ISSN 1009 - 3095 *Journal of Zhejiang University(SCIENCE)* V.2, No.2, P.196 - 203, Apr. - June, 2001
http://www.chinainfo.gov.cn/periodical; http://www.zju.edu.cn;
http://lib.zju.edu.cn/English; http://www.zjupress.com

A NEW APPROACH TO INCREASE THE ATTAINABLE RICE YIELD IN INTENSIVE IRRIGATED RICE SYSTEMS OF ZHEJIANG PROVINCE, CHINA*

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Received July 18, 2000; revision accepted Dec.7, 2000

Abstract: A new site-specific nutrient management approach was developed to break the apparent attainable yield barrier of 6 t·ha^{-1} in the double rice cropping system of Zhejiang. On-farm experiments involving 21 rice-growing farmer families and NPK long-term experiments commenced in 1997 in the central part of Zhejiang Province to assess the status of soil fertility and productivity under intensive rice-rice cropping. A new site-specific nutrient management (SSNM) approach has been developed for this studied area. Field-specific fertilizer recommendations are calculated considering indigenous nutrient supply, reasonable grain yield targets and corresponding nutrient demand, nutrient balance and nutrient use efficiency, as well as socio-economic factors. The agronomic performance of SSNM was tested against the farmer's fertilizer practice (FFP) in four 1998 - 1999 cropping seasons. Across seasons and years, SSNM consistently increased plant nutrient uptake, grain yield and profit by about 10% - 15% compared to the FFP. Yield levels of 7.5 t·ha^{-1} or more seem achievable and sustainable through introduction of SSNM and improved extension services in Zhejiang Province.

Key words: rice, yield potential, nutrient efficiency, site-specific nutrient management
Document code: A **CLC number:** S131, S511

INTRODUCTION

Zhejiang Province located in southeastern China belongs to the subtropical climatic zone with warm temperature (mean temperature 15 - 18 ℃) and adequate rainfall (annual precipitation 1100 - 1900 mm). Of the total of 1.62 million ha cultivated land in this province, 1.27 million ha are riceland with convenient irrigation and drainage systems (Zhejiang Statistics Bureau, 1998). Research reports showed that the climate adjusted genetic yield potential of modern rice varieties currently grown in Zhejiang is about 10 to 12 t·ha^{-1}. The yield potential is generally slightly lower in the early rice cropping season from April to July when inbred varieties are preferred compared to the late cropping season from July to October when higher yielding hybrid varieties are planted (Zheng et al., 1997a; Ten Berge et al., 1997).

Since the middle of the 80's, this province has gradually become one of the more developed areas in China. The relatively rapid industrialization and urbanization have greatly decreased the rice growth area, and exerts pressure on the existing agricultural production systems, especially on rice production. For the past two decades, farmers have been maintaining rice yield of about 5.5 to 6.0 t·ha^{-1} mainly through increasing chemical fertilizer inputs, and also by the extensive use of high yield rice varieties, especially hybrid rice. However, from 1985 to 1997, the rice yield per unit area seemed to be stagnating and the total rice yield declined. The current average rice yield is only about 50% to 60% of the estimated yield potential for the

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* Project supported by the International Fertilizer Industry Association(IFA), the Potash and Phosphate Institute, Canada(PPIC), and International Potash Institute(IPI).

modern rice varieties growing in this area. Limiting factors for rice production might exist in this area. As there is little scope for increasing the land area for agricultural, future increase in rice production will have to come from optimizing productivity. There are reports showing that different crop management practices by individual farmers had already resulted in great differences in soil fertility and productivity (Wang et al., 1994). Meanwhile, non-point sources of nutrient runoff pollution from rice fields have been a serious source of concern (Zhang et al., 1999).

To satisfy the increasing needs for rice from the continual population growth and cope with the decreased land area for growing rice, factors limiting rice production should be identified and remedial measures should be implemented. The main objective of this research was to quantify the current levels of productivity, fertilizer use, nitrogen efficiency, and indigenous nutrient supply in farmers' fields, and to identify the key nutrient problems so far for rice production in Zhejiang Province. Based on information collected, a new approach called site-specific nutrient management (SSNM) has been developed for the studied area (Dobermann et al., 1999), and the agronomic performance of SSNM was tested against the farmer's fertilizer practice (FFP).

MATERIALS AND METHODS

The experimental area is located in Jinhua district, central Zhejiang. On-farm monitoring experiments involving 21 rice-growing families belonging to 7 villages within a radius of 15 km around the Jinhua Agricultural Research Station commenced in 1997. Thirteen farmer families rented 0.2 to 0.5 ha rice fields each, the other eight were so called 'big food production families' renting 2 to 5 ha rice field each. Crops were harvested by hand (sickle) leaving only little straw in the field, or combine harvested leaving moderate amounts of straw in the field, where it was burned later. Only three of the 21 collaborating farmers occasionally applied farmyard manure. All the farmers adopted the early rice-late rice double cropping system. There farms were the typical farms implementing typical rice management measures and represent a range of socio-economic conditions in this region.

The soils of 19 farms were derived from alluvial deposits, those of the other two from red soil. Some basic soil characteristics of these farms for on-farm research are given in Table 1. The soils were moderately to slightly acid. Plant available P as measured with the Olsen-method ranged from 7.6 to 60.5 mg·kg^{-1}. Most of the soils had quite high Olsen-P content because farmers applied P fertilizer consecutively every crop season so that some P accumulated in the soils. Potassium levels were moderate to low. Generally say, soil organic matter and total N were quite high. There was no Zn deficiency in these soils.

Table 1 General soil properties in 21 rice farms in Jinhua, Zhejiang, China[a]

Soil properties	Min.	25%	Median	75%	Max.
Clay content (%)	24.2	30.1	31.2	36.6	45.0
Silt content (%)	39.9	43.3	44.4	49.6	58.1
Sand content (%)	6.2	14.9	24.3	26.2	30.3
Soil organic C (g·kg^{-1})	15.5	18.1	18.6	19.8	23.0
Total soil N (g·kg^{-1})	1.63	1.92	1.98	2.12	2.57
Soil pH (1:1 H_2O)	4.8	5.1	5.3	5.6	6.3
Cation exchange capacity (cmol·kg^{-1})	6.9	9.6	10.8	12.4	16.3
Exchangeable K (cmol·kg^{-1})	0.12	0.19	0.23	0.28	0.85
Exchangeable Na (cmol·kg^{-1})	0.11	0.15	0.22	0.30	0.44
Exchangeable Ca (cmol·kg^{-1})	3.27	5.62	6.58	7.85	16.88
Exchangeable Mg (cmol·kg^{-1})	0.25	0.42	0.68	0.88	1.19
Extractable P (Olsen-P, mg·kg^{-1})	7.62	11.61	17.44	23.70	60.52
Extractable Zn (0.05mol/L HCl, mg·kg^{-1})	1.42	1.65	1.85	2.18	5.43

[a] Measured on initial soil samples collected before the 1997 early rice crop

In each field, three nutrient omission plots (PK, NK, NP) with two replicates were established to measure the indigenous nutrient supply. We defined the indigenous nutrient supply as plant nutrient uptake with above-ground biomass in a plot in which only the nutrient of interest is limiting. Thus, total N uptake in a PK plot was used as an estimate of the indigenous N supply (INS, kg $N \cdot ha^{-1}$), total P uptake in a NK plot as an estimate of the indigenous P supply (IPS, kg $P \cdot ha^{-1}$), and total K uptake in a NP plot as an estimate of the indigenous K supply (IKS, kg $K \cdot ha^{-1}$). Therefore, the indigenous supply included nutrients released from soil solids as well as inputs of plant available nutrients from non-fertilizer sources such as irrigation, rainfall, or biological N fixation during one growth period of rice. The fertilizer rates in the omission plots were 160 – 180 kg $N \cdot ha^{-1}$, 35 kg $P \cdot ha^{-1}$, 150 kg $K \cdot ha^{-1}$ to ensure that no other nutrient was limiting. The plots were moved to new locations in the farmer practice field after every crop season. The remaining field area was managed by the farmers following their standard practice and samples for monitoring of soil and plant were collected in two separate sampling plots of this farmers' fertilizer practice (FFP) (Olk et al., 1999).

Based on the results in 1997, a new site-specific nutrient management (SSNM) approach was developed in 1998 for this studied area. A single large plot (500 to 1000 m^2) was embedded in the experimental rice field. Fertilizer recommendations for SSNM were calculated considering indigenous nutrient supply, reasonable grain yield targets and corresponding nutrient demand, nutrient balance and nutrient use efficiency, as well as socio-economic factors (Dobermann et al., 1999; Witt et al., 1999). The agronomic performance of SSNM was tested against a farmer's fertilizer practice (FFP) in four 1998 – 1999 cropping seasons.

RESULTS AND DISCUSSION

1. Current nutrient management practice

Chinese rice farmers have a long history of applying organic manure for rice. But now the situation has changed in Zhejiang. Rice farms nowadays can produce much less farmyard manure than before because they keep fewer animals due to farm mechanization. Also, farmers would rather like to use the small quantity of manure they produced for vegetable or other cash-making crops, not for the rice fields. While the large quantity of organic manure produced in the big animal farms (pig, chicken, and dairy farms), because of lack of labor and low profit, is usually wasted or not distributed evenly to the rice fields where it is needed. Among the 21 experimental farms in Jinhua, only 3 farms occasionally apply some farmyard manure to their rice fields. Straw is normally removed from the field after harvesting the early rice, and often remains in the field and is burned later after the late rice season. As a matter of fact, most of the rice fields do not receive any manure from 1997 to 1999. Mainly depending on chemical fertilizer as nutrient input in rice production is nowadays a popular practice in Zhejiang. However, the effects of the current fertilizer practices on soil organic matter quality and microbial activity, which control the C and N cycling in intensive rice system, are still uncertain.

Long-term experiments in Zhejiang showed that organic manuring was a key practice in maintaining grain yield stability for rice, and that application of organic manure to rice field every year was necessary (Li, 1993). Recent research on the nutrient cycle and balance of paddy fields showed that the return of crop residues to the fields could increase soil organic carbon content and available P and K poor significantly (Li et al., 1998). It seems that straw and stubble management is of crucial importance to the sustainability of the rice system. Increasing return of crop residues and optimizing fertilization by a combination of organic and inorganic fertilizers is the direction for the reform of fertilization systems in rice production in Zhejiang.

Although farmers usually applied quite high amount of N fertilizer, N use efficiency is low (Table 2). All fertilizers were applied very early (50% basal, 50% 5 – 10 days after transplanting) to promote tillering. Very few farmers apply N after panicle initiation. Across years and seasons, farmers on average applied 156 to 196 kg $N \cdot ha^{-1}$ per crop. The agricultural efficiency of applied N (AE_N) (kg grain yield increase per kg N applied) were only 4.6 to 8.2 $kg \cdot kg^{-1}$. Also there were big variations in fertilizer applications and fertilizer use efficiency among the farms.

Other studies in China showed that applying more N fertilizer during middle growth stages improved N use efficiency and increased N uptake and grain yields (Zheng et al., 1997b; Zheng et al., 1992). Current N fertilization strategy in Jinhua was not geared for optimizing N efficiency. N fertilizer was mainly used to promote tillering during the very early growth stage. Thus N application was not fine-turned to synchronize supply and plant demand, which caused high N loses to the environment.

2. Indigenous nutrient supply

The indigenous nutrient supply of the rice soils for 1997 and 1998 are shown in Fig. 1. The indigenous N supply was similar in all three crops sampled and was 50 to 115 kg N·ha^{-1} (average 72 kg N·ha^{-1}). Apparently, the long winter fallow period did not increase the INS for early rice compared to the late rice crop grown shortly after harvest of early rice. Similarly, the indigenous P supply was about 21 kg P·ha^{-1} in early and late rice crops ranged from 13 to 32 kg ·P ha^{-1}. Values were, on average, sufficient for yields of about 7 t·ha^{-1} without P fertilizer. The average IKS ranged from 107 kg·ha^{-1} in 1998 early rice to 125 kg·ha^{-1} in 1998 late rice. Since most farmers grew conventional rice varieties as early rice and hybrid rice varieties as late rice, higher IKS in late rice might be due to the more vigorous root system and greater soil K extraction power of hybrid rice. Note, however, the very large range of IKS in the 1997 and 1998 late rice crops.

Different crop management practices by individual farmers resulted in great variation in soil fertility and productivity, as shown in the variations of grain yields (Table 2) and indigenous nutrient supply (Fig. 1) among the farmer's fields. However, routine soil testing for fertilizer recommendation for rice is now rarely used in Zhejiang. The fertilizer recommendation given by the agricultural sectors at different levels are only for large areas and not based on a more site-specific knowledge of soil nutrient status. The gap between the average farm yield of about 6 t·ha^{-1} and the highest farm yield of more than 8 t·ha^{-1} is large (Table 2).

Table 2 Grain yield(kg·ha^{-1}), fertilizer N rates (kg·ha^{-1}), and agricultural efficiency of fertilizer N (AE$_N$, kg grain yield increase per kg N applied) for rice in Jinhua, Zhejiang (21 farmers)

	Season	Mean	CV	Max.	Min.
Grain yield(kg·ha^{-1})	1997ER(kg·ha^{-1})	5917	0.15	7583	4698
	1997LR(kg·ha^{-1}	6051	0.14	7984	4658
	1998ER	5918	0.12	7117	4356
	1998LR	6908	0.09	8444	5904
	1999ER	4905	0.15	6556	3540
	1999LR	5888	0.14	7846	4324
Fertilizer N(kg·ha^{-1})	1997ER	159	0.26	233	96
	1997LR	196	0.19	270	86
	1998ER	159	0.15	196	118
	1998LR	156	0.18	198	96
	1999ER	170	0.16	217	120
	1999LR	179	0.20	248	77
AE$_N$(kg·kg^{-1})	1997ER	4.6	1.09	22.8	0.0
	1997LR	4.6	0.73	12.5	0.0
	1998ER	6.1	0.51	15.3	0.9
	1998LR	8.2	0.40	16.1	2.7
	1999ER	5.6	0.51	12.7	-0.6
	1999LR	5.7	0.55	13.0	1.9

* ER, early rice; LR, late rice.

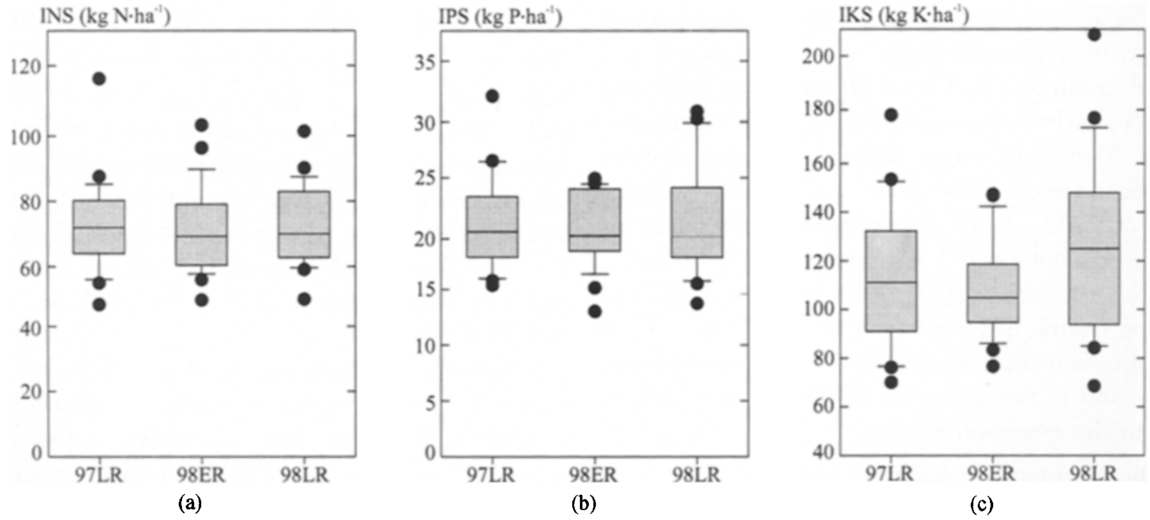

Fig.1 Variability of the indigenous N (INS), P (IPS) and K (IKS) supply in 21 farmers' fields in Jinhua, China (1997 – 1998)(ER = early rice, LR = late rice)
a. INS; b. IPS; c. IKS

3. Site-specific nutrient management

The strategy. Fertilizer recommendations for SSNM were calculated on a field- and crop-specific basis and detailed descriptions are given elsewhere (Dobermann et al., 1999; Witt et al., 1999). The INS, IPS, and IKS estimates for the 1997 LR crop were used as model inputs for the rice crops in 1998 and the target yield was set to 7.5 – 8.0 t·ha^{-1} in ER and 7.5 to 8.5 t·ha^{-1} in LR. In 1999, average values of the INS, IPS, and IKS measured in the 1998 ER and LR crops were used as model inputs and the target yield was set to 7.2 – 8.0 t·ha^{-1} in ER and 8 t·ha^{-1} in LR. First crop recovery fractions of 0.4, 0.2, and 0.5 kg·kg^{-1} were assumed for fertilizer N, P, and K, respectively. The climatic yield potential was set to 9 t·ha^{-1} for ER and 10 t·ha^{-1} for LR (Zheng et al., 1997a). Fertilizer sources used were urea (46% N), single superphosphate (6.1% P), and KCl (50% K). All P fertilizer was incorporated into the soil before transplanting (100% basal). K fertilizer was split into 50% basal plus 50% at PI stage.

In 1998, N (urea) was applied in three splits at fixed growth stages (40% was incorporated into the soil 1 or 2 days before transplanting; 20% was topdressed 14 days after transplanting and 40% topdressed at PI stage). Compared to most farmers' two early applications, this splitting represented already a more evenly distributed N application scheme. However, results obtained in 1998 suggested that further fine-tuning could be achieved by a more dynamic, plant-based N management. Therefore, in 1999, N was input as two fixed applications and one or two more topdressings depending on SPAD readings at critical growth stages (Peng et al., 1996).

The performance of site-specific nutrient management. Plant NPK uptake, grain yield and profit were greater by SSNM than those achieved in FFP in both seasons and years (Fig.2). As soil P and K supplies were not limiting plant growth and yield, as indicated by IPS and IKS measurements, the benefit of SSNM mainly related to improved splitting and timing of fertilizer N applications leading to increased plant N, P and K uptake and to greater plant biomass production. This was particularly evident in 1999, when nutrient uptake, grain yield and profit were significantly greater in SSNM than in FFP although fertilizer N, P and K rates were all lower in SSNM, and the improved N strategy in SSNM resulted in an average saving fertilizer 61 kg N·ha^{-1} compared to the FFP. Across seasons and years, the average increase in plant nutrient accumulation due to SSNM was 7.7 kg N·ha^{-1} (8%), 2.4 kg P·ha^{-1}(14%), and 11.8 kg K·ha^{-1}(10%). These increases were significant. The corresponding significant yield increase due to SSNM was 0.45 t·ha^{-1}. Note that SSNM performed equally well in both years although yields were considerably lower in 1999 due to unfavorable climatic conditions. SSNM performed equally well in the case of ER and LR. Yields were highest in the 1998 LR crop, when the average yield

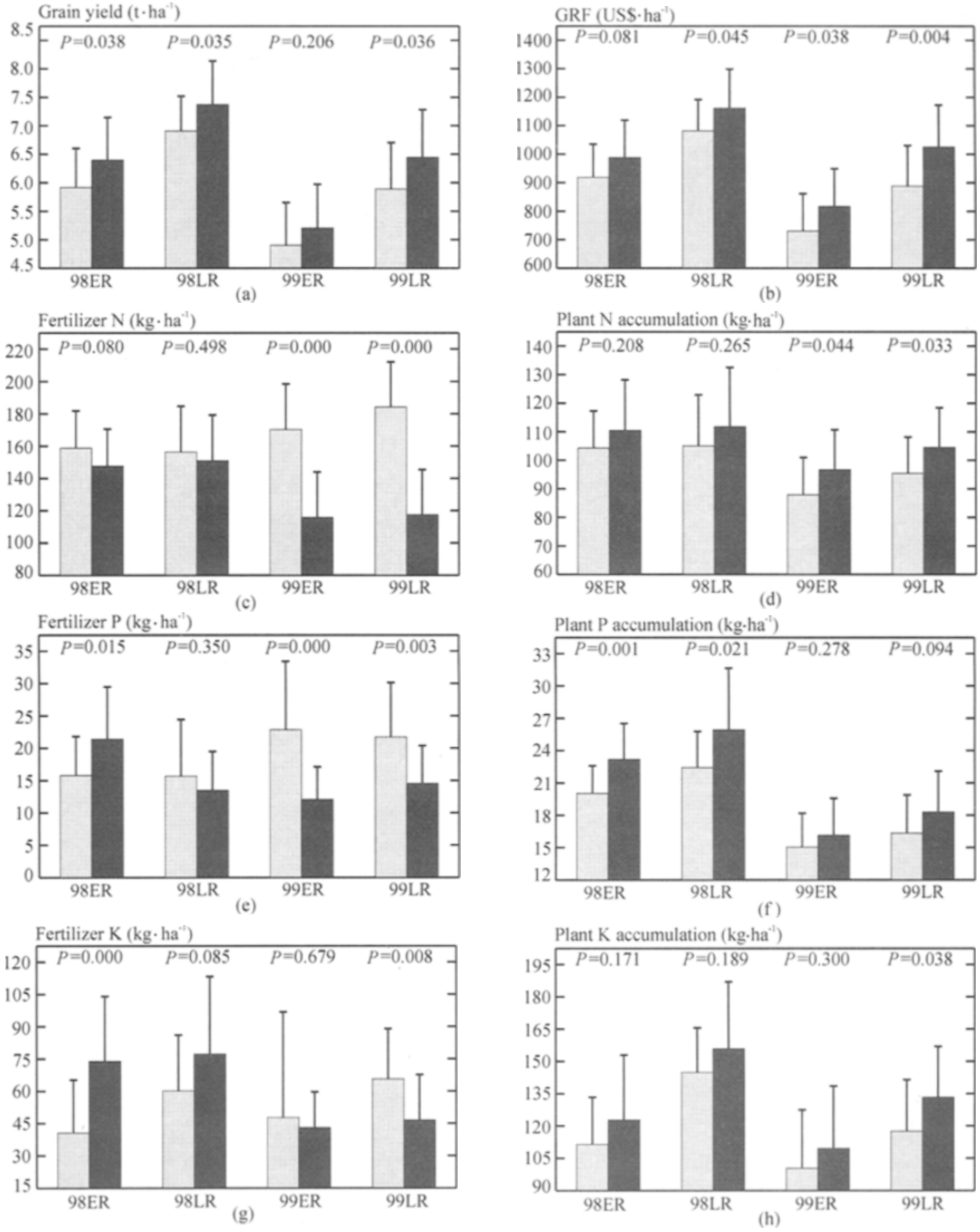

Fig.2 Grain yield, gross return above fertilizer cost (GRF), applied amounts of fertilizer NPK and corresponding plant N, P, and K accumulation in the farmers' fertilizer practice and site-specific nutrient management plots in Jinhua, China, 1998 to 1999 (mean and standard deviation)

a. grain yield; b. GRF; c. fertilizer N; d. plant N accumulation; e. fertilizer P;
f. plant P accumulation; g. fertilizer K; h. plant K accumulation

▨ farmers' fertilizer practice(FFP) ■ site-specific nutrient management(SSNM) by SSNM was 7.4 $t\cdot ha^{-1}$. Yields by SSNM exceeded 8 $t\cdot ha^{-1}$ in five farms, where maximum was 8.7 $t\cdot ha^{-1}$. The average profit increase in all four crops grown was US \$ ·93 ha^{-1} $crop^{-1}$ (10%), but significantly larger in 1999 (US \$ 112·ha^{-1} $crop^{-1}$, 14%) than in 1998 (US \$ 75·ha^{-1} $crop^{-1}$, 8%). Compared to ER, farmers also achieved greater profit in LR because hybrid rice varieties with longer growth periods and higher yield potential were grown. The profit increase by SSNM over that in FFP was larger in the case of LR (US \$ 108·ha^{-1} $crop^{-1}$) than in the case of ER (US \$ 78·ha^{-1} $crop^{-1}$, 14%).

The N use efficiencies increased significantly with SSNM since plant N uptake and grain yield were greater despite lower N rates (Fig.3). For all four crops grown, and compared to the FFP, AEN was increased by 5 $kg\cdot kg^{-1}$(81%), REN by 0.11 $kg\cdot kg^{-1}$(53%), and PFPN by 12.2 $kg\cdot kg^{-1}$(34%). Differences in the impact of SSNM on N use efficiency in the case ER and LR were small. SSNM had no effect on the physiological N efficiency (PEN), which suggests that between SSNM and FFP, there is little difference in crop management and in factors other than N. Nitrogen use efficiency was generally low in FFP, and also very variable among the farmers.

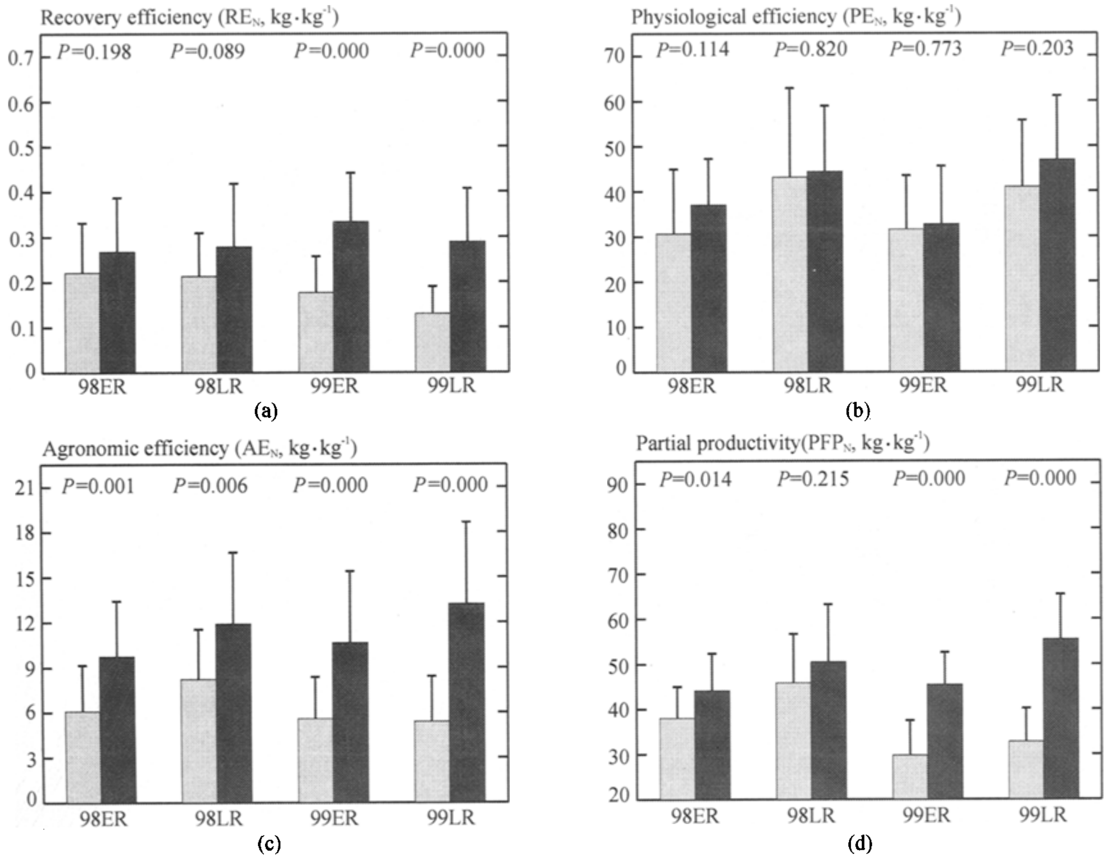

Fig.3 Fertilizer nitrogen use efficiencies in the farmers' fertilizer practice and site-specific nutrient management plots in Jinhua, China (1998 – 1999; bars: mean; errors bars: standard deviation)
a. recovery efficiency; b. physiological efficiency; c. agronomic efficiency; d. partial productivity
▨ farmers' fertilizer practice(FFP) ■ site-specific nutrient management(SSNM)

CONCLUSIONS

Average rice yield in Zhejiang is about 5.5 to 6 $t\cdot ha^{-1}$ or only 60% of the climatic and genetic yield potential. Currently, farmers only receive blanket fertilizer recommendations from the government-owned agricultural extension stations. Nitrogen fertilizer is often used to promote tillering during early growth stage and N losses into the environment are large. Large variability in indigenous nutrient supplies among fields and low N use efficiencies due to poor congruence of N supply with crop N demand indicated significant potential for site-specific nutrient management. The new SSNM approach increased grain yield and nutrient uptake by almost 10% with less fertilizer applied, resulting in large increases in N use efficiency and profit.

ACKNOWLEDGEMENTS

We wish to thank Piedad Moya, Don Pabale, and Marites Tiongco (IRRI) for help with the socioeconomic farm monitoring, Ma. Arlene Adviento (IRRI) for help with the soil and plant analysis work, and Gregorio C. Simbahan (IRRI) for help with data management and statistical analysis. Many thanks also go to Mr. Ding Xiang-hai, Mr. Wu Jian-xiang and Ms. Huang Xue-ping of Jinhua Agricultural Bureau, and Dr. He Yunfeng and Professor Huang Changyong of Zhejiang University, for their excellent work in participating the implementation of the project.

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