Planting tests with wastewater treatment sludge compost in China

The paper shows that the use of compost from sewage sludge leads to high yields in fruit farming.

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Abstract

In 2020 China is expected to have a sewage sludge generation of 60 million tons without having adequate treatment in place. As a pilot project 40 tons of sewage sludge were processed into compost in the mechanical biological treatment (MBT) plant Gaobeidian. The compost was refined by blending with mineral fertilizer and applied in field testing. The yield from cherry trees was found to be equal to conventional farming using mineral fertilizer. In parallel, the soil properties improved. The economic analysis shows that sludge compost can be produced for 61.5 €/t and refined fertilizer (N-P-K 5-5.5-3) for 122 €/t. The market analysis shows that this price is competitive, since farmers are spending between 305-527 €/t for mineral fertilizer (N-P-K 15-15-15).

Objective

The disposal of wastewater treatment sludge is increasingly becoming a challenge in PR China. In 2008 the government launched a program aiming on reducing emissions from untreated wastewater by means of establishing wastewater treatment plants. By September 2011 3078 wastewater treatment plants were in operation in China with a total capacity of 136 million m^3/day. 1600 plants were under construction. As a consequence a sludge generation of 60 million t per year is expected by the year 2020. An integrated, sustainable national concept for sludge management is still missing. Just one fourth of the facilities is linked to sludge treatment installations, only 60 plants have anaerobe sludge digestion in place. The sludge management is one of the urgent environmental challenges for China. Consequently in the 12th 5 years national master plan the government claimed the goal of establishing sludge treatment for 40 % of the sludge by 2015. In this context the utilization of sludge in agriculture is an interesting option, particularly because in many regions agricultural land suffers from loss of organic soil content and inadequate mineral fertilizing. Since Chinese law restricts the utilization of sewage sludge in agriculture an appropriate sludge treatment is required. The project aims on establishing a high end utilization of sewage sludge in agriculture by means of producing fertilizer. The application of any fertilizer products in Chinese agriculture requires a state controlled approval procedure, which in case of success results in a state issued product certificate. The German project developer AWN Umwelt has conducted this certification procedure during the period August 2014 till November 2015 for a fertilizer enriched sludge compost. The results are presented in this article.

Production of compost

Facility

Since 2006, AWN Umwelt operates as a joint venture partner a wastewater treatment (WWT) plant in Gaobeidian (Hebei province, PR China), a city located 80 km south of Beijing. Between 2008-2011 AWN Umwelt established a mechanical biological treatment (MBT) plant at the same location, which has been transferred to the municipality (Kölsch and Ginter, 2014). The plant consists of a recycling compound and a 4000 m^2 roofed biological treatment area (Figure 1). The biological treatment

Key facts:

- Composting of 40 t sewage sludge and 16.5 t peanut shells
- Planting tests with cherry, apple and wheat at 2 ha testing fields
- Test variation with parallel tests and reference plots (mineral fertilizer, not fertilized)
- Test duration 1.5 years
- Comprehensive marketing study for compost utilization in Rongcheng and Yantai

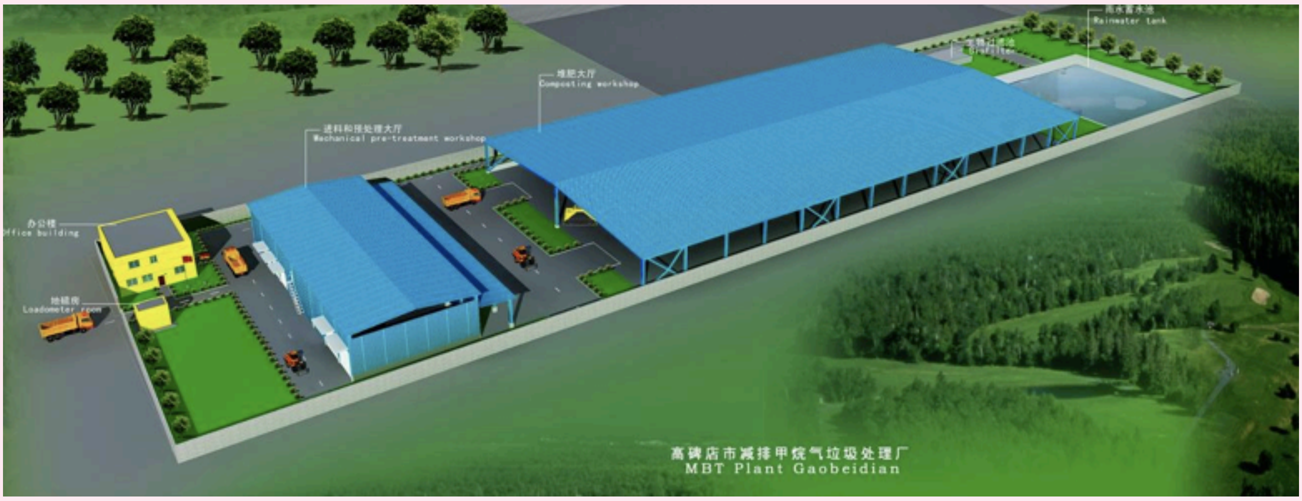

Figure 1. MBT plant Gaobeidian – schematic air view

Figure 2. Preparing of peanut shells

Figure 3. WWT sludge and mixing process

features an actively aerated composting ground (bottom ventilated) and a mobile windrow turner. The annual capacity is 40.000 tons. The compost has been produced in the MBT facility using sewage sludge from the WWT plant Gaobeidian.

Composting process

Approximately 40 tons of WWT sludge have been treated in the facility. Alternative structure materials had been investigated in trials. Finally, grinded peanut shells were selected, because this structure material was easier to process and has a better degradability and a higher water retaining capacity than the alternative (cheaper) corn

Figure 4. Composting windrows

cobs (Figure 2). The sewage sludge (approx. 83% moisture content) was mixed with 16.5 t of peanut shells (approx. 13% moisture content) and stocked onto windrows, together with 4.66 t inoculated bacteria material. Figure 3 illustrates the mixing process.

After setting up the windrow heaps the temperature inside the windrows (Figure 4) increased up to 65°C during the first 3 days. Despite the active aeration of the compost windrows, a lack of oxygen occurred temporarily in the core of the windrows, which was eliminated by frequent turning the windrows. In order to increase the porosity of the material, the height of the windrows had been decreased by dividing them during the following days. The total treatment time was 3 weeks.

The final product was analyzed in the laboratory at Yantai University. Table 1 shows the results in comparison to German (Düngemittelverordnung DÜMV) and Chinese legal standards (organic fertilizer directive NY 884/2012). The input concentrations of the WWT sludge are listed as a reference.

The Output Material shows relatively high values for nutrient content (N+P+K = 7,61%). Compared to the input content, heavy metal concentrations had decreased during the composting process, which is partly owed to dilution effects due to added (clean) structure material.

Production of biofertilizer

Market analysis in the targeted project region Rongcheng (Shandong province) had obtained that local farmers are not very interested in using pure sewage sludge compost as organic fertilizer due to its limited fertilizing effect. Therefore, the idea was developed increasing the market chances by refining the sewage sludge compost by means of adding mineral fertilizer. In August 2014 the compost from Gaobeidan was transported to Yantai for further treatment and finishing. Depending on the required nutritive compounds for the organic fertilizer, various mineral fertilizers had been added to the compost. Applied were following:

- diammonium phosphate DAP (N-P-K: **18-46**-0), $(NH_4)_2HPO_4$
- urea (N-P-K: **46**-0-0)
- potassium sulphate (N-P-K: 0-0-**50**), K_2SO_4

Agricultural planting tests

Background

The Chinese law requires on site field planting tests for fertilizer products. test have to be carried out in parallel and redundant testing plots on different soil types over a full harvesting period with the plants, the fertilizer shall be approved for. The procedure includes reference plots

Table 1. Laboratory analyses of input and output materials of the composting process compared to legal standards

Parameter	Unit	Sewage sludge	Compost	Chinese standards (NY 884/2012)	German standards (DÜMV)
pH	-		6.48	5.5-8.5	-
moisture content	%		21.9	< 30	-
loss on ignition	%		46.1	> 40	-
N	%		2.97	-	-
P	%		3.89	-	-
K	%		0.75	-	-
As	mg/kg	15.6	11.7	15	40
Cd	mg/kg	0.045	0.54	3	1.5
Cr	mg/kg	380	130	150	300
Pb	mg/kg	98	24	50	150
Hg	mg/kg	1.55	0.05	2	1
Zn	mg/kg	2378	270	-	5000

under conventional fertilizing and other plots without any use of fertilizer. The targeted project region (and anticipated future market) is well known for the production of fruit, particularly cherry and apple. The profitability of fruit production is much better than for grain, thus fruit farmers were identified as preferred potential customers. However, wheat farmers are also seen as potential customers, since the total fertilizer consumption is much higher than in fruit farming due to larger planting areas.

Test results - Cherry

As an example the test results for the cherry trees are presented in detail. The testing field was situated in Songjiazhuang (Laishan district, City of Yantai, Shandong province). The location lies 56 m above sea level, the annual rainfall is about 652 mm on average. The annual average temperature is

11.8 °C. Because of its intensive sunshine (2698 h/a or 5224 MJ/m²) and long vegetation periods of about 210 days, the city of Yantai is famous for its fruit growing, especially apples, cherries, pears and grapes.

The testing field with a total area of 9.15 Mu (6100 m²) had been divided in 2 sections for testing purposes. On the northern block (3.3 Mu or 2200 m²) 195 cherry trees had been planted, on the southern block (5.85 Mu or 3900 m²) 350 cherry trees. Prior to the testing campaign the fields were cultivated in a conventional way. The soil shows a pH value between 5.2-5.4 and an organic content of 0,64-0,94 %.

Different fertilizer applications were carried out on the fields: Table 2 summarizes the applied nutrition amounts and concentrations.

- I refined AWN sludge compost (N-P-K: 4.8-5.5-2.1 or 5.3-5.8-2.4)
- II standard mineral fertilizer for cherries (N-P-K: 15-15-15)
- III reference field, unfertilized

Table 2 illustrates that the load per tree is 2.5 kg (conventional) and respectively 2.5 kg or 5 kg (AWN Mix), what results in lower nutrient supply by the AWN mix. In conventional fertilizing the nutrient provision is 375 g N-P-K per tree, whereas for the refined compost fertilizer 240-275-105 g or 133-145-60 g N-P-K was applied. The planting test started in August 2014 and ended June 2015. Figure 5 shows the bag packing and field application of the refined sludge compost.

Table 2. Planting tests cherry - application of fertilizer (per tree)

		N	P	K		N	P	K
	dose [kg/tree]	[%]	[%]	[%]		[g]	[g]	[g]
Cherry north								
I: AWN-Mix	5	4,8	5,5	2,1		240	275	105
II: Cherry fertilizer	2.5	15	15	15		375	375	375
Cherry south								
I: AWN-Mix	2.5	5.3	5.8	2.4		133	145	60
II: Cherry fertilizer	2.5	15	15	15		375	375	375

Figure 3. Flow chart of the treatment & reuse system (source: ESF; 2014)

Table 3. Harvesting yield from cherry testing fields

Fertilizer	Load kg/tree	N-P-K g/tree	Yield north kg/tree	Yield south kg/tree
I: AWN-Mix	5	240-275-105	28.1	
	2.5	133-145-60		32.9
II: Mineral	2.5	375-375-375	29.3	
	2.5	375-375-375		31.7
III: without	0	0-0-0	22.9	
	0	0-0-0		25.4

Table 4. Soil properties

Fertilizer	pH -	Organic content %	Alkali-hydrolysable N mg/kg	Available P mg/kg	Available K mg/kg
Start	5.4	0.94	76.5	52.8	177.5
I: AWN-Mix	5.7	1.13	94.5	59.9	183.8
II: Mineral	5.4	0.88	86.1	55.7	181.3
III: without	5.8	0.63	61.8	26.5	82.9

At the beginning of the flowering phase there were no visible differences between variants I and II, in the full flowering phase only slightly notable differences. A remarkable difference was noted in comparison to the non-fertilized trees. Also during the fruit phase only small differences were observed between the fertilized trees, in contrast to the non-fertilized trees which carried less and smaller amount of fruits

The yield is the most relevant criteria for evaluation of the fertilizing effect. Table 3 shows the results for the cherry planting test. The yield results prove that the southern testing area generally showed higher yields than the northern area. In both areas the differences between mineral fertilizer and refined sludge compost were very small (- 4.1 % and + 3.8 %), while the non-fertilized reference fields obtained significantly smaller yields (- 22.7 % and - 29.5 % compared to AWN mix).

Before the test and during the harvesting time the soil properties were analysed in the laboratory. The results are presented in Table 4.The results illustrate that the application of refined compost sludge increases the organic content in the soil as well as the availability of nutrients. It indicates that the compost improve the soil structure and acidification and enhance the nutrient holding capacity reducing the loss and leaking of nutrients. However, the investigation period of 1 year is too short to reliably assess the long term effects in soil improvement.

I (AWN-Mix) **II (Mineral)** **III (without)**

Figure 6. Wheat before harvesting

Table 5. Cost for compost production

		Unit cost	Units	Total cost	Cost/ton compost	
		[€]		[€/year]	[€/t]	[RNB/t]
Input						
WWT sludge	100 t/d			(253'472)	(8.86)	(64)
Structure						
Peanut shells	25 t/d	97	9'125	887'153		
Corn cobs	10 t/d	43	3'650	157'153		
Corn straw	15 t/d	25	5'475	136'875		
Total structure				**1'181'181**	**41.28**	**297**
Operation						
Personnel				54'000	1.89	14
Maintenance				92'754	3.24	23
Consumption				97'600	3.41	25
Depreciation				334'483	11.69	84
Total operation				**578'837**	**20.23**	**146**
Grand total costs (for 28.613 t output)				**1'760'018**	**61.51**	**443**

Other tests

Similar planting tests have been carried out for apple trees and wheat. The total testing area for all tests comprised of approximately 2 ha. The field results for all agriculture products are comparable. The wheat showed even larger differences in the plant appearance due to the improved water retaining capacity of the soil. Generally, the effect of improved water supply for the crops was easier to observe with grain than with fruit trees (Figure 6).

Technical application

Economic analysis

The costs for the production of sludge compost have been calculated in a feasibility study for a facility in Rongcheng (Shandong province). The facility is designed for a capacity of 150 t/day (100 t/day sludge + 50 t/day structure material). Total investment is estimated to 3.3 million € excluding land acquisition and engineering. The costs for compost production in this facility are estimated to 61.5 €/t (443 RNB) not considering revenues from sludge disposal. The cost breakdown is shown in Table 5.

The cost estimation indicates that the largest portion of production costs refer to the acquisition of structure material (2/3), in particular for the peanut shells, which have currently a market price of 100 €/ton. Thus, the costs for the structure material include are still a large opportunity for savings. The processing costs (O+M) represent a small portion of the total costs (14 %), only. It might be reasonable to process cheaper structure materials, even if that would require longer treatment periods or more comprehensive pre processing. Further, the calculation does not consider revenues from the sludge disposal, which are expected to 50-80 RNB/ton.

The costs of refining the sludge compost into a fertilizer, which is comparable to the one used in the planting tests, are summarized in Table 6. The total costs for the refined sludge compost (N-P-K 5-5,5-3) are 122,1 €/t. The mix contains 87 % of sludge compost and 13 % mineral fertilizer. The cost breakdown shows that the sludge contributes less than 50 % to the final costs, which makes almost the same share as DAP and potassium sulphate have.

Compost marketing

A comprehensive market analysis has been elaborated during the feasibility study for the facility. As in many places worldwide the acceptance of the organic fertilizer by the farmers is limited and needs strong and effective awareness raising activities. Comparing simply the fertilizing effect of the refined sludge compost, the farmers would have to apply about three times the amount of fertilizer than exclusively using mineral fertilizer, Thus, the total competing costs would be 2637 RNB and 366 € per batch, respectively. Considering additional revenues from sludge disposal (gate fees), the total costs could be reduced to 2469 RNB and 343 € per batch. The market analysis revealed that fruit farmers currently pay between 2200-3800 RNB/t for mineral fertilizer (equivalent to 305-527 €/t). Thus, the AWN-Mix is situated rather in the lower price range of the fertilizer market. Positive long term effects and improvements in nutrient availability as observed in the planting tests have not even been considered, yet. From this aspect the marketing prospects are promising, however farmers acceptance and innovation capacity are still seen as a major constraint and a significant project risk.

Table 6. Cost for compost refinement

	Input		N	P	K	C	Costs Input	Costs Mix	
	[kg]	[%]	[kg]	[kg]	[kg]	[kg]	[RNB/t]		[€/t]
Sludge compost	1000	87	29.7	38.9	7.5	461	443	386	53.6
Urea	40	3	18.4	0	0	0	2712	95	13.2
DAP	52	5	9.4	23.9	0	0	3950	179	24.9
Potassium	54	5	0	0	27	0	4650	219	30.4
	1146		57.5	62.8	34.,5	461		**879**	**122.1**
	N-P-K-C [%]		**5.0**	**5.5**	**3.0**	**40.2**			

Way forward

AWN Umwelt is currently developing the business model for the planned facility and is moving forward towards implementation.

Conclusion

Composting of wastewater treatment sludge can be a reasonable and environmental sound solution for the treatment and disposal of sludge. Refining the compost with mineral fertilizer can improve the marketing opportunities of the compost. The main cost factor of the compost production is the structure material. Many of the attractive materials are already otherwise utilized in agriculture and they have a (high) market price. However, regarding the marketing of compost the price is just one aspect. The major constraint results from the low acceptance and the lack of innovation by the farmers. Setting up a composting facility requires careful assessment of the framework conditions in order to make the project viable.

References

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