Changes in Soil Fertility Parameters and the Environmental Effects in a Rapidly Developing Region of China

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ABSTRACT

An extensive knowledge of the temporal variability of soil fertility parameters and how those changes affect the environment is imperative to a wide range of disciplines within agricultural science for optimal crop production and ecosystem preservation. This paper examines the spatial and temporal variability of some important soil fertility parameters on Cambosols (Entisols) (n=179) and Anthrosols (Inceptisols) (n=95) in Zhangjiagang County, China from 1980 to 2004. Nutrient input was monitored from 1983 to 2004. Annual N fertilizer rates were significantly increased dramatically after 1989 and then decrease after 1999. Annual P fertilizer rates were significantly increased after 1993. No change was found in K fertilizer rates. Soil pH marginally increased in Cambosols, but dramatically decreased in Anthrosols. Organic matter (OM), cation exchangeable capacity (CEC), and total nitrogen (TN) increased in both soil orders. Total phosphorus (TP) decreased in Anthrosols. Available P (P_{Av}) increased and available (K_{Av}) decreased in Cambosols. Fertilizer input rates are causing nutrient imbalances, contributing to acidification in Anthrosols, and decreasing C/N ratios. Nutrient loading of N and deficiency of K is also a potential problem in the area. Efforts should be made to readjust soil nutrient inputs to reach an optimal, sustainable level.

1. INTRODUCTION

In China, intensive farming coupled with rapid urbanization poses a wide range of threats to the environment and human health in peri-urban areas. In many of these areas, nutrient loading adversely affects water bodies and in extreme instances causes severe eutrophication. Excess nitrogen (N) and phosphorus (P), along with potassium (K) deficiency in the soil is a result of improper recommendations and subsequent fertilizer and manure application, however, a thorough understanding of how these fertilizer and management processes affect long-term soil fertility of conventional cropping systems in large areas is still lacking. Ramifications of these processes in such a system may be more difficult to pin-point and at the same time more harmful than those in peri-urban areas because of its large and non-point nature. The objectives of this study are to (i) assess the temporal variability of soil fertility parameters in Zhangjiagang County from 1980 to 2004, a period of rapidly economic development, (ii) evaluate how fertilizer application affects temporal variability of soil fertility parameters in the county, and (iii) put forward suggestions to decrease environmental impact while improving soil fertility.

2. MATERIALS AND METHODS

Zhangjiagang County extends over a 999 km^2 level alluvial plain area, of which 799 km^2 is terrestrial area in the Yangtze River Delta Region, China (Fig. 1). It has a sub-tropical monsoon climate with annual temperature of 15.2^{o}C, annual soil temperature at 5 cm of 16.8^{o}C, annual rainfall of 1039.3mm, and annual evaporation of 800.0mm. The county currently possesses approximately 38,600 ha of arable land and decreasing compared to 40,500 ha 20 years ago. Since the 1980's, the county has been one of the most rapidly developing areas in China. The Yangtze River Delta Region is 1% of China's land area, but accounts for 16% of GDP.

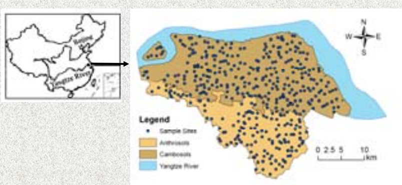

Fig 1. Soil map of Zhangjiagang City, China and sampling sites.

Aquic Cambosols (Entisols) derived from neo-alluvial parent materials with medium-light loamy texture and contained a certain amount of free carbonate occupy the northern part of the county along the Yangtze River (Fig. 1). The cropping system on this soil is predominantly rice-wheat, though historically cotton-wheat was more common. Stagnic Anthrosols (Inceptisols) derived from lagoon-phase paleo-alluvium with high clay content and extractable iron are the dominant sub-order on the plains of the southern part. The cropping system on the soils has historically been rice-wheat.

In 1980, sites were randomly sampled throughout the county on agricultural land (n=273), which included 179 Cambosol sites and 95 Anthrosol sites. In 2004, sites were again visited and samples were taken. Sample sites were registered in 2004 using a hand-held global positioning system (GPS).

Fertilizer application data was collected from the local county extension agency. Meticulous records of amount of every type of fertilizer applied in selected plots in terms of crop rotations were recorded from 1983 to 2004.

Some soil parameters were determined, including soil pH (soil/water=1:2.5), soil organic matter (OM) (Walkley and Black method), Cation exchange capacity (CEC) (ammonium acetate method), Total soil N (TN) (Kjeldahl method), Total P (TP) (Murphy and Riley method), Olson-P (P_{Av}), and available K (K_{Av}) NH_4OAc-extractable K.

3. RESULTS

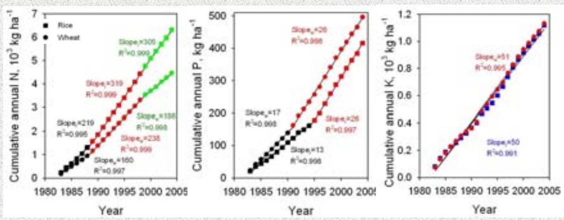

Fig. 2. Cumulative annual rates of N, P, & K applied from 1980 to 2004 against year.

Table 1. Soil fertility parameters within soil groups from 1980 to 2004.

Parameters	Cambosols		Anthrosols		Soil Order	Year	S×Y
	1980	2004	1980	2004			
pH	7.9±0.2b	8.1±0.3a	7.4±0.5c	6.4±0.9d	***	***	***
CEC(cmol kg^{-1})	10.2±2.2d	11.8±2.3c	14.8±2.5b	16.5±2.2a	***	***	NS
OM(g kg^{-1})	16.9±3.5d	18.7±3.4c	22.1±3.9b	25.1±4.5a	***	***	*
TN (g kg^{-1})	1.1±0.2d	1.2±0.3c	1.4±0.2b	1.7±0.4a	***	***	***
C/N	9.1±1.1b	9.1±1.1bc	9. 6±1.1a	8.8±1.5c	NS	***	**
TP (mg kg^{-1})	872±83a	863±79a	674±136b	604±119c	***	***	***
P_{Av} (mg kg^{-1})	8.1±4.9b	12.9±9.3a	9.4±4.9b	9.8±8.6b	NS	***	**
K_{Av} (mg kg^{-1})	71±33a	56±25b	76±31a	74±28a	**	**	*

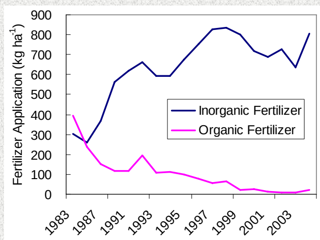

Fig. 3. The trends of inorganic and organic fertilizers applied during past 20 years.

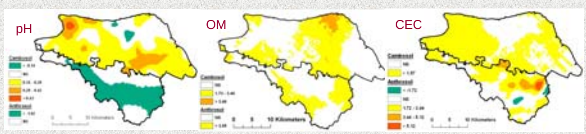

Fig. 4. Temporal variation of pH, OM, and CEC within two soil groups of Zhangjiagang, China between 1980 and 2004 according to their calculated confidence intervals. NS denotes no significant difference.

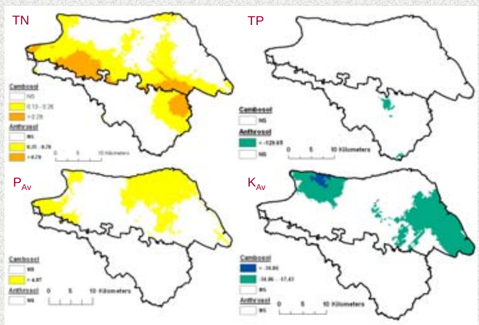

Fig. 5. Temporal variation of total N and P and available P and K within two soil groups of Zhangjiagang, China between 1980 and 2004.

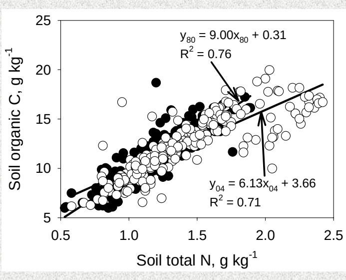

Fig. 6. Correlation between soil total N and organic C across soil orders as affected by year.

4. DISCUSSION

4.1. Variability of NPK Applications

Annual N application has overloaded the European Union Council (1991) 210 kg N ha^{-1} yr^{-1} threshold for each crop since 1990 (Fig. 2). This is a severe risk for the aquatic environment of the local area. P application is reasonable because significant accumulation in soils has not taken place since the 1980's (Table 1, Fig. 6) though annual P recommendations have almost doubled since the mid-1990's (Fig 2). Available K significantly decreased during the past 21 years on Cambosols (Fig. 6).

It is important to supply balanced nutrient inputs corresponding with plant requirements. In our study area, the N:P:K ratio is about 13:1:3 and 7:1:2 to 12:1:4 for rice and wheat. Compared to the N:P:K ratio of 6:1:6 (Dobermann et al., 1998) and 3:1:3 (Vitosh et al., 1989) for rice and wheat, fertilizer application for rice and wheat production in Zhangjiagang had much more N and much less K during past 21 years, even though N input has declined in recent years (Fig. 2).

4.2. Acidification

Remarkably, soil pH drastically decreased 1-2 pH units in Anthrosols during the 24 year (Table 1, Fig. 4). This will adversely affect soil properties such as metal bioavailability, fertility, and microbiology. Both intrinsic and exogenous factors played a role in soil pH changes. Anthrosols experienced strong development accompanied by strong leaching of base cations for an extended period of time, resulting in a weak H^+ buffering capacity. In contrast, Cambosols had weak development with a high level of free carbonate, strong buffer capacity, and no significant pH change. Some exogenous factors such as an increase of fertilizer input, a high ratio of N input, incorporate crop residues into the soil after each harvest on Anthrosols area, and multiplied factories in recent years most likely caused the severe acidification in Anthrosols. Regardless of the causes, soil acidification will become a serious threat to soil fertility if this trend continues.

4.3. Soil C/N variability

Although both soil TN and OM (or soil organic C) across soil orders have increased in the past 24 years, increased TN was significantly greater than increased organic C in soil, resulting in a lower regression slope in 2004 than 1980 (Fig. 6). The decrease of C/N in conjunction with the increase of the soil OM and TN indicates that the increase in N buildup was more rapid than C over the past 24 years. Excess N fertilizer application and decreased organic/inorganic fertilizer ratios (Fig. 3) are most likely responsible for this trend. The C/N ratio decrease may enhance the activity of microbes and accelerate the mineralization of soil OM, resulting in decreased C fixation capacity due to C release from the soil. Meanwhile, it may also result in high N mineralization rates and N leaching. C release contributes to the greenhouse effect and N leaching threatens the safety of ground water and rivers.

5. CONCLUSIONS

Fertilizer application in the county has been inconsistent with crop demands and environmental concerns. If current trends continue, nutrient loading of N will continue to escalate rapidly and crops will suffer further K deficiency. In addition, continued pH decrease in Anthrosols will render them useless for crop production within the next 25-30 years. Drastic changes in soil pH affect all flora and fauna and can disrupt the overall ecosystem. Soil C/N ratios continue to decrease in the county as well, decreasing their C sequestration capacity.

The most pressing environmental issues in the study area are strongly tied to N fertilizer input. A drastic decrease in N in the county would restore a healthy nutrient balance, improve the C/N ratio, reverse acidification, and decrease non-point source pollution of N to surrounding water bodies and leaching to groundwater. A reversal in the pH trend would also favorably affect P availability. Though N fertilizer is most likely the driving force behind pH increase, a decrease in acid deposition from local factories would also favorably affect pH.

N fertilizer decrease and input of K to the soil is also recommended and would most likely contribute to a dramatic increase in crop production. Efforts should be made to readjust soil nutrient inputs to reach an optimal and sustainable level.

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