Development of Site-Specific Nutrient Management (SSNM) Recommendations for Irrigated Rice in Region VI (Capiz, Aklan, and Antique)

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ABSTRACT

Site-specific nutrient management (SSNM) is a plant-need-based approach for optimized application of nitrogen, phosphorus, and potassium fertilizers. This study developed and evaluated SSNM recommendations for irrigated rice in Aklan, Antique, and Capiz. Field trials using the nutrient omission plot technique provided information to calibrate Nutrient Manager for Rice, a computer-based decision tool. Additional field trials compared SSNM-based fertilizer recommendations of Nutrient Manager with farmer's fertilizer practices. Measured soil properties were not well related to rice yields measured in nutrient omission plots suggesting soil properties are not good predictors of nutrient supply in rice soils. Relationships of yield in nutrient omission plots with yield in full fertilized plots were comparable to relationships from other regions of the Philippines already used in Nutrient Manager. This provides confidence that Nutrient Manager is well adapted for Region 6. Fertilizer management based on Nutrient Manager increased yield by 370 kg per hectare per season. Results suggest an increased income of PhP 4500 per hectare per season is a realistic target with Nutrient Manager. When factors other than nutrients — such as pests, diseases, or poor crop management — limit rice yield, improved nutrient management should be combined with practices to overcome these constraints.

Keyword: Site-specific nutrient management, irrigated rice, Western Visayas

INTRODUCTION

Site-specific nutrient management (SSNM), as developed through more than a decade of research with rice involving the use of the nutrient omission plot technique in Asia, now provides scientific principles on nutrient best management practices for rice (IRRI, 2010; Witt et al., 2007). These scientific principles of SSNM enable the pre-season determination of crop needs for fertilizer N, the within-season distribution of fertilizer N to meet crop needs, and the pre-season determination of fertilizer P and K rates to match crop needs and sustain soil fertility. Fertilizer best management for rice is tailored to field-specific conditions for crop yield, crop residue management, historical fertilizer use, use of organic materials, and nutrient inputs through irrigation water.

The West Visayas State University (WVSU) in collaboration with the Philippine Council for Agriculture Resources Research and Development (PCARRD), the University of the Philippines Los Baños (UPLB), and the International Rice Research Institute (IRRI) developed a site-specific nutrient management (SSNM) recommendation for Iloilo Province in 2006 through the use of the nutrient omission plot technique. The initial SSNM recommendation was field evaluated and refined in 2007-2008. The refined recommendation is now disseminated in Iloilo Province with the partnerships of the Department of Agriculture, Philippine Rice Research Institute (PhilRice), and IRRI. Through this undertaking, it is envisioned that the province will be able to improve its rice productivity thus contributing to the country's rice sufficiency program.

The widespread uptake by farmers of improved nutrient management requires transforming science-based information into locally adapted tools that enable extension workers, crop advisors, and farmers to rapidly develop and implement best management practices for specific fields and growing conditions. Through a partnership of organizations in the Philippines, the results from more than a decade of research on SSNM for rice were used to develop *Nutrient Manager for Rice* decision support software initially released in 2008 for extension and farmers in the Philippines. More recently it has been developed into Web and mobile phone applications in English and dialects of the Philippines (IRRI, 2011).

This project addresses the Philippine Agriculture 2020 targets on rice self-sufficiency, i.e. increasing the base yield of 3.5 t/ha for inbred rice by 0.10 to 0.14 t/ha per year and increasing net income from P17,216/ha to P25,824/ha to reduce poverty. This helps achieve Millennium Development Goal # 1 to eradicate extreme poverty and hunger. Improved nutrient management with the right amount and timing also helps protect the environment from pollution thus addressing Millennium Development Goal #7 to ensure environmental sustainability.

Objectives were to develop SSNM recommendations for irrigated rice in Region VI (Aklan, Antique, and Capiz) through the use of simple tools and measurements, to use this information to calibrate *Nutrient Manager for Rice*, and then to evaluate the performance of *Nutrient Manager for Rice*. The results when combined with results in other regions contribute to enhancing the effectiveness of *Nutrient Manager* as a tool for providing field-specific fertilizer guidelines across the Philippines.

REVIEW OF RELATED LITERATURE

Soil and land resources along with water are important factors in agricultural production. There is a continual fluctuation in the yield of rice which is usually below the potential yields of the released varieties. The difference between the potential yield and the actual yield is called yield gap. Yield gaps can be attributed to climate, crop management, inherent soil fertility, and socio-economic factors. More efficient and balanced use of fertilizer can be important to closing the yield gap (Witt et al., 2007).,

Site-specific nutrient management (SSNM), as developed though years of research in Asian rice-producing countries provides an approach for "feeding" rice with nutrients when needed (Dobermann et al., 2002; 2004; Gines et al., 2004). SSNM strives to enable farmers to dynamically adjust fertilizer use to optimally fill the deficit between the nutrient needs of a high-yielding crop and the nutrient supply of naturally occurring indigenous sources such as soil, crop residues, manures, and irrigation water (Dobermann et al., 2002; Buresh et al., 2010). SSNM aims to apply nutrients at optimal rates and times to attain high rice yield and high efficiency of nutrient use resulting in high cash value of the harvest per unit of fertilizer invested, sustainability, and protection of the environment (Pampolino et al., 2007).

SSNM showed the potential of obtaining higher yields with increased fertilizer N use while maintaining low N_2O emissions in India, the Philippines, and Vietnam (Pampolino et al., 2007). SSNM showed greater yields with less fertilizer N through improved fertilizer use efficiency, which could reduce N_2O emissions and global warming. Based on simulations the use of SSNM never increased emissions of N_2O per unit of grain yield, and in environments where higher yield could be obtained with less fertilizer N, the use of SSNM could reduce N_2O emissions per unit of grain yield.

The SSNM approach utilizes the nutrient omission plot technique for determining indigenous nutrient supply, which is the supply of a nutrient from sources other than fertilizer (Witt et al., 2007). The indigenous nutrient supply can be indirectly estimated as plant uptake of a nutrient in a plot without addition of the nutrient. Such a plant-based estimate of nutrient supply integrates under field conditions the supply of a nutrient from all indigenous sources including organic manures, irrigation water, and biological N_2 fixation. The estimation of indigenous nutrient supply through use of nutrient omission plots can thereby provide an alternative to soil testing. Previous studies have reported little or no relationships between soil analyses for N, P, and K and the indigenous supply of these nutrients as measured by plant uptake in nutrient omission plots (Dobermann et al., 2003).

Fertilizer recommendations developed from soil test results can vary among laboratories because of the different philosophies and approaches used. In the United States, university laboratories historically followed a "feed the crop" approach in making fertilizer recommendations whereas many commercial laboratories tend to use a maintenance approach focusing on maintaining input levels to match outputs. Most research results showed that university recommendations were more profitable than commercial laboratories recommendations (Lessman, 1986; Savoy, 2002).

MATERIALS AND METHODS

Nutrient omission plot trials

The fields were thoroughly plowed, harrowed, and leveled. Sets of five experimental plots measuring 5 m x 5 m were installed in farmer's fields near and parallel to an irrigation canal to ensure the irrigation water flowed directly into the plots. Each plot was enclosed with a bond of sufficient height to prevent water and fertilizer flow between plots. Five treatments were randomly assigned to the plots in a farmer's field.

1) NPK + Zn: Addition of N, P, K, and Zn
2) NPK: Addition of N, P, and K; but not Zn
3) -N: Addition of P, K, and Zn; but not N
4) -P: Addition of N, K, and Zn; but not P
5) -K: Addition of N, P, and Zn; but not K

Each set of five plots in a farmer's field represented a replication.

The experiment used registered seeds of NSIC Rc146 for Capiz, PSB Rc10 for Aklan, and NSIC Rc160 for Antique. The seeds were directly sown at 100 kg per hectare. Nutrient additions were sufficiently high to ensure yield was not limited by an insufficient supply of the added nutrients. The rates of fertilizer were 90:50:70 kg/ha for N, P_2O_5, and K_2O in the wet season and 130:50:70 kg/ha for N, P_2O_5, and K_2O in the dry season. Good crop management with provision for irrigation water and good weed and pest management was practiced. Grain yield was expressed at 14% moisture content.

One composite soil sample for each set of five plots was collected at final land preparation within the plow layer, which was to about 15 to 20 cm depth. Soils were analyzed for exchangeable K, extractable P, exchangeable Ca, Mg, and K, and pH.

Data analysis was performed using the MIXED procedure of Statistical Analysis System (SAS) version 9.1.2 (SAS Institute, 2003) to determine the effects of season, fertilizer treatments, and season by fertilizer treatment interactions on grain yield. The residual plots were used in checking for the homogeneity of error variances. A combined analysis of variance (ANOVA), with season and fertilizer treatment as fixed factors and replicate as the random factor, was performed individually on each province. The effect of fertilizer treatment on grain yield was determined using F-test, after which, multiple mean comparisons of fertilizer treatments within a season were performed using the Tukey-Kramer test (Tukey's HSD). The magnitude of N, P, K, and Zn responses was analyzed using box-and-whisker plots (NIST/SEMATECH e-Handbook of Statistical Methods, 2010).

Comparison of improved nutrient management and farmer's practice

The sites were selected to ensure diversity of farmer's fields ranging in soil type, topography, drainage, and source of irrigation water. Two replicate treatment plots each measuring 250 sq m were placed in each farmer's field: Improved nutrient management based on *Nutrient Manager for Rice* (SSNM) and farmer's fertilizer practice (FFP), which served as reference. All management practices except for fertilizer management were identical for FFP and SSNM. The data gathered in each field location included yield, input costs, and financial analysis using collected prices for fertilizer and unmillled rice.

The analysis of the SSNM and FFP was performed using the MIXED procedure of Statistical Analysis System (SAS) version 9.1.2 (SAS Institute, 2003) to determine the effects of season, fertilizer treatments, and season by fertilizer treatment interactions on grain yield, fertilizer N rate, fertilizer P_2O_5 rate, fertilizer K_2O rate, and total fertilizer cost. For added benefit of SSNM, only the analysis for the effect of season was performed. The residual plots were used in checking for the homogeneity of error variance.

A combined analysis of variance (ANOVA), with season and fertilizer treatment as fixed factors and replicate as the random factor, was performed individually on each province. The effect of fertilizer treatment was determined using F-test, after which, multiple mean comparisons were performed using the Tukey-Kramer test (Tukey's HSD). For grain yield, fertilizer N rate, fertilizer P_2O_5 rate, fertilizer K_2O rate, and total fertilizer cost the means of each fertilizer treatment (FFP and SSNM) within a season were compared. For added benefit of SSNM, only the means for the two seasons (wet and dry) were compared. All grain yields are expressed at a fresh weight basis.

RESULTS AND DISCUSSION

Nutrient omission plot trials

Yield gains from N, P_2O_5, and K_2O fertilizers

Yield gains from N were significant in Aklan and Capiz, amounting to 1.3 t/ha in Aklan and 1.2 t/ha in Capiz during the wet season (Table 1). In the dry season, yield gains from N were higher in all three provinces, ranging from 0.6 t/ha to 1.0 t/ha.Yield gains from P, K, and Zn were significant in Capiz during both the wet and dry seasons (Table 1). Other provinces did not show significant yield gains from the application of P, K, and Zn in both seasons.

Nitrogen was limiting across all locations indicating the need for fertilizer N to achieve target yields. Yield gain for fertilizer N was highly variable across farms indicating a need for field-specific fertilizer management (Fig. 1). Mean yield gains from fertilizer P, K, and Zn were small (Table 1), but the range was very high across seasons and locations, indicating the need for field-specific fertilizer management (Fig. 1).

Yields were relatively lower in Antique than in Capiz and Aklan (Fig. 1). This can be attributed to constraints other than nutrients such as poor irrigation water and crop management as well as pest and disease problems.

Indigenous nutrient supplies measured in omission plots

During the wet season in Aklan, yield in the N omission plot was significantly lower than the rest of the treatments, which attained comparable yield levels (Fig. 1). The same trend was observed in the dry season where the -N plot obtained the significantly lowest yield and the remaining plots were comparable in yield.

In Aklan, the wet season yield gains from N varied widely with the middle 50% of the fields having yield gains of 0.8 t/ha to 2 t/ha with a median of 1 t/ha (Fig. 1). The yield gains from P, K and Zn were lower than N with medians near 0. Similar yield gains for P, K and Zn were obtained during the dry season. For yield gains from N in the middle 50% of the fields had yield gains ranging from 0.8 t/ha to 1.2 t/ha, which was a narrower range than in the wet season.

Table 1. *Yield gain of rice from applied nutrient as measured from the differences in grain yield between NPK fertilized plots and nutrient omission plots in 2009-2010.*

Responses	Wet season		Dry season	
	Grain yield (t/ha)	**P>/t/**	**Grain yield (t/ha)**	**P>/t/**
Yield gain from N				
Aklan	1.3	<.0001	1.0	<.0001
Antique	0.5	0.13	0.6	0.017
Capiz	1.2	<.0001	0.7	0.001
Yield gain from P				
Aklan	0.03	0.87	0.2	0.28
Antique	0.01	0.95	0.01	0.95
Capiz	0.4	0.004	0.3	0.019
Yield gain from K				
Aklan	-0.1	0.41	0.1	0.38
Antique	-0.04	0.87	-0.1	0.65
Capiz	0.5	0.003	0.3	0.038
Yield gain from Zn				
Aklan	-0.04	0.83	0.2	0.33
Antique	0.1	0.71	-0.1	0.58
Capiz	0.3	0.048	0.3	0.043

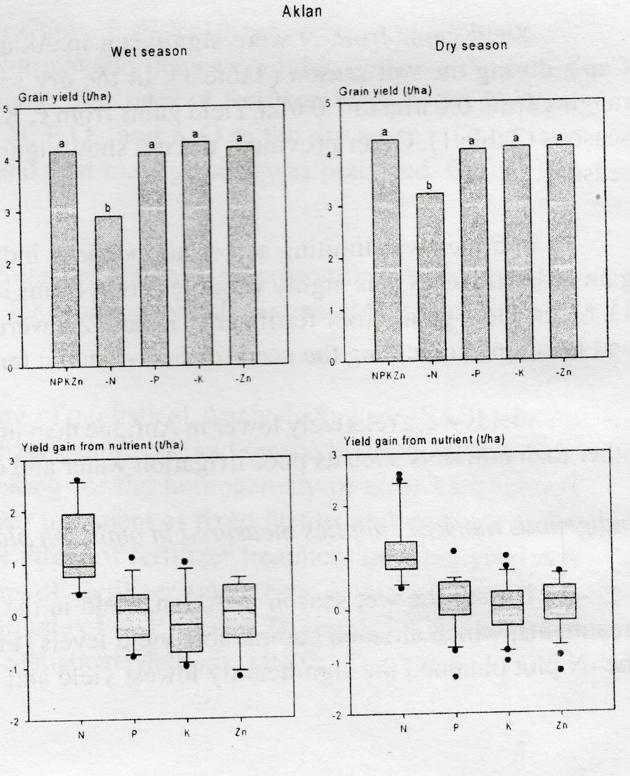


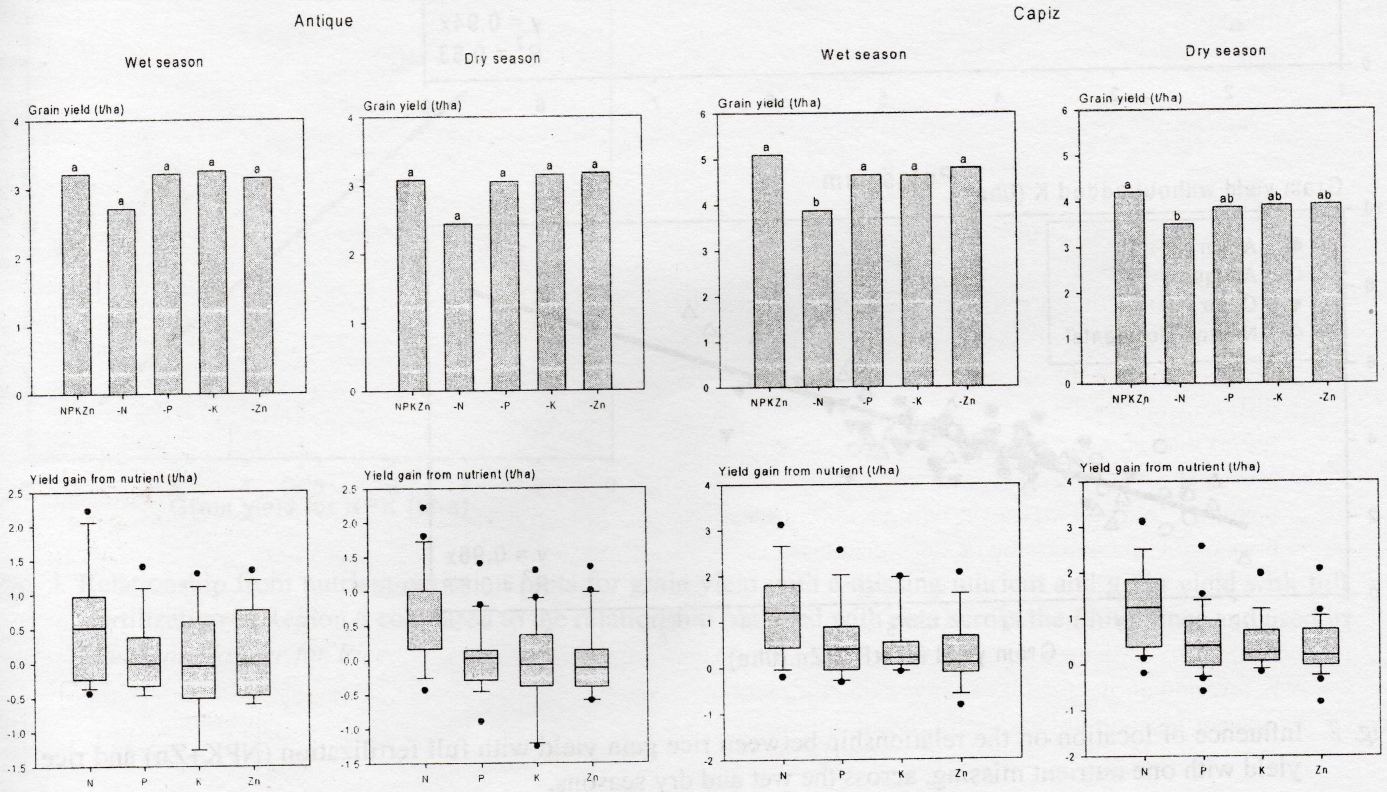
Fig. 1. Effect of omitting a nutrient on grain yield of rice in farmer's fields in Aklan, Antique, and Capiz. Treatments with the same letters are not significantly different at 5% level (0.05) using Tukey–Kramer test. Yield gain from applied nutrient as measured from the difference in grain yield between NPK fertilized plots and nutrient omission plots. The horizontal line within the box represents the median, the boundary of the box closest to zero indicates the 25th percentile, and the boundary of the box farthest from zero indicates the 75th percentile. Whiskers below and above the box indicate the 10th and 90th percentiles, and bullets are outlying points.

Antique had lower yield levels in the wet season than Capiz and Aklan (Fig. 1). Further, no significant differences were observed among treatments. In the dry season, yields were still lower in Antique at 2.4 t/ha for -N and 3.1 to 3.2 t/ha for -P, -K, and -Zn. All treatments were not significantly different in yield. Yield gains for Antique were lower and highly variable for both wet and dry season (Fig. 1). Median yield gains were near 0.5 t/ha for N and near 0 t/ha for P, K, and Zn during the wet and dry seasons.

In Capiz, yields in the wet season were 3.9 t/ha for -N, 4.6 t/ha for -P and -K, and 4.8 t/ha for -Zn (Fig. 1). Yields without N were significantly lower than with full fertilization and with -P, -K and -Zn. In Capiz, during the wet season, the yield gain with N for the middle 50% of the fields was between 0.4 t/ha to 1.8 t/ha (Fig. 1). The median was 1.2 t/ha. During the dry season in Capiz, lower yield gains were observed with medians of 0.6 t/ha for N, 0.2 t/ha for P, 0.1 t/ha for K, and 0.1 t/ha for Zn. The middle 50% of the fields had small yield gains less than 1 t/ha for P, K, and Zn fertilizers (Fig. 1).

Yields were generally lower during the dry than the wet season in the three provinces. The measured yields in Aklan and Antique, but not Capiz, are lower than the means observations from nutrient omission plots in 96 irrigated farms in Iloilo during the crop year 2005-2006. In the said year, -N plots averaged 3.5 t/ha, -P plots averaged 4.4 t/ha, and -K plots averaged 4.5 t/ha (Gabinete, 2006).

The relationships of yield between nutrient omission plots and full fertilized plots (NPKZn) are comparable across provinces (Fig. 2). The -P yields are 94% of the yield with full fertilization, while the -K yields are 96% of the yield with full fertilization. This indicates that yields without added nutrient (i.e., the indigenous nutrient supply) are related to the yield with full fertilization. These relationships are essential for the determination of N, P, and K fertilizer rates within *Nutrient Manager for Rice*.



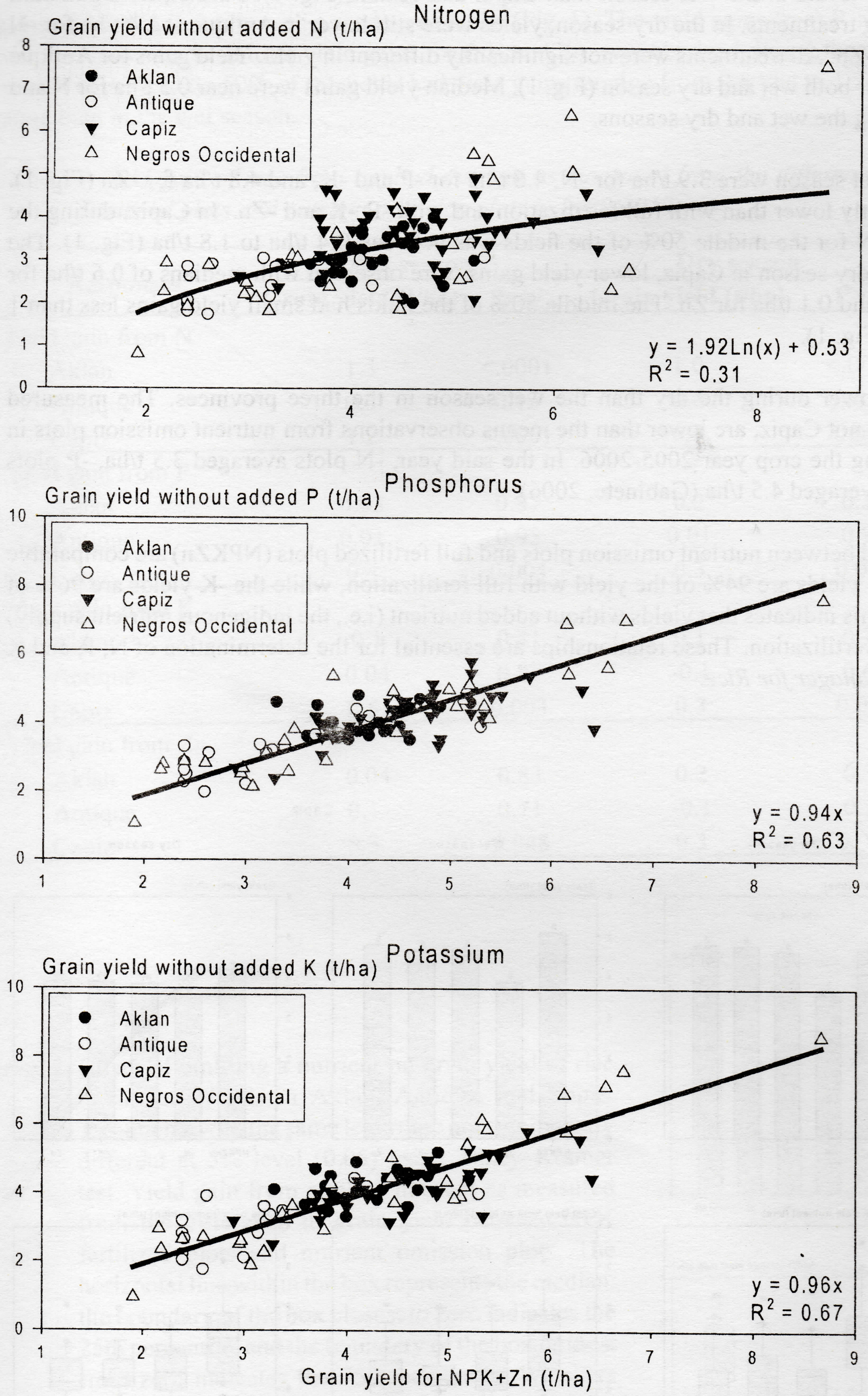


Fig. 2. Influence of location on the relationship between rice gain yield with full fertilization (NPK+Zn) and rice yield with one nutrient missing, across the wet and dry seasons.

Fig. 3 illustrates the relationship between grain yields in nutrient omission plots (indigenous supply of N, P, or K) with yield in adjacent full fertilized plots using this dataset collected from Region 6 and an earlier dataset largely collected from Central Luzon, which is currently used in *Nutrient Manager for Rice*. The close similarity for the relationship observed from the current research in Region 6 and the previous data used in *Nutrient Manager* implies that data and calculations used in *Nutrient Manager* are very much applicable to Region 6.

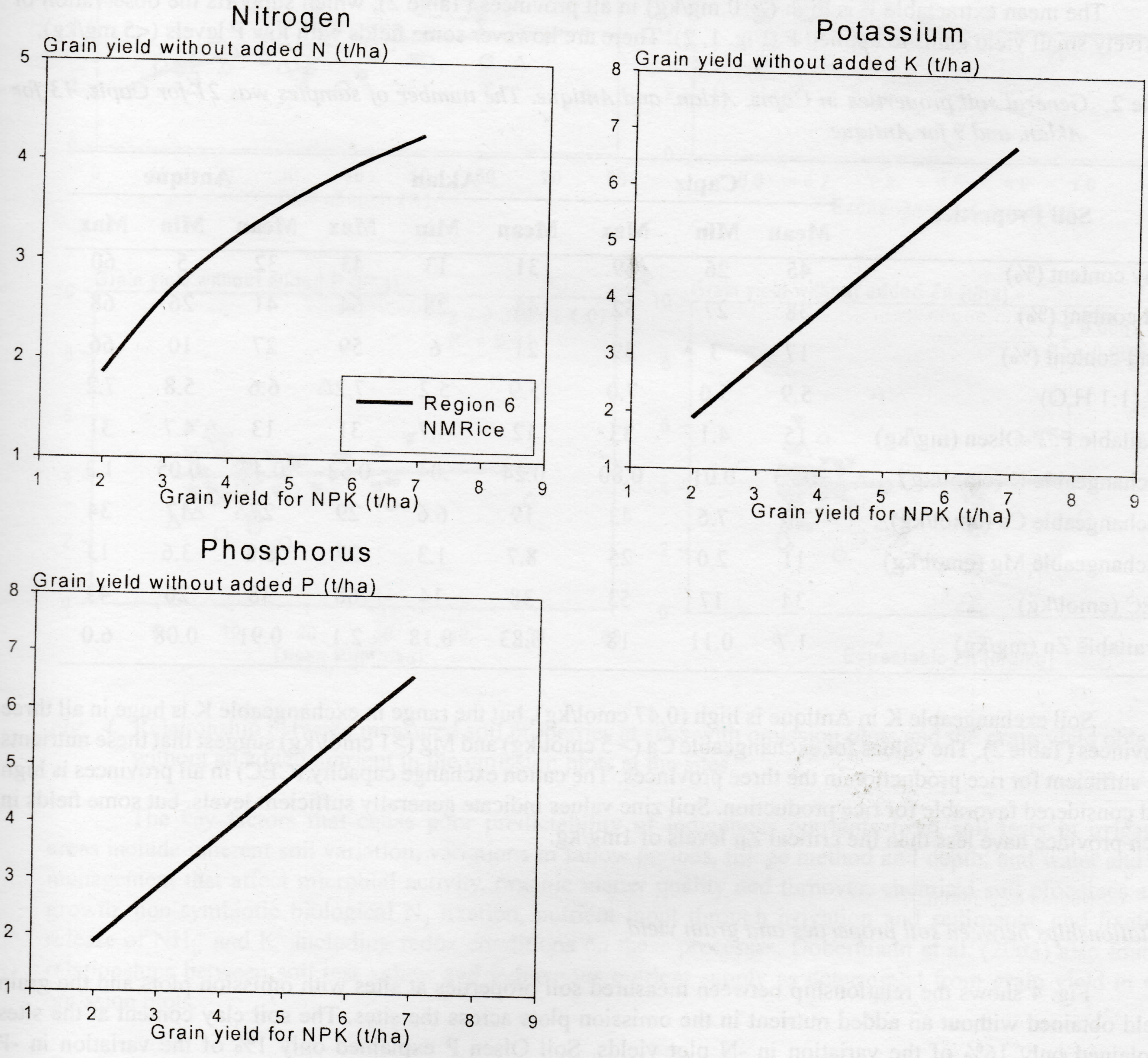


Fig. 3. Relationship from nutrient omission plots for grain yield with a missing nutrient and grain yield with full fertilization in Region 6 compared to the relationship obtained with data across the Philippines and used in *Nutrient Manger for Rice*.

General soil properties

The general properties of soils at the nutrient omission plot study fields in Capiz, Aklan, and Antique are shown in Table 2. Capiz soils are clay while soils of Aklan and Antique are clay loam. Capiz and Aklan soils are slightly acidic while Antique soils are near neutral.

The mean extractable P is high (>10 mg/kg) in all provinces (Table 2), which supports the observation of relatively small yield gains to applied P (Fig. 1, 2). There are however some fields with low P levels (<5 mg/kg).

Table 2. *General soil properties in Capiz, Aklan, and Antique. The number of samples was 21 for Capiz, 13 for Aklan, and 9 for Antique*

Soil Properties	Capiz			Aklan			Antique		
	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Clay content (%)	45	26	69	31	13	43	32	5	60
Silt content (%)	38	27	52	48	28	64	41	26	68
Sand content (%)	17	3	39	21	6	59	27	10	66
pH (1:1 H_2O)	5.9	5.0	7.0	5.9	5.2	7.2	6.6	5.8	7.2
Available P; P-Olsen (mg/kg)	15	4.1	33	12	4.7	31	13	4.7	31
Exchangeable K (cmol/kg)	0.23	0.01	0.80	0.24	.04	0.53	0.47	0.05	1.3
Exchangeable Ca (cmol/kg)	20	7.6	43	19	6.6	29	27	17	34
Exchangeable Mg (cmol/kg)	11	2.0	25	8.7	1.3	27	8.8	3.6	13
CEC (cmol/kg)	34	17	53	38	14	68	38	26	43
Available Zn (mg/kg)	1.7	0.11	18	0.83	0.18	2.1	0.91	0.08	6.0

Soil exchangeable K in Antique is high (0.47 cmol/kg), but the range in exchangeable K is huge in all three provinces (Table 2). The values for exchangeable Ca (> 5 cmol/kg) and Mg (>1 cmol/kg) suggest that these nutrients are sufficient for rice production in the three provinces. The cation exchange capacity (CEC) in all provinces is high and considered favorable for rice production. Soil zinc values indicate generally sufficient levels, but some fields in each province have less than the critical Zn levels of 1mg/kg.

Relationships between soil properties and grain yield

Fig. 4 shows the relationship between measured soil properties at sites with omission plots and the grain yield obtained without an added nutrient in the omission plots across the sites. The soil clay content at the sites explained only 16% of the variation in -N plot yields. Soil Olsen P explained only 1% of the variation in -P plot yields while exchangeable K and explained only 4% of the variations in –K plot yields, and extractable zinc explained only 4% of the variation in -Zn plot yields.

The gain in grain yield from addition of a nutrient as obtained from the nutrient omission plot trials, was also not well related to soil properties (Fig. 5). Soil properties and soil analyses of nutrient status were poor determinants of indigenous nutrient supplies or rice grain yield measured in nutrient omission plots.

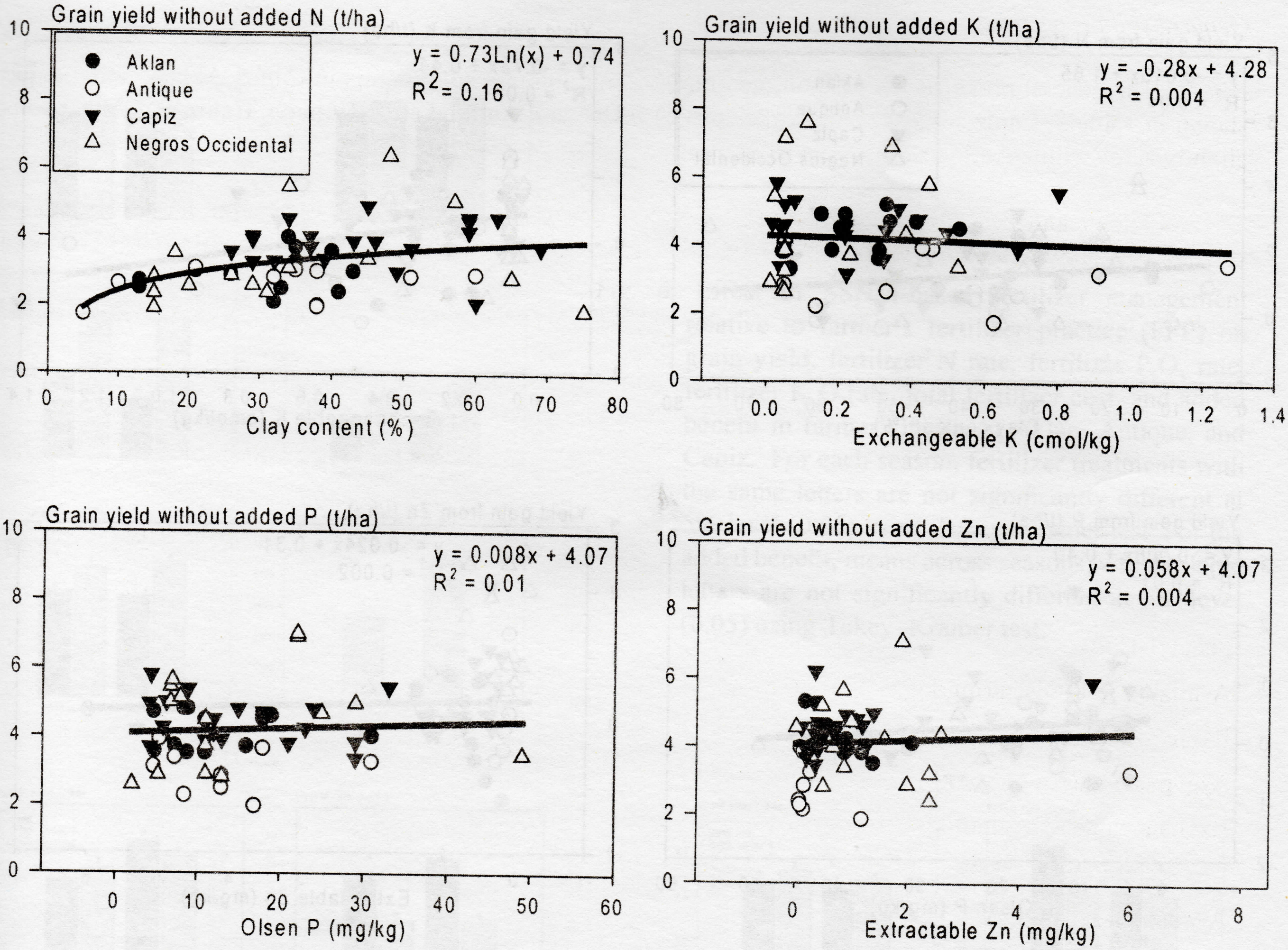


Fig. 4. Relationship between measured soil properties at sites with omission plots and the grain yield obtained without an added nutrient in the omission plots at the sites.

The key factors that cause poor predictability of indigenous nutrients from soil tests in irrigated rice areas include inherent soil variation, variations in fallow periods, tillage method and depth, and water and residue management that affect microbial activity, organic matter quality and turnover, chemical soil processes and root growth, non-symbiotic biological N_2 fixation, nutrient input through irrigation and sediments, and fixation and release of NH_4^+ and K^+ including redox conditions on these processes. Dobermann et al. (2003) also found poor relationships between soil test values and indigenous nutrient supply as determined from grain yield in nutrient omission plots.

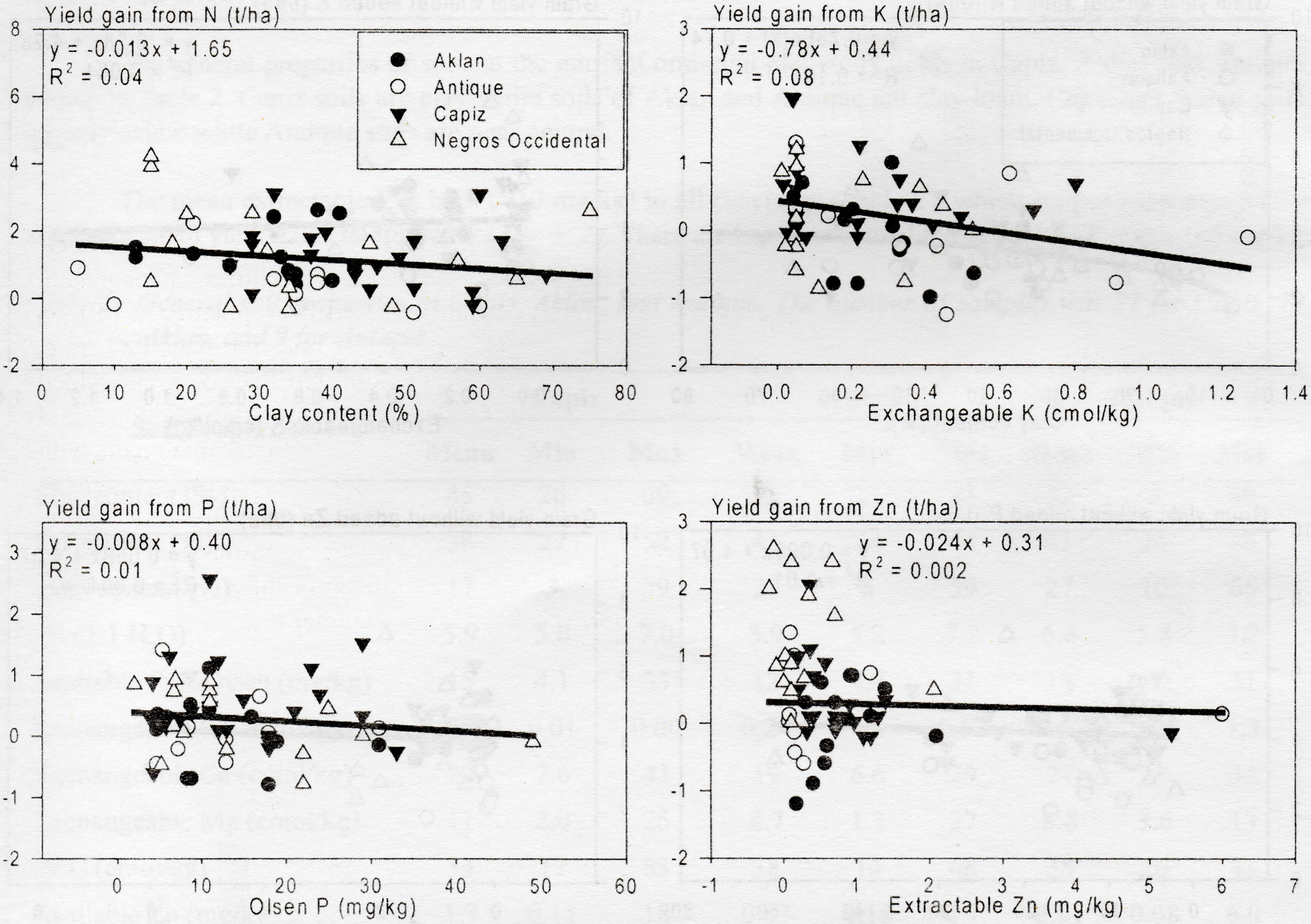


Fig. 5. Relationship between measured soil properties at sites with omission plots and the gain in grain yield from addition of the nutrient at the sites.

Comparison of improved nutrient management and farmer's practice

The effects of SSNM-based fertilizer management relative to farmer's fertilizer practice (FFP) on grain yield, fertilizer N rate, fertilizer P_2O_5 rate, fertilizer K_2O rate, total fertilizer cost, and added benefit in farmer's fields are shown in Fig. 6. In Aklan during the wet season, yields in SSNM fields did not vary significantly from the yields in FFP fields. Fertilizer N, P_2O_5, and K_2O rates were statistically similar in SSNM and FFP fields; and the total fertilizer costs were also statistically similar for SSNM and FFP. The slightly higher yields with SSNM nonetheless resulted in an added benefit of PhP 2,600 per hectare during the wet season.

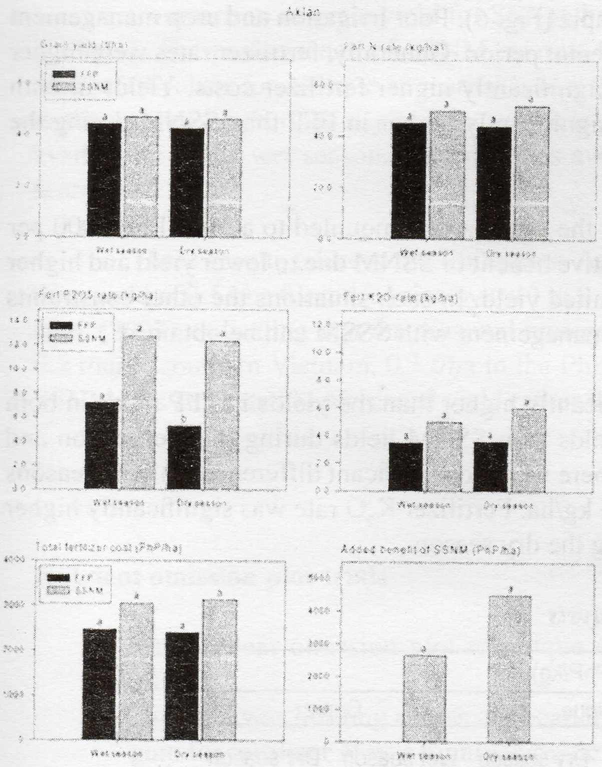
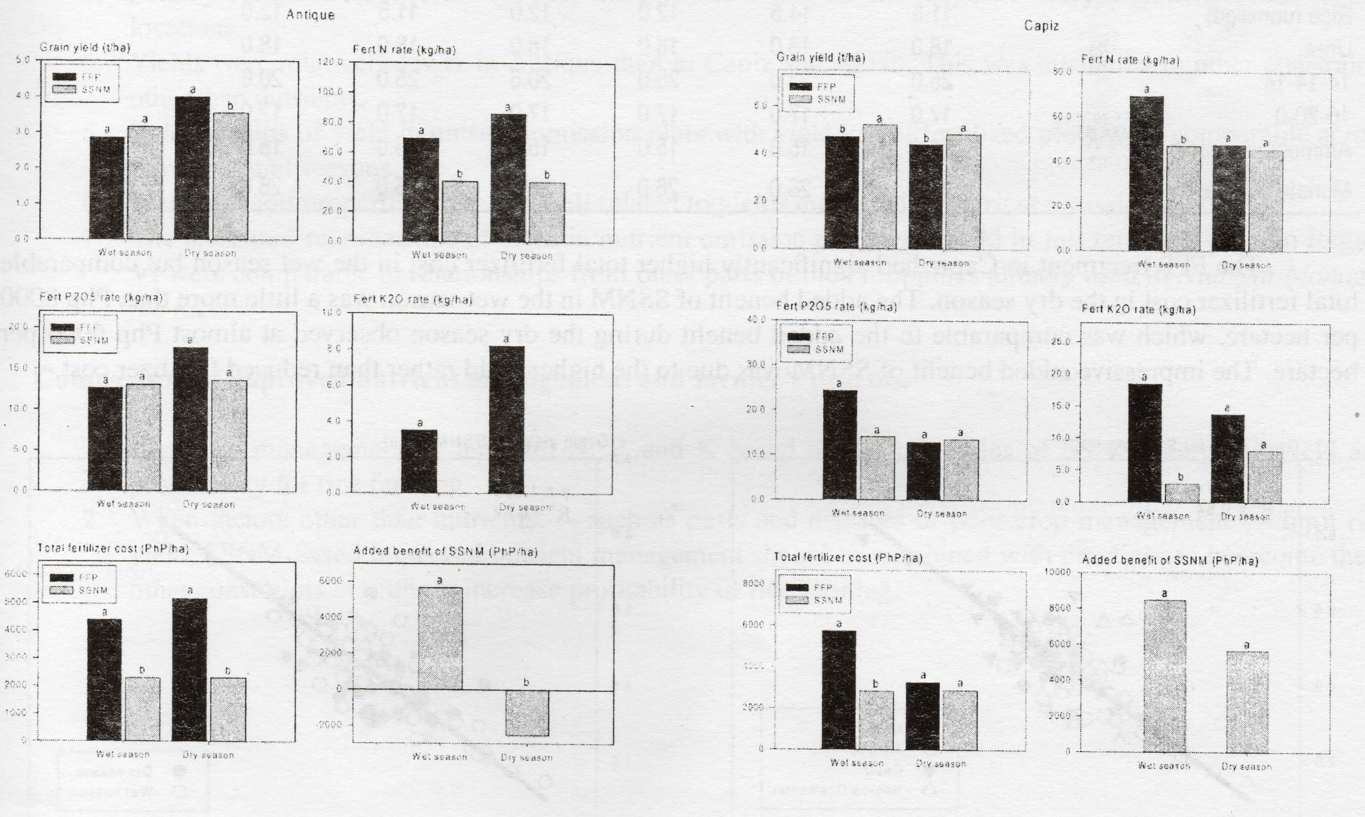


Fig. 6. Effect of SSNM-based fertilizer management relative to farmer's fertilizer practice (FFP) on grain yield, fertilizer N rate, fertilizer P_2O_5 rate, fertilizer K_2O rate, total fertilizer cost, and added benefit in farmer's fields in Aklan, Antique, and Capiz. For each season, fertilizer treatments with the same letters are not significantly different at 5% level (0.05) using Tukey–Kramer test. For the added benefit, means across seasons with the same letters are not significantly different at 5% level (0.05) using Tukey–Kramer test.



During the dry season, almost the same trend was observed in Aklan, except for P_2O_5 rate in SSNM was significantly higher than for FFP. The added benefit of SSNM amounted to PhP 4500 per hectare. The added benefit, however, was not significantly higher than the wet season benefit. The higher benefit in the dry season was also related to a higher price of unmilled rice in the dry season (Table 3).

In Antique, yields were lower than those in Aklan and Capiz (Fig. 6). Poor irrigation and crop management and pest and disease problems were observed during the experimental period. Generally, fertilizer rates were higher in FFP fields than in SSNM fields in both seasons resulting in significantly higher fertilizer costs. Yields in both treatments were statistically similar during the wet season, but significantly higher in FFP than SSNM during the dry season.

For Antique (Fig. 6), the added benefit of SSNM during the wet season amounted to almost PhP 6000 per hectare due to higher yield. But in the dry season there was a negative benefit of SSNM due to lower yield and higher added fertilizer cost. Factors other than nutrients presumably limited yield. In such situations the other constraints must be first overcome before the benefits of improved nutrient management with SSSM can be obtained.

In Capiz (Fig. 6), the yields in SSNM fields were significantly higher than the yields in FFP fields in both seasons. Significantly higher fertilizer N was applied in FFP fields than SSNM fields during the wet season and relatively similar amounts were applied during the wet season. There were no significant differences in both seasons in the amount of P_2O_5 applied, which ranged from about 15 to 25 kg/ha. Fertilizer K_2O rate was significantly higher in FFP than SSNM during the wet season and comparable during the dry season.

Table 3. *Prices for rice and fertilizers used in the economic analysis*

Item	Price (PhP/kg)					
	Aklan		Antique		Capiz	
	Wet season	Dry season	Wet season	Dry season	Wet season	Dry season
Rice (unmilled)	11.5	14.5	12.0	12.0	11.5	12.0
Urea	18.0	18.0	18.0	18.0	18.0	18.0
14-14-14	25.0	23.0	25.0	20.6	25.0	20.6
16-20-0	17.0	17.0	17.0	17.0	17.0	17.0
Ammonium sulfate	15.0	15.0	15.0	15.0	15.0	15.0
Muriate of potash	26.0	26.0	26.0	26.0	26.0	26.0

The FFP treatment in Capiz had significantly higher total fertilizer cost in the wet season but comparable total fertilizer cost in the dry season. The added benefit of SSNM in the wet season was a little more than Php 8000 per hectare, which was comparable to the added benefit during the dry season observed at almost Php 6000 per hectare. The impressive added benefit of SSNM was due to the higher yield rather than reduced fertilizer cost.

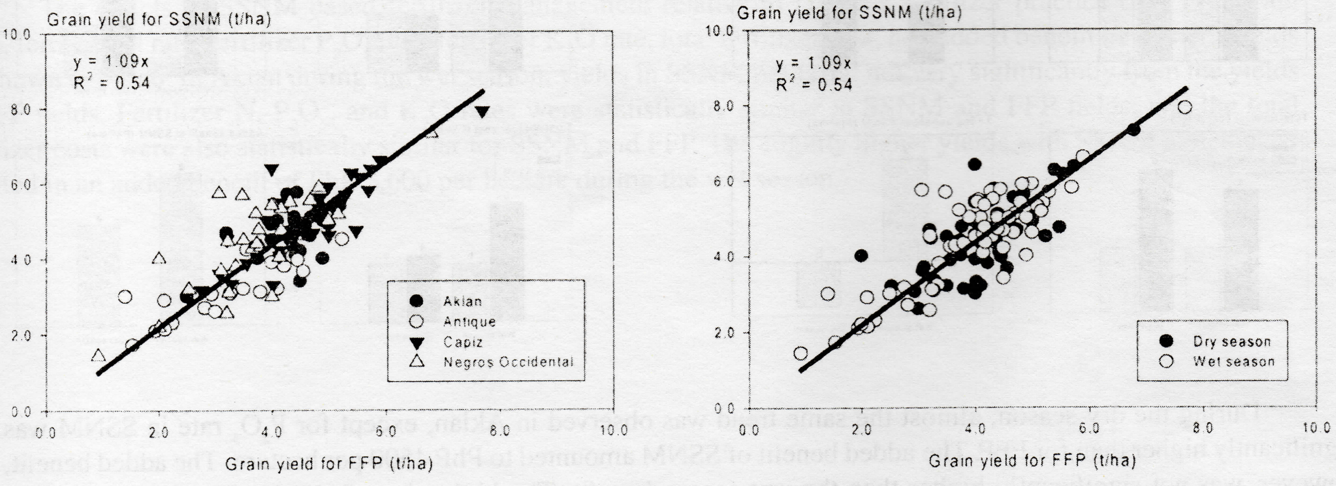


Fig. 7. Comparison of grain yield for SSNM-based fertilizer management relative to farmer's fertilizer practice (FFP) across provinces of Region 6 in the Philippines and across the wet and dry seasons.

Comparison of grain yield for SSNM-based fertilizer management relative to FFP across all sites is shown in Fig. 7. The performance of SSNM relative to FFP tended to be poorest in Antique as indicated by the large number of values for Antique appearing below the best fit line. SSNM yields tended to better than FFP yields more in the wet season than the dry season, which is probably due to better nutrient efficiency arising from better water availability in the wet season. SSNM yields averaged 9% higher than FFP yields (0.37 t/ha) across the sites and seasons.

These results address the Philippine Agriculture 2020 targets on rice self-sufficiency (i.e. increasing the base yield of 3.5 t/ha for inbred rice by 0.10 to 0.14 t/ha per year). These results further conform those of Pampolino et al. (2007), indicating that the seasonal increase in yield of farmers was solely due to the use of SSNM averaged 0.2 t/ha in southern Vietnam, 0.3 t/ha in the Philippines, and 0.8 t/ha in southern India. The increased benefit with SSNM was attributed to increased yield rather than reduced cost of inputs.

CONCLUSIONS

Nutrient omission plot trials

1. The nutrient omission plot technique enables a field assessment of the limitation of a nutrient on rice yield.
2. Nitrogen was limiting across all locations, indicating the need for fertilizer N to achieve target yields. Yield gain for fertilizer N was highly variable across farmer's fields.
3. Mean yield gains from fertilizer P, K, and Zn were small, but the range was very high across seasons and locations.
4. Yields were relatively lower in Antique than in Capiz and Aklan. This was attributed to other constraints other than nutrients.
5. Relationships of yield in nutrient omission plots with yield in full fertilized plots were comparable across provinces and seasons.
6. Measured soil properties were not well related to yields measured in nutrient omission plots.
7. The measured relationships of yield in nutrient omission plots with yield in full fertilized plots in Region VI were comparable to relationships from other parts of the Philippines already used in *Nutrient Manager for Rice*.

Comparison of improved nutrient management and farmer's practice

1. Improved management of fertilizer N, P, and K based on the principles of SSNM increased yield and profitability for rice farming.
2. When factors other than nutrients — such as pests and diseases or poor crop management — limit rice yield, SSNM-based improved nutrient management should be combined with practices to overcome these other constraints in order to increase profitability of rice farming.

IMPLICATIONS AND RECOMMENDATIONS

Nitrogen was limiting across all locations indicating the need for fertilizer N to achieve target yields. Yield gain for fertilizer N was highly variable across farmer's fields indicating a need for field-specific fertilizer management. Mean yield gains from fertilizer P, K, and Zn were small, but the range was very high across seasons and locations, indicating the need for field-specific fertilizer management. Measured soil properties were not well related to yields measured in nutrient omission plots suggesting that soil properties are not good predictors of indigenous nutrient supply in rice soils. The measured relationships of yield in nutrient omission plots with yield in full fertilized plots in Region VI were comparable to relationships from other parts of the Philippines already used in *Nutrient Manager for Rice*. This provides confidence that *Nutrient Manager for Rice* is well adapted for Region 6. Based on the results, the following are recommended:

1. Field-specific management of fertilizers N, P, and K is necessary to achieve yield targets and higher yield gains and
2. *Nutrient Manager for Rice* is an appropriate tool to develop field-specific management of fertilizers N, P, and K in Region 6.

The results of the study contribute significantly to the achievement of the Philippine Agriculture 2020 targets on rice self-sufficiency. This helps achieve Millennium Development Goal # 1-to eradicate extreme poverty and hunger. Improved nutrient management with the right amount and timing also helps protect the environment (air, water and soil) from pollution thus addressing Millennium Development Goal #7-to ensure environmental sustainability.

The government in its pursuit of rice self-sufficiency and food security has embarked on several strategies and thrusts, one of which is the development and adoption of new or improved technologies. The results in this study demonstrate the potential for improved nutrient management based on SSNM principles to contribute to rice self-sufficiency. The dissemination of this technology is the next vital step to concretely realize the increased yield and profitability targets of Philippine Agriculture 2020. For this technology and other technologies to reach the farmers, there is a need for full government support in terms of making available incentives that will enhance increased production. The government needs an effective mechanism to promote and enforce its policies and regulations.

This sustainable and environment-friendly technology is a means of uplifting human conditions by preserving or restoring the fragile rice lands of the country. The results from the field evaluation of SSNM suggest that increased profitability of Php 4500 (or about US$ 100) per hectare per rice-growing season is a realistic target with *Nutrient Manager for Rice*, which uses the SSNM-based approach. Based on the results of this study, the following are recommended:

1. Field-specific fertilizer management as provided through *Nutrient Manager for Rice* is ready for wide-scale promotion and dissemination.
2. For areas with serious constraints to increased yield in addition to nutrient limitations, the *Nutrient Manager for Rice* should be combined with improved crop management practices to overcome the constraints.

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