TA-K_02 Organic residue management options in a Chinese peri-urban region with intensive animal husbandry and high nutrient loads

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1. Objectives

The "N and P costs" of food production in China almost doubled between 1980 and 2005 [1]. In the peri-urban region of Beijing with very high livestock densities, industrialized land-less animal operations are facing a large number of small-scale crop farmers. Shunyi District in particular has a very intensive animal production [2] with very high livestock densities amounting to 10.6 livestock units (LU) ha^{-1} arable land in 2007 ([3], calculated from [4]; 1 LU approx. 500 kg). High amounts of organic residues are improperly disposed of, causing severe environmental pollution. At the same time, the National Development and Reform Commission (NDRC) of China is seeking to vastly expand energy production from biogas. The aims of the research were to:

- estimate N and P inputs, outputs and balances of major cropping systems in a typical peri-urban area of China at a farmer's field scale and a cropping system scale
- compare different manure treatment systems under nutrient, soil fertility and economic aspects
- elaborate recommendations for improving the current soil nutrient status.

2. Methodology

A large pig farm in the Shunyi District of Beijing with attached biogas and composting plants served as pilot farm for investigations 2008-2011. On this farm pig production is carried out on a dual scale. Large-(industrial-)scale: The "Centralized pig plant" has an annual stock of 12,000 breeding boars and 20,000 fattening pigs yr^{-1}, with less than 10 ha cropland area. Small-(household-)scale: Meat production is also carried out in so-called "Ecological Feeding Gardens" as part of the same farm, consisting of 160 households with a total cropland area of 25.33 ha and producing a total of about 25,000 fattening pigs yr^{-1}. Each of the small-scale farm households sells on average 140 fattening pigs yr^{-1} and has approx. 0.2 ha of cropland. [5]. The so-called *gan qing fen* system [6] is used as manure system on both the large and the small-scale farms, with pigs housed on solid floors and the solids and liquids in manure separated manually. For this study, three major investigations were carried out on the farm and in the wider surrounding area.

- A soil screening investigation covering 26 plots under the five major cropping systems of the area (winter wheat-summer maize double-crop rotation, Chinese cabbage (Brassica rapa, ssp. pekinensis)-maize (glutinous corn, with a higher amylopectin content) double-crop rotation, open-field vegetables, orchards and poplar plantations) was carried out from 2009 to 2011 [7]. In the Shunyi and Huairou Districts of Beijing, 19 and 7 farmers' fields were selected, respectively. These included plots belonging to the "Centralized pig plant", to the "Ecological Feeding Gardens" as well as to crop farms in the area surrounding the large farm of the study. In March 2009, 2010 and 2011, as well as at the end of each growing season after summer crop harvest in September/October 2009, 2010 and 2011, soil samples were taken with an auger in 0-200 cm, in six depth increments.
- In another area of Shunyi District, soil surface N balances (68 households, two-year period, 2008/2009 - 2009/2010 [3]) and P balances (65 households, one year period, 2008/2009 [8]) were calculated for the cropland. Three specific villages with cereals (maize and wheat double-crop rotation), orchards and open-field vegetables as the predominant cropping systems were selected, and smallholder households with an arable land area ranging from 0.2 to 1.5 ha per farm were monitored during interviews performed twice over the two-year period. The N and P balances were calculated separately on an annual and per hectare basis as well as on a farmer's field and a cropping system scale [3; 8].
- In a life cycle assessment (LCA), the required cropland area for a sound disposal of biogas effluent from animal wastes was calculated based on crop demand [9]. Annual input and out-

put of different types of pigs of the “Centralized pig plant” was calculated on the basis of LU. The then “current” system (status quo) regarding manure treatment, with 75% of the solid fraction (pig feces) used in a biogas plant and 25% in a composting plant, without, and with land application of biogas effluent (Option 1) was compared to two alternative management systems: In Option 2 all the feces were used in an improved composting plant, while in Option 3 100% of the feces were fed to the biogas plant, in both cases with land application of biogas effluent.

3. Results and discussion

3.1 Soil nutrient status

Typical soil types in Shunyi and Huairou Districts of Beijing are classified as Eutric Cambisols (WRB) with relictic hydromorphic characteristics and a silt loam texture [7]. The soils were heavily over-fertilized. Residual mineral nitrogen (N_{min}: NO_3^--N + NH_4^+-N) contents in 0-200 cm soil profiles sampled at five different dates during 2009-2011 ranged from 412 ± 281 to 1299 ± 287 kg N ha^{-1}, showing no significant differences between plots of the five cropping systems and seasons [7]. N_{min} contents in topsoils (0-20 cm) were equally very high, corresponding to 10-20% of the amounts in the 0-200 cm profiles [7].

The mean available P content (Olsen P) on all the 26 plots monitored was 73 ± 55 mg kg^{-1} in 0-20 cm topsoils, with half of the 26 investigated plots showing “very high” (>50 mg kg^{-1} available P contents in topsoils (Fig. 1) [7]; classification according to [10]. On the 19 investigated plots in Shunyi District, mean contents of available P had increased almost tenfold from 1981 to 2009, from 7.3 to 67 mg kg^{-1}, respectively, and this increase was very likely mainly due to high farmyard manure (FYM) inputs [7]. On average, the critical limit for increased risk of P loss of 30 mg kg^{-1} Olsen P in soil (cited in [11]) was reached or exceeded in all five cropping systems in the study [7].

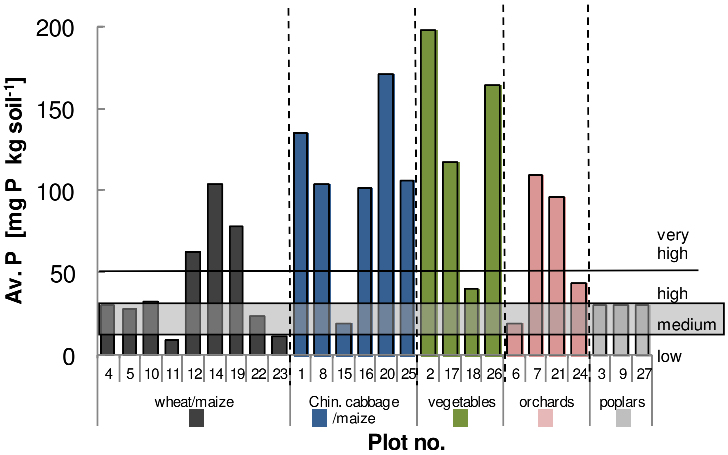

Figure 1: Available P contents in topsoils (0-20 cm) on 26 plots of the five major cropping systems in Shunyi and Huairou Districts of Beijing in March 2009 (classified according to [10]. Plot no. designates the number of each individual plot (from [7], modified).

3.2 Soil surface N and P balances

Extremely high amounts of FYM, ranging from 6-293 t DM ha^{-1} yr^{-1}, mean 45 ± 69 t DM ha^{-1} yr^{-1} were applied to most of the observed field plots receiving FYM (n=19) in 2008, resulting in the investigated soils being vastly over-supplied with nutrients from organic and inorganic sources [7].

The mean annual soil surface P balance surpluses calculated for the three cropping systems (Table 1) amounted to 83 kg P ha^{-1} yr^{-1} for cereal crops, 130 kg P ha^{-1} yr^{-1} for orchards and 492 kg P ha^{-1} yr^{-1} for the vegetable production system, the latter significantly higher (P<0.05) than the other two [8]. Based on these values, upscaling to the level of the whole of Shunyi District, the total annual surplus P amounts on cropland reached 4,300 tons (Table 1; Hou, 2009, unpublished). For the whole of Beijing Municipality, an annual P surplus of 15,689 t ha^{-1} was calculated for the year 2011 [2].

The soil surface N balances calculated for the cropping systems in the three specific villages of Shunyi District resulted in annual balance surpluses of 531, 519 and 1,548 kg N ha^{-1} yr^{-1} for the cereal crops, orchards and vegetable production systems, respectively [3]. Upscaling by the respective cropping areas of the whole of the District (see Table 1), the annual surplus N amounts reached 11,294 t N yr^{-1} for cereal, 634 t N yr^{-1} for orchard and 7,501 t N yr^{-1} for open field vegetable systems, totaling 19,429 t N yr^{-1} (Hou, 2009, unpublished). These high P and N surpluses pose a serious threat to the environment.

Fertilization in all three cropping systems, and to vegetables in particular, exceeded crop demand by far (Fig. 2). There was a great variation amongst the different farms in mineral fertilizer N and animal manure N input for the three cropping systems [3]. Farmyard manure requires higher labour for transport and handling and was therefore only applied to open-field vegetables and orchards from which higher economic benefit is achieved in this peri-urban area with high off-farm labour and income opportunities. However, the nutritive value of FYM was not properly taken into account since farmers also applied additional mineral N and P fertilizer (Fig. 2, Table 1).

Table 1: Soil surface P balance calculation for three major cropping systems based on a survey of 65 households in Shunyi District (2008/2009). Mean values and range (in brackets) (from [8]). Upscaled figures for Shunyi District: Hou (2009, unpublished). Sown area in Shunyi District from [4].

P balance items	**Cropping systems**		
	Cereals (n=21) kg P ha^{-1} yr^{-1}	**Orchards (n=23) kg P ha^{-1} yr^{-1}**	**Vegetables (n=21) kg P ha^{-1} yr^{-1}**
Inputs			
Mineral fertilizer	111.3 (28.5 - 271.1)	89.8 (0 - 350.4)	59.6 (0 – 98.2)
FYM	3.9 (0 - 35.6)	59.1 (0 – 304.5)	617.7 (177.1–1298.6)
Incorporated residues	13.1	2.6	0
Atmospheric P deposition	0.25	0.25	0.25
Total	128.6 (44.0 - 286.9)	151.8 (2.8 - 479.8)	677.6 (226.4–1362.7)
Outputs			
Crop product	45.9 (29.1 - 59.4)	22.3 (7.4 – 39.6)	185.7 (66.0 – 351.9)
P Balance			
Surplus/deficit	82.7 (-1.4 – 294.0)	129.5 (-10.7 – 464.8)	491.8 (111.3–1198.8)
Upscaling to Shunyi District			
Sown area Shunyi District (year 2009) [ha]	21262	1221	4847
Total annual P surplus Shunyi District [t yr^{-1}]	1758	158	2383

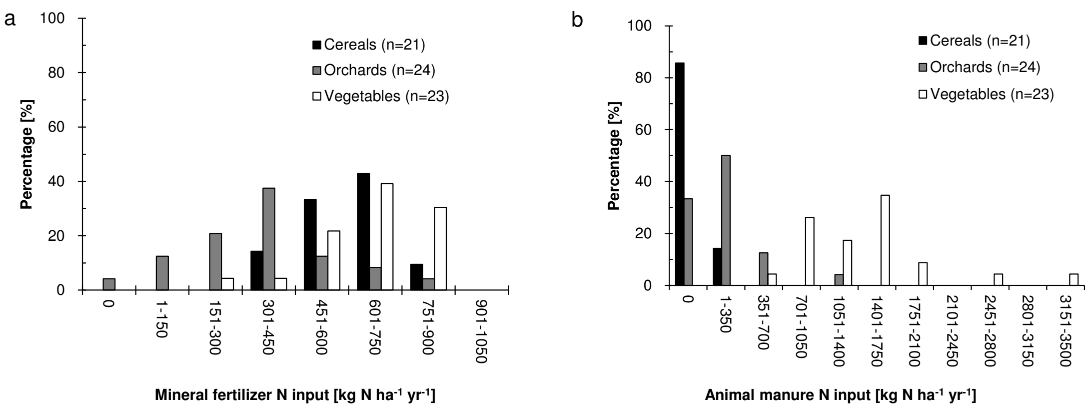

Figure 2: Frequency distribution (in percent) of number of surveyed farms based on different classifications of mineral fertilizer N input (a), animal manure N input (b) (mean value of the investigated two years) for the three cropping systems (after [3], modified).

3.3 Life Cycle Assessment (LCA)

In the year 2011, the centralized pig plant had a stock of 1,037 LU and produced 1,956 LU annually [9]. Only the P flows are presented here. The annual P input and output of the pig plant, the biogas plant and the composting plant for the "Current" manure management system without, and with (Option 1) land application of biogas effluent, as well as for Options 2 and 3 in 2011 is given in Table 2. Input and output flows of the pig plant, the biogas plant and the composting plant between the “Current” manure system and Option 1 were equal (Table 2), the difference consisting in the use of the biogas plant output. Under the “Current” manure management system, a large part of the liquid biogas plant effluent flowed into a nearby lagoon (with no insulation-liner) and was frequently discharged into a semi-dry riverbed, with very little proper land application [9]. Phosphorus losses during composting were assumed to be zero. The improved compost under Option 2 can be sold and thus offers the possibility of exporting surplus nutrients to other farms with nutrient demand. Thus in the LCA the cropland area required considered only biogas effluent.

Table 2: Annual P input and output of the centralized pig plant, biogas plant and composting plant of the Pilot Pig Farm (based on Life Cycle Inventory (LCI, year 2011) under the current manure management system without and with land application of effluent, as well as for two alternative options (adapted from [9 and] [12]). (Unit: tons P yr^{-1}).

Pig stables		Biogas plant		Composting plant	
Input	**Output**	**Input**	**Output**	**Input**	**Output**
Current manure management system without and with (=Option 1) land application of effluent (unit: t P yr^{-1})					
Feed: 23.64 t	Pigs to market: 1956 LU	Pig faeces: 9.89 t	Liquid effluent: 13.32 t	Pig faeces: 3.30 t	Compost: 3.99 t
	Dead pigs: 49 LU	Poultry manure: 1.16 t	Biogas sludge: 0.68 t	Biogas sludge: 0.68 t	
	Pig faeces: 13.19 t	Wastewater: 2.95 t		Sawdust: 0.02 t	
	Wastewater: 2.95 t				
Sum: 23.64 t		**14.0 t**	**14.0 t**	**4.00 t**	**3.99 t**
Option 2: All pig feces to improved composting plant (unit: t P yr^{-1}) with land application of effluent					
Feed: 23.64 t	Pigs to market: 1956 LU	Pig faeces: 0 t	Liquid effluent: 2.95 t	Pig faeces: 13.19 t	Compost: 19.57 t
	Dead pigs: 49 LU	Poultry manure: 0 t	Biogas sludge: 0 t	Corn stalks: 0.61 t	
	Pig faeces: 13.19 t	Wastewater: 2.95 t		T-Superphos. 5.76 t	
	Wastewater: 2.95 t				
Sum: 23.64 t		**2.95 t**	**2.95 t**	**19.56 t**	**19.57 t**
Option 3: All pig feces to biogas plant (unit: t P yr^{-1}) with land application of effluent					
Feed: 23.64 t	Pigs to market: 1956 LU	Pig faeces: 13.19 t	Liquid effluent: 16.14 t	Pig faeces: 0 t	Compost: 0 t
	Dead pigs: 49 LU	Poultry manure: 0 t	Biogas sludge: 0 t	Biogas sludge: 0 t	
	Pig faeces: 13.19 t	Wastewater: 2.95 t		Sawdust: 0 t	
	Wastewater: 2.95 t				
Sum: 23.64 t		**16.14 t**	**16.14 t**	**0.0 t**	**0.0 t**

[a] T-Superphos. = Triple-superphosphate

Biogas effluent should be applied onto the surrounding cropland area but strictly based on crop nutrient demand. A typical winter wheat-summer maize double-crop rotation in Shunyi District has an approximate nutrient demand per ha and year of 338 kg N, 56 kg P, 263 kg K and 50 kg Mg [7; 9] in a balanced system (optimum plant-available nutrient contents in soil). The resulting cropland area demand for a sustainable land application of biogas effluent for the “Current” system with land application (Option 1) would then be 238 ha yr^{-1} (with 14.3 L effluent m^{-2}, limited by P demand of crops), for Option 2 it would be 139 ha yr^{-1} (24.4 L m^{-2}, limited by N demand), while for Option 3, the demand would be 288 ha yr^{-1} (11.8 L effluent m^{-2}, limited by P demand) [9; 12]. However, as long as the cropland is over-supplied with nutrients (see 3.1), the land area necessary for a sustainable utilization of the wastewater nutrients would be 476 ha yr^{-1} at the “Current” manure management (Option 1), 168 ha yr^{-1} for Option 2, and 576 ha yr^{-1} for Option 3 (nutrient recommendations based on one half of the annual crop requirement during years 1-5) (Schuchardt, Luo, Heimann, 2012; unpublished). However, the centralized pig plant only cultivated about 10 ha. If all solids were used for composting (Option 2), it would be possible to transfer 87% of P, 29% of total N, 34% of K and 75% of magnesium (Mg) to compost for export out of the farm and region [9]. Outlying areas of the North China Plain have low soil organic matter (SOM), total N and low to medium available P and K contents. Transport of processed manure would lead to a better and faster build-up of SOM compared to returning crop straw alone in this sub-humid region.

4. Conclusion and outlook

- Differences in farming practices within and among cropping systems should be taken into account when calculating nutrient balances and designing strategies of integrated nutrient management on a regional scale [3].
- As an immediate measure, part of the excessive FYM should be processed (e.g., composted) and surpluses nutrients be transported out of the peri-urban region via marketable products [7].
- Governmental subsidies to compost production are in place in several Chinese provinces [7]. It is assumed that the market price for quality fertilizer products is likely to increase. Good composting procedures may become economically attractive without subsidies in the future.
- The question of whether to promote manure processing or whether to focus on energy production from biogas and subsequent nutrient removal from effluent via technological means can only be solved on a case by case basis in China.
- There is an urgent need for on-farm research on the use of biogas effluent in Chinese cropping systems, considering nutrient as well as emission (NH_3, N_2O, N leaching) aspects.
- In the medium term, a reduction of livestock densities, by moving part of the intensive, landless livestock operations to surrounding provinces closer to the cropland demand, is essential.

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