畜禽粪便污染的农业系统控制模拟及系统防控对策

RESEARCH ON PREVENTION AND CONTROL SYSTEM OF LIVESTOCK AND POULTRY EXCRETA

柳建国◎编著

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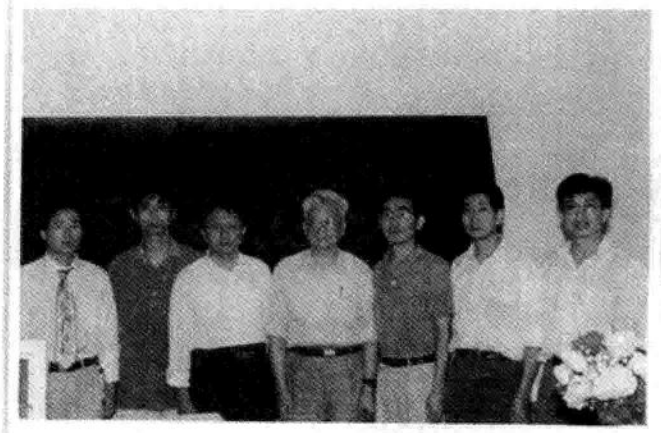

1996 年 8 月与导师合影

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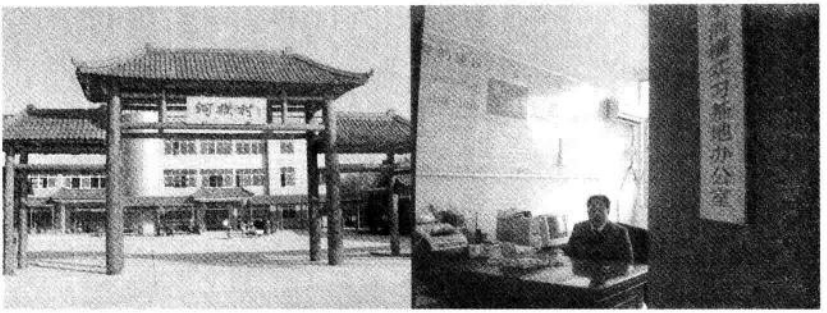
新年快乐

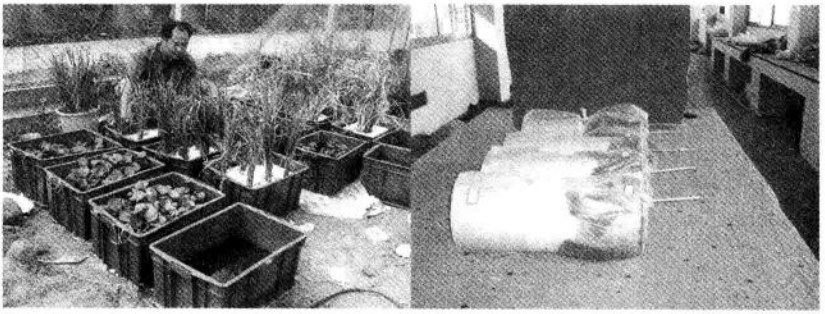
Happy New Year

江苏省人民政府 张桃林
Jiangsu Provincial People's Government



江苏泰州河横村

河横村污水处理实验照片



南京农业大学实验照片

序

伴随全面建成小康社会的催人步伐，加快改变农村面貌到了一个关键时期。按照党的十八大提出的“推动城乡发展一体化”要求，必须下更大的决心、花更大的气力，加快改善农村生产生活条件，合力建设农民安居乐业的美丽乡村。加强农村生态建设、环境保护和综合整治的步伐要整体推进，使美丽乡村成为美丽中国的坚实基础。

以往对畜禽粪便处理的研究多停留在局部和技术层面上，对畜禽粪便处理研究也是以定性为主，定量化的研究主要停留在对某些因素之间关系的研究上，主观性强，不利于对系统运行的整体理解和把握。因此建立畜禽粪便农业处理系统动力学模型，通过计算机仿真，并把仿真结果以图形的形式直观地表现出来，从而为系统的优化和系统最佳发展道路的选择提供准确的量化参考依据，显得十分必要。《畜禽粪便污染的农业系统控制模拟及系统防控对策》研究发现，农田畜禽粪便安全经济承载力为 $35t \cdot hm^{-2} \cdot a^{-1}$ 至 $60t \cdot hm^{-2} \cdot a^{-1}$ 猪粪当量，用作物秸秆吸附净化养殖污水经济有效。该研究具有一定的创新性和实用性。

柳建国博士先后从师于南京农业大学柯建国教授、中国科学院张桃林研究员、南京农业大学卞新民教授，长期从事农业和农村环境研究，参与了《江苏省农村环境综合整治“十一五”规划》起草工作。他积多年研学功力，集科学、工程、管理多专业跨学科之综合学识，不仅熟稔专业理论，而且深入实际，运作专题研究，既付旷

日之功，方得今日之绩。《畜禽粪便污染的农业系统控制模拟及系统防控对策》一书的问世，对于农村环境保护和生态经济建设既是一个重要贡献，也是一次强有力的推动。

我国正处于工业化、城镇化、农业现代化的过程之中。即使已经经历了30余年的高速发展，以中国人口之众多和疆土之辽阔，发展可持续性的挑战和机遇依然是无比巨大的。农业现代化是中国经济进一步向纵深健康发展并保持强劲动力的必由之路。希望本书在这样一个波澜壮阔的历史进程中做出自己独特而有意义的贡献。

是为序。

中国人民大学环境学院院长教授、博导

2013年5月5日

要点导读

本文立足于江苏农业面源污染成因调查与农户行为分析，基于农田畜禽粪便安全经济承载力和畜禽养殖污水生态处理技术，用循环经济的理念，建立了畜禽粪便污染的农业系统控制的动力学模型，运用 MATLAB 和计算机仿真技术对姜堰市河横村畜禽粪便污染进行了农业系统控制模拟，从系统的角度提出畜禽粪便污染防控对策。

In line with pollution condition of livestock and poultry excreta in Jiangsu province, dynamic model of control on agricultural system of livestock and poultry excreta was built with circular economy idea as key point by using of safety economic bearing—capacity on field's livestock and poultry excreta as well as ecological treatment of breeding sewage; control on agricultural system of pollution by livestock and poultry excreta in Heheng village of Jiangyan City was simulated by using of MatLab and computer simulation; strategies of prevention and control were put forward from the point of system. The main research contents and results are as follows:

1 农田畜禽粪便安全经济承载力

在大田生产条件下，重点研究水稻、大麦对氮、磷养分的利用吸收，通过测定和估算氮磷的富余量和富余率，分析土壤－作物系统处理粪便的能力。试验结果表明，在一定范围内，随着畜禽粪便施用量的增加，作物对氮磷的吸收量也随之增加，但是相邻处理间氮磷吸收量相差较小，因此随着畜禽粪便施用量的成倍增加，氮磷的损失量、损失率也在成倍增加。在一年时间里，两季作物最高带走氮 368.4kg·hm^{-2}、磷 81.98kg·hm^{-2}，为不让过多的氮磷流入周围水体造成二次污染，全年农田猪粪施用量不超过 34.6t·hm^{-2} 比较合理；不同施肥量的产值分析表明，猪粪年施用量 60－120t·hm^{-2} 产值较高。综合生态环境、肥料利用效率、产量等多种因素，在不使用化肥的情况下，农田畜禽粪便安全经济承载力为35t·hm^{-2}·a^{-1} 至 60t·hm^{-2}·a^{-1} 猪粪当量。

Field－experiment was adopted to conduct research on the capability of

rice and barley absorbing N and P. We analyzed the livestock and poultry deject disposal capability of crop by determining and estimating losing amount and ratio of N and P in soil. The result showed that, in a certain range, amount of crop absorbing N and P rose with increasing of livestock and poultry deject using. But there was no significant difference between each treatment, which means losing amount and ratio of N and P increased by times with increase of livestock and poultry deject using. Crop absorbed368. 4kg/hm^2 N and 81. 98kg/hm^2 P from soil at most in one year, under 34. 6t · hm^{-2} pig feces using amount per year was suitable to prevent secondary pollution that caused by the influx of excessive N and P to around water system. Basing on the analysis of production value of different fertilizer using amount, 60 — 120t · hm^{-2} per year was optimal. Therefore, considering integrated factors including ecological environment and fertilizer using ratio as well as yield, the safety economic bearing — capacity on field's livestock and poultry excreta was 35 — 60t · hm^{-2} · a^{-1} · a pig feces equivalent on the precondition that no other fertilizer was used.

2 江苏省畜禽粪便污染负荷及评价

1997—2006 年，江苏省养殖业发展有明显的两个阶段，1997—2003 年是养殖业快速发展期，苏州、无锡 2003 年养殖规模比 1997 年分别扩大 346%、300%，增加最少的南通市养殖规模也扩大了 44%；2003 年以后，江苏省养殖规模进入调整期，常州、南通、镇江三地市养殖规模有小幅度增长，南京、无锡、苏州等 10 个地市养殖规模呈下降趋势。2006 年耕地年畜禽粪便污染实际负荷，无锡市最高(46. 75t · hm^{-2})，其次是南京(41. 59t · hm^{-2})，苏州以 34. 44t · hm^{-2} 居第三位，淮安、扬州、镇江、宿迁负荷量较低，只有 20t · hm^{-2} 左右。

以农田畜禽粪便安全经济最大承载力 60t · hm^{-2} 猪粪当量为标准，对 2006 年江苏省各地市耕地污染负荷进行评价，结果显示，无锡市警报值为 0. 78，畜禽粪便产生量对环境构成威胁，淮安、扬州、镇江、宿迁和泰州的警报值分别为 0. 31、0. 34、0. 34、0. 34 和 0. 38，畜禽粪便产生量对环境不构成威胁，其余地市处于稍有威胁状态。

从江苏省省域范围来看，2006 年江苏省畜禽粪便污染负荷为 28. 59t · hm^{-2}，其

警报值为 0.47，处于稍有威胁状态低线。

Development of raising industry inJiangsu province consisted of two phases. During the first speed development phase from 1997 to 2003, breeding scale of Suzhou and Wuxi in 2003 expanded 346% and 300% compared to 1997, respectively, even 44% in least expanded Nantong. In adjustment phase after 2003, breeding scale in Changzhou, Nantong, and Zhenjiang increased in small range, while declined in 10 cities like Nanjing, Wuxi and Suzhou. Wuxi's 46.75t/hm^2 ranked the foremost real load of farmland livestock and poultry excreta in 2006, following as Nanjing (41.59t · hm^{-2}) and Suzhou (34.44t · hm^{-2}). Load value around 20t · hm^{-2} of Huaian, Yangzhou, Zhenjiang and Suqiang were relatively lower than that of other cities.

Pollution load of each city inJiangsu province were evaluated with 60t · hm^{-2} as the alarm value of the safety economic bearing－capacity on field's livestock and poultry excreta. Results showed that environment of Wuxi(0.78) was in danger with livestock and poultry excreta volume, Huaian (0.31), Yangzhou(0.34), Zhenjiang(0.34), Suqiang(0.34) and Lianyungang(0.38) were out of danger and the rest cities were in less polluted position.

Pollution load of livestock and poultry excreta of overallJiangsu province in 2006 was 28.59t · hm^{-2}, warning value was 0.47, being in less threatened position.

3 畜禽养殖污水生态处理技术

在试验室条件下，用 4 种不同长度的小麦秸秆吸附过滤畜禽养殖污水，吸附截留率一般在 10%－20%，分层状秸秆比整体状、棍断状、粉碎状三种形式秸秆能更好地吸附养殖污水中的氮磷。采用分层处理，处理 90 分钟时可以达到最佳处理效率，每 kg 秸秆对总氮和总磷的最佳吸附容量分别为 286.42mg 和 110.81mg。

水葫芦(饲料植物)、水花生(饲料植物)、香根草(湿地护坡植物)、水稻(农作物)四种水生植物漂浮生长在养殖污水中，30d 对污水的净化率，水葫芦 76%－90%，水花生 51%－65%，香根草 42%－67%，水稻 66%－88%，净化能力大小顺序为：水葫芦＞水稻＞水花生＞香根草。在高浓度污水(N

含量 97.3mg·L^{-1}、P 含量 39.7mg·L^{-1}）中，30d 植物体重量增加率，水葫芦 82.1%，水花生 37.5%，香根草－3.2%，水稻 4.6%，说明水葫芦适宜用于对高浓度养殖污水的净化，香根草不能用于对高浓度畜禽养殖污水的净化。

30d 试验表明，水稻、水葫芦和水花生每增加 1kg 生物量，平均净化污水中氮磷总量分别为 48g、2.9g 和 2.5g。

Treatment combined with grain straw and hydrophytes was adopted to purify breeding sewage in this study.

Under laboratoryconditions, livestock excrement waste water was purified by adsorbing on 4 different length Straws of wheat. The results showed that they have interception rates 10 － 20%, among which absorption of N and P in layer form was better than those of in whole, fracture, or ground form. When using the layer form, the optimum treatment time is 90 min, at which point the best absorption quantity of total N and total P in per Kg straw are 286.42mg and 110.81mg respectively.

Four hydrophytes, *Eichhornia crassipes*, *Alternanthera philoxeroides*, *Vetiveria zizanioides* and *rice*, were planted in breeding solid water to research their purification capacity. The result showed that purification ratio of *Eichhornia crassipes*, *Alternanthera philoxeroides*, *Vetiveria zizanioides* and *rice* were 76－90%, 51－65%, 42－67% and 66－88%, respectively in 30 days. The purification capacity of these 4 hydrophytes was arranged as follow: *Eichhornia crassipes* > *rice* > *Alternanthera philoxeroides* > *Vetiveria zizanioides*. In high concentration sewage (97.3mg·L^{-1} N, 39.7mg·L^{-1} P) absorption, the increasing ratio of *Eichhornia crassipes*, *Alternanthera philoxeroides*, Vetiveria zizanioides and rice were 82.1%, 37.5%, －3.2% and 4.6%, respectively in 30 days, which showed that *Eichhornia crassipes* was suitable for purifying high concentration solid water while *Vetiveria zizanioides* was not.

The experimental in 30 daysshowed that when the biomass of rice, *Eichhornia crassipes*, *Alternanthera philoxeroides* increased 1Kg, the mean purification quantity of total NP were 48g, 2.9g , 2.5g respectively.

4 畜禽粪便污染农业系统控制模拟

通过对农田畜禽粪便安全经济承载力及畜禽养殖污水生态技术处理的研究，运用系统动力学的建模方法，对畜禽粪便污染的农业系统控制的过程假定和系统分析，利用 MATLAB 工具和计算机仿真技术对模型进行了基于仿真实验的结构设计、参数和性能优化。通过对河横村畜禽粪便污染农业系统控制模型合理地进行结构设计与参数优化，设定系统的状态变量 6 个，并分别赋予其理想的系统工作点值，以 2007 年为基准年，进行系统仿真实验。结果表明，系统可以从目前不太理想的初值，经过不到 20 年的时间和较小的波动，达到理想的稳定状态，即河横村从 2007 年开始，经过不到 20 年的时间，就可以达到协调可持续发展的要求。

利用河横村历史数据(1991－2007)对系统模型进行有效性检验，6 个状态变量的 R2 最小为 0.8，最大为 0.94，平均为 0.855，STD 均较小，说明建立的畜禽粪便污染的农业系统控制模型是科学可行的。

原发展模式(未加入生态工程)系统 2030 年的终值与加入生态工程并优化后的系统 2030 年的终值相比，未加入生态工程的系统比加入生态工程的系统不仅经济指标明显下降，而且环境指标也较差，比如，未加入生态工程的系统在比加入生态工程的系统养殖规模小 5.6%的情况下，周围水体中的氮磷是后者的 14 倍。可见未加入生态工程的系统经济发展不足，环境保护欠缺，不符合循环发展要求，而加入生态工程并优化后的系统符合可持续发展的要求。

Based on the study of safety economic bearing－capacity on field's livestock and poultry excreta as well as ecological treatment of breeding sewage, researches such as optimizing construction, parameter and performance of simulation model and self－motion were conducted with MATLAB and computer simulation by using dynamic model, process hypothesis, and system analysis. System simulation was experimented by optimizing construction and parameter of control model of agricultural system of livestock and poultry excreta in Heheng village when hypothesized 6 State Variables, an ideal working－point－value of system, basic year 2007 for comparison. The results showed that the system had become an ideal Stability state from an unsatisfied initial－value when ex-

perienced less than 20 years and little fluctuation, that is to say, the development of Heheng village can reach a requirement of sustainable development before 2027.

Text of model efficiency by earlier data (1991 — 2007) of Heheng village demonstrated that it is feasible to establish the control model of agricultural system of livestock and poultry excreta (R^2 min = 0.8, R^2 max = 0.94, v = 0.855, n = 6).

Compared to optimizing system, economic index in 2030 predicted by former model system declined significantly, breeding scale of former system was smaller than optimizing system, and crop yield reduced 15%. On the precondition of 5.6% reduction of breeding scale, NP in water of former system was 14 times higher than optimizing system. Development system without ecological project brought less economic interests and more environmental pollution, which couldn't meet requirement of circular agriculture. On the other hand optimizing system with ecological project was an ideal development model that met requirement of sustainable development.

5 农业面源污染原因调查与行为分析

对江苏省高淳县、江阴市、江都市、姜堰市、阜宁县、灌南县等市县农村环境存在的问题和原因进行实地考察，并召开由政府相关部门、当地农民参加的座谈会。调查表明，苏中苏北农业面源污染与经济因素有关，尤其是苏北，环境保护意识不强和经济总量不足是造成农业面源污染的重要原因。

通过对195户农户调查后发现，100%的农户都使用化肥，只有62.3%的农户愿意使用有机肥。对畜禽粪便处理方式，29%的农户随意抛弃，61%农户还田，10%的农户卖给有机肥厂。对于环境保护与污染治理的责任，62.1%的农户认为是政府的责任，33.8%的农户认为是企业的责任，4.1%的农户认为是个人责任，说明环境保护与治理，政府承担主要责任。

农户对环境保护支付意愿，4%的农户不愿意出资，46.9%的农户表示看情况而定，49.1%的农户愿意为治理环境出资，最高可承受的费用是年收入的2%，平均支付意愿是年收入的0.798%。

生态意识度与农户年收入相关度0.928，与居民文化水平相关度0.94。因此，发展地方经济，加强环境保护教育，提高人们的文化水平，使农民具有环保意愿的驱动力，对畜禽粪便污染的控制具有重要的意义。

The problems and factors existing in ruralenvironment of Gaocun, Jiangyin, jiangdu, jiangyan, Funing, Guannan in Jiangsu were analyzed by the on－site investigation and the informal discussion meeting. The results showed that factors of agricultural non－point source pollution in Mid－Jiangsu or north－Jiangsu were relation with socioeconomic, especially the absence of environment protection and Economic aggregate in north－Jiangsu.

Questionnaires covering 195 farmers showed that all the farmers used chemical fertilizer, only 62.3% farmers preferred organic manure. 29% farmers abandoned livestock and poultry excreta, 61% farmers returned them to fields, 10% farmers sold them to organci fertilizer factory. 62.1% farmers thought government should be responsible for rural environmental control, 33.8% farmers thought it is enterprise's responsibility, 49.1%, only 4.1% farmers thought it is them－selves responsibility. The above results showed that government should abandon the main responsible for rural environmental control.

4% farmers were unWillingness to pay for environment protection; 46.9% farmers depended on the pay situation is; 49.1% farmers were Willingness to Pay for environmental control, of which the highest bearing pay is about 2% total annual income and the mean pay is about 0.798% total annual income. The correlation between farmer's environmental awareness and average net income per year was 0.928, and the correlation between environmental awareness of rural residents and their educational level was 0.94 that higher than correlation of their income level. Therefore, several measures, such as developing local economy, enhancing environmental education, raising people's educational level, would make farmers be willing to protect environment, which was important to control livestock and poultry excreta pollution.

6 畜禽粪便污染的防控对策

基于畜禽粪便污染原因及农户环保行为分析和畜禽粪便污染的农业系统控制模拟，从系统动力学出发，提出“政策引导、规模协调、技术配套、机制完善”的畜禽粪便污染防控对策。

Based on the pollution factors oflivestock and poultry excreta, the behaviors analysis of farmers' environmental protection, and the control simulations of agricultural system, strategies of prevention and control on pollution of livestock and poultry excreta of "policy—guidance, scale—harmonious, matching—technology, mechanism—perfection" were put forward from the point of system dynamic.

缩 略 语

N	总氮
P	总磷(P_2O_5)
NP	物质或系统内总氮总磷之和

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