The bio-gas in Baobab Trust. Internship Report 14/06/04 to 15/08/04 Mombasa Kenya

Auteurs: Agathe Henry, student in second year of ENSAM,
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School tutors: Mister WERY, teacher at ENSAM
Mister CISS E, teacher at ENESAD

Master of internship: Doctor Haller, Director of Baobab Trust

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Acknowledgement.

We would like to thanks Dr Haller, executive director Baobab Trust, for having accommodated us, as well as Marion Teichmann for having helping us and supervised us.

We also would like to thanks the people of the Shamba for all the things they do for us, by helping us and showing and teaching us so much things. It really was an enrichment experiment for us and we have learnt a lot, thanks to everybody.

Baobab Trust is a non-profit organisation founded in 1991 by Dr Haller who now acts as executive trustee. The trust was formed to take over the non-commercial activities at the former Baobab Farm Ltd (now called Lafarge Eco-Systems).

The Baobab Trust runs the Mtopanga Demonstration Farm (the Shamba) which is an organic farm with vegetables, rain fed crops, livestock poultry integration and the production of bio-gas. The farm organises training sessions in co-operation with the Kenyan Ministry of Agriculture to educate local farmers in best farming methods. The farmers can participate in theoritical and practical lessons on relevant subjects such as principles of organic farming, economic use of farming, etc. The Shamba uses organic methods of production, without input on any chemical products and favours the use of natural treatments. For one year a small bio-gas production unit has been run to provide the fuel for cooking on the site.

The Baobab Trust also runs the Nguuni Nature Sanctuary and is involved in Turtle conservation as well as the Annual International Beach clean up.

I. <u>Context. Baobab Trust bio-gas.</u>

<u>1. What is bio-gas?</u>

The bio-gas is a mixture of 60% methane and 40% carbon dioxide. It is produce by the anaerobic digestion of faecal matter by methane producing bacteria. These bacteria ferment in a closed container called a digester. This fermentation produces bio-gas, and a slurry. This bio-gas can be used directly as a kind of fuel or can be transformed into power. The slurry can be used as a fertiliser. This fermentation can be made with a solid biomas (waste) or a liquid biomas (effluent).

The bio-methano-genesis process:

There are three processes involved with the production of bio-gas. During the first stage long carbon chains are broken down by the action of bacteria. The second stage (acido-genesis) uses acid producing bacteria, which produce volatile fatty acids, alcohol, carbon dioxide and hydrogen atoms. The third stage called methano-genesis produces methane, carbon dioxide and water, methane and carbon dioxide forming the useable bio-gas.

Production of bio-gas is both temperature and pH dependent, as well as relying on the presence of all three types of bacteria and the ratio of carbon and nitrogen (C/N) within the organic matter, the time the biomas is allowed to ferment will also affect production of bio-gas.

This process presents three advantages in a tropical climate: the recycling of organic matter in tropical soils that are poor in nutrients, the hot climate assists the production of gas by keeping the temperature wthin the digester in the optimum temperature range, lastly energy can be produced in areas where other energy sources are rare such as firewood and other fuels.

There are aspects of agriculutural interests with this process, which are outlined below. A by-product of biogas production is slurry. This slurry could be used as a fertiliser for crops. During the methano-genesis process, the agricultural characteristics of properties as a product reahed with an aerobic way, like compost making:

The dry material quantity and the volatile material
The biological stability sign
The nutriments quantities (N, K, Ca, etc)

The nitrogen contained in the manure remains throughout methano-genisis process. However, its form changes: in the fresh manure it is as organic nitrogen, and as NH4+ (ammonium) in slurry. The plants can more easily use NH4+, but it is very volatile, and easily washed out of the soil. Therefore the fertilisers need be apply when the plant can use them directly.

After the methano-genesis process, the slurry can be put directly on the ground, or in a transformed form (for technical, economical or commercial aims, to sell the product, or to improve its image). For example, water volume can be reduced, in order to facillitate its transport. This can be carried out by squeezing, centrifuge, thermal drying etc.) in order to finish its fermentation and to make it hygienic (maturing, co-compost, liming etc.) and to condition it for its final use (screening, sieving, in order to eliminate indesirable elements etc.)

If the slurry is dehydrated, the ammonia, which is soluble, will be principally in the aqua phase, whereas the volatile materials and the phosphorus will be concentrated in the solid phase. Thus, the solid phase is rather an organic enrichment for the soil rather than directly for the crops, whereas the aqua phase, rich of ammonia which is easily used by the plants, can be use by the same way as a mineral fertiliser. The dangers of ammonia volatilisation during the stocking and during the spreading are improved. The farmers who use the slurry from bio-gas production are using adapted material.

There are two questions about the use of slurry from bio-gas production as a natural fertiliser: at what time will the fertilisation of the plants by this slurry be most efficient, and which treatments are adapted to the use of this slurry both within the means of the smallest and the poorest farms.

2. The Baobab organisation.

The roots of the Baobab Trust lie within Baobab Farm and Bamburi Cement. The farmer Baobab Farm was a subsidiary of Bamburi Cement Ltd., a cement factory founded in 1954 by the Swiss firm: Cementia-Holding. The cementery is situated on the Indian Ocean coast, north of Mombasa town. This factory is now managed by the French holding Lafarge.
In 1959, the cement factory employed a Swiss agronomic engineer, René Haller, to develop a small farm, which could produce vegetables for its workers. This aim was quickly reached. So René Haller decided to create sheep, goat, dairy cow, chicken breeding programmes.
The farm has fowls (chicken, quails, and guinea fowls), dairy cows, ostriches, goats (32), sheeps (40), fish and some crops (maize, manioc, sorghum, mil, sweet potatoes...). There is also a garden with fruit trees (lemon, coconut, banana etc.) as well as market gardening (tomatoes, cabbages, melons etc.) Baobab Trust tries to market all these products, in order to be self-sufficient.

3. The bio-gas production at Baobab Trust.

The production unit consists of three digesters, which are working on manure to produce biogas. The system was installed one year only, and the bio-gas production is still subject to experimentation. Today, the produced bio-gas is used for cooking. The digesters have a volume of sixty approximately litres and are linked together. Every two days, they are opened and approximately ten kilograms of slurry are removed from each of these three digesters. Then, one bucket of cow manure again (approximately ten kilograms) is added with water, so that the mixture in the digester stays liquid. These digesters are constructed from metal oil drums, they were built with basic and cheap material, that is really available in Kenya. The aim of this experiment was to study the bio-gas production which could be carried out in poor and small scale farms in Kenya and in the African continent.

At prevent fresh manure is added to the digester however the two days period of digestion has not been tested. Thus, it would be interesting to know if a longer period could allow producing more bio-gas with the same quantity of manure, in order to optimise this production. The slurry could be not totally digested within this time.

The slurry obtained is currently used as a fertiliser. It is not treated in any way, it has no maturation, and the applied doses depend just of the quantity of slurry. But this slurry is liquid and it contains ammonium, which is interesting because ammonium can be more easily used by the plant, but which can be bad on a poor soil, because of its acidity.

It would be interesting to know how this slurry can be best used as a fertiliser, at dose and if its fertilising power is better than other fertilizers such as compost.

Moreover, this slurry is just used as an extra fertiliser. During the soil work, before the seeding, the soil is worked with chicken manure. Could'nt the slurry from bio-gas production also be used as an interesting enrichment for the soil?

Thus, we will realise a study on two different items of the bio-gas production: the different possible uses of this slurry and the optimisation of the bio-gas production.

II. Study on the different possible uses of the slurry from bio-gas production.

We will so study several points on the use of the slurry from bio-gas production: the treatments that we can apply on this slurry, the comparison between this fertiliser and the others that are used in this farm, and the best application.

1. Different treatments of slurry from bio-gas production before using.

We will try to find the best type of fertiliser to apply to the ground, from the slurry. These treatments will need really few means, in order to be accessible and easily realisable.
We will so compare the slurry from bio-gas production used directly after the digestion, with slurry which was left sitting for two weeks outside (protected from rain) and with slurry which was left sitting for one month and compost made with this slurry. Moreover, we will compare all these fertilisers with compost made with chicken manure, with cow manure and with vegetable wastes.

We want to know if, after the compost process, cow manure digested by methanical bacteria has a better fertilizing power. You can make compost with this slurry. We used also about 45 litres of slurry from bio-gas production, which we have mixed with vegetable wastes. We obtained a height of about 70 centimetres like the other composts made in the farm. We decided to let this compost mature for one month (21st June to the 20th July) in order to be able to use it on crops and to measure its effects. Thus, we will be able to compare it to other composts made with chicken manure, vegetable wastes and cow manure. As the high of this compost decreased, we added some vegetable wastes with 15 litres of slurry on the 1st July. (If the size of the compost is not big enough, the fermentation can't start because the temperature isn't high enough). In addition we mixed it regularly in order that the bacteria have access to the oxygen. We measured the temperature regularly to see if the process was working. We never noticed an important increasing of temperature, so that we can suppose that this process didn't work very well. We don't know if it is because of the slurry's properties, because it can also be for other reasons for example the compost was maybe not high enough or we didn't have enough time to complete the experiment (optimum period for decomposition is 3 months).

It would be interested to repeat this experiment, making compost with the slurry from bio-gas production, in order to know if it is possible and if the slurry has not been too digested by methane producing bacteria to be composted.

We want to know if the slurry from bio-gas production has still fertilizing properties after having been left sitting, and if these properties are better or not than the 'raw' slurry.

On the 23rd June, we put about 45 litres of slurry outside, in a protected place, in order to leave for one month to dry and mature. On the 4th July, again we put about 45 of slurry in a similar place. However there were not two similar containers big enough at the farm. So the second one's area was bigger than the first one and the slurry dried faster. These fertilizers will be tested on a plot.

2. Comparison between the different produces and other fertilizers.

We tested these produce on Mchicha (a local vegetable which looks like spinach). We compared how these plants grow with the different fertilizers that we applied. We want to determinate which fertilizer is the best for this kind of soil and this kind of crop. We compared these fertilizers with cow manure directly applied.

3. The best application of the different produces.

We wanted to test two things: the best application moment, and the applied amount.

Before the seeding, the soil is dug with chicken manure which is used in order to enrich the soil, giving the seeds the necessary elements for its germination. Then, three weeks after the seeding, we apply a second organic fertilizer, in order to give the plant the nitrogen it needs, at the time it needs it. We decided to test this on both application dates. Therefore, we separated the field into two sections. In one of them, we worked the soil with chicken manure and in the other; we worked the soil with slurry from bio-gas production. We will thus see the best association of fertilizers.

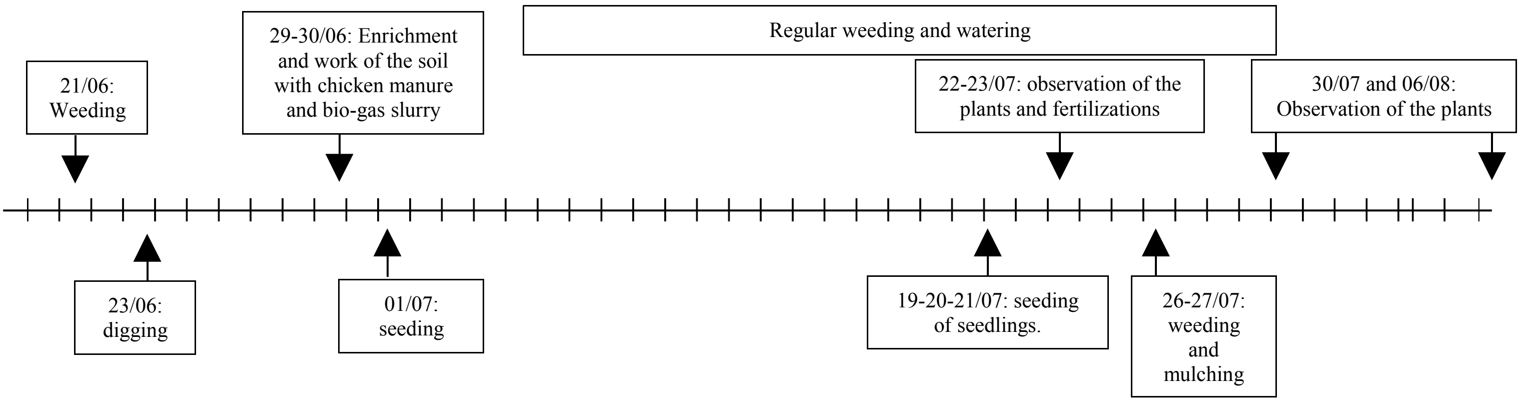
We also wanted to study the effect of different amounts of these fertilizers on the plants.

Testing on the field:

On the 1st July, we seeded Mchicha in these plots. As these seeds are very small, you can't count and separate them. That is why we mixed them with sand (to disseminate them). In every section we made three lines about 10 centimetres deep. We put the seeds inside and covered them with soil, in order to avoid them to be washed away. The aim was so that after they had germinated we would replant them in rows, leaving the same space between each plant. We watered them because the soil was very dry. About two weeks later, as we hadn't enough plants, so we planted out seedlings from the farm nursery. Therefore, we are not able to say which one of our two soil enrichment was better, because we didn't have plants enough to see a difference in germination. We can see that in the first and in the last sections of the field there were more Mchicha plants but as these plots were spreading with different fertilizers (chicken manure and slurry from bio-gas production), we can't conclude.

Then we spread the different fertilizers on different sections of the field and we then observed the crop's growing over the following weeks. We noticed that some fertilizers were more difficult to spread: dried bio-gas slurries, because they were not liquid enough or solid enough.

Calendar:



We share our field with another group of students who is working on compost.
The plan of this field is following.
Each section has an area of about 1,5m².

No fertilizer		No fertilizer and no soil enrichment	
Fresh slurry from bio-gas production c'2	Slurry from bio-gas production which was left sitting for one month to mature c'2	Compost using slurry from bio-gas production c'1	Slurry from bio-gas production which was left sitting for one month to mature c'1
Slurry from bio-gas production which was left sitting for two weeks to mature c'1	Fresh slurry from bio-gas production c'1	Slurry from bio-gas production which was left sitting for two weeks to mature c'2	Compost using slurry from bio-gas production c'2
Slurry from bio-gas production which was left sitting for one month to mature c'1	Compost using slurry from bio-gas production c'2	Slurry from bio-gas production which was left sitting for one month to mature c'2	Slurry from bio-gas production which was left sitting for two weeks to mature c'1
Fresh slurry from bio-gas production c'1	Slurry from bio-gas production c'2	Slurry from bio-gas production which was left sitting for two weeks to mature c'2	Compost using slurry from bio-gas production c'1
Fresh bio-gas slurry from bio-gas production c'2	Slurry from bio-gas production which was left sitting for one month to mature c'2	Compost using slurry from bio-gas production c'1	Slurry from bio-gas production which was left sitting for one month to mature c'1
Slurry from bio-gas production which was left sitting for two weeks to mature c'1	Fresh bio-gas slurry from bio-gas production c'1	Slurry from bio-gas production which was left sitting for two weeks to mature c'2	Compost using slurry from bio-gas production c'2
Slurry from bio-gas production which was left sitting for one month to mature c'1	Compost using slurry from bio-gas production c'2	Slurry from bio-gas production which was left sitting for one month to mature c'1	Slurry from bio-gas production which was left sitting for two weeks to mature c'1
Fresh slurry from bio-gas production c'1	Fresh slurry from bio-gas production c'2	Slurry from bio-gas production which was left sitting for two weeks to mature c'2	Compost using slurry from bio-gas production c'1

Cow manure c'1	Cow manure c'2	Cow manure c'1	Cow manure c'2	Nothing

Soil enrichment of chicken manure.

Soil enrichment of bio-gas slurry.

C'1 (about 5 litres) and c'2 (about 10 litres) are the both different amounts of fertilizers.
All experiments are repeated twice.

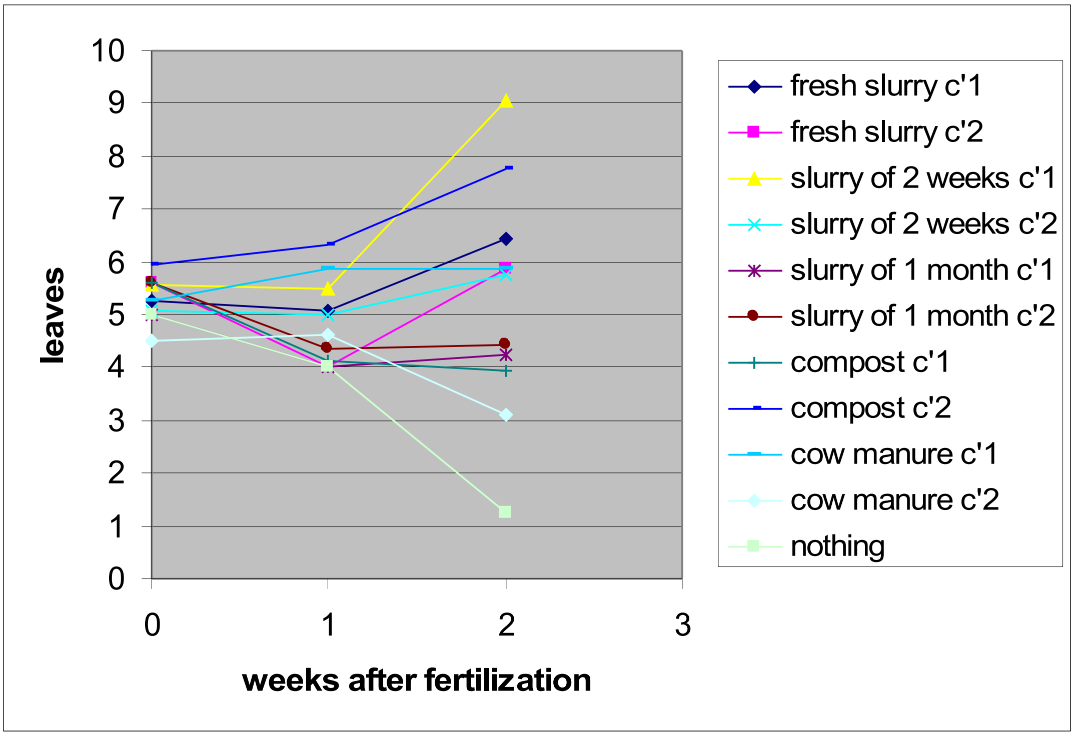
In each section of every plot, we chose four plants which were healthy so to observe their evolution with the different fertilizer. As possible as it was, we tried to choose four different sizes of plants in each plot, and the same sizes between the plots. We chose four kinds of plants:

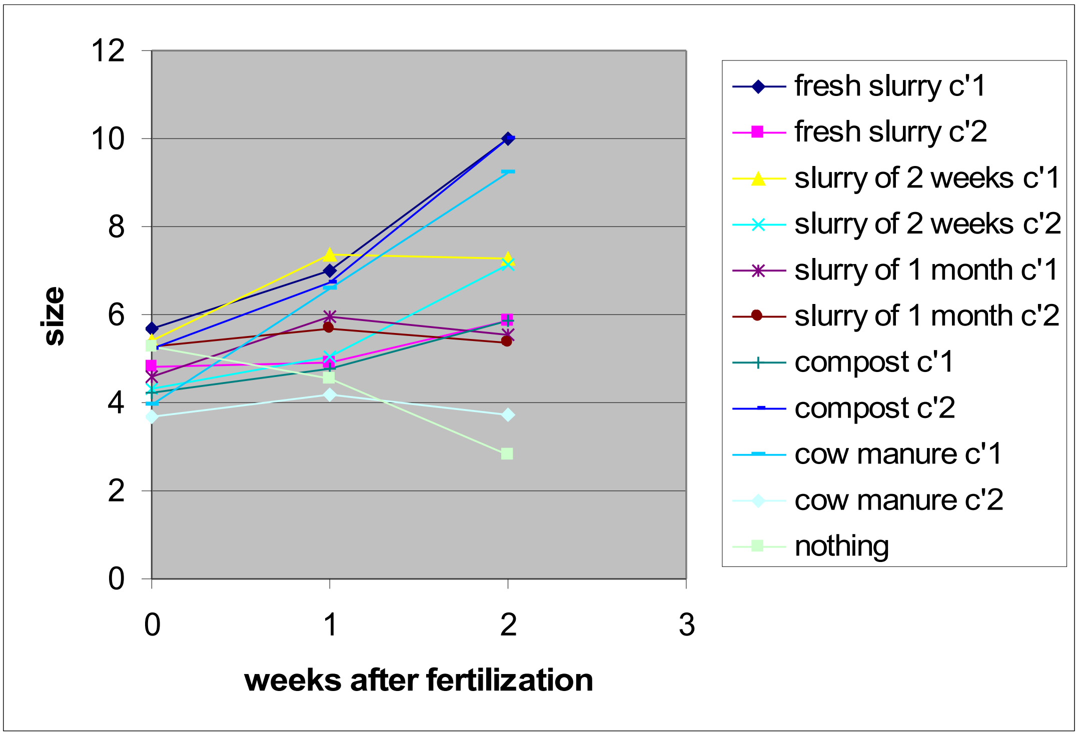
- few leaves
- many leaves
- few leaves and a flower
- many leaves and a flower

Normally on the Shamba flowers are regularly removed in order that the plants grow faster.
Then, one and two weeks after the fertilization, we observed again these plants to see if their evolution depends on the fertilizer which was applied.
See appendix 1: observation of the field.

Results:
The measures of the plants are in appendix 1.

We can see the evolution of the plants after one and two weeks according to the fertilizer.





We made some average of the evolution of the size and the leaves of the plants, according to the size and the number of leaves before fertilization, in order to be able to see the different effects of the fertilizers.
Example : (size average week 2 with fresh slurry c'1-size average week 0 with fresh slurry)/size average week 0 with fresh slurry

average for each fertilizer

evolution after the first week

	Leaves	size
fresh slurry c'1	-0.05134	0.41952
fresh slurry c'2	-0.08021	0.131051
Slurry 2 weeks c'1	-0.02113	0.419655
Slurry 2 weeks c'2	-0.11369	0.042453
Slurry 1 month c'1	-0.23467	0.388419
Slurry 1 month c'2	-0.17879	0.127176
compost c'1	-0.29149	0.308554
compost c'2	0.060441	0.748649

evolution between the first and the second week

	Leaves	Size
fresh slurry c'1	-1.0625	-0.4375
fresh slurry c'2	1.5625	0.5625
Slurry 2 weeks c'1	-1.125	-2.79375
Slurry 2 weeks c'2	-0.125	0.9
Slurry 1 month c'1	-1.125	-1.975
Slurry 1 month c'2	-1.25	-2.1875
compost c'1	-1.75	-1.89375
compost c'2	-0.0625	1.5625

evolution after the second week

	Leaves	size
fresh slurry c'1	1.1875	4.31875
fresh slurry c'2	1	1.05
slurry 2 weeks c'1	3.9375	2.56875
slurry 2 weeks c'2	0.6875	2.61875
slurry 1 month c'1	-0.75	0.9375
slurry 1 month c'2	-1.1875	0.11875
compost c'1	-1.3125	0.51875
compost c'2	1.8125	4.76875

A fertilizer seems to be useful. Indeed we can see that without fertilization the size of the plants and the number of the leaves decrease.

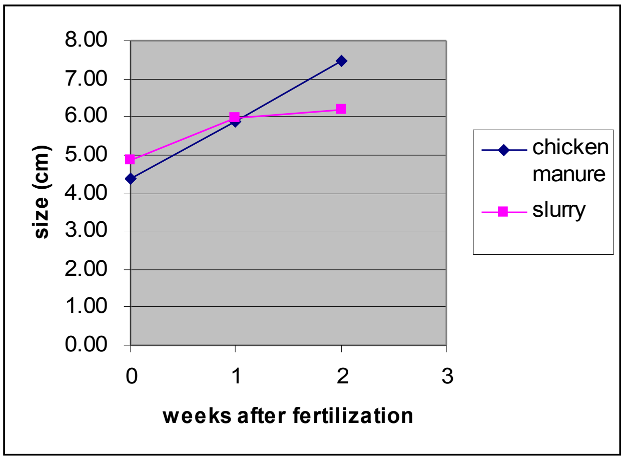
The best fertilizer seems to be the compost at the bigger quantity about 10 litres of compost for 1,5m². We can notice that if we put too much cow manure or slurry on our crop, the efficiency of the fertilizers decreases. Indeed, both the size and the number of leaves are less important with the big quantity.

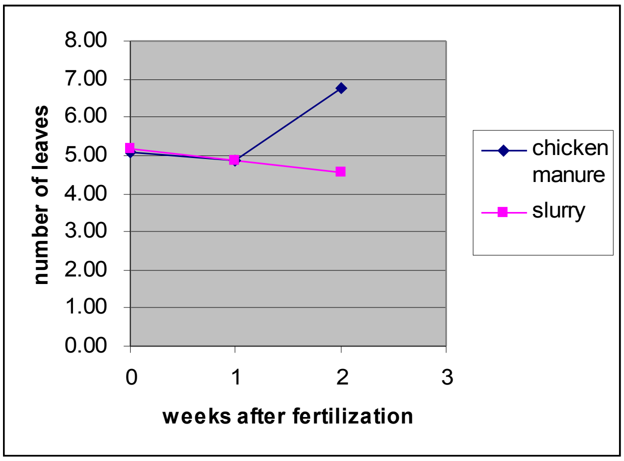
If we compare the effect of the different slurries, the best fertilizer seems to be the slurry which was staying for two weeks at the quantity of about 5 litres for 1,5 m². If it stays for one month, it seems to be less efficient. But we didn't send them in the same recipient and the one which stayed for two weeks seemed to be drier than the other, so maybe that is why it was more efficient.

We can also notice that concerning the number of leaves, the best fertilizer seems to be the slurry of biogas which has stayed for two weeks. And the number of leaves is the most important for a Mchicha crop because it is what is eaten.

We also wanted to compare the chicken manure and the slurry as a soil enrichment. We compared the two parts of our field, the one with chicken manure and the one with slurry.

<u>Evolution of the plants according to the time after the fertilization.</u>





We also calculated some average of the evolution of the plants, according to the state of the plants at the beginning.

evolution after the first week

	average leaves	average size
chicken manure	-0.16	0.38
slurry	-0.06	0.31

Evolution after the second week

	average leaves	average size
Chicken	1.48	3.05
Slurry	-0.17	1.60

Evolution between the first and the second week

	average leaves	average size
Chicken manure	0.22	0.47
slurry	-1.83	-2.19

Chicken manure seems to be a better soil enrichment than the slurry. Maybe with a longer period between the spreading of the slurry and the seeding, the slurry would be more appropriated.

4. A complementary experiment on sweet peppers.

Usually, the slurry is put on sweet pepper crops every two days, but it represents a very important quantity of slurry. Maybe it could be bad for the soil or / and for the plants and its fruits. Therefore we did another experiment to check the effect of the slurry on these plants. On a sweet peppers crop we determinated some similar regrouping, therefore we counted the number of plants and we measured their size and the number of leaves and took pictures of the pepper plants. We made also three groups of plants:

-on the first group, we didn't put any slurry,

-on the second, we put one bucket of slurry mixed with one bucket of water,

-and on the third, we put two bucket of slurry.

After one week we took some pictures again, and we compared them with the first serie of pictures, to see their evolution.

Results:

(See appendix2 : sweet peppers)

The slurry seems to have a relatively good effect on the buds and on the flowers. Indeed, the number of buds of the plants which have not been fertilized by slurry has increased of 17%, whereas the number of buds of fertilized plants increased of 63% and of 89% for the plants fertilized by a half dose. The number of flowers with fertilization increased of 10% whereas it decreased of 10% for half fertilization and of 11% for the no fertilized plants. We can't really conclude about the size of the plants because we think that the slurry has not a real effect (we can just notice a difference of 2 or 3 %, which is not enough).

We can't assure that this experiment is really available because there were maybe other reasons for the evolution of the plants (ants and monkeys, lack of water…)

Notes: We wanted to take other measurement after another week, and to put slurry on the sweet peppers, to see if the second application could have an effect on the crop. But all the leaves of plants were eaten by ducks. We had to stop this experiment, we couldn't valid our observations.

III. Optimisation of the bio-gas production.

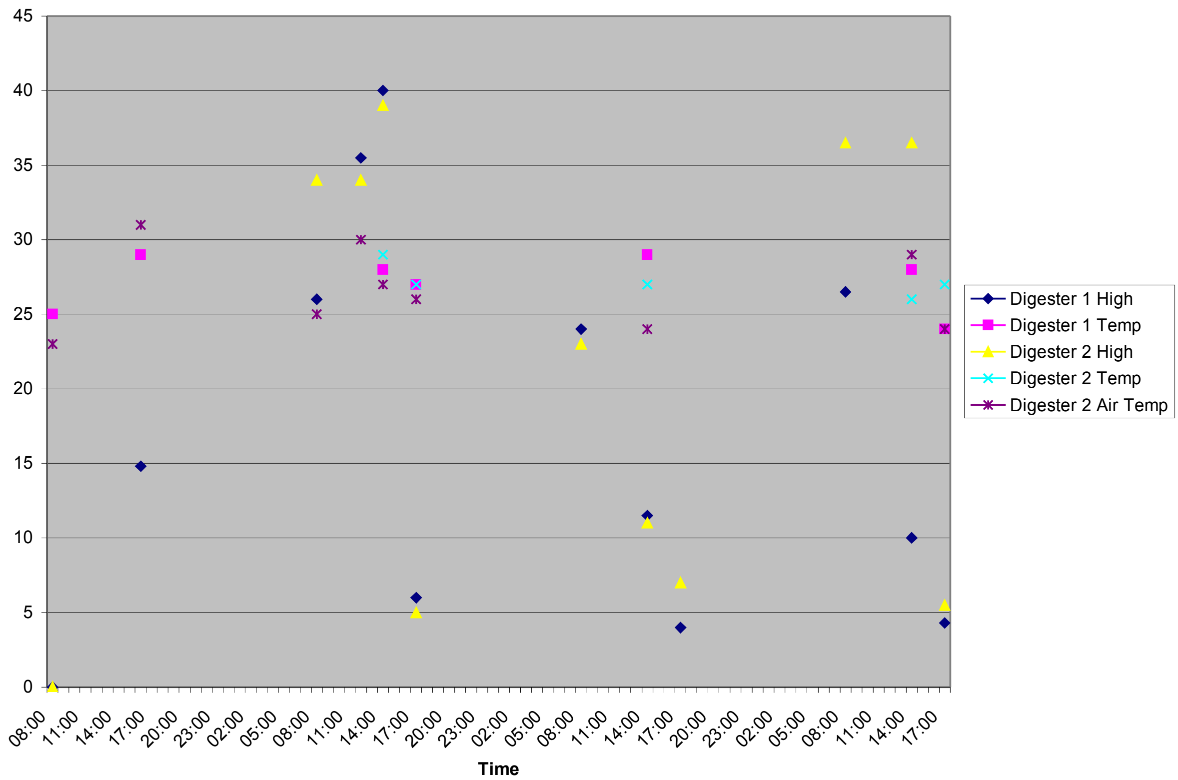
1. Methano-genesis period.

The renewal period of the biomass in the digesters is usually two days. This short period is not a problem here, because there is a lot of available cow manure but in little poor farms with only few cows, the small amount of manure could be a problem. We so want to know the maximal renewal period while keeping a sufficient production.

In this experiment, we used a closed digester, in which we didn't add new manure. Every day, before using the bio-gas, we compared the difference of high between this one, and a control digester (in which we have added fresh manure). This difference of height corresponds to a difference in bio-gas production. Then, we empted the digesters and on the next day, we measured the height of produced bio-gas again.

Results:

DATE	Time.	Weather	Digester 1		Digester 2		Note.
			High	Temp (°C)	High	Temp (°C)	
13/07	8h35	Clouds 23 °C	/	25	/	26	Digesters were emptied
	16h00	31 °C	14.8	29	7.5	29	digester 2 was not totally closed
14/07	8h00	25 °C	26	/	25.5	/	/
	12h00	Sun 30 °C	35.5	/	34	/	/
	14h20	27 °C	40	28	39	29	Gas was removed
	17h15	26 °C	6	27	5	27	Gas was removed
15/07	8h30	Sun	24	/	23	/	/
	14h20	24 °C clouds	11.5	29	11	27	Digester 2 was fulled. Gas was removed
	17h00	/	4	/	7	/	Gas was removed
16/07	8h35	/	26.5	/	36.5	/	/
	14h20	29 °C	10	28	36.5	26	Gas from digester 1 was used. Gas was removed.
	17h00	24 °C	4.3	24	5.5	27	/



We notice a large difference of bio-gas production between the two digesters, as soon as we add fresh manure in the digester 2. 2 hours 40 minutes after the addition of fresh manure we observed difference in height between the digesters of about 43%. This difference doesn't correspond to a difference of 43% neither to the produced bio-gas volume, nor of the produced biogas weight because we don't know the pressures inside the bio-gas digesters. We can conclude all the same that the renewal of biomass is immediately efficient. But after 15 hours the difference is less important (about 27%). We can find two hypotheses to explain it.

First, after a longer period, the production is greater, and so the pressure inside the digester is higher. Thus this high difference of bio-gas production can correspond to a bigger quantity of bio-gas.

Second, maybe after the addition of fresh biomass the production increased for a short period, and then, after a few hours, it stabilises again.

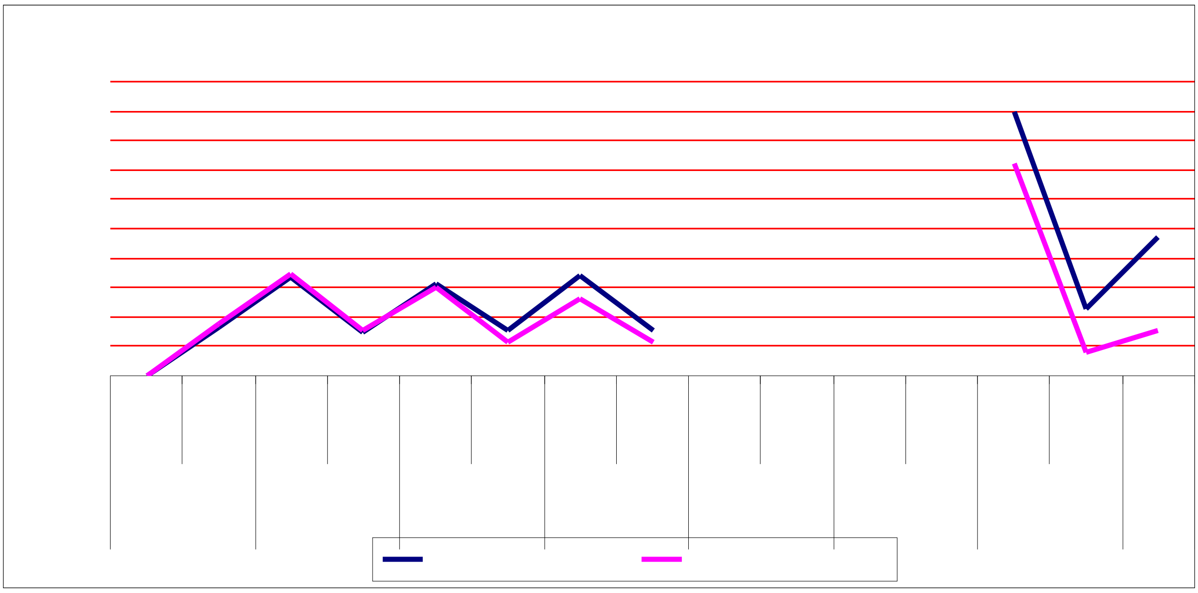
As we didn't have the last measurement (because the bio-gas was used), we will conduct better experiment.

We also want to know how long bacteria can produce methane if we don't add any fresh biomass if we don't renew the biomass in one of the digester, until the production has stopped. We can then compare the difference of production between this digester and a control one. We also want to check the heights of each digester more regularly to ensure more accurate results.

This time, we put fresh in only one of the two digesters. . Every day, at 9:30 a.m. we remove the bio-gas from the both digesters, after having measured the height of the produced biogas. We so can put the biogas in the third digester in order that the people can use it. To do it at the same time is important because the pressure can have an effect on the biogas production. We can so compare the difference of biogas production between the two digesters, and the evolution of this difference of production as long as we don't add fresh manure. Every two days at 9:30 a.m. we add new fresh manure in one of the digesters, which is the control digester.

Results

DATE	Time.	Digester 1	Digester 2	Note.
		High	High	
03/08	9:30 a.m.	0	0	Fresh manure was added in the both digesters
	4:30 p.m.	8.3	8.9	
04/08	9:30 a.m.	16.9	17.3	Biogas removed after measurement
	4:30 p.m.	7.5	7.7	
05/08	9:30 a.m.	15.5	15.0	Fresh manure was added in the digester 1 Biogas removed after measurement
	4:30 p.m.	7.6	5.7	
06/08	9:30 a.m.	17.1	13.2	Biogas removed after measurement
	4:30 p.m.	7.6	5.7	
07/08	9:30 a.m.			
	4:30 p.m.			
08/08	9:30 a.m.	47	40	Biogas removed after measurement
	4:30 p.m.			
09/08	9:30 a.m.	45	36	Fresh manure was added in the digester 1 Biogas removed after measurement
	4:30 p.m.	11.5	4	
10/08	9:30 a.m.	23.7	7.7	Biogas removed after measurement
	4:30 p.m.			
11/08	9:30 a.m.			Fresh manure was added in the digester 1 Biogas removed after measurement
	4:30 p.m.			



results:

2. Adapted substratum.

The bio-gas is produced only with cow manure at the farm. It would be interesting to see if chicken manure, which could be more accessible in several Kenyan farms, could also be productive. We devised an experiment which could be made. We were not able to realise this experiment because the people working at the Shamba needed the bio-gas during our internship. But it could be made another time.

We could compare the bio-gas production with chicken and cow manure. Two digesters are necessary: in one of them we will put chicken manure, and in the other one, cow manure. However it can be difficult to use chicken manure, which is less fluid because it is mixed with leaves or other vegetable wastes. Moreover, it would be necessary to empty one of the digester, and so to interrupt bio-gas production of one digester. So this experiment is really restricting. After that, you can compare the high of the bio-gas production between the two digesters in the same way.

Conclusion:

The biogas productions seem to be a good way to produce energy with a few main in a tropical country, and to enhance the value of the cow manure. Indeed its slurry seems to be a good fertilizer. Used as compost or applied alone on the crop, it can increase the size and the number of leaves of the plants. But the quantity, the date and the way of application have to be organised in order to be the most efficient.

But our study has been made only on one field and one kind of crop, so it must be purchased on other crops, and other types of soil. Moreover, the length of this work was really short and it could be necessary to observe the effect of these fertilizers on a longer period. Therefore, even if it is not complete, our work can be a good base for future studies on this subject.

The biogas digestion period of two days seems to be appropriated, even if it could be shorter. Indeed, the production of biogas decreases after two days of digestion, the digester is still producing biogas and if the needs of the people are not too important, a period of renewing of three days can be enough (50 centimetres of biogas allow to cook for 40 minutes, and one digester still produce about 15 cm of biogas each per day. Thus on the third day the production of biogas could be enough to supply the energy of one meal). In order to be sure of the result, it would be interesting to do the experiment again, in other temperature conditions.

APPENDIX.

1. OBSERVATION OF THE FIELD

2. SWEET PEPPERS

Appendix 1: Observation of the field.

Plot 13

Number	leaves	size (cm)	One week after fertilization	Leaves	size (cm)	Two weeks after fertilization	leaves	size (cm)
13.1	9	4.9		9	7.8		15	10.6
13.2	8	12.0		4	12.2		4	11.9
13.3	5	3.7		4	6.5		13	10.7
13.4	5	3.0		4	2.5		4	2.2

Number	leaves	size (cm)	One week after fertilization	Leaves	size (cm)	Two weeks after fertilization	leaves	size (cm)
13.5	5	2.4		4	3.8		5	4.7
13.6	8	4.5		Dead			0	0
13.7	5	4.2		5	5.2		7	6.8
13.8	8	5.8		5 eaten	6.2		0	0

Number	leaves	size (cm)	One week after fertilization	Leaves	size (cm)	Two weeks after fertilization	leaves	size (cm)
13.9	5	2.9		5	3.7		6	4.2
13`10	9	3.4		7	7.2		10	13.2
13.11	7	4.8		4	5.6		0	0
13.12	5	2.7		5 eaten	2.3		0	0

Number	leaves	size (cm)	One week after fertilization	Leaves	size (cm)	Two weeks after fertilization	leaves	size (cm)
13.13	5	3.7		Eaten	8.2			
13.14	5	3.0		4 eaten	3.8		5	3.8
13.15	5	2.4		5	3.6		0	0
13.16	7	4.4		12 eaten	7.6		14	15.4

Plot 14

Number	leaves	size (cm)	One week after fertilization	Leaves	size (cm)	Two weeks after fertilization	leaves	size (cm)
14.1	5	4.6		4	4.1		50	0
14.2	7	5.2		9	6.1		16	13.7
14.3	6	6.0		7	9.7		9	14.4
14.4	6	11.4		5	13.5		6	15.4

Number	leaves	size (cm)	One week after fertilization	Leaves	size (cm)	Two weeks after fertilization	leaves	size (cm)
14.5	5	2.3		4	3.1		4	3.4
14.6	4	2.1		3	3.7		5	4.6
14.7	8	5.4		5	9.6		10	19.8
14.8	9	7.3		9	7.8		13	11.3

Number	leaves	size (cm)	One week after fertilization	Leaves	size (cm)	Two weeks after fertilization	leaves	size (cm)
14.9	4	2.0		3	2.2		5	3.2
1410	10	7.3		9	7.3		9	8.6
14.11	5	5.3		3	7.2		13	14.1
14.12	2	4.0		Dead	4.0		0	0

Number	leaves	size (cm)	One week after fertilization	Leaves	size (cm)	Two weeks after fertilization	leaves	size (cm)
14.13	4	2.0		Eaten	8.2		9	9.7
14.14	9	7.2		4 eaten	3.8		15	15.6
14.15	5	4.8		5	3.6		6	8.4
14.16	7	7.0		12 eaten	7.6		10	18.8

Plot 15

Number	leaves	size (cm)	One week after fertilization	Leaves	size (cm)	Two weeks after fertilization	leaves	size (cm)
15.1	4	2.4		0 eaten dead	3.7			
15.2	4	3.5		3 eaten	4.4		5	4.8
15.3	5	5.2		5 eaten	7.6		4	7.8
15.4	6	3.2		3	3.2		3	3.2

Number	leaves	size (cm)	One week after fertilization	Leaves	size (cm)	Two weeks after fertilization	leaves	size (cm)
15.5	5	2.3		6	6.2		6	15.2
15.6	4	0.4		2	2.2		6	3.8
15.7	7	9.2		8	11.2		13	16.8
15.8	7	4.6		6	5.3		8	7.9

Number	leaves	size (cm)	One week after fertilization	Leaves	size (cm)	Two weeks after fertilization	leaves	size (cm)
15.9	4	7.2		5	8.2		6	9.2
15.10	4	2.6		5	3.6		6	4.6
15.11	6	4.3		4	4.2		4	4.4
15.12	6	3.0		5	4.9		7	6.4

Number	leaves	size (cm)	One week after fertilization	Leaves	size (cm)	Two weeks after fertilization	leaves	size (cm)
15.13	5	3.7		5	4.6		6	5.2
15.14	5	3.0		5	2.7		7	4.8
15.15	5	2.4		4	4.2		8	7.9
15.16	7	4.4		8	8.3		8	7.8

Plot 16

Number	leaves	size (cm)	One week after fertilizat ion	Leaves	size (cm)	Two weeks after fertilizat ion	leaves	size (cm)
16.1	4	10.5		3	10.0		4	17.2
16.2	4	4.2		4	4.0		3	4.7
16.3	8	10.3		5	9.6		9	15.7
16.4	5	10.5		6	13.2		9	13.8

Number	leaves	size (cm)	One week after fertilizat ion	Leaves	size (cm)	Two weeks after fertilizat ion	leaves	size (cm)
16.5	6	5.0		5	4.3		9	8.2
16.6	4	1.6		4	2.4		7	3.9
16.7	5	8.0		6	7.6		7	10.2
16.8	5	4.5		5	5.0		5	5.2

Number	leaves	size (cm)	One week after fertilizat ion	Leaves	size (cm)	Two weeks after fertilizat ion	leaves	size (cm)
16.9	7	5.5		5	5.4		5	7.6
16.10	3	3.8		4	3.4		5	4.4
16.11	6	7.0		4	7.3		4	6.7
16.12	8	7.4		14	13		12	25.8

Number	leaves	size (cm)	One week after fertilizat ion	Leaves	size (cm)	Two weeks after fertilizat ion	leaves	size (cm)
16.13	4	4.3		5	4.6		6	5.4
16.14	7	4.2		5	2.7		6	6.4
16.15	4	11.8		4	4.2		5	12.2
16.16	4	2.3		Dead	8.3		4	7.2

Plot 17

Number	leaves	size (cm)	One week after fertilization	Leaves	size (cm)	Two weeks after fertilization	leaves	size (cm)
17.1	3	11.6		4eaten	11.5		2	10.3
17.2	4	2.6		3	3.2		7	3.7
17.3	4	7.3		3eaten	7.2		0	0
17.4	8	6.7		6	8.5		9	10.8

Number	leaves	size (cm)	One week after fertilization	Leaves	size (cm)	Two weeks after fertilization	leaves	Size (cm)
17.5	5	3.4		3	2.4		0	0
17.6	5	9.8		4	9.3		4	10.2
17.7	5	2.1		3	3.2		10	5.6
17.8	6	8.3		6	8.2		5	8.4

Number	leaves	size (cm)	One week after fertilization	Leaves	size (cm)	Two weeks after fertilization	leaves	size (cm)
17.9	4	1.8		5	8.5		5	3.4
17.10	7	7.4		5	7.2		4	7.7
17.11	5	2.6		Dead			0	0
17.12	6	3.2		Dead			0	0

Number	leaves	size (cm)	One week after fertilization	Leaves	size (cm)	Two weeks after fertilization	leaves	size (cm)
17.13	4	2.6		3	4.6		3	2.8
17.14	5	4.2		3eaten	2.7		0	0
17.15	3	2.8		Dead	4.2		0	0
17.16	6	6.3		4	8.3		3	5.4

Plot 18

Number	leaves	size (cm)	One week after fertilization	Leaves	size (cm)	Two weeks after fertilization	leaves	size (cm)
18.1	4	5.6		4	11.6		0	0
18.2	4	5.8		4	7.7		3	6.8
18.3	7	4.1		7	9.4		10	2.2
18.4	6	2.4		7	6.8		4	7.7

Number	leaves	size (cm)	One week after fertilization	Leaves	size (cm)	Two weeks after fertilization	leaves	Size (cm)
18.5	3	8.7		3	9.2		2	8.2
18.6	5	4.2		4	4.6		5	5.2
18.7	6	5.9		6	5.7		7	7.2
18.8	4	1.3		4	5.5		3	4.8

Number	leaves	size (cm)	One week after fertilization	Leaves	size (cm)	Two weeks after fertilization	leaves	size (cm)
18.9	3	1.6		7	3.3		5	4.2
18.10	4	3.7		5	5.4		5	5.3
18.11	6	4.2		4 eaten	3.2		3	3
18.12	5	3.1		5	3.9		5	3.8

Number	leaves	size (cm)	One week after fertilization	Leaves	size (cm)	Two weeks after fertilization	leaves	size (cm)
18.13	5	6.8		8	10.8		7	6.8
18.14	6	4.1		6	7.1		6	7.1
18.15	4	7.2		5	3.7		5	3.9
18.16	8	7.3		9	9.7		6	10.1

Plot 19

Number	leaves	size (cm)	One week after fertilization	Leaves	size (cm)	Two weeks after fertilization	leaves	size (cm)
19.1	4	10.8		5	10.3		4	10.8
19.2	4	3.6		6	5.3		8	9.3
19.3	7	10.6		5	10.3		10	11
19.4	6	4.7		6	7.6		9	14.1

Number	leaves	size (cm)	One week after fertilization	Leaves	size (cm)	Two weeks after fertilization	leaves	Size (cm)
19.5	9	7.3		9	9.4		7	12.6
19.6	5	4.8		4	5		0	0
19.7	6	3.3		11	8.4		14	17.4
19.8	4	5.7		6	5.2		6	6.2

Number	leaves	size (cm)	One week after fertilization	Leaves	size (cm)	Two weeks after fertilization	leaves	size (cm)
19.9	6	6.4		8	7.2		6	7.4
19.10	4	4.2		4	5.7		0	0
19.11	6	7.2		4	8.4		5	7.7
19.12	7	8.7		5	10.4		6	10.6

Number	leaves	size (cm)	One week after fertilization	Leaves	size (cm)	Two weeks after fertilization	leaves	size (cm)
19.13	4	3.2		5	4.4		4	3.8
19.14	7	7.8		5	8.0		5	7.7
19.15	5	8.2		4	7.6		5	7.8
19.16	6	8.8		5	9.3		4	11.2

Plot 20

Number	leaves	size (cm)	One week after fertilization	Leaves	size (cm)	Two weeks after fertilization	leaves	size (cm)
20.1	7	5.6		10	10.3		11	15.6
20.2	4	5.8		4	6		5	7.2
20.3	5	4.1		11	10		13	21
20.4	3	2.4		Dead			0	0

Number	leaves	size (cm)	One week after fertilization	Leaves	size (cm)	Two weeks after fertilization	leaves	Size (cm)
20.5	5	2.1		3	3.2		11	11
20.6	6	4.2		3	5		6	4.6
20.7	4	2.4		8 eaten	5.1		12	8.9
20.8	10	4.4		Dead			7	5.7

Number	leaves	size (cm)	One week after fertilization	Leaves	size (cm)	Two weeks after fertilization	leaves	size (cm)
20.9	3	1.2		Dead			0	0
20.10	5	3.8		9	7.3		13	17.6
20.11	6	6.1		4	6.2		4	7.4
20.12	4	2.8		4	1.7		4	2.7

Number	leaves	size (cm)	One week after fertilization	Leaves	size (cm)	Two weeks after fertilization	leaves	size (cm)
20.13	8	8.4		13	16.4		14	32.4
20.14	6	3.5		5 eaten	4.2		0	0
20.15	5	1.6		3	1.6		3	1.4
20.16	4	2.8		Dead			0	0

Plot 21

Number	leaves	size (cm)	One week after fertilization	Leaves	size (cm)	Two weeks after fertilization	leaves	size (cm)
21.1	4	5.6		6	7.4		9	9
21.2	6	5.8		5	7.3		5	7.7
21.3	3	4.1		4	3.4		6	5.9
21.4	5	2.4		9	9.6		9	16.6

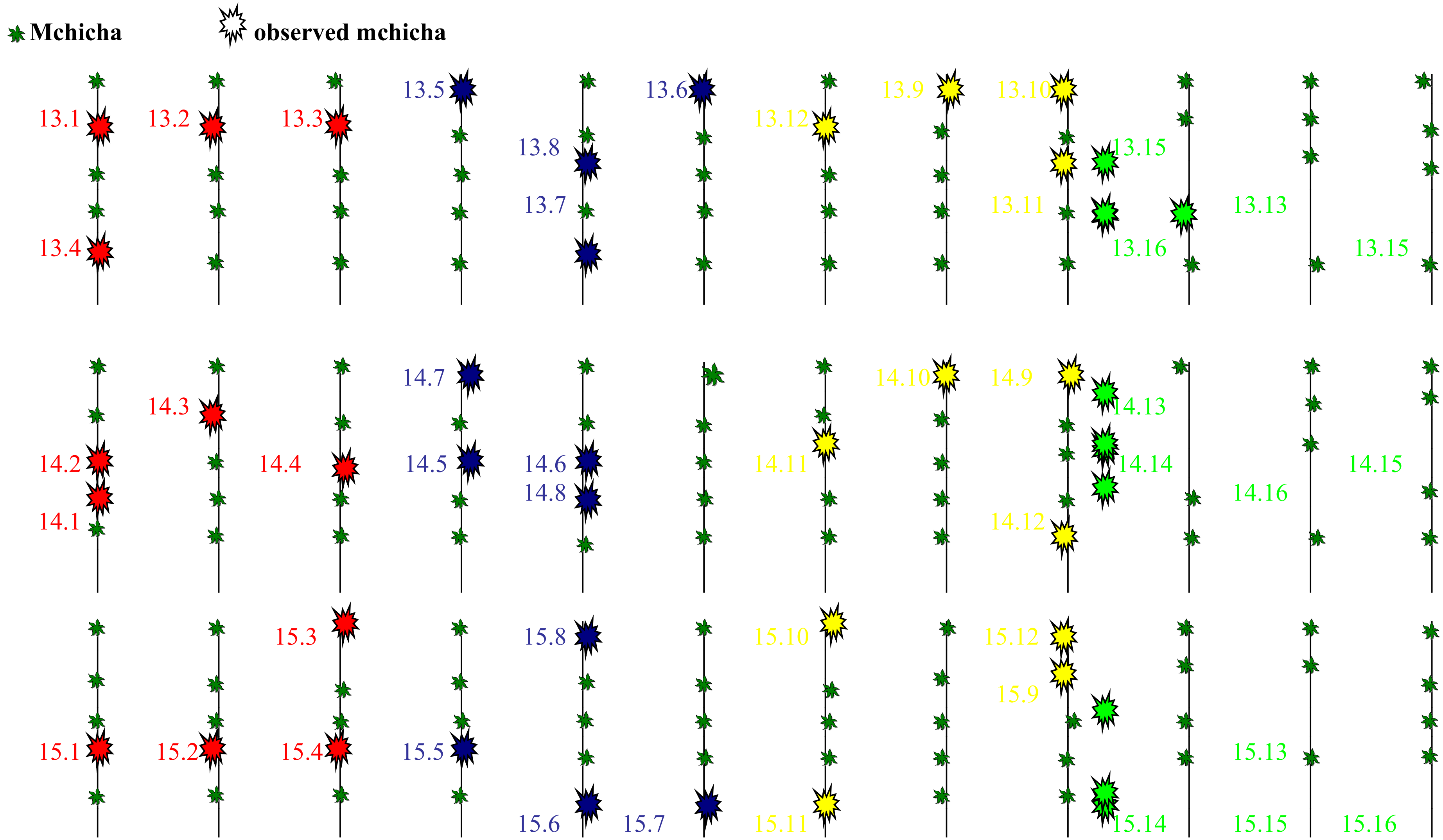
Number	leaves	size (cm)	One week after fertilization	Leaves	size (cm)	Two weeks after fertilization	leaves	Size (cm)
21.6	3	4.2		3	2.6		6	4.6
21.7	4	2.4		4	5.1		4	7.3
21.17	4	2.0		6	3.7		7	6.3
21.18	4	5.0		5 eaten	3.7		5	5.6

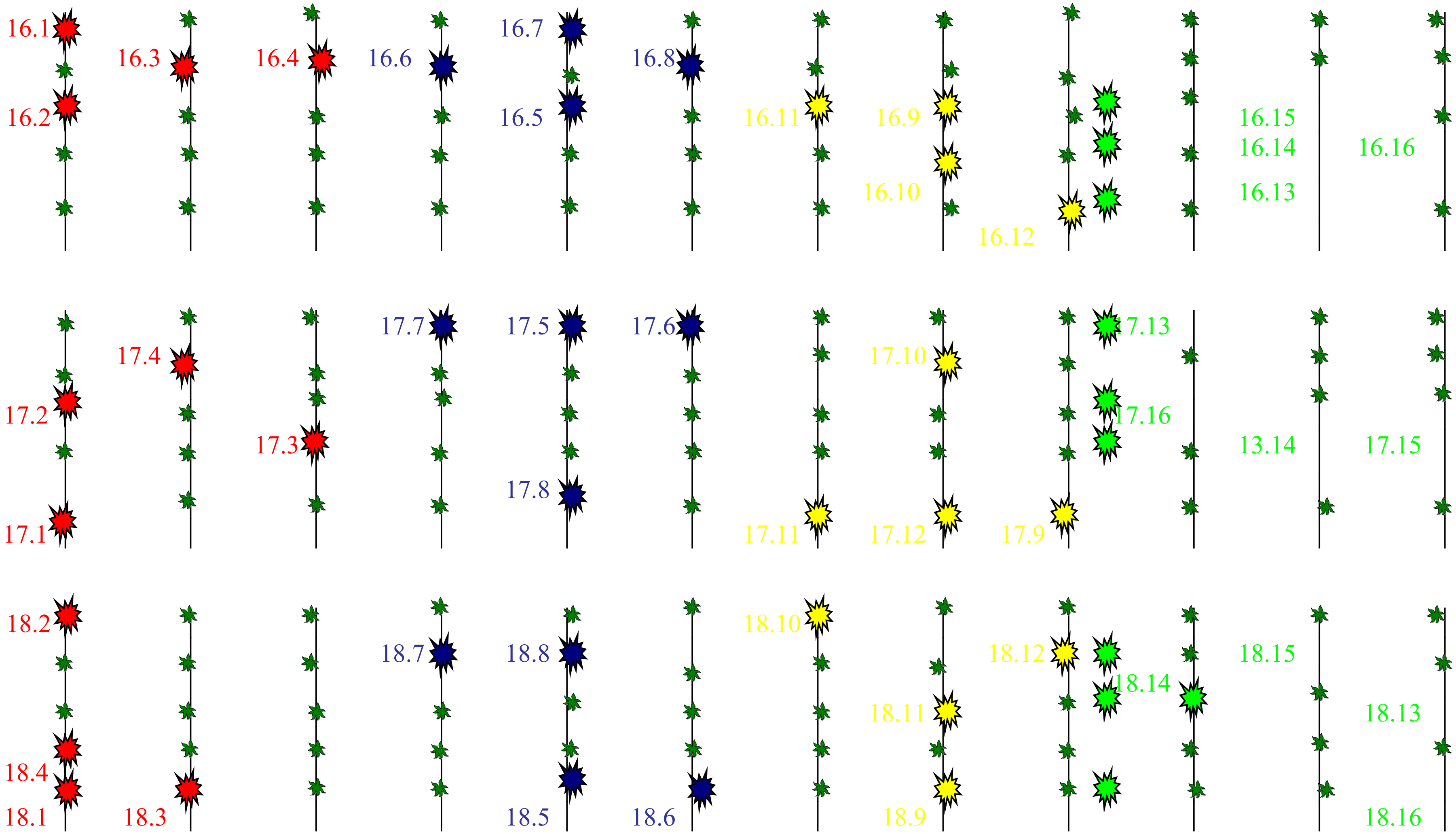
Number	leaves	size (cm)	One week after fertilization	Leaves	size (cm)	Two weeks after fertilization	leaves	Size (cm)
21.5	10	2.1		7	9.4		4	11.2
21.8	4	4.4		5	3.6		3	3.3
21.9	7	1.2		11 eaten	12		11	20.2
21.11	3	6.1		Dead			0	0

Number	leaves	size (cm)	One week after fertilization	Leaves	size (cm)	Two weeks after fertilization	leaves	size (cm)
21.10	5	3.8		3	3		0	0
21.12	6	2.8		5	5.3		0	0
21.16	6	5.3		8	4.5		0	0
21.19	4	4.0		3	5.5		3	6.1

Number	leaves	size (cm)	One week after fertilization	Leaves	size (cm)	Two weeks after fertilization	leaves	size (cm)
21.13	8	5.3		5 quite dead	3.2		0	0
21.14	3	3.8		4	4.2		0	0
21.15	5	7.0		5quite dead	6.2		3	7.1
21.20	4	5.0		2	4.6		2	4.2

PLAN OF THE FIELD





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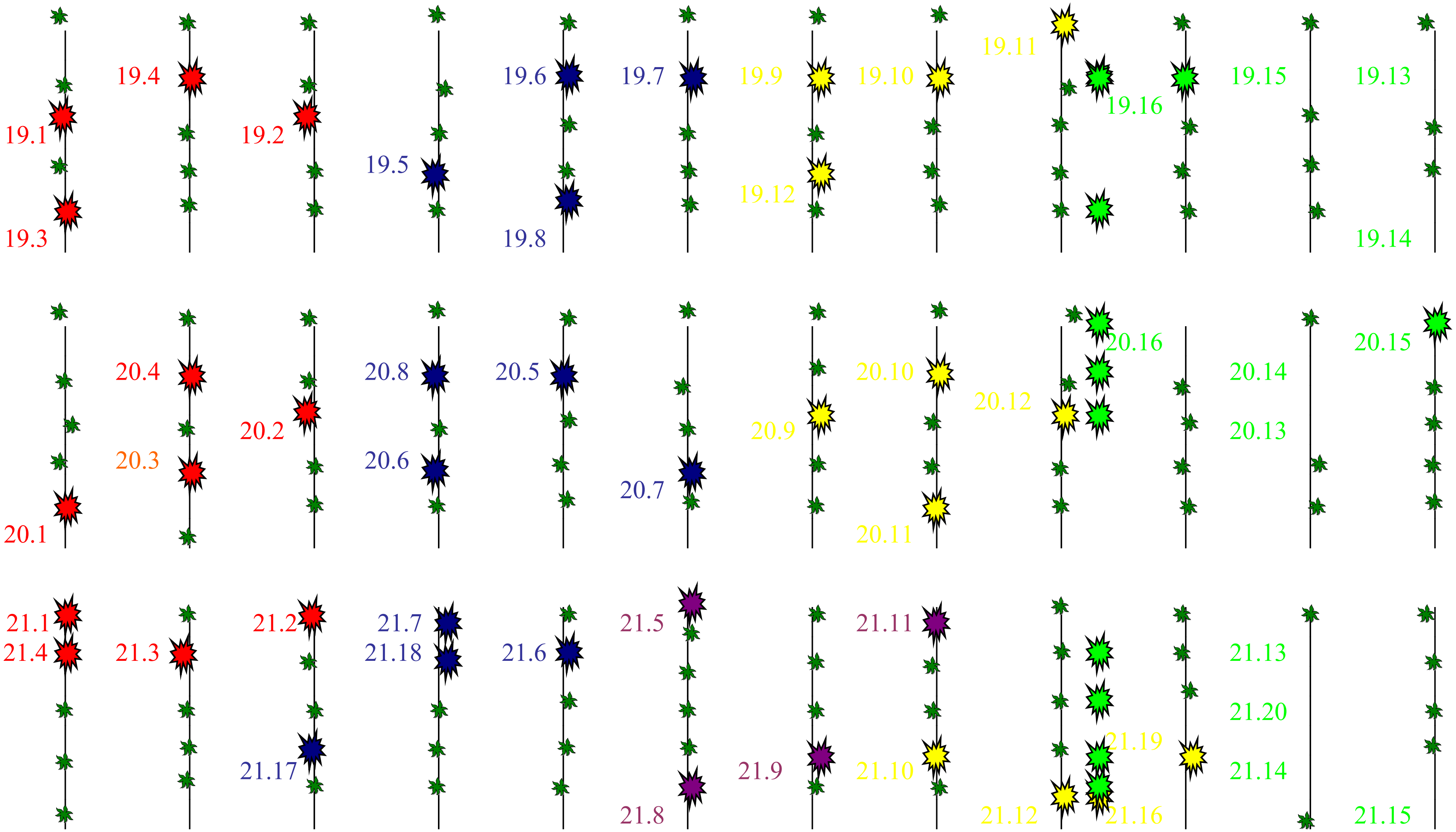
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APPENDIX 2: SWEET PEPPERS

fertilized by slurry

	before fertilization					after fertilization					
plant number	bud	flower	pollinated flower	fruit	size	bud	flower	pollinated flower	fruit	size	note
4			4	4	30	4		3		29	2 eaten
6	13		1	1	40	61				40	2 eaten
8	3		11	5	30	8	2	6		40	3 eaten/lying plant
11	4		1		26	2	1	1		24	light green
14	12		6		28	22	1	1	1	32	bad plant with yellow and wilting leaves/3 eaten
19	1		1		35	12	1	7		38	ants/ very wilting leaves
20	11		7		33	4		4		31	3 eaten fruits/yellow and wilting leaves
22	10	1	3		22	12	1	1		24	yellow and wilting leaves
25	>50		2		66	>50	4	5		56	wilting leaves/1eaten fruit
33	2		6		52			3	1	50	2 eaten fruits/wilting leaves
38	17	1	13		35			3	1	34	2 eaten fruits/yellow leaves
39	>52	7			53	21	6	22		54	wilting leaves
40	1	3	10		47			2	2	45	1 eaten fruit/ light leaves
average	7,4	3	5,42	3,33	38,23	16,22	2,29	4,83	1,25	38,23	

	difference between before and after pollinisation					relative difference				
	bud	flower	pollinated flower	fruit	size	bud	flower	pollinated flower	fruit	size
4	4,00	0,00	-1,00	-4,00	-1,00	#DIV/0 !	#DIV/0 !	-0,25	-1,00	-0,03
6	48,00	0,00	-1,00	-1,00	0,00	3,69	#DIV/0 !	-1,00	-1,00	0,00
8	5,00	2,00	-5,00	-5,00	10,00	1,67	#DIV/0 !	-0,45	-1,00	0,33
11	-2,00	1,00	0,00	0,00	-2,00	-0,50	#DIV/0 !	0,00	#DIV/0 !	-0,08
14	10,00	1,00	-5,00	1,00	4,00	0,83	#DIV/0 !	-0,83	#DIV/0 !	0,14
19	11,00	1,00	6,00	0,00	3,00	11,00	#DIV/0 !	6,00	#DIV/0 !	0,09
20	-7,00	0,00	-3,00	0,00	-2,00	-0,64	#DIV/0 !	-0,43	#DIV/0 !	-0,06
22	2,00	0,00	-2,00	0,00	2,00	0,20	0,00	-0,67	#DIV/0 !	0,09
25	0,00	4,00	3,00	0,00	-10,00	#DIV/0 !	#DIV/0 !	1,50	#DIV/0 !	-0,15
33	-2,00	0,00	-3,00	1,00	-2,00	-1,00	#DIV/0 !	-0,50	#DIV/0 !	-0,04
38	-17,00	-1,00	-10,00	1,00	-1,00	-1,00	-1,00	-0,77	#DIV/0 !	-0,03
39	21,00	-1,00	22,00	0,00	1,00	#DIV/0 !	-0,14	#DIV/0 !	#DIV/0 !	0,02
40	-1,00	-3,00	-8,00	2,00	-2,00	-1,00	-1,00	-0,80	#DIV/0 !	-0,04
average	4,64	0,31	-0,54	-0,38	0,00	0,63	0,10	-0,10	-0,12	0,00

fertilized by a half dose of slurry

	before fertilization					after fertilization					
	bud	flow er	pollinated fl	fruit	size	bud	flow er	pollinated fl	fruit	size	note
5	1	0	11	2	22	3	0	6	1	22	1 eaten
7	0	0	1	3	40	4	0	0	1	39	1 eaten
9	0	1	4	0	25	14	0	2	3	31	1 fruit rotten
10	5	0	2	4	48	23	1	3	0	45	
13	35	0	2	2	32	33	4	2	0	32	ants and other insects
18	13	9	9	0	45	3	0	22	1	49	yellow leaves
21	27	0	2	0	41	57	2	6	1	44	1 eaten
24	3	0	9	0	53	18	0	2	2	60	sick, insects, ants
28	8	0	5	0	45	7	2	3	0	46	yellow , w ilting leaves
30	13	0	1	0	37	47	0	1	0	38	w ilting, eaten leaves
31	10	0	0	0	37	21	2	4	0	35	w ilting, eaten leaves
34	0	0	1	0	30	0	0	3	0	27	yellow , w iting leaves
35	12	5	12	0	58	2	3	14	0	56	
37	5	1	5	0	34	17	0	1	0	35	
average	9,43	1,14	4,57	0,79	39,07						

	bud	flow er	pollinated flow er	fruit	size	bud	flow er	pollinated flow er	fruit	size
5	2,00	0,00	-5,00	-1,00	0,00	2,00	0,00	-11,00	-2,00	-22,00
7	4,00	0,00	-1,00	-2,00	-1,00	#DIV/0 !	0,00	-1,00	-3,00	-40,00
9	14,00	-1,00	-2,00	3,00	6,00	#DIV/0 !	-1,00	-4,00	0,00	-25,00
10	18,00	1,00	1,00	-4,00	-3,00	3,60	0,00	-2,00	-4,00	-48,00
13	-2,00	4,00	0,00	-2,00	0,00	-0,06	0,00	-2,00	-2,00	-32,00
18	-10,00	-9,00	13,00	1,00	4,00	-0,77	-9,00	-9,00	0,00	-45,00
21	30,00	2,00	4,00	1,00	3,00	1,11	0,00	-2,00	0,00	-41,00
24	15,00	0,00	-7,00	2,00	7,00	5,00	0,00	-9,00	0,00	-53,00
28	-1,00	2,00	-2,00	0,00	1,00	-0,13	0,00	-5,00	0,00	-45,00
30	34,00	0,00	0,00	0,00	1,00	2,62	0,00	-1,00	0,00	-37,00
31	11,00	2,00	4,00	0,00	-2,00	1,10	0,00	0,00	0,00	-37,00
34	0,00	0,00	2,00	0,00	-3,00	#DIV/0 !	0,00	-1,00	0,00	-30,00
35	-10,00	-2,00	2,00	0,00	-2,00	-0,83	-5,00	-12,00	0,00	-58,00
37	12,00	-1,00	-4,00	0,00	1,00	2,40	-1,00	-5,00	0,00	-34,00
average	8,36	-0,14	0,36	-0,14	0,86					
						0,89	-0,13	0,08	-0,18	0,02

not fertilized

	before fertilization					after fertilization					
	bud	flow er	pollinated fl	fruit	size	bud	flow er	pollinated fl	fruit	size	note
1	0	0	7	5	47	0	0	8	1	40	
2	0	2	5	3	63	0	0	0	0	53	
3	18	0	2	0	27	18	4	1	1	25	eaten fruit
12	17	0	20	0	38	26	3	10	3	27	
15	2	0	5	3	38	1	0	6	0	36	
16	16	6	4	0	38	12	5	7	0	36	very yellow
17	0	0	2	0	28	3	0	0	1	37	eaten fruit
23	55	0	2	0	37	17	2	13	3	38	
26	10	5	0	0	23	4	1	7	0	25	
27	15	5	16	0	54	13	1	12	9	55	
29	5	0	1	0	20	6	0	1	0	19	
32	2	1	6	2	33	47	0	1	0	38	
36	15	0	6	0	39	34	1	2	0	40	
average	11,92	1,46	5,85	1	37,31						

	bud	flow er	pollinated flow er	fruit	size	bud	flow er	pollinated flow er	fruit	size
1	0,00	0,00	1,00	-4,00	-7,00	#DIV/0 !	0,00	-7,00	-5,00	-47,00
2	0,00	-2,00	-5,00	-3,00	-10,00	#DIV/0 !	-2,00	-5,00	-3,00	-63,00
3	0,00	4,00	-1,00	1,00	-2,00	0,00	0,00	-2,00	0,00	-27,00
12	9,00	3,00	-10,00	3,00	-11,00	0,53	0,00	-20,00	0,00	-38,00
15	-1,00	0,00	1,00	-3,00	-2,00	-0,50	0,00	-5,00	-3,00	-38,00
16	-4,00	-1,00	3,00	0,00	-2,00	-0,25	-6,00	-4,00	0,00	-38,00
17	3,00	0,00	-2,00	1,00	9,00	#DIV/0 !	0,00	-2,00	0,00	-28,00
23	-38,00	2,00	11,00	3,00	1,00	-0,69	0,00	-2,00	0,00	-37,00
26	-6,00	-4,00	7,00	0,00	2,00	-0,60	-5,00	0,00	0,00	-23,00
27	-2,00	-4,00	-4,00	9,00	1,00	-0,13	-5,00	-16,00	0,00	-54,00
29	1,00	0,00	0,00	0,00	-1,00	0,20	0,00	-1,00	0,00	-20,00
32	45,00	-1,00	-5,00	-2,00	5,00	22,50	-1,00	-6,00	-2,00	-33,00
36	19,00	1,00	-4,00	0,00	1,00	1,27	0,00	-6,00	0,00	-39,00
average	2,00	-0,15	-0,62	0,38	-1,23					
						0,17	-0,11	-0,11	0,38	-0,03

Notes about the digester experiment

we had some difficulties to conclude this experiment. Indeed we had problems tot ake the measurements.

Advices:

- start this experiment on a Monday to be at the shamba every day during the week
- take measurements always at the same times during the day
- check that the stones on the top of the digesters eight the same
- check that you add the same quantity of manure
- check that the digesters are closed
- the most important: check that you are at the shamba to take measurement if hey used the gaz