Fermentation versus composting

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1 Introduction

Composting of organic (waste) materials has already been applied for many years in the agro- and horticulture. During composting, the material is aerated by regularly turning the windrow with a grinder. This strongly stimulates the growth of microorganisms. These microorganisms break down the organic matter. This will heat up the windrow and a considerable part of the organic matter will get lost during this process.

Another option is fermentation of the organic (waste) materials. This process takes place without aeration and without any extra processing. Seashell lime, Clay minerals and Microferm (Effective Microorganisms) are added to the windrow when the windrow is prepared for fermentation. After this the windrow will be closed by putting a plastic foil tightly stretched over the windrow. After a period of 6 to 8 weeks the windrow is fermented. This is called Bokashi; fermentated organic matter.

The goal of this experiment was to compare the effect of fermentation of organic (waste) materials with the common way of composting. It was expected that through anaerobic conversion (fermentation) of organic material more nutrients will be retained in the product.

This report describes first the materials and methods. In chapter 3 the results are given. After this follows a discussion. The conclusions are given in chapter 5.

2 Materials and methods

The following materials were used for the experiment:

- 26,800 kg road side cutting material
- 29 liter Microferm
- 293 liter well water
- 300 kg Edasil clay minerals
- 300 kg Ostrea seashell lime
- 200 liter tank
- 2 x 12 liter buckets
- 2 x 10 liter watering cans
- Weigh bridge
- Tractor with dumper
- Tractor with grinder
- Wheel loader (with a closed bucket)
- Temperature indicator
- Silage plastic of minimal 4 by 20 m
- Gravel bags
- Sand
- Protection cover of minimal 3 by 19 m, for protecting the silage plastic
- Air tight bags
- Waterproof marker
- Scales for up to 5 kg

The experiment was carried out at Van den Hengel farm composting in Achterveld (The Netherlands). Two windrows were made in a barn with a concrete floor:

1. Bokashi: made by the Bokashi method of Agriton;
2. Common Compost: made by the traditional composting method.

Table 1 shows the experimental design per windrow.

Table 1: Experimental design of both windrows.

	Windrow 1: Bokashi	**Windrow 2: Common Compost**
1. Organic (waste) material	26,800 kg road side cutting material from the Romeinenbaan in Wijk bij Duurstede (The Netherlands)	
2. Determine m3 of the material	29,700 kg is +- 65 m3, so 26,800 kg is +- 58.7 m3	
3. Determine the temperature	39.1 °C	
4. Make a homogeneous mixture	All the material was put down in one windrow and has been mixed once with the grinder	
5. Take samples	6 samples were taken on equally divided places	
6. Divide into two windrows, which are as identical as possible	13,400 kg, so +- 29.3 m3	13.400 kg, so +- 29.3 m3
7. Build up windrows with similar width and length	Layer wise 2.9 m x 18.6 m 0.5 m high	 2.9 m x 16.5 m. 1.1 m high in the middle
- During building up windrows: add 1 liter Microferm/m3, 10 kg Edasil clay minerals/m3 and 10 kg Ostrea seashell lime/m3	After each layer a part of the additions is added. The total additions are: - 29 liter Microferm solved in 293 liter well water with a 200 liter tank, 12 liter buckets and watering cans. - 300 kg Edasil clay minerals with a wheel loader with a closed bucket - 300 kg Ostrea seashell lime with a wheel loader with a closed bucket	n.a.
8. Mixing after building up a windrow	Once with the grinder	n.a.
9. Press with a wheel loader	Yes	n.a.
10. Measure the temperature	At 3 places in the windrow	At 3 places in the windrow
11. Close up with silage plastic, protection cover and strengthen with gravel bags and sand	Yes	n.a.
Turn the windrow once a week	n.a.	See appendix I
Weekly measurement of the temperature of the windrows and of the environment	See appendix I. At 3 places in the windrow (close up holes in the plastic with tape)	See appendix I. At 3 places in the windrow
Take samples (three per windrow)	See appendix I. After 3 and 6 weeks	See appendix I. Each week
Weigh the whole windrow after 6 weeks	See appendix I	See appendix I

The added additions to the Bokashi windrow comprised Microferm solved in well water, Edasil clay minerals and Ostrea seashell lime. Microferm contains several microorganisms from 5 different groups, 10 different families and 80 species. Table 2 shows the groups and families.

Table 2: Composition of Microferm

Groups	Families
Lactic acid bacteria	Streptomyces albus albus
Photosynthetic bacteria	Rhodopseudomonas sphaeroides
Yeast	Lactobacillus plantarum
Actinomyces	Propionibacterium freudenreichii
Moulds	Streptococcus lactis
	Streptococcus faecalis
	Aspergillus oryzae
	Mucor hiemalis
	Saccharomyces cerevisiae
	Candida utilis

Table 3 shows the composition of well water.

Table 2: Composition of well water

Parameter	Amount
Escherichia coli (cfu/ml)	<1
Escherichia coli (cfu/100 ml)	0
Aerobic bacterial count 22°C (cfu/ml)	50
pH-water	7.2
Hardness (°D)	6
Manganese (mg/l)	<0.05
Nitrite (mg/l)	<0.05
Iron (mg/l)	<1.10
Nitrate (mg/l)	<10
Chloride (mg/l)	<35

Table 4 shows the composition of Edasil clay minerals.

Table 4: Composition Edasil clay minerals

Parameter	Amount
Montmorillonite level (%)	70-80
Specific surface (m2/g)	600-800
Ion exchange capacity (mvol/100g)	70-85
Water uptake capacity (%)	135
Water level (%)	6-8
pH value	7-8
Alkaline function (%)	4
Density (g/cm3)	2.6
Silicon oxide (%)	56
Iron oxide (%)	0.4
Aluminium oxide (%)	16.0
Calcium oxide (%)	4.0
Magnesium oxide (%)	4.0
Potassium oxide (%)	2.0
Sodium oxide (%)	0.4
Boron (ppm)	1.000
Cobalt (ppm)	35
Copper (ppm)	20
Manganese (ppm)	300
Molybdenum (ppm)	20
Nickel (ppm)	50
Zinc (ppm)	90

Table 5 shows the composition of Ostrea seashell lime.

Table 5: Composition Ostrea seashell lime

Parameter	Amount
Dry matter (%)	99.5
Ash (%)	97.5
Phosphorous (%)	0.05
Calcium (%)	37.7
Carbonate (%)	96.1
Sodium (%)	0.4
Potassium (%)	<0.01
Magnesium (%)	0.02
Copper (mg/kg)	1
Iron (mg/kg)	5,266
Manganese (mg/kg)	63
Zinc (mg/kg)	5
Cobalt (mg/kg)	<0.5
Arsenic (mg/kg)	15.9
Selenium (mg/kg)	0.03
Cadmium (mg/kg)	<0.2
Lead (mg/kg)	<0.2
Mercury (mg/kg)	0.03
Sulfate (mg/kg)	454
Chloride (mg/kg)	870
Iodide (mg/kg)	<15
Fluor (mg/kg)	160

Figure 1 shows a picture of the Bokashi windrow at the start of the experiment. The windrow with Common Compost at the start of the experiment is shown in figure 2.

Figure 1: Windrow 1 Bokashi at the start

Figure 2: Windrow 2 Common Compost at the start

Three mixed samples were made of:

- the road side cutting material at the start of the experiment;

- Bokashi at the end of the experiment;

- Common Compost at the end of the experiment.

These samples were analyzed by Agrarisch Laboratorium Noord Nederland in Ferwerd (The Netherlands). The used analytical methods and measure uncertainty are shown in table 6.

Table 6: Used analytical methods and measure uncertainty (Agrarische Laboratorium Noord Nederland)

Parameter	Analytical method	Measure uncertainty
Moisture	gravimetric	1.34%
Dry matter	gravimetric	3.10%
N Total	continuous flow analyzer	2.56%
N Mineral	continuous flow analyzer	6.50%
N Organic	continuous flow analyzer	4%
Crude ash	gravimetric	2.41%
Crude protein	continuous flow analyzer	0.49%
Crude fiber	gravimetric	3.20%
Fat	after hydrolysing	6%
PH	pH indicator	0.15%
Sugar	luff schoorl-method	6.80%
NDF	van Soest method	13.0%
ADF	van Soest method	13.0%
ADL	van Soest method	13.0%
Potassium	ICP	3.64%
Sodium	ICP	5.30%
Calcium	ICP	4.67%
Magnesium	ICP	3.35%
Phosphorous	ICP	5.95%
Manganese	ICP	7.62%
Iron	ICP	8.68%
Zinc	ICP	5.30%
Cobalt	ICP	16%
Molybdenum	ICP	3.36%
Sulfur	ICP	2.10%
Selenium	ICP-MS	15.60%
Chlorine	continuous flow analyzer	7.44%

Hemicelluloses was calculated according to the following formula:

Hemicelluloses = NDF – ADF

Cellulose was calculated according to the following formula:

Cellulose = ADF – ADL (Spiller, 1992)

3 Results

3.1 Temperature

The temperature of both windrows as well as the environmental temperature were measured weekly. Figure 3 shows the results. The road side cutting material had an average temperature of 39.1 °C at the start of the experiment. The Common Compost increased in a week to an average temperature of 73.3 °C, while the Bokashi decreased to an average temperature of 15.5 °C. Bokashi decreased to an average temperature of 13.7 °C during 6 weeks. The temperature of the Bokashi was similar to the environmental temperature. The temperature of the Common Compost decreased from day 7 onwards. It decreased from an average temperature of 73.3 °C at day 7 to an average temperature of 47.4 °C at day 42. Calculated over the period from day 7 to 42, the Common Compost had an average temperature of 60.5 °C.

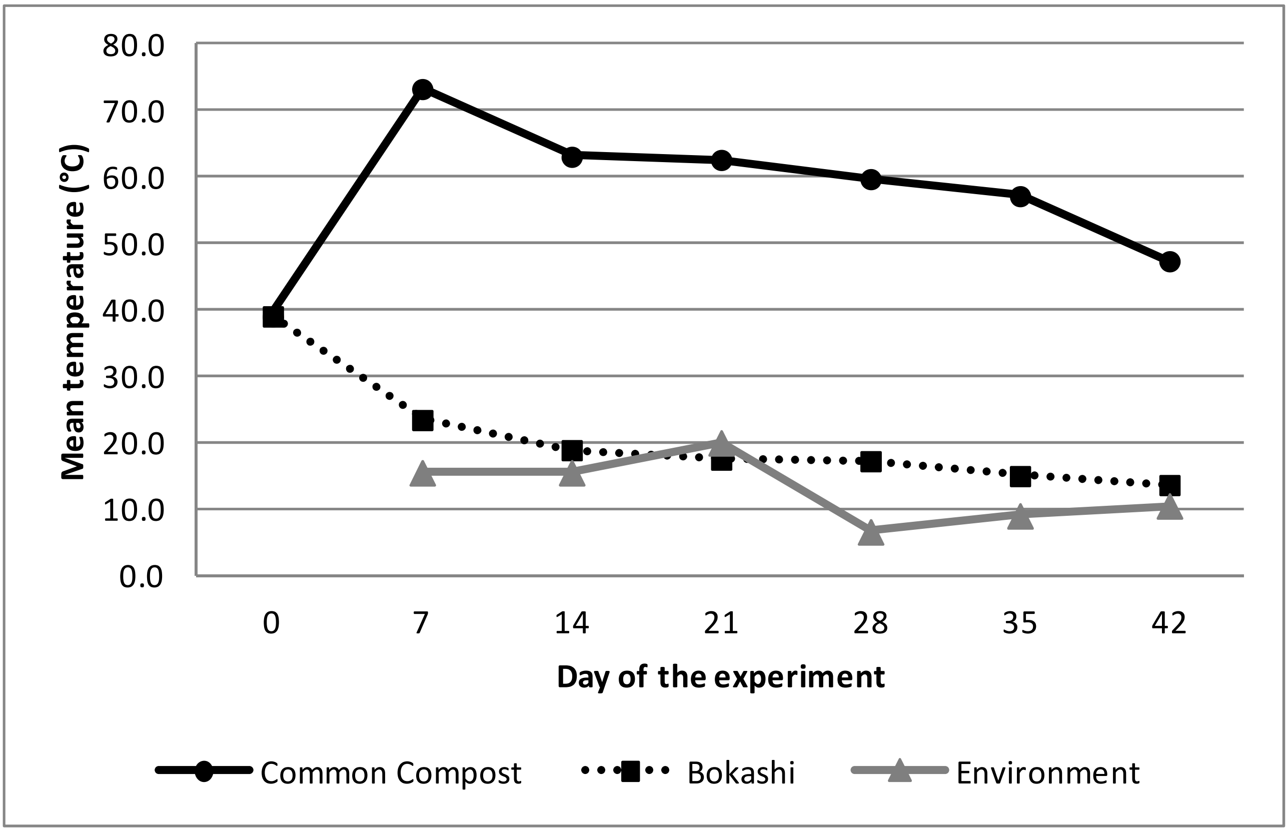

Figure 3: Course of the temperature from Common Compost, Bokashi and the environment.

3.2 Weight

Table 7 shows the start and end weight of both windrows. 13,400 Kg of road side cutting material has been used to make both windrows. 922 Kg of additions have been added to the Bokashi windrow, so this windrow had a starting weight of 14,322 kg. Also several times there were samples taken from the windrows. The end weight of the Common Compost was 5,070 kg and of the Bokashi 13,870 kg. 8,336 Kg (60.2% of the starting material) of the Common Compost had “disappeared” and only 459 kg (3.2% of the starting material)of Bokashi had “disappeared”.

Table 7: Change of the weights (kg) of both windrows

	Common Compost	Bokashi
Starting weight	13,400	13,400
Additions	0	922
Starting weight	**13,400**	**14,322**
Minus samples	6	7
End weight	**5,070**	**13,870**
"Disappeared" weight	**8,336**	**459**

3.3 Composition

Figure 4 shows a picture of the Bokashi after 6 weeks of fermentation. Figure 5 shows a picture of Common Compost after 6 weeks of fermentation. Bokashi was comparable with grass silage and had a sweet smell. Common Compost had a much darker color.

Figure 4: Bokashi after 6 weeks of fermentation

Figure 5: Common Compost after 6 weeks of composting

3.3.1 Analytical results

The analytical results of road side cutting material, Common Compost and Bokashi are shown in table 8. Common Compost had the highest dry matter level, but this material showed the highest losses. The composition of Bokashi is more comparable with the composition of the road side cutting material, because much less of the material had “disappeared”.

Table 8: Analytical results of the road side cutting material, Common Compost and Bokashi

	Road side cutting material	Common Compost	Bokashi
DM (g/kg product)	202	273	222
Organic matter (g/kg DM)	787.1	637.4	675.7
C total (g/kg DM)	396	318.7	337.8
N total (g/kg DM)	17.9	31.4	17.2
N mineral (g/kg DM)	2.2	1	0.7
N organic (g/kg DM)	15.7	30.4	16.5
C/N ratio	22	10.1	19.5
Gross energy (MJ/kg DM)	16.11	13.4	13.98
Crude ash (g/kg DM)	211	363	328
Crude protein (g/kg DM)	134	216	130
Crude fiber (g/kg DM)	310	198	271
Crude fat (g/kg DM)	27	13	29
pH	7.3	7.9	7.1
Sugar (g/kg DM)	32	18	25
NDF (g/kg DM)	631	464	542
ADF (g/kg DM)	479	483	418
Hemicelluloses (g/kg DM)	152	-19	124
Cellulose (g/kg DM)	345	221	290
ADL (g/kg DM)	134	262	128

Table 9 shows the total levels in road side cutting material, Common Compost and Bokashi. Organic matter is nutrition for soil life and plants. In Common Compost 58.0% of the organic matter "disappeared", while in Bokashi it was mainly retained (97.6%).
Bokashi had a C/N ratio of 19.5 and Common Compost of 10.1. A high C/N ratio is important for the organic matter content in the soil and soil fertility.
More material was broken down in Common Compost than in Bokashi. This is also shown by the hemicelluloses level of Common Compost. Hemicelluloses is rapidly degradable, followed by cellulose. ADL on the other hand, is hardly degradable. That's why it can be assumed that during the 6 weeks the absolute amount of ADL only slightly changed. The hemicelluloses level is almost zero (the negative value is caused by inaccuracies of the analysis multiplied with the amount of material) for Common Compost, which indicates that hemicelluloses is completely degraded in Common Compost. Besides that, road side cutting material and Bokashi had a comparable hemicelluloses level. The results confirm that ADL wasn't degraded during the experiment. Road side cutting material, Common Compost and Bokashi show a comparable amount of ADL.

Table 9: Total level in road side cutting material, Common Compost and Bokashi

	Road side cutting material	Common Compost	Bokashi
Kg product	13,400	5,070	13,870
DM (kg)	2,706.8	1,384.1	3,079.1
Organic matter (kg)	2,130.6	882.2	2,080.5
C total (kg)	1,072.0	441.1	1,040.3
N total (kg)	48.2	43.6	52.7
N mineral (kg)	6.7	1.5	2.8
N organic (kg)	41.5	42.1	49.9
C/N ratio (kg)	22	10.1	19.5
Gross energy (MJ)	215.9	67.9	193.9
Crude ash (kg)	576.2	501.9	1,012.5
Crude protein (kg)	361.8	299.1	402.2
Crude fiber (kg)	844.2	273.8	832.2
Crude fat (kg)	72.4	18.3	88.8
pH	7.3	7.9	7.1
Sugar (kg)	87.1	24.3	76.3
NDF (kg)	1,701.8	643.9	1,664.4
ADF (kg)	1,299.8	669.2	1,289.9
Hemicelluloses (kg)	402.0	-25.4	374.5
Cellulose (kg)	938.0	304.2	901.6
ADL (kg)	361.8	365.0	388.4

As table 7 already showed, 8,336 kg product "disappeared" during composting and 459 kg product during fermentation. Table 10 shows an overview of the "disappeared" or increased amounts when looking at the total amounts in the end material minus the total amounts in road side cutting material. This table shows that Common Compost had lower amounts of all parameters than Bokashi.

Table 10: End material versus starting material (kg)

	Common Compost	Bokashi*
DM (kg)	-1,322.7	372.3
Organic matter (kg)	-1,248.4	-50.1
C total (kg)	-630.9	-31.8
N total (kg)	-4.6	4.5
N mineral (kg)	-5.2	-3.9
N organic (kg)	0.5	8.4
C/N ratio (kg)	n.a.	n.a.
Gross energy (MJ)	-147.9	-22.0
Crude ash (kg)	-74.3	436.3
Crude protein (kg)	-62.7	40.4
Crude fiber (kg)	-570.4	-12.0
Crude fat (kg)	-54.1	16.4
pH	n.a.	n.a.
Sugar (kg)	-62.8	-10.8
NDF (kg)	-1.057.9	-37.4
ADF (kg)	-630.6	-9.9
Hemicelluloses (kg)	-427.4	-27.5
Cellulose (kg)	-633.8	-36.5
ADL (kg)	3.2	26.6

* The additions, Microferm solved in water, Edasil clay minerals and Ostrea seashell lime, to the road side cutting material are not taken into account

3.3.2 Minerals

Table 11 shows the mineral levels of the road side cutting material, Common Compost and Bokashi. Some additions, like Edasil clay minerals and Ostrea seashell lime, were added to Bokashi. Edasil clay minerals contain all kinds of minerals whereas seashell lime mainly contains calcium. This can be seen in the mineral levels. Bokashi contained a higher calcium level than the road side cutting material. Compared to the road side cutting material, Common Compost contained higher levels of minerals This is caused by the "disappearance" of a large part of the material, causing increased concentrations of the non-disappearing minerals. Table 12 shows this effect.

Table 11: Analytical results of minerals in the road side cutting material, Common Compost and Bokashi

	Road side cutting material	Common Compost	Bokashi
Potassium(g/kg DM)	17.7	24.4	17.1
Sodium (g/kg DM)	1.8	2.1	1.8
Calcium (g/kg DM)	12.3	13.7	21.8
Magnesium (g/kg DM)	2.9	3.6	3.3
Phosphorus (g/kg DM)	3.4	5.1	2.2
Chloride (g/kg DM)	0.15	13.6	8.3
Sulfur (g/kg DM)	2.5	4.1	2.6
Manganese (mg/kg DM)	153	189	171
Iron (mg/kg DM)	529	454	941
Zinc (mg/kg DM)	61	101	69
Cobalt (mg/kg DM)	0.56	1.1	0.12
Molybdenum (mg/kg DM)	1	2.8	1.3
Selenium (mg/kg DM)	0.24	0.6	0.26

Table 12 shows the total amount of minerals in the road side cutting material, Common Compost and Bokashi. Common Compost showed a higher level per kg DM (table 11), but looking at the total amount of minerals it can be seen that in Common Compost less minerals are retained compared to the road side cutting material and Bokashi.

Table 12: Total amount of minerals in the road side cutting material, Common Compost and Bokashi

	Road side cutting material	Common Compost	Bokashi
Kg product	13,400	5,070	13,870
Potassium(g/kg DM)	47.8	33.8	52.7
Sodium (g/kg DM)	4.8	2.9	5.5
Calcium (g/kg DM)	33.2	19.0	67.3
Magnesium (g/kg DM)	7.8	5.0	10.0
Phosphorus (g/kg DM)	9.2	7.1	6.9
Chloride (g/kg DM)	0.4	18.8	26.4
Sulfur (g/kg DM)	6.7	5.6	8.3
Manganese (mg/kg DM)	415.4	263.6	527.1
Iron (mg/kg DM)	1,433.8	628.7	2,898.8
Zinc (mg/kg DM)	160.8	142.0	208.1
Cobalt (mg/kg DM)	1.5	1.5	0.4
Molybdenum (mg/kg DM)	2.7	3.9	4.0
Selenium (mg/kg DM)	0.7	0.9	0.8

3.4 CO_2-foot print

The CO_2-foot print declares how many CO_2-equivalents per kg compost is released. Diesel was used for the transport of the road side cutting material to the Composting company. Also the additons for Bokashi needed to be transported to the Composting company. Diesel is also used for mixing the materials. Next to the influence of the use of diesel on the CO_2-equivalents, also the emission during the composting process plays a role. Table 13 shows the results of the kg CO_2-equivalents calculation for this experiment. The underlying calculations can be found in appendix II. The kg CO_2-equivalents for diesel are lower for Common Compost than for Bokashi. In Bokashi some additions are added needed to be transported to the Composting company, through which the diesel use for Bokashi was higher. But Bokashi only needed to be mixed once, while for Common Compost this was almost daily. The kg CO_2-equivalents per ton starting material were for Bokashi almost 10 times lower than for Common Compost. The kg CO_2-equivalents per ton product were for Bokashi almost 27 times lower than for Common Compost.

Table 13: Kg CO_2-equivalents

	Kg CO_2-equ windrows	kg CO_2-equ diesel	kg CO_2-equ total	kg CO_2-equ/ton starting material	kg CO_2-equ/ton product
Common Compost	3305	87	3391	253	669
Bokashi	166	184	350	26	25

4 Discussion

The temperature increased during composting. Through this, “combusting” took place and material “disappeared”. 62.2% Of the material of the Common Compost “disappeared” and 3.2% of Bokashi. The temperature didn’t increase during fermentation. The high temperatures of Common Compost has the advantage that weed seeds lose their germination capacity. Weed seeds lose their germination capacity at a temperature of more than 50°C. Common Compost had an average temperature of 60.5°C. Practical experiments of Agriton using the Bokashi method, showed that fertilizing with Bokashi did not lead to weed in the land or garden. Probably the weed seeds germinate during the Bokashi process, but die through a lack of light. This could be investigated in an additional small experiment by adding seeds to the starting material and checking the condition of the seeds after the process.

Both windrows were laying in a barn on a concrete floor. This means that no rain from the sky or organisms from the soil could enter the windrows. It was, however, possible that water ran out of the windrows. Herewith, water soluble minerals, like potassium and sodium, could also disappear.

Cell-wall proteins and pectins also play a role in calculating hemicelluloses and cellulose. For the calculation it is assumed that the effect of cell-wall proteins and pectins are negligible.

Table 10 shows an overview of the “disappeared” or increased levels in both windrows compared to the starting material. Only the road cutting material is included in the calculation of the end material of Bokashi minus the starting material. The additions, Microferm solved in water, Edasil clay minerals and Ostrea seashell lime, also belong to the starting material, but aren’t included in the calculation. Microferm solved in water influences especially the fermentation. Edasil clay minerals contain especially clay minerals which influenced the mineral composition of the end material. Ostrea seashell lime is mainly a calcium source and influences the calcium level. This can be found back in the analytical results. Bokashi contains a higher calcium level than the road side cutting material.

Several assumptions are made for the calculation of the CO_2-foot print. This calculation resulted in an estimation of the CO_2-foot print. The CO_2 emission for Bokashi is per ton of end product considerably lower than for Common Compost. The biggest part of the difference is caused by the huge difference in losses, respectively 3.2% and 62.2%, for Bokashi and Common Compost.

Fermentation gives a valuable product according to the results; hardly any energy losses take place. Herewith, the availability of the nutrients for plants hasn’t been taken in account. This point needs further research.

5 Conclusions

Fermentation has several advantages compared to composting according to this experiment:

- Nutrients were more retained by fermentation of the (waste) materials than by composting these materials.
- Fermentation didn't need extra processing during the process, while compost needed to be mixed regularly.
- Fermentation took place with a comparable temperature as the environment, while compost had an average temperature of 60.5°C.
- 3.2% of the starting material "disappeared" during fermentation, while 60.2% "disappeared" during composting.
- A large part of the organic matter degraded and disappeared (under influence of the strong aeration) with the traditional way of composting, while 97.6% of the organic matter was retained with the Bokashi method. The organic matter is good for the soil life and eventually for the crops.
- The Bokashi method had a considerably lower CO_2-foot print than Common Compost.
- The effects of Bokashi on plant growth after addition to the soil needs to be further investigated.

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Appendix I: Log book

Table 14: Log book of fermentation versus composting

Week	Day	Fermentation	Composting
0	friday 28th of September 2012	Setting up	Setting up
1	saturday 29th of September 2012	Bringing sand at the sides of the windrow	Once a day mixing
	sunday 30 th of September 2012		
	monday 1st of October 2012		Once a day mixing
	tuesday 2nd of October 2012		Once a day mixing
	wednesday 3rd of October 2012		Once a day mixing
	thursday 4th of October 2012		Once a day mixing
	friday 5th of October 2012	Measure temperature	Measure temperature – take 3 samples – once a day mixing
2	saturday 6th of October 2012		Once a day mixing
	sunday 7th of October 2012		
	monday 8th of October 2012		Once a day mixing
	tuesday 9th of October 2012		Once a day mixing
	wednesday 10th of October 2012		Once a day mixing
	thursday 11th of October 2012		
	friday 12th of October 2012	Measure temperature	Measure temperature – take 3 samples – once a day mixing
3	saturday 13th of October 2012		Once a day mixing
	sunday g 14th of October 2012		
	monday 15th of October 2012		Once a day mixing
	tuesday 16th of October 2012		Once a day mixing
	wednesday 17th of October 2012		
	thursday 18th of October 2012		Once a day mixing
	friday 19th of October 2012	Measure temperature – take 3 samples	Measure temperature – take 3 samples – once a day mixing
4	saturday 20th of October 2012		Once a day mixing
	sunday 21th of October 2012		
	monday 22nd of October 2012		Once a day mixing
	tuesday 23rd of October 2012		
	wednesday24 th of October 2012		Once a day mixing
	thursday25 th of October 2012		
	friday 26th of October 2012	Measure temperature	Measure temperature – take 3 samples – once a day mixing

5	saturday 27th of October 2012		
	sunday 28th of October 2012		
	monday 29th of October 2012		Once a day mixing
	tuesday 30th of October 2012		
	wednesday 31th of October 2012		Once a day mixing
	thursday 1st of November 2012		
	friday 2nd of November 2012	Measure temperature	Measure temperature – take 3 samples – once a day mixing
6	saturday 3rd of November 2012		
	sunday 4th of November 2012		
	monday 5th of November 2012		Once a day mixing
	tuesday 6th of November 2012		
	wednesday 7th of November 2012		Once a day mixing
	thursday 8th of November 2012		
	friday 9th of November 2012	Measure temperature – take 3 samples – determine end weight	Measure temperature – take 3 samples – determine end weight

Appendix II: CO_2-foot print calculation

CO_2-equivalents from the windrows

<u>**Conversion of carbon**</u>

Assumptions:
The additions to Bokashi don't have influence on the emission.
CH_4 and CO_2 are the only reaction products of the conversion of the available C.
2.4% Of the converted C has been converted to CH_4 (Boldrin et al., 2008, table 4).
Assumed is that 97.6% of the converted C has been converted into CO_2.

Based on unconverted C

Common Compost		
molar mass		
C	12.01	g/mol
O	16.00	g/mol
H	1.01	g/mol
Ratio of reaction		
Forming of CO_2	97.6%	
Forming of CH_4	2.4%	
Disappeared C		
Mass	630.90	kg
Mol	52.53	kmol
Formed CO_2		
Reaction	$C + O_2 \rightarrow CO_2$	
mol C	51.27	kmol
mol CO_2	51.27	kmol
mass of CO_2	**2256.41**	kg
Formed CH_4		
Reaction	$C + 2\ H_2O \rightarrow CH4 + O_2$	
mol C	1.26	kmol
mol CH_4	1.26	kmol
mass of CH_4	**20.22**	kg

Bokashi		
molar mass		
C	12.01	g/mol
O	16.00	g/mol
H	1.01	g/mol
Ratio of reaction		
Forming of CO_2	97.6%	
Forming of CH_4	2.4%	
Disappeared C		
mass	31.80	kg
mol	2.65	kmol
Formed CO_2		
reaction	$C + O_2 \rightarrow CO_2$	
mol C	2.58	kmol
mol CO_2	2.58	kmol
mass of CO_2	**113.73**	kg
Formed CH_4		
reaction	$C + 2\ H_2O \rightarrow CH_4 + O_2$	
mol C	0.06	kmol
mol CH_4	0.06	kmol
Mass of CH_4	**1.02**	kg

Conversion of nitrogen

Assumptions:
The additions to Bokashi don't have influence on the emission.
NO_2 is the only reaction product of the conversion of the available N.
1.15% From the available N in the starting material will be converted to NO_2 (Bondrin et al., 2009, table 4)

Ratio of reaction		**molar mass**		
Forming of NO_2 from N of road side cutting material	1.15%	N	14.01	g/mol
		O	16.00	g/mol

Common Compost

N of road side cutting material

Mass	48.20	kg
Mol	3.44	kmol

Formed CO_2

Reaction	$N + O_2 \text{-->} NO_2$	
mol C	0.04	kmol
mol NO_2	0.04	kmol
mass NO_2	**1.82**	kg

Bokashi

	C total (kg)	**% of disappeared C**	**Formed NO_2 (kg)**
Road side cutting material	1072.00		
Common Compost	441.10	58.9	1.82
Bokashi	1040.30	3.0	**0.09**

	C total	**% of disappeared C**	**Formed CO_2**	**Formed CH_4**	**Formed NO_2**	**CO_2-equ**
Road side cutting material	1072.00					
Common Compost	441.10	58.9	2256.41	20.22	1.82	**3304.51**
Bokashi	1040.30	3.0	113.73	1.02	0.09	**166.47**

CO_2-equivalents of the use of diesel

	Compost	Bokashi	Source
1. Transport			
Distance truck with road side cutting material (km)	30.80	30.80	*Distance Wijk bij Duurstede - Achterveld*
Distance truck with additions (km)	0.00	124.00	*Distance Agriton - Achterveld*
Use of diesel (l per km)	0.37	0.37	*Assumption from Dekker et al. (2010) page 12*
Total use of diesel (l)	11.40	57.28	
Energy use of diesel (MJ/l)	42.40	42.40	*Assumption from Dekker et al. (2010) page 26*
Total energy use for transport (MJ)	483.19	2428.50	

2. Transport at the Composting company

The road side cutting material was deposited in the same barn as where the windrows were made, through which the energy use of bringing the material at the place of the windrow is the same for both windrows.

	Compost	Bokashi	Source
3. Mixing			
Number of times mixed	26.00	2.00	*Experimental design and log book*
Use of diesel (l/hour)	10.00	10.00	*Assumption from Dekker et al. (2010) page 26*
Duration of one mixing (minutes)	3.75	3.75	*John van de Hengel*
Total duration of mixing (minutes)	97.50	7.50	
Total use of diesel (l)	16.25	1.25	
Energy use of diesel (MJ/l)	42.40	42.40	*Assumption from Dekker et al. (2010) page 26*
Total energy use of mixing (MJ)	689.00	53.00	
Total energy use (MJ)	1172.19	2481.50	
CO_2- equ (1 MJ = 0.074 kg CO_2-equ)	**86.74**	**183.63**	*Mombarg et al. (2003) page 3*