Understanding the Overuse of Chemical Fertilizer in China
A synthesis of historic trends, recent studies, and field experiences

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Introduction

China is currently the world leader in chemical fertilizer production, consumption, and imports. With food security firmly in mind, the Chinese government has been promoting the use of chemical fertilizers since the early 1960s, and China is currently ranked 4th globally in chemical fertilizer use intensity (Zhang et al. in prep). According to the FAO (Food and Agriculture Organization of the United Nations), chemical fertilizers are the single most important contributor to the increase in world agricultural productivity over the past 30 years. The cultural reforms of the late 1970s and early 1980s brought a surge in food production that has been sustained to the present; China now produces a surplus of grain and has captured one third of the global export market for fruits and vegetables.

With 10 percent of the world's arable land mass (Li, et al. 1997) and 20.3 percent of the world's population (GeoHIVE 2005), agriculture in China is nothing if not intensive. This inevitably raises concerns about the economic and environmental sustainability of agriculture in China. Deteriorating soil quality requires increasing inputs to maintain high yields. This, in turn, threatens future food security and raises production costs for often already impoverished farmers. With high population density and scarce per capita water resources, non-point source pollution from agricultural run-off continues to put pressure on drinking water and aquatic ecosystems.

Following a brief history of agriculture, with an emphasis on trends in fertilizer use, this paper will discuss the overuse of chemical fertilizers by farmers in China. Recent and on-going studies demonstrate that farmers in China are applying more chemical fertilizer than is economically optimal. Taking into consideration concerns about the sustainability of input-intensive agriculture and the economic, ecologic, and environmental effects of chemical fertilizer over-use, it is clear that over all application should be reduced. Ultimately, individual farmers make decisions about agricultural practices. In order to change behavior regarding chemical fertilizer application it is necessary to understand the factors that influence how farmers make these decisions. Household surveys and discussions with farmers in China's Yunnan province in June of 2005 illustrate the complex interplay of factors in these decisions in addition to the variability in farmers' practices. In some instances agricultural technical extension agencies strongly influence how farmers apply fertilizer. These agencies must take an active role in meeting farmer's changing needs. In the near future, contracts with procurement and distribution companies may play a larger role in determining chemical fertilizer applications. Programs and policies that intend to reduce the application of chemical fertilizers must first seek to understand farmers' reasons for their practices and then empower and assist them in making more economically, ecologically, and environmentally sustainable choices.

Food production and fertilizer use in China: Historical perspective and recent trends

At the establishment of the People's Republic of China in 1949, much of China's agricultural land was already depleted in plant nutrients and organic matter following as much as thousands of years of cultivation (Wang et al. 1995). The Chinese government has paid special attention to fertilization of soils since the early 1950's, at which time the goal was utilizing all possible sources of organic fertilizer. During the Great Famine of 1959-1961, in the aftermath of the Great Leap Forward, as many as 30 million people died of starvation in China. In the early 1960's, as the limitations of organic fertilizer were realized, the emphasis was shifted to chemical fertilizers. The Chinese government promoted the use of chemical fertilizers through investing in domestic production, increasing imports, and putting in place price subsidies for farmers (Wang et al. 1995). Domestic production and imports are still on the rise, although subsidies to farmers have since been eliminated.

Food production in China has surged over the past two and a half decades (figure 1). The dramatic increase in food production began during the cultural reforms of the government of Deng Xiaoping, beginning in 1978. These reforms included the abolishment of the commune system, which allowed farmers to partially privatize their farms under the new household responsibility system (Hamburger 2002). Once communities and individuals had satisfied their grain quotas, farmers could sell cash crops at market prices. From 1978 to 1984, China's grain production increased by more than five percent annually from 238 million tons to 322 million tons (Bach and Martin 1997). This is even more remarkable given that arable landmass saw a net decrease of 4.5 million hectares during the same period of time (US Embassy 1996). In 1982, application of chemical fertilizer surpassed that of organic fertilizer in terms of contribution to the total nutrient supply to agricultural lands (Wang et al. 1995).

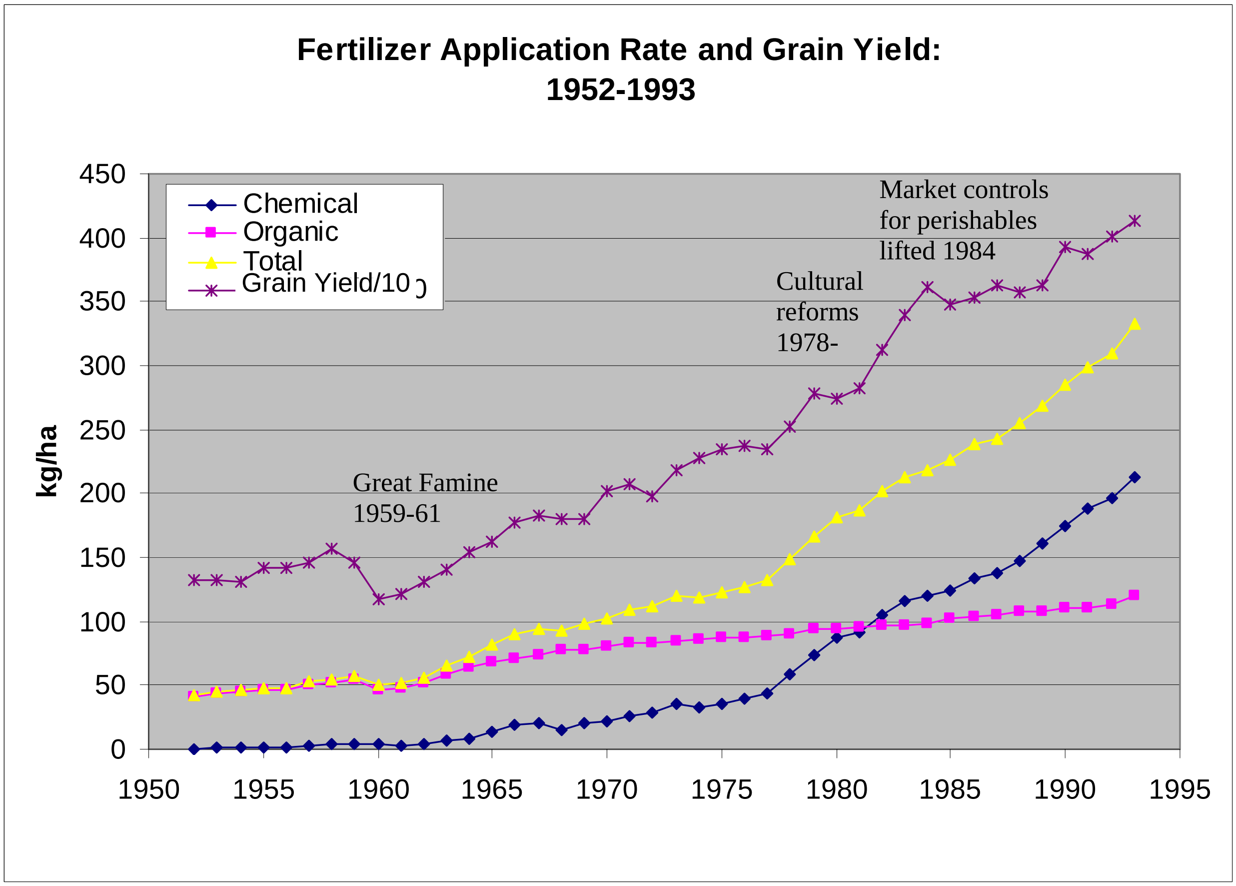

Figure 1. Trends in fertilizer use and grain yield, 1952-1993. Data source: Wang *et al*. 1996.

In 1984, further reforms included the lifting of market controls for perishables. This resulted in a dramatic increase in production and consumption of fruit, vegetables, eggs, and meat. By the year 2000, the total output value of China's fruits and vegetables reached US$42 billion and exports captured one third of the global vegetable export market (Hamburger 2002). The growing food supply has far surpassed food demand, leading to a grain surplus. China's current ability to feed its growing population has been achieved primarily through the increasing use of modern agricultural inputs and technologies (Zhang et al. in prep). The growing use of agrochemicals, especially chemical fertilizer, has been integral in getting the most out of technological advances. According to the Food and Agriculture Organization (FAO) of the

United Nations, 50 percent of the increase in global agricultural productivity in the last 30 years can be attributed to chemical fertilizer use. The official Chinese estimate attributes 40 percent of China's production increase to chemical fertilizer (Wang et al. 1995). Farmers also recognize the significant role of chemical fertilizers; according to a 1998 and 1999 survey done in Inner Mongolia, farmers cited chemical fertilizer, followed closely by new crop varieties, as the most important factor that has affected production in the preceding 20 years (Brogaard and Zhao 2002).

In the late 1990's, China became the world's largest producer, consumer, and importer of chemical fertilizers (Zhang et al. in prep). The supply of chemical fertilizers from domestic sources has increased by four percent annually since 1980. Several factors led to the increased use of chemical fertilizers in the 1980's, including the growing scarcity of agricultural land, falling input prices, and policy trends that reduced implicit taxes on agriculture. Especially following the economic reforms of the 1980's, the rising opportunity cost of labor has encouraged rural residents to reduce the amount of time spent on farm production. The first twenty years of economic reform saw China's chemical fertilizer applications double twice (figure 2). Although China only contains 10 percent of the world's arable land, it has consumed 25 percent of the annual global supply of chemical fertilizers since 2002. The average national per hectare application of chemical fertilizers in China reached 280 kilograms in 2000 – three times the world average. The increase has been rapid; in 1975 China's farmers applied about 70 kilograms per hectare, which was just about equal to the world average. Currently, China ranks 4th globally in per hectare fertilizer use after the Netherlands, South Korea, and Japan. Those countries, however, support output values of crops at roughly five times those faced by farmers in China (Zhang, et al. in prep).

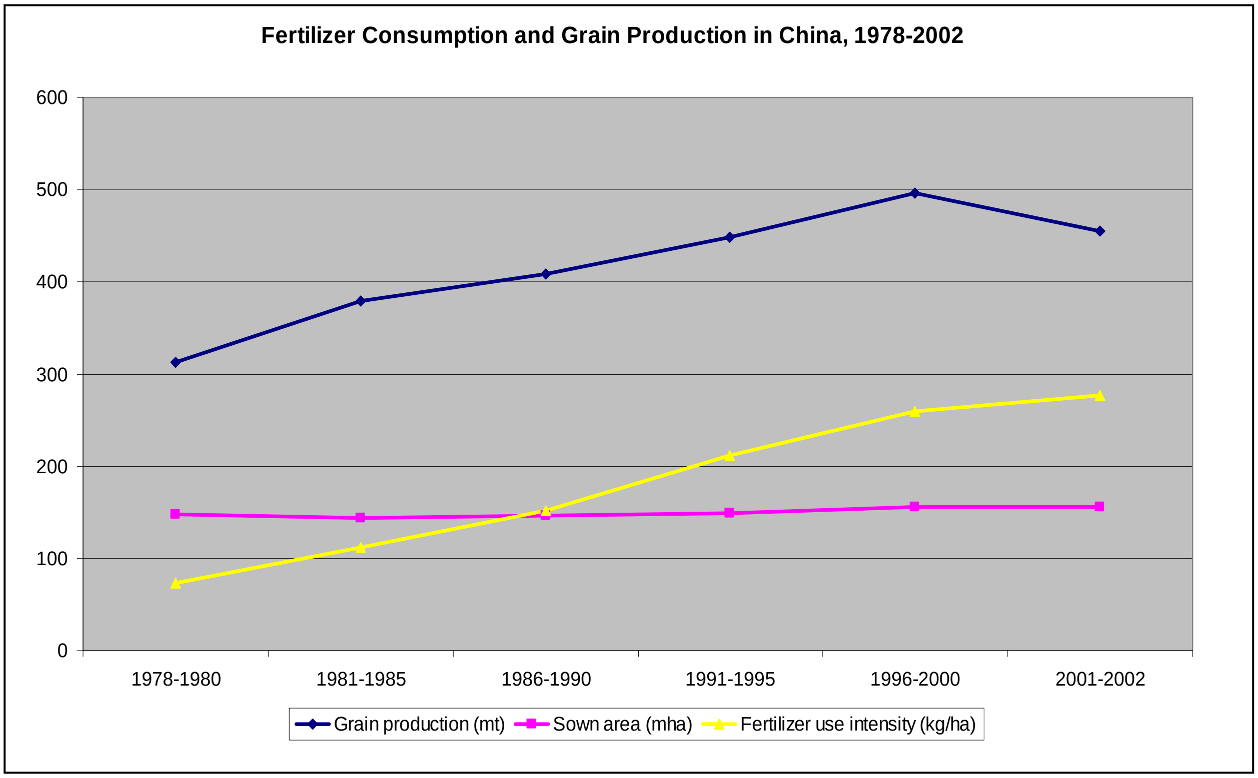

Figure 2. Recent trends in fertilizer use intensity, sown area, and grain production. Data source: Zhang *et al*. in prep.

The increase in consumption of chemical fertilizers over the past few decades spurred the Chinese government to promote fertilizer production, which jumped from 12 million tons (nutrient weight) in 1980 to 36 million tons in 2002. In 1996, China surpassed the United States as the world's largest producer of chemical fertilizers. Still, increases in production could not keep pace with increases in consumption. In the 1990's China imported about 25 percent of the chemical fertilizer it consumed (Li et al. 1996).

Chemical fertilizers can be applied in a variety of chemical combinations, including individual nutrients and pre-prepared mixes of nutrients. This allows nutrient prescriptions to be tailored to specific conditions. The general fertilizer ratio of nitrogen to phosphorus to potassium (N:P:K) recommended by agronomists and soil scientists is 100:60:40, with nitrogen typically being the most limiting nutrient. The application ratio of these nutrients is gradually becoming more balanced in China; in 1980 it was 100:30:4, improving to 100:29:11 in 1992 and to 100:39:24 in 2003 (figure 3) (China Statistical Yearbook 2004).

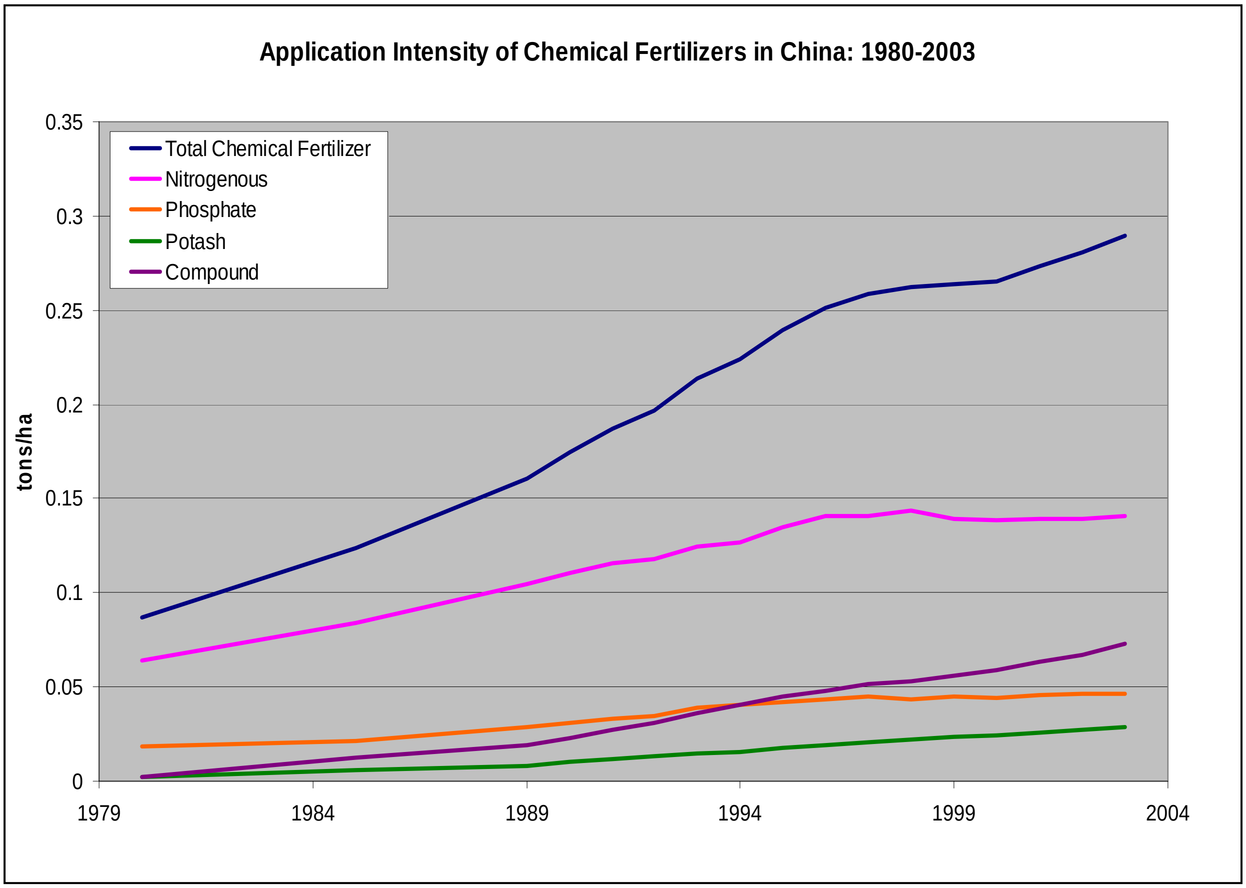

Figure 3. Application intensity of chemical fertilizers, 1980 to 2003, showing different types of chemical fertilizer. Data source: China Statistical Yearbook 2004.

A trend in the ratio of application rates of organic to inorganic fertilizers can also be observed. This ratio declined from 60 percent in 1980 to 46 percent in 1995 due to an increase in use of agrochemicals resulting from technical extension and, until recently, subsidies to farmers (Wang et al. 1996). Furthermore, these calculations of organic fertilizer application have been based on the assumption that utilization rates of organic fertilizer have remained constant throughout time. It is likely, however, that applications of organic fertilizers have declined due in part to the labor intensity of collection and application, and the increasing emphasis put on chemical fertilizers. Lack of accurate information about trends in organic fertilizer use has prevented more accurate modeling to date (Wang et al. 1996). Although current figures are unavailable, it is reasonable to assume that the ratio has continued to decline to the present.

Is intensive agriculture sustainable? Food security, rural economy, and the environment

Food security has always been a high priority for the Chinese government, especially in light of the Great Famine (1959-1961) and current global concerns about feeding China's growing population. These events have strongly influenced Chinese agricultural policy, especially the emphasis placed on national grain self-sufficiency. Traditionally, national food security refers to the ability of a country to produce enough grain to feed its citizens and prevent starvation. China currently produces an excess of grain, although Li et al. (1997) identify three main trends that threaten the future of national food security. The first is the continued exploitation of an already limited natural resource base. Much agricultural land in China has been under cultivation for hundreds or even thousands of years. Soil and other resources must be managed appropriately to maintain long-term agricultural productivity. Secondly, with improving living standards in China, the food habits of the population are changing. Urban dwellers in particular are consuming less grain and more meats, fruits, and vegetables, and this trend will spread as the per capita income of Chinese citizens continues to improve. As the net availability of agricultural land remains relatively stable, China's growing population continues to demand ever-increasing yields. The remarkable success China has had in achieving food security over the past several decades will be made more challenging in years to come as a result of these three trends (Li et al. 1997).

In order to guarantee long-term food security in China, agricultural practices must be sustainable. That is, current practices should not threaten the ability of agricultural land to be equally productive in the future and retain the capacity either to feed people directly or to acquire enough through foreign exchange earnings to secure the volume of food necessary for subsistence. As with other agricultural technologies, chemical fertilizers must be applied in a sustainable manner to ensure future food security and maintain high levels of productivity. Overuse of chemical fertilizers has deleterious effects on soil health, air quality, and water quality. As soil health deteriorates, the application of more and more chemical fertilizers becomes necessary, thus creating a vicious cycle.

Continuous cultivation of the same crop, combined with intensive use of chemical fertilizers, can cause significant reduction in soil nutrient status and organic content. In a study rice and wheat in India, the growth in productivity had slowed considerably over time where fertilizer use was above recommended levels (Yadav et al. 1998). This study, along with several other studies of long-term yield declines in agrochemical intensive cropping systems highlight how these systems can, over time, affect soil properties and the ability of crops to utilize applied nutrients. Farmers in Inner Mongolia have reported that they must apply more and more chemical fertilizer every year to maintain the same yields (Brogaard and Zhao 2002). On several occasions, rural farmers that we spoke with in Yunnan Province were well aware of the deleterious effects of over-application of chemical fertilizers, and were especially concerned about the compaction and hardening of red soils. In China, the proportion of soils with good inherent fertility has decreased from nearly 33 percent in 1980 to 20 percent in 1995, suggesting unsustainable agricultural practices that may include the over-application of agrochemicals (Li et al. 1997).

For the application of chemical fertilizers to be environmentally sustainable, there must be no deleterious effects on the ecosystem. Environmental sustainability can be equated with long-term and large-scale economic sustainability – for example, the application of agrochemicals should not affect future productivity of downstream fisheries, jeopardize drinking water sources, or cause degradation of lands that will impact regional climate. Non-point source pollution from agriculture is becoming the dominant source of water pollution and contributing significantly to air pollution in China (Zhang et al. in prep). The accumulation of excess nutrients, such as nitrogen and phosphorus, can cause eutrophication of surface waters. Based on data available in 1996, 30 percent of chemical fertilizer applied in China was nitrogenous fertilizer in the form of ammonium bicarbonate. This chemical is extremely volatile and allows much of the nitrogen to escape to the atmosphere before plants can utilize the nutrient (Li et al 1996). In a recent study in northern China, nitrate concentration exceeded the safe drinking level (50 mg/L) in over half of the 69 locations examined. In areas with high nitrate concentration in the groundwater, high volumes of nitrogenous fertilizer were being applied to agricultural lands (van den Berg, et al. in prep). Chemical fertilizer is a significant contributor to the pollution of major lakes and rivers such as Dianchi Lake (Yunnan Province), Chao Lake (Anhui Province), and the Huai River, among others. Chemical fertilizers account for 23 percent of the discharge of nitrogen into Taihu Lake (located on the border between Zhejiang and Jiansu Provinces). The overuse of nitrogenous fertilizers on grain and vegetable production in China causes the loss of 1.74 million tons of nitrogen per year (Zhang et al., in preparation).

Certain fertilizer technologies have been developed in an attempt to reduce nitrogen emission. Enzyme inhibitors prohibit urea hydrolysis and reduce ammonium losses. While fertilizers with enzyme inhibitors have been on the market for many years, in most circumstances their benefits are not significant enough to justify their use. In the future, however, N_2O emissions may become sufficient justification for policy makers if not for farmers. Controlled release fertilizers release nutrients gradually in step with crop nutrient needs. In practice, however, success has been limited. Controlled release fertilizers are expensive, coatings easily become damaged, and the nutrient release rate is difficult to control (Bockman and Olfs 1998). Site-specific nutrient management/integrated plant nutrition management (discussed below) may be simpler alternatives to fertilizer technologies.

Improving farmers' livelihoods and reducing chemical fertilizer applications: recent and ongoing studies

The short-term economic overuse of fertilizer occurs when farmers decrease their profit margin by purchasing and using too much fertilizer. In cases where economic overuse of chemical fertilizers is occurring, farmers could reduce the amount of chemical fertilizer they apply and this would lead to both increased profitability for farmers and less air and water pollution. Researchers at the Center for Chinese Agricultural Policy (CCAP) in Beijing are currently investigating the economic overuse of chemical fertilizers in grain production in China. Since rural poverty alleviation and environmentalism are priorities for the Chinese government, reducing chemical fertilizer use could positively contribute to achieving national goals. According to Zhang et al. (in prep), surprisingly little research has been done on the relationship between chemical fertilizer application and agricultural productivity in China. The research team was able to identify only 20 studies on the economic relationship between chemical fertilizer use and output, while studies done in many Western nations number in the hundreds.

Zhang et al. conclude that China's farmers do use chemical fertilizers far in excess of the point of optimal profitability (figure 4). Moreover, the results are robust and consistent regardless of the crop, the time period, or the estimation methodology. The percent of overuse in all cases rises with time. Farmers in Jiangsu overuse chemical fertilizer by 44%, and overuse nitrogenous fertilizers by 59-67%. Farmers in Hebei and Liaoning overuse chemical fertilizers by 16-35%. In general maize growers overuse chemical fertilizers by 50-75%, wheat growers by 33-81%, and rice growers by 36-73%. Further survey-based study of the microeconomic reasons for chemical fertilizer overuse is forthcoming from CCAP.

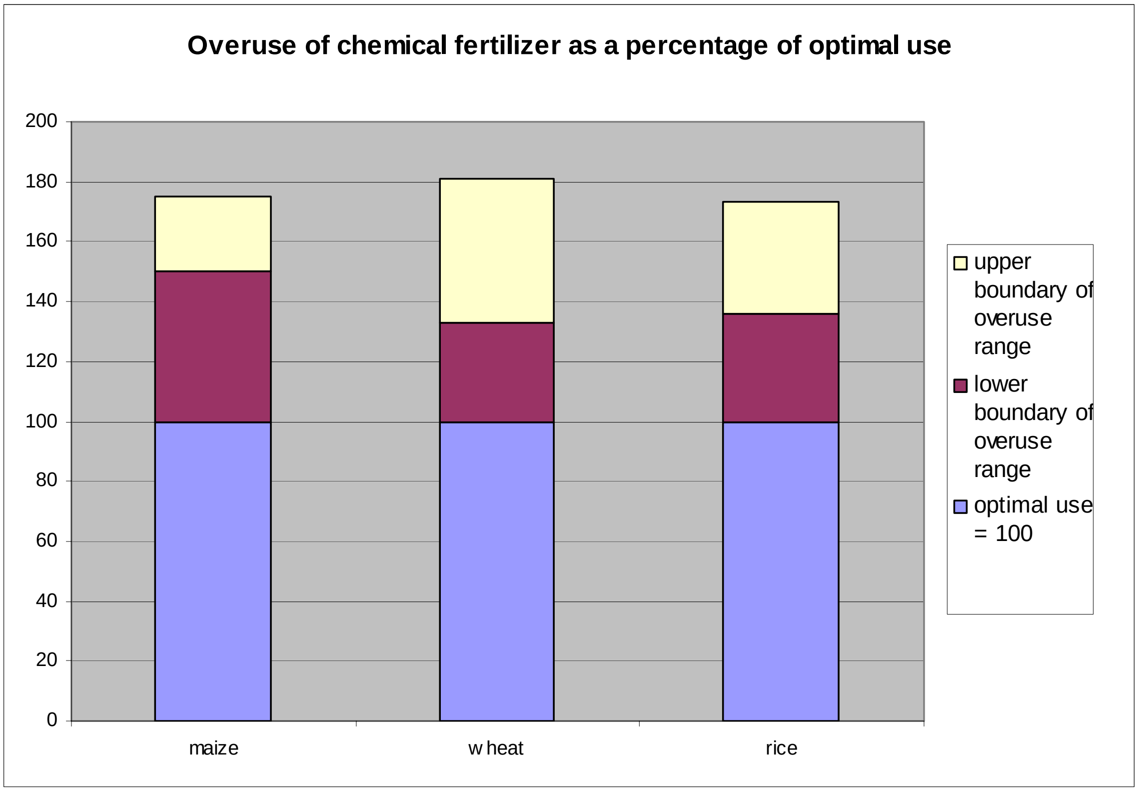

Figure 4. Overuse of chemical fertilizers as a percentage of optimal use for all of China for three different grain crops. Data source: Zhang *et al*. in prep.

The CCAP study examines economic over-use given farmers' current application practices. As the following case study from Zhejiang Province illustrates, there may be even greater potential for reducing chemical fertilizer inputs if fertilizer practices are tailored to the nutrient needs of the crop.

Zhejiang Province, located in southeast China, accounts for 7% of the nation's rice production. One point three million hectares are used for irrigated rice cropping, mostly under the double cropping system introduced in the 1960s. Given the low availability of per capita agricultural land, intensive use of labor has allowed farmers in this area to generate some of Asia's highest rice yields (van den Berg et al. in prep). The climatic and genetic yield potential for paddy rice grown in the area is 10 to 12 tons per hectare. However, rice yields have remained relatively stable at 5.5 to 6 tons per hectare for the past two decades (figure 5) (Wang et al. 2001b). These yields have been both attained and maintained through the introduction of hybrid rice varieties and increasing inputs of chemical fertilizers, which have increased five percent annually during the 1980s and early 1990s (van den Berg et al. in prep). Scientific studies throughout irrigated rice producing areas in China indicate a similar inefficiency in nitrogen uptake. In addition, recent land use changes associated with urbanization and industrialization have resulted in a two percent per year decrease in rice cultivation area totaling in losses of about 500,000 hectares of rice harvest from 1980 to 2000 (van den Berg et al. in prep). Despite increasing inputs, rice production in Zhejiang actually declined annually from 1985 to 1997 as a result of decreasing agricultural land area and slowing growth in yield (Wang et al. 2001a).

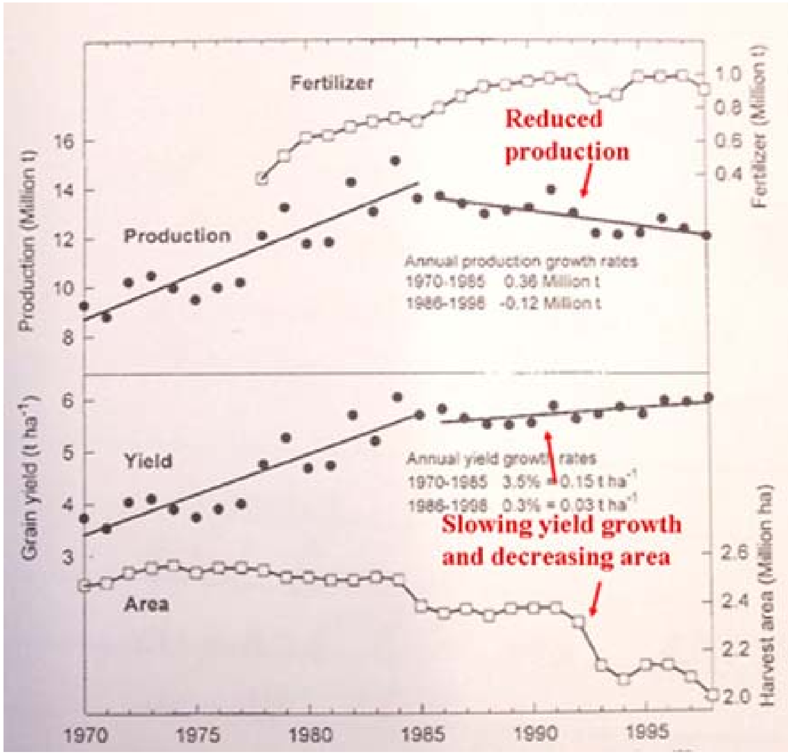

Figure 5. Trends of rice production, area, yield, and total fertilizer consumption in Zhejiang Province. Chart reproduced from Wang et al. 2001b.

Rice farmers in Zhejiang province and elsewhere have a long history of utilizing organic manure, but now, given that there are fewer animals due in part to the increasing mechanization of agriculture, farmers prefer to use the limited organic fertilizer on vegetable production. This is a cause for concern, given that long-term experiments have shown that yearly application of organic manure, including straw and stubble, is key in maintaining yield stability in rice paddies in China (Li 1993).

Recently, the International Rice Research Institute (IRRI) in combination with Zhejiang University demonstrated that site-specific nutrient management (SSNM) tools could produce high-yield rice paddies at greatly reduced nitrogenous fertilizer applications. SSNM is defined as "the dynamic, field-specific management of nutrients in a particular cropping season to optimize the supply and demand of nutrients according to their difference in cycling through soil-plant systems" (Wang et al. 2001b). Other similar approaches include "integrated plant nutrition management" or "prescribed fertilizer technologies". The purported benefits of these systems are enhanced soil fertility, reduced pollution, reduction in incidence of pests and diseases, decreased crop production cost, and increased output and income (Li et al 1997).

In Jinhua district, Zhejiang Province, improper timing and rates of application of chemical fertilizers are resulting in unnecessary nitrogen loss into surface and ground water. The typical practice of farmers in the study was to apply two large doses of 40 to 160 kilograms of nitrogenous fertilizer per hectare within the first two weeks after transplanting the rice. In 1998 and 1999, the years of the study, SSNM techniques resulted in a mean grain yield increase of eight percent, or 0.5 tons per hectare, while decreasing applications of nitrogenous fertilizer by an average of 26 percent, or 34 kilograms per hectare. One of the key differences in SSNM was a late season application of nitrogenous fertilizer, whereas in traditional farm methods, fertilizer was only applied early in the growing season. In this case, the use of SSNM reduced fertilizer expenditures by US$15 per hectare per crop, and increased gross return above fertilizer cost by US$88 per hectare per crop. The labor costs of using SSNM are minimal compared to the gains. This research resulted in an International Development Research Center grant to CCAP to develop farmer field schools in ten different villages at five sites in southern China. By 2006, CCAP plans to develop recommendations for implementing site-specific nutrient management systems nationally.

Given the high opportunity cost of farmers' time and the nationwide trend away from labor-intensive agriculture as more farmers take off-farm and part time jobs to augment their incomes, the economic gains associated with site-specific nutrient management must be sufficient to justify its adoption. SSNM reduces fertilizer inputs and increases yields, but large-scale adoption of SSNM will require technical assistance and facilitation. The type of site-specific modeling conducted in the study would be an impossible undertaking for every farm plot if SSNM were widely adopted. Alternatively, site classifications schemes and fertilizer regimes can be derived from a more generalized model. According to the research team, the performance of a simplified approach would likely be comparable to the results obtained in the study. Clearly such an approach would require technical facilitation. A logical source for such facilitation would be local agricultural extension agencies (discussed below).

Understanding the farmer's perspective: discussions in Yunnan Province

Ultimately, the individual farmer makes the decision about what kinds of fertilizer to apply and how to apply it. Any policy, regulation, incentive scheme, or outreach program designed to change fertilizer application practices must take into consideration how a farmer makes decisions about what kind of fertilizers to use and how to apply them. Discussions with nine farmers in Yunnan province in the summer of 2004 illustrate the complexity of a farmer's decision. Fertilizers used in the households interviewed include nitrogen, phosphorus, potassium, and composite chemical fertilizers, in addition to compost, plant residues, food processing residues, biogas slurry, and human and animal manure (figure 6).

Figure 6. Biogas pits in a) Shangri-la (Yunnan Province) and b) Inner Mongolia, June 2005. The end product of biogas production, called biogas slurry, makes excellent organic fertilizer.

Most farmers depend strongly upon their personal experience and the aggregate experience of their community with respect to chemical and organic fertilizer use. This was the most important factor among the small sample interviewed. The weather and the season were extremely important in determining when and how to apply fertilizers. Availability of water, including rainfall and access to irrigation, influenced the decision of whether or not to apply chemical fertilizers. Six out of nine farmers cited the effectiveness of the fertilizer as a key consideration. Several farmers also took into account the characteristics of the soil and concern for soil quality, particularly compaction of red soils. While the cost of the fertilizer was a consideration for some farmers, for most it was not. This may change as the cost of chemical fertilizer continues to rise. Concerns about the rising cost of chemical fertilizer were not voiced by farmers themselves, but rather by scholars and extension agents. Although the price of fertilizer is determined by market forces, it is government controlled to assure that prices do not become too high or too low. A few farmers also took into consideration the practices of other farmers, and the advice of the agricultural extension service.

Of the nine farmers interviewed, three used absolutely no chemical fertilizer. They, and farmers who limited chemical fertilizer application, cited many reasons for this choice, including the expense of buying chemical fertilizer, the better flavor of vegetables and fruit grown without chemical fertilizer, and the ineffectiveness of chemical fertilizer without irrigation water, at high elevation, and on certain crops (e.g. chicken peas). Some farmers chose not to use chemical fertilizers because no one else in their village does, and consequently had never considered using chemical fertilizers and were unsure how effective they would be. Typically, those who exclusively applied organic fertilizers used the advice of the extension service more than those who used chemical fertilizers, suggesting that technical extension for chemical fertilizer use is limited. Farmers using chemical fertilizers often do so because they believe the effectiveness of the fertilizer provide benefits that outweigh the cost of purchasing it. Also, access to manure is limited and can be labor intensive to collect, whereas chemical fertilizers are easy to obtain if a given farmer can afford it.

In summary, the decision about fertilizer use is complex and takes many variables into account. The importance of different factors varies widely from one individual to another, although themes are apparent. For many farmers, the decision not to use chemical fertilizer is often due to a lack of technical extension and irrigation constraints. Farmers limited their use of chemical fertilizer based on the cost, the impact on the soil, and on the taste of their produce. A significant obstacle to the use of organic fertilizers is access to animal wastes and the labor involved in collecting and applying it.

The Agricultural Technical Extension Service: a key player in agricultural practice

Technical extension agencies can be an important force in how agriculture in China is done, and thus have a role in facilitating sustainable fertilizer use. Following rural reforms and the implementation of the household responsibility system beginning in 1980, the clientele of the extension service shifted from a relatively small number of communes, brigades, and production teams, to millions of individual rural households. Significant extension reforms have occurred in response. Currently, the main roles of the extension service are experimentation on agricultural technology, demonstration, training, and commercial services such as supplying inputs (Yang 1993). The extension service operates out of county level centers and township level stations and is under the jurisdiction of government agriculture bureaus and departments. State extension personnel as well as technicians (who provide clinical services and are paid by individual farmers or villages) implement the extension service.

Agricultural extension services also provide farmers with a certified source of farm products. The head of one rural household in Lijiang municipality voiced concern over the sales of fake fertilizers by uncertified salesmen. Farmers count on the extension agency for providing good products. Other, however, have raised concerns about conflicts of interest with respect to agrochemical sales by extension agencies. Due to funding shortages, many extension agencies have also developed their own enterprises to secure additional income. These are usually, but not exclusively, related to agriculture, and commonly take the form of agrochemical sales. With a vested economic interest, extension agents have an incentive to recommend the overuse of agrochemicals. With respect to pesticide use, the potential for conflicts of interest is present not just in extension agencies, but at other levels as well – the Institute for the Control of Agrochemicals, for example, is responsible for both marketing and inspecting pesticides. Also, county plant protection stations are responsible both for the sale of pesticides and the promotion of ecological pest management (Hamburger 2002). Whether or not similar conflicts of interest are occurring in chemical fertilizer consumption remains uninvestigated.

Extension agencies face many challenges in keeping up with the recent and continuing changes in agriculture in China. For example, in Jinhua district, insufficient knowledge and guidance from the extension service has allowed for the over-application of chemical fertilizers in non-rice agricultural production (van den Berg et al. in prep). Based on data from a survey of 107 households conducted in the winter of 2002 in Pujian county (Jinhua district), average chemical fertilizer application for single-crop rice was at the upper limit of the recommended levels, and application for double-crop rice exceeded recommended levels by 25 percent. The application of relatively appropriate levels of chemical fertilizer is attributed to the strong technical extension with respect to rice cultivation. But only about half of all chemical fertilizer application in the area is on rice. Farmers are using chemical fertilizer at rates far exceeding the recommendation for other crops, such as fruits and vegetables. Fruit and vegetable cropping is gaining popularity because farmers can use these high value crops to increase their income. Technical extension for non-rice cropping is under-developed and little research has been done. This is unsurprising, given that agricultural extension agencies in China have traditionally focused on grain production according to the priority given to food security. Farmers in Pujian County are left without good advice and severely over-use chemical fertilizers in fruit and vegetable production. In addition, even recommended levels for rice cropping may be too high if chemical fertilizer application is timed according to plant needs, as demonstrated by Wang et al. (2001). Hopefully, recent studies will result in the modification of fertilizer application advice given by extension agencies. However, Dr. Wu Jiaping of Zhejiang University expressed concern that barriers to knowledge transfer between research institutions and extension agencies results in the inefficient utilization of advances in agricultural research (pers. comm.).

In Lijiang municipality, farmers earn an average income of 1200 to 1300 RMB (US$146-159) (Li, per. comm.). Good agricultural land is scarce; 90 percent of the land base is hilly, and only six percent is flatlands and valleys. Of the 13,900 mu (927 ha) of cultivated land, 8,000 mu (58 percent) are irrigated. Chemical fertilizer use varies widely among farmers; some rely exclusively on organic manures, while others use primarily chemical fertilizers. Following with the national trend, the Lijiang extension focuses primarily on grain production, although attention to vegetable production is growing. They require farmers to apply “non-polluting” agrochemicals to vegetables, and the dosage of certain chemicals is limited. Experimentation and follow-up testing is done to see how much of the chemical is retained in the produce. The goal of these “non-polluting” chemicals regulations is to ensuring that the food produced is fit for human consumption and while any reduction in chemical application is also environmentally advantageous, the program does not necessarily reflect environmental concerns. The enforcement of such a policy may be facilitated by farmers’ practice of purchasing agrochemicals from government and extension stores. The stores would then have the ability to limit the amount sold. Despite this, however, it remains unclear as to extensions capability to enforce these regulations.

The Lijiang agricultural extension agency is also engaged in soil testing activities for vegetable crops. The limited soil-testing program, implemented just last year, has resulted in increased application of potassium and decreased application of phosphorus. The office plans to extend the service, which is paid for by individual farmers, in the future. Mr. Li, the Extension Chief, was unaware of whether or not this type of testing was practiced elsewhere in China.

Making contracts with farmers

One of the ways in which the extension service functions is through technology contracts with farmers. Farmers can borrow against their harvest for technical guidance and input supply. The program is popular nationwide, and apparently unique to China (Yang 2003). Through this process, the economic interests of the farmer and the extension agent are closely linked. As of 2004, farmers in Lijiang were able to make contracts with companies responsible for the procurement and distribution of farm products, similar in some ways to the contracts made with extension agencies. Although individual contracts vary, farmers are given a guaranteed buyer and price for their vegetable products. The program has thus far been very popular in Lijiang as it provides increased security to farmers. Some contracts provide farmers directly with necessary inputs, such as agrochemicals, while other arrangements allow farmers to borrow against their harvest. The companies provide technical specifications that often include instructions for fertilizer applications. This could potentially optimize chemical fertilizer use through the facilitation of more precise fertilizer applications. Companies may have the resources to conduct soil tests and engage in their own scientific research. Given a proper incentive structure, companies could also introduce new fertilizer technologies along the lines of enzyme inhibitor and controlled release fertilizers. On the other hand, companies engaging in one-year contracts have no inherent incentive to invest in long-term sustainability. In the interest of their own short-term economic gain, these companies may specify high fertilizer inputs to maximize yields for that year with little thought to soil compaction, depletion in nutrient content and organic matter, and pollution of the watershed. Farmer associations in Lijiang are in the formative stages, and hopefully in the future such associations may have increased negotiating power with companies. As of yet, the impact of these contracts on chemical fertilizer and other agrochemical application is unclear.

Towards the sustainable use of chemical fertilizers

In June of 2002, the government of Jinhua announced that “after three years’ effort, the unit amount of chemical fertilizer and pesticide application should be reduced one third, to ensure Jinhua’s agro-products to be green, safe and environmentally healthy” (van den Berg et al. in prep). As of yet, however, the government of Jinhua has not presented any specific and detailed plan to achieve this objective.

Despite rampant overuse, farmers in China cannot be expected to decrease chemical fertilizer applications independently and without assistance and incentives. In 2002, the average annual income of farmers in China was 5,383 RMB (US$656). Traditionally, agriculture in China has been heavily taxed and has not received the heavy grain production subsidies typical of European nations and the United States. While the recent grain surplus has been good for China’s food security, falling grain prices have hurt grain-producing farmers. As shown, the precision of chemical fertilizer application in China can be improved significantly. Much of this change would actually better the economic situation of farmers by allowing them to apply less chemical fertilizers while maintaining or increasing yield.

Although it is the farmers who choose what to do in their fields, with little money come few options (figure 7). Two farmers interviewed in household surveys stated that they would like to take factors such as concern for the health and quality of land and water into consideration when applying agro-chemicals, but this is not feasible given economic constraints. It is not clear, however, whether this response indicates environmental awareness or simply a desire to please

Figure 7. Farming on slopes along the Yangtze River. When farmers are impoverished, agriculture practices are driven by necessity and circumstance.

the interviewers. Other farmers stated that they believed agrochemicals do not affect water quality, and the preliminary finding of the CCAP research team indicate similar unawareness of the environmental impacts of chemical fertilizers among farmers throughout China (Zhang, pers. comm.). Environmental consciousness and stewardship are often considered "luxuries" individuals can afford only once they have met their basic needs. For farmers in China, meeting basic needs is still a top priority. But taking into consideration China's growing population, small arable land base, valuable water resources, and deteriorating soil quality, concern for the environment is a necessity. Technical extension agencies, guided by the advances of China's research institutions, can continue to play an important role in influencing chemical fertilizer application. It is also likely that contracts with procurement and distribution companies will play an increasingly influential role in this regard. Better understanding of the factors that determine a farmer's decision are needed to ensure that these roles be deliberate and beneficial to individual farmers and to the whole of China by supporting and sustaining poverty alleviation, agricultural production, and environmental health.

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APPENDIX A. Survey Methodology and Questions

A total of eight household surveys were conducted on June 7th, 8th, and 14th in Yunnan Province. Participants were asked a 54 question survey which typically took between 60 and 90 minutes to implement. A translator read the questions in English, asked them in Chinese, and then translated the answer back to English so that notes could be taken by about four to seven students present. The survey began with demographic information and covered topics including awareness of NGO's, energy consumption, poverty indicators, impacts of the logging ban, etc. Questions asked for this study are as follows:

How many mu do you cultivate and with what crops?

What types of fertilizer do you use? If organic, please list all types (human manure, animal manure, biogas residue, compost, etc.)

If you use chemical fertilizer, how much do you apply?

I am going to list a number of factors one by one. After I read each one, please discuss how each impacts how you decide what kind of fertilizer to apply and how to apply it.

The cost of the fertilizer
How easy or difficult it is to obtain
How effective the fertilizer is
The advice of the extension service
Practices of your father
Practices of other farmers
Characteristics of the soil
The crop it is being applied to
The weather
The time of year
Concern for health and quality of the land
Concern for health and quality of water
Laws and regulations