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Identification of technology options for reducing nitrogen pollution in cropping systems of Pujiang*

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Abstract: This work analyses the potential role of nitrogen pollution technology of crop systems of Pujiang, County in Eastern China's Zhejiang Province, rice and vegetables are important cropping systems. We used a case study approach involving comparison of farmer practices and improved technologies. This approach allows assessing the impact of technology on pollution, is forward looking, and can yield information on the potential of on-the-shelf technology and provide opportunities for technology development. The approach particularly suits newly developed rice technologies with large potential of reducing nitrogen pollution and for future rice and vegetables technologies. The results showed that substantial reductions in nitrogen pollution are feasible for both types of crops.

Key words: Nutrient emissions, Pollution, Rice, Vegetables
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INTRODUCTION

Between 1965 and 2002, production of cereals increased by 148 percent and production of vegetables and melon increased by 703 percent in China (FAO, 2004). From 1995 to 1993 research-induced technical change increased agricultural growth by 20% (Fan and Pardey, 1997). Important aspects of the new technologies are improved seeds and intensive use of agrochemicals. Total fertilizer use, for example, rose from 0.7×10^6 Mt in 1962 to 35×10^6 Mt in 2001, with China now consuming about 30 percent of the world's nitrogen fertilizer (FAO, 2004).

The intensive use of agrochemicals associated with production growth has negatively impacted environmental quality. Gaseous nitrogen losses from paddy fields contribute significantly to global warming. On a local scale, losses of fertilizers from agricultural fields have resulted in eutrophication of surface water in the intensively cultivated East (Ellis and Wang, 1997). Furthermore, a recent study on water quality in vegetable-production areas in northern China showed that nitrate pollution in ground and drinking water has become a serious problem (Zhang *et al*., 1996). Nitrate contents exceeded the European limit of 50 mg/L for drinking water in over half of the 69 sites investigated, and in the worst case the nitrate content of the groundwater reached 3.5 times the drinking-water limit. In all sites surveyed, high amounts of nitrogen fertilizer were applied: recorded N rates reached up to 1900 kg/ha per year. Similar levels of fertilizer input and emissions were observed in vegetable production in eastern and southern China (Sheldrick *et al*., 2003).

Agricultural research recognized the downside of the rapid rise in agrochemicals use and focused increasingly on the development of more sustainable technologies (Smil, 1998; Zhu and Chen, 2002). The

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question is how large is the potential impact of research in decreasing agricultural pollution, what are the possible effects of improved nitrogen recovery on pollution in rice-based systems?

This paper analyses these issues for Pujiang, a Zhejiang Province County in Eastern China. We used a scenario-type of analysis to assess whether science and innovation can indeed play an important role in increasing the sustainability of agricultural production in the area considering both local on-the-shelf technologies for improved nitrogen recovery and future technologies that seem realistic given experience in other areas.

The case study approach used in this study involves comparing farmer practices with data from local research and technologies developed for other regions. This approach deviates from the standard economic method used to assess the impact of research: the production function approach, involving estimation of total agricultural production at the regional or national level as a function of inputs or resources and research expenditures (Fan, 2000). The approach has the advantage of achieving valid results for large areas but cannot be used to assess the impact of research on agricultural pollution, as the required data on nutrient losses are not available. Moreover, the case study approach has the advantage of being forward looking. We assess the potential future impact, not the past impact of research as in the production-function approach.

AGRICULTURAL TECHNOLOGY AND FERTILIZER USE

When farmers decide on fertilizer application, they mostly do not simply balance fertilizer prices and expected marginal returns. Farmers often use more than the profit-maximizing level of fertilizers (Babcock, 1992). They use decision criteria such as “fertilizing for the good years” or “applying a little extra fertilizer just in case it is needed”. This behavior is the result of risk aversion and weakens the direct link between prices and fertilizer use, but is not necessarily inconsistent with expected profit maximization. If ex post optimal fertilizer rates are positively correlated with yield, which is the case if fertilizer is inexpensive relative to its marginal value in production when less-than-optimal rates are applied, fertilizing for average conditions leads to relatively high levels of foregone income in good years, while the costs of some additional fertilizers in normal years are relatively low (Babcock and Blackmer, 1994). Likewise, uncertainty on the availability of nutrients in the soil can explain the observed high levels of fertilizer application. If the marginal product of a nutrient is a convex function, increasing uncertainty on the availability of soil nutrients will increase nutrient application. In this case, when farmers use more nutrients than needed given average soil nutrients, they gain much when soil nutrients are below average and lose only little when soil nitrogen is average or above. This is true for many functions, such as the Cobb-Douglas and the Mitscherlich production function (Babcock, 1992). Summarizing, uncertainty on weather conditions and soil quality will induce risk-averse farmers to apply more fertilizers than the static profit-maximization amount.

Typical fertilizer recommendations from agricultural research institutes are independent of prices and reflect ‘optimal’ fertilizer rates, i.e., the minimum amount of fertilizer needed to reach maximum yield under optimal conditions. This type of recommendation disregards economic optimization, but is not inconsistent with the general farmer strategy of fertilizing “for the good years”: good years being the farmer’s equivalent of optimal conditions at the research stations. Hence, optimizing farmers have no reason to apply more than this amount of fertilizers, unless the rates are only optimal with a costly technology or farmers have large surpluses of organic fertilizers from intensive livestock production and the cheapest means of disposal is on-farm application. Hence, it seems reasonable to assume that farmers will adopt typical fertilizer recommendations if these involve lower fertilizer rates than they currently apply, unless the recommendations are associated with costly supplementary measures.

Not fertilizer use per se but its impact on the quality of soils, water and other natural resources are relevant for sustainability. The intensive agriculture in Zhejiang Province results in large emissions of nutrients to the environment. These emissions depend not only on the amount of fertilizer applied but also on the method of fertilization. Agronomic research has aimed to increase both crop yields and nutrient uptake, through, for example, fine-tuning the timing and doses of fertilizer applications with respect to crop requirements under given local conditions. That is, improved technologies not only involve higher yields but also higher use efficiency and thus lower nutrient losses per kg of product.

Fig.1 shows the relation between technology, fertilizer use and losses. The positive *Y*-axis represents yield. There are two non-decreasing production functions. The continuous line above the dotted line of current farmer practice represents an improved technology developed at the research station. Both lines are functions increasing to plateaus that lie below the potential yield as determined by crop characteristics, temperature and radiation. It is assumed that the only difference between the two existing technologies lies in the timing of fertilizer applications. Hence, shifting from farmer to improved technology only requires additional knowledge/skills and no change in inputs other than fertilizers. The lines below the *X*-axis represent the relation between fertilizer dose and fertilizer losses. Fertilizer uptake rates are highest for the improved technology. That is, for the improved technology the same fertilizer application leads to lower losses to the environment than for the current farmer practice. Additional research could result in further increase in fertilizer uptake rates and uplifting of the yield plateau to not higher than the potential yield.

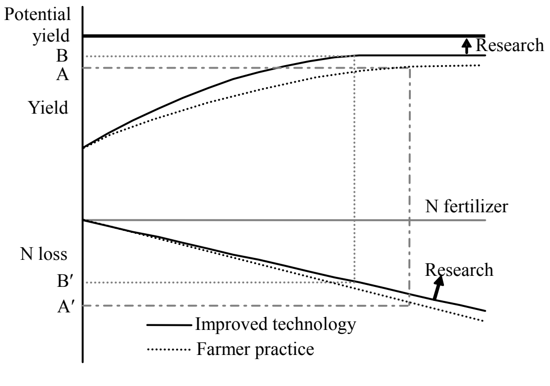


Fig.1 Fertilizer productivity and losses for different technologies

A knowledgeable farmer aiming for maximum yield with minimum fertilizer use will produce A with fertilizer loss A′. After being informed about the new technology, he will shift to slightly higher yield B with lower fertilizer use B′. Hence, the improved technology results in a reduction in fertilizer losses from A′ to B′ through both decreasing total fertilizer use and the share of fertilizers lost to the environment.

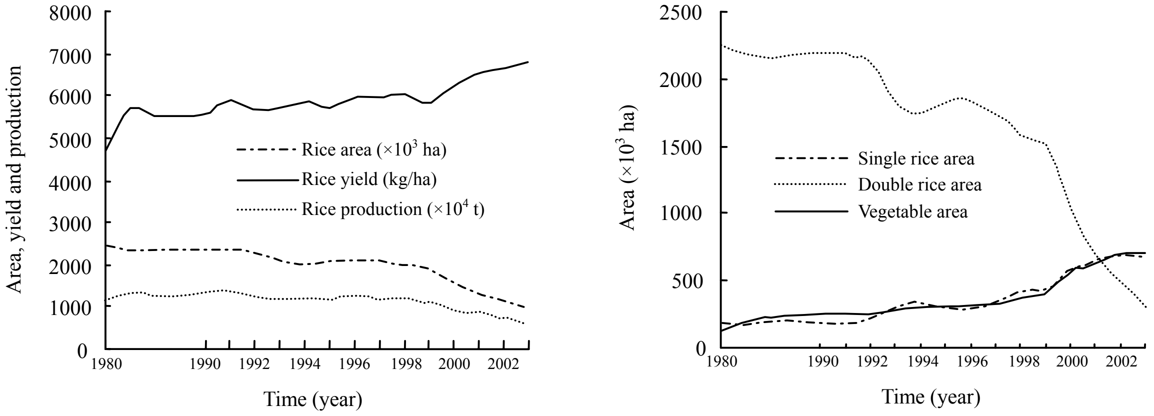
MATERIALS AND METHODS

Fertilizer use and environmental problems in Pujiang

Fertile soils and abundant water resources make Zhejiang and the other parts of China's greater Yangtze River Delta, one of the world's most productive rice growing regions. With low per-capita land available, farmers here have traditionally generated some of Asia's highest rice yields through intensive use of labor. Throughout the People's Republic period, continuous population growth and a concern for rice self-sufficiency stimulated technological development, which increased yields even further. The modern technologies involve dwarf-varieties and hybrids that are highly responsive to fertilizers and have a climate-adjusted, genetic yield potential of 10~12 t/(ha crop) in Zhejiang Province (Huang and Rozelle, 1996; Widawsky *et al*., 1998). Zhejiang farmers have adopted at a large scale these varieties and have increased their use of chemical fertilizers at about 5 percent per year during the 1980s and early 1990s (Widawsky *et al*., 1998).

Despite these large technological developments, farmer yields have stagnated at 5.5~6 t/(ha crop) since 1985, and total rice production has decreased dramatically, especially since the late 1990s (Fig.2). Industrialization and urbanization have caused a decline in rice production area of about 2 percent per year between 1980 and 2003, which has resulted in a loss of about 500 000 ha of rice cultivation area (Wang *et al*., 2001). Moreover, Zhejiang was the first province where farmers became completely free in their choice of crops. Rice prices have been low (Dawe, 2002) and many farmers have replaced double rice for single rice production or for alternative crops such as fruits and vegetables. These crops used about half of all fertilizers applied in the province in 2001 (Zhejiang Statistic Bureau, 2001).

At a national level, grain production showed a declining trend for four consecutive years since 2000. Out of concern for the nation's food security, the gov-



(a) (b)

Fig.2 Rice (a) and vegetable (b) production in Zhejiang Province (Zhejiang Statistic Bureau, 2001)

ernment promulgated a series measures to rejuvenate grain production in 2004. Major policies include setting minimum product prices, lowering agricultural taxes, giving subsidies to grain producers directly, and abolishing industrial development zones (People's Daily Online, 2004a; 2004b). Preliminary statistics indicated that these policies have resulted in a favorable turn for grain output from decline to growth at the national level (People's Daily Online, 2004c). In Zhejiang, rice prices increased by about 30 percent. This seems to have resulted in a significant increase in rice production, but corroborating data are not yet available. The future will show whether the shift in policy will overturn Zhejiang Province's decline in rice production.

Zhejiang faces severe water quality problems, partly caused by agriculture. One of the three most polluted lakes in China, Lake Taihu, lies on the border between Zhejiang and Jiangsu Province. The lake water is highly eutrophicated by nutrients, no longer fit for drinking. During summer, excessive algae growth produces a foul smelling layer on the lake surface. The water quality of tributary rivers, canals and ditches is even worse (Luijkx, 2002). Chemical fertilizers accounted for 23 percent of nitrogen discharged into Taihu Basin (NIES, 1996; Luijkx, 2002).

Data collection

In November and December 2003, we conducted a survey among 156 randomly selected farm households in Pujiang, a Zhejiang Province County under the jurisdiction of Jinhua City (Fig.3). The main purpose of the survey was to get insight into the diversity of agricultural technologies used in the area. Pujiang County covers both lowland and upland areas. Rice and horticultural crops are the dominant cropping systems in the lowlands, while tea, mulberry and fruit trees are grown on sloping land. Livestock production is gaining importance in the region, with several farms specialized in the production of chickens, ducks or pigs.

The surveyed households were selected in a number of steps (Fang, 2004). To begin with, the spread of households over the county was decided. The number of households to be interviewed per agro-ecological zone was determined according to population proportions, and the minimum number of households in each of the 16 townships was set to 5. A list of farm types was made which should all be represented in the survey, e.g., rice farm, vegetable farm, pig farm, chicken farm. For the larger farm types, e.g., those for intensive livestock production, fruit plantations; households were selected randomly from a complete list of farms from the Agricultural Bureau. As smallholder farms were not formally listed, the survey group drafted lists with local officials. The group first went to different township offices and had discussions with the officials in charge of agriculture. Based on these discussions, the group selected representative villages and then went to the selected villages where the village head drew up a list of the farm types. Survey households were randomly selected from these lists.

During the survey, data on crop production and input use were collected for each farm plot separately. This yielded input and output data for 138 fields with single rice, double rice, or horticultural crops. In our analysis we focused on the use and losses of nitrogen, the nutrient causing most problems to the environment. Virtually all fertilizers applied are inorganic, as organic manure is produced mainly in specialized farms and not traded with crop farmers.

Computing nitrogen losses using TechnoGIN

Nitrogen losses were computed for each cropping system at average fertilizer applications for all fields using TechnoGIN (Ponsioen *et al.*, 2005), a generic expert tool for integrating different types of information on crop production (Hengsdijk and van Ittersum, 2003). Based on soil, crop and technology characteristics, TechnoGIN allows characterization of cropping systems in terms of inputs and outputs, including the amount of nutrients lost to the environment. TechnoGIN has been calibrated for conditions in Pujiang on the basis of the 2002 survey and local experimental data (Wang *et al.*, 2001; Fang, 2004). TechnoGIN computes per hectare nitrogen leaching and gaseous nitrogen losses, which we combined to total nitrogen losses for Pujiang County using data from the Zhejiang Statistic Bureau on county-level acreage per cropping system.

RESULTS

Survey results

Average fertilizer use was especially high for horticultural crops: 920 kg N/(ha·a), compared to 350 kg N/(ha·a) for double rice crop and 200 kg N/(ha·a) for single rice crop (Table 1). Previous research suggested that these high values are realistic. The average fertilization rate of field-grown vegetables was

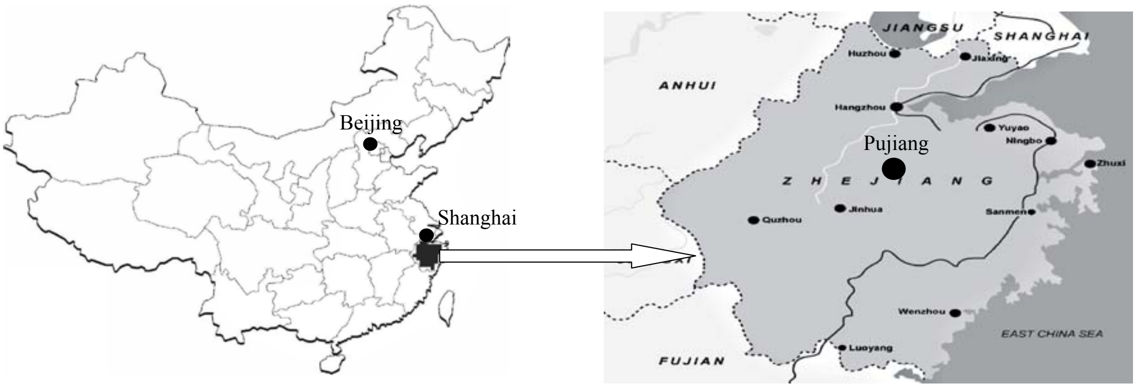


Fig.3 Pujiang County, Zhejiang Province

Table 1 Nitrogen use and losses in Pujiang County

	Double rice	Single rice	Annual horticulture
Field-level averages			
Number of observations	38	56	44
N-fertilizer (kg/(ha·a))[a]	350	200	920
N-leaching (kg/(ha·a))[b]	28.2	21.3	449.1[e]
Gaseous N losses (kg/(ha·a))[b]	221.7	138.8	242.3
Apparent N-recovery efficiency (ANRE)[b,d]	0.17	0.21	0.14[e]
County-level estimates			
Total area under cropping system (ha)[c]	4187	5105	3729
Total N-leaching ($\times10^3$ kg/a)[f]	118.07	108.74	1674.70
Total gaseous N-losses ($\times10^3$ kg/a)[g]	928.26	708.57	903.54

Sources: [a]Own survey in December 2003; [b]TechnoGIN computations; [c]Zhejiang Statistic Bureau (2002);

Notes: [d]ANRE=(crop uptake N-uptake N on 0 N plot)/N fertilizer; [e]Computed for the common cropping system greens-celery-radish with average fertilizer use of 920 kg N/ha. This is higher than average, since not all systems have triple crops. Single or double cropping systems have lower fertilizer N input, but also lower crop uptake; [f]Total N-leaching=N-fertilizer×Total area under cropping system; [g]Total gaseous N-losses=Gaseous N losses×Total area under cropping system found to be 781 kg N/ha in Beijing suburbs and 1894 kg N/ha in Fanzuhuang, Yutian (Härdter and Fairhurst, 2003; Zhang *et al.*, 1996). Fertilization of greenhouse vegetables was even more excessive, with measured averages of 2388 kg N/ha in Shouguang, Shandong (Härdter and Fairhurst, 2003).

As nitrogen uptake efficiency was low for all crops, the greater part of all nitrogen fertilizer ended up in the environment. The estimated county-level total losses of nitrogen are highest for single rice, the dominant cropping system in the county: 817 t/a estimated total losses for single rice; 1046 t/a for double rice and 2578 t/a for annual horticulture. The differences in total estimated nitrogen losses between the systems are small relative to the differences in acreage: on a per-hectare basis, single rice crop has the smallest nitrogen losses and annual horticulture the largest. This is not only the result of larger cropping intensity, but also of less efficient fertilizer use as reflected by a lower apparent nitrogen-recovery efficiency (ANRE, Table 1).

Due to the relatively large share of leaching in total nitrogen losses for horticultural crops, horticulture already contributed more to water pollution than rice did. If the trend of substitution of rice for horticulture continues, this will cause further deterioration of ground and surface water quality. Research in northern China indicated that the nitrate content in groundwater exceeds the European limits for drinking water when more than 500 kg N/ha is applied and less than 40 percent of applied N is taken up (Zhang *et al.*, 1996). In Pujiang fertilization of vegetables largely exceeds these limits. On the other hand, if China's new policies to stimulate rice production succeed in offsetting the trend of increased cultivation of horticultural crops, water quality is likely to improve.

While leaching from rice cultivation is limited, gaseous nitrogen losses from paddy fields are relatively large. These gasses contribute to global warming and are thus harmful for the global environment. The market-induced shift from double to single rice is good news in this respect: it involves a significant reduction in nitrogen losses.

The local government recognizes the damage that intensive fertilization can do to the environment and has declared its intention to reduce fertilizer use. At the same time, fertilizer intensity is likely to increase in the near future due to an ongoing shift in the cropping pattern from rice to horticultural crops. Although the government has not announced specific measures, the proclamation stresses the role of research and technology. Below, we analyze the potential impact of recently developed technologies and realistic development of more advanced future technologies.

Improving nitrogen efficiency in rice

In recent experiments on 21 farms in seven villages in Jinhua district, which also comprises Pujiang County, researchers have succeeded in increasing the ANRE in double rice from 0.2 kg plant N/kg fertilizer N in the farmer's fertilizer practice to 0.3 kg plant N/kg fertilizer N using site-specific nutrient management (SSNM) (Wang *et al.*, 2001). The SSNM approach optimizes the use of nutrients from soil, crop residues, and fertilizers. Whereas most farmers supply all fertilizers within the first 10 d after transplanting, SSNM involves a basic dressing and three top dressings at different development stages of the crop. Moreover, the new technology involves giving up the common practice of mid-season drainage, which causes large losses of nitrogen to the atmosphere. The result is an 8 percent higher yield at a 25 percent lower N-fertilizer use (Table 2). This is associated with a reduction in gaseous losses of 26 percent and leaching of 32 percent.

We translated the experimental results for SSNM in double rice to single rice. We assumed the yield increase from farmer practice to SSNM and the ANRE of SSNM to be the same for single rice as for double rice. The ANRE in farmer practice was higher in single rice than in double rice, but SSNM as defined has still significant impact on nitrogen losses: Nitrogen leaching decreased by 20 percent and gaseous nitrogen losses by 19 percent.

The newly developed technology of SSNM seems attractive for farmers, especially for double rice. It enables increase in yields at lower fertilizer use. The additional costs are low. Planting density is somewhat higher, which requires more seeds and labor. But these additional costs are more than compensated for by the lower fertilizer costs and higher yields. There are also additional labor costs for real-time N management. These costs are low, but involve some daily work over a longer period. It has been argued that this could be problematic in a region where many farmers are involved in nonfarm employ-

Table 2 Comparison of N use and losses between farmer practice and improved technologies for rice

Items	Double rice	Single rice
Farmer practice		
Yield ($\times10^3$ kg/(ha·a))	10.7	7.1
N-fertilizer (kg/(ha·a))	350	200
N-leaching (kg/(ha·a))	28.2	21.3
Gaseous N losses (kg/(ha·a))	221.7	138.8
Site-specific nutrient management (SSNM)		
Yields ($\times10^3$ kg/(ha·a))	11.5 (8%)	7.7 (8%)
N-fertilizer (kg/(ha·a))	263 (−25%)	150 (−25%)
N-leaching (kg/(ha·a))	20.9 (−26%)	17 (−20%)
Gaseous N-losses (kg/(ha·a))	151.3 (−32%)	112 (−19%)
Change in net income (Yuan/(ha·a))	1405	1067
Future-oriented technology: apparent N-recovery=0.40		
Yields ($\times10^3$ kg/(ha·a))	11.5 (0%)	7.7 (0%)
N-fertilizer (kg/(ha·a))	198.2 (−25%)	105 (−30%)
N-leaching (kg/(ha·a))	14.7 (−30%)	12 (−29%)
Gaseous N-losses (kg/(ha·a))	100.1 (−34%)	87.9 (−22%)
Change in net income (Yuan/(ha·a))	1543	1162
Future-oriented technology: apparent N-recovery=0.50		
Yields ($\times10^3$ kg/(ha·a))	11.5 (0%)	7.7 (0%)
N-fertilizer (kg/(ha·a))	132 (−50%)	84 (−44%)
N-leaching (kg/(ha·a))	12 (−43%)	10 (−41%)
Gaseous N-losses (kg/(ha·a))	81 (−46%)	52 (−54%)
Change in net income (Yuan/(ha·a))	1648	1207

Sources: Farmer yields and fertilizer use are survey averages. Yields for SSNM are 8% higher than average farmer yields (Wang *et al*., 2004); Fertilizer use for SSNM is computed based on an apparent N recovery of 0.27 and indigenous nutrient supply of 0.7 kg/d (Wang *et al*., 2004); All nitrogen losses are computed by TechnoGIN;

Note: Numbers in parentheses are change with respect to farmer practice for SSNM and changes with respect to SSNM for future technologies; Changes in net income are the difference between average farmer practice and the improved technology using 2004 prices

ment, but that this problem could be overcome through a community-oriented program with one person doing it for many (say about 20) fields per day (Wang *et al*., 2004). Alternatively, the task could be assigned to those household members who are not involved in nonfarm employment or who are involved in local nonfarm employment and thus live on the farm. Taking into account the yield increase and lower nitrogen use but ignoring the (only slightly) higher seed and labor costs, the increase in income that farmers can gain from the new technology is 1405 Yuan for double rice and 1067 Yuan for single rice. Most of this rise is due to the increase in yields associated with the improved technology.

Despite these recent technological developments, there is still scope for improving N-use efficiency in rice. Apparent recovery rates of SSNM are 0.3 kg plant N/kg fertilizer N, while with good management it is possible to achieve rates of 0.5~0.6 in irrigated rice (Fischer, 1998). These rates could be reached through an even more real-time N management (Peng *et al*., 1996). We computed nitrogen requirements and losses for apparent N-recovery rates of 0.4 and 0.5 to gain insight on the consequences of the development and adoption of such technologies for environmental sustainability (Table 2). The results showed that much could be gained from these technologies in terms of sustainability. An increase of the apparent N-recovery of 0.3 to 0.4 results in a decrease in total nitrogen losses of 32 percent for double rice and 25 percent for single rice. A further increase to 0.5 would result in another decrease of 14 and 16 percentage points for double and single rice, respectively. The direct economic gains for farmers from increasing nitrogen efficiency without increasing yields are, however, relatively low, as fertilizers are relatively cheap.

Improving nitrogen efficiency in vegetables

Fertilizer recovery rate for rice production is even lower than that for horticultural production (Table 3). Extension for non-rice crops is relatively weak, and there is limited site-specific research on annual vegetables and fruits. Hence, we could not find data on improved non-rice technologies. To compensate for this absence of field data, we used TechnoGIN to compute potential technologies for the common rotation of greens-celery-rice. We increased the ANRE from 0.14 in farmer practice to 0.20 and 0.25 assuming that yields remain the same. Like SSNM techniques in rice, these changes could be achieved by fine-tuning fertilizer input to crop requirements. The results of our computations were promising: Increase of ANRE from 0.14 to 0.20 resulted in a decrease in nitrogen fertilizer of 32 percentages and a decrease in nitrogen losses of 29 percentages. A consecutive increase of ANRE to 0.25 would imply another decrease in nitrogen costs by 14 percentage points and nitrogen losses by 16 percentage points. Although we assumed yields to be the same, these potential technologies result in significant increase in net income due to a reduction of fertilizer use, especially for the first efficiency increase: 628 Yuan for an increase in ANRE to 0.20 and another 167 Yuan for the increase in ANRE to 0.25. These computations indicate that there is ample scope for the introduction of new technologies beneficial for farmer income and the environment.

CONCLUSION

This paper analyses the potential role of agricultural technology for Pujiang, a county in Zhejiang Province. We used a case study approach involving comparison of farmer practices and improved technologies. The analyses showed that fertilizer intensity and emissions to the environment are high in single rice, double rice and annual horticulture in the three main cropping systems of the Pujiang lowland. Until 2004, the share of vegetables was increasing at the cost of rice production, but recent policies to promote grain production have offset this trend at least temporarily. In 2003, annual horticulture contributed more than rice to water pollution, despite the still limited area assigned to horticultural crops. Rice production, on the other hand, contributed significantly to global warming through losses of nitrogen to the atmosphere. Government agricultural production policies therefore not only affect China's self-sufficiency in staples, but also agricultural pollution of the groundwater and the atmosphere.

Comparison of average farm practice with improved technologies indicated newly developed rice

Table 3 Comparison of N use and losses between farmer practice and improved technologies for vegetables

Items	Greens-celery-radish
Farmer practice	
Yield ($\times10^3$ kg/(ha·a))	42.2-50-30
N-fertilizer (kg/(ha·a))	920
N-leaching (kg/(ha·a))	449.1
Gaseous N losses (kg/(ha·a))	242.3
Future-oriented technology: apparent N-recovery=0.20	
N-fertilizer (kg/(ha·a))	625 (−32%)
N-leaching (kg/(ha·a))	330 (−27%)
Gaseous N-losses (kg/(ha·a))	168 (−31%)
Change in net income (Yuan/(ha·a))	628
Future-oriented technology: apparent N-recovery=0.25	
N-fertilizer (kg/(ha·a))	500 (−46%)
N-leaching (kg/(ha·a))	259 (−42%)
Gaseous N-losses (kg/(ha·a))	132 (−46%)
Change in net income (Yuan/(ha·a))	895

Sources: Farmer yields and fertilizer use are survey averages. Future technologies and nitrogen losses are computed by TechnoGIN as described in Table 2. Yields are assumed identical for all technologies;

Note: Changes in net income are the difference between average farmer practice and the improved technology using 2004 prices; Quantity in parentheses represents change with respect to the farmer practice technologies have large potential for decreasing fertilizer pollution, especially when they are associated with increases in yields. The monetary costs for the new technologies are lower than the gains, but implementation requires knowledge and small amounts of daily labor over a longer period. Extension, supported by enabling policies, could cover these factors to promote adoption. Besides, there is potential for additional research on increasing fertilizer efficiency through crop management. We could not find any information on on-the-shelf technologies that decrease nitrogen losses for annual horticulture. Model computations, however, indicated that there is large potential for increasing fertilizer efficiency and decreasing nitrogen use in these crops.

Yet we realize that development of new technologies alone may have limited impact on nitrogen losses. The motivation of the extension service to disseminate new, more sustainable, fertilizer technology is likely to be low, as extension workers currently earn money from selling fertilizers. A first important step of the government in decreasing agricultural pollution would therefore be increasing basic funds for extension and severing the link between extension and fertilizer sales. This will allow the potential of existing technologies to be better exploited.

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