste calcined at 550 °C

2.2.3. *pH and electric conductivity (EC)*

pH of wastes is determined according to Japanese Industrial Standards (JIS) K 0102 [14] using a pH meter inoLab. Calibration is performed with buffer solutions of pH 4 and 7 at 20 °C. The accuracy in the measurement given by the manufacturer is ± 0.1 pH unit.

The EC was measured using a conductivity meter BIOBLOCK SCIENTIFIC apparatus.

2.2.4. *Total organic carbon*

The total organic carbon (TOC) in waste can be estimated from the volatile dry matter or organic matter (OM), by the following formula [15]:

$$TOC = 0.51(VDM - 1) + 0.48$$

VDM: Volatile Dray Matter

2.2.5. *Elements (K^+, Na^+ and Ca^{2+}) measurement*

The elements K^+, Na^+ and Ca^{2+} were measured out according to the procedure described by [16], which consists of an aqueous extract, after drying and grinding in the presence of ammonium acetate (1N) followed by filtration and reading by flame spectrophotometry.

2.2.6. *P_2O_5 measurement*

The measure of assimilable phosphorus (P_2O_5) consists of an aqueous extraction in the presence of $NaHCO_3$ (0.5 N) and activated charcoal, then read by atomic spectrophotometer [16].

2.2.7. *Total nitrogen*

The technique used is the modified Kjeldahl method (Nitrate-N not included in the total N) [7].

2.3. *UV - visible characterization of processed digestate*

Many authors used the UV-visible spectroscopy to characterize humic substances [17,18]. The principle of the UV-visible spectroscopy is based on electronic transitions, the transition of an electron from a stable orbital to an unstable orbit, caused by the absorption of electromagnetic radiation in the UV region (200-400 nm) and visible (400-800 nm). In the case of organic compounds, the electronic transitions correspond to molecular orbital changes of specific functional groups (chromophores). Thus, the absorption spectra of a compound can be used for its characterization.

The method is used to characterize the compost, and it consists in a shaking in the presence of NaOH (0.5 N), followed by centrifugation, filtration and reading the optical density (OD) at different wavelengths (280, 472 and 664 nm), to determine three ratio: Q2/6 = (OD 280/OD664), Q4/6 = (OD472 / OD664) and Q2/4 = (OD280/OD472).

- ✓ Q2/4 ratio reflects the proportion between the lignin and other materials at the beginning of humification, and the material content at the beginning of transformation;
- ✓ The ratio Q2/6 shows the relationship between the non humified material and highly humified material;
- ✓ Q4/6 ratio is often called "humification index." It is the most widely used ratio. Typical values for Q4/6 of a humified material are less than 5.

2.4. *Germination and root development test*

The use of bioassay using plants, e.g. *Lepidium sativum*, to test impacts of compost applications on soil is recommended [19]. This plant was selected for this biological standardization thanks to its good response to toxic materials and its rapid and easy germination [20]. The principle of the test involves placing cress seeds in a series of Petri dishes with filter paper soaked with increasing doses of processed digestate extract: 50%, 75% and 100% (3 replicates per treatment) [21]. Another control series (distilled water) is prepared. At the end of the incubation period (3 days at 27 °C), the number of germinated seeds and root length are evaluated. This calculates a Germination Index (GI):

$$GI=(TG/CG).(TL/CL).100$$

GI: germination index;
TG: number of germinated seeds in filter paper amended with diegestate;
CG: number of germinated seeds in the case of control;
TL: Root length in the case of treatement with processed digestate;
CL: Root length in the case of control.

Since the GI is below 60%, soil amendment with this compost should be done 90 days before farming. If the GI is below 50%, the compost is not yet mature and it is recommended to continue composting until maturity [22].

2.5. *Cress germination test*

This test is close to the previous test. It consists in seedling cress seeds in a mixture of 2/3 of peat and 1/3 compost. The test was conducted in 7 days. The parameters studied are, among others, the germination rate at the 3rd and 7th day [22].

2.6. *Anaerobic digestion test*

The laboratory setup described by [23] consists of digester trial of 5 L (Figure1); containing organic substrate well homogenized and drowned in water at 8% DM. Digesters are placed in a water bath at a mesophilic temperature (35C°). The digesters are batch type; each batch is connected to an inner tube for the biogas product storage.

2.7. *Digestate maturation device*

After the AD phase lasting about 35 days (HHW1) and 25 days (HHW2), the digestate is submitted to a second phase of draining and drying in a device designed for this task (Figure 2). The digestate maturation device is of cylindrical form made of metal, size 70 cm diameter and 1.65cm long [24]. Turning was performed after 2, 4, 8, 14 days, until the finished product (methacompost).

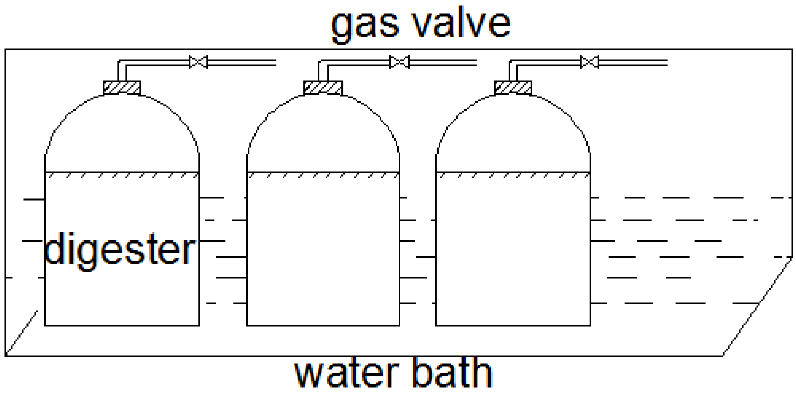

Figure 1. Fermentation device

Figure 2. Digestate maturation device.

3. Results and Discussion

To assess the performance of AD and its efficiency as the best recovery process of organic waste, several analysis of substrates were carried out, as well as finished product (processed digestate or methacompost) based on the physical, chemical and biological characteristics.

3.1. *Physical and chemical characterization of raw material*

Table 1 shows that chemical composition of organic waste, can vary from sample to sample, which is related to the difference of meals (HHW1 and HHW2) (Table 1). So special attention should be given when collecting organic waste and mixing in order to ensure a relatively uniform finished product of a sample to another.

Table 1 also shows that all studied organic wastes are favorable for AD in order to produce a good fertilizer, after anaerobic treatment followed by an aerobic maturation phase of digestate, this refers to the basic elements (nitrogen, potassium, phosphorus, and carbon), which should not vary in the finished product if the leaching is avoided, for recycling the liquid or its use for irrigation. In the other hand, household waste seems to be wetter. All of the nitrogen contained in the organic wastes is retained during methanization. However, it is converted from organic to inorganic forms: available as organic nitrogen in fresh residues, it is found in the form of ammonium NH^{4+} in the effluent. The ammonium form of nitrogen is more readily available to plants but highly volatile and easily leached out. The HHW had high contents of organic matter (89% and 94% DM basis), carbon (45.36 and 47.91 DM), organic and NH_4 nitrogene (2.45% and 1.75% DM basis) respectively in HHW1 and HHW2 (Table 1), this confers an optimal C/N ratio.

(27.37) for anaerobic digestion of HHW2 but low C/N ratio (18.51) for the same processus of HHW1 [3]. The initial pH of the studied organic waste is also avantageous for methanic fermentation. For acid substrates (HHW2: pH = 4), it should be mixed with other waste, which would accelerate the hydrolysis stage, then allowing quick transition to the anaerobic stage [25].

Table 1 . Physical and chemical characteristics of studied organic waste

Analysis	Parameters	Raw waste	
		HHW1	HHW2
Physical	Moisture (%)	88	87
	Mineral matter % DM	11	6
	Density (kg/m^3)	400.00	680.70
Chemical	Organic Matter % DM	89	94
	N_{org}, NH_4-N (%) DM	2.45	1.75
	TOC (%)	45.36	47.91
	C/N	18.51	27.37
	Ca^{2+} (%DM)	36.20	7.72
	Na^+ (%DM)	9.17	8.94
	K^+ (%DM)	66.60	45.98
	P_2O_5 (g/kg DM)	1.23	1.86
	pH	7	4
	EC (mS/cm)	3.44	3.21

3.2. *Physical, chemical and biological characterization of processed digestate*

The evaluation of physical and chemical parameters of processed digestate is summarized in (figure 3). The loss of OM in the finished product is a result of the biodegradation and digestion by microorganisms during the fermentation process.

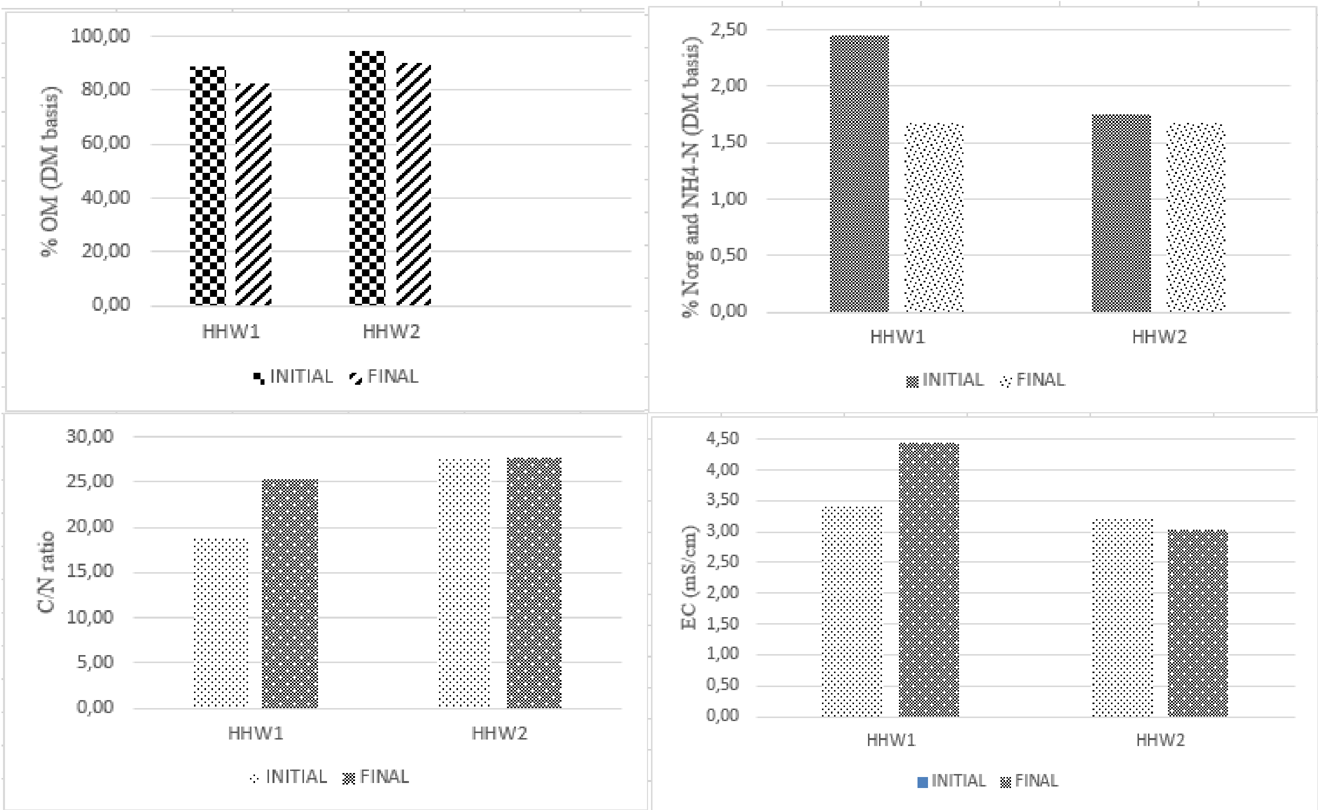

Figure 3. Synthetic representation of levels of OM, modified kjeldahl N, C/N, pH and EC of studied waste before and after AD (AD duration = 35 days for HHW1 and HHW2 for 25 days)

The rate of OM decrease is related to the stay time in the bioreactor and to microbial activity, according to different optimization parameters (temperature, pH, shaking, pourcentage and nature of the microbial inoculum etc.), these parameters are being investigated at a pilot bioreactor already installed. The two processed digestate have excellent C/N ratio, which make it possible to have a good compost. The french standard (U44-051) considers that the marketing of organic amendments must have a C/N ratio greater than 8, this is the case of our

products. The C/N ratios increased for both digestates at the end of digestion (Figure 3). This increase would be the consequence of insufficient duration of digestion, and also the leaching of nitrogen and passage through the liquid phase. The influence of treatment duration, either during the anaerobic fermentation, or during aerobic maturation of the solid fraction (maturation of digestate) should be optimized to ensure good and rapid degradation of the material organic. The optimization of anaerobic digestion leads to a reduction in the time of waste degradation, which makes this process very efficient as conventional composting.
An assessment of the maturity degree of methacompost was also conducted by biological tests: namely, root development test (Figure 4), cress germination test (Figure 5), and spectral test: UV-visible spectroscopy (Figure 6).

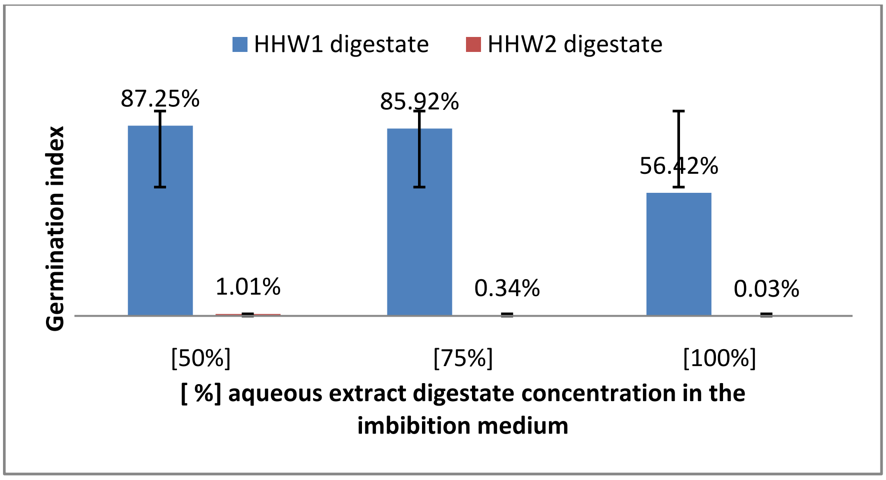

Figure 4 : Phytotoxicity test**:** Germination index.

The results presented in figure 4, indicate that the germination index is inversely proportional to the extract processed digestate dose applied to cress seeds (figure 4). This corresponds to the behavior of a conventional compost when it is applied with increasing doses on plants: it causes a depressive effect on germination seeds and root development. This phytotoxic effect is due to the presence of organic acids released by immature compost, including acetic acid and other compounds (acetaldehyde, ethanol, acetone, ethylene ...) contributing to the phytotoxic effects [18]. Unlike HHW2, the processed digestate from the anaerobic degradation of HHW1 had a GI> 50% in the case of pure extract of processed digestate [100%]. We observed that HHW2 had a low germination rate. It is probably due to the insufficient anaerobic digestion duration (25 days) compared to HHW1 (AD duration=35days); therefore the biodegradability of organic components was low which had limited the seeds germination. The methacompost (HHW1) may therefore be considered without phytotoxic effect. It had rather a biostimulant effect on cress seeds germination and root elongation. The main diference between HHW1 and HHW2 is the duration of treatment.
However, this test is still insufficient to assess the digestate maturity. It must be completed by other tests: cress germination test (Figure 5) and the UV-visible spectral test (Figure 6).

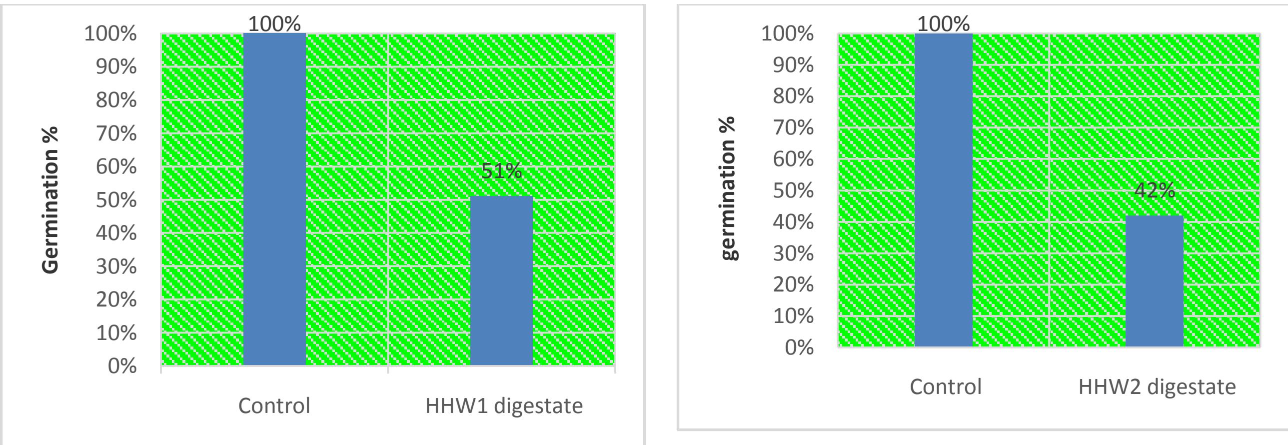

Figure 5. Cress germination test

The results show that the germination percentage watercress seeds treated by processed digestate is lower than that of the control in both types of processed digestate. These results confirm previous test phytotoxicity. The HHW1digesate always showed a less depressant effect on the germination of cress (51% of germination compared to control). While HHW2 processed digestate still have an inhibitory effect cress germination (42% compared to control) (figure 5).

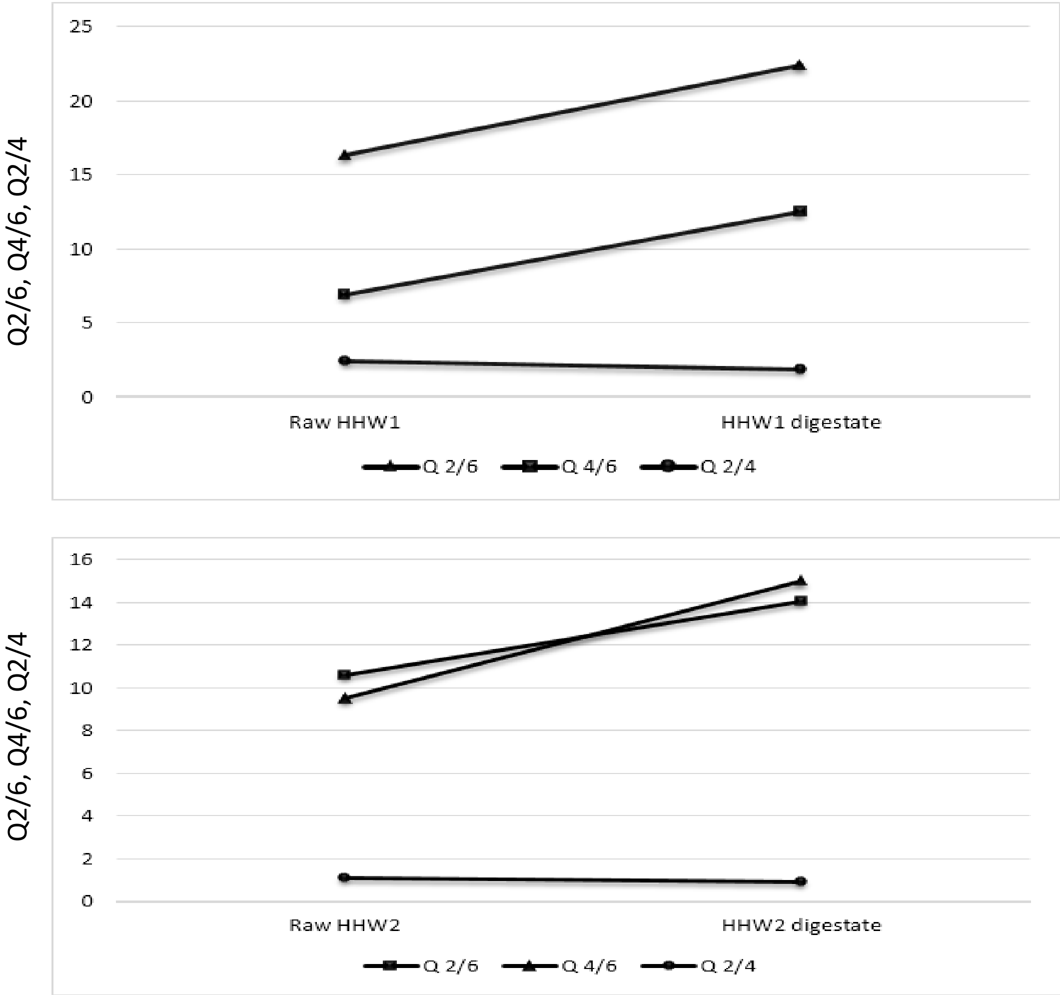

Figure 6. UV-v results before (raw HHW) and after maturation (processed digestate)

The UV-visible absorbance, used to determine the degree of humification of methacompost, (Figure 6) shows the increase of both Q2/Q4 and Q4/6 ratios, and decreasing Q2/4 ratio in both HHW1 and HHW2 processed digestates after maturation process within 15 days and 20 days respectively. This demonstrates that the organic materials are still at the beginning of humification. This can be checked by the value of Q4/6 ratio which is> 5, which thus reveals clearly the beginning of humification of organic matter.The test plant (germination index test and watercress ...) has shown a fairly significant level of maturity. This confirms previous findings, namely that the 15 days and 20 days of maturation time for respectively HHW1 and HHW2 processed digestates did not lead to complete maturity of the finished product. In our case, it is possible to accelerate the AD process in a short time of about 20 days, by microbial activator adition. This inoculum is particularly active in the hydrolysis phase.

Conclusions

Anaerobic digestion is a promising method for recovery of organic waste since it allows, in addition to the extraction of energy in the form of biogas, to obtain the digestate which can undergo a maturation phase to reach a stabilized product with agronomic interesting value.

In the light of the results obtained, the methacompost (HHW1) may therefore be considered without phytotoxic effect and it always showed a less depressant effect on the germination of cress (51% of germination). While the methacompost (HHW2) processed digestate still have an inhibitory effect cress germination (42% of germination). For the degree of humification of these methacomposts, we noticed the increase of both Q2/Q4 and Q4/6 ratios, and the decrease of Q2/4 ratio in both HHW1 and HHW2 processed digestates after maturation process within 15 days and 20 days respectively. It was demonstrated that digestate processing can be an effective way for production of fertilizer because it usually contains residual organic matter and nutrients, once maturity is reached. This should encourage socioeconomic actors, to invest in pilot instalations, for a return of experience and lead to a Moroccan model suitable bioreactor.

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