

Spatio-Temporal Distributions and Environmental Safety Threshold of Cropland Fertilization of Jiangsu Province, China

Qinpu Liu^{1,a}, John P. Giesy^{2,3,4,5,b}, Zhaohui Li^{1,c}

¹School of Bio-chemical and Environmental Engineering, Nanjing Xiaozhuang University, Nanjing, 211171 China

²Toxicology Centre and Department of Veterinary Biomedical Sciences, University of Saskatchewan, Saskatoon, Saskatchewan, Canada

³School of Biological Sciences, University of Hong Kong, Hong Kong, SAR, China

⁴Department of Biology and Chemistry and State key Laboratory in Marine Pollution, City University of Hong Kong, Hong Kong, SAR, China

⁵State Key Laboratory of Pollution Control and Resource Reuse, School of the Environment, Nanjing University, Nanjing, China

^aliuqinpu@163.com, ^bJGiesy@aol.com, ^clizhh6710@126.com

Keywords: Grain Production; Agriculture; China; Jiangsu Province; Fertilization

Abstract: Correlations and non-linear regression analyses were used to determine the optimal rate of fertilization that would maximize production of grain while minimizing effects on the environment in Jiangsu Province, China. Correlation coefficients between the amounts of cereal grain produced and rates of fertilization were 0.880, 0.606, and 0.212 for the periods 1970-1983, 1984-1997, 1998-2011, respectively. Current amounts of chemical fertilization used are causing adverse effects on the environment. By use of simulation analyses, it was determined that 550 - 600 kilogram of fertilizers (a mix of N, P₂O₅, K₂O) per hectare is the upper limit amount of fertilization that balances production and potential for eutrophication in Jiangsu. Amounts of fertilizer applied are greater in the North of Jiangsu Province with three-fold more fertilizers applied than in the south. Factors such as proportion of farmers in the regional population, incomes of farmers, multiple cropping index, proportion of land irrigated, proportion of land in agricultural production all influence the amount of fertilizers applied in this region.

Introduction

With development of modern agriculture, there were globally, approximately 30%~50% of surface water bodies that have become polluted by non-point source pollutants [1]. Approximately 12% of 1.2×10⁸ hectare of arable land has been degraded due to agricultural non-point source pollution [2]. According to the survey by the EPA of U.S. in 2003, non-point pollution from agriculture is the main source of pollution of rivers and lakes, causing about 40% rivers and lakes unqualified for water use, as well as pollution of groundwater and degradation of wetlands [3]. The situation of non-point pollution from agriculture is more serious in China. To achieve high yields of agricultural products, China consumes one third of the fertilizer produced globally and the amount used per hectare is three-fold greater than the global average [4]. However, efficiencies of chemical fertilizers of N, P, Potassium (K) in China are 30-35%, 20-30%, 30-50% respectively. So there are a lot of fertilizers lost annually to the environment. This can cause serious environmental problems such as cultural eutrophication of surface waters in rivers, lakes and reservoirs and the coastal sea water [5]. In 2008, China conducted the first national pollutants sources census, which showed that total N from agricultural sources accounts for 57.2% of total emissions of N from activities of humans [6].

Jiangsu Province has the most intense agriculture in China, with more fertilized cropland than most other provinces. Amounts of fertilization ranged from 83.28 kg/ha in 1970 to a maximum of 734 kg/ha, which occurred in 2009. Overuse of fertilizers has resulted in serious non-point pollution,

principally cultural eutrophication with associated toxic algal blooms, and has been deemed to be unsustainable for Jiangsu Province [7]. Therefore, it was deemed necessary to develop methods to determine optimal rates of fertilization and improve efficiency of fertilization to maintain current agricultural production while protecting the environment, particularly quality of surface waters. The purpose of this study was to investigate spatio-temporal variation of uses of fertilizers in Jiangsu Province, determine if too much fertilizer was being used relative to the increases in yields of crops, and find out the environmental safety threshold of cropland fertilization of Jiangsu.

Data and Methods

Data collected. Data used in the analyses presented here come from the *2012 Jiangsu Statistical Yearbook* compiled by Jiangsu Province Bureau of Statistics [8]. Part of the data were collected and calculated according to the basic data in *2012 Jiangsu Statistical Yearbook*.

Methods. Pearson Product-moment correlations were used to generate linear correlations between the dependent variable of yield of grain (y) and independent variable of amount of fertilizer (x_1), and income per farmer (x_2), proportion of farmers (x_3), population density (x_4), farmland rate (x_5), multiple cropping index (x_6), and irrigation land rate (x_7) were selected in order to measure their relationship with amount of fertilizers (x_1) applied in Jiangsu.

Quadratic polynomial regression analysis is a common way to simulate the effectiveness of fertilizers applied for grain production (Eq. 1).

$$y = a + bx + cx^2 \quad (1)$$

Where: y is the dependent variable (grain production), x is the independent or explanatory variable (fertilizer applied). The goal of the non-linear regression was to obtain estimates of the unknown parameters a , b and c , which indicate how a change of the independent variables affects the values taken by the dependent variable. "Coefficient of Determination", R^2 , defines the amount of the variation in y that is attributable to variation in x . Values of R^2 range from +1 to 0. So the greater R^2 value, the more predictive the model. Because Quadratic polynomial regression equation is a parabolic curve, there is a maximum value of y in a certain value of x such that the value of x can be derived when the first order derivative of y equals zero.

Results and Discussion

Correlation between rates of fertilization and production of grain. Based on information collected by the provincial government [8], the amount of fertilizers (a mix of N, P_2O_5 , K_2O) used for agriculture in Jiangsu has increased steadily from 83.28 kg ha^{-1} in 1970 to $707.86 \text{ kg ha}^{-1}$ in 2011. During this period, yields of cereal grain increased from 3537.19 to $6943.53 \text{ kg ha}^{-1}$. Over the 42 yrs period, there were 17 yrs of increasing and 25 yrs of decreasing production of grain (Fig. 1).

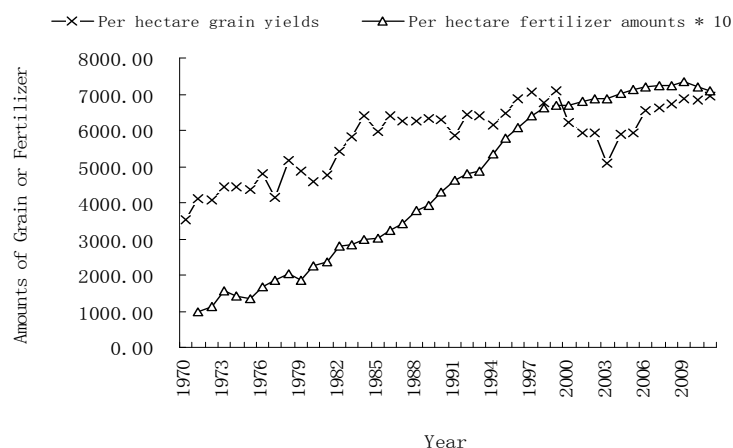


Fig. 1 Yields (kg ha^{-1}) of cereal grain and amounts (kg ha^{-1}) of fertilizers in Jiangsu from 1970 to 2011.

The period of 42 yrs from 1970 to 2011 was divided into three sub-periods for correlation analyses. Correlation coefficients (r) between production of grain and amount of fertilizer applied for each period vary from greater to lesser (Table 1). From these correlation analyses it can be concluded that the incremental contribution of fertilizer to yield of grain decreases as the total amount of fertilizer applied increases, which follows the law of diminishing returns.

Table 1 Correlation coefficients (r) between the production of grain and fertilizer applied.

| Periods | No. years | Correlation Coefficients(r) | Significance (2-tailed) | Grain Yields Per Unit Fertilizer (kg kg^{-1}) |
|-----------|-----------|---------------------------------|-------------------------|----------------------------------------------------------|
| 1970-1983 | 14 | 0.880 | $P = 0.000$ | 25.82 |
| 1984-1997 | 14 | 0.606 | $P = 0.021$ | 14.26 |
| 1998-2011 | 14 | 0.212 | $P = 0.467$ | 9.12 |

Overuse of fertilizers is not only detrimental to aquatic environments but also can damage crops and result in lesser production of grains. Excess fertilization can cause deterioration of soil, pollution of air and water and low quality agricultural products, eventually, and in some cases result in adverse effects on health of people, such as methemoglobinemia caused by nitrite (NO_2^-). Excess N in surface and groundwater mainly originates from farmland, onto which excess inorganic N-containing fertilizers are applied. Specifically 51% of anthropogenic N in the surface water is from farmland. One reason for the outbreak of blue-green algae observed during 2007 in *Tai Lake* in Jiangsu was non-point pollution from agriculture[9,10].

Simulation to determine Environmental Safety Threshold (EST) of fertilization. In order to prevent non-point pollution, optimal and maximum amounts of fertilization should be considered in Jiangsu Province. In some more developed countries, 225 kg per hectare of chemical fertilizer (mix of N, P_2O_5 , K_2O) is considered to be the upper limit for the safety of environment. Here it is defined as Environmental Safety Threshold (EST), which is the maximum amount of fertilizer applied to soil without adverse effects on the environment. Use of fertilizers in Jiangsu Province is currently greater than EST. Current rates of used fertilizers are greater than 700 kg of a mix of N, P_2O_5 , K_2O per hectare, which is 3.3-fold greater than the EST suggested by more developed countries. Jiangsu consumed too much N, less P, very little K fertilizers for the agriculture production before 1996 (Table 2). It was an imbalance to meet the need of crops for NPK. The situation was better for the balance of NPK in 2011. However, much of the N and P leached into surface waters, causing eutrophication.

Table 2 Changes of grain yield, fertilizers and proportion of N : P_2O_5 : K_2O in Jiangsu

| Periods | Grain Yields (kg ha^{-1}) | Fertilizers (kg ha^{-1}) | N : P_2O_5 : K_2O (Means) |
|-------------|--------------------------------------|-------------------------------------|-----------------------------------------------------------|
| 1970 - 1979 | 3537.9 – 4873.73 | 83.28 – 185.78 | 1 : 0.36 : 0.01 |
| 1980 -1985 | 4590.2 – 5977.72 | 224.33 – 301.70 | 1 : 0.26 : 0.03 |
| 1986 - 1996 | 6401.24 – 6867.95 | 325.28 – 605.82 | 1 : 0.27 : 0.07 |
| 1997 - 2009 | 7049.10 – 6890.06 | 638.25 – 733.78 | ----- |
| 2011 | 6943.53 | 707.86 | 1 : 0.4 : 0.3 |

Scholars have been appealing for establishment of guidelines for use of fertilizers. Ministry of Environmental Protection of P.R.C sets the fertilization standard, less than 250 kg ha^{-1} of chemical fertilizer (mix of N, P, K), for the construction of ecological county, city and province in China[11]. Based on results of long-term tests, Zhu Zhaoliang, who is an academician of the Chinese Academy of Sciences (CAS) has suggested that $150\text{-}180 \text{ N kg ha}^{-1}$ would be suitable for most cereal crops grown in China [12]. It has been suggested that 500 N kg ha^{-1} would be suitable for vegetable crops, 400 N kg ha^{-1} for cereal crops in northern China [13], $222\text{-}261 \text{ N kg ha}^{-1}$ has been suggested as the maximum rate of fertilization of rice in paddies adjacent to *Tai Lake* in southern Jiangsu[14]. The suggestions given above demonstrate amounts of fertilization vary among locations and from crop to crop.

Determining the optimal amounts of N fertilizers or mix of N, P, K fertilizers applied is thus specific to crops and geographic regions. For this reason, instead of relying on estimates of optimal rates of fertilization for other regions or countries, it was decided to develop EST specific for Jiangsu Province, based on its technical, social, economic and ecological factors.

According to the scatter plot of two variables of grain yield and amount of fertilizers (a mix of N, P₂O₅, K₂O) applied in Jiangsu Province from 1970 to 2011, a numerical simulation of quadratic polynomial regression was used to determine the EST for fertilization (Fig. 2).

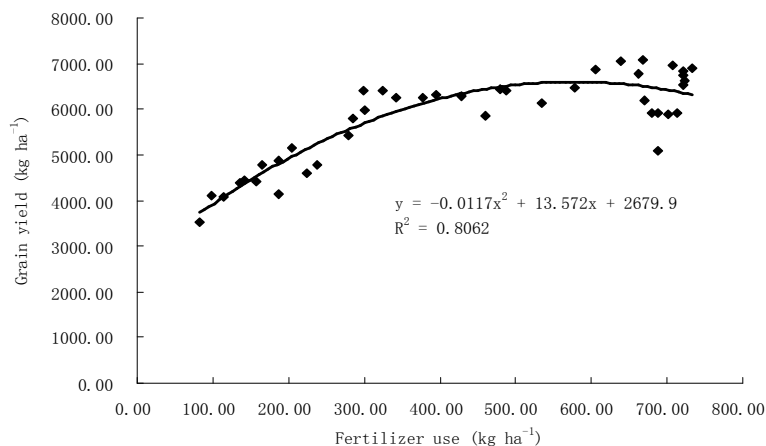


Fig. 2 Fertilizer-productivity curve for Jiangsu Province

There was a strong association between amount of fertilizers applied and grain productivity ($R^2 = 0.8062$, Sig. $F = 0$) (Equation 2).

$$y = -0.0117x^2 + 13.572x + 2679.9 \quad (2)$$

Where: y = grain yield per hectare produced; x = fertilizer amount used per hectare.

Based on extreme value theory, if the first order derivative (dy/dx) is taken and the equation is equal to zero, the optimum rate of fertilizer use would be 580 kg ha^{-1} (Equations 3 and 4).

$$dy/dx = -0.0234x + 13.572 = 0 \quad (3)$$

$$x = 580 \text{ kg ha}^{-1} \quad (4)$$

This result indicates that obtaining the best yield of grain, 580 kg ha^{-1} fertilizer is affordable. Based on the most recent statistics available, the yield of cereal grain in Jiangsu Province in 1999 was $7083.75 \text{ kg ha}^{-1}$, which was the best yield of grain ever recorded (Fig. 1). To attain that level of productivity the rate of fertilization was $667.57 \text{ kg ha}^{-1}$, with a mix of N, P₂O₅, K₂O in a proportion of 1.0: 0.30 : 0.14[15], which is greater than the predicted optimum. So in general farmers are adding more N and P than needed to reach the maximum yield before it is limited by something other than N or P. Based on this information, it is suggested that a maximum rate of 550 - 600 kg, with a mix of N, P₂O₅, K₂O in a proposed proportion of 1:0.5:0.5, should be applied per hectare, which is considered as EST of fertilization in Jiangsu Province, 20% less than what is currently being applied. This means that the difference between the optimum for productivity and that being applied is basically being wasted and also adding to potential enrichment of surface water. The EST of 550 - 600 kg per hectare is the mean in Jiangsu, so the rate of fertilizer application could be locally reduced by 10-30% immediately, which would minimize adverse effects on the environment without affecting yields of grain crops. If the appropriate measures are taken for improving the efficiency of fertilizers, crop yield would not decrease if the amount of fertilized applied were reduced by 10-15%, 15-20%, and 25-30%, in northern, central and southern areas of Jiangsu, respectively. In addition, the lesser magnitude of non-point pollution of soil with excess N and with subsequent contamination of surface water and groundwater will improve environmental quality and minimize risks to humans.

Reasons for spatial variation of fertilization. In order to find the distribution of rates of application of fertilizers in sub-administrative regions in Jiangsu, upward ranking of them were made

with some factors related with amount of fertilization (x_1), such as grain yield per hectare (y), income per farmer(x_2), proportion of farmers(x_3), population density(x_4), farmland rate(x_5), multiple cropping index(x_6), and irrigation land rate(x_7), are listed (Table 3).

Table 3 Factors related to fertilization and production of grain in Jiangsu Province during 2011

| Areas | x_1 (kg ha ⁻¹) | y (kg ha ⁻¹) | x_2 (rmb cap. ⁻¹) | x_3 | x_4 (person km ⁻²) | x_5^a | x_6^b | x_7^c | Location in Jiangsu |
|-------------|---------------------------------|-------------------------------|------------------------------------|-------|----------------------------------------|---------|---------|---------|------------------------|
| Nanjing | 349.07 | 6962.41 | 13108 | 0.23 | 966.00 | 0.37 | 1.37 | 0.54 | South |
| Zhenjiang | 373.46 | 6963.55 | 12825 | 0.26 | 707.00 | 0.44 | 1.40 | 0.56 | South |
| Suzhou | 395.24 | 7203.26 | 17226 | 0.14 | 757.00 | 0.26 | 1.20 | 0.68 | South |
| Changzhou | 396.19 | 7221.49 | 14838 | 0.20 | 830.00 | 0.38 | 1.37 | 0.63 | South |
| Wuxi | 457.56 | 7030.35 | 16438 | 0.17 | 1011.00 | 0.29 | 1.32 | 0.72 | South |
| Nantong | 507.29 | 6261.68 | 11730 | 0.23 | 956.00 | 0.59 | 1.82 | 0.48 | Middle |
| Taizhou | 591.74 | 7371.90 | 11046 | 0.23 | 876.00 | 0.54 | 1.84 | 0.49 | Middle |
| Yangzhou | 634.12 | 7370.58 | 11217 | 0.20 | 698.00 | 0.45 | 1.69 | 0.57 | Middle |
| Huaian | 749.19 | 6976.55 | 8645 | 0.42 | 539.00 | 0.49 | 1.59 | 0.41 | North |
| Yancheng | 758.52 | 6919.02 | 10511 | 0.39 | 484.00 | 0.46 | 1.88 | 0.42 | North |
| Suqian | 909.88 | 6472.09 | 8344 | 0.40 | 649.00 | 0.51 | 1.61 | 0.50 | North |
| Lianyungang | 912.26 | 7093.59 | 8434 | 0.50 | 663.00 | 0.49 | 1.63 | 0.50 | North |
| Xuzhou | 1181.07 | 6260.48 | 9490 | 0.41 | 867.00 | 0.52 | 1.88 | 0.42 | North |

^aproportion of land in agricultural production

^bratio of sown area to total area of arable land

^cproportion of arable land that is irrigated to total sown area

Rates of fertilization in Jiangsu Province increase from south to north areas (Table 3). Xuzhou city, located in the north of Jiangsu Province, used the greatest amount of fertilizer (1181.07 kg ha⁻¹), while in the region around Nanjing, which is in the southern part of the province, the rate of application was only 349.07 kg ha⁻¹. Thus, non-point pollution is more serious in north part than south part of Jiangsu.

There are some factors that influence rates of fertilization (Table 4). Results of correlation analysis shows that income of farmers (x_2) and proportion of irrigated land (x_7) were significantly and negatively related to rate of fertilization, but the proportion of the population that are farmers(x_3), multiple cropping index(x_6) and proportion of land in cultivation(x_5) were all significantly and positively associated with rate of fertilization (x_1). There was a negative association ($r = -0.472$) between yield of grain (y) and the amount of fertilizer applied(x_1), which is exactly what would be expected because the relationship between productivity and fertilization had reach a maximum and plateaued such that there was no added benefit of adding additional fertilizer. Thus, applying the proposed maximum rate of fertilization (i.e. EST) would result in lesser costs and thus greater income to farmers and benefit to environment. In addition, greater irrigation will also reduce the amount of fertilizer needed to achieve the same yield.

Table 4 Correlation coefficients (r) between rate of fertilization and some factors

| | | y | x_2 | x_3 | x_4 | x_5 | x_6 | x_7 |
|-------|---------------------------------|--------|--------|-------|--------|-------|-------|-------|
| x_1 | Pearson Correlation coefficient | -0.472 | -0.783 | 0.823 | -0.381 | 0.556 | 0.663 | -0.66 |
| | Sig.(P) (2-tailed) | 0.103 | 0.002 | 0.001 | 0.2 | 0.049 | 0.014 | 0.014 |

Conclusion

Based on results of a correlation analysis on 42 yr of data on production of grain and use of fertilization in Jiangsu province, China, it was concluded that the incremental contribution of fertilizer to yield of grain decreases as the total amount of fertilizer applied increases, which follows the law of diminishing returns. Current amounts of chemical fertilization used are causing adverse effects on the environment. By use of simulation analyses, it was determined that 550 - 600 kilogram

of fertilizers (a mix of N, P₂O₅, K₂O) per hectare is, at the average, optimum amount of fertilization for the whole province, although it will be different for specific regions or plants. Amounts of fertilization applied are greater in the north of Jiangsu Province with three-fold more fertilizers applied than in the south. Factors such as the proportion of farmers in the regional population, incomes of farmers, multiple cropping index, proportion of land irrigated, and proportion of land under cultivation all influence the amount of fertilizers applied in a region. Goals for fertilization in agriculture should emphasize conservation of resources, improving efficiency of production and ensuring quality of agriculture products.

Acknowledgements

The project was supported by the Jiangsu Ecology Key Discipline Construction Project; the Nanjing Environmental Science Key Discipline Construction Project and the Nanjing Xiaozhuang University Scientific Research Project (2012NXY24). Prof. Giesy was supported by the Canada Research Chair program, 2012 program of "High Level Foreign Experts" (#GDW20123200120) funded by the State Administration of Foreign Experts Affairs, the P.R. China to Nanjing University, the Einstein Professor Program of the Chinese Academy of Sciences, and a Distinguished Visiting at the Department of Biology and Chemistry and State Key Laboratory in Marine Pollution, City University of Hong Kong.

References:

- [1] L. C. Dennis, J. V. Peter, L. Keith. *Environmental Science and Technology*, 8 (1997), p.2157-2175
- [2] L. Dennis. *Soil & Water Conservation*, 1(1998), p.75-88
- [3] US Environmental Protection Agency. Non-point source pollution from agriculture. Information on <http://www.epa.gov/region8/water/nps/npsurb.html>, 2003
- [4] S. Ding, H. W. Zang.. *Modern Agricultural Science and Technology* (in Chinese), 23 (2009), p. 275-276
- [5] C. Gao, T. L. Zhang. *AMBIO*, 39(2010), p.385-393
- [6] J. H Ge, Sh. D. Zhou. *China's Rural Economy* (in Chinese), 5 (2011), p. 72-80
- [7] F.Zhang, H. Hao, H. Zhang. *China Population, Resources and Environment* (in Chinese), 8(2010), p. 80-85
- [8] Jiangsu Province Bureau of Statistics. *Jiangsu Statistical Yearbook* (2000-2012) Information on <http://www.jssb.gov.cn/jstj/tjsj/tjnj/>.
- [9] G. Y. Zou. The spatio-temporal distribution and sources of NO₃-N and NO₂-N in water at high risk cancer regions, in Huai River watershed (master thesis). Henan University, 5/2011
- [10] X. P. Ge, J. ZH. Chen, W. Wu. *China Aquatic* (in Chinese), 3(2008), p. 7-11
- [11] Ministry of Environmental Protection of P.R.C. Information on http://www.zhb.gov.cn/gkml/zj/wj/200910/t20091022_172492.htm
- [12] Zh. L. Zhu, D. Norse, B. Sun. *Agricultural non-point source pollution control countermeasures in China*. Beijing: China Environmental Science Press (in Chinese), 2006
- [13] W. L, Zhang, Zh. X. Tian, N. Zhang, X. J. Li. *Journal of Plant Nutrition and Fertilizer* (in Chinese), 2(1995), p. 80-86
- [14] Y. T. Cui, X. Cheng, Ch. R. Han, R. G. Li. *Acta Ecologica Sinica* (in Chinese), 4 (2000), p. 659-662
- [15] Y. P. Lu, Q. R. Zhao. *Phosphatic Fertilizer and Compound Fertilizer* (in Chinese), 4(1998), p. 61-64

Resources and Sustainable Development III

10.4028/www.scientific.net/AMR.962-965

Spatio-Temporal Distributions and Environmental Safety Threshold of Cropland Fertilization of Jiangsu Province, China

10.4028/www.scientific.net/AMR.962-965.2110