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Institute of Geoecology

Agricultural Use of Manure and Biogas Effluent from Industrial-Scale Animal Operations – The Chinese Experience

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Beijing, June 19, 2013

GEFÖRDERT VOM
Bundesministerium für Bildung und Forschung
Projektträger Jülich
Forschungszentrum Jülich
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Traditional Chinese agriculture

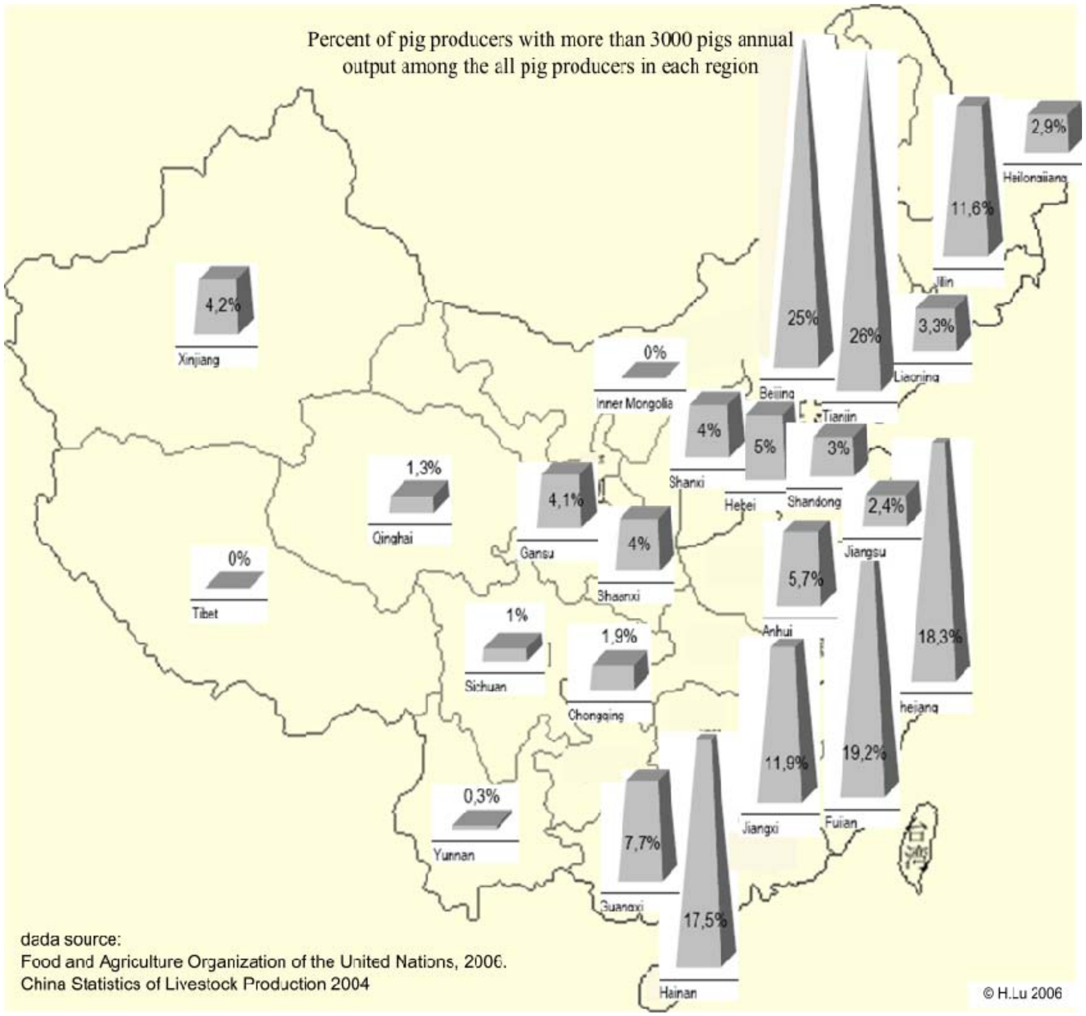
- China carried out sustainable agriculture for thousands of years (e.g. King, 1911)
- Multicropping, intercropping, complex rotations, maximum nutrient recycling
- Preserved soil structure, organic matter and nutrients, controlled weeds and pests
- Without large anthropogenic imports, water pollution, or diminished productive capacity
- Sustained relatively high yields and dense human populations
- Extremely high labour requirements caused social hardships for farmers

Changes in the past 25 years

- China's land use and agricultural production have been undergoing rapid changes
- Limited land base; loss of arable land
- Over-supply with nutrients from mineral and organic sources
- Very high mineral fertilizer application rates (esp. N)
- Straw frequently burnt on the field
- Systems transformed from a nutrient-limited to a nutrient-saturated state
- Progressive de-coupling of plant production and animal husbandry
- High nitrogen (N) deposition rates (60-70 kg N ha^{-1} yr^{-1} in Beijing region)


- In the peri-urban areas of Beijing livestock densities reach 10-15 livestock units (LU) ha^{-1} (1 LU = 500 kg)
- Pollution from livestock raising, wastewater is often dumped into rivers or canals
- Soil pollution (HM, antibiotics)
- Landless livestock farms – logistical problems due to surrounding small-scale farmers

Distribution of intensive pig production in China



China slaughters nearly half (48.9% in 2009) of the world's pigs

About 30% of animals in China are being raised in large-scale operations (2011)

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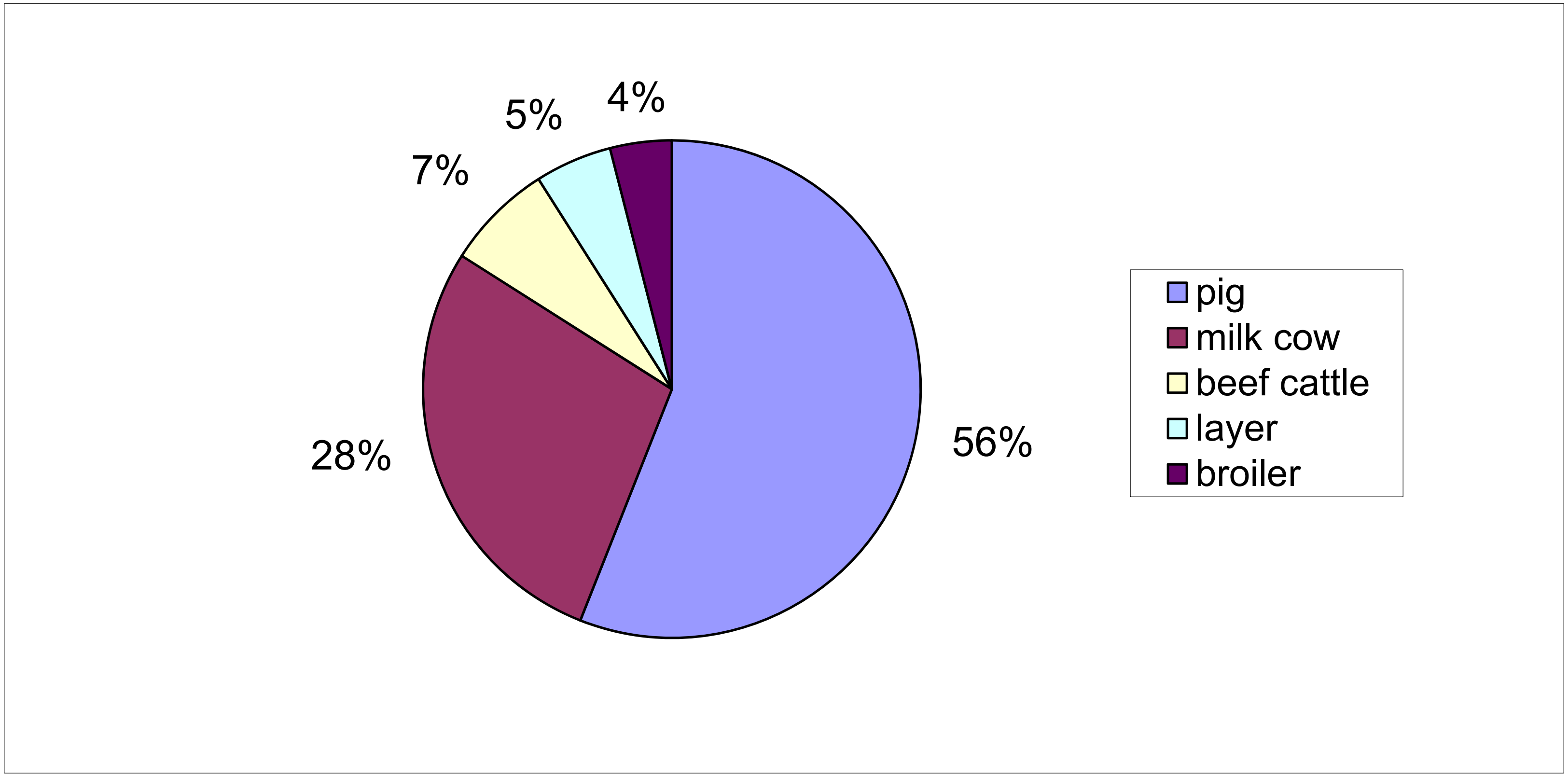
Lu, H.Y., 2006

IfaS Institut für angewandtes Stoffstrommanagement

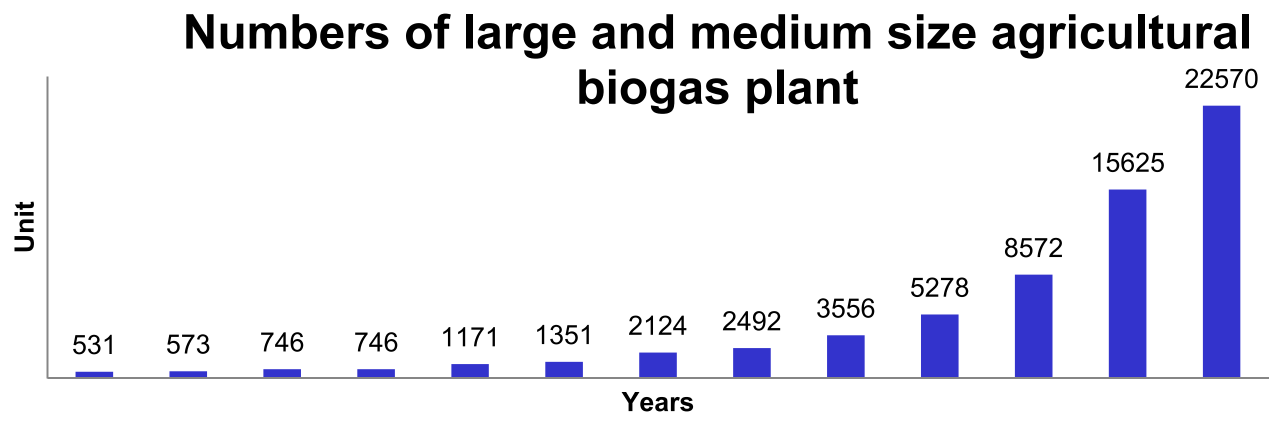
Biogas production potentials from animal wastes of large and medium sized livestock and poultry farms (2007)



MOA statistics; China Animal Industry Yearbook, 2009

Sino-Danish Renewable Energy Development Programme Report (2011)

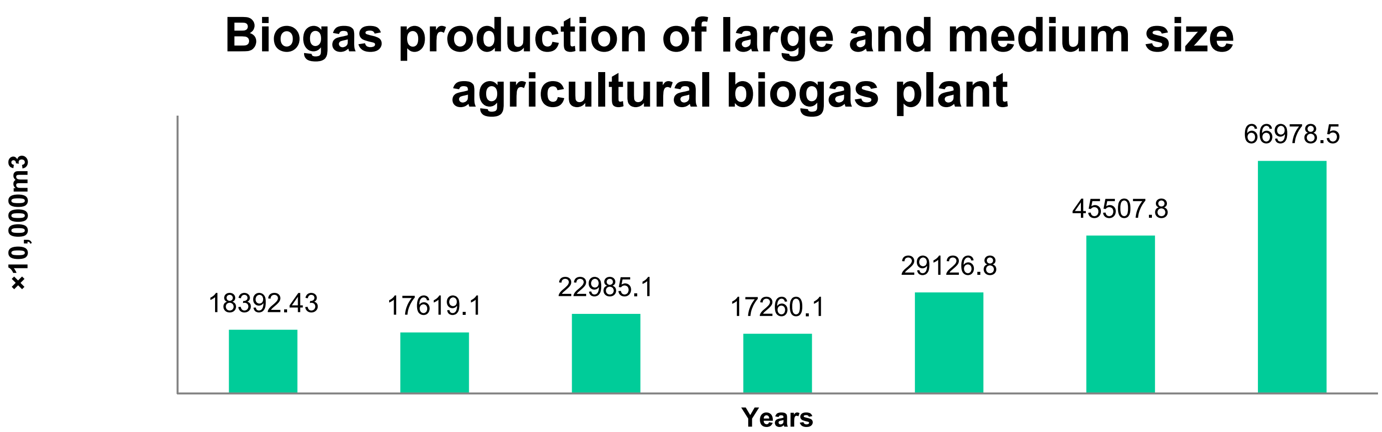
Status quo of agricultural biogas plant of China



Low temperature

Poor supervision

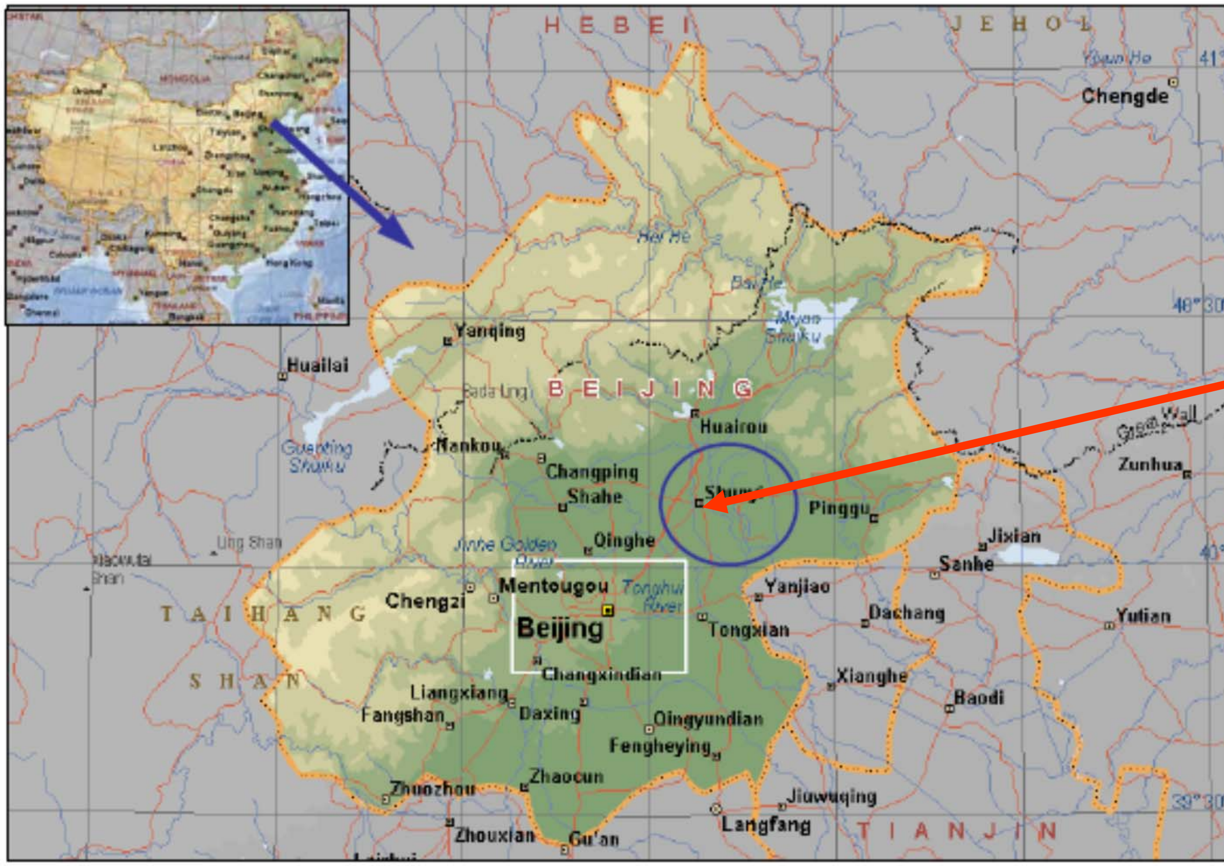
No monitoring of technology and performance efficiency



Dong, Guo, Clemens et al. (2010)

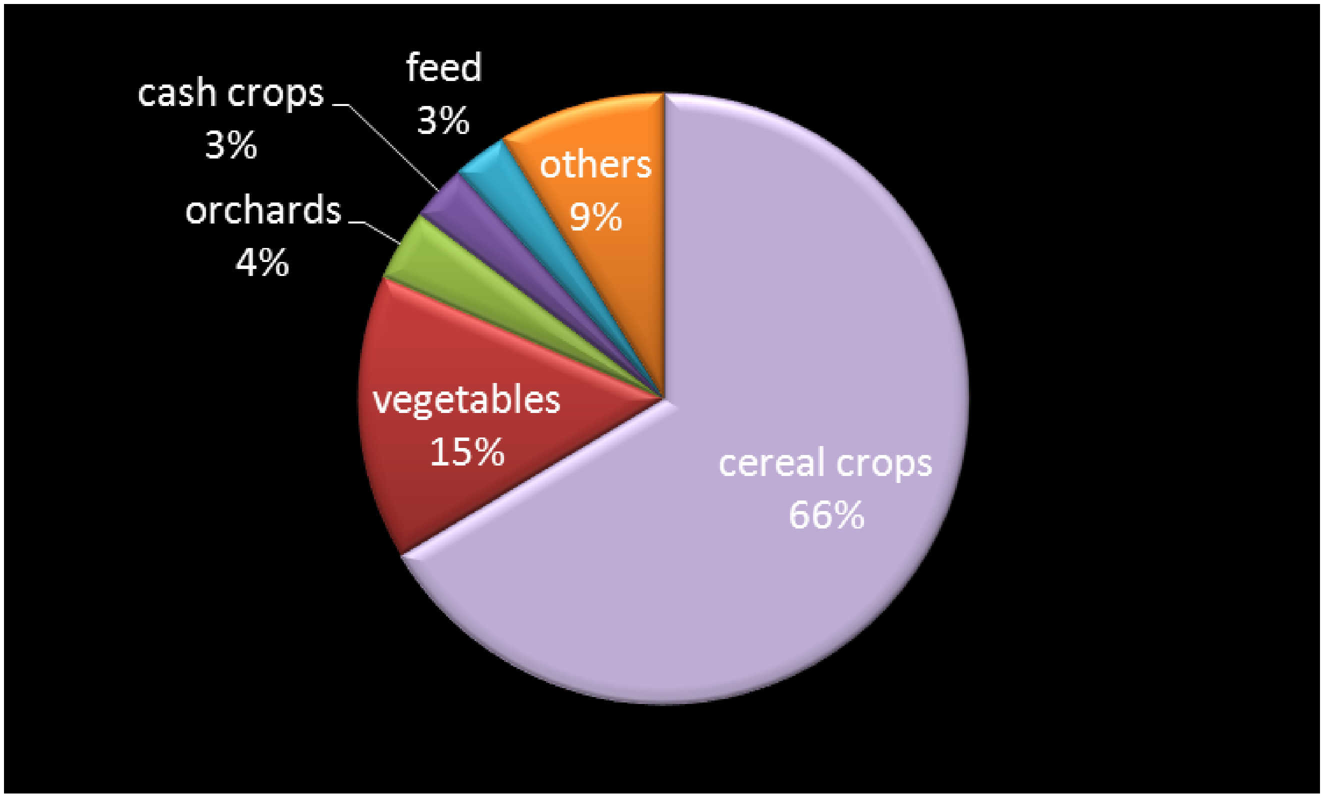
Research region

Shunyi District in the Beijing Municipality



Pilot pig production farm

Materials and Methods
Shunyi District cropping structure



(2007)

Pilot Pig Farm in Shunyi District

Centralized pig plant:
Pig breeding (~ 12,000 pigs yr^{-1})
Pig fattening (~ 20,000 pigs yr^{-1})
~ 9.5 ha cropland area

"Ecological Feeding Gardens":
160 households:
~ 140 fattening pigs yr^{-1} each
~ 0.2–0.33 ha cropland each
~ 25,000 fattening pigs yr^{-1}
~ 25.3 ha cropland area

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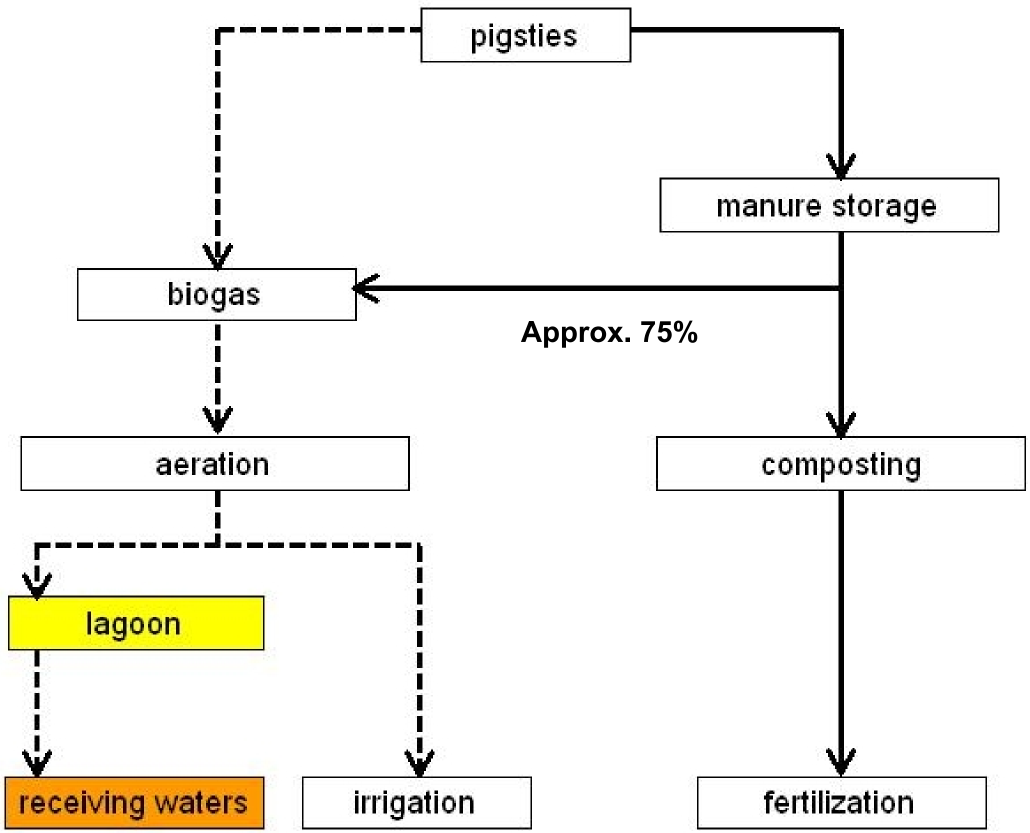
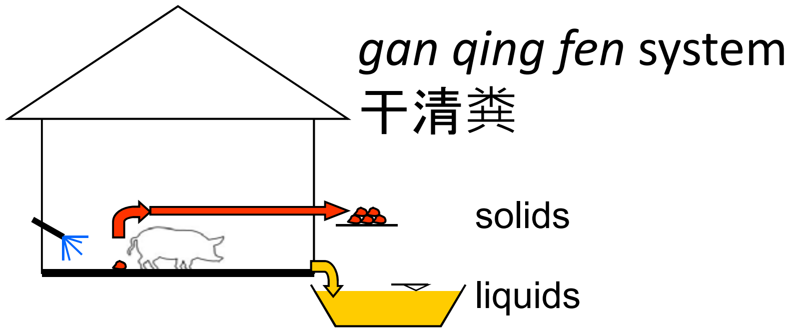
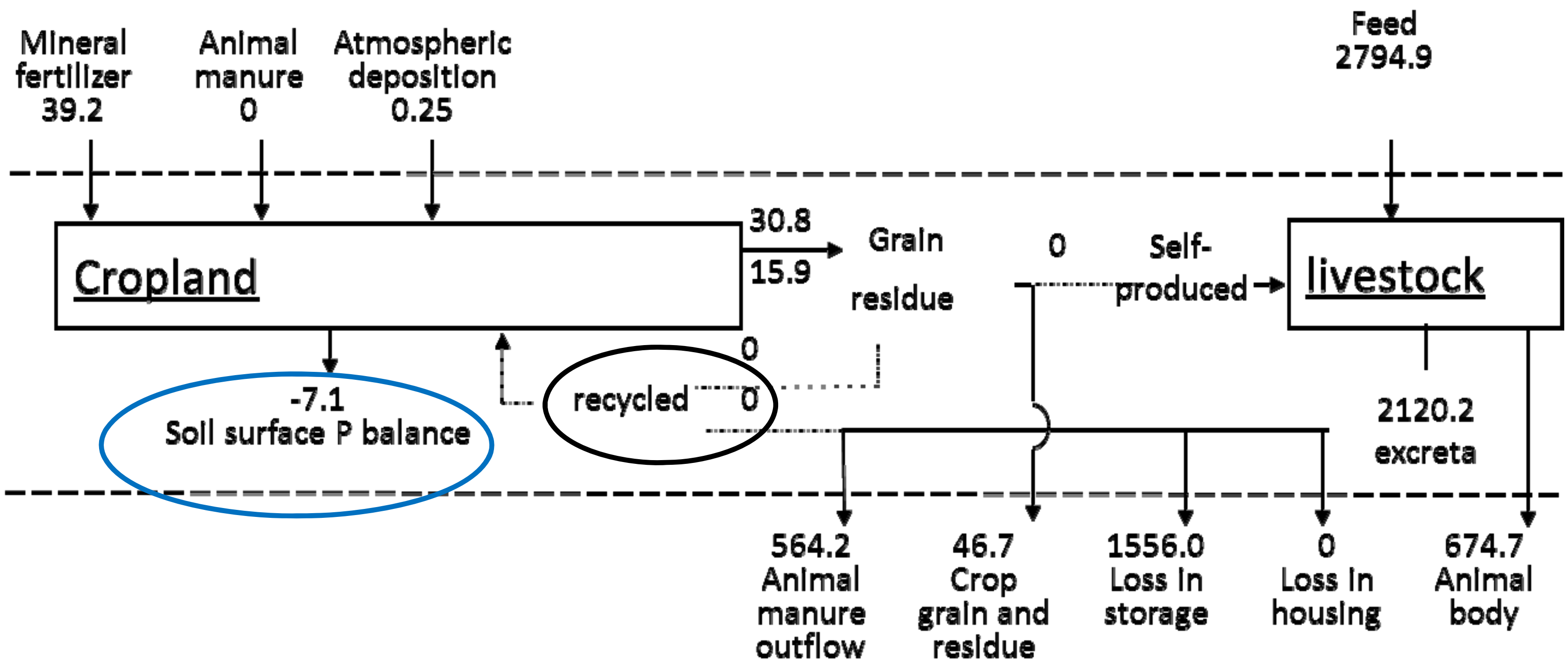
Current matter (nutrient and pollutant) fluxes on Pilot Farm





Phosphorus flow in centralized plant of Pilot Pig Farm (year 2009)



[kg P ha^{-1} yr^{-1}]

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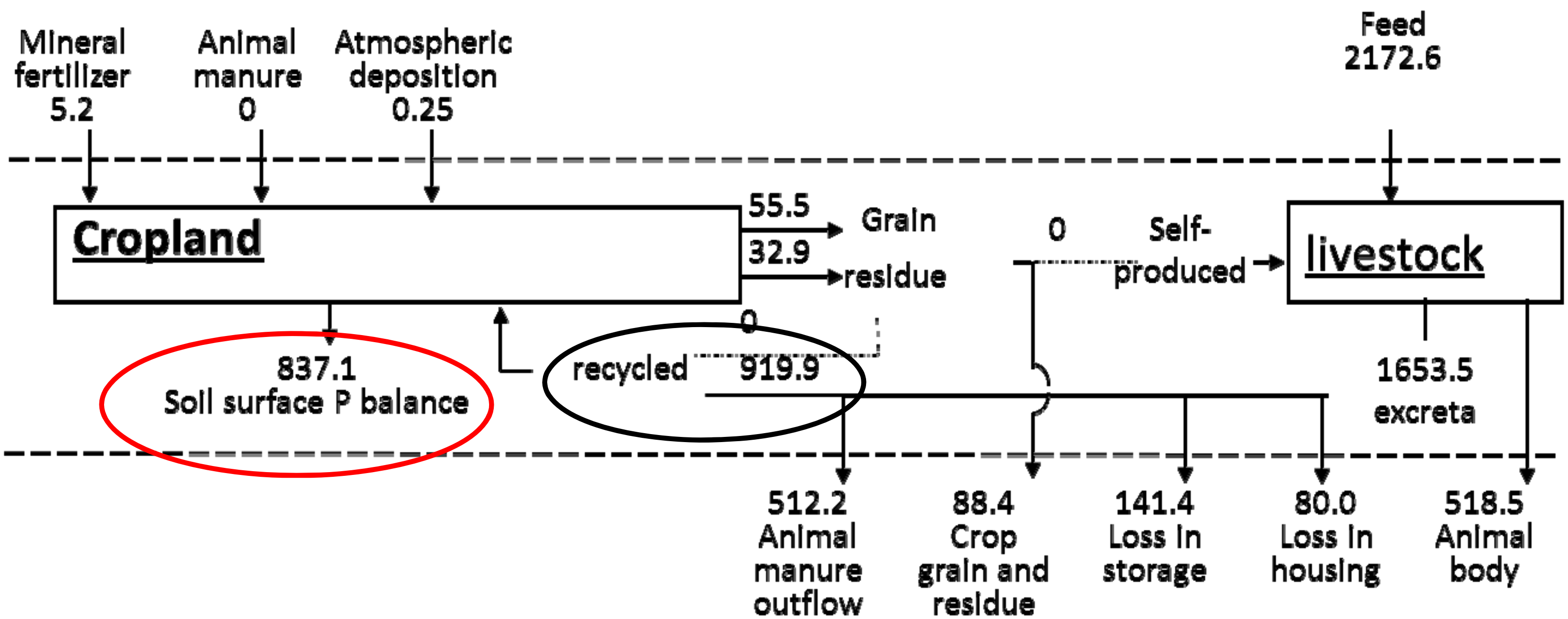
Hou et al., Journal of Anhui Agricultural Sciences, 2011

Phosphorus flow in “Ecological Feeding Gardens” of Pilot Pig Farm (year 2009)



[kg P ha^{-1} yr^{-1}]

Hou et al., Journal of Anhui Agricultural Sciences, 2011

Composting

Pig faeces

Corn stalks

• Progress in composting process (mainly through application of straw):
- NH_3-N losses reduced from 40% to 8%.
- GHG emissions (CO_2 eq kg^{-1}) reduced from 440 g kg^{-1} to 47 g kg^{-1}.

• Compost is a profitable market product
• Compost can reduce the nutrient load in an area if exported to regions with soil nutrient and SOM deficiency
• Compost builds-up stable SOM, better than straw alone, esp. under sub-humid conditions

• Compost, adequately prepared, can meet **revised Chinese Quality Standard NY525-2011:** **Moisture content ≤30%** (total dry matter (DM) content ≥70%); (oDM) content ≥45%.

Guo et al., 2012; Jiang et al., 2011; 2013; Ren et al., 2010

Shunyi and Huairou Districts cropping systems and hot spots

Heimann, 2013; Ostermann, 2013

Heimann, 2013; Ostermann, 2013

Soil nutrient and pollutant status

- Soil sampling campaign in Shunyi and Huairou Districts over 3 years (2009-2011) (6 cropping seasons)
- **Soil types:**
  - Eutric Cambisols (冲积物潮土) (冲积物褐潮土)
  on alluvial deposits, with relictic hydromorphic characteristics
- **5 cropping systems** (double or multiple cropping):
  - winter wheat-summer maize
  - spring maize-Chinese cabbage,
  - vegetables
  - orchards
  - poplar plantations
- **26 selected plots** in sampled 0-200 cm in 6 depth increments
- **On hot spots:** Soil corer sampling (0-400 cm)
- **Soil chemical analyses:**
  - soil pH, $CaCO_3$ contents
  - soil organic matter, DOC and DON
  - total and mineral/plant available macronutrients (N, P, K, S)
  - heavy metals (Cu, Zn, Cr, As)
  - antibiotics

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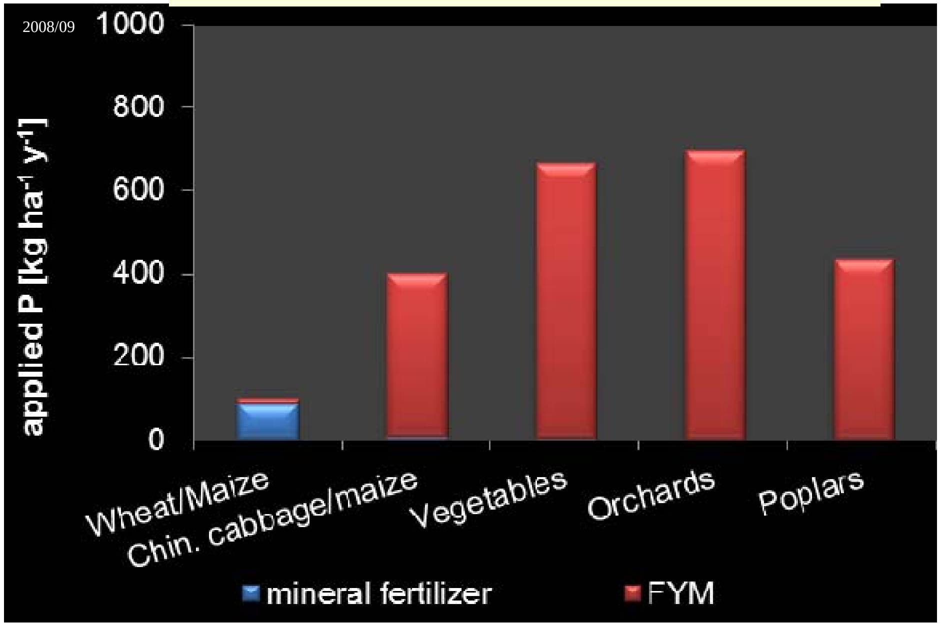
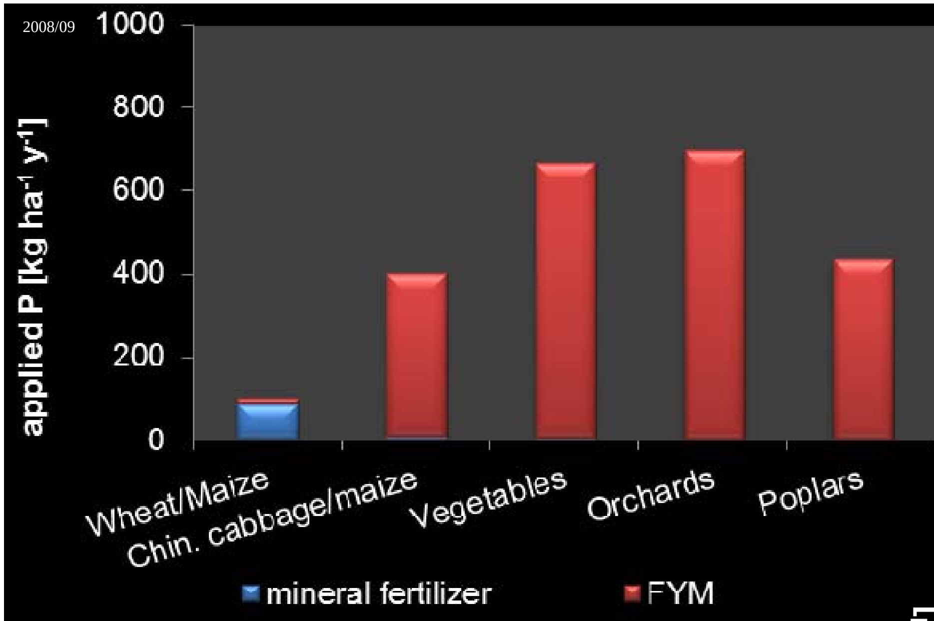
Heimann, 2013; Ostermann, 2013

Very high P inputs



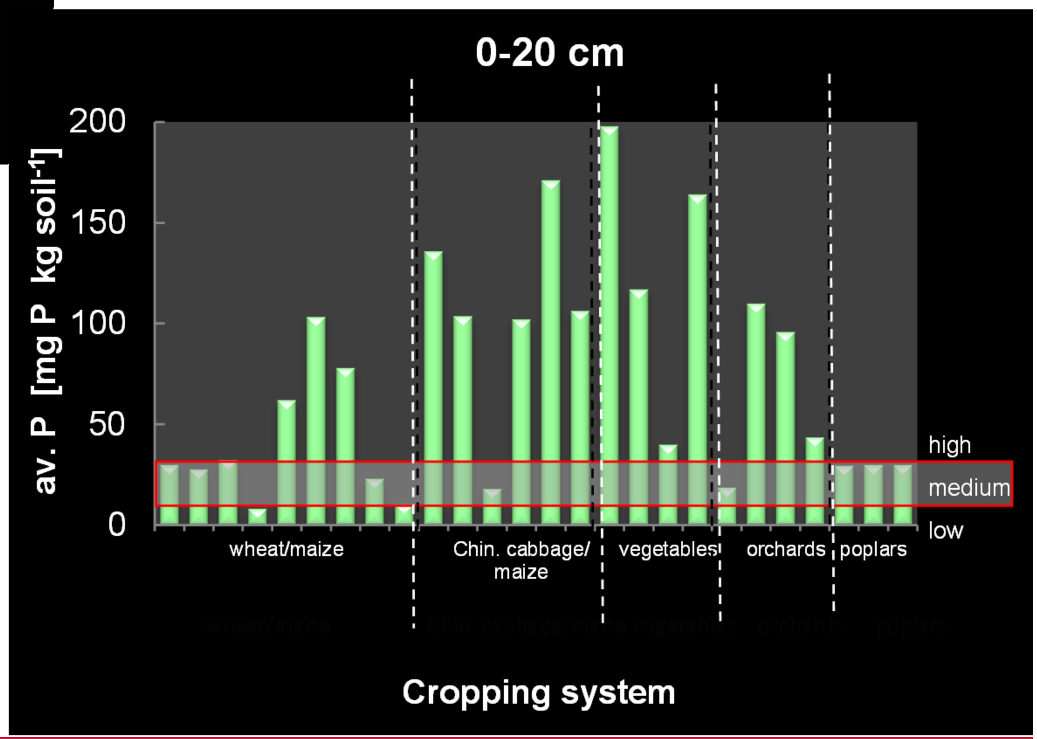
Heimann, 2013

Very high P inputs



Available P [mg kg^{-1}]	1981	2009
Wheat/maize	2-13	37 ± 31
Chin. Cabbage/maize	n.a.	115 ± 18
Vegetables	n.a.	118 ± 79
Orchards	n.a.	75 ± 49
Poplars	n.a.	30

Very high av. P contents in soils



Heimann, 2013

Plant available P contents in topsoils (0-20 cm)

24 agricultural fields in Shunyi and Huairou Districts of Beijing with different fertilization background

Olsen P: 74 mg kg^{-1} (mean value)

Demand of crops in China: 10-20 mg kg^{-1} (Li et al., 2011)

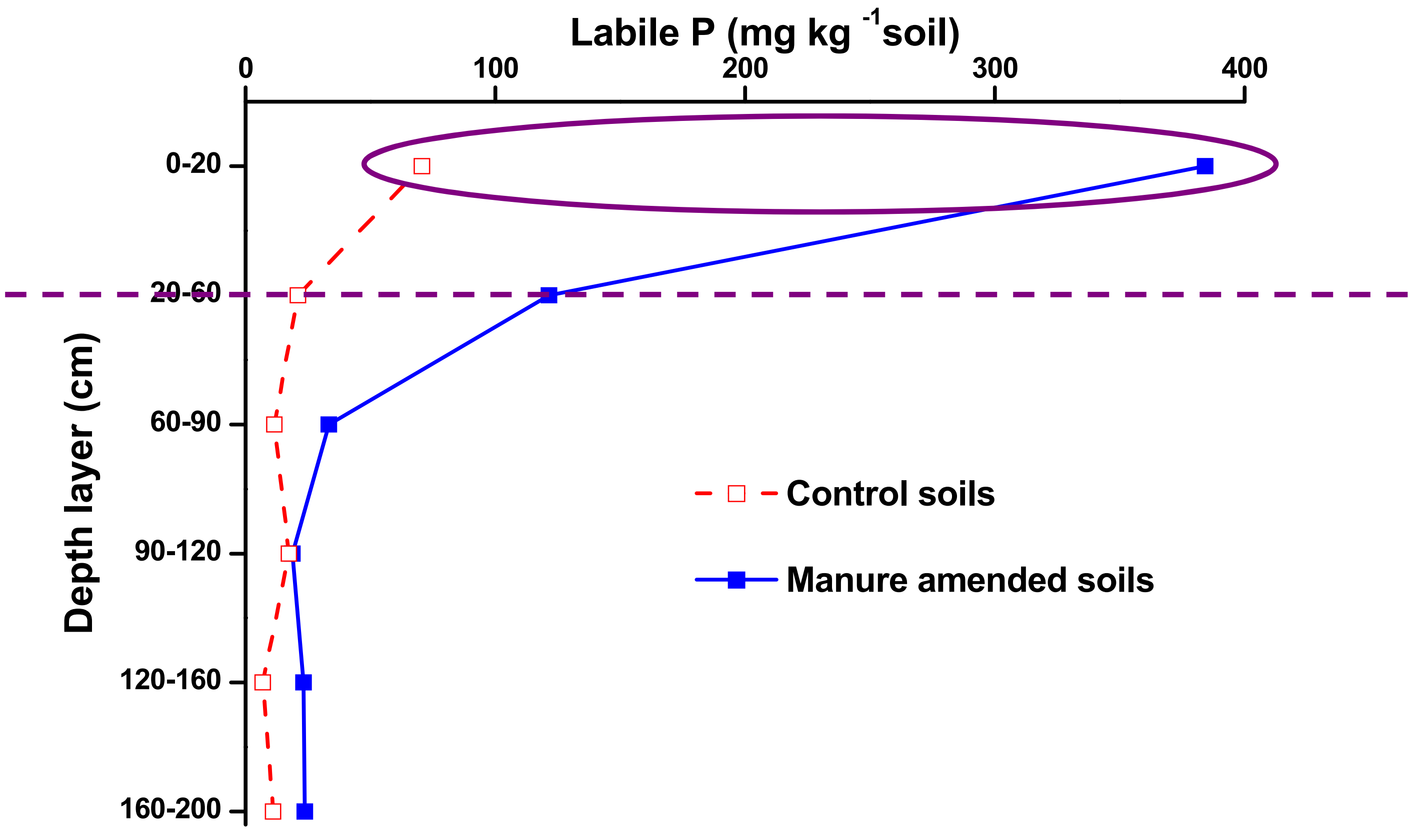
11% of unmanured sites

60% of manured sites

Exceeding threshold value of 60 mg kg^{-1} (Brookes et al., 1995)

Xue et al., J Soils Sediments, 2013

Soil phosphorus fractionation



Distribution of labile P through the whole soil profile (0-200 cm)

Xue et al., J Soils Sediments, 2013

Soil surface P balance for Shunyi District (2008/2009)

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	89.8	59.6
FYM	**3.9**	**59.1**	**617.7**
Incorporated residues	13.1	2.6	0
Atmospheric P deposition	0.25	0.25	0.25
Total	128.6	151.8	677.6
Outputs			
Crop product	45.9	22.3	185.7
P Balance			
Surplus/deficit	**82.7**	**129.5**	**491.8**

Hou et al., Journal of Anhui Agricultural Sciences, 2011

P surplus for Shunyi District (2008/2009)

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			
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Outputs			
Crop product	45.9	22.3	185.7
P Balance			
Surplus/deficit	**82.7**	**129.5**	**491.8**
Upscaling Shunyi District			
Sown area (year 2009) [ha]	**21261.8**	**1220.9**	**4846.9**
Total annual P surplus Shunyi District [t yr^{-1}]	**1758.4**	**158.1**	**2383.7**

Hou et al., Journal of Anhui Agricultural Sciences, 2011

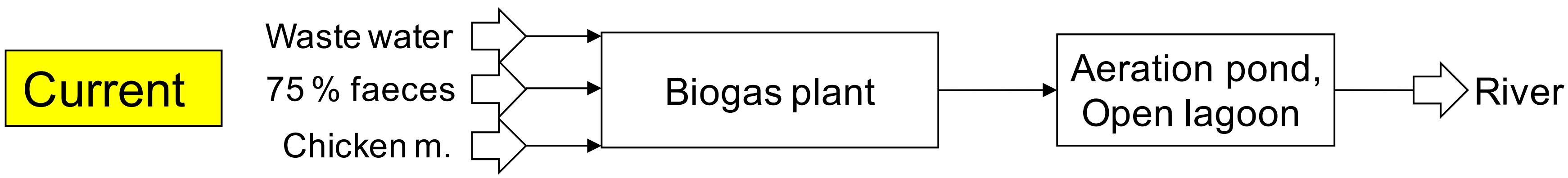
Life Cycle Assessment (LCA)

Integration of results from different subprojects:

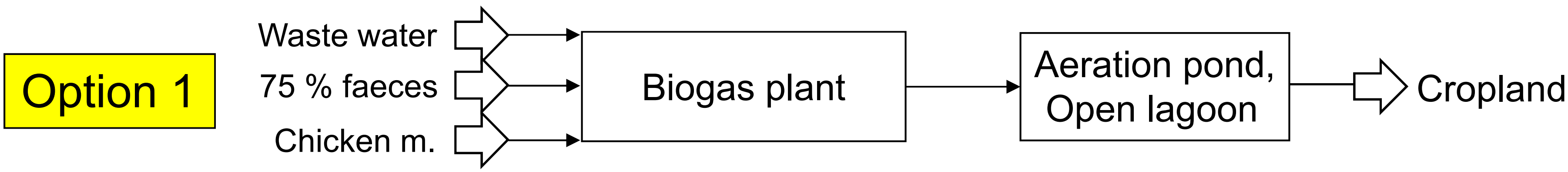
- Nutrient flows (N, P, K)
- Gaseous nitrogen emissions (NH_3, N_2O)
- Greenhouse gas emissions (CH_4, N_2O)
- Energy flows

Luo et al., 2013

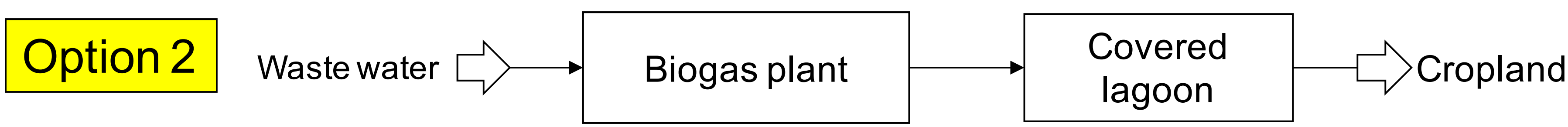
LCA - Waste water management options



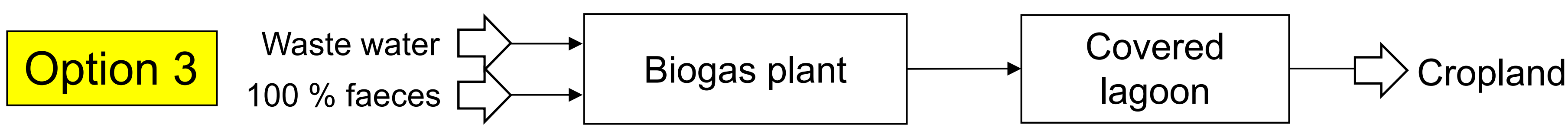
To utilize the waste water nutrients as much as possible…



To utilize all nutrients and maximize export …

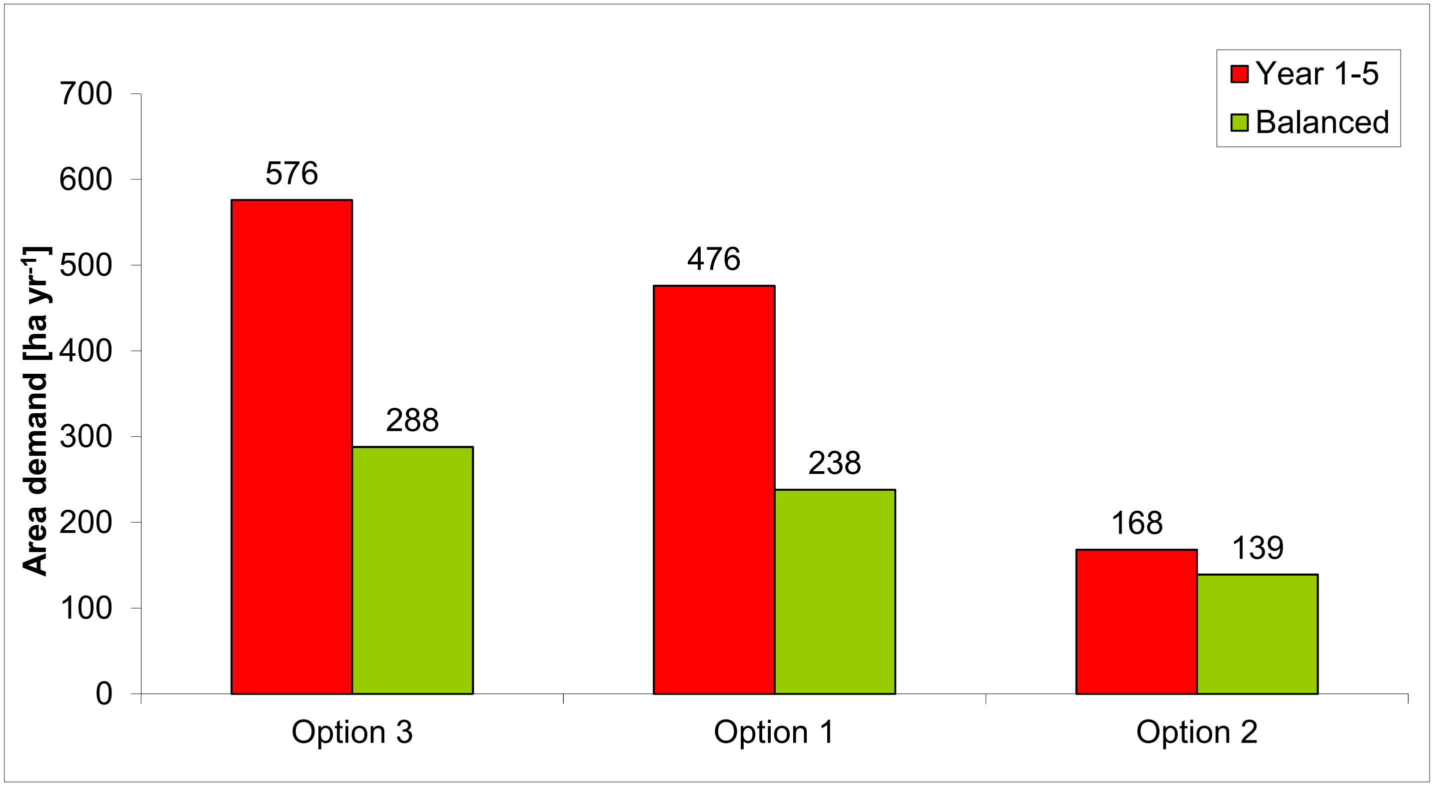


To maximize biogas production without additional nutrients input…



Luo et al., 2013

LCA
Cropland demand [ha yr^{-1}] for the biogas effluent
Current over-fertilized and "balanced" cropland



With: 100% faeces to biogas 75% faeces 0% faeces
Limited by: P demand P demand N demand

Year 1 to 5:
over-fertilized system (current situation):
Nutrient application reduced by 50%
(1/2 of crop demand)

„Balanced“ system:
Nutrient application according to crop demand

If all faeces used for composting (Option 2), it is possible to export **23% of N_{tot}** (currently 4%), **87% of P, 24% of K** and **75% of Mg** by compost

Luo et al., 2013

LCA
Eutrophication Potential (EP) of waste management system
Current and Options 1-3

EP	Current	Option 1	Option 2	Option 3
	75% faeces into biogas plant	75% faeces into biogas plant Effluent land application	0% faeces into biogas plant Effluent land application	100% faeces into biogas plant Effluent land application
t PO_4-Eq	91.7	56.0	34.1	68.0

Improvement of EP compared to Current system due to:

- Enhanced nitrogen and phosphorus recovery
- Utilization of effluent instead of discharge into lagoon and riverbed

Luo et al., 2013

LCA
Conclusions

1. If all faeces used for composting (Option 2), it is possible to export **23% of N_{tot}** (currently 4 %), **87% of P, 24% of K** and **75% of Mg** by compost
2. As long as the cropland is over-fertilized **476 ha** are necessary for sustainable utilization of the waste water nutrients at the current manure management (Option 1)
3. In a balanced fertilizer system with modified manure management (Option 2) “only” **139 ha** cropland are necessary
4. Currently, the centralized pig plant only owns about **10 ha!**
5. The use of biogas in a CHP plant is more profitable and sustainable than for external use for cooking and heating.

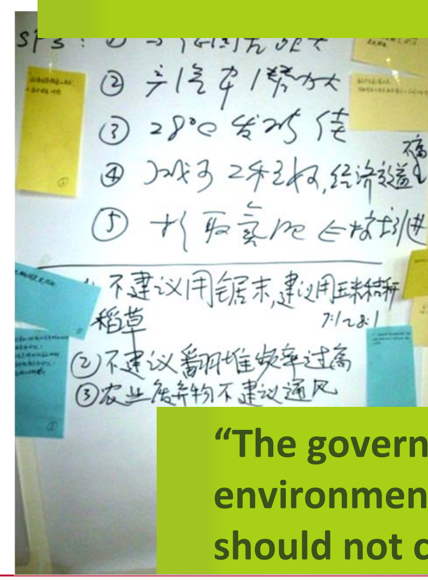
Luo et al., 2013

Environmental economics

- Quantitative farm household survey (n=205) in a peri-urban village of Beijing (500 households; 1500 inhabitants; 320 ha farmland; pilot pig farm)

- Data collection on the pilot farm and biogas plant ("face-to-face"-interviews)

"Scientific results are interesting, but difficult to change, sometimes not realisable."



"The government should reduce environmental pollution and it should not cost me any money!"

- Participatory workshop March 31, 2011

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Lu et al, 2010; 2011; Ma, 2010

Recommendations for remediation

Phosphorus, Potassium:

- Establish optimum plant available P (Olsen) (10-30 mg kg^{-1}, according to crops) and available K (50-100 mg kg^{-1}) contents in soil
- Reduce excessive manure application to cash crops
- P and K derived from FYM is sufficient in most cases
- If FYM available, then apply some to cereal crops (basal fertilization)
- Beginning acidification in topsoils → Reduce mobility of dissolved P in runoff or leachate by adding amendments (such as $CaCO_3$)
- Reduce P content in manure by decreasing P content in feed

Nitrogen:

- Reduce mineral and organic N fertilization
- Nutrients applied (mineral and organic) should not exceed crop removal; N_{min} method

Heavy metals and antibiotics:

- Input reduction required. No routine use of HM and antibiotics as feed additives!
- Risk assessment indispensable
- Loading capacity of soil is limited

Recommendations on technologies

Export of nutrients vs. improvement of biogas efficiency?

- Export of nutrients in form of transportable and marketable fertilizers
  → e.g. by composting the solid phase of animal excreta
- If energy production as main aim, then high carbon (COD) content in liquid phase preferred
  → but only C is reduced; more nutrients (NPK) remain in liquid phase or in digestate
- High P and N recovery potential through struvite precipitation and ammonia stripping
- Drying and pelletizing of digestate another option to transport nutrients
- Decisions about technologies/recommendations must be region- and case-specific
- Recommendations should be based on holistic view – animal production, crop farming, energy production, etc.

Recommendations for peri-urban areas in northern China:

- Reduce very high nutrient surpluses and pollutants caused by animal husbandry
- Reduce livestock density of 11 LU per ha in Shunyi District to 3-4
- Nutrients from organic sources should be exported out of the peri-urban region in form of organic fertilizers, to outlying areas in the NCP lower in SOM and with less livestock
- *gan qing fen* system is to be favoured
- Storage basins should be sealed

Policy options

Subsidy policy for anaerobic digestion (biogas plants):

- In China, subsidies paid in relation to biogas plant investment rather than performance → construction of numerous low-performing biogas plants.
- Centralized electricity grid; low compensation
- Progress may be made with a new feed-in or subsidize law oriented towards performance
- New subsidy policy necessary similar to the German Renewable Energy Law (EEG)

Subsidy policy for compost production:

- Governmental subsidies to compost production in place in several Chinese provinces.
- For Beijing (2011): Subsidized price: 600 Yuan per ton;
  Market price without subsidies: 120-350 Yuan per ton.
- Composting being controversially discussed in China
- Government should support economic manure treatment sites if it has the political will to improve the current situation
- Market price for quality fertilizer products likely to increase → good composting procedures or high-end biogas plants may become economically attractive without subsidies in future.

Policy recommendations

- No specialization between crop farming and animal production, integrated systems in agriculture would be preferable.
- "Re-coupling" of animal and plant production needed
- Chinese government should create an awareness and ask for an organic fertilizer concept from the animal operation or the biogas plant before giving it environmental permission.

Polluter Pays Principle:

- The producer of waste/wastewater would be responsible for its treatment and utilization
- → Equilibrium; as well as more balanced distribution of livestock densities
- → Also conflict of interests, since the Polluter Pays Principle enforced by the government, which at the same time wants to secure animal production
- Feasible for intensive animal farms, not for small household-scale operations


Recycling of organic residues from
agricultural and municipal origin in China
www.organicresidues.org
BMBF FKZ: 0330847A-H
Sept. 01, 2008 – March 31, 2012
MOST grant no. 2009DFA32710
Oct. 01, 2009 – Sept. 30, 2011
DAAD: 50117102
2010-2011