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ScienceDirect
Agricultural Systems 94 (2007) 331–340
AGRICULTURAL SYSTEMS
www.elsevier.com/locate/agsy

Farmer participatory testing of standard and modified site-specific nitrogen management for irrigated rice in China

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Received 24 March 2006; received in revised form 8 September 2006; accepted 4 October 2006

Abstract

Rice in China receives high amounts of fertilizer nitrogen (N) that are often not used efficiently by the crop. A recently developed site-specific N management (SSNM) approach enables the application of fertilizer N to dynamically match the field- and season-specific needs of the rice crop for N. We used farmer participatory research for on-farm testing of N fertilization by standard and farmer-modified SSNM for irrigated rice. Our study was done in 14 villages in four provinces of China in 2003 and 2004. Twelve to 15 farmers were randomly selected in each study village in each year for a dialogue with the research team and for a rapid rural technology assessment (RRTA). Based on the information obtained from the RRTA, modified SSNM (MSSNM) schemes were developed through dialogue between a research team and farmers at a workshop in each village. Modification mainly involved decreasing the number of fertilizer-N topdressings and increasing the rate of basal N application. Among the 514 farmers surveyed during the workshops, 95% were willing to adopt SSNM and MSSNM technologies and 76% were willing to conduct SSNM or MSSNM experiments. More than two-thirds of the farmers preferred adopting MSSNM rather than the standard SSNM. Based on the farmers' willingness, 144 farmers were selected to conduct an experiment to compare SSNM or MSSNM with the farmers' fertilizer practices (FFP). The rate and distribution of fertilizer N during the growing season of MSSNM were in between those of SSNM and FFP. SSNM and MSSNM, compared with FFP, maintained rice yields with significantly less fertilizer N and no significant increase in total labour input. The reduction in fertilizer-N input averaged 48 kg N/ha for SSNM and 23 kg N/ha for MSSNM. The study suggests that there is potential for large-scale dissemination of SSNM technology in China.

Keywords: Farmers' fertilizer practices; Farmer participatory research; Rice; Site-specific nitrogen management

1. Introduction

Rice farmers in China often use high rates of fertilizer nitrogen (N), leading to low agronomic N use efficiency, expressed as the gain in yield per unit of N applied (Zhu, 1985; Zhang et al., 1988; Li, 1997; Li, 2000). This inefficient use of fertilizer N can harm the environment through losses of excess N into the atmosphere or water bodies (Zhu, 2003). It can also increase the susceptibility of the crop to lodging and disease (Webster and Gunnell, 1992) and constrain opportunities to increase rice yield (Peng et al.,

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0308-521X/$ - see front matter
doi:10.1016/j.agsy.2006.10.002

2002). Excess application of fertilizer N favours the survival, fitness, and reproduction of insect pests (Lu et al., 2004), which can lead to increased use of pesticides by farmers.

Peng et al. (2006), in studies across major irrigated rice-growing areas of China, reported considerable opportunities for site-specific N management (SSNM) to maintain or even increase yield with less fertilizer N than typically used by farmers. With SSNM, the timing and rates of fertilizer N are dynamically adjusted to match the field- and season-specific needs of the crop for N (Wang et al., 2001; Buresh et al., 2005; IRRI, 2006). The needs of the rice crop for N depend upon its growth stage. Young rice plants grow slowly and have relatively low demand for N. SSNM therefore advocates the use of only small to moderate amounts of fertilizer N during the first two weeks after transplanting. At subsequent growth stages of tillering and panicle initiation, the crop requires more N to support its relatively rapid growth. SSNM advocates the matching of fertilizer-N use at these critical stages with the need of the crop as determined by leaf colour, which serves as an indirect measure of leaf N status. Either the frequency or the dosage of fertilizer-N application is increased as plants become more yellowish green, indicating a lower leaf N status and higher need for supplemental N.

In research trials, comparable or higher rice yields were achieved with SSNM while saving 30% or more fertilizer N compared with farmers' fertilizer-N management at study sites in four provinces in China (Peng et al., 2006). This suggested that the SSNM technology has huge potential to increase the efficiency of fertilizer-N use and reduce negative environmental impacts from excess fertilizer use if the technology is diffused and adopted by farmers. However, effectively extending this technology faces challenges because it differs significantly from current farmers' fertilizer practices (FFP).

Farmers usually modify newly developed technologies to fit their specific production environments and their personal financial capacity (Anderson, 1993; Byerlee, 1993; Adesina and Chianu, 2002). Extension technicians could play a useful role by "moderating" the modification process, and thus collaborating with farmers to avoid yield reduction or the tendency to use excessive inputs. Scientists could also participate in the process, providing scientific knowledge in areas where farmers and technicians are not very familiar with the technology. Farmer participatory research (FPR) can be an effective approach in rural technology development and diffusion (Rhoades, 1997; Croxton, 1999; Poudel et al., 2000; Huan et al., 2005). It is used as one of the approaches to improve agricultural technologies in China (Hu et al., 2002), although it is still not widely practiced. It builds on early work by Rhoades and Booth (1982), who introduced the farmer-back-to-farmer model. This paper presents the processes and results of on-farm testing of standard and modified SSNM technologies through FPR for irrigated rice in four provinces in China.

2. Materials and methods

Our FPR approach was divided into four phases: site selection, consultation between farmers and researchers to design the modified SSNM (MSSNM) schemes, decision-making by farmers to evaluate SSNM or MSSNM, and the implementation of an FPR experiment on the evaluation of SSNM or MSSNM technology.

2.1. Site selection

One county from each of four provinces in China was selected, Xinxing from Guangdong, Ningxiang from Hunan, Xiaonan from Hubei, and Hanjiang from Jiangsu. In 2003, three villages each from Xinxing and Ningxiang counties were selected randomly for the FPR study. In 2004, two villages each from all four counties were selected randomly for the FPR study. In Xinxing and Ningxiang, the two villages selected in 2004 were different from the three villages selected in 2003. The study included a total of 14 villages across 2003 and 2004.

The four provinces are the major rice-producing provinces in China. Rice accounts for more than two-thirds of the cropped area in all four counties, and rice yields in the selected counties are higher than or close to the provincial average (Table 1). The cropping systems were double-season rice in Hunan and Guangdong, single-season rice in Jiangsu, and both double- and single-season rice in Hubei. The topography was plain for Hanjiang and parts of Ningxiang and Xiaonan, mountainous for Xinxing, and hilly for parts of Xiaonan and Ningxiang. All four counties are located in the subtropics.

2.2. Farmer–researcher dialogue to design MSSNM schemes

The following activities were done in designing MSSNM schemes:

Rapid rural technology assessment (RRTA): Twelve to 15 farmers were randomly selected to attend a dialogue between farmers and researchers in each selected study village in each year. Through this dialogue, an RRTA survey was conducted to understand the current FFP, inputs and outputs, market infrastructure for rice grain, profitability of rice production, cropping system, varieties, and local practices and conditions for rice production. After completing the RRTA, the research team, including agronomists, economists, and local technicians, asked local leaders to invite village farmers to attend a workshop on SSNM technology the following day in the village.

Proposed modification of SSNM technology: The research team used information obtained from the RRTA and knowledge of SSNM technology to develop a set of initial suggestions for the modification of SSNM technology in the village. These suggestions were prepared based on the RRTA before the workshop with farmers, and farmers were given the opportunity to further modify the recommendations during the workshop.

Workshop on SSNM and modification of SSNM: The workshop was divided into three phases. In the first phase, the research team presented information collected from the RRTA on current FFP for rice in the village. Additional information on FFP from the farmers who did not attend the RRTA was also included. Then, the scientists presented the results of previous SSNM experiments conducted in the local county or province and presented the proposed modification of the SSNM technology. The third and most important phase of the workshop was a dialogue between researchers and farmers on the local FFP and the proposed modification of SSNM. After sufficient discussion, workshop participants finalized the MSSNM and local FFP schemes.

Table 1
Information on the rice production system in the study counties

County	Province	Rice planting area ($\times 10^3$ ha)	Rice relative to total cropped area (%)	Rice yield (t/ha)	Average rice yield in the province (t/ha)	Rice cropping system	Topography
Xinxing	Guangdong	20	84	7.0	5.5	Double-season rice	Mountainous
Ningxiang	Hunan	102	89	6.4	6.0	Double-season rice	Plain/hilly
Hanjiang	Jiangsu	21	67	8.4	7.6	Single-season rice	Plain
Xiaonan	Hubei	27	67	7.2	7.4	Single- or double-season rice	Plain/hilly

Source: Locally published statistics and China Agricultural Year Book, 2004 MOA (2004).

2.3. Decision-making by farmers to evaluate SSNM or MSSNM technologies

After MSSNM schemes were finalized, farmers were given some time to reflect on and understand the technology. Then, the research team asked the farmers who participated in the workshop whether they were willing to adopt SSNM and MSSNM technologies and, if so, which of the two they preferred to adopt.

Among the farmers who expressed their willingness to adopt SSNM or MSSNM technology, the research team further asked who was willing to conduct FPR experiments to evaluate SSNM or MSSNM technology. After making sure that farmers understood the work and risk involved with the experiments, eight farmers in each village were selected to conduct the experiments in 2003. Two farmers conducted SSNM experiments and the other six conducted MSSNM experiments. In 2004, 12 farmers in each village were selected to conduct the experiments. Three farmers conducted SSNM experiments and the other nine conducted MSSNM experiments. A total of 36 and 108 farmers conducted SSNM and MSSNM experiments, respectively (Table 2).

2.4. Implementation of FPR experiments

After the workshop on SSNM technology and the modification of SSNM, the selected FPR farmers met with the research team to discuss details of the experiments. The farmers were asked to keep a daily record of their rice production activities, particularly fertilizer use. By the end of the meeting, the selected farmers understood how to do the experiment and how to record their rice production activities. Each selected farmer conducted an FPR experiment in one plot.

Each selected experimental plot was divided with a levee into two sub-plots of equal size and with similar levels of soil fertility. The levee was covered with plastic film to ensure that fertilizer N did not leak between the two sub-

Table 2
Number of farmers who conducted field experiments to evaluate site-specific nitrogen management (SSNM) or modified site-specific nitrogen management (MSSNM) in 2003 and 2004

Year	Number of counties	Number of villages	Number of farmers to test SSNM[a]	Number of farmers to test MSSNM[a]	Number of farmers to test SSNM or MSSNM
2003	2	6	12	36	48
2004	4	8	24	72	96
Total	4[b]	14	36	108	144

[a] In 2003, two farmers conducted SSNM experiments and six farmers conducted MSSNM experiments in each village. In 2004, three farmers conducted SSNM experiments and nine farmers conducted MSSNM experiments in each village.
[b] Two counties were the same in 2004 as in 2003.

plots. Plot size varied from 500 to 1500 m^2. The SSNM or MSSNM treatment was randomly assigned to one of the two sub-plots and the other to the FFP. For the MSSNM treatment, farmers managed fertilizer N based on the MSSNM scheme that they selected during the workshop. For SSNM, fertilizer-N management was based on the standard SSNM technology.

Details of the SSNM approach are provided elsewhere (Dobermann and Fairhurst, 2000; Peng et al., 2006). In brief, grain yield response to fertilizer-N application was set to 2–2.5 t/ha and agronomic N use efficiency was set to 15–18 kg grain/kg N applied based on the results of previous SSNM experiments conducted in the local county or province (Peng et al., 2006). Total N rate was estimated using the grain yield response to applied N and agronomic N use efficiency. Total N was applied four times at basal, midtillering, panicle initiation, and heading. The rates of N topdressing at midtillering and panicle initiation were adjusted according to leaf N status measured with the leaf colour chart (LCC). The N topdressing at heading was optional depending on the LCC reading.

Other fertilizers, including P and K, were applied in SSNM and MSSNM in the same way as in FFP. According to the local rates of P and K, a slight increase in input was made in some villages to ensure sufficient P and K for crop growth. The soil was basically acid, with pH ranging from 5 to 6.5. A large variation in soil texture and soil organic carbon content existed across counties, villages, and farmers because the villages were randomly selected within each county and the farmers were randomly selected within each village.

The research team ensured that only fertilizer-N management differed between the two sub-plots. Water, pest, and weed management were the same for both sub-plots. Hence, any difference in yield would reflect only differences in fertilizer-N management between the two sub-plots. Yields were measured by harvesting the plants from four 5-m^2 harvest areas in each sub-plot. The samples were threshed and the grains air-dried. Debris and unfilled grain were removed, and then the samples of filled grain were weighed to estimate the yield of each plot. Sub-samples of filled grain were oven-dried to determine moisture content. Grain yield was adjusted to the standard moisture content of 14%.

3. Results and discussion

3.1. Farmers' modifications of SSNM technology

Most farmers actively participated in the workshop when the research team presented the standard SSNM technology, FFP, the initial modified SSNM recommendations, and local constraints to rice production. More than half of the participating farmers suggested modifications to the standard SSNM technology. A set of newly modified SSNM technologies was designed for each village through discussion and dialogue between researchers and farmers. Several different FFP and MSSNM schemes ranging in rate of fertilizer N and number of N applications were planned in each study village (Table 3).

In one MSSNM scheme, the number of N applications was reduced from four to three as compared with SSNM by combining the N applications at midtillering and panicle initiation or eliminating N application at heading. The number of N topdressings decreased in MSSNM because labour was not available for N application during the growing season when many farmers were engaged in non-agricultural work in the city. In another MSSNM scheme, the N rate of basal application was increased compared with SSNM because some farmers feared that a decrease in basal N application rate would reduce grain yield. Another difference between SSNM and MSSNM was the N topdressing during the first two weeks after transplanting. During this period, there was N topdressing in one MSSNM scheme but not in the standard SSNM. The LCC was not used in MSSNM to adjust the rate of N topdressing.

As a result of the modification process, the amount and times of planned fertilizer-N applications differed between MSSNM and SSNM. On average across all planned schemes, SSNM would use 23 kg/ha less fertilizer N than FFP, and MSSNM would use 32 kg/ha less fertilizer N than FFP. MSSNM involved fewer applications of fertilizer N than SSNM in Ningxiang and Xiaonan. The number of fertilizer-N applications was fewer for MSSNM than for FFP only in Xinxing. Averaged across the four counties, the number of fertilizer-N applications was 2.9 for MSSNM versus 3.2 for FFP according to the planned fertilizer schemes. The average number of fertilizer-N applications was between 3 and 4 for the standard SSNM.

Table 3
The number of N fertilization schemes, range in the rate of fertilizer-N input, and range in the number of N applications for planned fertilizer-N treatments of farmers' fertilizer practices (FFP), site-specific nitrogen management (SSNM), and modified site-specific nitrogen management (MSSNM)

Village	Number of N fertilization schemes		Total fertilizer-N rate (kg/ha)			Number of N applications (times)		
	FFP	MSSNM	FFP	SSNM	MSSNM	FFP	SSNM	MSSNM
Xinxing (Guangdong)								
Picun (03)[a]	4	5	200–225	136–177	128–148	3–5	3–4	3–4
Yecun (03)	2	5	151–204	136–177	134–148	5	3–4	3–4
Lianquan (03)	3	5	158–163	136–177	128–151	4–5	3–4	3–4
Guandong (04)	4	3	179–265	101–151	135–137	4	3–4	3–4
Shefeng (04)	4	3	150–162	101–151	135–137	4	3–4	3–4
Ningxiang (Hunan)								
Nongyi (03)	4	3	158–179	136–177	115–147	2–3	3–4	2–3
Xinqiao (03)	4	3	158–179	136–177	115–157	2–3	3–4	2–3
Yuexin (03)	4	3	158–179	136–177	115–132	2–3	3–4	2–3
Wanshan (04)	4	2	172–215	105–143	111–133	2–3	3–4	2–3
Yangxu (04)	5	2	143–162	105–143	111–133	2	3–4	2–3
Hanjiang (Jiangsu)								
Qinjian (04)	6	4	220–306	133–167	157–174	4	3	3–4
Jianhua (04)	4	3	185–284	133–167	157–207	2–4	3	3–4
Xiaonan (Hubei)								
Qiaoxi (04)	4	4	104–175	127–174	140–153	2	3–4	2–3
Jiagou (04)	4	3	159–194	105–143	126–139	1–3	3–4	2–3

[a] Number in parentheses indicates the year when the survey was conducted in that village.

3.2. Farmers' willingness to adopt SSNM and MSSNM technologies and conduct the experiments

Most farmers who attended the workshop were willing to adopt new technologies of SSNM or MSSNM (Table 4). Although the average percentage of willingness to adopt SSNM or MSSNM technologies was 95%, there were large differences among villages. For example, in Nongyi village (Ningxiang, Hunan), 74% of farmers were willing to adopt the new technologies, significantly lower than the average level. Even in the same county in Ningxiang, the percentages of willingness to adopt SSNM or MSSNM in the other four villages were more than 90%, even reaching 100%. The same situation occurred in Picun village in Xinxing, Guangdong. The percentage of willingness to adopt SSNM or MSSNM was 85% in Picun village, which was lower than in the other four villages in the same county.

The differences in farmers' willingness to adopt SSNM or MSSNM technologies might be related to the percentage of farmers engaged in non-agricultural work and other farmers' personal characteristics (Cao et al., 2005). Our previous study indicated that in Nongyi village, Ningxiang County, and in Picun village, Xinxing County, a higher percentage of farmers worked in non-agricultural jobs.

More than two-thirds of the farmers willing to adopt SSNM and MSSNM technologies preferred adopting MSSNM to the standard SSNM technology. In terms of variation in willingness to adopt either technology, the largest variation took place within counties, rather than between counties (Table 4). However, variation occurred between counties in the willingness of farmers to adopt the standard SSNM technology.

A higher percentage of farmers was willing to adopt SSNM or MSSNM technologies than to conduct experiments on these technologies (Table 4). The willingness of farmers to conduct experiments was related to their willingness to adopt the technologies, but, in Shefeng village in Guangdong, Yangxu village in Hunan, and Qiaoxi village in Hubei, the willingness to conduct experiments was markedly lower than the willingness to adopt. In these villages, unlike other villages, less than 60% of the farmers were willing to conduct experiments. The lower percentages were probably associated with the location of village and infrastructure of rice farming. In nearly all of the mountainous or hilly villages with poor irrigation infrastructure, lower percentages of farmers were willing to conduct SSNM and MSSNM experiments because they were concerned with the risk and additional labour requirement involved with the experiments.

3.3. Implementation of farmers' participatory experiments

Most FPR farmers followed the timing for fertilizer-N applications as planned for SSNM or MSSNM (Table 5). Among a total of 144 experiments, 114 farmers or 79% fertilized the SSNM or MSSNM plots at the planned time. However, only 40% of the farmers applied fertilizer to the FFP sub-plots according to the planned time for the FFP scheme. These findings imply that most farmers felt that they could produce better yields by following the timing for fertilizer N used with SSNM or MSSNM, and therefore more than half of them modified their original FFP scheme when they conducted their experiments.

Although most farmers conducted their experiments according to the planned timing of fertilizer-N application

Table 4
Farmers' willingness to adopt site-specific nitrogen management (SSNM) or modified site-specific nitrogen management (MSSNM) and to evaluate SSNM or MSSNM

Village	Number of farmers	Farmers willing to adopt SSNM or MSSNM (%)			Farmers willing to evaluate SSNM or MSSNM (%)		
		Total	SSNM	MSSNM	Total	SSNM	MSSNM
Xinxing (Guangdong)							
Picun (03)[a]	27	85	7	78	67	7	60
Yecun (03)	18	100	17	83	100	17	83
Lianqun (03)	21	100	19	81	100	19	81
Guandong (04)	32	97	25	72	75	22	53
Shefeng (04)	35	100	14	86	54	11	43
Ningxiang (Hunan)							
Nongyi (03)	19	74	21	53	68	21	47
Xinqiao (03)	22	90	18	72	86	55	31
Yuexing (03)	36	100	36	64	97	36	61
Wanshan (04)	33	100	21	79	79	21	58
Yangxu (04)	52	96	52	44	42	17	25
Hanjiang (Jiangsu)							
Qinjian (04)	48	98	27	71	79	23	56
Jianhua (04)	62	100	18	82	73	11	62
Xiaonan (Hubei)							
Qiaoxi (04)	63	95	25	70	59	14	45
Jiagou (04)	46	100	24	76	89	22	67
Average		95	23	72	76	20	56

This survey was conducted based on a total of 514 farmers during the first year in each village.
[a] Number in parenthesis indicates the year when survey was conducted in that village.

Table 5
Percentage of farmers who conducted their experiments by following the planned schemes

Year	Farmers (% of total)					
	Followed planned timing of N application			Followed planned rate of N application		
	FFP[a]	SSNM	MSSNM	FFP	SSNM	MSSNM
2003	38	85	86	36	38	30
2004	41	88	70	31	75	50
Average	40	86	74	34	62	44

[a] FFP = farmers' fertilizer practices; SSNM = site-specific nitrogen management; MSSNM = modified site-specific nitrogen management. 48 and 96 farmers conducted experiments in 2003 and 2004, respectively.

in SSNM or MSSNM sub-plots, a much lower percentage of the farmers applied the quantity of fertilizer N according to the planned scheme (Table 5). The results indicated that although timing of fertilizer application was according to the planned scheme, many farmers modified the planned fertilizer-N rate in SSNM and MSSNM. Many farmers also modified their planned rate of fertilizer-N application in FFP, presumably because of their exposure to SSNM or MSSNM.

The actual timing, rate, and distribution of fertilizer-N application for SSNM, MSSNM, and FFP are presented in Fig. 1 and Table 6. Among 36 farmers who conducted the SSNM experiment, N application rates, especially basal N rates, were significantly higher in FFP than in SSNM (Fig. 1a vs 1b). The average total N rate was 133.4 kg/ha for SSNM and 180.7 kg/ha for FFP. A large proportion of fertilizer N was applied after the maximum tillering stage in SSNM compared with more N applied during the early vegetative stage in FFP (Table 6). The average number of N applications was 3.4 for SSNM and 2.8 for FFP. Among 108 farmers who conducted MSSNM experiments, N application rates were also higher in FFP than in MSSNM (Fig. 1c vs 1d). The average total N rate was 150.0 kg/ha for MSSNM and 173.4 kg/ha for FFP. A large proportion of fertilizer N was applied between 11 and 40 days after transplanting in MSSNM compared with more N applied at basal in FFP (Table 6). The average number of N applications was 2.8 for MSSNM and 2.7 for FFP.

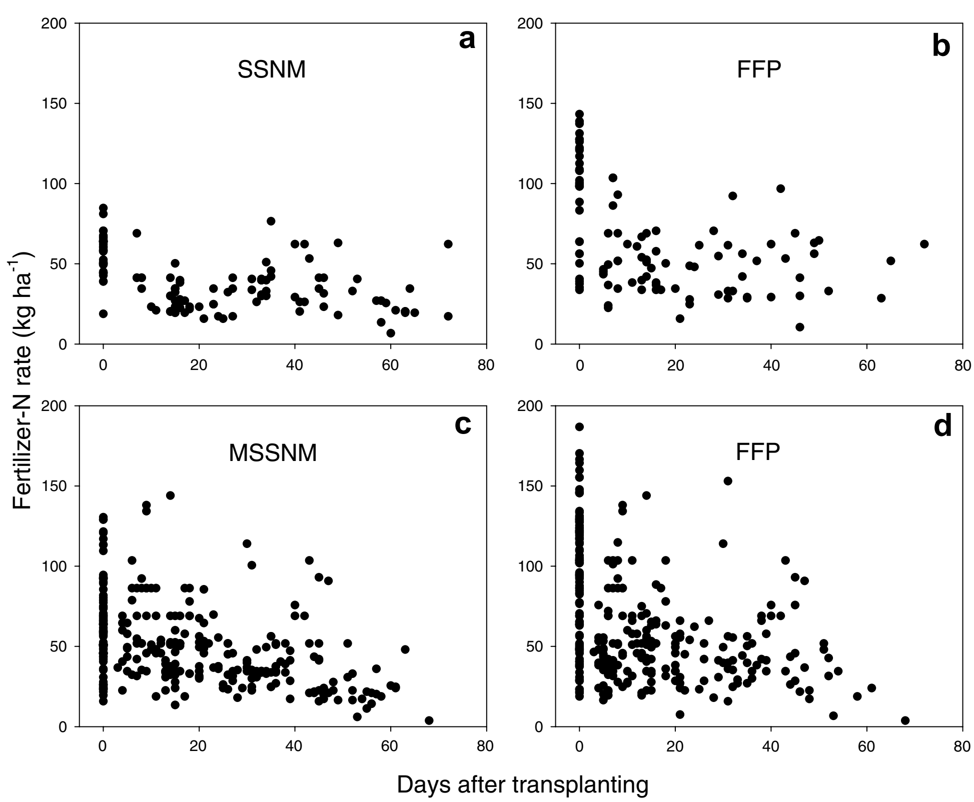

Fig. 1. Fertilizer-N rate of each application during the growing season for all 36 farmers who compared (a) site-specific nitrogen management (SSNM) with (b) farmers' fertilizer practices (FFP) and for all 108 farmers who compared (c) modified site-specific nitrogen management (MSSNM) with (d) FFP in 2003 and 2004. Basal N application was designated at zero days after transplanting.

Table 6
The distribution of fertilizer-N application within a growing season in site-specific nitrogen management (SSNM), modified site-specific nitrogen management (MSSNM), and farmers' fertilizer practices (FFP)

Treatment	Fertilizer N applied (% of total)				
	Basal	1–10 DAT[a]	11–25 DAT	26–40 DAT	After 40 DAT
SSNM	42	6	17	17	18
MSSNM	39	14	24	15	8
FFP	49	17	18	10	6

Data are from the field experiments in a comparison between SSNM or MSSNM and FFP conducted by 144 farmers in 2003 and 2004.
[a] DAT = days after transplanting.

3.4. Results of farmers' participatory experiments

Despite the lower use of fertilizer N, rice yields with SSNM and MSSNM were 0.2 t/ha higher than for FFP (Table 7). An analysis controlling variance of year, village, and the three treatments indicated that rice yields for SSNM and MSSNM were statistically comparable at the 5% level with rice yields for FFP. Both SSNM and MSSNM had a higher partial factor productivity of applied fertilizer N than FFP. Total labour input was not significantly different among SSNM, MSSNM, and FFP. The SSNM or MSSNM technologies maintained rice yields with significantly less fertilizer N. Based on the data in Table 7, the increase in profit was estimated at US$82 per ha for SSNM and US$63 per ha for MSSNM compared with FFP. The profit in SSNM and MSSNM resulted from the slight increase in grain yield and significant reduction in fertilizer-N input compared with FFP.

Although all farmers who conducted SSNM or MSSNM experiments were aware of the technical suggestions made concerning timing and quantity of fertilizers, some farmers did not follow them due to a working schedule conflict or labour opportunity costs. Many of the farmers who did not follow the plans of timing and rate of fertilizer application were also engaged in non-agricultural work. When only the farmers who followed the planned timing and rate of N application in SSNM or MSSNM were included for the same analysis as made in Table 7, the differences in grain yield, total N rate, and partial factor productivity of applied fertilizer N between the treatments did not change significantly (data not shown). In addition, many farmers did not follow their original FFP scheme when they conducted their experiments because of the influence from SSNM or MSSNM. This probably caused an underestimation of the economic benefits resulting from SSNM or MSSNM.

In this study, the performance of SSNM and MSSNM could not be compared directly because (1) the two treatments were not evaluated side by side in a same plot and (2) the numbers of farmers who tested SSNM or MSSNM were not equal. Our primary interest was the comparison between SSNM or MSSNM and FFP. The difference between SSNM and MSSNM could be determined indirectly by comparing their relative performance over FFP. For example, SSNM saved fertilizer N two times more than MSSNM while the differences in their grain yield from FFP were the same. This was why SSNM had slightly greater economic benefit than MSSNM.

The MSSNM schemes were basically simplified versions of SSNM. The simplification would result in greater convenience for farmers to adopt knowledge-intensive technology and increase the adoption potential. However, there was a possibility of oversimplification, which would lead away from the highest economic benefit. The rate and distribution of fertilizer N during the growing season of MSSNM was in between SSNM and FFP. This suggests

Table 7
Comparison of site-specific nitrogen management (SSNM) or modified site-specific nitrogen management (MSSNM) with farmers' fertilizer practices (FFP) in grain yield, fertilizer-N rate, partial factor productivity of applied N (PFP), and total labour input

Treatment	Yield (t/ha)	N rate (kg/ha)	PFP (kg/kg)	Labour input (days/ha)
SSNM experiments				
FFP	5.7	181	31	162
SSNM	5.9	133	44	158
Difference[a]	0.2	−48**	13**	−4
MSSNM experiments				
FFP	6.1	173	35	159
MSSNM	6.3	150	42	158
Difference	0.2	−23**	7**	−1

* and ** denote significance at 5% and 1% levels, respectively.
[a] Based on the results of variance analysis that controls the variances of year, village, and treatment. The variance analysis results indicated that the F values of treatments for yield, N-fertilizer rate, partial factor productivity of applied N, and total labour input are 6.0, 16.8, 10.9, and 0.1, respectively. The F value of the treatment for labour variances did not reach a significant level.

that some local technicians and farmers were initially not fully convinced that SSNM would outperform their local practices. For example, even some local researchers worried that a reduction in N applications at basal and during the early vegetative stage in SSNM would decrease crop yield before they tested SSNM.

4. Conclusion

The process of farmer participatory modification of SSNM technology was successfully tested and analyzed. It appears to be advantageous to offer a locally adapted modification of SSNM to farmers by extension staff for the greater convenience of adoption. However, oversimplification of standard SSNM technology that could reduce its economic benefit should be avoided. Although SSNM is knowledge-intensive, skilled extension staff could introduce the technology to the farming community following the farmer participatory approach. The high rate of willingness to participate in this study was an indicator for a successful introduction of this knowledge-intensive technology. Results indicate that savings of fertilizer N with positive environmental effects while maintaining or slightly increasing yield lead to economic benefits of US$82 per ha for SSNM and US$63 per ha for MSSNM. On average, SSNM saved 48 kg N/ha compared with FFP, which is comparable with the value reported by Peng et al. (2006) for rice crop in China. If this magnitude of N saving can be realized in the 28.5 million ha of rice crop in China, the total saving in the cost of fertilizer N would be about 0.67 billion US dollars per year for the whole country. Assuming fertilizer-N recovery efficiency of 35% (Peng et al., 2002), SSNM would reduce N loss from rice fields to the environment by about 0.89 million tons per year in China. The study suggests that there is potential for large-scale dissemination of SSNM technology in China. A constraint to the adoption of SSNM despite the participatory approach was observed in some cases where farmers had other sources of income.

Acknowledgements

The authors acknowledge financial support from the International Development Research Centre of Canada and the National Natural Science Foundation of China (Grant Number 70325003). Scott Rozelle, Nongron Huang, Qiyuan Tang, and Kehui Cui are particularly acknowledged for their contributions to the experimental design and data collection. Ronnie Vernooy provided useful feedback on our research work and on a draft of this article.

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