VALORIZATIONS ENERGY AND AGRONOMIC OF THE INDUSTRIAL BIOMETHANISATION APPLIED TO AVICOLOUS BIOMASS IN TUNISIA

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Abstract. *- This work consists in studying the anaerobic fermentation, applied to the avicolous biomass, established on the level of the industrial digester of Sousse Hammam, Tunisia.*

The present study was interested towards:

- The qualitative productivity of produced biogas (gas composition, calorific value).

- The partial substitution of the forestry compost (FC) by the avicolous methacompost refined in its two states (exits of the decanter and of digester) according to the same ratio of 20%. It is a question of following the germination and the growth of the seedlings of Acacia cyanophylla installed on the prepared substrates.

The synthesis of the principal results is the following one:

- The value of the energy produced and of the purification of the biogas produced.

- The incorporation of the avicolous methacompost has a remarkable positive effect on germination, and consequently, on the growth of the seedlings of Acacia cyanophylla.

Key words: *Biomethanisation industrial avicolous, gas composition, calorific value, methacompost avicolous, substrate of culture, seedlings of Acacia cyanophylla.*

VALORISATIONS ÉNERGÉTIQUE ET AGRONOMIQUE DE LA BIOMÉTHANISATION INDUSTRIELLE APPLIQUÉE À LA BIOMASSE AVICOLE EN TUNISIE

Résumé.*- Dans le cadre de ce travail, on a cherché à étudier la fermentation anaérobie, appliquée à la biomasse avicole, établie au niveau du digesteur industriel de Hammam Sousse, Tunisie.*

La présente étude s'est intéressée à deux tâches majeures :

- La productivité qualitative de biogaz (composition gazeuse, pouvoir calorifique).

- La substitution partielle du compost forestier (CF) par le métacompost avicole affiné dans deux états (sorties du décanteur et du digesteur) selon un rapport de 20% pour chacun, afin de suivre la germination et la croissance des jeunes plants installés sur les substrats élaborés.

Les principaux résultats sont :

- L'intérêt de l'énergie produite et du pouvoir de purification du biogaz produit.

- L'incorporation du méthacompost avicole a un effet positivement remarquable sur la germination et sur la croissance des plants d'Acacia cyanophylla.

Mots clés : *Biométhanisation avicole industrielle, composition gazeuse, pouvoir calorifique, méthacompost avicole, substrat de culture, plants d'Acacia cyanophylla.*

Introduction

One of technologies allowing the treatment of the organic fraction of waste is the biomethanisation which can transform a problem of waste into a source of richnesses [1]. There exists, indeed, several recycling appropriatenesses of organic waste, in particular for the energy production and for the fertilization of agricultural land, so as to reduce the quantity of buried organic waste and to diversify the sources energy of substitution.

The animal manure is particularly interesting to use when they are produced in significant amounts and regular [2] and especially when they are treated by biomethanisation before use [3; 4].

Alkaline fermentation is, today, the bioenergetic die with the most promising prospects [5; 6]. Its industrial application, after progress of the last years of research, starts to become a reality. Indeed, the techniques available are right now sufficiently powerful to return the systems proposed economically acceptable [7].

The degradation of organic matter (OM) by anaerobic way is recognized more and more like fundamental method of a advanced technology allowing environmental protection and the conservation of the resources [8; 9; 10; 11]. The good performance (depollution, energy potentiality) of this kind of process is largely conditioned by the physicochemical conditions (nature, pH, DM…) of the substrates implemented.

The present study aims primarily the assessment of energy performance of industrial digester (powered by poultry droppings) installed in Hammam Sousse, while limiting themselves to a restricted follow-up of its qualitative productivity of biogas (Composition in Biomethane: CH_4 and Calorific value: CV).

Concerning the digestate (secondary by-product of the biomethanisation), the use particularly of its solid fraction called methacompost, like partial substitute of the Forestry Compost (FC) considered as substrate of reference for the production of the forest seedlings, could constitute an interesting alternative to improve its chemical quality especially, and consequently, the quality of the produced forest seedlings.

This work is directed towards the focusing in the substrates of growth containing mixture of compost and Avicolous Methacompost (AMC), adequate for the production except ground of the forest seedlings. In addition, an indirect evaluation was undertaken, primarily aiming the appreciation of the germination of the seeds and the growth in height and diameter, of the seedlings of Acacia cyanophylla installed, on the one hand, on the FC alone in a pure state, and on the other hand, on the FC mixed with the AMC in its two states, namely at the exit of the decanter (AMCA) and at the exit of digester (AMCA') according to the same ratio, at a rate of 20% in each mixture.

1.- Material and methods

1.1.- Experimental device

1.1.1.- Technical presentation of the studied digester

It is a pilot digester with cylindrical form, installed in a poultry farm since the year 2000, of a service output of 300 m³, fed uninterrupted daily by 10 m³ of substrate made up from approximately 1/3 of avicolous biomass and 2/3 of water.

The quantities of droppings available represent the day laborer production of an avicolous breeding out of cages around 20000 layers. The installation is designed to treat 4 tons of fresh dejections daily and to produce 200 m³ biogas/ day which can be transformed into 300 kWh electric of which 5 to 10% only are currently consumed by owner [11] to feed the generators and to satisfy thus the needs for the farm and the station in electrical energy.

Besides the energy objective, the unit of biomethanisation has an environmental objective which consists in reducing the pollution generated by the droppings.

1.1.2.- Circuits of the avicolous droppings

In the digester, the produced digested droppings cross three different basins (fig. 1): a first basin receiving the substrate digested for a weak residence time (called basin of the digested droppings) before remaining in the second basin called decanter or mud tank. Starting from this last, muds of the elutriated droppings will be dried and transformed into methacompost. As for water supernatant (Juice of process) the mud tank, it passes in the third basin to be used for scraping of the fresh droppings of the hen houses.

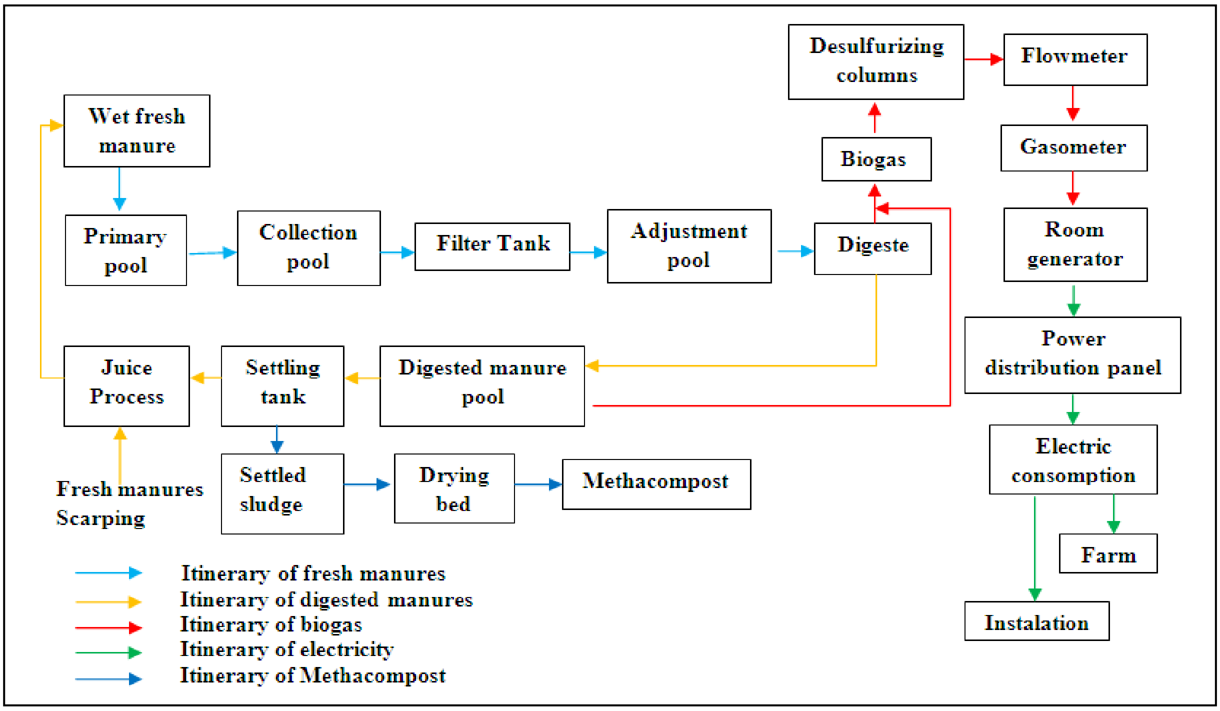

Figure 1. - Diagram of the different circuits of the industrial poultry Biomethanisation instalation

1.2.- Qualitative follow-up of the gas productivity

The qualitative analyzes of biogas was effected in the test laboratories of the Tunisian Company of Industries of Refining (TCIR) of Bizerte.

The evaluation of the gas productivity imposes the quantitative and qualitative follow-up of biogas produced on the level of the industrial digester. Following the dysfunction of the flowmeter installed, the quantitative follow-up could not be carried out and we are limited only to the qualitative follow-up which related to biogas taken, once flammable by determining of its gas composition and its calorific value.

1.2.1. - Composition in gas elements

The quality of biogas is evaluated primarily by the measurement of % methane (CH_4) which it contains. Indeed, a biogas is as much better than its % CH_4 is high. But, it also rests on the determination of % CO_2, % H_2S and % H_2. In opposition to CH_4, more the % of these elements are reduced, more the quality of biogas produced is better.

1.2.2. - Calorific value

The calorific value of a fuel is the quantity of heat released by the complete combustion of 1 Normal m^3 of dry gas (quantity of gas matter which 1 m^3 under the normal conditions of temperature and pressure occupies: 0°C under 1 Atmosphere) in the air with a constant absolute pressure.

It is a question of evaluating the lower calorific value (LCV) and the higher calorific value (HCV) expressed in (kcal/Nm³). The LCV is calculated when the water produced by this combustion remains with the vapor state and which are linked by expression (1) following:

$$\mathbf{HCV = LCV + heat\ of\ vaporization} \quad (1)$$

According MONZAMBE (2002), the calorific value of biogas is proportional to its content of CH_4. It varies between 5000 and 8500 kcal/Nm³ [12].

The water formed during combustion is brought back in the liquid state, the other products being with the gas state. Thus, the latent heat of vaporization is that necessary to transform 1kg water into vapor.

1.3.- Possibilities of agronomic valorization except ground of the avicolous méthacompost

1.3.1.- Vegetable material

A leafy forest species with rapid growth, Acacia cyanophylla, was used to study the vegetable answer with respect to various substrates of growth tested. The seeds of this species were provided by the Head Office of Forests (HOF), and were collected starting from shrubs located in the area of Enfidha, Sousse (Tunisia).

1.3.2. - Substrates of culture

The made substrates, object of this study, are obtained following the mixture of pure compost of vegetable origin with a methacompost of animal origin.

The green biomass, in the form of branchs of Acacia cyanophylla, was used to produce a compost with the characteristics necessary for the breeding of forest seedlings in modern seedbed [13; 14; 15]. The compost of produced Acacia constituted the basic matrix in the preparation of the substrates of culture tested.

The pure substrates are the following:
- Forestry Compost, (FC) produced in the modern forest seedbed of Chott-Mariem, Sousse.

It is resulting from the branches of Acacia cyanophylla crushed successively by a simple knife crusher and a simple hammer crusher equipped with a grid of calibration of mesh 30 mm.
- Avicolous Methacompost (AMC), solid residue resulting from a unit of industrial biomethanisation in Hammam Sousse, in its two states, namely at the exit of decanter (AMCA) and at the exit of digester (AMCA') according to the same ratio of mixture, at a rate of 20%.

The evaluated substrates are 3:
SA: Standard substrate FC (pilot)
SB: Mix 80% FC + 20% AMCA
SC: Mix 80% FC + 20% AMCA'

The two made mixtures appeared the best, following the direct evaluation of the physicochemical properties of various mixtures made starting from three pure components considered.

1.3.3.- Agronomic follow-ups

1.3.3.1. - Test of germination on leguminous plants

The aim of the biotest is to evaluate the maturity of the methacompost, to envisage the possible existence of some elements phytotoxic, while putting in consideration the photosensitivity of the seeds of Plant-tests [16]. For the appreciation of the maturity of the FC, we used two leguminous plants: the bean and the chick-pea. The bean translates the phytotoxicity by a yellowing of the sheets and a depressed growth, even null. Pea-Chiche is selected because of its prompt response.

This biotest studies of the germination and of the growth during 28 days [17; 18] of the plant-tests cultivated out of containers filled of the FC produced with the seedbed. For each specie of plant, we used 4 containers (15 cavities x 4 containers x 2 species = 120 plant-tests). The biotest touched only the FC, since the AMC studied on the outlet side of the digester or decanter is already ripe. The measured parameters are the duration of germination and the percentage of germination.

1.3.3.2. - Evaluation of the behavior of the seedlings of Acacia

To appreciate the vegetative behavior of the seedlings considered, we were satisfied to follow the evolution of 4 morphological parameters hereafter.
- Percentage of germination of the seeds of Acacia: Measurements of germination were taken one week after sowing, while ensuring counting cumulated every 4 days.
- Increase in height in seedlings: The follow-up of the evolution of the air part of the seedlings was led starting from the measurements in cm (with 15 days more or less regular intervals) since the collet to the apical bud using a digital slide caliper.
- Increase in diameter in seedlings: The measurements in mm were taken at the same time as those of the increase in height and with the same material.

It should be noted that, for each container, we chose 5 seedlings (5 seedlings / container, 1 seedling/3 cavities) to by chance take measurements in height and diameter.
- Ratio of robustness of the seedlings: It is equal to the ratio Height /Diameter (H/D), expressed in cm/mm.

The experimental device implemented calls upon a plan in complete random blocks (CRB) with a studied factor (3 substrates) and a controlled factor (3 blocks). They are 18 containers distributed as follows: 2 containers x 3 substrates x 3 blocks.

2. - Results and discussion

2.1. - Establishment of the assessments of purification

The biogas produced by the industrial digester undergoes purification by calling upon a desulphurization with the iron hematite. In this respect, the follow-up was carried out before and after purification to appreciate the interest of this treatment. The evaluation of the performance of the conditioning carried out is interpreted starting from the results of analysis of the composition of biogas and its calorific value.

2.1.1. - Effect of purification on the composition of produced biogas

Table 1 illustrates the variation of the gas composition of the product before and after purification. Purification consists in eliminating not only the elements traces like the steam, the hydrogen sulfide, the halogenous compounds, but also the carbonic gas, in order to enrich the concentration of methane.

According to the results obtained, % CH_4 largely increased by 15% after purification, whereas % CO_2 and % H_2S, on the contrary, decreased the first from almost 5% and the second about 10%. The biogas is of as much better than its % CH_4 is high and than the other components are reduced as much as possible.

Table I.- Effect of purification on the composition of produced biogas

Composition (%)	**CH_4**	**CO_2**	**H_2S**
Before purification	59.68	30.00	10.28
After purification	74.54	25.45	00.01

The results obtained are indices of the good performance of the process of purification and the great importance of the treatment of biogas, since it ensures a more reduction in polluting elements (CO_2 and H_2S) as well as an intensification in concentration of CH_4.

3.1.2.- Effect of purification on the calorific value

The results corresponding to the LCV and HCV of the biogas produced before and after purification are reported in table II.

Table II.- Variation of the CV of biogas before and after purification

	LCV (kcal/Nm³)	**HCV** (kcal/Nm³)
Before purification	5110	5684
After purification	6389	7106

After purification, there is a clear improvement of the calorific value. We can say that industrial biogas produces present valid energy potentialities before and after purification. The energy valorization of biogas can be a relevant source of incomes to amortize the initial investment [19] since biogas is converted into practically all useful shapes of energy [20; 21]. It makes it possible the farm to acquire a fuel autonomy for the production of heat and, if the installation comprises an production unit of electricity, to reduce the costs of its purchase and to possibly dispatch the surpluses on the network [22; 23]. However, it is advisable to more improve the output of purification of biogas to reach the theoretical maximum equal to 8500 kcal/Nm^3 [12].

The use of the anaerobic digestion applied to biomassanimal as a process of remediation and of production of energy has reasonable strengths [24].

2.2. - Results of the agronomic follow-up

2.2.1. - Biotest of germination

Table III. - Results of the biotest of germination

Plants-test	Period of germination (days)	% of germination
Chick-pea	8	88
Bean	12	85

A follow-up of the germination of the chick-pea and bean seeds sown at the same time in the pure forestry compost to be tested, was carried out during 28 days. The results of follow-up are posted in table III.

It is noted that the biotest carried out gave a high germination higher than 80% for bean like for chick-pea. In the same way, it is noticed that the two leguminous plants show a better growth of the air part. Therefore, the FC, product with the seedbed can be considered ripe. The good germination indicates that the compost does not contain phenolic substances which can block the germination of the seedlings [25].

The compost can be employed for the production of seedlings, with, as favors compared to the peat, to produce plants more resistant to pathogenic [26]. The potential use of the composts is promising, but remains strongly dependant on their qualitative aspect.

2.2.2. - Follow-up of germination of the seeds of Acacia

Figure 2 illustrates the evolution of the percentage of germination of the seedlings of Acacia according to the substrate in the course of time. The cumulated percentages of germination correspond to the averages of two containers per substrate.We can distinguish 3 phases:
- A phase of latency, necessary to the appearance of the first germinations which is prolonged four days for the various substrates. During this phase, the rate of germination remains weak. The duration of this phase is variable according to the nature of substrate. The SC presents the highest % of about 30% towards the end of this phase.
- An appreciably linear phase, corresponding to a fast increase in the rate of germination which evolves proportionally with the number of days. The increase is about 50% for the three substrates tested.

- A stage representing the final percentage of germination.

It appears that the rate of germination of substrate SC evolves more quickly than the other substrates. However, the slowest evolution of the rate of germination is observed on the level of substrate SA. The substrate SB has an intermediate behavior.

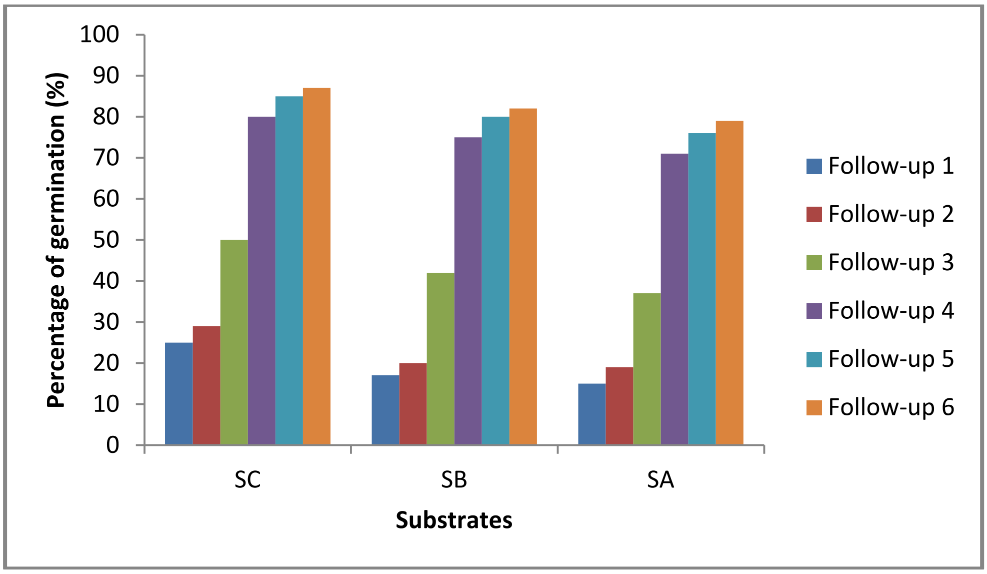

Figure 2. - Variation of the kinetics of germination of seeds of Acacia

2.2.3. - Increase in height of the seedlings of Acacia

Figure 3 illustrates the evolution height of the seedlings of Acacia. The results are the averages of measurements in height at a rate of 10 seedlings/substrate x 3 blocks = 30 seedlings/substrate.

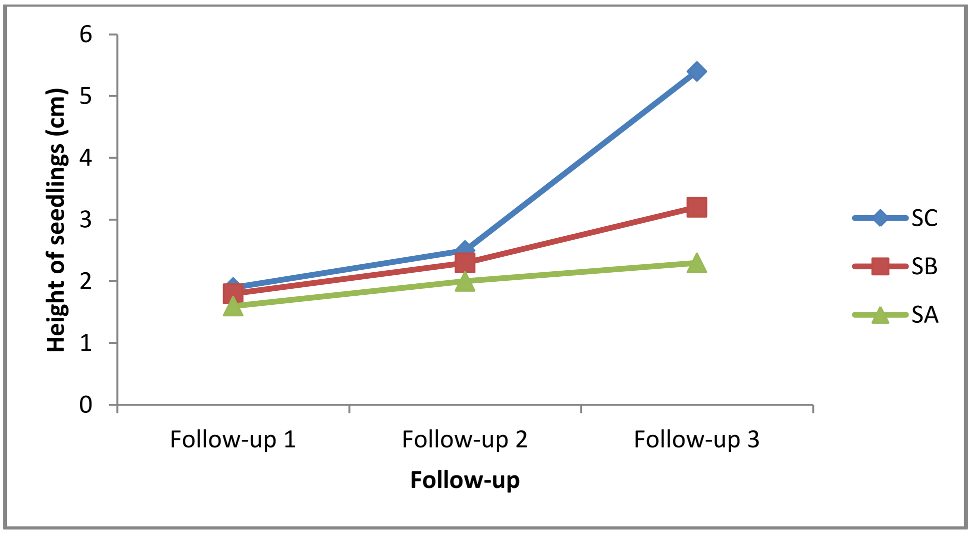

Figure 3.- Variation of the averageheight of the seedlings of Acacia

According LAMHAMEDI and coll. (1997) and LAMHAMEDI and coll. (2006), the height constitutes a good indicator of photosynthetic level and surface of perspiration which are narrowly correlated with the number of the sheets [13; 15]. It seems to predict the growth in height of the seedlings.

The evolution height of the seedlings of Acacia according to the number of days after sowing, watchs that the answer of these seedlings with respect to the various substrates is not the same one. The seedlings are sensitive during the first stages of growth to the nature and the composition of the substrates. This sensitivity is generally in keeping with the physicochemical properties of each substrate, in particular its physical quality.

It is noted that the seedlings installed on the FC alone present in the beginning a delay of growth compared to those installed on the two made mixtures, probably due to a bad contact of seed with the coarse surrounding particles, or to the low richness of the FC in fertilizing elements.

2.2.4.- Increase in diameter of the seedlings of Acacia

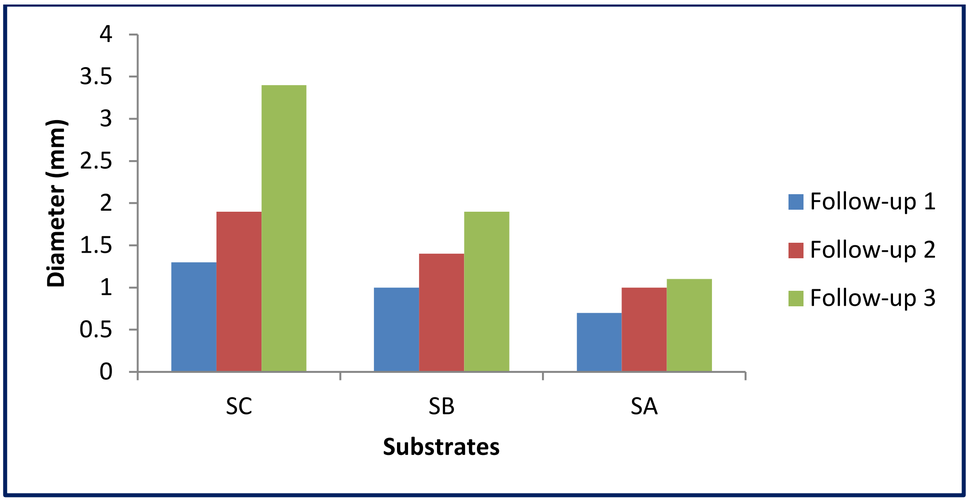

Figure 4.- Variation of the average diameter of seedlings of Acacia

According LAMHAMEDI and coll. (1997) and LAMHAMEDI and coll. (2006), the seedlings having a large diameter generally have a well developed side roots [13, 15]. The diameter in the collet is the best parameter of prediction of survival.The evolution of the diameter of the seedlings of Acacia is illustrated on figure 4 hereafter. This evolution corresponds to the average of 30 specific measures to the diameter for each substrate.

The substrate SC presents the most considerable diameter growth of about 3.4 mm. As for the height, the substrate SB gives median values, whereas the FC comes in last position with largely lower values.

2.2.5.- Ratio of robustness

The results relative to this parameter are represented on figure 5. The goal of this control is to reach a format of ideal height, diameter and ratio of robustness of seedling. These standards quality are relating not only to morphology but also to the physiology of the seedlings.

According to the standards quoted by [13], the ratio of robustness (H/D) should be lower than 7. So the results are in conformity with the standards. It should be noted that this report cannot be a criterion of characterization of the substrates of growth considering the seedlings of Acacia did not reach along the period of follow-up a advanced developmental stage. Such a result should be raised with prudence.

This study joins several other research to show the importance of the use of forestry compost as standard substrate for the production of seedlings in nurseries, particularly forestry nurseries, and thus constitutes an alternative to the soil use especially not standardized (integration within the framework of the national strategy of Tunisia in matters of environmental protection) and of imports of peat (significantly reduced dependence of Tunisia vis-à-vis the producer countries peat substrates). In fact, several techniques should be mastered by the nursery to produce a quality compost. The size adjustment of forestry compost by various mesh of screening using various techniques (single or dual) and methods (sieving of undersize or refusal) is proved interesting [27].

According M'SADAK and BEN M'BAREK (2015), the mixture (80% Peat + 10% Avicolous Methacompost + 10% Forestry Compost) seems to be the best substrate to advocate to produce quality vegetable seedlings, while limiting peat imports [28].

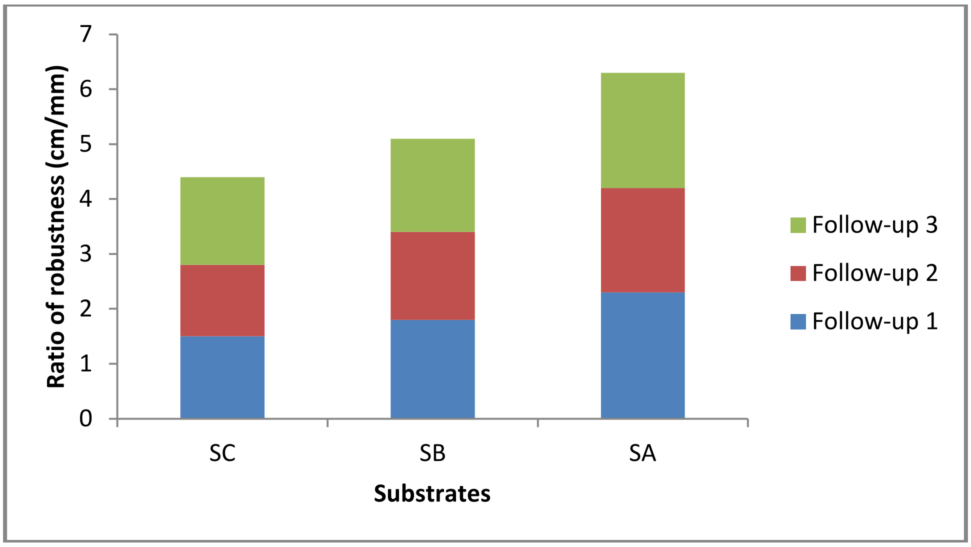

Figure 5.- Variation of the ratio of robustness of seedlings of Acacia

Conclusion

The energy follow-ups, led in the level of the industrial digester of Hammam Sousse, made it possible to justify the energy potentialities of the biogas produced starting from the animal manure and particularly starting from the fresh avicolous biomass.

This observation is all the more justified by analyzing the results of the follow-up of the energy parameters. The biogas undergoing a stage of purification which makes it possible more respectively to improve % methane and the LCV while passing from 60 to 75 % and from 5110 to 6389 kcal/Nm³.

The agronomic use of the residues of the biomethanisation is integrated well in the current trend towards the agrobiologic practices, taking into account the important reduction of the polluting load of the dejections after biological treatment. However, the installation needs some modifications in order to improve its effectiveness as environmental and energy performances more regards, for example the installation of a heating system or in order to improve the financial interest (profitability) of the project by developing the produced quantities of digestates. In this respect, the composting of the vegetable biomass and the biomethanisation of the animal biomass constitute an alternative face to the use of the forest or agricultural compost and the massive imports of the peat.

The study of partial substitution of the forestry compost (substrate of reference) by the avicolous methacompost in the formation of the substrates of growth of the forest seedlings makes it possible to draw the principal results hereafter.
- The appreciation of the maturity of the foresty compost produced with the seedbed on the leguminous plants (chick-pea and bean) proved a good state of maturation of this compost.
- There exists a light increase in the rate of germination of the seeds of Acacia cyanophylla sown on substrate containing mixture of foresty compost and avicolous methacompost. The foresty compost alone shows a weaker rate of germination and rather distant from those obtained for the case of the made mixtures.
- The growth in height and diameter of the seedlings of Acacia were significantly influenced by the type of the methacompost incorporated. The mixture containing the AMCA' showed a clear superiority as regards evolution of the seedlings in height and in diameter, on the other hand, the ratios of robustness are overall lower than that of the seedlings cultivated on the foresty compost.

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