



Livestock housing and manure storage need to be improved in China

Bai, Zhaohai; Li, Xiaoxin; Lu, Jie; Wang, Xuan; Velthof, Gerard L.; Chadwick, David; Luo, Jiafa; Ledgard, Stewart; Wu, Zhiguo; Jin, Shuqin; Oenema, Oene; Ma, Lin; Hu, Chunsheng

Environmental Science and Technology

DOI:

[10.1021/acs.est.7b02672](https://doi.org/10.1021/acs.est.7b02672)

Published: 01/01/2017

Peer reviewed version

[Cyswllt i'r cyhoeddiad / Link to publication](#)

Dyfyniad o'r fersiwn a gyhoeddwyd / Citation for published version (APA):

Bai, Z., Li, X., Lu, J., Wang, X., Velthof, G. L., Chadwick, D., Luo, J., Ledgard, S., Wu, Z., Jin, S., Oenema, O., Ma, L., & Hu, C. (2017). Livestock housing and manure storage need to be improved in China. *Environmental Science and Technology*, 51(15), 8212-8214. <https://doi.org/10.1021/acs.est.7b02672>

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1 **Improving livestock housing and manure storage is essential**
2 **for reducing environmental and human health impacts of**
3 **animal production in China**

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5 Zhaohai Bai†, Xiaoxin Li†, Jie Lu†, Xuan Wang†, Gerard L. Velthof‡, David
6 Chadwick§, Jiafa Luo#, Stewart Ledgard#, Zhiguo Wu//, Shuqin Jin∇, Oene Oenema‡,
7 Lin Ma†*, Chunsheng Hu†*

8
9 † Key Laboratory of Agricultural Water Resources, Center for Agricultural Resources Research,
10 Institute of Genetic and Developmental Biology, The Chinese Academy of Sciences, 286
11 Huaizhong Road, Shijiazhuang 050021, Hebei, China;

12 ‡ Wageningen Research, Environmental Research P.O. Box 47, 6700 AA, Wageningen, The
13 Netherlands;

14 § School of Environment, Natural Resources and Geography, Bangor University, Bangor,
15 LL57 2UW, UK;

16 # AgResearch Limited, Ruakura Research Centre, Private Bag 3123, Hamilton, New Zealand;

17 // University of Pennsylvania, School of Veterinary Medicine, 3800 Spruce Street, Philadelphia,
18 Pennsylvania 19104, America;

19 ∇ Research Center for Rural Economy Ministry of Agriculture, No. 56, Xisizhuanta Hutong,
20 Beijing 100810, China.

21 *Corresponding authors: email: malin1979@sjziam.ac.cn, cshu@sjziam.ac.cn.

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23 Feeding a burgeoning human population with limited land and water is always a
24 challenge, but especially for China, where *per capita* arable land and fresh water
25 reserves are much lower than world averages. China has strongly increased the
26 production and *per capita* consumption of animal-source food, but improper
27 management of animal manure has resulted in excessive losses of nutrients to the
28 environment. These losses cause severe pollution of: i) air, via ammonia (NH₃)
29 emissions that contribute to smog and eutrophication, and via methane and nitrous
30 oxide emission that contribute to climate change; and ii) water, via direct discharge of
31 manure to watercourses and leaching of nitrate (NO₃⁻), causing nitrate accumulation
32 in drinking water¹⁻⁴.

33 **Current polices related to nutrient management**

34 China has learned that poor nutrient management has an environmental cost. The
35 government recently introduced several legislations to control air and water pollution
36 and the use of chemical fertilizers. These legislations include “Ten-Point Air Plan”
37 (http://www.gov.cn/jrzq/2013-09/12/content_2486918.htm), “Ten-Point Water Plan”
38 (http://www.gov.cn/zhengce/content/2015-04/16/content_9613.htm), and “Zero
39 Increase Action Plan”³. Most of these regulations have the point of fertilizer
40 application at fields, greenhouses and orchards, but so far miss livestock housing and
41 manure storage systems.

42 According to data for 2010³, animals excrete 19 Tg nitrogen (N) and 4.1 Tg
43 phosphorus (P) in housing annually. Livestock production in China is rapidly
44 expanding, however, little has been done to improve manure management. Direct

45 discharge of manure to surface watercourses continues to be seen on farms, and
46 housing and manure stores continue to be left unattended to emit N. We believe that
47 environmentally sustainable animal food production must include proper manure
48 management. Improvements must be made in livestock housing and manure storage in
49 order to reduce losses of manure N and P to air and waterbodies.

50 **Nitrogen losses from livestock housing and storage**

51 High atmospheric PM_{2.5} concentrations are of major concerns for China². Ammonia
52 plays an important role in the formation of secondary inorganic aerosols, a main
53 component of PM_{2.5}². Reducing NH₃ emissions is therefore an effective approach to
54 decrease PM_{2.5} concentrations. Estimates suggest that livestock production in China
55 emitted 6.7 Tg NH₃-N in 2010, equivalent to 49% of the total NH₃ emissions from
56 agriculture³. Housing systems and manure storage are the major sources of NH₃
57 emission, representing up to 73% of the total NH₃ emissions from livestock
58 production. Inadequate manure collection and storage are the main sources for the
59 release³ (see also Fig 1). In addition, manure treatment and application accounted for
60 0.8 and 1.0 Tg NH₃-N, respectively (Fig 1a). The externality costs of NH₃ emissions
61 from housing and manure storage to human health in China is estimated at \$26-106
62 billion annually, based on the approach of the European Nitrogen Assessment⁵, and
63 ought to be considered against the costs of implementing mitigation strategies.

64 A large proportion of the rivers, lakes and coastal waters in China are suffering from
65 severe eutrophication. Approximately 46% of the rivers in China were classified as
66 harmful for direct human contact¹. The nutrients causing eutrophication are mainly

67 emitted from industrialized animal production systems, which are becoming
68 increasingly disconnected with crop production. Direct manure discharge into surface
69 waters accounts for over two-thirds of the N and P in the northern rivers and for 20–
70 95% of the N and P in the central and southern rivers². In 2010, 5.5 Tg of manure N
71 entered the surface water system, with 97% from livestock manure seepage and direct
72 discharge from housing and manure storage. The other 3% was came from manure
73 application through runoff, erosion etc. (Fig 1a, c). Direct discharge of manure results
74 mainly from the lack of i) enforcement of regulations for manure storage capacity, ii)
75 obligation to recycle manures back to crop production, iii) appropriate monitoring and
76 control, and iv) appreciation of the fertilizer value of manures³⁻⁴.

77 In a recent study¹, 62% of the drinking water wells monitored in China exceeded the
78 50 mg L⁻¹ standard set by the World Health Organization¹. The main sources of nitrate
79 in drinking water wells identified by isotopes are agricultural fertilizers, untreated
80 wastewater, and livestock manure¹. N losses from livestock housing and manure
81 storage are larger than losses occurring during manure treatment and land application
82 (Fig 1a). In an analysis of soil cores from the edge of a 20-year old layer hen manure
83 store, NO₃⁻-N was 50 to 130 mg kg⁻¹ in the top 100 cm soil, greater than in the soil of
84 a nearby 30-year old fertilized wheat-maize rotation system. Similarly high soil
85 NO₃-N concentrations were found near a 12-year old dairy manure store (Fig 1b).
86 There also might be higher soil organic N concentrations nearby the manure storage
87 places. The soil nitrate concentration would be even higher at the center of these
88 manure stores. Clearly, current livestock housing and manure storage in China pose a

89 great threat to groundwater quality. The estimated externality cost associated with
90 surface water eutrophication and groundwater pollution is \$40-159 billion annually⁵.

91 **Implications for research and practice**

92 Manure management must be improved in China. A systems approach is needed to
93 reduce losses of manure N and P³. Improved manure management focused on
94 livestock housing and manure storage would greatly reduce N losses in NH₃
95 emissions, discharge of manure and NO₃⁻ leaching. It would also contribute to the
96 implementation of the 'Zero Increase Action Plan' as a result of increased manure N
97 and P recycling and reduced use and manufacture of synthetic N and P fertilizers.
98 Proper manure management requires the understanding of N and P loss pathways,
99 mitigation mechanisms and options in animal housing and manure storage, and of the
100 loss vulnerability of different production systems, including traditional, mixed and
101 industrialized landless systems. Policy makers, scientists and farm managers need to
102 work together to develop standards and regulations for livestock housing and manure
103 storage systems. Adoptions of cost-effective technologies are necessary. The use of
104 manures as fertilizer and soil conditioners should be promoted in crop production
105 systems. We also recommend that governmental subsidies currently used for synthetic
106 fertilizer N and P production be redirected to renovation of livestock housing and
107 manure storage facilities, and to infrastructure development for manure treatment,
108 transportation and application to cropland. Improvements in manure management
109 would contribute to significant reductions in manure N and P losses, greenhouse gas
110 emissions, and losses of other nutrients (such as potassium), and at the same time

111 would contribute to soil carbon sequestration and a decrease in the use of synthetic
112 fertilizer. The investments required for improved manure management ought to be
113 considered relative to the externality costs of the current mismanagement of manures.

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115 **AUTHOR INFORMATION**

116 Corresponding Authors

117 *Phone/Fax: 86-0-311-85810877. E-mail: malin1979@sjziam. ac.cn.

118 *Phone/Fax:86-0-311-85814360. E-mail: cshu@ sjziam. ac.cn.

119 Notes

120 The authors declare no competing financial interest.

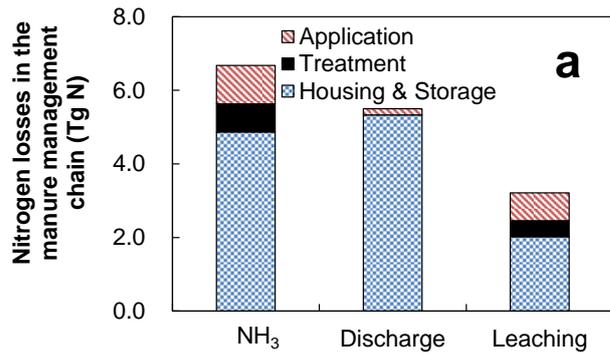
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122 **ACKNOWLEDGMENTS**

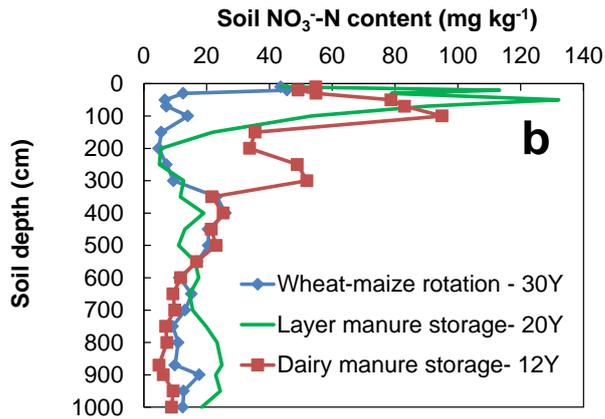
123 This work was financially supported by The National Key Research and Development
124 Program of China (2016YFD0800106); The National Key Research and Development
125 Program of China (2016YFD0200105); the National Natural Science Foundation of
126 China (31572210); Distinguished Young Scientists Project of Natural Science
127 Foundation of Hebei (grant number D2017503023); the Hundred Talents Program of
128 the Chinese Academy of Sciences; the President's International Fellowship Initiative
129 (PIFI) of the Chinese Academy of Science (2016DE008 and 2016VBA073); the
130 UK-China Virtual Joint Centre for Improved Nitrogen Agronomy (CINAg) funded by
131 the Newton Fund via UK BBSRC/NERC (BB/N013468/1); Program of International
132 S&T Cooperation (2015DFG91990).

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Direct discharge of waste water from a dairy cattle farm, which can result in eutrophication



An uncovered pig manure store, where higher NH₃ emission and N leaching occurs

146

147 Fig 1. Total nitrogen losses from the manure management chain in China in 2010 (a),

148 NO₃-N contents of different soil depth from different management systems in North

149 China Plain (b), direct discharge of manure from a dairy farm (c) and an uncovered

150 cattle manure store (d) in the North China Plain (in 2016).

151 *Note: a, derived from Bai et al., 2016; b, derived from on farm sampling and laboratory*

152 *analysis in 2016.*

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