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TITLE: Enhancing Productivity of Red Clay Soil for Maize Cropping by Organic Fertilizer Application in Combination with Mineral Fertilizers

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THESIS

ENHANCING PRODUCTIVITY OF RED CLAY SOIL FOR MAIZE CROPPING BY ORGANIC FERTILIZER APPLICATION IN COMBINATION WITH MINERAL FERTILIZERS

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A Thesis Submitted in Partial Fulfillment of
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Application of organic materials in crop production has been strongly encouraged in many places as a replacement for part or all of the mineral fertilizer, but often without due consideration to their quality and profitability. The objectives of the present study were to 1) determine economic and agronomic rates of organic manures applied to Pak Chong soil series for maize production 2) explore the possibility of developing a model for predicting optimum combined rates of organic manure and mineral fertilizers for maize; and 3) examine the effect of soil types and types of organic manure on maize response. Compost (with C/N ratio lower than 15) even at 7.5 t ha^{-1} and after five repeated annual applications showed no consistent positive significant response in yields and N and K uptake of maize, though it increased cumulative shoot P uptake after 5 years. This lack of response was due to low N, P and K contents of compost. Moreover, a negative effect of low rates of compost was found on shoot N uptake and grain yields in year 1 which were attributed to short-term N immobilization. Stubble removal with or without mineral fertilizer reduced N balance of the soil and rendered N and P balances negative without mineral fertilizer application. Soil types, organic matter content of soil and nutrient content of organic manure are factors affecting response of maize to organic matter applied based on pot trial. Compost nutrient concentration, ratio of compost price to NP fertilizer price and level of organic matter of the soil were factors determining efficient combination of compost and mineral fertilizer in maize cropping. The Decision Support System for Agrotechnology Transfer (DSSAT) yield simulation and Seasonal Analysis module of DSSAT provided a framework whereby the suitability of compost as N fertilizer replacement for maize could be determined based on its nutrient composition, rate of application and price.

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Student’s signature Thesis Advisor’s signature

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Sutisa Pinitpitoon
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TABLE OF CONTENTS

LIST OF TABLES

LIST OF TABLES (Continued)

Table **Page**

Appendix Table

LIST OF TABLES (Continued)

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

Figure **Page**

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

Figure **Page**

Appendix Figure

LIST OF ABBREVATIONS

AEM	=	anion-exchange membrane
Al	=	aluminum
AOAC	=	Association of Official Analytical Chemists
APSIM	=	Agricultural Production Systems Simulator
AWC	=	available water capacity
BD	=	bulk density
CERES	=	Crop Environment Resource Synthesis
CEC	=	cation exchange capacity
cm	=	centimeter
C/N ratio	=	carbon per nitrogen ratio
CSM	=	Cropping System Model
CV	=	coefficient of variation
Δ	=	delta
DSSAT	=	Decision Support Systems for Agrotechnology Transfer
DUL	=	volumetric soil water capacity at drained upper limit
EC	=	electrical conductivity
E(x)	=	net return
Fe	=	Iron
FOM	=	fresh organic matter
FYM	=	farmyard manure
G2	=	maximum possible number of kernels per plant
G3	=	kernel filling rate during the linear grain filling stage and under optimum conditions
Γ(x)	=	Gini coefficient
GIS	=	Geographic Information Systems

LIST OF ABBREVATIONS (Continued)

k	=	constant value
LL	=	volumetric soil water capacity at drained lower limit
M	=	molar
m	=	meter
mJ	=	milli-Joule
mm	=	milli-meter
mS	=	mill-siemen
^{15}N	=	an isotope of nitrogen with a mass number of 15
NH_4^+	=	ammonium ion
NO_3^-	=	nitrate ion
N_0	=	potentially mineralizable N
N_t	=	total mineralized inorganic N at time
NuMaSS	=	Nutrient Management Support System
P1	=	thermal time from seedling emergence to the end of the juvenile phase (expressed in degree days above a base temperature of 8ºC)
P2	=	extent to which development is delayed for each hour increase in photoperiod above the longest photoperiod at which development proceeds at a maximum rate
P5	=	thermal time from silking to physiological maturity (expressed in degree days above a base temperature of 8ºC)
PAPRAN	=	Production of Arid Pastures Limited by Rainfall and Nitrogen

LIST OF ABBREVATIONS (Continued)

PHINT	=	Interval in thermal time (degree days) between successive leaf tip appearances
QUEFTS	=	Quantitative Evaluation of the Fertility of Tropical Soils
r^2	=	coefficient of determination
RMSE	=	root means square error
SAT	=	volumetric soil water capacity at saturation
SOC	=	soil organic carbon
SOILN	=	N mineralization module
SOM	=	soil organic matter
SRG	=	soil root growth factor
TSP	=	triple super phosphate
US$	=	United States dollar

ENHANCING PRODUCTIVITY OF RED CLAY SOIL FOR MAIZE CROPPING BY ORGANIC FERTILIZER APPLICATION IN COMBINATION WITH MINERAL FERTILIZERS

INTRODUCTION

Application of organic materials in crop production has been strongly encouraged in many places as a replacement for part or all of the mineral fertilizer, but often without due consideration to their quality and profitability. Where the main purpose of recommendation to use organic materials is to decrease the required rate of mineral fertilizer, this raises questions about the optimal proportions of organic and inorganic fertilizers for profitability and soil productivity. Profitability assessment should consider crop yield, price of grain, price and amount of organic and inorganic fertilizer and quality of organic fertilizer. Soil productivity assessment should consider nutrient balance, soil type, and changes in other soil chemical properties, especially soil physical and biological properties. Therefore, determination of suitable organic - inorganic fertilizer combinations involves multiple variables.

A modeling framework is ideal to handle the multi-variate nature of the decision-making challenge in using combinations of organic materials and mineral fertilizers. Criteria for the determination of optimal combinations of compost and mineral fertilizer should be determined. It is a great challenge to use a crop simulation model to provide a framework for determining replacement of mineral fertilizer by compost application. In this study, the Decision Support System for Agrotechnology Transfer (DSSAT) was examined for this purpose. In addition, effects of different organic and inorganic fertilizer on N and P balance of soil were examined.

OBJECTIVES

Ultimate objectives

1) To find economic and agronomic rates of organic manures applied to Red Clay soils (an important group of soil types consistently used for maize production in Thailand) in maize production.

2) To explore the feasibility of developing a model for predicting optimum rates of organic manure and mineral fertilizers for maize.

3) To study effects of types of organic manure and soil types on response to manure of maize.

To attain the ultimate objectives the following experiments were conducted.

Experiment 1: Effects of annual applications of mineral fertilizers and compost and stubble removal on maize cropping for 5 years and effects of repeated application of organic material on soil properties

1) To study effects of compost and mineral fertilizer on maize yields on Pak Chong soils in a medium term (5 annual successive years).

2) To study effects of repeated application of organic and inorganic fertilizer in combination on N and P balances and changes in other properties of Pak Chong soil series.

3) To examine the possibility of using DSSAT to provide a framework for determining suitable combination of compost and mineral fertilizer applied in Pak Chong soil series for maize production.

Experiment 2: Effects of compost at different rates on availability of N and P in soils with and without previously applied compost

1) To examine effects of compost at different rates with and without mineral fertilizer on availability of N and P in soils.

2) To examine effects of increasing soil organic matter on N and P availability.

3) To examine capability of DSSAT and APSIM to predict mineralization in soils.

Experiment 3: Effects of types of organic manures and soils on the influence of manures on maize

To examine effects of types of organic manures and soils on the effectiveness of manures applied for maize.

LITERATURE REVIEW

1. Background of maize cropping in red clay soils of Thailand

Maize is the second most important cereal grain produced in Thailand. In the year 2002/2003, the harvested area of maize was 1.17 million hectares with 4.2 million tons of grain produced (Center for Agricultural Statistics, 2004). Maize producing areas are distributed in the Central plain, North and Northeast of Thailand. Maize yields are generally high in the central plain and the northern regions compared to those in the northeastern region (Land Development Department, 2004), due to more intensive cropping system in the Central and Northern regions. Red clay soil (Red color indicates the presence of free iron oxides) is one of the important soil types for maize production in Thailand. Maize production on this soil type covers 157,487 hectares (approximately 13.5% of harvested area), whereas maize production on the Pak Chong soil series (very fine, kaolinitic, isohyperthermic, Rhodic Kandiustox) was 56,739 hectares (approximately 4.9% of harvested area) (Land Development Department, 2004). The Pak Chong soil series occupies 36.0% of the area covered by red clay soil.

2. Effects of organic manure and mineral fertilizer on soil physical and chemical properties

The use of organic and mineral fertilizers has been found to enhance desirable soil properties including decrease in bulk density, and increases in soil porosity, hydraulic conductivity and soil organic matter (SOM). However, application of mineral fertilizer may produce undesirable effects such as soil acidification. The major mechanism of soil acidification by mineral fertilizer is related to H^+ ion released through nitrification of NH_4^+ where NH_4^+ comes from N fertilizer (Bouwman *et al.*, 1995). Organic manure may either have no effect on soil pH or decrease or increase soil pH, presumably depending on pH's of the manure and the soil.

Stokes *et al.* (2003) studied effects of 2 years repetitive applications of 45 and 90 t ha^{-1} compost, to light clay texture (black Vertisol soil) and found that the soil bulk density decreased from 1.22 to 1.08 and 1.01 mg m^{-3}, respectively. In addition, application of 45 and 90 t ha^{-1} increased total porosity from 54.1 to 59.3 and 61.8%, respectively and increased SOM from 44.3 to 49.3 and 60.3 g kg^{-1}, respectively.

A decrease in bulk density was also observed with mineral fertilizer on Pak Chong soil in Thailand. Suwanarit *et al.* (2000) examined residual effects of 20 successive annual applications of N and P fertilizer for maize production and found that application of 120-120-120 and 180-180-180 kg N- P_2O_5-K_2O ha^{-1} gave trends to decrease soil bulk density from 1.28 to 1.26 and 1.24 mg m^{-3}, respectively. The decrease in bulk density was associated with an increase in hydraulic conductivity from 0.73 in the unfertilized plots to 2.53, 1.39 and 1.2 cm h^{-1} on the treatments 60-60-60, 120-120-120 and 180-180-180 kg N- P_2O_5-K_2O ha^{-1} yr^{-1}, respectively.

Tattao (1987) found that application of 120-120-120 kg N- P_2O_5-K_2O ha^{-1} as mineral fertilizers decreased soil pH from 5.6 to 5.1 but increased SOM from 21 to 25 g kg^{-1}. Similarly, Suwanarit *et al.* (2000) found that soil pH decreased from 7.22 in control treatment to 6.69 and 6.27 following application with 120-120-120 and 180-180-180 kg N- P_2O_5-K_2O ha^{-1} yr^{-1}, respectively, and SOM increased from 26.9 g kg^{-1} in control treatment to 27.7 and 30.4 g kg^{-1} in 120-120-120 and 180-180-180 kg N-P_2O_5-K_2O ha^{-1} yr^{-1}, respectively, after 20 successive annual crops.

Regmi *et al.* (2000) studied effects of organic manure applied to 54 successive crops (18 years) in a rice-rice-wheat cropping system. The results showed that long-term application of farm yard manure (FYM) did not affect soil pH but increased SOM. However, Mikhailova *et al.* (2003) showed a different result. In a study on soil properties after 4 successive annual applications of mineral fertilizer and organic manure on orchard grass, they found that application of 16.8 and 33.6 t of dairy manure ha^{-1} yr^{-1} decreased soil pH from 7.6 to 7.1 and 6.8, respectively. The author suggested that decrease in soil pH after fertilization might be due to acidity of organic materials. In contrast with the finding of Mikhailova *et al.* (2003), Obi and Ebo

(1995) found that application of 10 t poultry manure ha^{-1} applied in two growing seasons increased soil pH from 4.0 to 4.4. Unfortunately, pH's of the manure and the soil were not reported.

3. Comparative effects of organic manure and mineral fertilizer on soil properties

Many researchers studied effect of application of organic manure and mineral fertilizer in short and long terms on soil physical and chemical properties. The following studies are selected to illustrate effects of organic manure and mineral fertilizer.

Marinari *et al.* (2000) studied the effect of organic and mineral fertilizers at the same rate of 200 kg total N ha^{-1} for one crop of corn production. They found that application of organic manure increased percent porosity from 10.7 to 15.7%, whereas application of NH_4NO_3 increased percent porosity from 10.7 to 12.7%.

Mikhailova *et al.* (2003) studied soil properties after 4 successive annual applications of mineral fertilizer and organic manure on orchard grass and found that application of 16.8 and 33.6 t of dairy manure ha^{-1} yr^{-1} decreased soil pH from 7.6 to 7.1 and 6.8, respectively, whereas application of 84 kg N ha^{-1} yr^{-1} and 11 kg P ha^{-1} yr^{-1} mineral fertilizers decreased soil pH from 7.6 to 6.6. Decrease in soil pH after fertilization might be due to acidity of organic materials and mineral fertilizer or the oxidation of ammonium-N to nitrate. However, there are only some types of mineral fertilizer such as ammonium-based N fertilizers resulting in soil acidity. This has been reported by Zhang *et al.* (2006) who studied effects of NPK fertilizers on grain yields and soil properties on long-term cropping of wheat and corn in China. They found that N fertilizer decreased soil pH while application of P or K fertilizer did not significantly change soil pH.

Obi and Ebo(1995) studied effects of poultry manure and mineral fertilizer application in two growing seasons. They found that 10 t of poultry manure ha^{-1}

decreased soil bulk density from 1.54 to 1.40 mg m^{-3}, whereas application of mineral fertilizer, at 49.5-35-55-20 kg N- P_2O_5-K_2O-Mg $ha^{-1,}$ decreased soil bulk density from 1.54 to 1.50 mg m^{-3}. In addition, they found that 10 t poultry manure ha^{-1} increased total porosity from 41.5 to 45.3%, whereas application of 49.5-35-55-20 kg N-P_2O_5-K_2O-Mg ha^{-1} fertilizer increased total porosity from 41.5 to 43.3%. Additionally, they found that application of 10 t poultry manure ha^{-1} increased hydraulic conductivity from 3.48 to 18.7 cm h^{-1}, whereas application of 49.5-35-55-20 kg N-P_2O_5-K_2O-Mg ha^{-1} mineral fertilizer increased hydraulic conductivity from 3.48 to 13.7 cm h^{-1}. Moreover, they found that application of 10 t poultry manure ha^{-1} alone increased soil pH from 4.0 to 5.5, increased percent SOM from 9.1 to 16.3 g kg^{-1} whereas application of 49.5-35-55-20 kg N- P_2O_5-K_2O-Mg ha^{-1} fertilizer alone increased soil pH from 4.0 to 4.4 and increased % SOM from 0.91 to 0.93. This increase in soil pH by the mineral fertilizer, which is in contrast to findings of others, such as that of Mikhailova *et al.* (2003) was presumably due to an alkaline form of Mg in the mineral fertilizer.

The results of the studies mentioned above showed that application of organic manure and mineral fertilizer at prevailing rates decreased bulk density, increased soil porosities, hydraulic conductivity and SOM. However, applications of organic manure have greater effects than mineral fertilizer did. Mineral N fertilizer decreases soil pH whereas organic manure has mixed effects (no affect or decreases or increases in soil pH) depending on pH of the manure and the soil.

4. Advantages and disadvantages of using organic and inorganic fertilizers in combination for nutrient availability, synchronization of nutrient release and properties of soils

Many long-term studies have shown that combinations of both organic and inorganic nutrient sources lead to enhanced nutrient availability and synchronization of nutrient release and uptake by crops and positive effects on soil properties. The following studies illustrate advantages of dual use of organic and inorganic fertilizers.

Goyal *et al.* (1999) studied SOM level, mineralizable C and N, microbial biomass C and dehydrogenase, urease and alkaline phosphatase activities in soils from a field experiment under a pearl millet-wheat cropping sequence receiving inorganic fertilizers and a combination of inorganic fertilizers and organic amendments after 11 annual crops. They found that urease and alkaline phosphatase activities of soils increased significantly with a combination of inorganic fertilizers and organic amendments. The results indicate that SOM level and soil microbial activities, vital for nutrient turnover and long-term productivity of soil, are enhanced by using organic amendments along with inorganic fertilizers.

Quedraogo *et al.* (2007), who conducted a field experiment on a loamy-sand with low SOM and nutrient concentration in semi-arid West Africa, found a positive interaction on sorghum yields when maize straw and urea were applied in combination. Yield increases over control by sole application of maize straw and by urea were 366 and 291 kg ha^{-1}, respectively, the while combination of straw and urea treatment increased sorghum yields by 1,400 kg ha^{-1} over control.

An advantage of using organic and inorganic fertilizer in combination is to reduce emissions from N fertilizer use as suggested by Pan *et al.* (2009) who conducted a long-term fertilization trial in a rice paddy in Tai Lake region, China. They concluded that combined organic/inorganic fertilization both enhanced C storage in soils, and reduced emissions from N fertilizer use, while contributing to high crop productivity in agriculture.

In contrast to the above studies, disadvantages of combined application of organic and mineral fertilizer have been reported. The following studies showed negative interaction on crop yields when using a combination of organic and mineral fertilizer.

In a long-term (5 years) study on effects of N, P and K fertilizers and organic manure on cassava grown on Huai Pong soil series, Sittibhud *et al.* (1990a) showed that mineral fertilizer at the rate 50-50-50 kg N- P_2O_5-K_2O ha^{-1} increased average (of

5 years) cassava yields by 2.6 t ha^{-1} over control whereas plowing stubble into the soil increased the yield by 700 kg ha^{-1}. Application of mineral fertilizer in conjunction with stubble incorporation gave cassava yield over control treatment by 2.2 t ha^{-1}. These results showed that sole application of mineral fertilizers gave greater cassava yield responses than application in conjunction with plowing cassava, illustrating a negative interaction between application of mineral fertilizers and stubble incorporation. Similarly, in a second study, Sittibhud *et al.* (1990b) reported that application of mineral fertilizers at 50-50-50 kg N- P_2O_5-K_2O ha $^{-1}$ in Korat soil series gave cassava yield increases (average of 5 years cropping) of 6.2 t ha $^{-1}$ over control treatment, incorporation of stubble into the soil gave 5.9 t ha $^{-1}$ over control treatment, whereas application of mineral fertilizers in conjunction with stubble incorporation gave 9.4 t ha $^{-1}$ cassava yields over control. These results also showed a less than additive response (negative interaction) to application of mineral fertilizers and stubble plowing.

Han *et al.* (2004) who examined interactive effects of a combined application of urea and compost on the fates of urea-N and net mineralization of compost-N in three soils with different contents of organic-C and inorganic-N through an aerobic 6-week incubation study. They suggested that compost blending would increase immobilization of urea-N in soils with high C and N contents whereas it would increase nitrification of fertilizer-N in soils with low nutrient contents.

Dual use of organic and inorganic fertilizer is suggested from many studies. However, dual use of organic and inorganic fertilizer is not, absolutely, recommended but it needs to consider environmental factor and, especially, soil type. For example, on soil with no critical limiting soil physical properties, application of organic fertilizer might not show significant effects, in that case application of organic fertilizer in this soil type is only useful for its nutrient supply.

5. Suitable combination of organic and inorganic fertilizers

Suitable combinations of organic and inorganic fertilizer can be considered as better options in increasing fertilizer use efficiency, and providing more balanced supply of nutrients (Donovan and Casey, 1998). Synergistic effects of combinations of organic and mineral fertilizer on crops have been reported due to synchronization of nutrient release and crop uptake due to the different nutrient release patterns of organic and mineral fertilizer. The following examples illustrate different suitable combinations that optimize crop yields on different treatment settings and environments.

In a trial on maize fodder production, Oad *et al.* (2004) found that application of mineral fertilizer at the rate 120 kg N fertilizer in conjunction with farm yard manure increased yields more than application of 90 and 150 kg N fertilizer, whereas application of 3.0 t of farmyard manure ha^{-1} in conjunction with mineral fertilizer at all of the rates used gave maize fodder yields greater than application of 1.5 and 4.5 t of farmyard manure ha^{-1}. They concluded that application of 120 kg N fertilizer with 3.0 t of farm yard manure ha^{-1} was the most suitable combination rate for maximizing yields of green maize fodder.

Erhart *et al.* (2005) investigated the performance of the 3 biowaste compost rates (9, 16 and 23 t ha^{-1} yr^{-1}) and 3 mineral fertilizer rates (25, 41 and 56 kg N ha^{-1} yr^{-1}) in agriculture on a fertile soil under relatively dry climatic conditions, as is typical for eastern Austria. They found that treatment combinations between highest N fertilizer rate with the lowest compost rate gave a higher rye yields than the combination of the lowest N fertilizer rate with the highest compost rate did.

One of the main factors affecting suitable combination rates is soil type as clearly defined by Soumare *et al.* (2003) who studied effects of municipal solid waste compost and mineral fertilizer on ryegrass in two Malian soils using twelve treatments (control, NPK, NPK+C_{25}, NPK+C_{50}, NPK+C_{100}, PK+C_{50}, NK+C_{50}, NP+C_{50}, K+C_{50}, P+C_{50}, N+C_{50} and C_{50}) in a pot experiment. They recommended a combination of NPK with 25 t compost for Gao soil (loamy sand) and 50 t compost with NPK for Bgda soil (sandy clay loam) for the highest yields.

It could be concluded that there is no general suitable combination rate of organic and inorganic fertilizer application for all sites. This is due to different environment and different soil type which results in varied crop response. Hence, the suitable combination rate recommended for a particular study could not be applied for other sites without some modification.

6. Factors determining the appropriate use of organic fertilizer for crop production

The factors determining the appropriate use of organic materials would be useful criteria for advising growers on how to optimize combinations with mineral fertilizers for sustaining and improving yields. Organic material quality, mineralization rate, soil type, nutrient balance after organic material application and economic effect are important factors to consider.

6.1 Organic materials quality

The total C and N concentrations in compost need to be considered both in the context of mineralization rate as well as for nutrient supply. Songmuang *et al.* (1999) reported that no significant change in paddy yield by low rates (2 t ha^{-1}) of rice straw compost applied in the first 3 years without mineral fertilizer application. This might be due to low compost quality, 6 g kg^{-1}N, 1 g kg^{-1}P, 15 g kg^{-1}K and C/N ratio of 14.

Carbon to N ratio is another criterion for estimating organic material quality. Mando *et al.* (2005) assess the effect of organic and inorganic fertilization on SOM fractions and sorghum yields in a long-term trial under Sudano-Sahelian conditions in West Africa. They found that soil organic matter and crop performance was better maintained using organic material with low C/N ratio (manure) than that with high C/N ratio (straw).

However, the C/N ratio alone is not a precise factor to determine organic materials quality. The degree to which organic materials are composted is a critical factor in determining the initial benefit of compost application. Cambardella *et al.* (2003) evaluated the impact of composting process conditions and the extent of compost decomposition on soil C and N mineralization after compost incorporation. They found that short-term immobilization of N occurred, even with a very high application of 80 t of hog manure compost ha^{-1} (C/N ratios of 12.1 to 15.1). No clear relationship between C/N ratio and N mineralization was found. Their results suggested that significant denitrification could occur in soil following compost incorporation and this may produce net immobilization of N rather than N mineralization. They concluded that mineralization of N from compost was a complex process and could not simply be explained by the C/N ratio but may involve several factors such as the raw material used for composting and the duration of composting.

6.2 Mineralization rate of organic manures

An aim of using organic manure, apart from improving soil physical properties, is to supply nutrients for crop growth. Knowing the mineralization rate or the decay series of organic manure assists farmers to estimate available nutrient loads after application and to design appropriate timing of N release that suits crop demand. However, this is not easy as the decay series differs among studies due to different test conditions. Some researchers have developed the decay series using different organic manure types and environments as illustrated in the selected studies below.

Pratt *et al.* (1973) developed a decay series for beef cattle manure which predicted loss equivalent to 0.35, 0.10. 0.05 and 0.02 of the initial manure in the 1st, 2nd, 3rd and 4th years after application. By contrast, the decay factors were 0.90 and 0.01 for years 1 and 2, respectively, for poultry manure and 0.75, 0.04 and 0.01 for years 1, 2 and 3, respectively, for swine manure. Klausner *et al.* (1994) developed a decay series for the more stable organic N fraction in dairy manure based on crop yield and N uptake. The study was carried out on a fine-loamy, non acid soil, with total precipitation of 447 mm in New York, USA. They found that decay of dairy manure over 5 years was equivalent to 0.16, 0.10, 0.03, 0.03 and 0.02 of the initial addition, respectively, based on crop yields, but equivalent to 0.21, 0.09, 0.03, 0.03 and 0.02, respectively, based on crop N uptake.

Eghball and Power (1999) evaluated the effects of application frequency and N-P based rates of manure and compost application on corn grain yield, N uptake and soil P level and weed control. The study was carried out in silty clay loam soil under rain fed conditions in Nebraska, USA. Soil in this study had 69 mg kg^{-1}P and pH of 6.2. They estimated P availability from compost of 0.6, 0.2, 0.1 and 0.1 in the 1^{st}, 2^{nd}, 3^{rd} and 4^{th} years after application.

6.3 Soil type and environmental factors

Soil type is a factor controlling crop response when organic and inorganic fertilizers are applied. Soil texture plays an important role in determining the nutrient availability of organic and inorganic fertilizer application as illustrated below. Some studies reported that N mineralization was positively correlated with total N and clay content.

Mafongoya *et al.* (1997) determined the effects of plant prunings quality over time, method of pruning and soil type on N recovery and the residual effects on maize N uptake and N recovery. They found N immobilization in sandy loam soil but not in sandy soil. They suggested that higher organic C content in soil caused high microbial activity and high N immobilization rate as clay particles would have protected decomposition products from microbial attack and reduce N mineralization rate.

Even though soil type could be used as a criterion for estimating N availability when organic and inorganic fertilizer was applied, the environmental factors are also important. This point has been raised by Quedraogo *et al.* (2001) who studied the influence of compost on soil properties and on crop performance on degraded soils in West Africa. They conducted a field study on the same soil type but with different soil surface thickness to simulate the effects of land degradation by erosion. They reported that with the shallower soil, application of 10 Mg of compost ha^{-1} produced a lower yield than 5 Mg of compost ha^{-1} from deeper soil surface. The authors suggested that in the deep soil, nutrients for crop growth and lateritic soil conditions are not limiting factors which contrast with the shallow soil.

6.4 Nutrient balance in soil

Nutrient addition through organic and mineral fertilizer must be considered as it is an important external source for plant growth. Plant takes up and accumulates nutrients in its biomass; this is a major pathway for nutrient removal from soil systems. Negative balance occurs when nutrient supply is not adequately replaced. The following examples showed a negative balance when growing crop without adding organic and/or inorganic fertilizer.

Lupwayi *et al.* (1999) studied nutrient balance in a hedgerow intercropping experiment with two rates of N fertilizer (0 and 40 kg N ha^{-1}) and two levels of air-dried cattle manure (0 and 3 t ha^{-1}). The result showed that nutrient balance in the control treatments were -19 kg N ha^{-1} and -12 kg P ha^{-1}. Application of N fertilizer led to net positive balances of 13 kg N ha^{-1}. While application of manure led to positive balance of 59 kg N $ha^{-1}$and 9 kg P ha^{-1}.

A similar result was found by Adu-Gyamfi *et al.* (2007) who studied nutrient balances at four locations for two years in Tanzania and Malawi. These areas have no report about mineral fertilizer application. The result showed that mean N balance of the sole maize plots in Malawi and Tanzania were -26.1 and -50.1 kg N ha^{-1}, respectively. However, when all the aboveground material was returned to the soil for sole maize in Malawi and Tanzania, N balance were less negative, i.e. -8.9 and -5.9 kg N ha^{-1}, respectively.

It could be seen that the negative nutrient balance mostly occur due to high yield production and nutrient removal from the soil that is not adequately replaced.

Continuous negative balance leads to nutrient depletion from soil. Adding organic and/or inorganic fertilizer could result in positive balance if the amount of nutrient addition exceeds nutrient removal and loss. However, effects of organic and inorganic fertilizer on nutrient balance are important and need to be considered as illustrated below.

Kristaponyte (2005) who studied effect of fertilization systems on the nutrient balance found that unfertilized treatment and application of 80 t FYM ha^{-1} showed negative P balance of -126 and -10.8 kg ha^{-1}, respectively. Whereas either application of sole NPK or in combination with 40, 60 and 80 t FYM ha^{-1} showed positive P balance of 42, 118, 156 and 185 kg ha^{-1}, respectively.

A similar result was found by Salazar *et al.* (2005) who studied the N budget for three cropping systems fertilized with manure and found that the treatments with manure slurries had much higher N balance than control in the first year. However, in the second year both slurry treatment and the control showed N balance decreasing on maize cropping even though the slurry supplied 200 kg N ha^{-1} year^{-1}.

Crop yield is an ultimate goal for crop production, however, nutrient balance in the soil after cropping is an important factor to keep in mind. From short- and long term studies illustrated above, it could be concluded that high yields need high amount of nutrient addition. Sufficient nutrient replacement is a key point for selection of fertilizer type and rate.

6.5 Economic effect

Economical evaluation is an important factor for crop production as mineral and organic fertilizer prices are expensive at present. Even though high-quality of organic materials is recommended, they have limitations for on-farm use because of the large amount of biomass and the associated labor requirements.

Gachengo *et al.* (1999) investigated two organic resources, *Tithonia diversifolia* (tithonia, flowering plant; 38.5 g kg^{-1}N, 3.3 g kg^{-1}P) and *Senna spectabilis* (senna, legume; 29.8 g kg^{-1}N, 2.0 g kg^{-1}P) and their combination with inorganic P for improving soil fertility and maize yields on a P-limiting soil in Western Kenya. They observed greater maize production through application of high-quality organic inputs like tithonia in combination with inorganic fertilizers as compared to sole application of mineral fertilizers that it could give higher economic gain to the farmer than application separately. However, the tithonia transfer system has limitations because of the large amount of biomass and the associated labor requirements for application.

Opala *et al.* (2010) tested the effect of FYM (18 g kg^{-1}N, 4 g kg^{-1}P and 12 g kg^{-1}K) and tithonia (30 g kg^{-1}N, 3 g kg^{-1}P and 38 g kg^{-1}K) and N fertilizer and three P sources on maize. They found that treatments including tithonia were more effective in increasing maize yields than those without it due to its high nutrient contents. However, from a profitability perspective, tithonia application was not worthwhile if it had to be imported from another place.

Moreover, large amount of organic materials applied for crop production imposed an enormous labour cost which decreased net return compared with mineral fertilizer treatment as found in Akanbi *et al.* (2006)'s study. They evaluated the economic viability of split organo-mineral fertilizer at different rates on Okra (*Albelmoschus esculentus* Moench) in Nigeria. They found that the recommended NPK fertilizer gave higher net return than 4 t ha^{-1} compost did though the treatment of 4 t compost ha^{-1} gave higher okra yields than NPK fertilizer treatment did.

Consequently, it could be concluded that application of organic fertilizer does not always achieve net profit, especially, if organic manures need to be imported from other places. Moreover, it is time consuming when large amounts of organic manure are applied. Hence, profitability should be taken into account for appropriate use of organic fertilizer in crop production.

7. Framework for determining the efficient combination of organic materials and mineral fertilizer applied in maize cropping

DSSAT have been used for many purposes such as prediction of crop yields to guide the suitable management and N fertilizer rate for the farmers. For example: Paz *et al.* (1999) developed a technique to use the CERES-Maize crop growth model to characterize corn yield variability and evaluate variable N prescriptions for a field in Iowa; and Soler *et al.* (2007) evaluated Cropping System Model-CERES-Maize, which was a combined module for DSSAT, for its ability to simulate growth, crop development and grain yield in Brazil.

Another application of DSSAT is to identify efficient treatments based on profit and risk. For example: Sarkar and Kar (2006) used DSSAT to choose the best management options for economically efficient production of rice and wheat crops on Red and lateritic agro-ecological region of West Bengal in India; and Miao *et al.* (2006) evaluated the potential of applying DSSAT to simulate maize yields at various N levels in different management zones and to estimate the optimal N rates to improve economic return.

Additionally, DSSAT models have been used for evaluating the impact of climate change on crop yields. For example: Mera *et al.* (2006) studied the effects of environmental/climate changes in radiation, temperature, and precipitation on crops, especially soybeans and corn, through crop yield and canopy water loss/evapotranspiration; and Felkner *et al.* (2009) evaluated effects of climate changes in Southeast Asia on rice yields by integrating multi-stage of rice growth model and economic module.

Moreover, some researchers combined Geographic Information System (GIS) with DSSAT for spatial analysis purpose such as the study of Meinke and Hammer (1995) that combined crop simulation with GIS to assess regional peanut potential for the Australian Peanut Industry and plans for expanding the production area. In addition, Badini *et al.* (1997) used GIS and DSSAT to quantify and map the water-limited areas on millet crop throughout the country for providing guideline for crop water management.

However, to date there appear to be no studies that have attempted to use DSSAT to provide a framework for making optimal choices of combinations of organic and mineral fertilizers for crop yield and profit.

MATERIALS AND METHODS

1. Experiment 1

A field experiment with five annual crops was carried out during the years 2002 – 2006.

1.1 Site and experimental design

The field experiment was conducted at the National Corn and Sorghum Research Center, Pakchong, Nakhon Ratchasima, Thailand. The soil has been classified as Pakchong series (Pakchong very fine, kaolinitic, isohyperthermic, Rhodic Kandiustox; Soil Survey Staff, 1999). The experiment was conducted with a randomized complete block design with 3 replications and 20 treatments. The treatments were 4x4 factorial combinations plus 4 additional treatments as follows:

<u>Factor 1</u>: Rate of compost application (for each crop)

1) No compost application (C_0).
2) Application of 1875 kg compost ha^{-1} (C_1).
3) Application of 3750 kg compost ha^{-1} (C_2).
4) Application of 7500 kg compost ha^{-1} (C_3).

<u>Factor 2</u>: Rate of mineral fertilizer application (for each crop)

1) No mineral fertilizer application (F_0)
2) Application of 31.25-31.25 kg N-P_2O_5 ha^{-1} as urea and triple superphosphate (TSP) (F_1)
3) Application of 62.5-62.5 kg N- P_2O_5 ha^{-1} as urea and TSP (F_2)
4) Application of 125-125 kg N- P_2O_5 ha^{-1} as urea and TSP (F_3)

<u>Additional treatments</u>

$C_0F_0S_0$

$C_0F_1S_0$

$C_0F_2S_0$

$C_0F_3S_0$

Where S_0 = maize stubble removal after ear harvest, except for the first cropping in which maize stubble was removed before land preparation for all plots.

The size of the plot for each treatment combination was 5.25 x 7m. Maize cultivar used was SW3851 hybrid. Plant spacing was 0.75 m between rows and 0.25 m between individual plants. Each plot had 7 rows but only plants in the 3 central rows, discarding two plants at each end, was accounted for in data collection.

The N fertilizer was applied by balanced split application at planting and one month after planting whereas all of the P fertilizer was applied at planting. The compost as well as N and P fertilizers were applied in a band at 5-8 cm depth and 5-10 cm from the plant row. Application of the N fertilizer at 30 DAP was banded on the soil surface at 5-10 cm from the plant row.

1.2 Soil

1.2.1 Soil sampling

1.2.1.1 Year 1 (2002)

Soil samples for chemical analysis were taken before maize planting. The soil was collected for three separated layers, i.e., at 0-15 cm, 15-30 cm and 30-50 cm depths by mixing the soil in each sampling quadrant (2 quadrants per one sample). The size of each quadrant was 0.75 x 0.25 m, with the larger side being across direction of plant rows. The soil from each layer was then air-dried and crushed to pass 2-mm and 0.5-mm sieves, respectively.

1.2.1.2 Year 2-3 (2003-2004)

Soil samples for chemical properties examination were taken before maize planting by digging out the soil from each quadrant (75 x 25 cm) to 20 cm depth, mixing the obtained soil well and then taking a sub-sample. Samples from two quadrants from each plot were then mixed well (1:1 ratio) to obtain a composite sample for the plot.

1.2.1.3 Year 5 (2006)

Soil samples for chemical and physical properties examination was taken after maize planting. Disturbed soil samples, for chemical properties and some physical properties were collected as described in 1.2.1.2. Undisturbed soil samples, for determination of water infiltration and bulk density, were collected by core sampling method at 0-15, 15-30 and 30-50 cm depths.

1.3 Soil analysis

1.3.1 Chemical analysis

Soil samples were analyzed for pH in water (1:1, soil:water) by pH meter (Peech, 1965). Organic carbon content of the soil was measured by Walkley and Black's method (Nelson and Sommers, 1996). Extractable N (NH_4^+ + NO_3^-) for years 1-3 was measured according to Ruzicka and Hansen (1975) and extractable N (NH_4^+ + NO_3^-) after year 5 was measured by Kjeldahl method (Bremner and Keeney, 1982). Total N was measured by micro Kjeldahl method (Bremner, 1965). The available P was measured by Bray II method (Bray and Kurtz, 1945). Exchangeable K was analyzed by extraction with 1*N* NH_4OAc (Pratt, 1987) by Atomic Absorption Spectrophotometer. The soil chemical properties of soils before the trial are shown in Table 1.

Table 1 Chemical properties of soils at 0-15 cm depth before the trial started.

Properties	Analysis
pH [1/]	6.55
Organic carbon [2/] (g kg^{-1})	15.6
Total N [3/] (g kg^{-1})	1.38
Extractable N [4/] (NH_4^+ + NO_3^-) (mg kg^{-1})	49.5
Bray II extractable P [5/] (mg kg^{-1})	10.4
Exchangeable K [6/] (mg kg^{-1})	260

[1/] 1:1, soil:water (Anonymous 1999); [2/] By Walkley & Black method (Nelson and Sommers, 1996); [3/] By Kjeldhal method (Jackson, 1965); [4/] By 2 M KCl extraction (Keeney and Nelson, 1982) and determination of NO_3^- and NH_4^+ according to Ruzicka and Hansen (1975); [5/] By Bray II method (Bray and Kurtz, 1945); [6/] By 1 *N* NH_4OAc extraction (Pratt, 1987) and determination of extracted K by Atomic Absorption Spectrophotometer.

1.3.2 Physical analysis

Soil samples were analyzed for water retention by soil core and pressure plate method (Klute, 1986). The hydraulic conductivity of saturated soils was determined according to Klute (1986) by falling head method. The core soil samples were oven dried at 105 ° to constant weights for gravimetric bulk density determination (Blake and Hartage, 1986).

1.4 Compost preparation and analysis

Commercial compost of the same brand was used over 5 years. Moist compost was crushed to pass a 5 mm sieve and well mixed before weighing out. The compost was kept moist in plastic bags for 7-10 days before application. Samples of the compost were also taken for moisture content determination by oven drying. Compost properties are shown in Table 2.

Table 2 Properties of compost used in years 1-3*.

Item	Year 1	Year 2	Year 3
Water content 1/ (g $100g^{-1}$)	24.0	16.5	11.2
pH 2/	7.9	8.0	7.4
Organic carbon 3/ (g kg^{-1})	73.3	50.4	35.5
EC 4/ (mS cm^{-1})	12.4	12.4	11.8
Total N 5/ (g kg^{-1})	5.9	5.3	5.3
Total P 6/ (g kg^{-1})	3.1	2.3	2.0
Total K 7/(g kg^{-1})	5.5	10.5	7.8
C/N ratio	12.4	9.5	6.7

* No compost analysis in years 4 and 5 by mistake; 1/ Oven dried at 105º C until constant weight; 2/ 1:1, soil:water (Anonymous, 1999); 3/ Walkley & Black method (Nelson and Sommers, 1996); 4/ 1:5, soil:water (Rhoades, 1996); 5/ Wet digestion and Kjeldhal method (Jackson, 1965); 6/ Wet digestion and ascorbic method (5:2, HNO_3:$HClO_4$; AOAC, 1990); 7/Wet digestion and atomic absorption spectrophotometer (Jackson and Mahmood, 1994)

1.5 Planting and harvest

During the 5 years, maize was sown in August and harvested in January of the following year, except that of year 4 which was harvested in late October because plants of some treatments were damaged by storms. Maize was harvested after physiological maturity for all crops, except that in year 4 which was harvested at 83 days after planting that was before physiological maturity. The harvested area was 6.0 x 2.25 m in year 1 and 5.0 x 2.25 m in the following years.

1.6 Rainfall and irrigation

The average annual rainfall was approximately 1,200 mm. August-November is the main rainy season when about 41% of total rainfall is recorded. The dry period from December to March has low rainfall. To ensure adequate water supply, supplemental irrigation was applied with sprinklers until 95 days after sowing. The irrigation was scheduled at 40 mm per week less rainfall recorded during the preceding week.

1.7 Crop residue management

The maize stubble of all plots, except for those of the additional treatments, were left on soil surface in the plots and then plowed into the soil during land preparation at about one month before the following cropping. In the case of the additional treatments, maize stubble was removed from the plots after ear harvest, except for the first cropping in which stubble was removed before land preparation.

1.8 Data collection and plant analysis

The height of maize plants were measured at 30, 45 and 60 DAP. At the tasselling and silking ages, shoot dry weight was recorded while grain yield was obtained at physiological maturity (except as described above for year 4). The grain and stubble samples were oven-dried to constant weight at 70 ^{o}C for determining their dry matter, and ground to pass a 1-mm sieve for N, P and K analysis. The total N was determined by the Kjeldahl method (Bremner and Mulvaney, 1982). Total P and K were obtained by nitric-perchloric acid digestion (Zasoski and Burau, 1977). Phosphorus was determined by the yellow molybdate method (Murphy and Riley, 1962). Potassium was determined by atomic absorption spectrophotometer (Jackson and Mahmood, 1994).

1.9 Determination of significance of nutrient fluxes in nutrient balance of the soil

The model of the N and P dynamics used in this study is presented in Fig. 1. The estimate of the annual total quantity of N and P **input (I)** comprised nutrients from: mineral fertilizer; compost mineralization; SOM mineralization; maize stubble mineralization; root mineralization; irrigation water supplied and rain; and nutrient credit. **Output (O)** consisted of: N and P uptake in the grain, the stubble and the root biomass components; gaseous losses (N) or P sorption by Al, Fe oxides; and N leaching. Erosion losses were not considered because the field was flat.

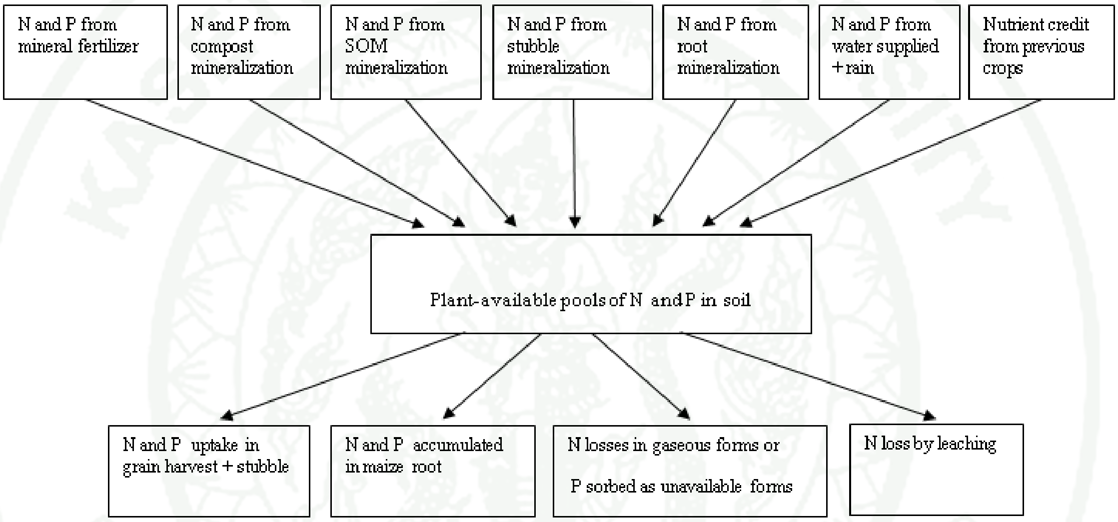

Figure 1 The model of N and P dynamics used in the present study.

Components of the nutrient budget were obtained either from direct measurement or by estimation using relevant data from reliable sources as described below.

1.9.1 Nutrient inputs

1) Fertilizer

The mineral fertilizers used, urea and TSP, contained readily available plant nutrients. Consequently, it was assumed that all N from urea and all available P from TSP were fully available for plant uptake when initially supplied to the soil.

2) Compost

The amounts of mineralizable N and P in compost within the 3 years after application were estimated from Klausner *et al.* (1994), who developed a decay series for manure (with N concentration range of 24-43 g N kg^{-1}) based on plant N uptake data: the decay series allowed for N uptake equivalent to 0.21, 0.09, and 0.03 of the N content in manure for years 1, 2, and 3, respectively, after application. The decay series was considered suitable for this study since the content of N in the organic manure used was similar to that used in the present study. Since the compost used in this study had low P concentration (Table 2) it was assumed that all P was organically-bound. In year 1, the same mineralization rate is assumed as for N. In years 2 and 3, the mineralization rates are assumed to be 0.20 and 0.10, respectively based on the study of Gilbertson *et al.* (1979).

3) Soil organic matter mineralization

Soil organic matter mineralization was calculated using a generalized soil organic matter mineralization equation which is based on the organic matter content, the amount of nutrient in soil organic matter and the general mineralization rate of organic matter (Brady and Weil 2008) as there is no specific *k* value (Stanford and Smith 1972) for SOM mineralization in the Pak Chong soil.

4) Mineralization from maize stubble

The amounts of mineralized N and P from maize stubble in the second and third years were calculated by the following equation proposed by Stanford and Smith (1972):

$$N_t = N_0[1-e^{(-kt)}] \quad (1)$$

where: N_t is total mineralized inorganic N at time t;

N_0 is potentially mineralizable N;

k is the mineralization rate constant.

Potentially mineralizable N and P were calculated from nutrient contents and dry matter of maize stubble from the previous year. For maize stubble, k_n and k_p values, 0.12 and 0.128 week^{-1}, respectively, were selected from Mubarak *et al.* (2002), who studied the decomposition and nutrient release from coarsely-chopped maize residues in nylon 2 mm mesh bags under tropical field conditions, on a Typic Paleudult.

5) Mineralization from root

The amounts of mineralized N and P from maize roots in the second and third years were calculated as for the maize stubble above. From the review paper of Amos and Walters (2006), an average root-shoot ratio for maize of 0.22 was selected to calculate root dry weight from the shoot dry weights measured in the present study. Percentage of N in maize roots was chosen from Roongtanakiat (1992) who conducted a lysimeter study on Pak Chong soil series. For maize root, the mineralization constant (k = 0.043 week^{-1}) was selected from Bertora *et al.* (2009), who studied yearly mineralization rates of N and in the different organic additions under a temperate sub-continental climate, on a Typic Udifluvent.

6) Nutrient input from irrigation water and rainfall

Irrigation water for maize crops was pumped from the underground water at the experiment site. Concentrations of nutrients of underground water were obtained from the field site by analysis. Total irrigation water applied in each year to the maize crop was approximately 250 mm. Nutrient input from irrigation was calculated from nutrient concentrations and volume of water applied. Nutrient concentrations in rainfall were obtained from Polthanee *et al.* (1998). The rain volumes of the 3 years were counted from the day of planting to the end of the moist soil period. Nutrient input from rain was calculated from nutrient concentration and rain volume. Total rainfall was 501, 445 and 372 mm in cropping periods for the first, second, and third crops, respectively (personal communication).

7) Nutrient credit

Since the period from harvest of one maize crop to the planting of another was fallow and dry for much of the time, the nutrient balance from one year was carried forward as a positive or negative nutrient credit to the next year's calculation.

1.9.2 Nutrient outputs

1) Nutrient loss through grain harvest and stubble

Nutrient loss through grain was calculated from the dry weight and nutrient concentration in grain. Nutrient loss through stubble removal was calculated from stubble weight and nutrient concentration.

2) Nutrient accumulated in root

Nutrient accumulated in the root which was not mineralized, at a particular time, was calculated from root dry weight and nutrient concentration in root. Root weight was calculated based on: (1) the average root-shoot ratio reported by Amos and Walters (2006), which summarized values under different management from 45 studies; and (2) the shoot yield obtained in the present experiment. N concentration was obtained from Roongtanakiat (1992) who reported 0.493 % N in maize root. P concentration was obtained from Vanlauwe *et al.* (2000) who studied maize N and P uptake in shoot and root under different land uses in savanna soils.

3) Gaseous losses (in case of N)

Gaseous losses of applied N were calculated by Roongtanakiat (1992) to represent 11.5 % of N fertilizer addition (40 kg N ha^{-1} as ^{15}N-labelled urea) on a Pak Chong soil in 60 cm depth lysimeters to which 40 mm of water was applied each week (from the sum of rainfall and irrigation) for 15 weeks. This loss was assumed to represent denitrification loss of N from soil in the present experiment.

4) Sorption of P

P sorption by Fe and Al oxides was assumed to be 73 % of available P input (Sharpley and Halvorson 1994) based on a mean of P sorption values for highly weathered soils.

5) Leaching losses (in case of N)

Leaching losses could be calculated from nitrate concentration in underground water at the site, and the volume of drainage water. It was assumed that 50 % of total water applied (rain amount in cropping period + irrigation) was drainage (Aronsson *et al.* 2007). However, from the results of a lysimeter study conducted with this soil series, only 0.73 % of applied N was leached from 60 cm depth (Roongtanakiat 1992).

1.9.3 Sensitivity analysis

Since the uncertainty of individual nutrient budget items varies, sensitivity analysis was calculated by varying the items up or down based on the range of values found for that item in the literature or in the present study.

1.10 Determination of suitable combination of mineral and organic fertilizers by DSSAT

Seasonal Analysis module in the Decision Support System for Agrotechnology Transfer (DSSAT) was used in this study. An advantage of the

Seasonal Analysis module in DSSAT is that it examines both the effect of crop demand on the response to organic and mineral fertilizer and the effect of the varied seasonal rainfall, temperature and radiation on crop demand. Additionally, the economic performance of organic materials and mineral fertilizer can be compared using the Seasonal Analysis module under Dominance Analysis tools (Thornton *et al*., 1994).

1.10.1 Model description

DSSAT v. 4.0 (Jones *et al.*, 2003) was brought as a tool in this study. In v. 4.0, all crop models were combined into the Cropping System Model (CSM), which is based on a modular modeling approach. The input requirements are obtained from direct field and laboratory measurements and literature sources.

1.10.2 Weather data

The minimum weather input requirements of the model are daily solar radiation (mJ m^{-2} d^{-1}), maximum and minimum temperature (° C) and precipitation (mm). Solar radiation was estimated basing on sunshine hours (Angstorm, 1924) and air temperature (Bristow and Campbell, 1984). The daily weather data were collected from a weather station adjacent to experimental site.

1.10.3 Crop management

Crop management and cultural practice include plant population, planting depth, date of planting, irrigation management (dates, amounts and schedule) and fertilizer management (dates, amounts, sources, method of incorporation, and depth of placement).

1.10.4 Soil inputs

Soil inputs include soil chemical properties, i.e. pH, %OC, ammonium, nitrate, phosphorus and potassium contents and CEC. Physical properties include soil particle size distribution, bulk density and soil water contents. Properties of the soil used in model evaluation are shown in Table 3.

1.10.5 Genetic coefficient

The coefficients were adjusted until there was a match between observed and simulated grain and above ground biomass. The genetic coefficients used in the work was based on the values derived by Asadi and Clemente (2003) for an application of the CERES-Maize model to simulate the growth and yield of Thai single cross hybrid, Suwan 3851, on the basis of a three year field experiment. Genetic coefficients for maize used in the present study are shown in Table 4.

Table 3 Chemical and physical properties of the soils used in model evaluations [1/].

Depth (cm)	LL[2/]	DUL[3/] (cm^3 cm^{-3})	SAT[4/]	SRGF[5/]	BD[6/] (Mg m^{-3})	SOC[7/]	Clay	Silt (%)	Sand	pH [8/]
0-20	0.25	0.33	0.38	1.00	1.13	1.56	72	21	7	7.0
20-40	0.24	0.30	0.42	0.50	1.25	0.81	77	17	6	7.1
40-60	0.24	0.30	0.48	0.01	1.25	0.33	93	4	3	6.3
60-85	0.26	0.35	0.52	0.00	1.18	0.24	83	11	7	4.9
85-105	0.26	0.35	0.51	0.00	1.22	0.20	97	3	0	5.2
105-130	0.26	0.34	0.52	0.00	1.19	0.19	93	7	0	4.6
130-150	0.26	0.34	0.51	0.00	1.19	0.18	92	5	3	4.8

[1/] Data obtained from soil analysis by Tawornpruek (2005) on some parameters on soil depth lower than 20 cm and from model calculation; [2/] Volumetric soil water capacity at drained lower limit (LL); [3/] Volumetric soil water capacity at drained upper limit (DUL); [4/] Volumetric soil water capacity at saturation; [5/] Soil root growth factor; [6/] Bulk density; [7/] Soil organic carbon content, [8/] 1:1, soil:water.

1.10.6 Seasonal analysis module

The Seasonal Analysis module of the DSSAT software (Thornton *et al*., 1994) was used to simulate the long-term effects of multi-year (2002 to 2006) crop management scenarios using historic weather data for Pak Chong station. The Seasonal Analysis module comprised both biophysical and economic analysis. Biophysical analysis was a simulation of plant growth and the outputs were means and standard deviations presented as box plots, cumulative function plots, or as means vs. variance relationships. Economic analysis involved a gross margin calculation based on predicted yields, grain prices and variable costs of production including fertilizer and organic materials input (equation 2).

$$\text{Gross margin} = (\text{Price x Yield}) - \text{Costs of production} \qquad (2)$$

Table 4 Genetic coefficients for Thai single cross hybrid of maize used in this study.

PHINT[1/]	G2[2/]	G3[3/]	P1[4/]	P2[5/]	P5[6/]
45.0	632	8.60	200	0.50	800

[1/] Interval in thermal time (degree days) between successive leaf tip appearances.

[2/] Maximum possible number of kernels per plant.

[3/] Kernel filling rate during the linear grain filling stage and under optimum conditions.

[4/] Thermal time from seedling emergence to the end of the juvenile phase (expressed in degree days above a base temperature of 8ºC).

[5/] Extent to which development is delayed for each hour increase in photoperiod above the longest photoperiod at which development proceeds at a maximum rate.

[6/] Thermal time from silking to physiological maturity (expressed in degree days above a base temperature of 8ºC).

In this study, prices and costs of maize in Thailand for economic analysis by the Seasonal Analysis module in DSSAT were as shown in Table 5. Mean-Gini Dominance Analysis is the predominant task in the Seasonal Analysis module. It calculates monetary return under each treatment combination and selects the most dominant treatment based on the highest economic return (Gini coefficient) (Sarkar and Kar, 2006).

Table 5 Prices[1/] and costs[1/] of maize in Thailand (2002), used in the economic evaluation with seasonal analysis of DSSAT v.4.0.2 of the field experiment data and modeled scenarios.

Costs and prices	Values
Base production cost for stubble return treatments [2] (US$ ha^{-1})	336
Base production cost for stubble removal treatments [3/] (US$ ha^{-1})	352
Price of harvest product [4/] (US$ t^{-1} of maize grain)	163 ± 24.4
Nitrogen fertilizer cost [5/] (US$ kg^{-1})	0.68
Cost per N fertilizer application [6/] (US$)	10.6 ± 1.58
	42.2 ± 6.32
Cost per irrigation application [7/] (US$ ha^{-1})	16.5
Seed cost [8/] (US$ kg^{-1})	1.06
Compost cost [9/] (US$ t^{-1})	92.1

[1/] The exchange rates of 1 US$ is 32.6 baht on July 13, 2010; [2/] Base production cost included plowing cost, chemical application to prevent grass weed and labor cost; [3/] Base production cost in [2/] plus the stubble removal cost; [4/] Grain price at 15 % moisture averaged for 5 years with ± 15 % range; [5/] Nitrogen fertilizer cost; [6/] Cost per N fertilizer application depends on N fertilizer application rate (the values used for predicting the highest net return of treatments from field experiment and also used for model application) with ± 15 % range; [7/] Irrigation labor cost; [8/] Maize seed cost; and [9/] Compost price in year 2002.

1.10.7 Data for model calibration and application

The treatments in the field experiment, which were described earlier, were used for model calibration. Calibration of the DSSAT model using data from year 1 was done by adjusting the initial mineral N. While only one composite soil sample was taken initially for the whole experiment, it is likely that the amount of initial mineral N varied among the treatments. Therefore adjustment of the value for initial mineral N for each treatment was used to achieve the best calibration for each treatment. Sensitivity analysis of the model was run by varying nutrient concentrations (from 2- to 8-fold) and rate of application of organic materials (from 1,875 to 7,500 kg ha^{-1}, based on field experimental treatments) (Table 6) with fixed compost price (3,000 baht t^{-1} equivalent to 92 US$ in July, 2010). The net return of the without compost treatment was the base value, hence, a higher net return from increased nutrient concentration in compost than without compost treatment indicated that these compost nutrient concentrations will be more profitable. The model was re-run assuming that the compost was available free of charge to see the minimum compost N concentration that would give a net return the same as that without adding compost. A regression line was used to estimate the rate of compost required to produce the same yields as the most efficient mineral fertilizer treatments.

Table 6 Selected organic material concentrations used in the model sensitivity analysis to find the efficient treatment.

Organic materials	Nutrient concentration (g kg^{-1})		
	N	P	K
(1) Compost in the present study	5.9	3.1	5.5
(2) 2-fold concentration increase	11.8	6.2	11.0
(3) 3-fold concentration increase	17.7	9.3	16.5
(4) 4-fold concentration increase	23.6	12.4	22.0
(5) 5-fold concentration increase	29.5	15.5	27.5
(6) 6-fold concentration increase	35.4	18.6	33.0
(7) 7-fold concentration increase	41.3	21.7	38.5
(8) 8-fold concentration increase	47.2	24.8	44.0

1.10.8 Model evaluation

The model was evaluated by using observed datasets, which included biomass and yield, from our field experiment of year 1 compared to values obtained by simulation using DSSAT model. Root mean square error (RMSE) (equation 3), normalized root mean square error (expressed as a percentage of the mean observed values normalized RMSE) (equation 4) and the D-index (index of agreement) (equation 5) were used to assess the acceptability of the model (Willmott *et al.*, 1985);

$$\text{Absolute RMSE} = \left[N^{-1} P_i - O_i)^2\right]^{0.5} \quad (3)$$

$$\text{Normalized RMSE (\%)} = \left(\frac{\text{Absolute RMSE}}{\text{Mean of the observed}}\right) \text{X } 100 \quad (4)$$

$$\text{D-index} = 1- \left(\frac{P_i - O_i)^2}{\text{I}P'_i\text{I} + \text{I}O'_i\text{I}]^2}\right) \quad (5)$$

$$|P_i| = a+bO_i,$$

$$P_i = P_i' - \bar{O};\ O_i' = O_i - \bar{O}$$

In equations 3 and 5, Pi and Oi are predicted and observed values, respectively and O is the observed mean value.

2. Experiment 2

2.1 Experimental design

A laboratory incubation experiment was carried out in a completely randomized design with three replications. The treatments were factorial combinations of four factors as follows:

1) Two selected soils collected from the field experiment before maize planting in year 2003: soils from the plots with no application of fertilizer (C_0F_0) and those from the plots that were treated with 7,500 kg compost ha^{-1} (C_3F_0).

2) Four levels of composts at the same rates as those for the field experiment: C_0, no compost application; C_1, compost equivalent to 1,875 kg ha^{-1} (0.0576 g/60 g soil); C_2, compost equivalent to 3,750 kg ha^{-1} (0.1152 g/60 g soil); and C_3, compost equivalent to 7,500 kg ha^{-1} (0.462 g/60 g soil).

3) Two levels of mineral fertilizers: f_0, (no NP fertilizer application) and f_1 [125-125 kg N -P_2O_5 ha^{-1} (0.00834 g urea and 0.00834 g TSP/60 g soil)].

4) Four incubation periods (0, 10, 20 and 40 days, referred to as T_0, T_1, T_2 and T_3, respectively).

2.2 Incubation protocol and extractable mineral N and extractable-resin P in incubated samples

Sixty grams of soil was weighed and mixed with compost and mineral fertilizer as required for each treatment. A ten gram portion of the mixture was weighed into each 250 ml non-translucent plastic bottle, and raised to 80 % water holding capacity. The bottle was then firmly capped and incubated at 30° C constant temperature. The incubation bottles were aerated by uncapping every 3-days for 15 minutes throughout the incubation period. The weight losses were compensated by addition of deionized water. The samples at 0, 10, 20 and 40 days after incubation were analyzed for extractable mineral N (NH_4^+ + NO_3^-). At the specified incubation period, 10 grams of each treated soil was added to 100 ml of 2M KCl and shaken for 1 hour on a reciprocating shaker. The mixture was then filtered and the filtrate was taken for determination of NH_4^+-N and NO_3^--N (Keeney and Nelson, 1982). Extractable P was determined using the anion-exchange membrane (AEM) method as described by Myers *et al.* (1999). The procedure was as follows: to each treated bottle was added 100 ml of deionized water, two AEM strips, which had been saturated with 0.5 M $NaHCO_3$ overnight, and bottles were shaken in a horizontal shaker for 16 hours. After removing from the bottle, the AEM strips were rapidly rinsed twice with deionized water, placed into 25 ml of 0.05 M H_2SO_4 and shaken for 5 minutes. The solution obtained was then sampled for extractable-P determination by the ascorbic acid molybdenum blue method (Kuo, 1996).

2.3 Testing prediction of N mineralization by DSSAT and Agricultural Production Systems Simulator (APSIM) for the incubation experiment

DSSAT (v. 4.0) and APSIM (v.7.3) were tested for their capabilities to predict N mineralization by comparing with incubation experimental results.

2.3.1 Mineralization module on DSSAT

There are two options for modeling soil organic matter accumulation and decomposition in DSSAT: the DSSAT-Century model (Gijsman *et al.*, 2002); and the CERES-based soil organic matter model (Godwin and Singh, 1998). The CENTURY-based module was based on the PAPRAN model of Seligman and Van Keulen (1981) and it then was developed to facilitate simulation of soil organic sequestration potential for different crop rotations over long time periods after initializing soil C and other variables at the start of the simulation. The CENTURY-based module distinguishes three types of SOM: (1) easily decomposable SOM designated as SOM1, (2) recalcitrant SOM designated as SOM2, which contains lignin and cell walls, and (3) an almost inert SOM designated as SOM3. At initialization of the simulation, the fractional ratio of these three pools is set, with SOM1 at about 2 % of total SOM while the rest vary with the management history of the soil (Jones *et al.*, 2003). The CERES-based module distinguishes three litter C pools (carbohydrate, cellulose and lignin) but there is only one litter N pool. For residues with C/N ratio < 25, the three litter pools decompose at a rate that is dependent of the residue's N concentration (Gijsman *et al.*, 2002).

2.3.2 Mineralization module on APSIM

APSIM is a modular modeling framework that has been developed by the Agricultural Production Systems Research Unit (APSRU), a collaborative group made up from CSIRO and Queensland State Government agencies.

The N mineralization module (SOILN) in APSIM, simulates the mineralization of N and thus the N supply available to a crop from the soil and from the residues/roots of previous crops. Its development can be traced back via CERES models to PAPRAN (Keating *et al.*, 2003). The greatest change from CERES is that soil organic matter in APSIM is treated as a three-pool system, instead of the two pools used in CERES. Crop residues and roots added to the soil, are designated fresh organic matter pool (FOM) which is considered to comprise three pools (FPOOLs), sometimes referred to as the carbohydrate-like, cellulose-like and lignin-like fractions of the residue. Each FPOOL has its own rate of decomposition, (0.2, 0.05 and 0.0095 day^{-1}, respectively under non-limiting temperature and moisture conditions). For inputs of crop residues and roots, it has usually been assumed that the added C in the three FPOOLs is always in the proportions 0.2:0.7:0.1.

The evaluation of the performance of the model was carried out based on the formula described under “1.10.8 Model evaluation”.

3. Experiment 3

3.1 Experimental design

A pot experiment was conducted using a 3 x 11 Factorials in Randomized Complete Block Design 5 replications. The experimental treatments were factorial combinations of 2 factors as follows:

<u>Factor 1</u>: Type of soil

1) Korat soil series

2) Pak Chong soil series with high organic matter content (collected from an area nearby the field experiment)
3) Pak Chong soil series with low organic matter content

Factor 2: Fertilizer treatment

1) No organic material addition (ctrl)
2) Application with 0.488 g urea and 0.398 g di-calcium phosphate pot^{-1}, equivalent to 62.5-62.5 kg N-P_2O_5 ha^{-1} (F)
3) Chicken manure (ch)
    a. Low rate [6.731 g pot^{-1}, equivalent to 1,875 kg ha^{-1}] (ch-A)
    b. Medium rate [13.46 g pot^{-1}, equivalent to 3,750 kg ha^{-1}] (ch-B)
    c. High rate [53.85 g pot^{-1}, equivalent to 15,000 kg ha^{-1}] (ch-C)
4) Compost (high N content) (cph)
    a. Low rate [6.731 g pot^{-1}, equivalent to 1,875 kg ha^{-1}] (cph-A)
    b. Medium rate [13.46 g pot^{-1}, equivalent to 3,750 kg ha^{-1}] (cph-B)
    c. High rate [53.85 g pot^{-1}, equivalent to 15,000 kg ha^{-1}] (cph-C)
5) Compost (low N content) (cpl)
    a. Low rate [6.731 g pot^{-1}, equivalent to 1,875 kg ha^{-1}] (cpl-A)
    b. Medium rate [13.46 g pot^{-1}, equivalent to 3,750 kg ha^{-1}] (cpl-B)
    c. High rate [53.85 g pot^{-1}, equivalent to 15,000 kg ha^{-1}] (cpl-C)

3.2 Collection of the soils for experiment and soil analysis

Bulk soil samples were collected from Nakhon Ratchasima province, Thailand. The soil samples were dried, crushed to pass a 2-mm or 0.5-mm sieve and mixed well before analysis. Chemical properties of the soils are shown in Table 7.

Table 7 Properties of soil used in pot experiment.

Items	Korat soil	Pak Chong soil (high % OM content)	Pak Chong soil (low % OM content)
pH [1/]	6.25	6.55	4.35
OM ($g\ kg^{-1}$) [2/]	8.20	26.9	12.5
EC [3/] ($mS\ cm^{-1}$)	0.21	nd	0.33

[1/] 1:1, soil:water (Anonymous, 1999); [2/] Walkley & Black method (Nelson and Sommers, 1996); [3/] 1:5, soil: water (Rhoades, 1996); nd not determined.

3.3 Preparation of organic fertilizers and their properties

Each kind of manure was air dried, crushed and passed through a 5-mm sieve then kept in closed plastic bags. Properties of the manures are shown in Table 8.

3.4 Application of basal fertilizers and treatment fertilizers

To enhance reasonable maize growth, basal fertilizer was applied to all pots by applying 0.244 g urea and 0.239 g di-calcium phosphate pot^{-1}, equivalent to 31.25-31.25 kg $N\text{-}P_2O_5$ ha^{-1}, before planting. The mineral fertilizers and organic manures for experimental treatments were applied in a straight band on one side of the center of the pot and 3-8 cm under the soil surface.

Table 8 Properties of organic materials used in pot experiment.

Items	Chicken manure	Compost (high N content)	Compost (low N content)
pH [1/]	7.5	5.30	7.9
EC (mS cm^{-1}) [2/]	10.1	4.03	nd
OC (g kg^{-1}) [3/]	143	192	73.3
Total N [4/] (g kg^{-1})	17.2	16.1	5.90
Total P [5/] (g kg^{-1})	27.5	2.4	3.10
Total K [6/] (g kg^{-1})	27.9	10.0	5.50

[1/] 1:1, soil:water (Anonymous, 1999); [2/] 1:5, soil:water (Rhoades, 1996); [3/] Walkley & Black method (Nelson and Sommers, 1996); [4/] Wet digestion and Kjeldhal method (Jackson, 1965); [5/] Wet digestion and ascorbic method (5:2, HNO_3:$HClO_4$; AOAC, 1990); and [6/] Wet digestion and atomic absorption spectrophotometer (Jackson and Mahmood, 1994), [nd] not determined.

3.5 Potting and cultural practices

Seven kilograms (dry weight basis) of soil was put in each pot and then mixed with organic materials and mineral fertilizers as required for each treatment. Six maize seeds (SW 3851 hybrid) were sown in each pot and the plants were thinned to 3 per pot at 12 days after planting (DAP). Tap water was liberally applied to the plants via saucers and on the soil surface when necessary to keep the soil surface moist.

3.6 Data collection and maize harvest

Height of maize plants was measured at 30 and 45 DAP. Maize shoots (3 plants/pot) were harvested on 7 days after maize tasselling. Maize shoots were oven-dried to constant weight at 70 ºC to determine their dry matter, and ground to pass a 1-mm sieve for N and P analyses. The total N was determined by the Kjeldahl method

(Bremner and Mulvaney, 1982). Total P was obtained by nitric-perchloric acid digestion (Zasoski and Burau, 1977). Phosphorus was determined by the yellow molybdate method (Murphy and Riley, 1962).

Places and Duration

1. Experiment 1

1.1 The field experiment was carried out at the National Corn and Sorghum Research Center, Pak Chong, Nakhon Ratchasima, Thailand for 5 years from August 2002 to January 2007.

1.2 Physical analysis of soil samples collected after year 5 was done in laboratories of the Department of Soil Science, Faculty of Agriculture, Kasetsart University, Bangkok, Thailand from February 2007 to October 2007.

1.3 Chemical analysis of soil samples were done in laboratories of the Department of Soil Science, Faculty of Agriculture, Kasetsart University, Bangkok, Thailand.

1.4 Plant nutrient analyses of maize were performed in laboratories of the Department of Soil Science, Faculty of Agriculture, Kasetsart University, Bangkok, Thailand after maize harvesting during 2003 to 2007.

2. Experiment 2

2.1 The incubation experiment was done in laboratories of the Department of Soil Science, Faculty of Agriculture, Kasetsart University, Bangkok, Thailand from February 2008 to April 2008.

2.2 Chemical analysis of soil samples from incubation experiment were done in laboratories of the Department of Soil Science, Faculty of Agriculture, Kasetsart University, Bangkok, Thailand from February to April 2008.

3. Experiment 3

3.1 Pot experiment was conducted in the greenhouse of the Department of Soil Science, Faculty of Agriculture, Kasetsart University, Bangkok, Thailand from November 2004 to February 2005.

3.2 Chemical analysis of soil samples from pot experiment were done in laboratories of the Department of Soil Science, Faculty of Agriculture, Kasetsart University, Bangkok, Thailand from March to April 2005.

3.3 Plant nutrient analyses of maize were performed in laboratories of the Department of Soil Science, Faculty of Agriculture, Kasetsart University, Bangkok, Thailand after maize harvesting from May to June 2005.

RESULTS AND DISCUSSION

Results

1. Experiment 1

1.1 Effects of annual application of mineral fertilizers and compost and stubble removal on maize cropping for 5 years

1.1.1 Height

In year 1, application of compost at the three rates without fertilizer and with 62.5-62.5 kg N-P_2O_5 ha^{-1} gave no significant effects on height of maize plants at 30, 45 and 60 DAP (Fig. 2). With 31.25-31.25 kg N-P_2O_5 ha^{-1} fertilizer, application of compost at the highest rate decreased plant height at the three stages whereas application of compost at the other rates mostly showed trends to decrease the height. With 62.5-62.5 kg N-P_2O_5 ha^{-1}, application of compost at all rates had no effects on the height. With 125-125 kg N-P_2O_5 ha^{-1} fertilizer, application of compost at the lowest rate (1875 kg ha^{-1}) either significantly decreased or tended to decrease plant height at the three stages whereas application at the two higher rates did not show its effect on plant height.

In year 2, at 30 DAP, application of compost at the three rates and maize stubble removal without and with 31.25-31.25 and 125-125 kg N-P_2O_5 $ha^{-1}yr^{-1}$ had no significant effect on height of maize plants (Fig. 3). With 62.5-62.5 kg N-P_2O_5 $ha^{-1}yr^{-1}$ fertilizers, application of 7500 kg $ha^{-1}yr^{-1}$ of compost significantly increased maize height. At 45 DAP, application of compost at the three rates and maize stubble removal without fertilizer and with the three rates of fertilizer had no significant effects on plant height. At 60 DAP, application of 1875 and 7500 kg $ha^{-1}yr^{-1}$ of compost alone significantly increased plant height whereas application of compost at the other rate and maize stubble removal had no significant effect on plant height.

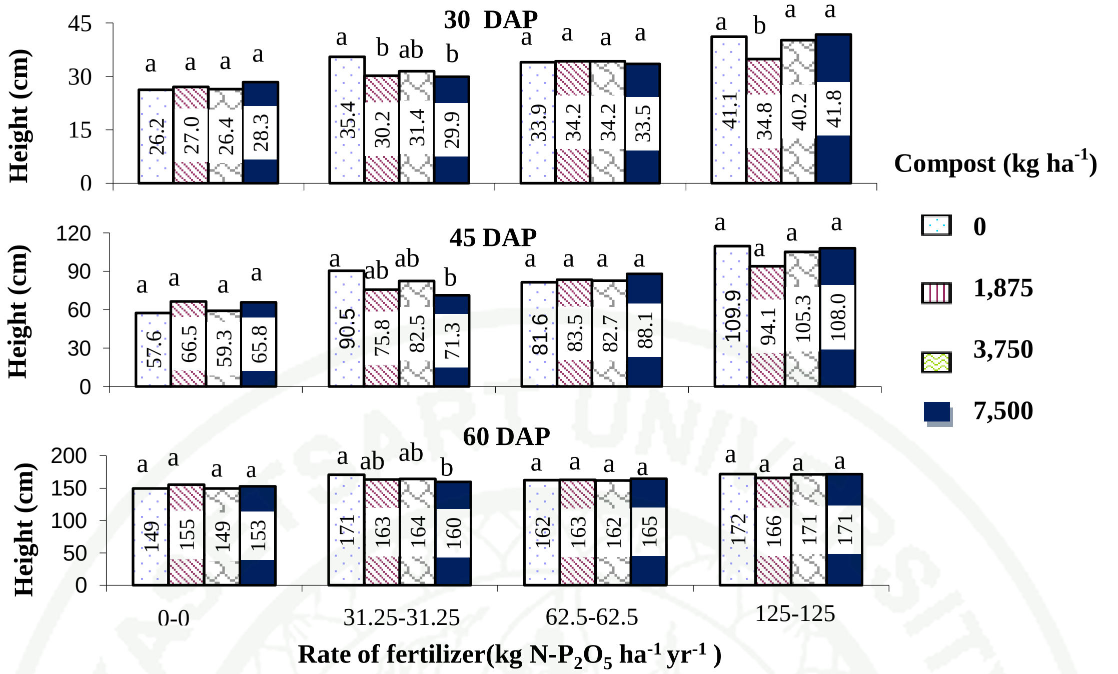

Figure 2 Effects of rates of mineral fertilizer and compost on plant height at 30, 45 and 60 days after planting (DAP) in year 1. Within the same rate of mineral fertilizer, bars with a common letter were not significantly different by Duncan's Multiple Range Test (P<0.05). CV: 8.3%, 11.1% and 3.3%, respectively.

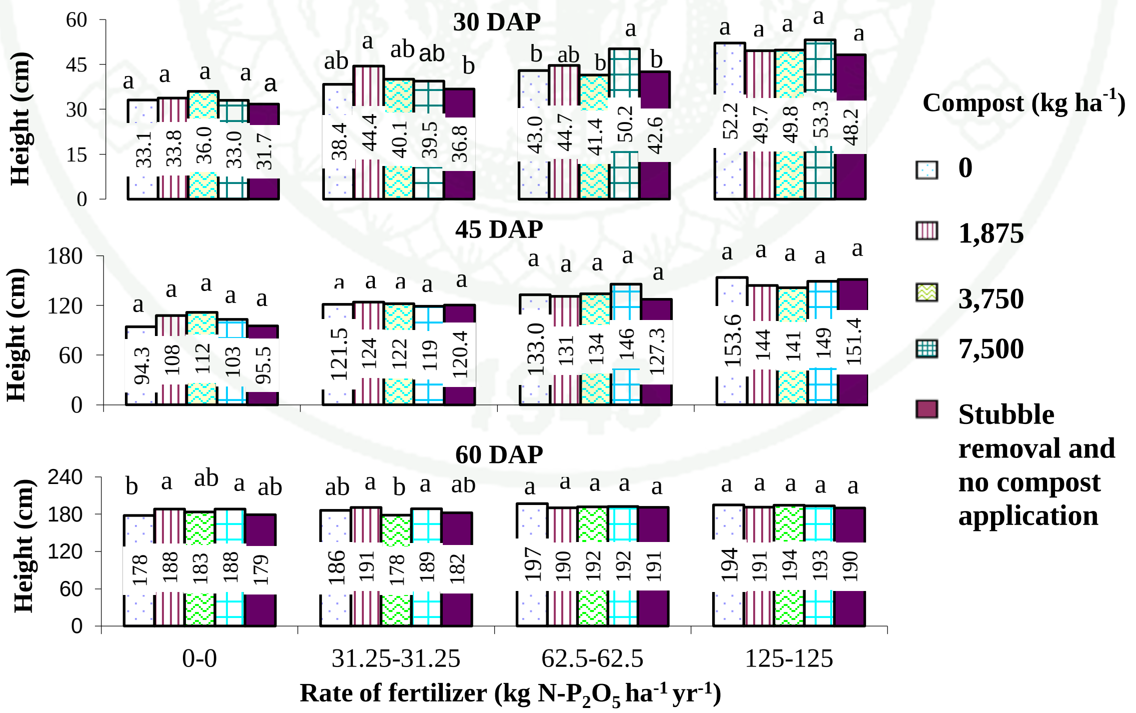

Figure 3 Cumulative effects of 2 annual applications of mineral fertilizers, compost and one annual maize stubble removal on the height at 30, 45 and 60 days after planting (DAP) of plants in the second cropping. CV: 9.2%, 8.8% and 2.7%, at 30, 45 and 60 DAP, respectively.

Application of compost at the three rates and maize stubble removal with 31.25-31.25, 62.5-62.5 and 125-125 kg N-P_2O_5 ha^{-1}yr^{-1} gave no significant effects on the plant height.

In year 3, at 30, 45, 60 DAP, application of compost at the three rates and maize stubble removal without and with 31.25-31.25, 62.5-62.5 and 125-125 kg N-P_2O_5 ha^{-1} yr^{-1} mostly had no significant effect on height of maize plants (Fig. 4).

In year 4, at 30 DAP, without mineral fertilizers and with 62.5-62.5 kg N-P_2O_5 ha^{-1}yr^{-1} applications of compost at 7500 kg ha^{-1}yr^{-1} significantly increased plant height at 30 DAP (Fig. 5). With 31.25-31.25 and 125-125 kg N-P_2O_5 ha^{-1}yr^{-1}, applications of 1875 kg ha^{-1}yr^{-1} significantly decreased plant height at 30 DAP. Without mineral fertilizer, stubble removal did not significantly affect the height whereas with the three rates of mineral fertilizers stubble removal either significantly decreased or tended to decrease the height at 30 DAP. At 45 DAP, without mineral fertilizer and with 31.25-31.25, 62.5-62.5 and 125-125 kg N-P_2O_5 ha^{-1}yr^{-1} compost at the three rates had no significant effect on maize height. Both without and with the three rates of mineral fertilizer, stubble removal did not significantly affect the height at 45 DAP. At 60 DAP, without mineral fertilizer and with 31.25-31.25, 62.5-62.5 and 125-125 kg N-P_2O_5 ha^{-1}yr^{-1} compost at the three rates had no significant effect on height. Without mineral fertilizer, stubble removal did not significantly affect the height whereas with 31.25-31.25 kg N-P_2O_5 ha^{-1}yr^{-1} stubble removal significantly decreased height at 60 DAP. With mineral fertilizer at the higher rates, stubble removal did not affect height at 60 DAP.

In year 5, at 30 DAP, without mineral fertilizer, compost at the highest rate significantly increased maize height at 30 DAP whereas at 45 and 60 DAP it showed no significant effects (Fig. 6). With 31.25-31.25, 62.5-62.5 and 125-125 kg N-P_2O_5 ha^{-1} yr^{-1}, compost at the three rates either decreased or tended to decrease maize height at 30 DAP but had no significant effect on maize height at 45 and 60 DAP. Stubble removal without and with the three rates of mineral fertilizer did not show significant effects on maize height at 30, 45 and 60 DAP.

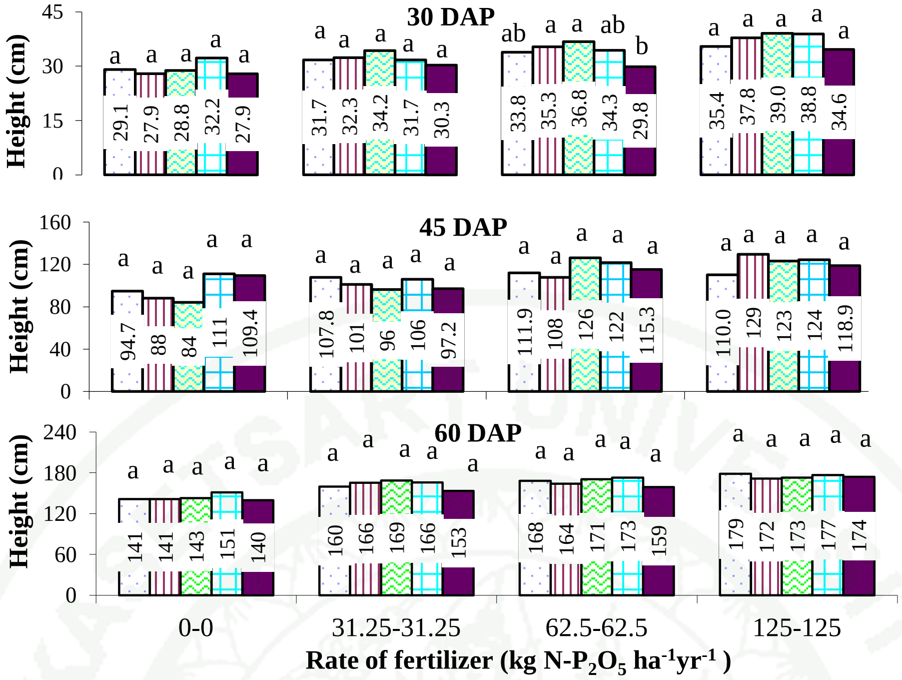

Figure 4 Cumulative effects of 3 successive annual applications of mineral fertilizers, compost and two annual maize stubble removal on the height at 30, 45 and 60 days after planting (DAP) of maize plants in the third cropping. CV: 8.3%, 16.3% and 5.2%, respectively. See Figure 3 for captions.

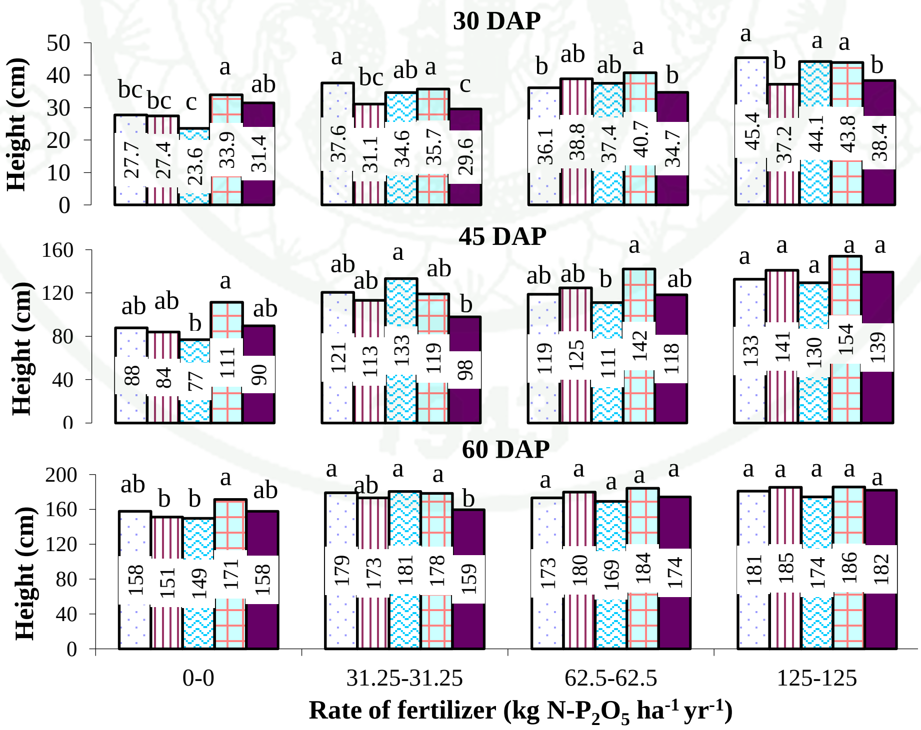

Figure 5 Cumulative effects of 4 successive annual applications of mineral fertilizers, compost and three annual maize stubble removal on height at 30, 45 and 60 days after planting (DAP) of maize plants in the fourth cropping. CV: 7.0%, 13.4% and 4.9% at 30, 45 and 60 DAP, respectively. See Figure 3 for captions.

1.1.2 Tasselling and silking

In year 1, application of compost at the lowest rate (1875 kg ha^{-1}) and the highest rate (7500 kg ha^{-1}) without fertilizer either significantly decreased or tended to decrease tasselling age whereas application at 3750 kg ha^{-1} alone had no effect on tasselling (Fig. 7). With 31.25-31.25 N- P_2O_5 ha^{-1} fertilizer, application of compost at the highest rates, 7500 kg ha^{-1}, resulted in increases tasselling age. With 62.5-62.5 and 125-125 N- P_2O_5 ha^{-1} fertilizer, application of compost at the three rates gave no significant effects on tasselling age of maize. Application of compost at the three rates without fertilizer and with 31.25-31.25, 62.5-62.5 and 125-125 N- P_2O_5 ha^{-1} gave no significant effects on silking age.

In year 2, application of compost at the three rates and maize stubble removal without and with 31.25-31.25, 62.5-62.5 and 125-125 kg N-P_2O_5 ha^{-1} had no significant effects on tasselling age (Fig. 8). Application of 7500 kg ha^{-1} of compost alone significantly decreased silking age whereas application of compost at the other rates and maize stubble removal had no significant effect on silking age.

In year 3, application of compost at the three rates without and with 62.5-62.5 and 125-125 kg N-P_2O_5 $ha^{-1}yr^{-1}$ had no significant effects on flowering ages whereas with 31.25-31.25 kg N-P_2O_5 $ha^{-1}yr^{-1}$, application of 3750 kg ha^{-1} decreased tasselling age but had no effect on silking age (Fig. 9). Without and with mineral fertilizer at the three rates, stubble removal did not significant affect the flowering ages.

In year 4, application of compost at the three rates without mineral fertilizer and with 31.25-31.25 and 125-125 kg N-P_2O_5 $ha^{-1}yr^{-1}$ had no significant effects on tasselling age (Fig. 10). With 62.5-62.5 kg N-P_2O_5 $ha^{-1}yr^{-1}$, application of 7500 kg $ha^{-1}yr^{-1}$ compost significantly decreased tasselling age. Without mineral fertilizer and application of 62.5-62.5 kg N-P_2O_5 $ha^{-1}yr^{-1}$, application of 7500 kg $ha^{-1}yr^{-1}$ significantly decreased silking age. Without mineral fertilizer and with 62.5-62.5

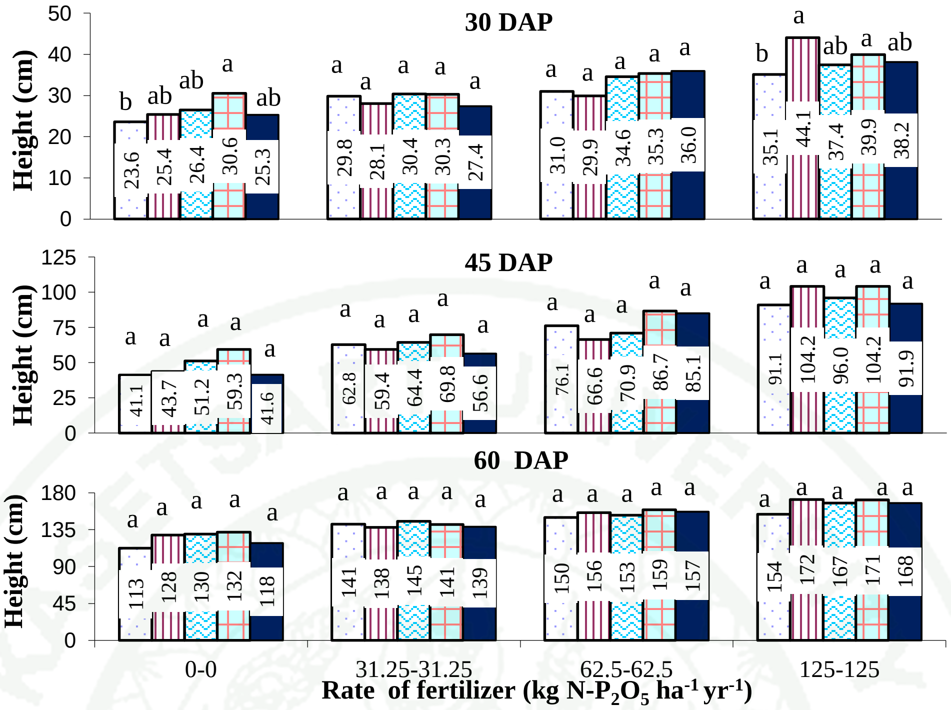

Figure 6 Cumulative effects of 5 successive annual applications of mineral fertilizers, compost and annual maize stubble removal for three years on height at 30, 45 and 60 days after planting (DAP) of maize plants in the fifth cropping cycle. CV: 11.6%, 19.7% and 7.7% at 30, 45 and 60 DAP, respectively. See Figure 3 for captions.

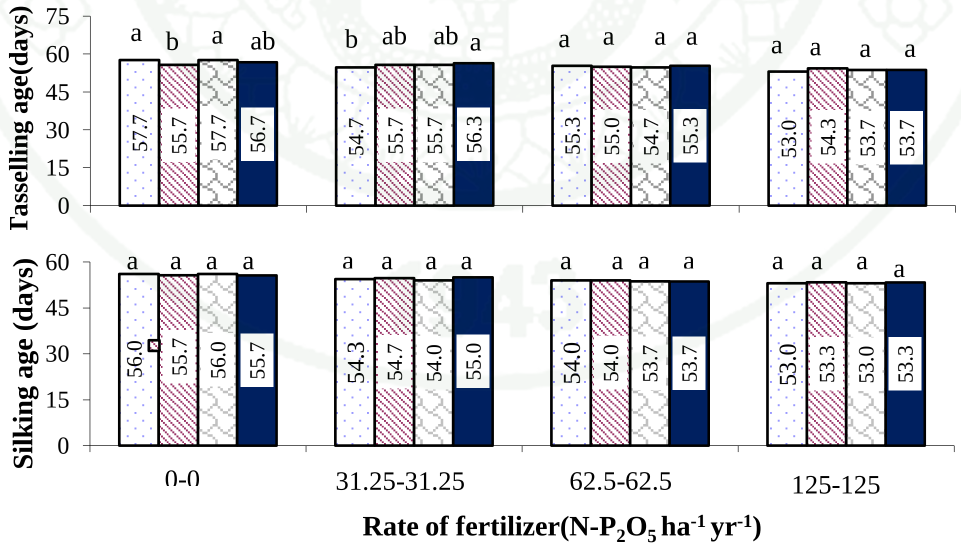

Figure 7 Effects of rates of mineral fertilizer and compost on tasselling and silking ages in year 1. Within the same of mineral fertilizer, bars with a common letter were not significantly different by DMRT.$_{05}$. CV: 1.7% and 1.3% for tasselling and silking ages, respectively. See Figure 2 for captions.

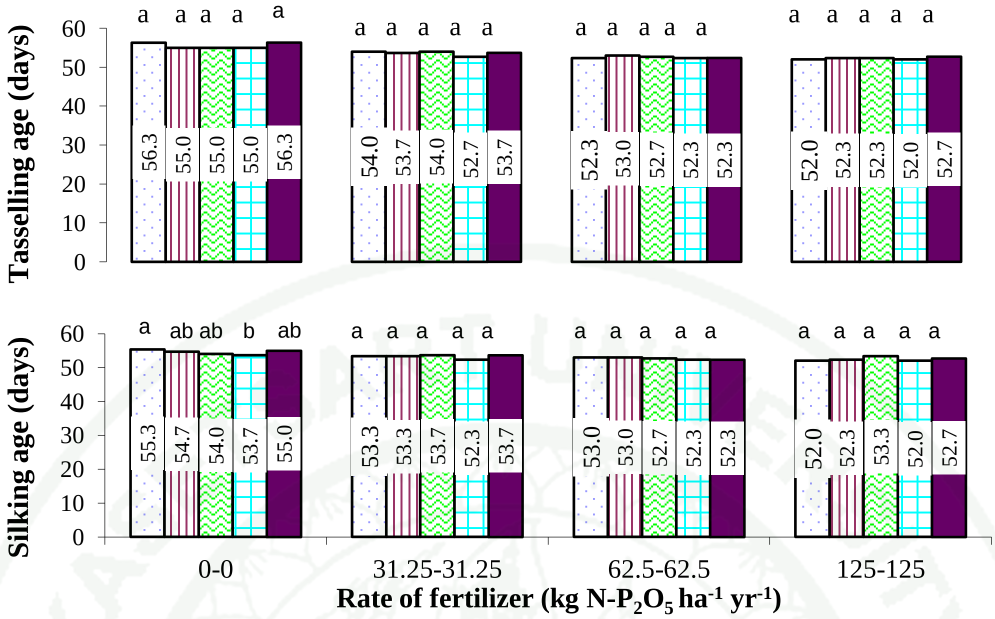

Figure 8 Cumulative effects of 2 annual applications of mineral fertilizer and compost and one annual maize stubble removal on tasselling and silking age of maize plant of plants in the second cropping. CV: 1.8% and 1.6 %, respectively. See Figure 3 for captions.

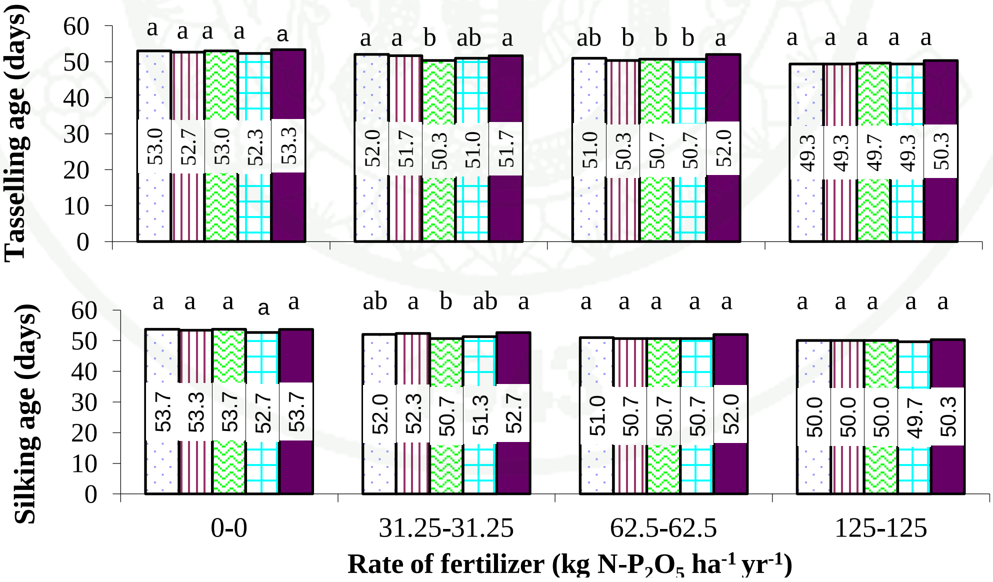

Figure 9 Cumulative effects of 3 annual applications of mineral fertilizer and compost and two annual maize stubble removal on tasselling and silking age of maize plant of plants in the third cropping. CV: 1.4% and 1.5%, respectively. See Figure 3 for captions.

and 125-125 kg N-P_2O_5 $ha^{-1}yr^{-1}$, stubble removal did not significantly affect the flowering ages whereas with the lowest fertilizer rate stubble removal significantly increased silking age and showed a trend to increase taselling age.

In year 5, application of 7500 kg ha^{-1} without mineral fertilizer significantly decreased tasselling age (Fig. 11). With the 3 rates of mineral fertilizer, application of compost did not affect taselling age. Stubble removal had no effect on flowering age regardless of mineral fertilizer rate.

1.1.3 Grain yields and shoot dry matter (SDM)

In year 1, application of compost at the three rates without fertilizer and with the three rates of mineral fertilizer gave no significant effects on grain yields (Fig. 12). Application of compost at the three rates without fertilizer and with 62.5-62.5 kg N-P_2O_5 ha^{-1} and 125-125 kg N-P_2O_5 ha^{-1}gave no significant effects on SDM after maturity. With 31.25-31.25 kg N-P_2O_5 ha^{-1} application of compost at the lowest rate decreased SDM at maturity whereas application of compost at the higher rates had no significant effect on SDM.

In year 2, application of compost at the three rates and maize stubble removal without mineral fertilizers and with the three rates of mineral fertilizers had no significant effects on grain yields (Fig. 13). Application of 7500 kg ha^{-1} yr^{-1} of compost alone significantly increased SDM whereas application of compost at the other rates or maize stubble removal alone had no significant effect on SDM. Application of compost at the three rates and maize stubble removal with application of the three rates of mineral fertilizers had no significant effect on SDM

In year 3, application of 7500 kg ha^{-1} yr^{-1} of compost alone significantly increased grain yields (Fig. 14). Application of compost at the three rates, with the three rates of mineral fertilizers had no significant effect on grain yields. Removal of maize stubble, without mineral fertilizers significantly increased grain yields, whereas with 62.5-62.5 kg N-P_2O_5 ha^{-1} yr^{-1} it significantly decreased

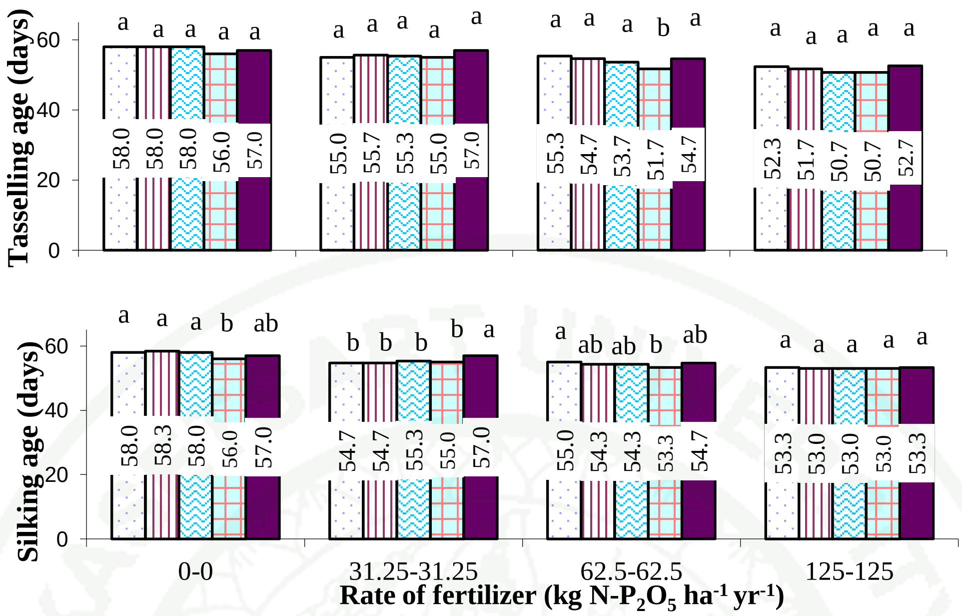

Figure 10 Cumulative effects of 4 annual applications of mineral fertilizer and compost and three annual maize stubble removal on tasselling and silking age of maize plant of plants in the third cropping. CV: 2.4% and 1.6%, respectively. See Figure 3 for captions.

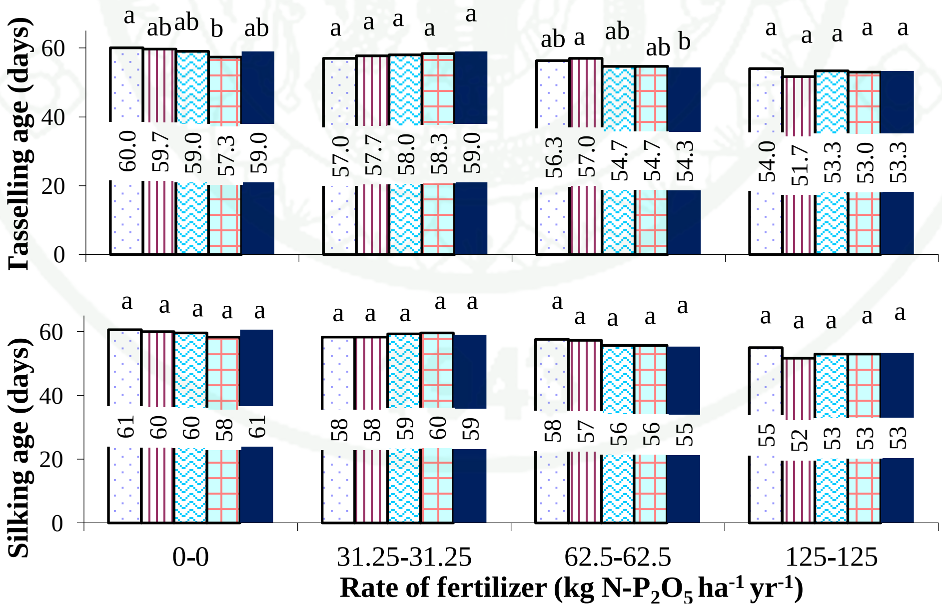

Figure 11 Cumulative effects of 5 annual applications of mineral fertilizer and compost and four annual maize stubble removal on tasselling and silking age of maize plant of plants in the fifth cropping. CV: 2.6 % and 3.5 %, respectively. See Figure 3 for captions.

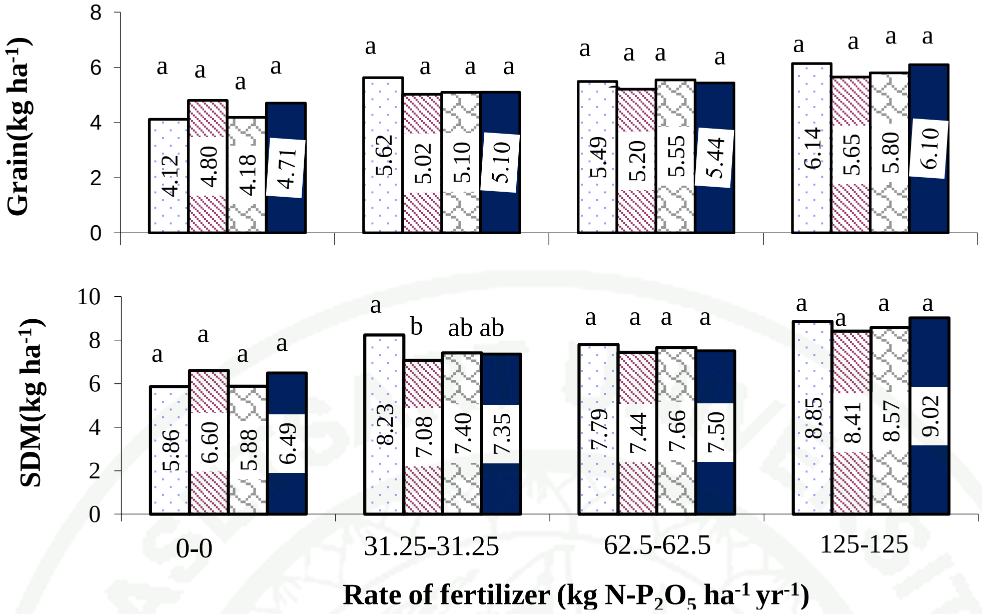

Figure 12 Effects of rates of mineral fertilizer and compost on weight of grain at 15% moisture content and shoot dry matter (SDM) of corn at harvest in year 1. CV: 8.2 % and 7.5 % for grain yields and SDM, respectively. See Figure 2 for captions.

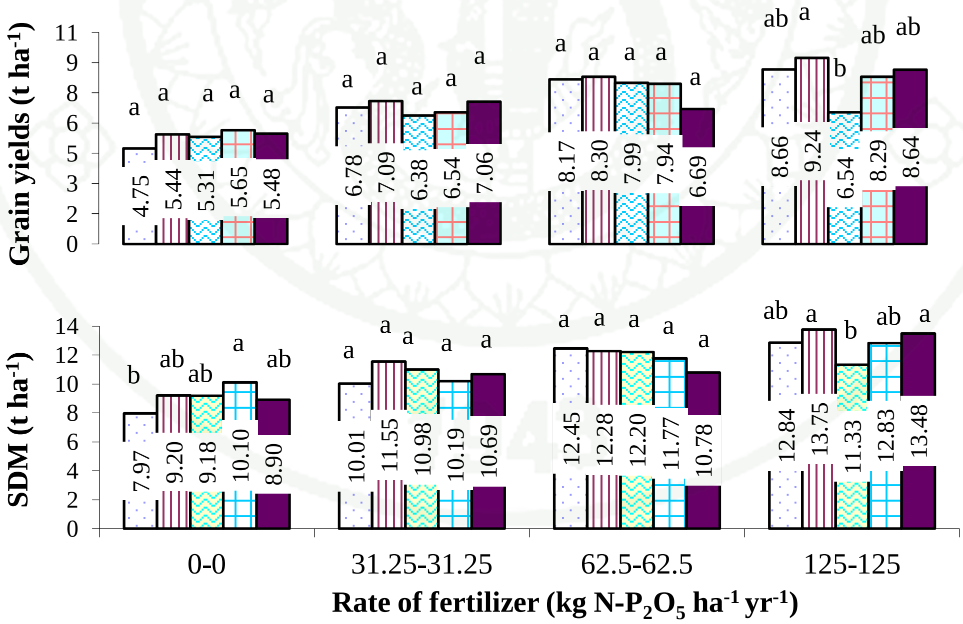

Figure 13 Cumulative effects of 2 annual applications of mineral fertilizer and compost and one annual maize stubble removal on weight of grain at 15% moisture content and shoot dry matter (SDM) of plants in the second cropping. CV: 14.2% and 9.5%, respectively. See Figure 3 for captions.

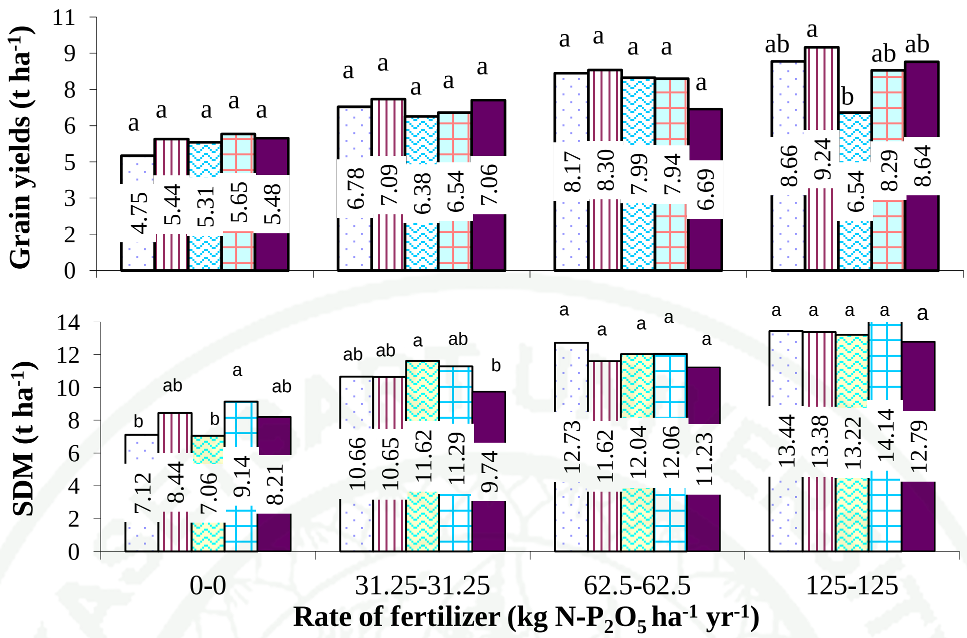

Figure 14 Cumulative effects of 3 annual applications of mineral fertilizers and compost and two annual maize stubble removal on grain yields and shoot dry matter (SDM) of maize plant in the third cropping. CV: 10.7% and 9.2%, respectively. See Figure 3 for captions.

grain yields. Application of 7500 kg ha^{-1} yr^{-1} of compost alone significantly increased SDM. Application of compost at the three rates and maize stubble removal with application of the three rates of mineral fertilizers had no significant effects on SDM.

In year 4, application of compost at the three rates without mineral fertilizer and with the three rates of fertilizer had no significant effect on grain yields and SDM (Fig. 15). Without mineral fertilizer and with 62.5-62.5 and 125-125 kg N-P_2O_5 ha^{-1} yr^{-1}, stubble removal did not significantly affect grain yields and SDM while with the lowest mineral fertilizer rate stubble removal significantly decreased SDM and showed a tendency to decrease grain yield.

In year 5, application of compost at the three rates and stubble removal had no significant effect on grain yield and SDM regardless of mineral fertilizer rates (Fig. 16).

1.1.4 Shoot N, P and K uptake

In year 1, without and with 62.5-62.5, 125-125 kg N-P_2O_5 ha^{-1} mineral fertilizer, application of compost at the three rates showed no significant effect on shoot N, P and K uptake whereas with 31.25-31.25 kg N-P_2O_5 ha^{-1}, application of compost at 1875 and 3750 kg ha^{-1} significantly decreased shoot N uptake but had no effect on shoot P and K uptake (Fig. 17).

In year 2, application of compost at the three rates and maize stubble removal had no significant effect on shoot N uptake regardless of mineral fertilizer rate (Fig. 18). Without mineral fertilizer and with 31.25-31.25 and 125-125 kg N-P_2O_5 ha^{-1} yr^{-1} application of compost at the three rates and maize stubble removal had no significant effect on shoot P uptake. With 62.5-62.5 kg N-P_2O_5 ha^{-1} yr^{-1} as mineral fertilizer, application of the three rates of compost had no significant effect on shoot P uptake whereas maize stubble removal significantly decreased shoot P uptake. Without and with 31.25-31.25, 62.5-62.5 kg N-P_2O_5 ha^{-1} yr^{-1} as mineral fertilizers, application of compost at the three rates and maize stubble removal had no significant effects on K uptake. With 125-125 kg N-P_2O_5 ha^{-1} yr^{-1} as fertilizer, application of 7500 kg ha^{-1} yr^{-1} compost and maize stubble removal significantly increased shoot K uptake whereas application of 1875 and 3750 kg ha^{-1} yr^{-1} compost had no significant effect on shoot K uptake.

In year 3, with mineral fertilizer at the three rates, application of compost at the three rates and maize stubble removal had no significant effect on shoot N uptake (Fig. 19). Without mineral fertilizer, application of 7500 kg ha^{-1} yr^{-1} of compost significantly increased shoot N uptake, whereas application of compost at the other rates did not affect it. Without mineral fertilizers, application of compost at the three rates had no significant effect on shoot P uptake. With 31.25-31.25 kg N-P_2O_5 ha^{-1} yr^{-1}, application of three rates of compost significantly increased shoot P uptake. With 62.5-62.5 kg N- P_2O_5 ha^{-1} yr^{-1}, application of 1875 kg ha^{-1} yr^{-1} of compost significantly decreased shoot P uptake whereas compost at the other rates did not affect it. With 125-125 kg N-P_2O_5 ha^{-1} yr^{-1}, application of compost at the three rates had no significantly effect on shoot P uptake. Stubble removal did not affect shoot P uptake regardless of mineral fertilizer rates. Without mineral fertilizer, application of

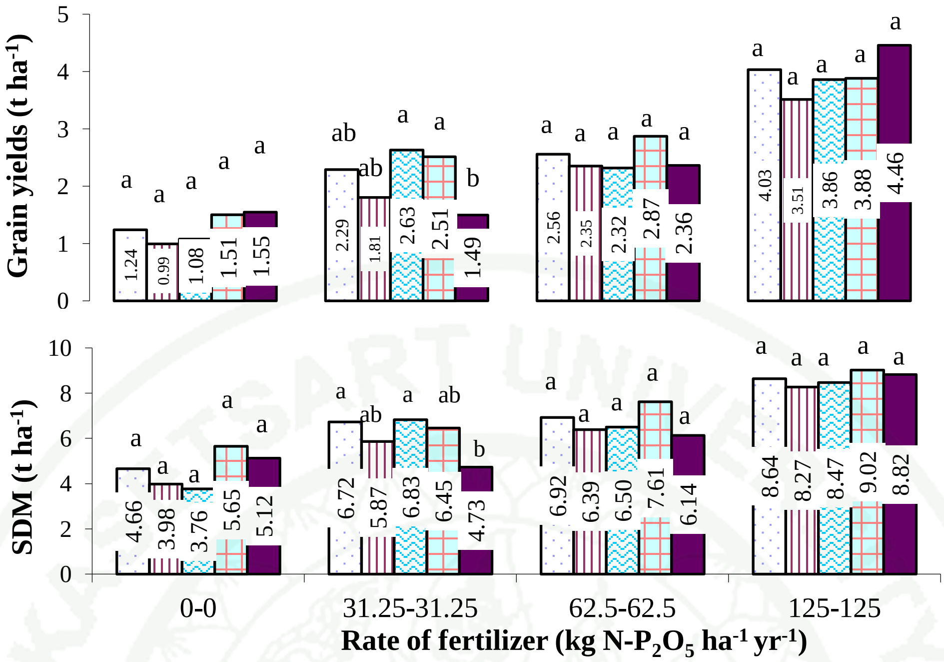

Figure 15 Cumulative effects of 4 successive annual applications of mineral fertilizer and compost and three annual maize stubble removal on grain yield at 15% moisture content and shoot dry matter (SDM) of maize plants in the fourth cropping. CV: 22.2 % and 16.7 %, respectively. See Figure 3 for captions.

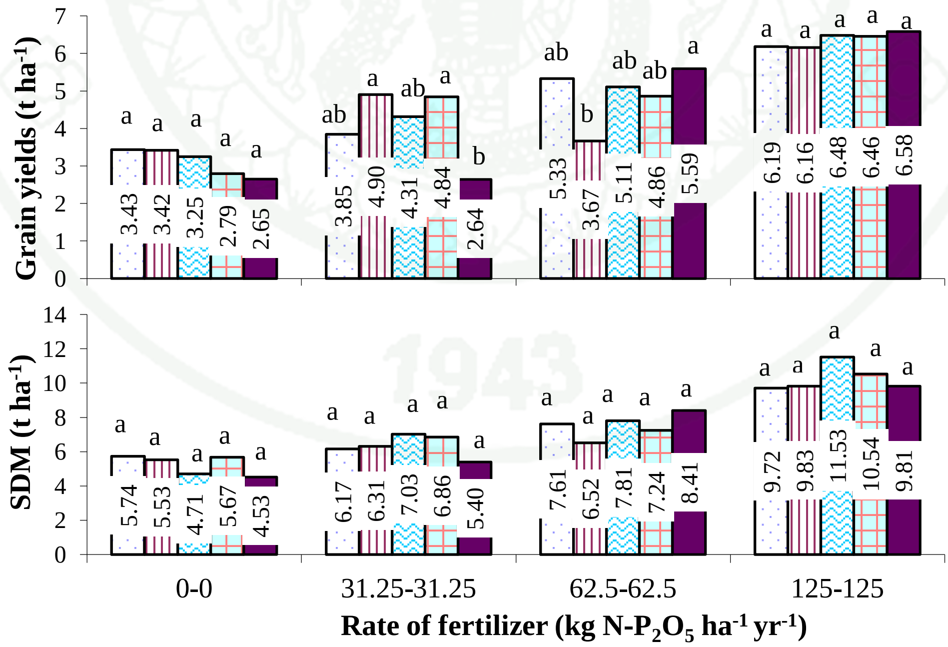

Figure 16 Cumulative effects of 5 successive annual applications of mineral fertilizer and compost and four annual maize stubble removal on grain yield at 15% moisture content and shoot dry matter (SDM) of maize plants in the fifth cropping. CV: 13.7 % and 14.1 %, respectively. See Figure 3 for captions.

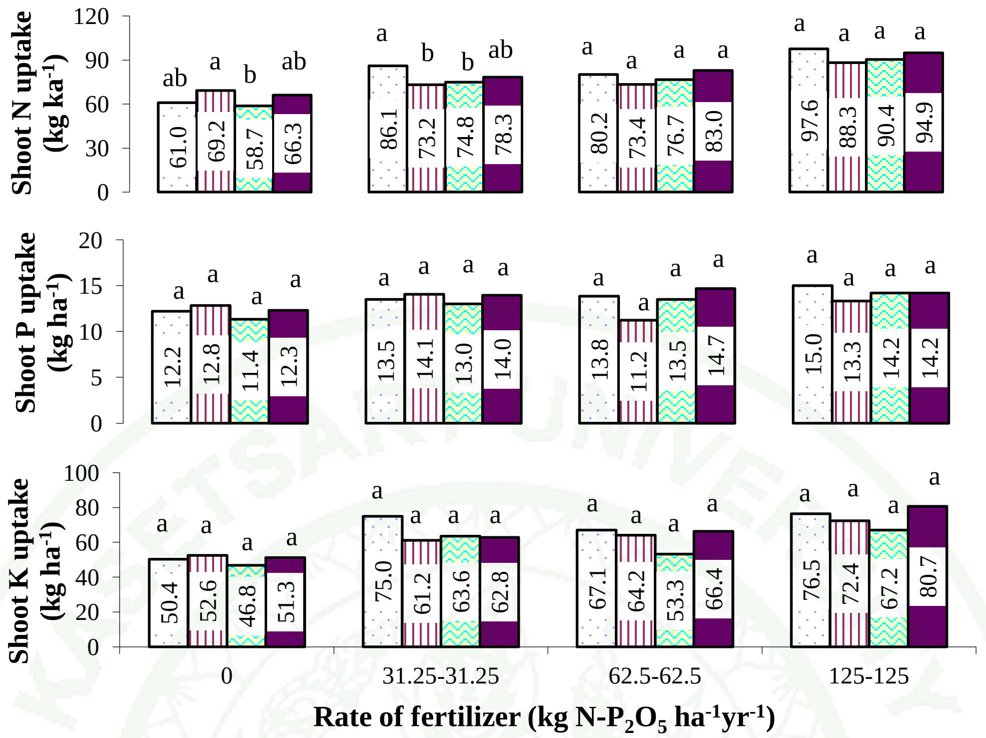

Figure 17 Effects of interactions between rates of mineral fertilizer and compost on shoot N, P and K uptake in year 1. Within the same mineral fertilizer level, bars with a common letter were not significantly different by DMRT$_{.05}$. CV: 7.4%, 12.7% and 12.0%, respectively. See figure 2 for captions.

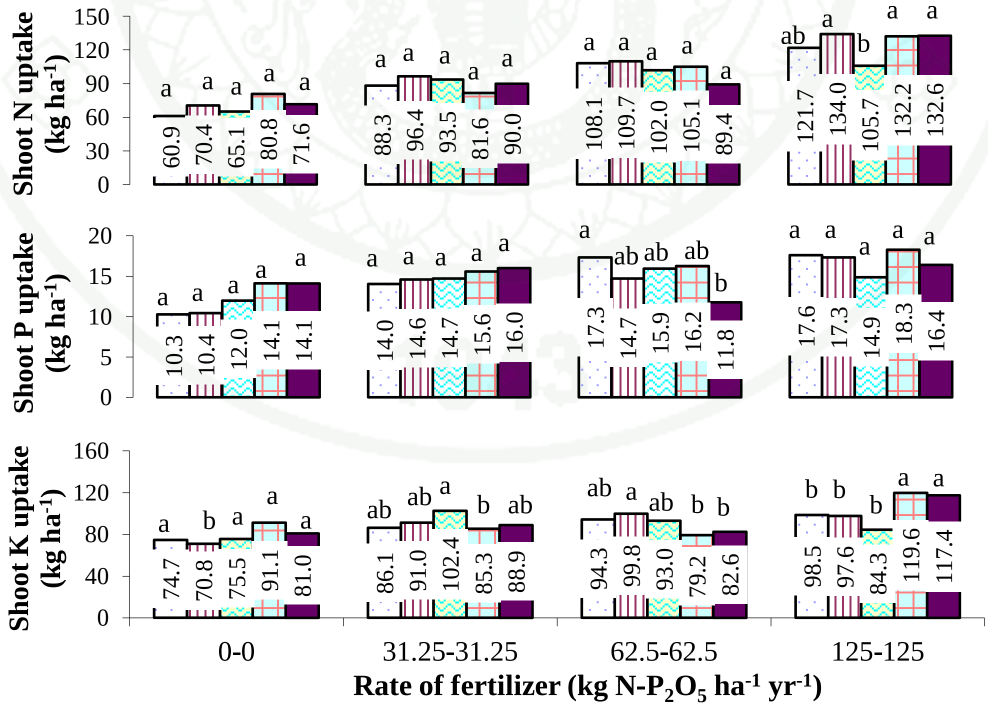

Figure 18 Cumulative effects of 2 successive annual applications of mineral fertilizer and compost and one annual maize stubble removal on shoot N, P and K uptake in the second cropping. CV: 12.8%, 14.1% and 10.1%, respectively. See Figure 3 for captions.

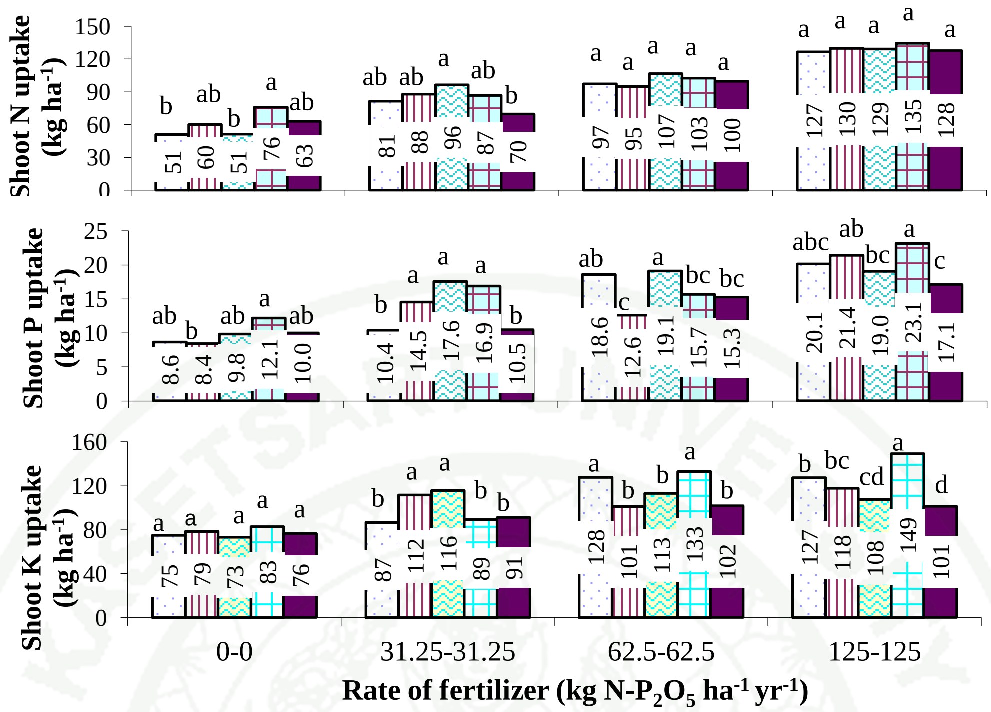

Figure 19 Cumulative effects of 3 successive annual applications of mineral fertilizer and compost and two annual maize stubble removal on shoot N, P and K uptake in the third cropping. CV: 14.1%, 13.0% and 7.5 % respectively. See Figure 3 for captions.

compost at the three rates showed no significant difference on shoot K uptake. With 31.25-31.25 kg N-P_2O_5 ha^{-1} yr^{-1}compost at the rate 1875 and 3750 kg ha^{-1} yr^{-1} significantly increased shoot K uptake whereas compost at the highest rate did not. With 62.5-62.5 kg N-P_2O_5 ha^{-1} yr^{-1}, compost at the rate 1875 and 3750 kg ha^{-1} yr^{-1} significantly decreased shoot K uptake whereas compost at the highest rate did not. With 125-125 kg N-P_2O_5 ha^{-1} yr^{-1}, compost at the highest rate significantly increased shoot K uptake whereas compost at the lower rates did not affect it. Without mineral fertilizer and with the lowest rate of mineral fertilizers, stubble removal did not affect shoot K uptake whereas, with the two highest rates of mineral fertilizers, stubble removal decreased K uptake.

In year 4, application of compost at the three rates and maize stubble removal had no significant effect on shoot N uptake regardless of mineral fertilizer rate (Fig. 20). Without mineral fertilizer, application of 7500 kg ha^{-1} yr^{-1} compost significantly increased shoot P uptake whereas compost at the lower rates had no effect. With 31.25-31.25 kg N-P_2O_5 ha^{-1} yr^{-1}, application of compost at the three rates had no significant effect on shoot P uptake. With 62.5-62.5 kg N-P_2O_5 ha^{-1} yr^{-1}, application of 7500 kg ha^{-1} yr^{-1} significantly decreased shoot P uptake. With 125-125 kg N-P_2O_5 ha^{-1} yr^{-1}, application of 3750 kg ha^{-1} yr^{-1} significantly decreased shoot P uptake. Without mineral fertilizer and with 125-125 kg N-P_2O_5 ha^{-1} yr^{-1}, stubble removal did not significantly affect shoot P uptake whereas with the other two rates of mineral fertilizers, stubble removal significantly decreased shoot P uptake. Without mineral fertilizer, application of compost at the three rates showed no significant difference on shoot K uptake. With 31.25-31.25 kg N-P_2O_5 ha^{-1} yr^{-1}, application of compost at 3750 kg ha^{-1} yr^{-1} significantly increased shoot K uptake whereas the other two rates did not affect it. With 62.5-62.5 kg N-P_2O_5 ha^{-1} yr^{-1}, application of compost at the rate 3750 kg ha^{-1} yr^{-1} significantly decreased shoot uptake whereas the other two rates did not affect it. With 125-125 kg N-P_2O_5 ha^{-1} yr^{-1}, application of compost at 1875 kg ha^{-1} yr^{-1} significantly decreased shoot K uptake. With the three rates of

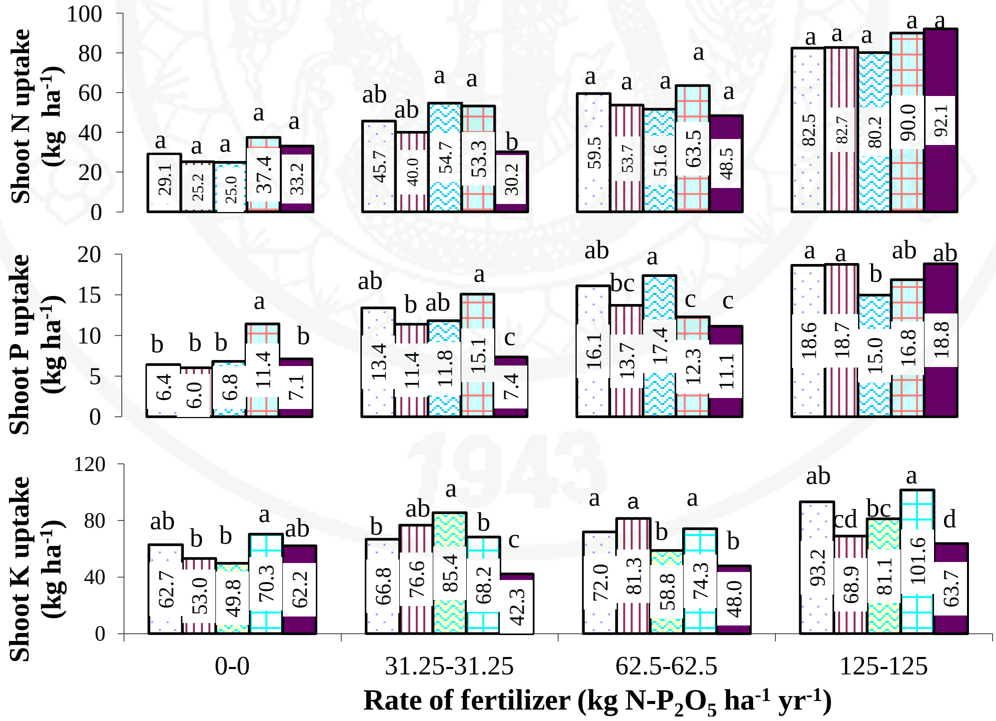

Figure 20 Cumulative effects of 4 successive annual applications of mineral fertilizer and compost and third annual maize stubble removal on shoot N, P and K uptake in the fourth cropping. CV: 17.8%, 15.6% and 16.7%, respectively. See Figure 3 for captions.

mineral fertilizer, stubble removal significantly decreased shoot K uptake whereas without mineral fertilizer, it did not affect shoot K uptake.

In year 5, without and with 62.5-62.5 kg N-P_2O_5 ha^{-1} yr^{-1}, application of compost at the three rates showed no significant effect on shoot N uptake (Fig. 21). With 31.25-31.25 kg N-P_2O_5 ha^{-1} yr^{-1}, application of compost at the highest rate significantly increased shoot N uptake whereas the compost at the other rates did not affect it. With 125-125 kg N-P_2O_5 ha^{-1} yr^{-1}, application of compost at rate 3750 kg ha^{-1} yr^{-1} significantly increased shoot N uptake whereas compost at the other rates did not affect it. Stubble removal showed no significant effect on shoot N uptake regardless of mineral fertilizer application. Without mineral fertilizer, application of compost at the three rates showed no significant different on shoot P uptake. With 31.25-31.25 kg N-P_2O_5 ha^{-1} yr^{-1}, application of compost at the three rates significantly increased shoot P uptake. With 62.5-62.5 kg N-P_2O_5 ha^{-1} yr^{-1}, application of compost at the lowest rate significantly decreased shoot P uptake whereas the two higher compost rates did not show significant effect. With 125-125 kg N-P_2O_5 ha^{-1} yr^{-1}, application of compost at the rate 3750 and 7500 kg ha^{-1} yr^{-1} significantly increased shoot P uptake. Stubble removal, without and with mineral fertilizer at the rate 31.25-31.25 and 62.5-62.5 kg N-P_2O_5 ha^{-1} yr^{-1} showed no significant effect on shoot P uptake whereas with 125-125 kg N-P_2O_5 ha^{-1} yr^{-1} it significantly increased shoot P uptake. Without and with 62.5-62.5 kg N-P_2O_5 ha^{-1} yr^{-1}, application of compost at the three rates showed no significant effect on shoot K uptake. With 31.25-31.25 kg N-P_2O_5 ha^{-1} yr^{-1}, application of compost at 3750 kg ha^{-1} significantly increased shoot K uptake. With 125-125 kg N-P_2O_5 ha^{-1} yr^{-1}, application of 1875 and 7500 kg ha^{-1} yr^{-1} significantly increased shoot K uptake. Stubble removal showed no significant effect on shoot K uptake regardless of mineral fertilizer application.

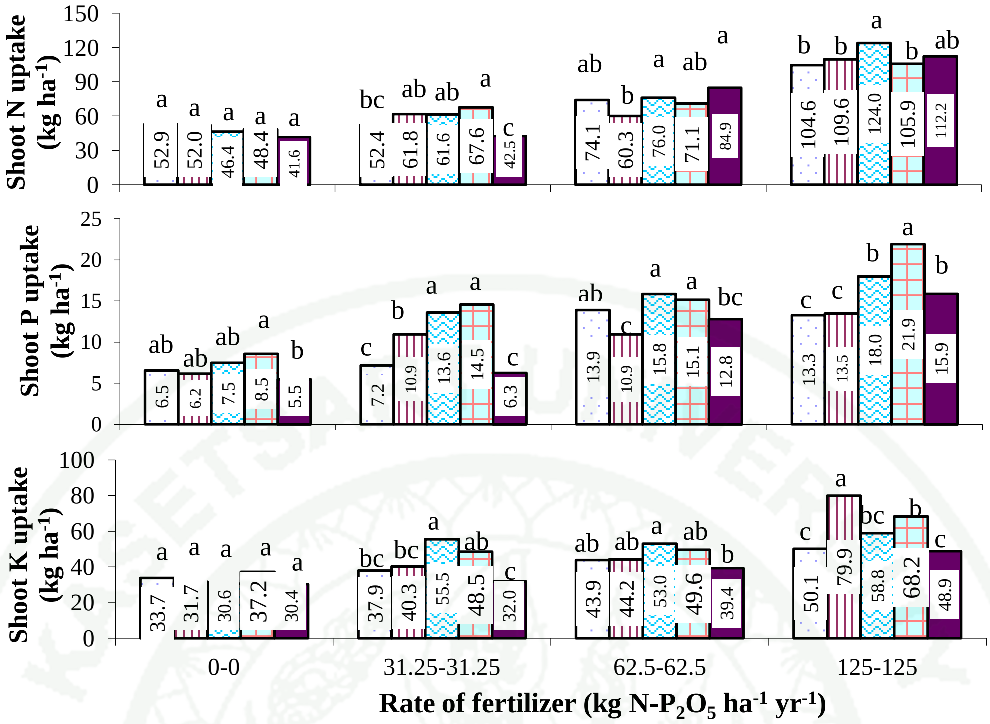

Figure 21 Cumulative effects of 5 successive annual applications of mineral fertilizer and compost and four annual maize stubble removal on shoot N, P and K uptake in the fifth cropping. CV: 11.3%, 11.4% and 15.0%, respectively. See Figure 3 for captions.

1.2 Effects of repeated application of organic material on soil properties

1.2.1 Soil chemical properties

In the case of soils collected before year 2 cropping, in the year 2003, there were no significant effects of mineral fertilizer, compost applied alone and in combinations or by stubble management on SOM content in soil (Table 9). With stubble return, application of mineral fertilizer in combination with compost increased total N and extractable P but did not show significant effects on extractable N; mineral fertilizer alone increased extractable N but did not show significant effects on total N and extractable P; and compost alone did not show significant effects on total N, extractable N and extractable P. With stubble removal, mineral fertilizer showed no significant effects on total N and extractable N but increased extractable P.

In the case of soil collected before year 3 cropping, in 2004, there were no significant differences in effects of mineral fertilizer, compost and stubble management on extractable N in soil (Table 9). With stubble return, application of mineral fertilizer in combination with compost increased extractable P and total N but did not show significant effects on SOM content; mineral fertilizer alone increased total N and extractable P but did not show significant effects on SOM content; and compost alone increased total N but it did not show significant effects on SOM content and extractable P. With stubble removal, mineral fertilizer showed no significant effects on total N and extractable N but increased extractable P.

In the case of soils collected after year 5 cropping, in 2006, with stubble return, mineral fertilizer alone, compost alone and their combinations similarly increased SOM after five annual applications (Table 9). With stubble removal, increased mineral fertilizer rate did not increase SOM. Indeed with the highest mineral fertilizer rate, stubble removal decreased SOM whereas without mineral fertilizer, stubble removal showed no effect. With stubble return, there were no significant effects of the two kinds of fertilizer applied alone or in combination on total N and mineral N (NH_4^++NO_3^-). Stubble removal showed no significant effects on total N and mineral N (NH_4^++NO_3^-). With stubble return, extractable P levels followed the increasing order of: no fertilizer < compost < mineral fertilizer < combination of the two kinds of fertilizers. With no fertilizer added, stubble removal did not affect extractable P ($C_0F_0S_0$ vs. C_0F_0) but with increased mineral fertilizer rates stubble removal decreased extractable P ($C_0F_3S_0$ vs. C_0F_3).

Table 9 Chemical properties of the soils (at 0-15 cm depth) in years 2002- 2006 1/.

Treatments	Soil chemical properties			
	SOM	Extractable N ($NH_4^+ + NO_3^-$)	Extractable P	Total N
	g kg^{-1}	mg kg^{-1}	mg kg^{-1}	g kg^{-1}
Year 2003 (before the 2nd annual cropping)				
C_0F_0	27.1 a	55.6 b	8.57 bc	1.14 b
C_3F_0	29.2 a	65.1 ab	9.79 bc	1.14 b
C_0F_3	28.0 a	69.0 a	15.10 b	1.04 bc
C_3F_3	28.7 a	67.1 ab	25.90 a	1.39 a
$C_0F_0S_0$	27.5 a	61.0 ab	7.00 c	0.85 d
$C_0F_3S_0$	26.4 a	56.1 b	15.70 b	0.92 cd
CV %	6.6%	10.0%	26.7%	6.8%
Year 2004 (before the 3rd annual cropping)				
C_0F_0	27.3 abc	33.6 a	9.11 cd	1.02 c
C_3F_0	30.3 a	36.8 a	14.5 cd	1.29 ab
C_0F_3	26.8 bc	37.3 a	26.9 ab	1.39 a
C_3F_3	30.0 ab	39.0 a	36.4 a	1.25 ab
$C_0F_0S_0$	27.3 abc	35.3 a	7.75 d	0.97 c
$C_0F_3S_0$	25.6 c	34.5 a	20.0 bc	1.11 bc
CV%	6.0%	12.6%	30.7%	8.6%
Year 2006 (after 5th annual cropping)				
C_0F_0	30.2 c	12.0 a	4.12 d	1.38 abc
C_3F_0	32.7 ab	15.1 a	23.2 c	1.61 a
C_0F_3	33.5 a	15.7 a	68.9 b	1.55 abc
C_3F_3	32.7 ab	14.5 a	86.5 a	1.59 ab
$C_0F_0S_0$	30.8 bc	11.3 a	3.06 d	1.31 c
$C_0F_1S_0$	30.0 c	nd	13.0 cd	1.39 abc
$C_0F_2S_0$	29.8 c	nd	27.9 c	1.34 bc
$C_0F_3S_0$	30.1 c	14.2 a	53.6 b	1.34 bc
CV%	3.6	16.4	28.7	9.4

[1/] Mean followed by a common letter within a column in each year are not significantly different at 5% level by DMRT. In years 2002 -2004, soils were collected before cropping start, while in year 2006, soils were collected after crop harvest. [nd] not determined.

1.2.2 Soil physical properties

For BD or AWC of soils in the three layers, here were no significant effects of compost alone, mineral fertilizer alone or their combinations applied in five annual croppings with stubble return (Table 10). Similarly there were generally no significant effects of stubble removal on BD or AWC of soils in the three layers. However, in the case of soils in the bottom layer, stubble removal decreased AWC when mineral fertilizer at the highest rate was applied and showed a trend to decrease it when no mineral fertilizer was applied.

Table 10 Effect of compost, mineral fertilizer and stubble management on bulk density (BD) and available water capacity (AWC) after 5 years cropping [1/].

Treatments [2/]	0-15 cm depth		15-30 cm depth		30-50 cm depth	
	BD ($Mg\ m^{-3}$)	AWC (% weight)	BD ($Mg\ m^{-3}$)	AWC (% weight)	BD ($Mg\ m^{-3}$)	AWC (% weight)
1. C_3F_3	1.25ab	3.95ab	1.17a	3.36ab	1.19a	4.44ab
2. C_3F_0	1.18ab	5.96a	1.15a	5.59a	1.14a	3.02bc
3. C_0F_3	1.12b	5.44ab	1.17a	5.76a	1.22a	5.51a
4. C_0F_0	1.17ab	4.42ab	1.22a	4.30ab	1.14a	3.30abc
5. $C_0F_3S_0$	1.20ab	2.71b	1.13a	2.63ab	1.14a	2.87bc
6. $C_0F_0S_0$	1.30a	2.97b	1.17a	1.66b	1.23a	1.73c
CV %	6.02	34.5	7.74	44.5	7.12	36.9

[1/] Means of three replicates. Within a column, means followed by a common letter are not significantly different by $DMRT_{0.05}$. [2/] Treatments with S_0 were those with removal of maize stubble from the previous crop whereas other treatments were with retention of maize stubble from the previous crop.

1.3 N and P budget

1.3.1 N budget in year 1

Mineral fertilizer was the largest component of total N input in treatments that received mineral fertilizer application followed by SOM mineralization (Table 11). With mineral fertilizer application, total N input was more than double that without mineral fertilizer. Without mineral fertilizer treatment, mineralization of N from SOM was the largest component of total N input. Shoot uptake accounted for more than 2/3 of total output and no other output component was large apart from gaseous N losses, which amounted to 25 % of output in the mineral fertilizer treatments. Mineral fertilizer treatments produced large N surpluses (70-80 kg N ha^{-1}) whereas without mineral fertilizer treatments, N balance was close to zero regardless of compost input.

Table 11 N budget (kg N ha^{-1}) of different treatments in year 1.

Parameter	Treatment			
	C_3F_3	C_3F_0	C_0F_3	C_0F_0
INPUT				
1. Mineral fertilizer	125	0.00	125	0.00
2. Compost	8.85	8.85	0.0	0.00
3. Irrigation water	6.25	6.25	6.25	6.25
4. Rainfall	1.13	1.13	1.13	1.13
5. Soil organic matter[1/]	78.5	78.5	78.5	78.5
Total input	220	94.7	211	85.9
OUTPUT				
1. Shoot uptake[2/]	94.9	66.3	97.6	61.0
2. Accumulated in root[2/]	9.78	7.04	9.60	6.36
3. Gaseous loss[2/]	25.3	10.9	24.3	9.88
4. Leaching loss	9.38	9.38	9.38	9.38
Total output	139	93.6	141	86.6
BALANCE	80.4	1.17	70.0	-0.74

[1/] Analysis of composite sample from the experimental area. [2/] Mean of three replicates

1.3.2 N budget in year 2

The N balance from year 1 was added as a nutrient credit (input) in year 2 (Table 12). It resulted in a larger total input in year 2 than in year 1 especially in the mineral fertilizer treatments. Additionally, N mineralization from maize stubble and root were added to inputs in year 2. However, the latter new added components were small relative to the mineral fertilizer input. The other input components were relatively similar to year 1. In year 2, shoot uptake continued to be the main output accounting for more than 2/3 of total output. In the mineral fertilizer treatments, N surplus continued being large and positive in year 2 although this was reduced somewhat by maize stubble removal. Without mineral fertilizer treatments there were slight positive N balances when stubble was returned but negative balance when stubble was removed.

1.3.3 N budget in year 3

Total input continued to increase in year 3 compared with year 2 due to the large amount of nutrient accumulation from year 2 as a nutrient credit where stubble had been returned in mineral fertilizer treatments (Table 13). However, total input declined relative to year 2 where stubble was removed. After application of compost for three years, it contributed an extra 24-47 kg N ha^{-1} to soil. Shoot uptake was the dominant N output as calculated in the previous 2 years. Due to rising total input in mineral fertilizer N, calculated N losses as leachate and denitrification also rose to become significant quantities. After 3 years, about 200 kg N ha^{-1} surplus in the mineral fertilizer treatments and 33-37 kg N ha^{-1} of surplus without mineral fertilizer treatments were estimated. Removal of stubble changed the calculated N balance to a small net negative value without mineral fertilizer treatment and reduced the N surplus in mineral fertilizer treatments by over 60 %.

Table 12 N budget (kg N ha^{-1}) of different treatments in year 2.

Parameter	Treatment					
	C_3F_3	C_3F_0	C_0F_3	C_0F_0	$C_0F_3S_0$	$C_0F_0S_0$
INPUT						
1. Mineral fertilizer	125	0.00	125	0.00	125	0.00
2. Compost	11.9	11.9	0.00	0.00	0.00	0.00
3. Maize stubble[1/]	16.9	10.4	16.7	10.5	0.00	0.00
4. Root mineralization[1/]	4.56	3.28	4.47	2.96	4.37	3.14
5. Irrigation water	6.25	6.25	6.25	6.25	6.25	6.25
6. Rainfall	1.00	1.00	1.00	1.00	1.00	1.00
7. Soil organic matter[1/]	84.2	85.2	82.2	79.2	77.2	80.2
8. Nutrient credits from year 1[2/]	80.4	1.17	70.0	-0.74	70.0	-0.74
Total input	330	119	306	99.0	284	90.0
OUTPUT						
1. Shoot uptake[1/]	132.0	80.8	122.0	60.9	133.0	71.6
2. Gaseous loss[1/]	38.0	13.7	35.2	11.4	32.6	10.3
3. Accumulated in root[1/]	13.9	11.0	13.9	8.65	14.6	9.66
4. Leaching loss	8.69	8.69	8.69	8.69	8.69	8.69
Total output	193	114	180	89.6	189	100
BALANCE	137	5.04	126	9.50	95.2	-10.4

[1/] Mean of 3 replicates. [2/] Nutrient balance in the previous year.

1.3.4 P budget in year 1

Fertilizer was the main P input in mineral fertilizer treatments whereas mineralized SOM was the main input without mineral fertilizer (Table 14). Total input of P in the mineral fertilizer treatments was more than double that without mineral fertilizer. Sorption of P was the main calculated P output from the available P pool followed by shoot uptake. With mineral fertilizer, available P balance of 8-10 kg P ha^{-1} was calculated whereas without mineral fertilizer, available P balances changed to negative values (-3 to -4 kg P ha^{-1}).

1.3.5 P budget in year 2

Total inputs in year 2 were comparable to year 1, since the nutrient credit from the previous year was small (Table 15). In addition, input from mineralization of maize stubble and root was relatively small. Inputs from mineral fertilizer treatments were double those without mineral fertilizer treatments. SOM mineralization of P was a dominant nutrient input without mineral fertilizer treatments. Nutrient output was dominated by P sorption of soluble P, while shoot uptake accounted for about 16-33 % of P output. As in year 1, available P balance was about 8-10 kg P ha^{-1} in mineral fertilizer treatments whereas without mineral fertilizer, soil P deficit was 2 to 4 kg P ha^{-1} increasing to about 7 kg P ha^{-1} when stubble was removed.

1.3.6 P budget in year 3

Input from compost started to positively affect the available P balance both with and without mineral fertilizer application in year 3 (Table 16). Similarly, cumulative effects of stubble removal were evident in the decline in P input relative to where stubble was retained. Shoot uptake in year 3 varied three-fold from control (C_0F_0) to mineral fertilizer and compost treatment (C_3F_3). However, P sorption remained the dominant output of soluble P. Phosphorus surpluses in mineral fertilizer treatments were only 5-7 kg P ha^{-1}, a decrease from years 1 and 2 due to increased P uptake. Without mineral fertilizer treatments, P balance was negative in compost treatment whereas it was more negative when stubble was removed without mineral fertilizer.

Table 13 N budget (kg N ha^{-1}) of different treatments in year 3.

Parameter	Treatment					
	C_3F_3	C_3F_0	C_0F_3	C_0F_0	$C_0F_3S_0$	$C_0F_0S_0$
INPUT						
1. Mineral fertilizer	125	0.00	125	0.00	125	0.00
2. Compost	12.9	12.9	0.00	0.00	0.00	0.00
3. Maize stubble[1/]	39.2	22.1	28.5	15.0	0.00	0.00
4. Root mineralization[1/]	6.80	5.35	6.81	4.23	7.14	4.72
5. Water application	6.25	6.25	6.25	6.25	6.25	6.25
6. Rainfall	0.84	0.84	0.84	0.84	0.84	0.84
7. Soil organic matter[1/]	87.7	88.8	78.2	80.2	75.1	79.7
8. Nutrient credit from year 2[2/]	137	4.99	126	9.50	95.2	-10.4
Total input	416	141	372	116	310	81.0
OUTPUT						
1. Shoot uptake[1/]	135	75.9	127	51.0	128	63.1
2. Gaseous loss[1/]	47.9	16.2	42.8	13.3	35.6	9.30
3. Accumulated in root[1/]	15.3	9.92	14.6	7.72	13.9	8.90
4. Leaching loss	7.78	7.78	7.78	7.78	7.78	7.78
Total output	206	110	192	80.0	185	89.1
BALANCE	210	31.4	180	36.2	124	-7.99

[1/] Mean of 3 replicates. [2/] Nutrient balance in the previous year.

1.3.7 Using differential ranges of variation for N parameters

The range of variation for N budget parameters was from 2 to 60 % of the initial values chosen (Table 17) and generally much greater than the arbitrary 10 % variation used for sensitivity analysis by Smaling *et al.* (1993). Nutrient credit was not directly tested in the sensitivity analysis since it is a dependent property of the N budget. In the fertilized treatments, 50 % decrease in mineral fertilizer N had a large overall effect on calculated N balance in year 3. The second most influential factor in N balance estimates of fertilized soil was the SOM mineralization constant followed by N concentration in organic matter. In the unfertilized treatments, the variation of mineralization constant and N content in SOM had the largest effect on calculated N balance. All of the other input and output parameters, except in the case of the stubble removal had similarly small effects on calculated N balance. Shoot uptake and gaseous losses were the two main influential factors for N output of the treatments with mineral fertilizer whereas shoot uptake was the most influential factor of the C_1F_0 and $C_0F_0S_0$ treatments. The other output parameters were comparable in their influence on accuracy of the N balance calculated.

Table 14 P budget (kg P ha^{-1}) of different treatments in year 1.

Parameter	Treatment			
	C_3F_3	C_3F_0	C_0F_3	C_0F_0
INPUT				
1. Mineral fertilizer	55.0	0.00	55.0	0.00
2. Compost	4.65	4.65	0.00	0.00
3. Irrigation water	0.25	0.25	0.25	0.25
4. Rainfall	0.62	0.62	0.62	0.62
5. Soil organic matter[1/]	36.7	36.7	36.7	36.7
Total input	97.2	42.2	92.6	37.6
OUTPUT				
1. Shoot uptake[2/]	14.2	12.3	15.0	12.2
2. P accumulated in root[2/]	2.30	1.99	2.43	1.98
3. Sorption of P[2/]	71.0	30.8	67.6	27.4
Total output	87.5	45.1	85.0	41.6
BALANCE	9.72	-2.89	7.56	-4.04

[1/] Analysis of composite sample from the experimental area. [2/] Mean of 3 replicates

Table 15 P budget (kg P ha $^{-1}$) of different treatments in year 2.

Parameter	Treatment					
	C_3F_3	C_3F_0	C_0F_3	C_0F_0	$C_0F_3S_0$	$C_0F_0S_0$
INPUT						
1. Mineral fertilizer	55.0	0.00	55.0	0.00	55.0	0.00
2. Compost	8.10	8.10	0.00	0.00	0.00	0.00
3. Maize stubble[1/]	1.28	0.86	1.22	0.97	0.00	0.00
4. Root mineralization[1/]	1.07	0.93	1.13	0.92	0.92	0.92
5. Irrigation water	0.25	0.25	0.25	0.25	0.25	0.25
6. Rainfall	0.55	0.55	0.55	0.55	0.55	0.55
7. Nutrient from SOM[1/]	39.4	39.9	38.5	37.1	36.1	37.5
8. Nutrient credits from year 1[2/]	9.72	-2.89	7.56	-4.04	7.56	-4.04
Total input	115	47.7	104	35.7	100	35.2
OUTPUT						
1. Shoot uptake[1/]	18.3	14.1	17.6	10.3	16.4	14.1
2. P accumulated in root[1/]	2.95	2.28	2.85	1.66	2.70	2.30
3. Sorption of P[1/]	84.2	34.8	76.1	26.1	73.3	25.7
Total output	105	51.2	96.5	37.9	92.3	42.1
BALANCE	9.95	-3.51	7.68	-2.28	8.05	-6.90

[1/] Mean of 3 replicates. [2/] Nutrient balance in the previous year.

Table 16 P budget (kg P ha^{-1}) of different treatments in year 3.

Parameter	Treatment					
	C_3F_3	C_3F_0	C_0F_3	C_0F_0	$C_0F_3S_0$	$C_0F_0S_0$
INPUT						
1. Mineral fertilizer	55.0	0.00	55.0	0.00	55.0	0.00
2. Compost	8.78	8.78	0.00	0.00	0.00	0.00
3. Maize stubble[1/]	3.63	2.55	2.02	1.35	0.00	0.00
4. Root mineralization[1/]	1.44	1.11	1.39	0.81	1.30	1.11
5. Irrigation water	0.25	0.25	0.25	0.25	0.25	0.25
6. Rainfall	0.46	0.46	0.46	0.46	0.46	0.46
7. Soil organic matter[1/]	41.1	41.5	36.6	37.5	35.2	37.3
8. Nutrient credit from year 2[2/]	9.95	-3.51	7.68	-2.28	8.05	-6.90
Total input	121	51.1	103	38.1	100	32.2
OUTPUT						
1. Shoot uptake[1/]	23.2	12.2	20.1	8.60	17.1	10.0
2. P accumulate in root[1/]	3.75	1.97	3.26	1.40	2.77	1.62
3. Sorption of P[1/]	88.0	37.4	75.5	27.8	73.2	23.5
Total output	114	51.5	98.9	37.9	93.0	35.1
BALANCE	5.66	-0.29	4.53	0.25	7.17	-2.91

[1/] Mean of 3 replicates. [2/] Nutrient balance in the previous year.

Table 17 N balances (kg N ha^{-1}) in year 3 for compost, fertilizer and stubble removal treatments recalculated after adjusting N budget parameters using either 25 % variation or a range of variation based on the literature or the present study[a].

Parameter	Adjustment made to parameter as a percentage of value used in Table 13	Treatment					
		C_3F_3	C_3F_0	C_0F_3	C_0F_0	$C_0F_3S_0$	$C_0F_0S_0$
N balance calculation for year 3 (see Table 13)	-	210	31.4	180	36.2	124	-7.99
INPUT							
1. Mineral fertilizer	-50%[b]	147	31.4	117	36.2	61.8	-7.99
2. SOM							
2.1 OM content	+4.92 to +9.62% [c]	214	37.6	184	43.9	130	-3.18
2.2 Mineralization constant	+31.6% [d/]	238	58.6	204	61.0	148	17.32
2.3 Soil weight	+2.08 to +11.61% [c]	212	35.9	182	38.4	133	-3.28
2.4 N content in SOM	+22.1% [d]	229	50.6	197	54.0	141	9.32
3. Maize stubble mineralization in year 2							
3.1 N_0	+2.28 to +19.0% [c]	217	34.6	181	37.0	124	-7.99
3.2 k	+28.5% [d]	213	33.1	182	37.4	124	-7.99
4. Compost							
1.1 N_0	+25% [e]	215	36.3	180	36.2	124	-7.99
1.2 k	+25% [e]	212	33.3	180	36.2	124	-7.99
5. Root mineralization							
1.1 shoot/root ratio	+44.8% [d]	213	33.8	183	38.1	127	-5.88
1.2 %N in root	+24% [d]	211	32.7	181	37.2	126	-6.86
1.3 k	+62.2% [d]	212	33.3	182	37.7	127	-6.31
6. Irrigation water							
6.1 %N in water	+25% [e]	211	33.0	181	37.8	126	-6.43
6.2 amount of water applied	+25% [e]	211	33.0	181	37.8	126	-6.43
7. Rainfall							
7.1 %N in water	+25% [e]	210	31.6	180	36.4	124	-7.78
7.2 amount of rainfall	+14.7% [c]	210	31.5	180	36.3	124	-7.87
OUTPUT							
1. Shoot uptake	+3.78 to +18.0% [c]	201	18.8	162	34.3	114	-19.4
2. Gaseous losses	+25% [e]	198	27.3	169	32.9	115	-10.3
3. Accumulation in root							
3.1 shoot/root ratio	+44.8% [d]	203	26.9	173	32.7	118	-12.0
3.2 %N in root	+29.5% [d]	205	28.5	175	33.9	120	-10.6
4. Leaching losses							
4.1 %N in ground	+25% [e]	208	29.5	178	34.3	122	-9.93

Table 17 (Continued)

Parameter	Adjustment made to parameter as a percentage of value used in Table 13	Treatment					
		C_3F_3	C_3F_0	C_0F_3	C_0F_0	$C_0F_3S_0$	$C_0F_0S_0$
4.2 drainage volume	+9.32%[c]	209	30.7	179	35.5	124	-8.68

[a] The 25 % variation was applied when no suitable values were found in the literature or measured in the present study. [b] 50% reduction in N rate used for N balance calculation based on the most economic rate recommended for farmers. [c] Variation of plus one standard error from the mean of replications or different years in the field experiment. [d] Variation of plus one standard error of the mean of the values reported in studies relevant to the present study (Polglase *et al.*,1992; Tian *et al.*, 1992; Mugendi *et al.*, 1999; Pare *et al.*, 2000; Mubarak *et al.*, 2002; Amos and Walters, 2006; Brady and Weil, 2008; Suwanarit *et al.*, 2008). [e] Arbitrary range of variation as used by Sheldrick *et al.* (2002).

1.3.8 Using differential ranges of P parameters

The range of variation for parameters in the P budget was from 2 to 62 % of the initial values chosen (Table 18), similar to that for N parameters. Regardless of stubble management, compost application or fertilizer, an accurate estimate of P mineralized from SOM had the greatest influence on calculated P balances. Uncertainties about the P mineralization constant, followed by P content in SOM, would have the greatest influence on accurate P balance calculations. In the fertilized treatments, reducing P input by 50 % to the present recommended P fertilizer rate would have an equally large effect on the calculated P balance. While P sorbed was a major form of P output in the P budget (Table 16), uncertainties about the amount of P sorption were less important to accurate P balance calculation. Similarly, variation in shoot P uptake had relatively small effects on the P balance calculation for each treatment. In the C_1F_1 treatment, uncertainties about the potentially mineralizable P fraction of compost could also introduce significant error to the P balance calculation. The other budget items such as stubble, roots and water had minimal consequence for the accuracy of the P balance calculated.

1.3.9 Nutrient balance versus soil analysis

Considering all 6 treatments, there was no significant relationship between calculated N balances and the increase in total soil N (Fig. 22). However, among the treatments without compost application, there was a strong linear relationship between calculated N balance and Δ total soil N (r^2=0.904). There was no relationship between soil mineral N (nitrate plus ammonium) and the calculated N balance. Indeed, soil mineral nitrogen after 5 years was lower than at the start of experiment (data not shown).

The regression coefficient of the linear relationships suggests that the increase in resin extractable-P was 0.318 kg ha^{-1} for every 1 kg ha^{-1} of surplus P in the calculated P balance (Fig. 23). There was a highly significant relationship (r^2=0.909) between the calculated P balance and the resin-extractable soil P considering all treatments including compost.

Table 18 P balances (kg P ha^{-1}) in year 3 for compost, fertilizer and stubble removal treatments recalculated after adjusting P budget parameters using either 25 % variation or a range of variation based on the literature or the present study[a].

Parameter	Adjustment made to the parameter as a percentage of value used in Table 16	Treatment					
		C_3F_3	C_3F_0	C_0F_3	C_0F_0	$C_0F_3S_0$	$C_0F_0S_0$
P balance calculation for year 3 (see Table 16)	-	5.66	-0.29	4.53	0.25	7.17	-2.91
INPUT							
1. Mineral fertilizer	-50%[b]	-21.8	-0.29	-22.97	0.25	-20.3	-2.91
2. SOM							
2.1 OM content	+4.92 to +9.62%[c]	7.69	2.71	6.53	3.85	9.80	-0.67
2.2 Mineralization constant	+37.8 %[d]	21.19	14.76	24.52	14.42	20.49	11.24
2.3 Soil weight	+2.08 to +11.6%[c]	6.95	1.45	9.85	1.41	11.28	-0.72
2.4 P content in SOM	+25 %[e]	15.93	9.50	19.26	9.61	15.99	6.46
3. Maize stubble mineralization in year 2							
3.1 P_0	+12.6 to +59.9%[c]	7.84	0.71	4.91	0.42	7.17	-2.91
3.2 k	+25%[e]	5.89	-0.13	4.67	0.34	7.17	-2.91
4. Compost							
4.1 P_0	+25%[e]	11.51	5.56	4.53	0.25	7.17	-2.91
4.2 k	+25%[e]	7.27	1.32	4.53	0.25	7.17	-2.91
2. Root mineralization							
2.1 shoot/root ratio	+44.8%[d]	6.33	0.23	5.17	0.63	7.75	-2.39
2.2 % P in root	+24%[d]	6.02	-0.02	4.88	0.45	7.48	-2.63
2.3 k	+62.2%[d]	6.20	0.12	5.04	0.55	7.63	-2.50
3. Irrigation water							
3.1 % P in water	+25%[e]	5.72	-0.23	4.59	0.31	7.23	-2.85
3.2 amount of water applied	+25%[e]	5.72	-0.23	4.59	0.31	7.23	-2.85
4. Rainfall							
4.1 % P in water	+25%[e]	5.77	-0.18	4.64	0.36	7.28	-2.80
4.2 amount of rainfall	+14.7%[c]	5.72	-0.23	4.59	0.31	7.23	-2.85
OUTPUT							
1. Shoot uptake	+4.89 to +20.1%[c]	3.32	-2.73	3.54	-0.65	5.17	-3.94
2. % P sorption	+17.8%[f]	-10.0	-6.94	-8.91	-4.70	-5.85	-7.10
3. Accumulation in root							
3.1 shoot/root ratio	+44.8%[d]	3.98	-1.18	3.08	-0.37	5.95	-3.64

Table 18 (Continued)

Parameter	Adjustment made to the parameter as a percentage of value used in Table 16	Treatment					
		C_3F_3	C_3F_0	C_0F_3	C_0F_0	$C_0F_3S_0$	$C_0F_0S_0$
3.2 %P in root	+23.7%[d]	4.77	-0.77	3.77	-0.07	6.53	-3.30

[a] The 25 % variation was applied when no suitable values were found in the literature or measured in the present study. [b/, c/, d/, e/] See Table 17 for further captions. [f/] Adjustment to P sorption was based on the upper limit of P fertilizer that was not extractable by resin among 40 highly weathered soils (Sharpley and Halvorson, 1994).

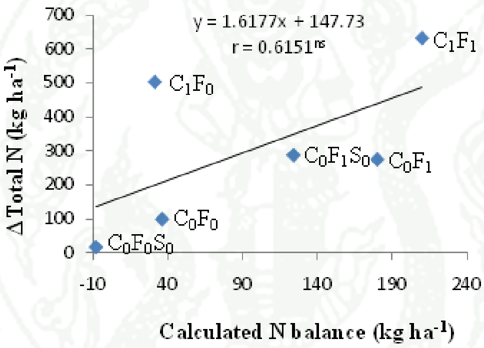

Figure 22 Relationship between Δ total N after year 5 and calculated N balance for year 3. [ns] indicates insignificant relationship for linear equation.

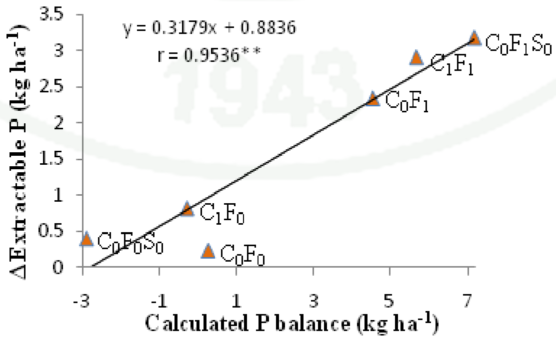

Figure 23 Relationship between Δ extractable P after year 5 and calculated P balance for year 3. ** indicates significant relationship at 0.01% level for linear equation.

1.4 Suitable combination of mineral and organic fertilizers as determined by DSSAT

1.4.1 DSSAT evaluation

The evaluation of the performance of the model was carried out using experimental data collected in 2002 to 2006. The model was calibrated using grain yields at maturity in year 1. Prediction for grain yields was better (normalized RMSE = 6.86 %; D-index = 0.917; and r^2 = 0.74) than for shoots that showed poorer agreement (Fig. 24) for model calibration. Predicted SDM was only 80 % of actual values even though the model explained 70.5 % of the variation in SDM. After calibration, the fit of the model to yield data was carried out for years 2 to 5. Model evaluation showed reasonably good agreement between observed and predicted grain yields in years 2 and 3 (normalized RMSE of grain yields was classified as good with values < 20 %) whereas SDM was only good to fair (normalized RMSE between 10 to 30 %) (Fig. 25). By contrast, in years 4 and 5 the model showed poor agreement with observed grain yields and SDM (i.e. normalized RMSE > 30 % generally, D-index <0.60 and r^2 <0.5). This might be due to maize lodging from strong wind before maturity in year 4 when maize was harvested at 83 days after planting. There is no apparent reason for the poor fit in year 5.

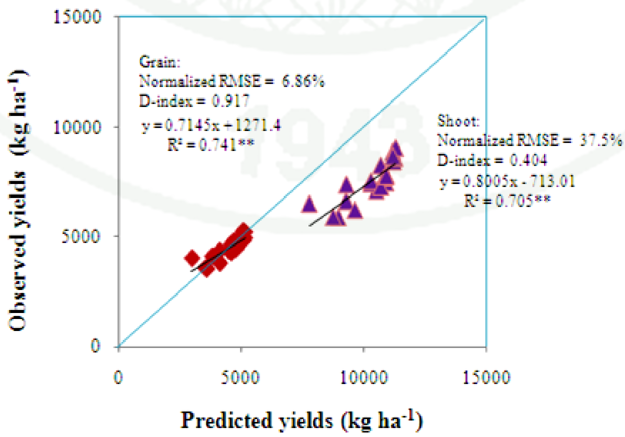

Figure 24 Relationship between predicted grain yields or shoot dry matter (SDM) and observed yields or SDM of year 2002 for model calibration: Shoot (▲); Grain yield (♦).

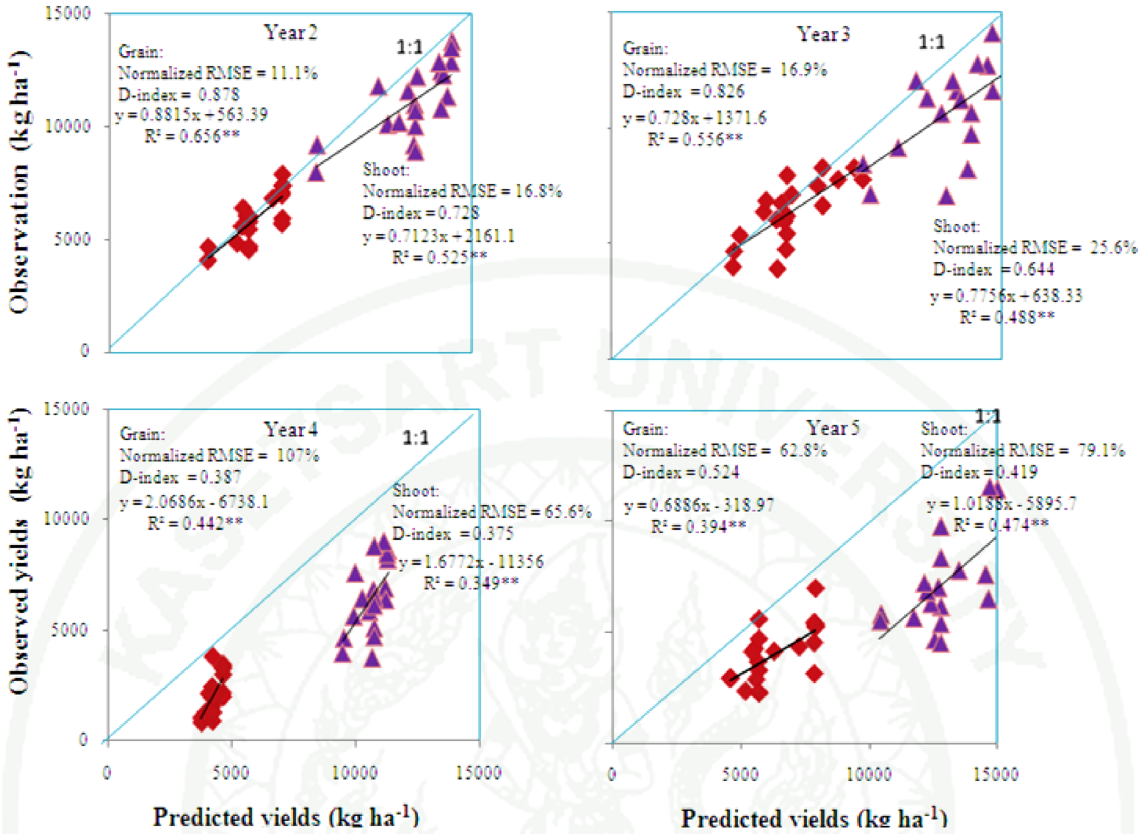

Figure 25 Relationship between predicted grain yields or shoot dry matter (SDM) and observed yields or SDM of years 2, 3, 4 and 5 for all treatments. ** indicate significant difference at 0.01% level by linear equation. Shoot (▲); Grain yield (♦).

1.4.2 Seasonal Analysis

Sensitivity analysis of the model was run by varying nutrient concentrations (from 2- to 8-fold) and rate of application of organic materials (from 1,875 to 7,500 kg ha^{-1}, based on field experimental treatments) with fixed compost price (3,000 baht t^{-1} equivalent to 92 US$ in July, 2010) (Table 5). The net return of the without compost treatment was the base value, hence, the higher net return of increased nutrient concentration in compost than without compost treatment indicated that these compost nutrient concentrations will be more profitable. The model was re-run assuming that the compost was available free of charge to see the minimum compost concentration that would give a net return the same as that without adding compost did. The three mineral fertilizer rates alone and in combination with the lowest compost rate showed a positive net return while compost alone at all rates used showed negative net return. Net returns of C_0F_1, C_0F_2 and C_0F_3 treatments were not dramatically different, but C_0F_1 and C_0F_2were the most efficient treatments predicted by Seasonal Analysis (Table 19).

A sensitivity analysis was carried out by running DSSAT with various N concentrations in compost and a range of application rates to identify combinations that were comparable in net return to the most efficient mineral fertilizer treatment. With compost price at US$ 92 t^{-1}, the most profitable option required low rates of compost and very high N concentrations. Compost with N concentration that is at least 7-fold (41.3 g kg^{-1} N) higher than the original material applied at the rate 1,875 kg ha^{-1} was predicted to give slightly higher net return than without N fertilizer (F_0) (Fig. 26). Lower net returns of compost application than without N fertilizer application were predicted when either lower percentage of N in compost or the other compost application rates were applied.

Table 19 Dominance analysis of different management strategies of maize cropping using the Pak Chong field study dataset. Net return is the mean for 5 consecutive years, 2002 to 2006.

Treatments	Maize cropping		
	$E(x)$[1/] ($ ha^{-1})	$E(x) - (x)$[2/] ($ ha^{-1})	Efficient (Yes/No)
1. C_0F_0	174	35.3	No
2. C_0F_1	326	167	**Yes**
3. C_0F_2	357	156	**Yes**
4. C_0F_3	322	126	No
5. C_1F_0	-71.8	-203	No
6. C_1F_1	110	-37.6	No
7. C_1F_2	175	-20.9	No
8. C_1F_3	162	-42.3	No
9. C_2F_0	-312	-427	No
10. C_2F_1	-108	-258	No
11. C_2F_2	-32.5	-201	No
12. C_2F_3	-11.5	-214	No
13. C_3F_0	-747	-845	No
14. C_3F_1	-565	-591	No
15. C_3F_2	-443	-581	No
16. C_3F_3	-372	-350	No
17. $C_0F_0S_0$	149	4.65	No
18. $C_0F_1S_0$	309	151	No
19. $C_0F_2S_0$	340	139	No
20. $C_0F_3S_0$	305	110	No

[1/]Net return (US$). [2/] $\Gamma(x)$ Gini coefficient (US$ ha^{-1})

In the case of compost available free of cost apart from the cost of application, 8 t ha^{-1} or more of compost containing 2-fold or more higher Nconcentration than the original compost gave similar or higher net return compared with F_0 (Fig. 27). Compost with 2-fold higher N concentration at application rates < 8 t ha^{-1} and compost with less than 2-fold higher N concentration applied at any rate were predicted to give lower net return than F_0 did

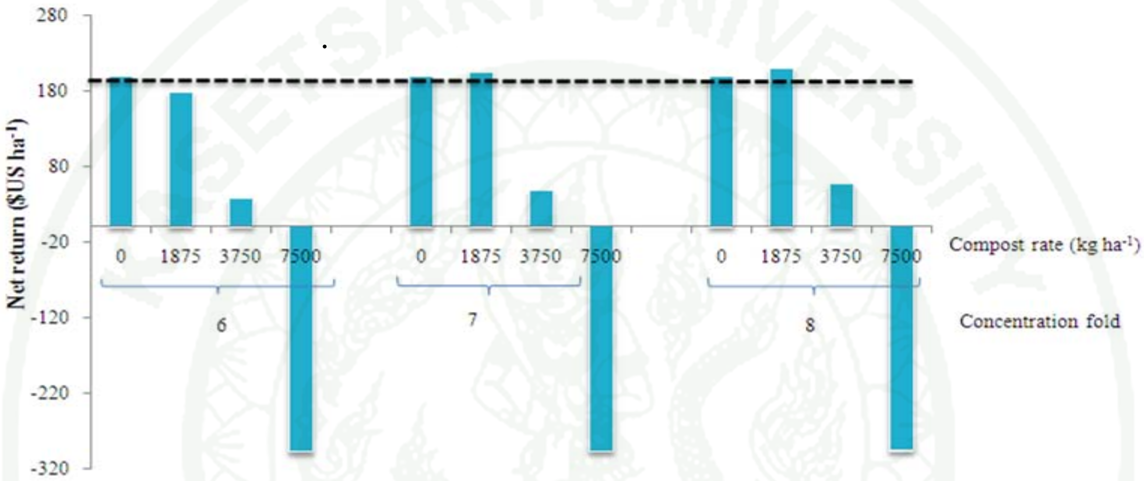

Figure 26 Average net return from seasonal analysis by varying compost concentrations. The dashed line is the net return of nil fertilizer treatment which is used as the base value for this study. See Table 30 for actual concentration of compost used in prediction.

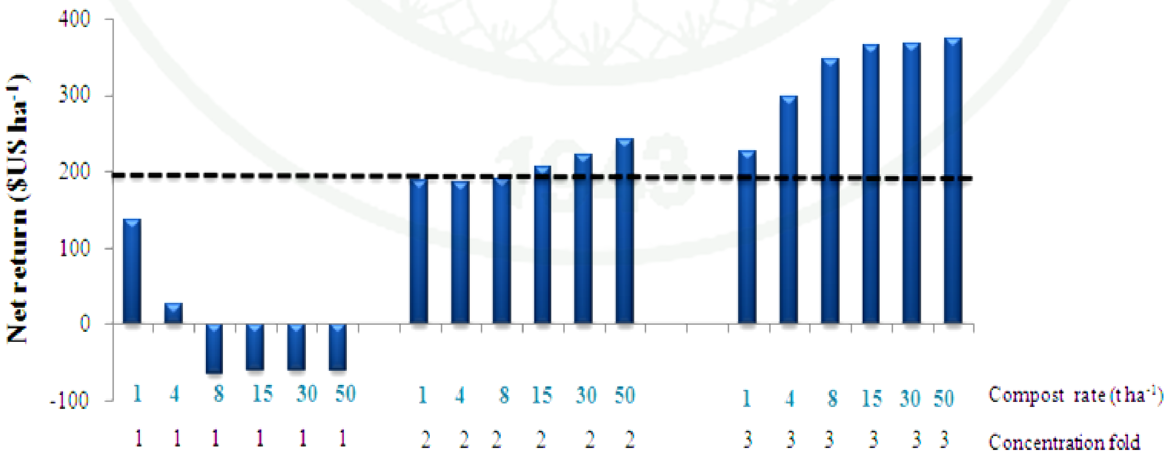

Figure 27 Average net return from seasonal analysis by varying compost rates and concentrations while holding compost cost constant. The dashed line is the net return of nil fertilizer treatment which is used as the base value for this study. See Table 30 for actual concentration of compost used in prediction.

A regression line was fitted to the average grain yield over the 5 years to estimate the rate of compost required to produce the same yields as the most efficient mineral fertilizer treatments. Application of compost at the rate 24 t ha^{-1} obtained the comparable yield with 31.25-31.25 kg N-P_2O_5 ha^{-1} (Fig. 28). That is 272 kg of 23-23-0 fertilizer ha^{-1} was predicted to produce comparable yield to 24 t of compost ha^{-1}. Consequently, the price of the low quality compost used in the present study should be no more than US$ 3.5 t^{-1}, or 0.9 % of NP fertilizer cost, in order to achieve the same net return as NP fertilizer which cost US$ 389 t^{-1}.

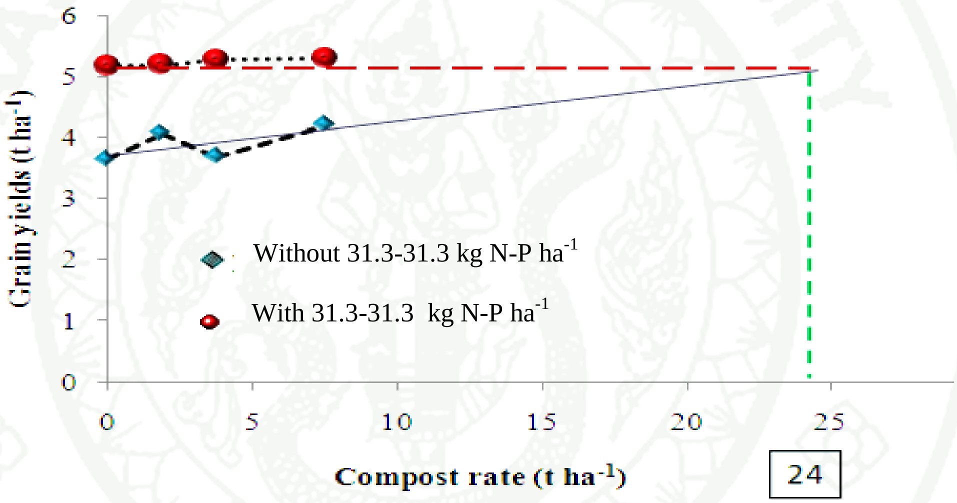

Figure 28 Prediction of compost rate required to attain the same maize grain yield produced by 31.3-31.3 kg N-P_2O_5 ha^{-1}. Maize yields are averages of those obtained in years 1-5.

2. Experiment 2

2.1 Nitrogen availability

Without NP fertilizer, application of compost equivalent to 1,875 kg ha^{-1} on soil with no fertilizer application (C_0F_0) decreased mineral N (NH_4^+ + NO_3^-) at the commencement of incubation (Fig. 29) while the other compost rates and the soil that had compost applied previously (C_3F_0) did not show this effect. In addition, without

NP fertilizer, increasing compost rate did not significantly increase mineral N on C_0F_0 and C_3F_0 soils after 10, 20 and 40 days of incubation. By contrast with the freshly applied compost, on day 0 previous compost application consistently increased mineral N in the soil without NP fertilizer. With NP fertilizer, application of compost did not show an obvious effect on mineral N on day 0 of incubation. However, mineral N was doubled by NP fertilizer relative to current and previous compost application after 10, 20 and 40 days of incubation.

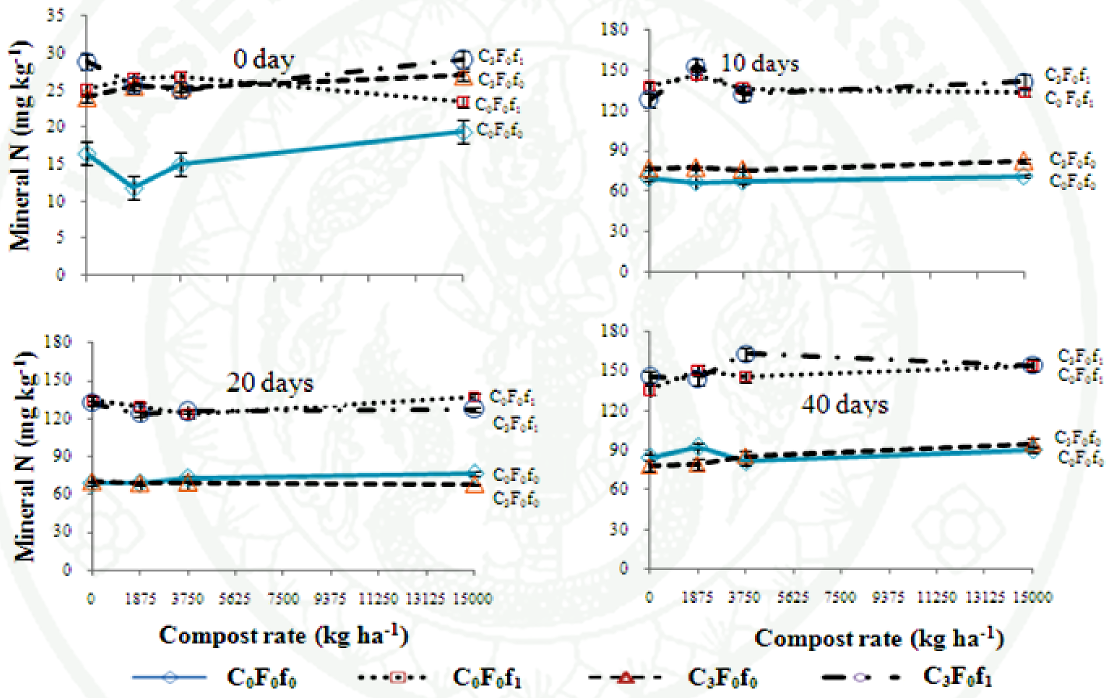

Figure 29 Mineral N (NH_4^++NO_3^-) of soil treated with 4 compost rates and 2 mineral fertilizer rates (f_0 = 0-0 kg N-P_2O_5 ha^{-1}, f_1 = 125-125 kg N-P_2O_5 ha^{-1}) on soil with no fertilizer application (C_0F_0) and soil previously treated with 7500 kg ha^{-1} compost (C_3F_0). Mineral N was sampled after 0, 10, 20 and 40 days of incubation, I = error bar. Note day 0 values are plotted on a different Y-axis range.

2.2 Phosphorus availability

On day 0, prior compost application (C_3F_0) had no effect on resin extractable P or a negative effect (with NP added). On days 10 and 20 and to a lesser extent on day 40, the combination of prior and higher rate of current compost increased resin extractable P. Resin extractable P decreased with time when NP fertilizer was applied especially 10 days after incubation (Fig. 30). NP fertilizer caused greater increases in resin extractable P than compost did on days 0 to 20 but not clearly on day 40. After 40 days of incubation, effect of mineral fertilizer was less pronounced than at the other periods for 2 soil types and all compost rates.

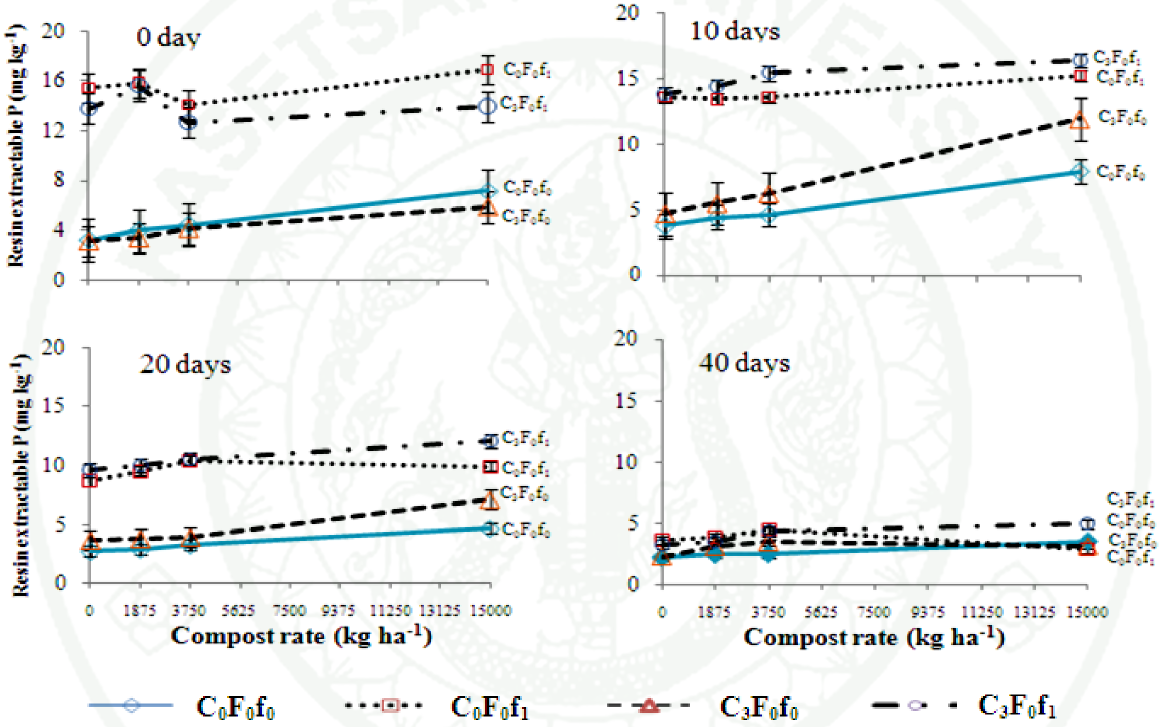

Figure 30 Resin extractable P of soil treated with 4 compost rates and 2 mineral fertilizer rates (f_0 = 0-0 kg N-P_2O_5 ha^{-1}, f_1 = 125-125 kg N-P_2O_5 ha^{-1}) on soil with no fertilizer application (C_0F_0) and soil previously treated with 7500 kg ha^{-1} compost (C_3F_0). Resin extractable P sampled after 0, 10, 20 and 40 days of incubation, I = error bar.

2.3 Capability of DSSAT to predict N mineralization

The DSSAT model was used to predict N mineralization from compost applications in the incubation experiment to determine whether this could be used to validate the present approach. The results showed that DSSAT could not predict mineral N along the period of 0 to 40 days after incubation in cases without prior N fertilizer addition (normalized RMSE more than 30 %) (Fig. 31a and 31c) and in the case with prior N fertilizer addition along with the highest rate compost (normalized RMSE more than 30%) (Fig. 31b and 31d).

2.4 Capability of APSIM to predict N mineralization

The APSIM model was used to predict N mineralization from compost applications in the incubation experiment to determine whether this could be used to validate the present approach. From APSIM simulations on the soil with prior N fertilizer addition, significant correlation were found between observed and predicted mineral N (normalized RMSE ranging between 10-30 % and $r^2 > 0.9$) (Fig. 32b, 32d). However, simulated mineral N was over-predicted at low fertilizer and under-predicted at high compost rate. After prior compost addition, predicted mineral N was also correlated with measured values in the incubation experiment, but all recorded values were substantially under-predicted (normalized RMSE > 30 %) (Fig. 32a, 32c).

Hence, neither DSSAT nor APSIM (Fig. 31, 32) could predict mineralization of compost in the incubation study. It was concluded that the incubation experiment had excessively high mineralization rates compared with field conditions and hence was not a suitable data set to validate the DSSAT predictions. The present study was limited to a single, low-quality compost type. Further validation of the DSSAT modeling framework with higher quality composts would be valuable. The lack of yield response to compost in the present study obviously removed one important validation data set for DSSAT modeling.

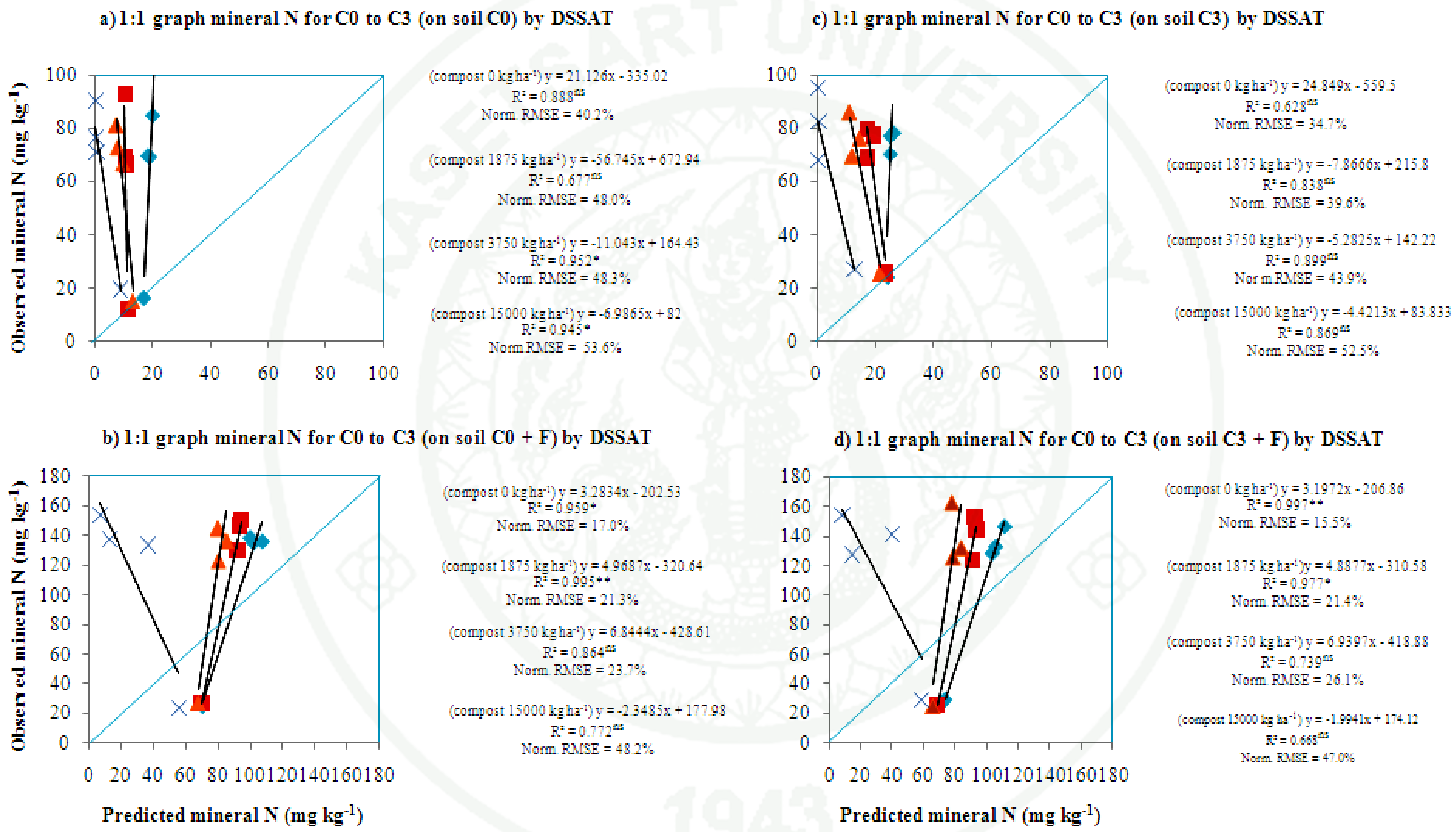

Figure 31 Relationship between simulated and observed mineral N of soil treated with 4 compost rates and 2 mineral fertilizer rates in the cases of soil with no previous compost application (a and b) and soil previously treated with 7500 kg ha^{-1} compost (c and d) using DSSAT. Compost: 0 kg ha^{-1} (◆); 1,875 kg ha^{-1} (■); 3,750 kg ha-1 (▲); and 15,000 kg ha^{-1} (×).

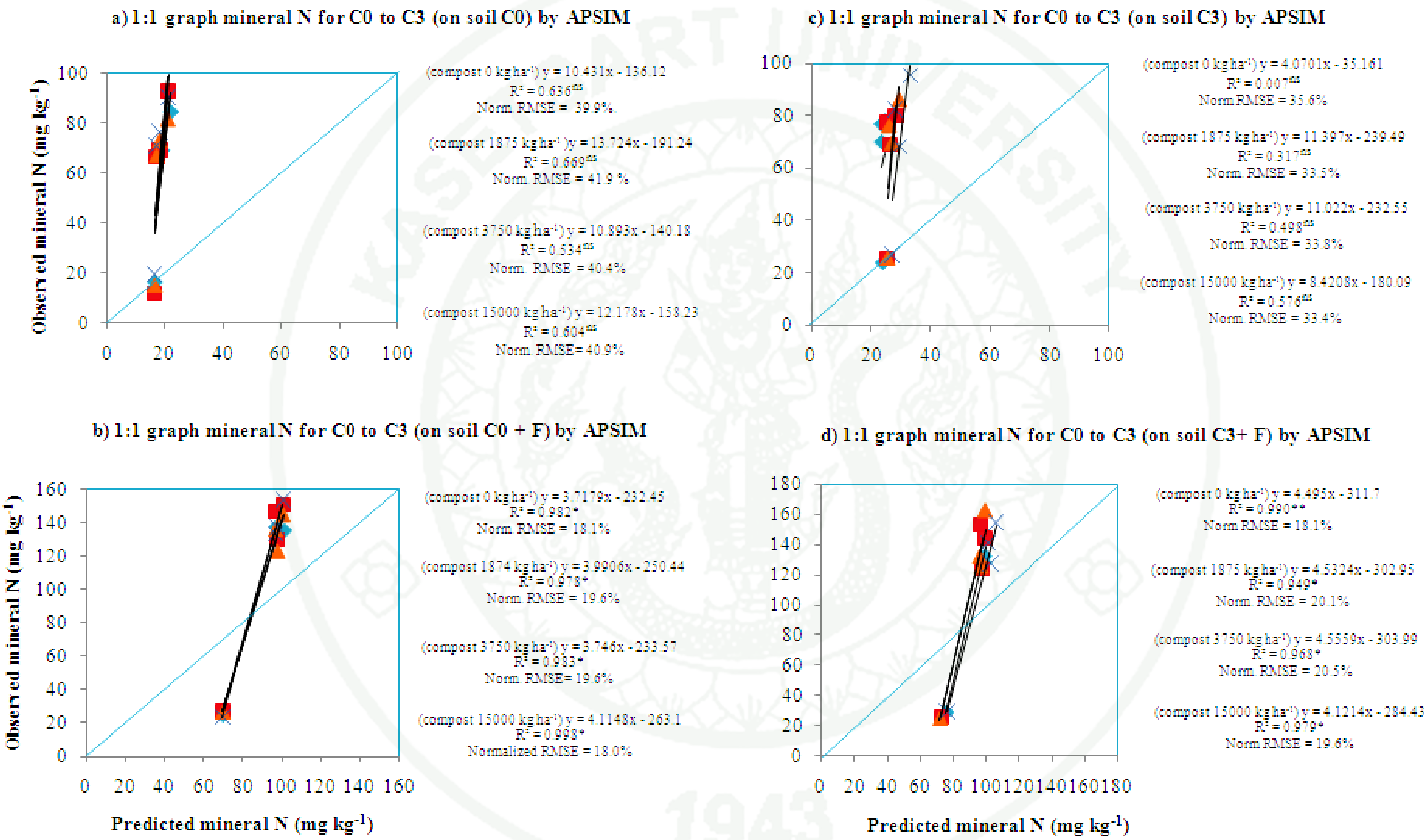

Figure 32 Relationship between simulated and observed mineral N of soil treated with 4 compost rates and 2 mineral fertilizer rates in the cases of soil with no previous compost application (a and b) and soil previously treated with 7500 kg ha^{-1} compost (c and d) using APSIM. Compost: 0 kg ha^{-1} (◆); 1,875 kg ha^{-1} (■); 3,750 kg ha-1 (▲); and 15,000 kg ha^{-1} (×).

3. Experiment 3

3.1 Height

3.1.1 Kt soil

Application of mineral fertilizer, chicken manure at the three rates, high quality compost and low quality compost at the highest rate significantly increased maize height at 30 and 45 DAP whereas application of the medium and the lowest rate of the two compost types showed no significant effects (Fig. 33A and 34A).

3.1.2 Pc soil with high %OM content

At 30 DAP, application of mineral fertilizer significantly increased maize height whereas application of the three organic fertilizer types at the three rates showed no significant effects (Fig. 33B).

At 45 DAP, application of mineral fertilizer, chicken manure at the highest rate and high quality compost at the highest rate significantly increased maize height (Fig. 34B). Application of low quality of compost at the three rates showed no significant effects on maize height at 45 DAP.

3.1.3 Pc soil with low %OM content

At 30 DAP, application of mineral fertilizer, chicken manure at the medium and the highest rate significantly increased maize height while the lowest rate of chicken manure showed no significant effect (Fig 33C). Application of the two compost types at the three rates showed no significant effects on maize height even at highest rate of compost (equivalent to 15,000 kg ha^{-1}) applied.

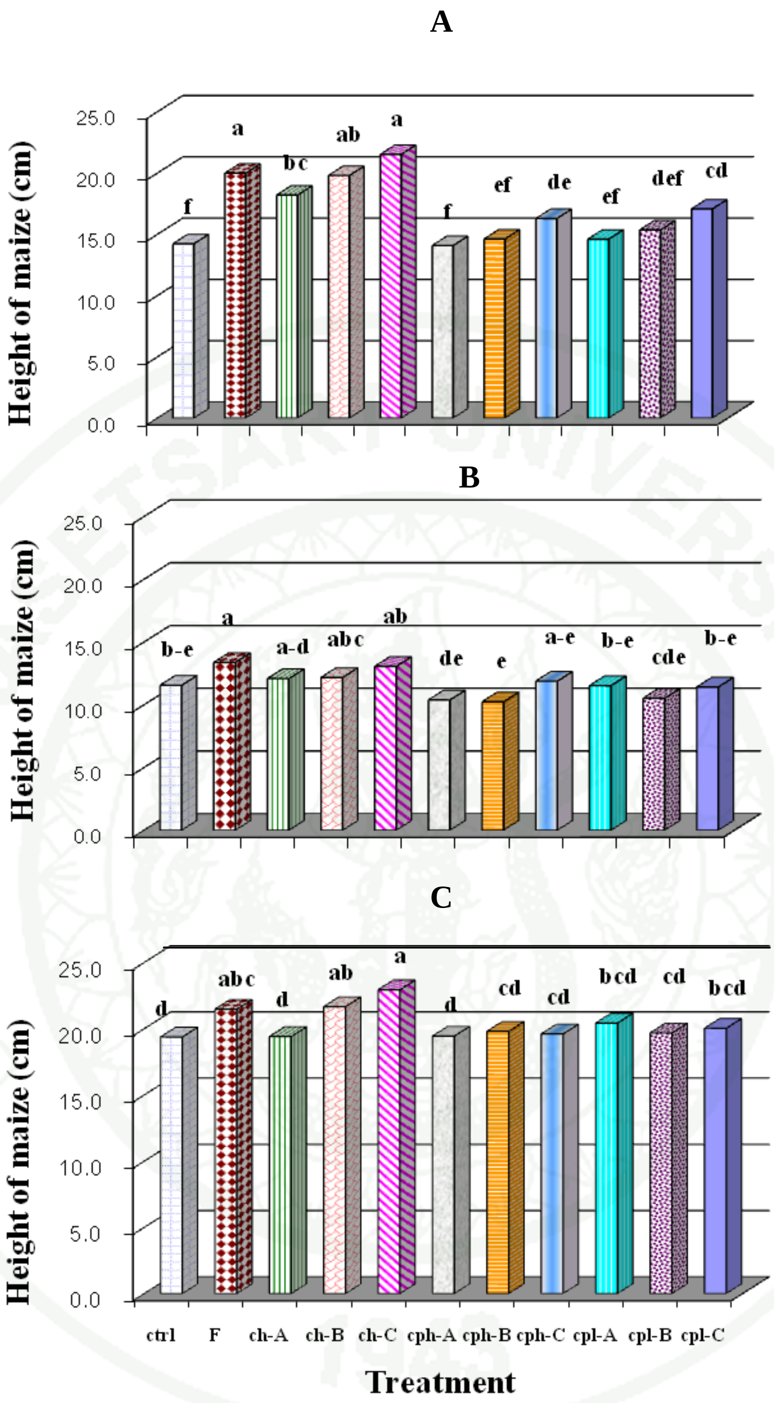

Figure 33 Height of maize at 30 days after planting in response to different treatments on 3 soil series (A) Korat soil, (B) Pak Chong soil with high %OM and (C) Pak Chong soil with low %OM. Within the same soil, bars with a common letter were not significantly different by $DMRT_{.05}$. CV: 7.6%, 10.2% and 6.5 % for (A), (B) and (C), respectively.

At 45 DAP, application of chicken manure at the highest rate significantly increased maize height while application at the medium and the lowest rates showed no significant effects (Fig. 34C). Application of mineral fertilizer and the two compost types at the three rates gave no significant effects on maize height.

3.2 Shoot dry weight

3.2.1 Kt soil

Application of mineral fertilizer, chicken manure at the three rates, high quality compost and low quality compost at the highest rate significantly increased shoot dry weight of maize whereas application of the medium and the lowest rate of the two compost types showed no significant effects (Fig. 35A).

3.2.2 Pc soil with high %OM content

Application of mineral fertilizer, chicken manure at the highest rate and high quality compost at the highest rate significantly increased shoot dry weight of maize (Fig. 35B). Application of high quality compost at the two lower rates and low quality compost at the three rates showed no significant effects on shoot dry weight of maize.

3.2.3 Pc soil with low %OM content

Application of mineral fertilizer and chicken manure at the highest rate significantly increased shoot dry weight of maize whereas at the medium and the lowest rate of chicken manure showed no significant effects (Fig. 35C). Application of the two compost types, at the three rates showed no significant effects on shoot dry weight even when the highest rate of compost (equivalent to 15,000 kg ha^{-1}) was applied.

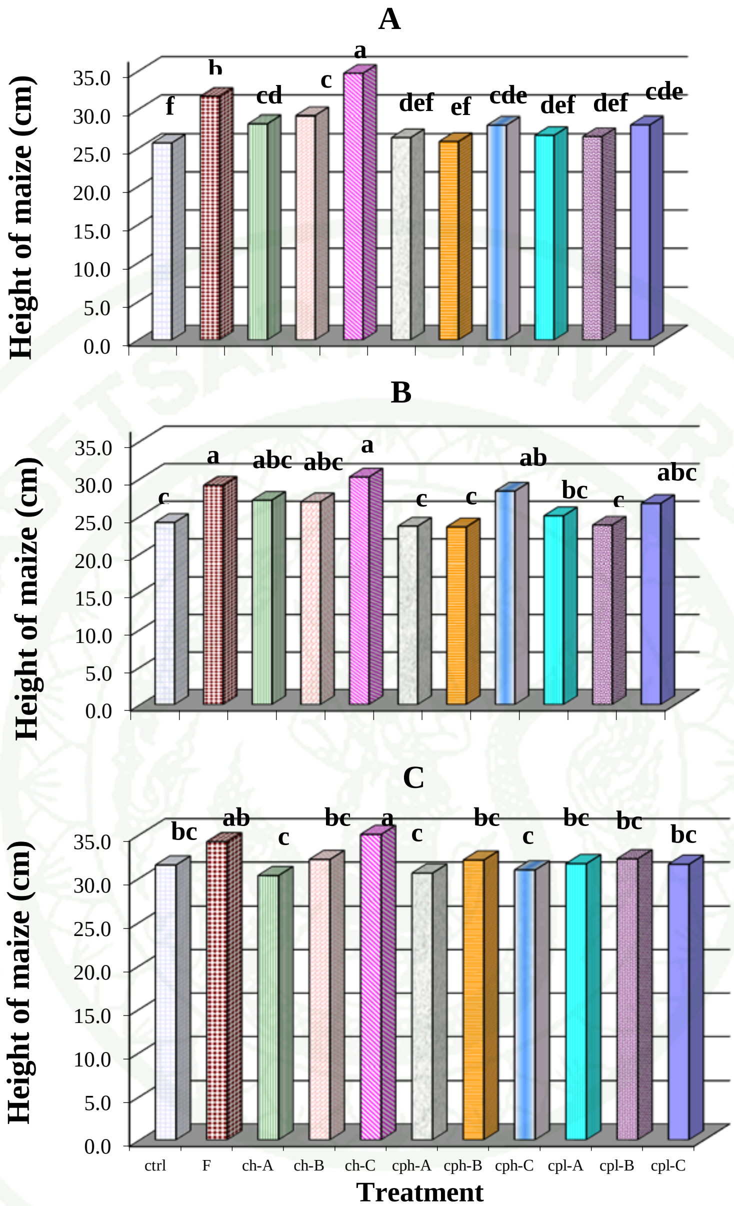

Figure 34 Height of maize at 45 days after planting in response to different treatments on 3 soil series. Within the same soil, bars with a common letter were not significantly different by $DMRT_{.05}$. CV: 5.4%, 10.3% and 5.9 % for (A), (B) and (C), respectively. Refer to Figure 33 for captions.

3.3 Nutrient uptake in maize

3.3.1 Kt soil

Application of mineral fertilizer, chicken manure at the three rates and high quality of compost at the highest rate significantly increased N uptake in maize whereas the medium and the lowest rate of high quality compost showed no significant effects on N uptake (Fig. 36A). Application of low quality compost at the highest rate significantly decreased N uptake in maize whereas the medium and the lowest compost rate showed no significant effects on N uptake in maize.

Application of mineral fertilizer, chicken manure at the three rates, high quality compost and low quality compost at the highest rate significantly increased P uptake in maize whereas application of the medium and lowest rate of the two compost types showed no significant effects (Fig. 37A).

3.3.2 Pc soil with high %OM content

Application of mineral fertilizer and chicken manure at the highest rate significantly increased N uptake in maize whereas the medium and the lowest rate of chicken manure showed no significant effects (Fig. 36B). Application of the two compost types, at the three rates showed no significant effects on N uptake in maize even highest rate of composts (equivalent to 15,000 kg ha^{-1}) was applied.

Application of mineral fertilizer, chicken manure at the three rates, high quality of compost at the medium and the highest rates and low quality compost at the medium rate significantly increased P uptake in maize (Fig. 37B). High quality compost at the lowest rate and low quality compost at the highest rate show no significant effects.

3.3.3 Pc soil with low %OM content

Application of mineral fertilizer and chicken manure at the highest rate significantly increased N uptake in maize while at the medium and the lowest rate of chicken manure showed no significant effects (Fig. 36C). Application of the two compost types, at the three rates showed no significant effects in N uptake.

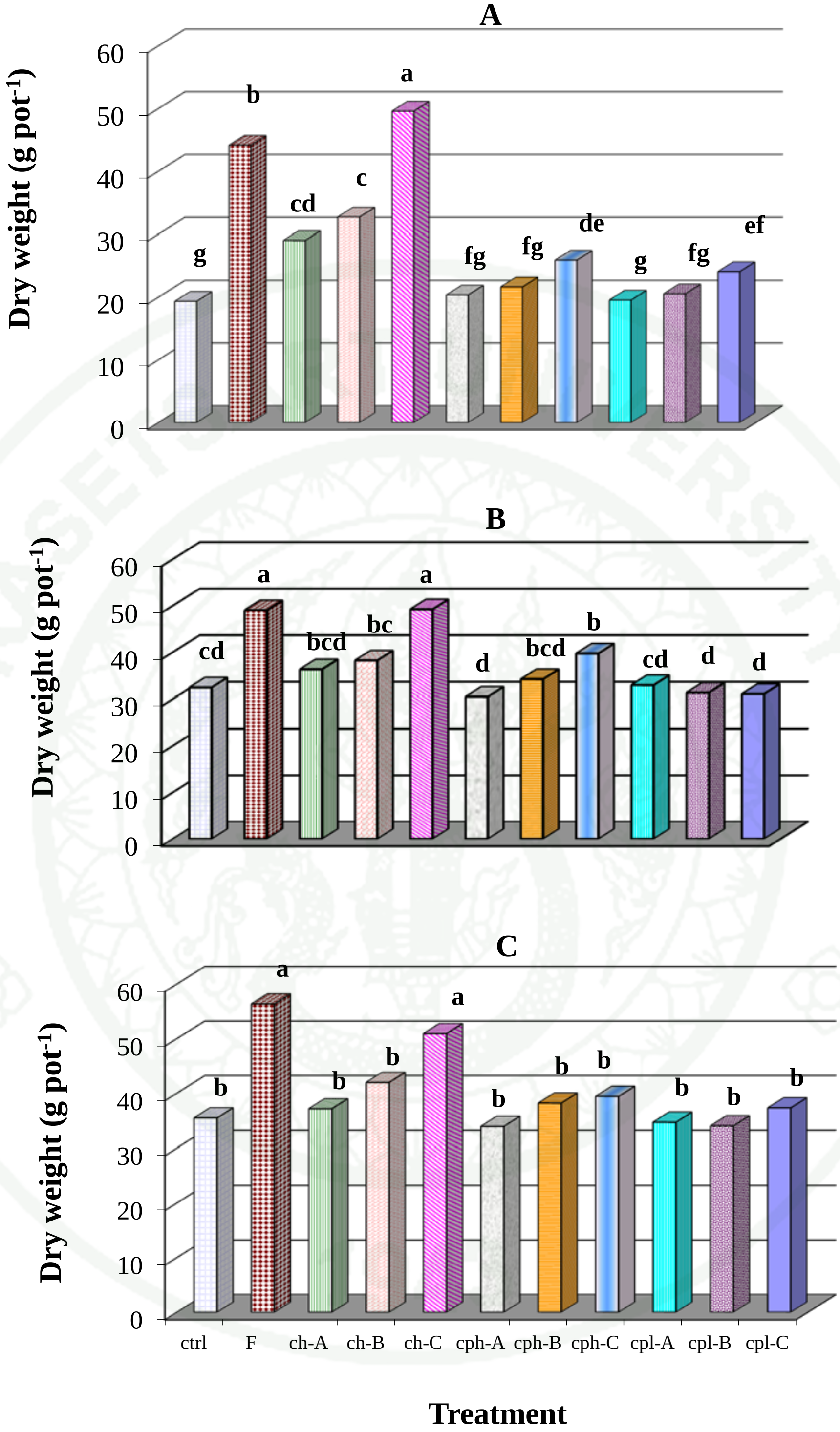

Figure 35 Dry weight of maize shoot at 45 days after planting in response to different treatments on 3 soil series. Within the same soil, bars with a common letter were not significantly different by DMRT$_{.05}$. CV: 10.0%, 10.8% and 12.5% for (A), (B) and (C), respectively. Refer to Figure 33 for captions.

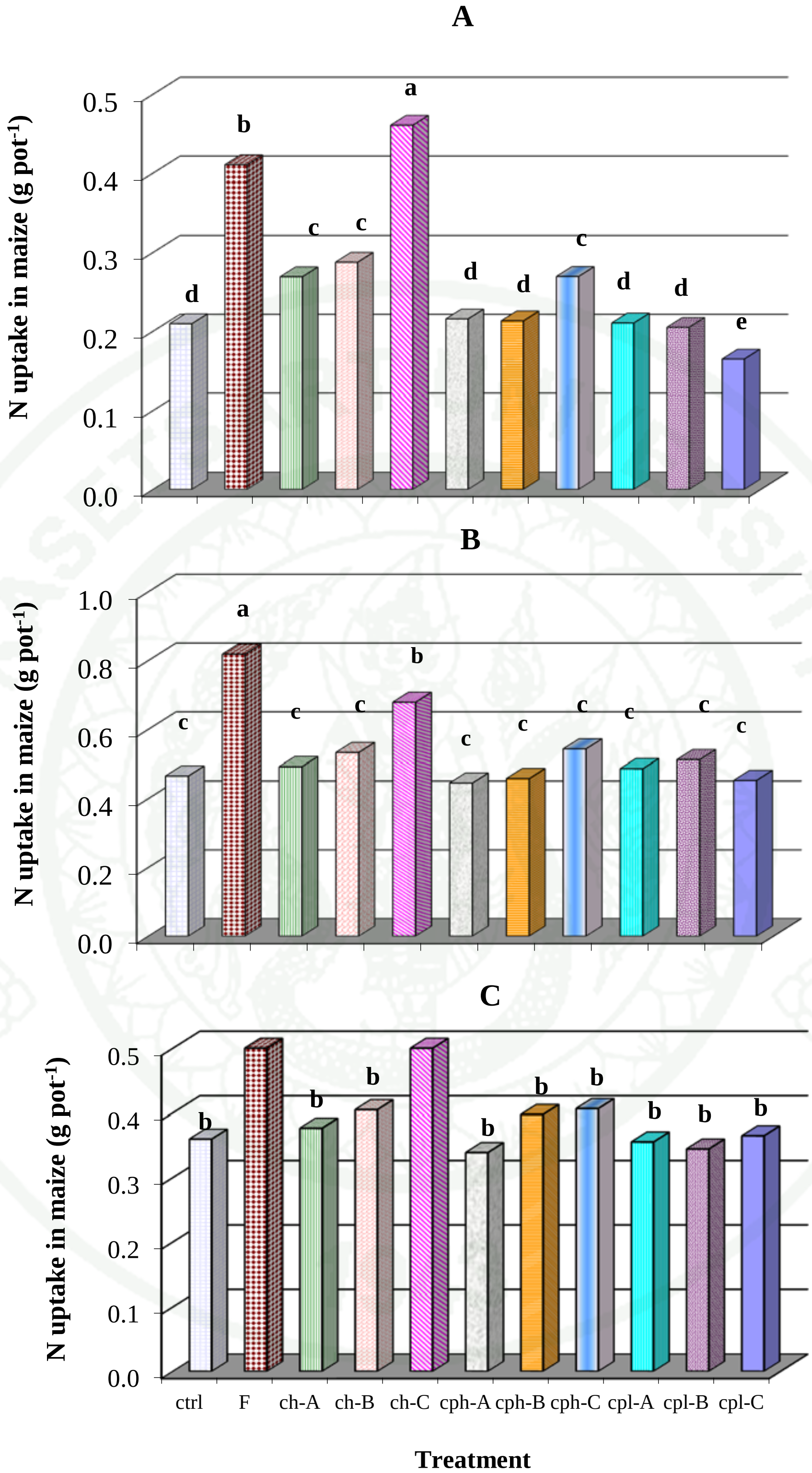

Figure 36 Nitrogen uptake of maize shoot at 45 days after planting in response to different treatments on 3 soil series. Within the same soil, bars with a common letter were not significantly different by DMRT$_{.05}$. CV: 9.9%, 12.2% and 11.3% for (A), (B) and (C), respectively. Refer to Figure 33 for captions.

Application of chicken manure at the medium and the highest rates significantly increased P uptake in maize whereas the lowest rate of chicken manure showed no significant effects (Fig. 37C). Application of the two types of compost, at the three rates showed no significant effects on P uptake in maize.

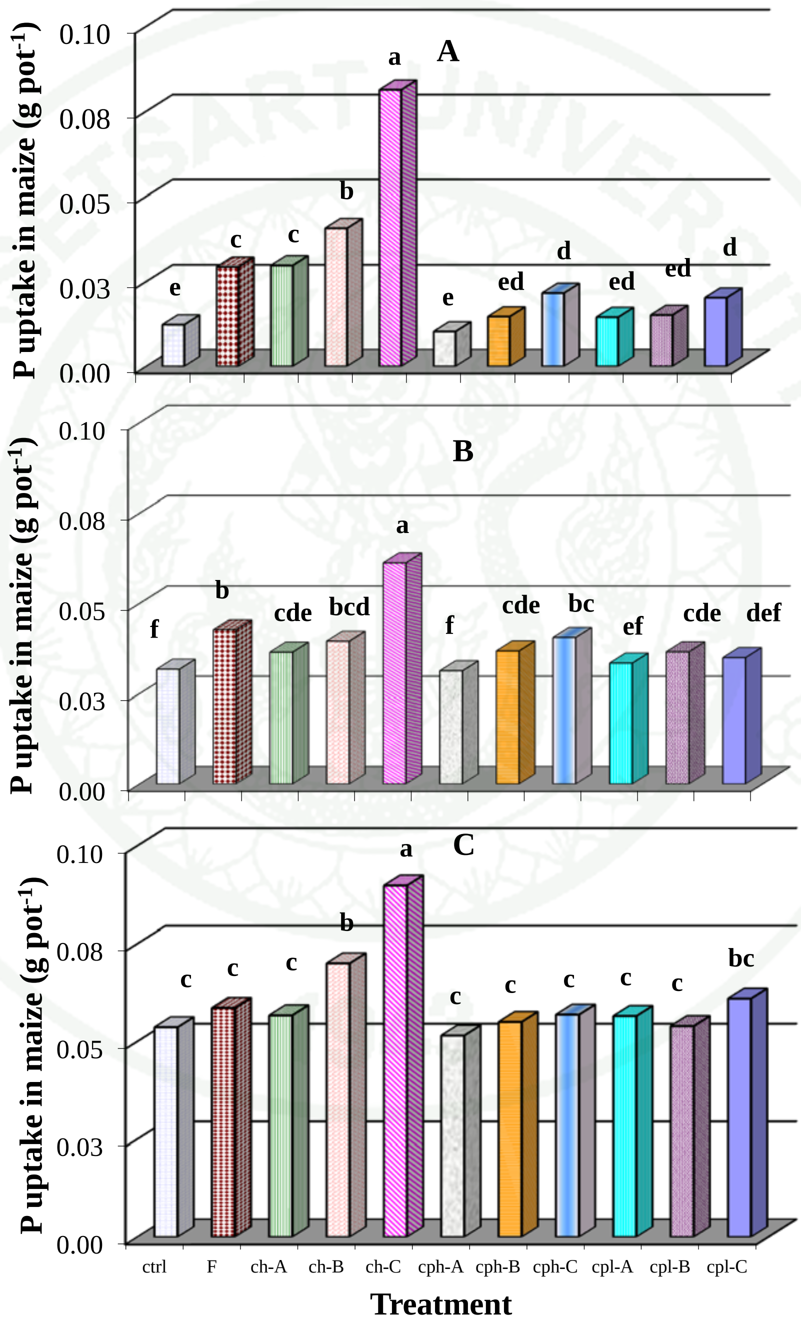

Figure 37 Phosphorus uptake of maize shoot at 45 days after planting in response to different treatments on 3 soil series. Within the same soil, bars with a common letter were not significantly different by $DMRT_{.05}$. CV: 17.1%, 7.7% and 10.7 % for (A), (B) and (C), respectively. Refer to Figure 33 for captions.

Discussion

1. Response to organic fertilizer, mineral fertilizer and stubble management

Cumulative yields showed that maize responded to NP fertilizer up to 125-125 kg N-P_2O_5 ha^{-1} (Table 20) confirming that the soil used in this study was still too low in N and P to maintain the high yield (> 5 t ha^{-1}), even though NP fertilizers were applied to the area continuously for more than 20 years (Tattao, 1987). There was no serious constraint in water supply, as the experiment was conducted in the main rainy season (August to November) with supplemental irrigation to ensure adequate water supply. The only clear constraint was wind damage in year 4.

1.1 Response of maize

Compost even at 7.5 t ha^{-1} and with five repeated annual applications showed no consistent positive significant response in yields and N and K uptake of maize, though, it showed positive effects on cumulative shoot P uptake after 5 years. This lack of response was similar to the result of Songmuang *et al.* (1999) who used low nutrient compost from rice straw and found no yield response during 2 years of application at 3 t ha^{-1}. However, unlike the present study, they found repeated application for 3 or more years increased yields with rice straw compost. In the present study compost showed no significant effect on soil extractable N and total N but significantly increased SOM. The lack of effect of compost on extractable N and total N explained the absence of response in yields and N uptake of maize. While compost increased extractable soil P levels, P was evidently not limiting to yield. Increase in SOM may have resulted in decreased P adsorption on this high P fixing soil (Tawornpruek, 2005) that in turn increased cumulative shoot P uptake (Hue, 1991).

Table 20 Cumulative grain yields, SDM, and shoot N, P and K uptake of maize for years 1-5.

Treatment [1/]	Cumulative values (years 1-5) [2/]				
	Grain at 15 % moisture (t ha^{-1})	SDM (t ha^{-1})	Shoot N uptake (kg N ha^{-1})	Shoot P uptake (kg P ha^{-1})	Shoot K uptake (kg K ha^{-1})
C_0F_0	18.3 g	31.3 h	255 hi	44.0 j	297 jk
C_1F_0	20.3 fg	33.8 fgh	277 ghi	43.9 j	287 k
C_2F_0	18.4 g	30.6 h	246 i	47.4 j	276 k
C_3F_0	20.9 fg	37.1 efg	304 gh	59.2 ghi	333 ij
$C_0F_0S_0$	19.7 fg	32.9 gh	270 ghi	48.9 ij	299 jk
C_0F_1	25.9 e	41.8 cde	354 ef	58.5 ghi	353 ghi
C_1F_1	25.9 e	41.4 cde	365 def	68.9 defg	382 efg
C_2F_1	26.4 de	43.9 bc	381 bcde	70.6 cdef	423 bcd
C_3F_1	26.5 de	42.1 cd	368 cdef	76.1 bcde	354 fghi
$C_0F_1S_o$	22.8 f	37.8 def	318 fg	53.6 hij	329 ij
C_0F_2	30.4 bc	47.5 b	419 bc	79.7 bcd	405 cde
C_1F_2	27.4 cde	44.2 bc	392 bcde	63.1 fgh	391 def
C_2F_2	29.4 bcd	46.2 bc	413 bcd	81.7 bc	371 efgh
C_3F_2	28.8 cde	46.2 bc	425 b	74.0 bcdef	403 cde
$C_0F_2S_0$	27.3 cde	44.3 bc	403 bcde	64.8 efgh	339 hi
C_0F_3	34.8 a	53.5 a	533 a	84.7 ab	446 b
C_1F_3	33.7 a	53.6 a	544 a	83.4 b	437 bc
C_2F_3	32.2 ab	53.1 a	530 a	81.0 bc	395 de
C_3F_3	34.5 a	55.5 a	552 a	94.3 a	518 a
$C_0F_3S_0$	35.2 a	53.6 a	562 a	83.2 b	407 cde
CV %	6.4	6.2	7.1	8.3	5.2

[1/] Treatments with S_0 were those with removal of maize stubble from the previous crop whereas other treatments were with retention of maize stubble from the previous crop.

[2/] Means of three replicates. Within a column, means followed by a common letter are not significantly different by $DMRT_{0.05}$.

The negative effects of the low rate of compost on shoot N uptake and grain yields in year 1, even though compost had a narrow C/N ratio (C/N ratio ~12, but compost contained low carbon and nitrogen concentrations) might be explained by the results of the incubation experiment which showed decreased mineral N (NH_4^+ and NO_3^-) with 1,875 kg of compost ha^{-1} on the day of incorporation (Fig. 29). Moreover, throughout 40 days of incubation increasing compost rate generally had no effect on total mineral N. In another study with low C/N ratio compost, Cambardella *et al.* (2003) found that short-term immobilization of N occurred, even with a very high application of 80 t of hog manure compost ha^{-1} (C/N ratios of 12.1 to 15.1). They found no clear relationship between C/N ratio and N mineralization. Their result suggested that significant denitrification could occur in soil following compost incorporation and this may produce net immobilization of N rather than N mineralization. However, they concluded that mineralization of N from compost was a complex process and could not simply be explained by C/N ratio but may involve several factors such as the raw material used for composting and duration of composting.

In addition to C/N ratio, the total C and N concentration in compost needs to be considered both in the context of mineralization as well as for nutrient supply. One major difference between the present study and that of Cambardella *et al.* (2003) was that they used compost with much higher C and N concentrations. Compost used in the present experiment was low in N and P concentration (5.9 g kg^{-1} N, 3.1 g kg^{-1} P) compared with those of others who reported significant N mineralization from compost (Gil *et al.*, 2008: 21 g kg^{-1} N, 10.4 g kg^{-1} P; Herencia *et al.*, 2007: 9 g kg^{-1} N, 5.8 g kg^{-1} P). The rice straw compost prepared by Songmuang *et al.* (1999) had no reported C/N ratio value but a similarly low N to the present study and even lower P. This suggested that C/N ratio alone is not a sufficient criterion for estimating fertilizer substitution values of compost but nutrient contents are also a key criterion.

The pot experiment showed that organic material containing higher nutrient concentration when applied at higher rates than in the field experiment gave higher maize dry weight and shoot P uptake on the same soil used in field experiment. Chicken manure (143 g kg^{-1}OC, 17.2 g kg^{-1}N) at 15,000 kg ha^{-1} showed a significant increase in dry weight and shoot P uptake while compost with lower total N, P and K content did not show this result even when the same rates of application were applied. Hence, the pot experiment's result supported the possibility suggested above that higher quality of organic materials could have showed a significant increase in maize yield on the soil used in field experiment.

Chicken manure application at the highest rate (15,000 kg ha^{-1}) on soil with lower organic matter (Kt soil) showed higher maize growth and yields than mineral fertilizer. This could be explained by 2 reasons. Firstly, Kt soil is a fine-loamy soil with low fertility and lacking of nutrients whereas chicken manure was rich of phosphorus contents. Hence, suitable response of chicken manure on Kt soil is shown obviously. Similarly, it was found that chicken manure application significantly increased maize height and grain yield in the two growing seasons on the severely degraded soil (Obi and Ebo (1995). Secondly, nutrients from mineral fertilizer are susceptible to loss by leaching after irrigation as this soil is free draining. Duxbury *et al.* (1989) have explained an advantage of organic materials over mineral fertilizer was that SOM from chicken manure is the major source of negative charge in tropical soils. Its maintenance is important for the adsorption of exchangeable cations.

Results of the pot experiment showed that the sandy and the two clayey soils gave similar trends of responses in dry matter yield and P uptake of maize to the NP fertilizer and chicken manure at the highest rate. Nevertheless, the sandy soil and the clayey soil with lower organic matter content showed trends of responses in N uptake that were different from that shown by the clayey soil with high organic matter content. The high-N compost gave similar trends of response in dry matter yield of maize and N-uptake among the three soils whereas the low-N compost on sandy soils gave a trend of response in dry matter yield that was different from those of the two clayey soil. These suggested that response of maize in dry matter yield and N uptake to organic manures varied with type of soil, organic matter content of the soil and nutrient content of organic manure.

The highest rate of NP fertilizer increased SOM when no compost was applied but showed no effect on SOM when the highest rate of compost was applied. One explanation is that in this soil type, with the cultivation practices and rainfall in this area, SOM is close to equilibrium. Tawornpruek (2005) reported that continuous maize cultivation in Pak Chong soil resulted in 36 g kg^{-1} SOM. This suggests that the SOM at the present site was near the equilibrium level for the prevailing conditions so that SOM responded to compost application alone, with no further increase from NP fertilizer application. Many factors such as land use, cultivation and rainfall influence SOM equilibrium (Allison, 1973). Changing cultivation and land use on Pak Chong soil to fast growing trees appeared to increase SOM to 41 g kg^{-1} (Tawornpruek 2005).

1.2 Response of soil physical properties

Response to compost commonly involves effects on soil physical properties as well on nutrient supply (Quedraogo *et al.*, 2001). Lack of compost effects on soil physical properties in this study might contribute to lack of yield responses to compost application. In a long term study, Hati *et al.* (2007), reported increased crop yield of wheat and soybean from the use of low nutrient farmyard manure (FYM) (6.5 g kg^{-1} N, 1.4 g kg^{-1} P and 6.0 g kg^{-1} K) which they attributed to improvement in soil physical properties including lower BD and increased soil porosity and AWC. However, these benefits were the result of 28 years of annual application of 15 t of FYM ha^{-1} that increased SOC from 5 to 8 g kg^{-1} (0-15 cm depth). One possible explanation for the lack of response in physical properties in the present soil was due to high initial SOM content (27 g kg^{-1}) and relatively low initial BD (1.13 g cm^{-3}). Zeleke *et al.* (2004) reported a decrease in BD after 3 years of crop residue addition on a sandy loam Andosol (20 % clay) but not on a Nithosol (40 % clay).

There was no direct comparison in this study between the effects of adding compost *vs* adding crop residue on soil physical properties. However, the removal of stubble was found to have a significant effect on AWC and SOM: both declined when crop residue was removed from fertilized plots. The response on soil physical properties after 4 years of annual stubble removal was similar to the effect of green manure and legume intercrop in corn field on the Pak Chong soil (Chaowanapong, 2000). In that study, 4 years of continuous intercropping corn with mimosa in particular increased AWC but not BD. One possible reason for the difference between compost and crop residue effects on soil physical properties is the uniform incorporation of crop residue compared with the banding of the compost in the row. Hence, direct benefit from compost on soil physical properties would likely be restricted to the planting row and measurement of this response would depend on sampling from that zone. In this case, soil samples for SOM were taken from 75 cm-long trenches across the crop row while samples for BD and AWC were taken between maize rows (75 cm wide). Hence, the present sampling would have underestimated any change in BD and AWC due to compost since it did not restrict sampling to the row where the major effect would occur. Nevertheless, despite inadequacy of the soil sampling design, compost had no effect on yield after 4 years, and hence the improvements in soil physical properties were clearly not very substantial.

Removing maize stubble decreased AWC but only significantly at 30-50 depth. This might be due to stubble return increasing maize root density at depth which in turn provided organic materials as a precursor for aggregate formation (Whitbread *et al.*, 2000) resulting in increased AWC. However, there was no difference BD among treatments that could explain the changing in AWC.

2. Significance of available nutrient fluxes in N and P budgets

2.1 Fertilizer and nutrient balance

The calculated available N and P balances were positive with fertilizer applied but negative with no mineral fertilizer application. That is, mineral fertilizer was the main input affecting available N and P balance in annual maize cropping as is generally the case in such studies (Lupwayi and Haque 1999; Bunemann *et al.* 2004; Adu-Gyamfi *et al.* 2007). However, shoot uptake was the dominating output for both unfertilized and fertilized treatments. N and P surpluses increased with successive crops of maize in treatments that received mineral fertilizers. This was attributed mostly to the available nutrient credit carried forward from the previous year. Large nutrient credit reflected the effect of accumulating N if the previous year had a positive N balance. The strong positive N balances calculated could be attributed in large part to the input of 125 kg N ha^{-1}, which was double the rate recommended currently to farmers (Department of Agricultural Extension 2009) but still comparable to the rate which gives maximum yield (Tattao 1987; Na Bhadalung *et al.* 2005). The sensitivity analysis (Table 17) showed that decreasing the N fertilizer input in year 3 to the rate recommended for farmers would substantially reduce the positive N balance. Hence, if available N balance over 3 years was calculated with the recommended fertilizer rate the N surplus would be greatly reduced.

SOM mineralization was the major source of N input when mineral fertilizer was not added, but it was also a major input with fertilizer added. The present Pak Chong soil had moderately high organic matter content (26.9 g kg^{-1}soil) which would ensure significant N release by mineralization. Other sites with the Pak Chong soil have up to 40 g kg^{-1} (Tawornpruek *et al.* 2006) or less than 19 g kg^{-1} (Attanandana *et al.* 2000) SOM and hence, reliance of unfertilized crops on mineralization for N uptake would produce greatly different yields across different sites. However, even with mineral fertilizer application, 78-82 kg N ha^{-1} was estimated as an input from mineralization of SOM (Tables 11 to 13). Hence, with and without fertilizer the calculated input of N from sources other than fertilizer were significant components of the N budget.

Application of mineral fertilizer produced an available P surplus whereas no mineral fertilizer application resulted in P deficits in years 1 and 2. However, all treatments had a positive available P balance with and without mineral fertilizer in year 3 reflecting the increased contribution of mineralization of P from SOM relative to P uptake. The low available P balance relative to the high P fertilizer input was attributed largely to absorption of phosphate ions on sesquioxidic surfaces reducing the proportion of plant available P (Sharpley and Halvorson 1994). While P sorption could be considered a removal from the plant available budget in the short to medium term, in the long term the sorbed P remains potentially available for plant uptake (Syers *et al.* 2008). Hence, if the nutrient budget were calculated over 5 to 10 years of cropping with annual P fertilizer added it may be necessary to add another P input reflecting the amount of P released annually from absorbed pools into the plant available P pools.

2.2 Compost and nutrient balance

Continuous application of compost showed similar available N and P balance values to the control (C_0F_0). N balance slightly increased over the 3 years whereas P balance showed an inconsistent trend. The compost used in this study was of low quality (5.9 g kg^{-1} N and 2.5 g kg^{-1} P) compared with other studies. For example, Shen *et al.* (2007) showed a greater N surplus where they had applied an average of 103 kg N ha^{-1} yr^{-1} and 83 kg P ha^{-1} yr^{-1} for 24 continuous years in manure treatments than those in mineral fertilizer treatments. In addition, Salazar *et al.* (2005), who studied the N budget for 3 cropping systems fertilized with manure, found that the treatments with manure slurries had much higher N balance than the control in the first year. However, in the second year both slurry treatment and the control showed N balance decreasing on maize cropping even though the slurry supplied 200 kg N ha^{-1} yr^{-1}. The low quality of compost was illustrated by the lack of yield response to compost applied annually at 7500 kg ha^{-1} in years 1 and 2 even though at this site maize yields responded to mineral fertilizer application. While it had no effect on the yield, the shoot N uptake did increase in response to compost and this output negated the extra input of N in compost compared with the control.

2.3 Effect of maize stubble removal on nutrient balance

Stubble removal with or without mineral fertilizer reduced available N balance (Tables 12 and 13). This trend was more pronounced in year 3 with stubble removal and no mineral fertilizer application suggesting a cumulative effect of stubble removal on N balance. These results illustrated the importance of continuing available nutrient budgeting over several years in order to fully account for the input from mineralization of organic materials such as crop residue. Whereas in a single-year nutrient budget, available nutrients from crop residue might appear an insignificant input, in the long term nutrient turnover from such pools might become a significant input.

By contrast with available N balance, stubble removal with mineral fertilizer produced a slightly higher available P balance than stubble return (Tables 15 and 16). In the P budget this was attributed to lower shoot P uptake and lower P sorption after maize stubble removal in fertilized maize, especially in year 3. Stubble removal without P fertilizer application produced a negative available P balance as in the case of N. This result was supported by Adu-Gyamfi *et al.* (2007) who estimated N and P balances in unfertilized maize crop in semi-arid Tanzania and Malawi. They found that above-ground return treatment showed lower negative N and P balance than above-ground removal treatment.

The present study examined available N and P balances only because these were the main nutrient constraints in Pak Chong soil (Ekasingh *et al.* 2004). However, the practice of stubble removal also causes a large output of K which impacts negatively on K balance (Hoa *et al.* 2006). The Pak Chong soil has high exchangeable K (Table 1) and therefore K deficit in the short term was unlikely to affect crop yields. However, in the long term the continual depletion of K might lead to deficiency. In other soils, K deficiency might be a greater risk to crop production and the balance of other nutrients besides N, P and K (such as S and micronutrients) would also need to be considered.

2.4 Nutrient balance validation

The calculated available nutrient balances, whether positive or negative, should be reflected in changes in soil nutrient levels provided an appropriate nutrient extractant is used to reflect these changes. Mineral N levels generally decreased over 5 years and hence did not support the available nutrient balance calculations. This suggests that surpluses of N in the maize cropping system on Pak Chong soil did not lead to accumulation of nitrate and ammonium-N in the soil. This might be due to denitrification or leaching losses greatly in excess of those calculated, or it might indicate N accumulation predominantly in organically-bound forms. The latter explanation was supported by the total N which increased over a 5-year time frame in treatments with largest N surpluses suggesting that the N budget calculation was an accurate reflection of the calculated inputs and outputs. However, total N values were quite variable suggesting that more sub-samples of soil need to be collected or a greater time lapse was needed to quantitatively validate the available N balance calculations. In particular, the N balance of the compost treatments were not well explained by total soil N compared with the other treatments. This might suggest that the *k* factor used for calculation of mineralized N from compost was lower than actual availability. In the present study, estimates of the availability of N in compost were 21, 9 and 3 % of total N in the first, second and third year, respectively (Klausner *et al.* 1994). However, Eriksen *et al.* (1999) and Zhang *et al.* (2006) reported that only 10 % of total N from compost would be available in the first year. Changing *k* series for compost mineralization in year 1 to 10 % only decreased the N balance by about 4 kg ha^{-1} and was therefore insufficient to explain the difference between calculated N balance and Δ total soil N. Likewise, changing the *k* value for compost mineralization in year 1 to 30 % would increase the N balance by about 4 kg ha^{-1} which was still insufficient for explanation of the total N results. An alternative explanation for the poor relationship between soil N and N balance calculations was that compost application increased the immobilization of mineral N into organically-bound forms. While Eriksen *et al.* (1999) found immobilization of mineral N following application of Municipal Solid Waste compost containing 0.99 % N, their rate of application were 10 to 30 times higher than the maximum rate in this study.

An attempt was made to explain the 50 % difference between positive N balance values and Δ total N values (Fig. 22) by increasing the respective decay series for SOM, maize stubble and root by 10 % in the first year calculation. The results showed that the positive N balance increased by only 4 % which did not explain the difference. Again, a more plausible explanation for the difference was that the surplus N was mainly in the organically-bound forms.

The positive available P balance calculated for fertilizer application was supported by higher soil resin-extractable P (Fig. 23). Hence the resin P values, while only accounting for about 30 % of the calculated P balance, supported the validity of the P balance calculations and hence suggest that the major budget items, P sorption and P mineralization, have been accurately estimated. Organically-bound P might be a significant pool of the 70 % of surplus P balance not accounted for, as suggested for N.

2.5 Uncertainties in the nutrient budget calculations

All the data used as inputs or outputs in a nutrient budget have degrees of uncertainty associated with either their measurement or their estimation. The items which had greatest impact on the accuracy of the calculated available N balance in this study were the actual rate of N supply from urea, shoot uptake, SOM mineralization and nutrient credit whereas the rate of P supply from TSP, the SOM mineralization and sorption of P were the main factors affecting accuracy of the available P balance calculation. Hence particular care was needed in assessing the accuracy of values of these items used in calculations. Whereas shoot uptake and fertilizer inputs can be reported with some certainty for a particular field and season, the mineralization of SOM, P sorption and nutrient credit for a specific site were subject to greater error or uncertainty. The other parameters such as input from root residue mineralization, rain and irrigation water had minor influences on the calculated nutrient balances in years 1-3. Nutrient input from stubble and compost which were minor contributors to the available nutrient balance in year 1 had a cumulative effect over time. This illustrated the importance of continuing available nutrient budget calculations for more than 1 year in order to fully estimate the contributions of slowly mineralizing organic matter inputs such as crop residue to the within-season nutrient supply.

The sensitivity analysis for the Pak Chong soil in the present study indicated that the selection of an appropriate *k* factor for SOM mineralization would have a much greater bearing on the accuracy of calculated available N balances than the measured variation in N concentration in SOM, level of SOM or the bulk density of this soil. However if using the available nutrient budget to make comparison among sites, variation in level SOM or bulk density might assume greater importance in accuracy of the calculation. For example, SOM in Pak Chong soils across a range of sites was reported to vary from less than 19 g kg^{-1} (Attanandana *et al.* 2000) to 40 g kg^{-1} (Tawornpruek 2005) which constituted a much larger range for SOM than that used in the present calculations.

As with the N budgets, fertilizer rates and SOM mineralization were the most influential factors for accuracy of the available P balance calculation (Table 18). Similar considerations to those discussed above for reducing uncertainty in the calculation of N mineralization from SOM would apply to P mineralization. While P sorption was a major output in the P budget, variation in levels of P sorption among highly weathered clay soils was not large enough (Sharpley and Halvorson 1994) to significantly affect accuracy of the P balance calculation. However, if comparing soils across a wider range or mineralogy the variation in P sorption would be a significant consideration.

Although large N surpluses were calculated there was no clear evidence that N leaching was underestimated in the N budget. Firstly, the ground water at the site contains low nitrate concentration (2.5 mg L^{-1}) even though maize had been grown annually for about 30 years with N fertilizer application. Secondly, mineral N level was similar in fertilized soil compared with compost treated soil where immobilization of mineral N was likely to protect it from leaching.

Sensitivity analysis suggested that gaseous losses of N had a more pronounced effect than nitrate leaching on the available N balances. The low mineral N in the soil in year 5 might indicate loss of nitrate N from the soil solution due to denitrification. However, the Pak Chong soil was free draining with adequate porosity as indicated by bulk density in the range 1.1 to 1.4 Mg m^{-3}. Hence there was no strong evidence that low soil mineral N would be connected to denitrification. Indeed, mineral N level was similar in fertilized soil compared with compost treated soil where immobilization of mineral N was likely to restrict the likelihood of denitrification.

3. Framework for determining the efficient combination of organic materials and mineral fertilizer applied in maize cropping

The present study was not designed to explore new models for predicting efficient combinations of organic and mineral fertilizer. Hence, existing crop models of interest were assessed for the suitability to examine this study's objective, which was to explore the possibility of a model for predicting optimum rates of organic manure and mineral fertilizers for maize.

Profitability of addition of compost should be taken into account when choosing appropriate rates to add for crop production. Accordingly, crop simulation modeling is used to examine effects of rate and nutrient concentration of organic material and its cost in predicting yield responses and profitability of inorganic and organic fertilizer applications.

The effect of combined compost and mineral fertilizer on crop yields has been reported to vary from negative (Iglesias-Jimenez and Alvarez, 1993; Choi *et al.*, 2004) to positive (Goyal *et al.*, 1999; Han *et al.*, 2004). In addition, profitability of addition of compost should be taken into account when choosing appropriate rates to add for crop production. Accordingly, crop simulation modeling is used to examine effects of rate and nutrient concentration of organic material and its cost in predicting yield responses and profitability of inorganic and organic fertilizer applications. Four crop models of interest were assessed for suitability, *viz*: DSSAT (Paz *et al.*, 1999; Soler *et al.*, 2007; Felkner *et al.*, 2009); QUEFTS (Dobermann and White, 1999; Dobermann and Cassman, 2002; Liu *et al.*, 2006); NuMaSS (Kebede and Yamoah, 2009; Walker *et al.*, 2009); and APSIM (Probert *et al.*, 2005; Mohanty *et al.*, 2011).

The advantage of DSSAT over NuMaSS and QUEFTS models is that DSSAT prediction depends on the crop demand which in turn reflects yields: moreover, it simulates the limitation on crop production from nutrient or water stress. APSIM predictions are also based on crop demand which is dynamic due to in-season variations in rainfall, temperature, radiation and N supply (Keating *et al.*, 2003). DSSAT considers soil-water relations as well as other soil physical properties that could be significant for long-term effects of adding materials like compost that can change these soil properties. By contrast, NuMaSS or QUEFTS are designed to predict crop yields from crop nutrient supply (Mulder, 2002; Osmond *et al.*, 2002). Additionally, DSSAT can predict nutrient availability of multi-year applications of organic materials using Seasonal Analysis module over consecutive years (Thornton *et al.* 1994).

In the context of mineral fertilizer and compost prices, the Dominance Analysis in DSSAT showed that only NP fertilizer was profitable while the present low-nutrient compost was not. Either 14 or 28 kg N ha^{-1} as mineral fertilizer gave similar profit. These rates were comparable to the NP recommended rate for maize production (Department of Agricultural Extension, 2009). The highest rates of compost in the present study supplied comparable amounts of N and P to the most profitable NP fertilizer rates. Yet at all levels of compost application, the present low-nutrient product decreased profit when applied with mineral fertilizer. Stubble removal also decreased the profit. Stubble removal not only increased production cost but also depleted soil N and P supply as described under section "2.3 Effect of maize stubble removal on nutrient balance".

Compost nutrient concentration and price are the main factors that determine profitability for crop productivity. In order for compost application to generate the same or higher net return as the control treatment, DSSAT modeling predicted that a seven-fold increase in N concentration of compost (41.3 g kg^{-1} N) was required. Such high concentrations can be found in manures such as poultry manure (Agbede and Ojeniyi, 2009). Agbede and Ojeniyi (2009) studied the effect of poultry manure (295 g kg^{-1} OC, 43.1 g kg^{-1} N) on soil fertility and sorghum yields. They found that such high nutrient contents in poultry manure improved soil organic C, total N, available P and grain yield of sorghum. When 31 kg N ha^{-1} was used as the benchmark for net return, the model predicted an extremely high concentration of nutrients was required in compost (12-fold concentration in combination with at least 800 kg ha^{-1}) for profitable use. The 12-fold increase in compost concentration (70 g kg^{-1} N) is theoretically possible for manures produced by housed animals fed on high quality rations if the manure is treated to prevent N loss (Van Horn, 1998) but such levels are rarely found in compost (Hargreaves *et al.*, 2008; Al-Turki, 2010).

In the case of free-of-charge compost, the DSSAT simulation showed that the minimum concentration of compost for profitable use was 11.8 g kg^{-1} N which is a relatively high concentration for compost (e.g. Celik *et al.*, 2004) but comparable to that reported for animal manure from housed animals raised on designed rations (Eghball, 2000).

A possible weakness of DSSAT for estimating the fertilizer value of organic amendments is the fixed decay rate constant for organic materials in the CERES-based module (Gijsman *et al.*, 2002). The quality and quantity of organic materials are important factors controlling N mineralization/immobilization, apart from the other factors such as time of application (Hadas and Portnoy, 1994). An accurate value for the mineralization constant is the most influential factor for the estimation of nutrient supply from SOM mineralization as described under section "2.5 Uncertainties in the nutrient budget calculations". Gijsman *et al.* (2002) concluded that the CENTURY model had greater capability for accurate simulation of SOM-C under different treatments than the CERES model while the latter model better simulated soil mineral N levels. In the present study, a comparison was made between the CENTURY and CERES models within DSSAT for predicting mineralization of SOM. Both CENTURY and CERES models predicted the same maize yields (data not shown) suggesting that any differences in simulated N mineralization from SOM by CENTURY and CERES models would have had little effect on the above conclusions.

While DSSAT simulations generally predicted maize yield well, and SDM reasonably well, there was no yield response to compost application to validate this aspect of the proposed approach for estimating optimal combinations of mineral and organic fertilizer. The DSSAT and APSIM models were used to predict N mineralization from compost applications in the incubation experiment to determine whether this could be used to validate the present approach. From APSIM simulations on the soil with prior N fertilizer addition, significant correlation were found between observed and predicted mineral N (normalized RMSE ranging between 10-30 % and $r^2 > 0.9$) (Fig. 32b, 32d). However, simulated mineral N was over-predicted at low fertilizer and under-predicted at high compost rate. After prior compost addition, predicted mineral N was also correlated with measured values in the incubation experiment, but all recorded values were substantially under-predicted (normalized RMSE > 30 %) (Fig. 32a, 32c). Hence, neither DSSAT nor APSIM (Fig. 31, 32) could predict mineralization of compost in the incubation study. It was concluded that the incubation experiment had excessively high mineralization rates compared with field conditions and hence was not a suitable data set to validate the DSSAT predictions.

The present study was limited to a single, low-quality compost type. Further validation of the DSSAT modeling framework with higher quality composts would be valuable. The lack of yield response to compost in the present study obviously removed one important validation data set for DSSAT modeling. While, neither DSSAT nor APSIM (Fig. 31, 32) predictions of mineral N level measured in the incubation experiment were accurate, the DSSAT prediction of maize yield in the field were sufficiently robust for estimating N response from mineral fertilizer and compost.

While the proposed DSSAT framework shows some promise for predicting optimum combinations of mineral N fertilizer and compost it does not presently have the capability to predict optimal combinations for P fertilizer. Furthermore, the capability of the P task module in DSSAT was checked by varying N fertilizer rate without varying P fertilizer. The results showed that maize yield prediction was similar to varying N and P fertilizers at the same time (r=0.861** for both cases, data not shown). In contrast running DSSAT by varying P fertilizer rate but without N fertilizer give poorer yield prediction (r=0.477*, data not shown). These results supported our deduction that the yield response of maize was primarily to N fertilizer. APSIM has some capacity for modeling P supply and P uptake (Probert *et al.*, 2004), but further improvements are under development (Enli Wang, personal communication).

CONCLUSION

1. Mineral fertilizer up to 125-125 kg of N-P_2O_5 ha^{-1} resulted in increased maize yields in each year regardless of stubble management whereas compost (up to 7,500 kg ha^{-1} yr^{-1}) did not affect yield, even after 5 annual applications. However, pot experiment results suggested that a significant increase in yield of maize grown on the soil used in field experiment would be obtained from organic materials with higher quality. Regression modeling suggested that up to 24 t of compost ha^{-1} would be needed to achieve the same yield increase as the lowest fertilizer rate applied.

2. Soil type, organic matter content of soil and nutrient content of organic manure were factors affecting response of maize to organic matter applied in a pot experiment, suggesting that a broader range of field trial sites are needed to validate the present experimental results.

3. Mineral fertilizer was the most important input affecting maize production and available N and P balance in this study. Stubble removal with or without mineral fertilizer reduced available N balance of the soil and rendered negative the available N and P balances of practices without mineral fertilizer application.

4. N immobilization appeared to limit availability of N in compost with low N content, even though compost was low in C/N ratio.

5. Compost nutrient concentration, ratio of compost price to NP fertilizer price and level of organic matter of the soil were factors determining efficient combination of compost and mineral fertilizer in maize cropping.

6. The DSSAT yield simulation and Seasonal Analysis provided a framework whereby the suitability of compost as N fertilizer replacement for maize could be determined based on its nutrient composition, rate of application and price.

RECOMMENDATION

Further validation for the framework approach is needed where the organic amendments have significant effects on soil physical properties and where other nutrients besides N are a significant factor in the yield response. Moreover, composts with higher nutrient concentrations that produce yield response in maize are also needed to support the framework approach.

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APPENDICES

Appendix Table

Appendix Table 1 Height (cm) of maize plant at 30, 45 and 60 DAP of field experiment (year 1).

Treatments	30 DAP				45 DAP				60 DAP			
	Rep 1	**Rep 2**	**Rep 3**	**Avg.**	**Rep 1**	**Rep 2**	**Rep 3**	**Avg.**	**Rep 1**	**Rep 2**	**Rep 3**	**Avg.**
C_0F_0	26.0	24.3	28.3	26.2	62.3	56.7	53.8	57.6	149.0	148.0	151.3	149.4
C_0F_1	32.0	37.8	36.5	35.4	80.2	99.8	91.5	90.5	161.2	181.5	169.0	170.6
C_0F_2	36.0	31.8	34.0	33.9	91.5	74.3	79.0	81.6	171.7	155.8	159.0	162.2
C_0F_3	42.5	42.7	38.2	41.1	108.8	125.5	95.5	109.9	170.7	172.3	171.5	171.5
C_1F_0	23.8	29.7	27.5	27.0	53.0	88.8	57.7	66.5	147.5	167.2	151.0	155.2
C_1F_1	29.3	31.7	29.5	30.2	71.0	90.2	66.3	75.8	158.2	166.2	165.3	163.2
C_1F_2	33.8	33.7	35.2	34.2	84.5	80.8	85.2	83.5	160.7	166.0	161.0	162.6
C_1F_3	34.8	34.0	35.7	34.8	99.5	89.0	93.7	94.1	168.0	164.7	164.3	165.7
C_2F_0	26.8	27.5	24.8	26.4	54.8	68.0	55.0	59.3	149.5	149.7	148.2	149.1
C_2F_1	28.5	32.0	33.7	31.4	76.8	87.0	83.7	82.5	166.2	164.5	161.5	164.1
C_2F_2	31.7	32.5	38.5	34.2	81.2	75.2	91.8	82.7	162.8	156.2	166.5	161.8
C_2F_3	36.8	37.0	46.7	40.2	105.7	106.5	103.8	105.3	168.5	166.0	178.2	170.9
C_3F_0	29.5	29.7	25.8	28.3	64.8	69.3	63.3	65.8	149.0	157.7	151.8	152.8
C_3F_1	29.3	30.7	29.7	29.9	72.0	75.8	66.0	71.3	157.5	158.8	162.7	159.7
C_3F_2	34.3	35.0	31.2	33.5	97.2	82.2	84.8	88.1	167.5	164.2	161.8	164.5
C_3F_3	42.7	36.7	46.0	41.8	111.5	96.0	116.5	108.0	176.2	168.7	169.3	171.4
$C_0F_0S_0$	27.9	29.5	29.9	29.1	73.6	88.7	89.7	84.0	139.5	159.8	147.0	148.8
$C_0F_1S_0$	29.9	30.4	32.8	31.0	85.9	94.5	98.7	93.0	159.7	161.7	154.2	158.5
$C_0F_2S_0$	35.1	35.8	36.5	35.8	110.3	110.7	113.4	111.5	169.6	169.1	172.3	170.3
$C_0F_3S_0$	37.4	42.7	39.5	39.8	125.3	137.2	113.5	125.3	178.6	178.3	178.4	178.4

Appendix Table 2 Height (cm) of maize plant at 30, 45 and 60 DAP of field experiment (year 2).

Treatments	30 DAP				45 DAP				60 DAP			
	Rep 1	**Rep 2**	**Rep 3**	**Avg.**	**Rep 1**	**Rep 2**	**Rep 3**	**Avg.**	**Rep 1**	**Rep 2**	**Rep 3**	**Avg.**
C_0F_0	34.8	35.7	28.8	33.1	95.2	110.3	77.5	94.3	169.8	184.2	179.0	177.7
C_0F_1	32.5	40.0	42.7	38.4	97.7	137.0	129.7	121.5	178.8	187.5	191.5	185.9
C_0F_2	46.0	42.2	40.8	43.0	140.5	127.8	130.7	133.0	197.2	198.0	195.2	196.8
C_0F_3	55.0	48.0	53.5	52.2	157.7	156.0	147.2	153.6	194.5	196.3	192.3	194.4
C_1F_0	31.7	28.3	41.3	33.8	91.5	104.5	127.7	107.9	186.7	182.5	194.7	188.0
C_1F_1	43.2	48.5	41.7	44.4	117.8	135.8	117.8	123.8	182.3	194.7	195.2	190.7
C_1F_2	48.3	38.8	47.0	44.7	147.8	123.7	120.8	130.8	185.7	188.3	196.0	190.0
C_1F_3	47.0	52.0	50.0	49.7	143.7	150.0	138.3	144.0	190.2	198.7	184.7	191.2
C_2F_0	37.0	38.7	32.3	36.0	109.8	123.0	102.0	111.6	180.5	185.5	183.2	183.1
C_2F_1	35.7	41.5	43.0	40.1	116.0	127.7	123.0	122.2	176.2	180.3	178.5	178.3
C_2F_2	41.5	40.0	42.8	41.4	131.3	131.3	139.8	134.1	193.5	191.7	189.5	191.6
C_2F_3	52.5	45.0	52.0	49.8	149.3	137.0	138.0	141.4	194.3	191.8	196.5	194.2
C_3F_0	30.5	35.5	33.0	33.0	104.8	96.2	108.7	103.2	188.2	195.5	179.8	187.8
C_3F_1	39.2	37.0	42.3	39.5	132.3	107.8	117.0	119.0	192.3	184.8	188.5	188.5
C_3F_2	53.8	45.5	51.3	50.2	144.2	143.3	149.7	145.7	192.7	195.2	187.5	191.8
C_3F_3	57.0	55.0	47.8	53.3	159.7	159.5	127.7	149.0	197.7	193.2	188.7	193.2
$C_0F_0S_0$	31.5	34.8	28.8	31.7	100.3	101.5	84.7	95.5	174.3	190.2	173.0	179.2
$C_0F_1S_0$	32.7	36.7	41.2	36.8	113.7	118.2	129.3	120.4	184.3	180.5	182.6	182.5
$C_0F_2S_0$	41.3	43.5	43.0	42.6	133.5	125.7	122.8	127.3	191.5	193.7	188.5	191.2
$C_0F_3S_0$	48.8	49.7	46.2	48.2	152.7	153.8	147.7	151.4	194.0	184.5	191.8	190.1

Appendix Table 3 Height (cm) of maize plant at 30, 45 and 60 DAP of field experiment (year 3).

Treatments	30 DAP				45 DAP				60 DAP			
	Rep 1	**Rep 2**	**Rep 3**	**Avg.**	**Rep 1**	**Rep 2**	**Rep 3**	**Avg.**	**Rep 1**	**Rep 2**	**Rep 3**	**Avg.**
C_0F_0	29.5	27.7	30.0	29.1	76.7	79.2	128.3	94.7	136.5	151.5	135.5	141.2
C_0F_1	30.0	28.0	37.2	31.7	95.0	97.5	130.8	107.8	149.2	152.3	177.2	159.6
C_0F_2	30.7	35.0	35.8	33.8	114.2	120.8	100.8	111.9	164.5	172.5	167.8	168.3
C_0F_3	31.7	35.2	39.3	35.4	116.7	86.7	126.7	110.0	176.2	183.0	176.7	178.6
C_1F_0	28.2	27.3	28.2	27.9	77.5	100.8	85.8	88.1	140.3	143.2	140.3	141.3
C_1F_1	30.0	35.0	32.0	32.3	93.3	115.8	94.2	101.1	156.7	183.5	156.3	165.5
C_1F_2	31.3	36.2	38.5	35.3	113.3	128.3	81.7	107.8	157.5	165.3	168.7	163.8
C_1F_3	34.7	42.2	36.5	37.8	127.5	136.7	124.2	129.4	166.0	178.8	169.7	171.5
C_2F_0	28.2	31.3	26.8	28.8	94.2	85.8	72.5	84.2	144.8	148.8	135.3	143.0
C_2F_1	31.0	36.5	35.2	34.2	112.5	100.8	75.0	96.1	161.0	171.7	173.0	168.6
C_2F_2	34.7	36.8	38.8	36.8	128.3	125.8	124.2	126.1	169.8	164.7	177.3	170.6
C_2F_3	33.0	38.3	45.7	39.0	122.5	110.8	135.8	123.1	162.8	175.2	181.3	173.1
C_3F_0	30.2	34.8	31.7	32.2	91.7	118.3	123.3	111.1	144.8	166.0	142.5	151.1
C_3F_1	32.5	33.7	29.0	31.7	107.5	98.3	111.7	105.8	156.3	184.0	157.7	166.0
C_3F_2	31.8	35.7	35.5	34.3	123.3	128.3	113.3	121.7	177.8	169.8	171.3	173.0
C_3F_3	38.0	40.0	38.5	38.8	134.2	122.5	116.7	124.4	180.8	176.5	173.3	176.9
$C_0F_0S_0$	23.8	29.5	30.3	27.9	75.8	109.2	143.3	109.4	123.7	154.7	140.7	139.7
$C_0F_1S_0$	29.2	26.7	35.0	30.3	88.3	85.8	117.5	97.2	152.8	151.3	156.2	153.4
$C_0F_2S_0$	29.7	31.3	28.5	29.8	104.2	118.3	123.3	115.3	166.2	153.8	157.0	159.0
$C_0F_3S_0$	28.2	38.5	37.2	34.6	130.8	139.2	86.7	118.9	174.5	168.3	179.5	174.1

Appendix Table 4 Height (cm) of maize plant at 30, 45 and 60 DAP of field experiment (year 4).

Treatments	30 DAP				45 DAP				60 DAP			
	Rep 1	Rep 2	Rep 3	Avg.	Rep 1	Rep 2	Rep 3	Avg.	Rep 1	Rep 2	Rep 3	Avg.
C_0F_0	27.5	28.0	27.7	27.7	86.2	90.5	86.7	87.8	155.8	161.7	155.0	157.5
C_0F_1	37.5	37.5	37.7	37.6	106.8	123.3	131.5	120.6	166.7	183.2	187.5	179.1
C_0F_2	35.8	31.3	41.0	36.1	109.8	114.3	132.7	118.9	178.3	170.8	170.0	173.1
C_0F_3	45.7	46.2	44.3	45.4	109.0	150.2	139.2	132.8	169.2	187.5	185.8	180.8
C_1F_0	28.7	29.0	24.5	27.4	74.8	99.8	77.2	83.9	150.0	167.5	135.8	151.1
C_1F_1	31.0	30.0	32.2	31.1	104.2	135.5	99.8	113.2	163.3	191.7	164.2	173.1
C_1F_2	38.7	39.5	38.3	38.8	121.3	135.0	117.7	124.7	178.3	184.2	176.7	179.7
C_1F_3	37.8	35.2	38.5	37.2	150.5	131.3	140.7	140.8	184.2	184.2	186.7	185.0
C_2F_0	22.8	24.5	23.5	23.6	82.3	92.3	55.7	76.8	151.7	160.0	136.7	149.4
C_2F_1	33.7	36.7	33.3	34.6	138.0	135.7	126.7	133.4	183.3	190.8	167.5	180.6
C_2F_2	37.8	36.0	38.5	37.4	74.8	119.0	139.5	111.1	145.8	178.3	183.0	169.1
C_2F_3	44.5	47.8	40.0	44.1	82.2	156.7	149.8	129.6	160.0	187.5	175.0	174.2
C_3F_0	33.0	35.0	33.8	33.9	121.5	118.5	94.3	111.4	170.8	174.2	168.3	171.1
C_3F_1	35.0	42.8	29.3	35.7	130.7	131.2	95.7	119.2	183.3	185.0	166.7	178.3
C_3F_2	40.7	41.3	40.2	40.7	148.8	146.5	131.2	142.2	188.3	187.5	176.7	184.2
C_3F_3	44.2	44.2	43.2	43.8	152.3	160.3	149.3	154.0	182.5	190.0	184.2	185.6
$C_0F_0S_0$	30.5	29.0	34.8	31.4	74.8	95.3	98.3	89.5	145.8	165.8	161.7	157.8
$C_0F_1S_0$	29.5	30.8	28.3	29.6	82.2	106.5	105.3	98.0	160.0	167.5	150.8	159.4
$C_0F_2S_0$	34.0	37.5	32.5	34.7	121.5	124.7	108.7	118.3	170.8	180.8	170.8	174.2
$C_0F_3S_0$	38.3	39.2	37.7	38.4	130.7	147.3	139.5	139.2	183.3	181.7	180.8	181.9

Appendix Table 5 Height (cm) of maize plant at 30, 45 and 60 DAP of field experiment (year 5).

Treatments	30 DAP				45 DAP				60 DAP			
	Rep 1	Rep 2	Rep 3	Avg.	Rep 1	Rep 2	Rep 3	Avg.	Rep 1	Rep 2	Rep 3	Avg.
C_0F_0	24.2	22.8	23.8	23.6	54.3	34.8	34.2	41.1	121.7	109.3	106.5	112.5
C_0F_1	27.0	32.8	29.7	29.8	54.3	85.8	48.3	62.8	129.2	160.8	134.3	141.4
C_0F_2	32.5	29.5	31.0	31.0	92.8	69.7	65.8	76.1	159.7	144.7	145.2	149.8
C_0F_3	36.8	39.0	29.5	35.1	92.0	104.2	77.2	91.1	154.8	153.3	153.0	153.7
C_1F_0	25.3	28.8	22.0	25.4	40.8	54.5	35.7	43.7	125.5	135.5	124.3	128.4
C_1F_1	28.0	31.7	24.5	28.1	58.8	70.0	49.3	59.4	140.7	143.7	129.3	137.9
C_1F_2	34.3	29.0	26.3	29.9	74.5	57.5	67.7	66.6	154.2	148.5	164.2	155.6
C_1F_3	44.0	39.8	48.3	44.1	85.0	106.2	121.5	104.2	168.8	167.7	178.8	171.8
C_2F_0	33.3	25.8	20.2	26.4	75.7	44.3	33.7	51.2	157.8	112.5	118.5	129.6
C_2F_1	28.0	29.5	33.7	30.4	60.2	58.8	74.2	64.4	141.2	136.3	157.5	145.0
C_2F_2	33.7	37.7	32.3	34.6	60.8	89.3	62.5	70.9	140.3	157.3	160.3	152.7
C_2F_3	34.8	39.0	38.5	37.4	76.2	106.7	105.2	96.0	159.7	173.8	168.5	167.3
C_3F_0	28.0	28.0	35.7	30.6	55.0	46.7	76.3	59.3	118.8	125.8	150.7	131.8
C_3F_1	29.7	31.8	29.3	30.3	67.5	76.7	65.3	69.8	135.2	139.8	148.8	141.3
C_3F_2	32.3	41.0	32.7	35.3	87.2	107.8	65.0	86.7	161.8	166.3	149.2	159.1
C_3F_3	39.8	37.5	42.5	39.9	112.8	94.5	105.2	104.2	167.2	167.0	179.2	171.1
$C_0F_0S_0$	25.7	24.7	25.5	25.3	43.3	48.8	32.5	41.6	114.2	128.3	112.8	118.4
$C_0F_1S_0$	28.2	27.5	26.7	27.4	59.3	67.5	42.8	56.6	141.5	147.5	127.0	138.7
$C_0F_2S_0$	35.3	30.8	41.8	36.0	82.2	74.2	99.0	85.1	150.0	148.0	172.8	156.9
$C_0F_3S_0$	34.3	43.3	36.8	38.2	87.0	108.7	80.0	91.9	162.5	178.8	161.3	167.6

Appendix Table 6 Tasselling and silking ages of maize of field experiment (year 1).

Treatments	Tasselling age (days)				Silking age (days)			
	Rep 1	**Rep 2**	**Rep 3**	**Avg.**	**Rep 1**	**Rep 2**	**Rep 3**	**Avg.**
C_0F_0	58	57	58	58	56	56	56	56
C_0F_1	55	54	55	55	54	55	54	54
C_0F_2	54	56	56	55	53	54	55	54
C_0F_3	53	53	53	53	53	53	53	53
C_1F_0	58	55	54	56	57	54	56	56
C_1F_1	56	55	56	56	55	54	55	55
C_1F_2	55	55	55	55	54	54	54	54
C_1F_3	54	55	54	54	53	54	53	53
C_2F_0	57	57	59	58	56	55	57	56
C_2F_1	56	56	55	56	54	54	54	54
C_2F_2	55	55	54	55	54	54	53	54
C_2F_3	54	54	53	54	53	53	53	53
C_3F_0	56	57	57	57	55	56	56	56
C_3F_1	56	56	57	56	55	54	56	55
C_3F_2	54	56	56	55	53	54	54	54
C_3F_3	53	55	53	54	53	54	53	53
$C_0F_0S_0$	56	56	57	56	57	56	57	57
$C_0F_1S_0$	56	55	55	55	56	56	55	56
$C_0F_2S_0$	53	54	54	53	53	55	53	54
$C_0F_3S_0$	52	52	53	52	52	52	53	52

Appendix Table 7 Tasselling and silking ages of maize of field experiment (year 2).

Treatments	Tasselling age (days)				Silking age (days)			
	Rep 1	**Rep 2**	**Rep 3**	**Avg.**	**Rep 1**	**Rep 2**	**Rep 3**	**Avg.**
C_0F_0	56	56	57	56	55	55	56	55
C_0F_1	56	53	53	54	54	53	53	53
C_0F_2	52	52	53	52	52	52	55	53
C_0F_3	52	52	52	52	52	52	52	52
C_1F_0	56	56	53	55	56	55	53	55
C_1F_1	53	52	56	54	53	52	55	53
C_1F_2	52	53	54	53	52	53	54	53
C_1F_3	52	52	53	52	52	52	53	52
C_2F_0	55	54	56	55	54	53	55	54
C_2F_1	54	53	55	54	54	53	54	54
C_2F_2	52	53	53	53	52	53	53	53
C_2F_3	52	52	53	52	55	52	53	53
C_3F_0	55	54	56	55	54	53	54	54
C_3F_1	53	52	53	53	52	52	53	52
C_3F_2	52	52	53	52	52	52	53	52
C_3F_3	51	52	53	52	51	52	53	52
$C_0F_0S_0$	56	56	57	56	55	54	56	55
$C_0F_1S_0$	54	54	53	54	54	54	53	54
$C_0F_2S_0$	51	53	53	52	51	53	53	52
$C_0F_3S_0$	53	52	53	53	53	52	53	53

Appendix Table 8 Tasselling and silking ages of maize of field experiment (year 3).

Treatments	Tasselling age (days)				Silking age (days)			
	Rep 1	**Rep 2**	**Rep 3**	**Avg.**	**Rep 1**	**Rep 2**	**Rep 3**	**Avg.**
C_0F_0	53	53	53	53	54	53	54	54
C_0F_1	53	52	51	52	53	52	51	52
C_0F_2	51	51	51	51	51	51	51	51
C_0F_3	48	49	51	49	49	50	51	50
C_1F_0	53	53	52	53	54	53	53	53
C_1F_1	52	51	52	52	53	51	53	52
C_1F_2	50	50	51	50	51	50	51	51
C_1F_3	50	48	50	49	50	49	51	50
C_2F_0	52	53	54	53	53	53	55	54
C_2F_1	50	51	50	50	51	51	50	51
C_2F_2	50	51	51	51	50	51	51	51
C_2F_3	50	49	50	50	50	50	50	50
C_3F_0	53	51	53	52	53	51	54	53
C_3F_1	51	51	51	51	51	51	52	51
C_3F_2	51	50	51	51	51	50	51	51
C_3F_3	49	49	50	49	49	50	50	50
$C_0F_0S_0$	54	53	53	53	55	53	53	54
$C_0F_1S_0$	52	52	51	52	53	53	52	53
$C_0F_2S_0$	52	52	52	52	52	52	52	52
$C_0F_3S_0$	50	51	50	50	50	51	50	50

Appendix Table 9 Tasselling and silking ages of maize of field experiment (year 4).

Treatments	Tasselling age (days)				Silking age (days)			
	Rep 1	**Rep 2**	**Rep 3**	**Avg.**	**Rep 1**	**Rep 2**	**Rep 3**	**Avg.**
C_0F_0	58	58	58	58	58	58	58	58
C_0F_1	56	55	54	55	55	55	54	55
C_0F_2	55	55	56	55	55	55	55	55
C_0F_3	55	51	51	52	55	52	53	53
C_1F_0	58	57	59	58	58	58	59	58
C_1F_1	57	54	56	56	55	54	55	55
C_1F_2	54	54	56	55	54	54	55	54
C_1F_3	53	51	51	52	53	53	53	53
C_2F_0	58	57	59	58	58	57	59	58
C_2F_1	54	54	58	55	54	54	58	55
C_2F_2	56	54	51	54	55	54	54	54
C_2F_3	51	50	51	51	53	53	53	53
C_3F_0	58	55	55	56	58	55	55	56
C_3F_1	54	54	57	55	54	54	57	55
C_3F_2	50	51	54	52	53	53	54	53
C_3F_3	50	51	51	51	52	53	54	53
$C_0F_0S_0$	57	57	57	57	57	57	57	57
$C_0F_1S_0$	57	57	57	57	57	57	57	57
$C_0F_2S_0$	54	55	55	55	54	55	55	55
$C_0F_3S_0$	53	51	54	53	53	53	54	53

Appendix Table 10 Tasselling and silking ages of maize of field experiment (year 5).

Treatments	Tasselling age (days)				Silking age (days)			
	Rep 1	Rep 2	Rep 3	Avg.	Rep 1	Rep 2	Rep 3	Avg.
C_0F_0	60	60	60	60	60	62	60	61
C_0F_1	58	55	58	57	60	55	60	58
C_0F_2	55	56	58	56	55	58	60	58
C_0F_3	53	53	56	54	54	53	58	55
C_1F_0	59	58	62	60	59	59	62	60
C_1F_1	58	55	60	58	60	55	60	58
C_1F_2	55	58	58	57	56	58	58	57
C_1F_3	51	52	52	52	51	52	52	52
C_2F_0	55	60	62	59	55	62	62	60
C_2F_1	58	58	58	58	60	60	58	59
C_2F_2	55	54	55	55	55	54	58	56
C_2F_3	54	51	55	53	54	51	54	53
C_3F_0	58	59	55	57	60	60	55	58
C_3F_1	58	58	59	58	60	60	59	60
C_3F_2	55	54	55	55	55	54	58	56
C_3F_3	52	54	53	53	52	54	53	53
$C_0F_0S_0$	58	58	61	59	60	61	61	61
$C_0F_1S_0$	60	58	59	59	60	58	59	59
$C_0F_2S_0$	54	55	54	54	55	58	53	55
$C_0F_3S_0$	53	53	54	53	53	53	54	53

Appendix Table 11 Grain yields at 15% and SDM of maize of field experiment (year 1).

Treatments	Grain yields at 15% (kg ha^{-1})				SDM (kg ha^{-1})			
	Rep 1	**Rep 2**	**Rep 3**	**Avg.**	**Rep 1**	**Rep 2**	**Rep 3**	**Avg.**
C_0F_0	4151	4116	4094	4120	5673	5479	6430	5861
C_0F_1	4918	6028	5915	5620	7273	8950	8467	8230
C_0F_2	5902	5211	5359	5491	8068	7370	7944	7794
C_0F_3	6196	5794	6420	6137	8889	8387	9283	8853
C_1F_0	4098	5557	4755	4803	5343	7872	6585	6600
C_1F_1	4835	5597	4632	5021	6947	7553	6726	7075
C_1F_2	4512	5361	5733	5202	7325	7633	7347	7435
C_1F_3	5580	5643	5717	5647	8348	8371	8505	8408
C_2F_0	4140	4631	3786	4186	5773	6552	5313	5879
C_2F_1	5215	4943	5130	5096	7537	7603	7067	7402
C_2F_2	5749	5049	5852	5550	7576	6802	8591	7656
C_2F_3	5675	5570	6159	5801	8471	8383	8848	8568
C_3F_0	4412	4575	5133	4707	6333	6579	6555	6489
C_3F_1	4753	5363	5176	5098	7152	7515	7390	7352
C_3F_2	5904	5373	5051	5443	7987	7253	7270	7503
C_3F_3	6495	5640	6180	6105	9509	8657	8890	9018
$C_0F_0S_0$	4086	4978	4269	4444	5042	7221	6339	6201
$C_0F_1S_0$	4672	5744	5111	5176	6514	8125	7122	7254
$C_0F_2S_0$	5560	5624	5688	5624	7336	8066	7768	7723
$C_0F_3S_0$	6255	5739	6471	6155	9176	7844	8925	8648

Appendix Table 12 Grain yields at 15% and SDM of maize of field experiment (year 2).

Treatments	Grain yields at 15% (kg ha^{-1})				SDM (kg ha^{-1})			
	Rep 1	**Rep 2**	**Rep 3**	**Avg.**	**Rep 1**	**Rep 2**	**Rep 3**	**Avg.**
C_0F_0	4863	5158	4235	4752	8454	8411	7048	7971
C_0F_1	5610	7156	7580	6782	8568	10381	11080	10010
C_0F_2	7790	7723	9006	8173	12429	11345	13565	12446
C_0F_3	7534	9461	8981	8659	12183	13139	13195	12839
C_1F_0	4785	5071	6477	5444	8426	8463	10709	9200
C_1F_1	6898	6652	7718	7090	10767	12094	11787	11549
C_1F_2	7894	8670	8344	8303	11788	12589	12462	12280
C_1F_3	8071	10540	9111	9240	12753	14358	14147	13752
C_2F_0	4771	5048	6106	5308	8938	8849	9762	9183
C_2F_1	5320	7263	6545	6376	9779	11748	11404	10977
C_2F_2	7456	7898	8643	7999	11150	12141	13315	12202
C_2F_3	8845	3792	8179	6939	12584	8501	12895	11327
C_3F_0	5467	5924	5574	5655	9859	10868	9558	10095
C_3F_1	6499	7780	5353	6544	9674	11588	9300	10187
C_3F_2	8048	7392	7031	7490	13123	11298	10889	11770
C_3F_3	9715	7458	7701	8291	13972	12296	12225	12831
$C_0F_0S_0$	5288	5584	5556	5476	8440	9497	8776	8904
$C_0F_1S_0$	6890	6209	8085	7061	10667	10220	11174	10687
$C_0F_2S_0$	6769	6321	6966	6685	10234	9835	12282	10784
$C_0F_3S_0$	9364	7997	8545	8635	14328	12823	13300	13484

Appendix Table 13 Grain yields at 15% and SDM of maize of field experiment (year 3).

Treatments	Grain yields at 15% (kg ha^{-1})				SDM (kg ha^{-1})			
	Rep 1	Rep 2	Rep 3	Avg.	Rep 1	Rep 2	Rep 3	Avg.
C_0F_0	5099	4611	4452	4721	7241	7066	7051	7119
C_0F_1	5940	6955	9041	7312	8835	10312	12845	10664
C_0F_2	9558	8371	8611	8846	13898	12048	12252	12733
C_0F_3	10013	10392	8906	9771	13871	13473	12970	13438
C_1F_0	5944	5535	5024	5501	8732	8571	8030	8444
C_1F_1	5924	7585	7874	7128	9075	11807	11053	10645
C_1F_2	7267	8116	8135	7839	10390	12579	11888	11619
C_1F_3	8791	10181	8541	9171	13499	14520	12127	13382
C_2F_0	5389	4032	4416	4612	7660	6707	6820	7062
C_2F_1	7886	8208	7803	7965	11743	11670	11445	11619
C_2F_2	7927	8056	9203	8395	11498	11354	13276	12043
C_2F_3	7921	9360	10210	9164	12213	13103	14359	13225
C_3F_0	6172	7195	5603	6323	8566	10595	8269	9144
C_3F_1	6111	8877	7579	7523	9301	13146	11429	11292
C_3F_2	8358	8380	7508	8082	13251	11790	11128	12056
C_3F_3	9136	10452	9726	9771	13432	14885	14093	14137
$C_0F_0S_0$	4688	5839	6279	5602	6771	8963	8884	8206
$C_0F_1S_0$	5834	6802	6596	6411	8999	9995	10220	9738
$C_0F_2S_0$	6859	6340	7910	7036	10857	11762	11057	11225
$C_0F_3S_0$	9790	8542	9800	9377	12721	12354	13304	12793

Appendix Table 14 Grain yields at 15% and SDM of maize of field experiment (year 4).

Treatments	Grain yields at 15% (kg ha^{-1})				SDM (kg ha^{-1})			
	Rep 1	Rep 2	Rep 3	Avg.	Rep 1	Rep 2	Rep 3	Avg.
C_0F_0	1593	1295	839	1242	4975	4995	3998	4656
C_0F_1	2132	2246	2493	2290	5997	7042	7134	6724
C_0F_2	2962	2708	1999	2556	7279	7340	6145	6921
C_0F_3	2728	4967	4406	4033	6496	9782	9653	8643
C_1F_0	1111	1424	830	1122	4759	4864	2308	3977
C_1F_1	1248	2681	1491	1807	4601	7917	5084	5868
C_1F_2	2373	2804	1880	2352	6530	6804	5837	6390
C_1F_3	4156	2756	3630	3514	10231	6767	7706	8235
C_2F_0	1176	1252	811	1080	4236	4209	2846	3763
C_2F_1	2865	2928	2107	2633	7845	7320	5322	6829
C_2F_2	2354	2199	2399	2317	5888	6400	7201	6496
C_2F_3	3061	4466	4063	3863	7701	9175	8526	8467
C_3F_0	968	1918	1630	1505	4207	5976	6770	5651
C_3F_1	2760	3142	1640	2514	6271	7759	5324	6451
C_3F_2	3635	2235	2741	2870	9382	5916	7535	7611
C_3F_3	3344	4534	3772	3883	8498	9650	8904	9017
$C_0F_0S_0$	1329	1515	1793	1545	4292	5295	5771	5119
$C_0F_1S_0$	1433	1670	1381	1495	4318	5660	4208	4729
$C_0F_2S_0$	2727	2392	1968	2362	6095	6778	5535	6136
$C_0F_3S_0$	3796	5579	3998	4458	9407	9373	7674	8818

Appendix Table 15 Grain yields at 15% and SDM of maize of field experiment (year 5).

Treatments	Grain yields at 15% (kg ha^{-1})				SDM (kg ha^{-1})			
	Rep 1	**Rep 2**	**Rep 3**	**Avg.**	**Rep 1**	**Rep 2**	**Rep 3**	**Avg.**
C_0F_0	4361	2579	3363	3434	5929	5338	5946	5738
C_0F_1	3464	4435	3639	3846	5703	7177	5626	6169
C_0F_2	5658	5712	4623	5331	8809	7141	6892	7614
C_0F_3	6115	5800	6642	6186	9847	9940	9363	9716
C_1F_0	3275	3548	3427	3417	5806	5492	5304	5534
C_1F_1	4832	5029	4847	4902	5246	6621	7053	6307
C_1F_2	3309	3760	3933	3667	5979	6396	7176	6517
C_1F_3	6409	5396	6664	6156	10781	8627	10087	9832
C_2F_0	3176	2784	3782	3247	4841	3758	5533	4711
C_2F_1	5390	4084	3464	4313	8882	5871	6339	7031
C_2F_2	4768	5861	4702	5110	8319	8030	7084	7811
C_2F_3	3094	9687	6647	6476	11656	12648	10273	11526
C_3F_0	2524	3048	2801	2791	5017	4416	7575	5669
C_3F_1	5123	4699	4705	4842	7021	6257	7293	6857
C_3F_2	4953	4722	4916	4863	7543	6938	7249	7244
C_3F_3	6886	6014	6466	6455	10055	8199	13369	10541
$C_0F_0S_0$	2899	2121	2918	2646	4926	4036	4614	4525
$C_0F_1S_0$	2543	2447	2928	2639	4447	4433	7322	5401
$C_0F_2S_0$	5610	5558	5599	5589	8435	8118	8680	8411
$C_0F_3S_0$	6688	6416	6636	6580	10330	9543	9570	9814

Appendix Table 16 N, P and K uptake of maize shoot of field experiment (year 1).

Treatments	Shoot N uptake (kg ha^{-1})				Shoot P uptake (kg ha^{-1})				Shoot K uptake (kg ha^{-1})			
	Rep 1	**Rep 2**	**Rep 3**	**Avg.**	**Rep 1**	**Rep 2**	**Rep 3**	**Avg.**	**Rep 1**	**Rep 2**	**Rep 3**	**Avg.**
C_0F_0	60.5	57.6	65.0	61.0	12.8	12.2	11.7	12.2	47.5	42.4	61.2	50.4
C_0F_1	72.7	99.0	86.7	86.1	10.4	13.2	17.0	13.5	70.0	72.9	82.2	75.0
C_0F_2	84.7	75.0	80.8	80.2	13.8	12.1	15.6	13.8	68.6	63.9	68.8	67.1
C_0F_3	95.3	95.6	102.0	97.6	15.1	13.4	16.5	15.0	73.4	72.2	83.9	76.5
C_1F_0	60.8	78.4	68.3	69.2	9.8	13.2	15.6	12.8	37.1	62.1	58.5	52.6
C_1F_1	70.1	78.5	70.9	73.2	11.6	17.3	13.3	14.1	55.2	66.7	61.8	61.2
C_1F_2	65.7	77.9	76.5	73.4	10.1	11.5	12.1	11.2	75.1	64.0	53.3	64.2
C_1F_3	87.0	87.8	90.0	88.3	12.7	13.9	13.5	13.3	64.5	71.8	80.9	72.4
C_2F_0	54.6	65.2	56.4	58.7	10.6	13.3	10.2	11.4	48.0	54.8	37.6	46.8
C_2F_1	72.6	77.5	74.2	74.8	11.9	13.3	13.8	13.0	58.1	68.7	63.9	63.6
C_2F_2	70.4	74.5	85.1	76.7	12.3	11.8	16.4	13.5	56.9	48.1	55.0	53.3
C_2F_3	88.7	89.5	93.1	90.4	12.2	14.7	15.7	14.2	66.3	70.6	64.6	67.2
C_3F_0	65.2	64.2	69.4	66.3	11.9	13.3	11.8	12.3	57.9	51.2	44.7	51.3
C_3F_1	78.7	77.3	78.9	78.3	12.6	13.3	15.9	14.0	61.9	57.1	69.5	62.8
C_3F_2	91.3	79.2	78.6	83.0	15.0	15.7	13.4	14.7	69.0	57.9	72.3	66.4
C_3F_3	99.8	91.2	93.9	94.9	15.3	14.2	13.1	14.2	86.1	72.5	83.4	80.7
$C_0F_0S_0$	60.5	57.6	65.0	61.0	12.8	12.2	11.7	12.2	46.5	41.5	60.1	49.4
$C_0F_1S_0$	72.7	99.0	86.7	86.1	10.4	13.2	17.0	13.5	70.0	71.9	83.2	75.0
$C_0F_2S_0$	84.7	75.0	80.8	80.2	13.8	12.1	15.6	13.8	67.8	64.7	69.7	67.4
$C_0F_3S_0$	95.3	95.6	102.0	97.6	15.1	13.4	16.5	15.0	73.4	72.2	83.0	76.2

Appendix Table 17 N, P and K uptake of maize shoot of field experiment (year 2).

Treatments	Shoot N uptake (kg ha^{-1})				Shoot P uptake (kg ha^{-1})				Shoot K uptake (kg ha^{-1})			
	Rep 1	**Rep 2**	**Rep 3**	**Avg.**	**Rep 1**	**Rep 2**	**Rep 3**	**Avg.**	**Rep 1**	**Rep 2**	**Rep 3**	**Avg.**
C_0F_0	63.5	63.3	55.9	60.9	11.9	10.7	8.2	10.3	86.2	76.8	61.1	74.7
C_0F_1	60.8	102.9	101.1	88.3	13.8	11.3	16.9	14.0	86.1	78.4	93.7	86.1
C_0F_2	114.7	94.0	115.6	108.1	16.9	17.2	17.8	17.3	101.4	96.2	85.2	94.3
C_0F_3	113.8	129.2	122.2	121.7	17.4	18.8	16.7	17.6	77.9	111.4	106.4	98.5
C_1F_0	65.5	67.6	78.2	70.4	9.0	9.7	12.7	10.4	75.9	70.2	66.2	70.8
C_1F_1	81.7	107.2	100.1	96.4	13.1	14.9	15.8	14.6	76.6	102.0	94.3	91.0
C_1F_2	114.5	104.4	110.3	109.7	12.4	17.5	14.2	14.7	94.9	98.1	106.3	99.8
C_1F_3	124.4	142.4	135.2	134.0	15.9	16.9	19.2	17.3	90.3	99.3	103.3	97.6
C_2F_0	65.3	63.2	66.9	65.1	12.3	12.3	11.2	12.0	67.7	73.5	85.3	75.5
C_2F_1	86.4	98.9	95.3	93.5	14.2	17.2	12.7	14.7	97.7	109.0	100.6	102.4
C_2F_2	93.4	93.3	119.2	102.0	14.2	15.7	17.9	15.9	80.6	101.4	97.0	93.0
C_2F_3	125.7	70.1	121.4	105.7	16.3	9.6	18.6	14.9	93.5	79.5	80.1	84.3
C_3F_0	79.6	86.4	76.4	80.8	11.4	16.6	14.3	14.1	82.1	110.7	80.6	91.1
C_3F_1	73.2	96.9	74.7	81.6	14.2	18.5	14.0	15.6	86.5	88.1	81.1	85.3
C_3F_2	118.3	99.8	97.4	105.1	16.2	16.3	16.2	16.2	68.0	90.2	79.5	79.2
C_3F_3	133.8	132.7	130.1	132.2	20.0	18.6	16.2	18.3	115.8	133.2	109.7	119.6
$C_0F_0S_0$	69.8	72.7	72.4	71.6	13.5	13.8	15.1	14.1	70.3	89.0	83.7	81.0
$C_0F_1S_0$	91.8	89.4	88.7	90.0	15.5	16.9	15.6	16.0	91.1	89.3	86.2	88.9
$C_0F_2S_0$	81.3	79.4	107.7	89.4	11.3	9.4	14.7	11.8	77.3	81.6	88.9	82.6
$C_0F_3S_0$	145.1	123.2	129.5	132.6	18.1	15.4	15.7	16.4	119.9	114.0	118.3	117.4

Appendix Table 18 N, P and K uptake of maize shoot of field experiment (year 3).

Treatments	Shoot N uptake (kg ha^{-1})				Shoot P uptake (kg ha^{-1})				Shoot K uptake (kg ha^{-1})			
	Rep 1	**Rep 2**	**Rep 3**	**Avg.**	**Rep 1**	**Rep 2**	**Rep 3**	**Avg.**	**Rep 1**	**Rep 2**	**Rep 3**	**Avg.**
C_0F_0	53.1	50.6	49.3	51.0	9.4	7.7	8.8	8.6	75.0	66.5	83.5	75.0
C_0F_1	68.7	75.2	100.2	81.4	9.7	10.0	11.4	10.4	79.4	94.2	86.8	86.8
C_0F_2	118.5	90.3	82.9	97.2	19.6	17.9	18.2	18.6	138.9	123.0	121.5	127.8
C_0F_3	144.1	127.2	108.3	126.6	19.2	21.1	20.1	20.1	117.9	129.2	135.3	127.5
C_1F_0	66.8	63.3	50.2	60.1	8.8	7.0	9.4	8.4	78.4	76.9	80.5	78.6
C_1F_1	71.9	99.9	91.7	87.9	9.6	19.6	14.4	14.5	95.6	123.8	115.9	111.8
C_1F_2	88.1	102.1	94.5	94.9	11.2	13.8	12.8	12.6	88.5	100.0	115.5	101.3
C_1F_3	129.3	143.6	116.5	129.8	21.3	23.7	19.2	21.4	116.0	124.1	113.2	117.8
C_2F_0	58.5	43.8	51.1	51.1	12.6	7.2	9.6	9.8	73.3	72.4	73.8	73.2
C_2F_1	100.8	97.2	91.3	96.4	16.5	18.6	17.6	17.6	111.6	120.3	115.9	115.9
C_2F_2	98.6	92.4	129.2	106.7	18.8	18.1	20.4	19.1	115.0	116.4	108.5	113.3
C_2F_3	131.7	122.7	133.4	129.3	15.9	18.7	22.6	19.0	108.7	104.9	109.1	107.6
C_3F_0	77.3	87.7	62.7	75.9	9.3	13.3	13.8	12.1	74.2	82.9	91.6	82.9
C_3F_1	75.4	102.7	82.4	86.8	13.7	18.4	18.5	16.9	79.6	98.8	89.2	89.2
C_3F_2	115.6	102.7	89.3	102.5	15.9	15.9	15.1	15.7	135.4	126.5	137.6	133.2
C_3F_3	133.0	144.3	126.6	134.6	20.7	23.3	25.4	23.1	133.5	149.4	165.4	149.4
$C_0F_0S_0$	55.8	57.2	76.1	63.1	8.8	10.4	10.7	10.0	67.6	83.3	78.2	76.4
$C_0F_1S_0$	63.5	77.4	68.2	69.7	10.8	10.1	10.4	10.5	85.1	85.3	102.7	91.1
$C_0F_2S_0$	100.4	102.7	96.2	99.7	14.5	13.6	17.7	15.3	97.3	106.5	101.9	101.9
$C_0F_3S_0$	131.1	116.2	135.9	127.7	15.2	19.2	16.9	17.1	102.9	92.7	108.2	101.3

Appendix Table 19 N, P and K uptake of maize shoot of field experiment (year 4).

Treatments	Shoot N uptake (kg ha^{-1})				Shoot P uptake (kg ha^{-1})				Shoot K uptake (kg ha^{-1})			
	Rep 1	**Rep 2**	**Rep 3**	**Avg.**	**Rep 1**	**Rep 2**	**Rep 3**	**Avg.**	**Rep 1**	**Rep 2**	**Rep 3**	**Avg.**
C_0F_0	33.7	29.3	24.5	29.1	6.5	7.0	5.7	6.4	57.8	69.1	61.3	62.7
C_0F_1	43.3	45.4	48.5	45.7	13.5	12.6	14.1	13.4	66.4	59.5	74.4	66.8
C_0F_2	64.1	65.4	49.2	59.5	16.7	15.6	16.0	16.1	78.0	71.9	66.0	72.0
C_0F_3	59.3	98.9	89.3	82.5	16.0	19.2	20.7	18.6	91.3	99.4	88.9	93.2
C_1F_0	28.1	30.4	17.1	25.2	5.8	6.6	5.6	6.0	52.1	68.8	38.1	53.0
C_1F_1	30.2	51.4	38.4	40.0	8.7	21.3	11.6	13.8	67.6	91.1	71.1	76.6
C_1F_2	56.1	57.1	47.9	53.7	12.7	16.9	11.5	13.7	81.9	88.5	73.5	81.3
C_1F_3	108.7	62.3	77.1	82.7	20.7	14.3	18.7	17.9	78.3	65.5	62.9	68.9
C_2F_0	26.8	27.8	20.3	25.0	7.5	6.7	6.2	6.8	52.7	56.9	39.7	49.8
C_2F_1	59.1	59.1	46.0	54.7	11.3	10.8	13.3	11.8	98.4	84.8	72.9	85.4
C_2F_2	50.1	46.0	58.6	51.6	17.7	17.5	16.9	17.4	56.6	58.8	61.2	58.8
C_2F_3	73.8	84.5	82.4	80.2	15.3	15.2	14.4	15.0	77.4	85.9	79.9	81.1
C_3F_0	28.2	44.3	39.8	37.4	10.0	13.5	10.7	11.4	67.1	79.6	64.3	70.3
C_3F_1	53.7	65.6	40.5	53.3	13.5	18.9	12.9	15.1	68.2	70.9	65.6	68.2
C_3F_2	80.8	53.6	56.2	63.5	14.2	9.3	13.3	12.3	85.0	65.2	72.5	74.3
C_3F_3	84.9	102.5	82.7	90.0	11.9	22.0	16.5	16.8	99.5	109.0	96.2	101.6
$C_0F_0S_0$	27.3	34.6	37.7	33.2	5.8	6.9	8.7	7.1	59.3	60.8	66.6	62.2
$C_0F_1S_0$	25.7	38.9	25.9	30.2	7.3	7.3	7.4	7.4	37.2	45.0	44.6	42.3
$C_0F_2S_0$	55.0	46.4	44.0	48.5	12.3	10.0	11.2	11.1	54.3	49.4	40.2	48.0
$C_0F_3S_0$	95.2	100.0	81.0	92.1	17.8	21.0	17.6	18.8	73.9	52.4	65.0	63.7

Appendix Table 20 N, P and K uptake of maize shoot of field experiment (year 5).

Treatments	Shoot N uptake (kg ha^{-1})				Shoot P uptake (kg ha^{-1})				Shoot K uptake (kg ha^{-1})			
	Rep 1	**Rep 2**	**Rep 3**	**Avg.**	**Rep 1**	**Rep 2**	**Rep 3**	**Avg.**	**Rep 1**	**Rep 2**	**Rep 3**	**Avg.**
C_0F_0	54.7	53.3	50.7	52.9	7.4	5.7	6.4	6.5	33.1	31.4	36.7	33.7
C_0F_1	51.2	55.7	50.3	52.4	5.8	7.6	8.1	7.2	29.7	38.8	45.2	37.9
C_0F_2	79.9	77.3	65.0	74.1	13.2	14.1	14.4	13.9	47.7	37.5	46.5	43.9
C_0F_3	109.7	102.7	101.4	104.6	13.0	13.9	12.9	13.3	49.8	51.7	48.9	50.1
C_1F_0	50.9	57.5	47.7	52.0	7.7	4.8	6.0	6.2	32.1	29.6	33.2	31.6
C_1F_1	69.1	71.0	62.7	67.6	11.5	12.4	11.9	11.9	41.0	40.9	42.0	41.3
C_1F_2	55.1	58.0	67.7	60.3	9.3	10.9	12.5	10.9	41.1	44.3	47.3	44.2
C_1F_3	122.1	99.5	107.3	109.6	15.6	12.5	12.3	13.5	83.4	77.6	78.7	79.9
C_2F_0	48.1	41.3	49.6	46.4	7.2	6.6	8.7	7.5	30.3	25.0	36.6	30.6
C_2F_1	66.2	62.4	56.2	61.6	15.1	13.0	12.6	13.6	65.6	44.5	56.5	55.5
C_2F_2	83.4	80.9	63.6	76.0	16.7	15.6	15.2	15.8	60.9	49.3	48.7	52.9
C_2F_3	125.8	140.8	105.6	124.0	17.7	19.3	17.0	18.0	47.6	68.6	49.4	55.2
C_3F_0	44.5	43.6	41.4	43.2	9.0	8.7	9.9	9.2	32.5	33.0	46.1	37.2
C_3F_1	73.8	66.1	62.9	67.6	13.2	14.6	15.8	14.5	44.6	44.9	56.1	48.5
C_3F_2	72.3	73.0	68.0	71.1	15.2	14.3	16.0	15.1	56.9	44.0	47.9	49.6
C_3F_3	99.3	106.3	94.1	99.9	20.2	21.7	23.9	21.9	66.4	66.2	66.7	66.4
$C_0F_0S_0$	48.4	36.8	39.6	41.6	5.8	5.4	5.2	5.5	27.9	33.7	29.6	30.4
$C_0F_1S_0$	37.0	39.9	50.7	42.5	5.5	6.0	7.2	6.2	27.4	19.2	49.4	32.0
$C_0F_2S_0$	88.2	83.8	82.7	84.9	12.2	11.3	14.9	12.8	40.2	35.9	42.1	39.4
$C_0F_3S_0$	122.8	109.0	104.9	112.2	15.5	14.5	17.6	15.9	41.2	51.2	54.1	48.9

Appendix Table 21 Mineral N (mg kg^{-1}) in incubation experiment**.**

Incubation period (days)	Tr.	Compost	Ammonium (NH_4^+) (mg kg^{-1})				Nitrate (NO_3^-) (mg kg^{-1})			
			Rep 1	Rep 2	Rep 3	Avg	Rep 1	Rep 2	Rep 3	Avg
0	$C_0F_0f_0$	C_0	12.9	13.1	12.4	12.8	3.81	3.57	3.81	3.73
		C_1	8.81	8.81	8.57	8.73	3.33	2.86	3.09	3.09
		C_2	14.0	14.5	13.8	14.1	0.95	1.19	0.71	0.95
		C_3	10.9	11.4	10.5	10.9	8.81	8.57	8.09	8.49
	$C_0F_0f_1$	C_0	19.9	18.1	19.0	19.0	5.95	6.43	5.71	6.03
		C_1	18.8	20.7	19.8	19.8	7.38	4.76	8.57	6.90
		C_2	19.5	18.6	18.8	18.9	7.62	7.62	8.57	7.93
		C_3	18.8	19.3	19.8	19.3	4.05	4.76	3.81	4.20
	$C_3F_0f_0$	C_0	16.9	16.7	16.7	16.7	6.90	7.85	7.14	7.30
		C_1	19.0	19.3	18.3	18.9	5.47	7.85	6.90	6.74
		C_2	18.8	19.0	19.5	19.1	6.66	5.95	6.43	6.35
		C_3	19.9	19.8	19.5	19.8	7.14	7.14	7.38	7.22
	$C_3F_0f_1$	C_0	19.5	21.4	20.5	20.5	8.81	8.09	8.33	8.41
		C_1	20.7	20.5	20.9	20.7	4.05	5.47	5.71	5.08
		C_2	20.9	22.9	19.0	20.9	4.05	4.05	4.05	4.05
		C_3	22.6	22.9	21.9	22.5	6.43	6.90	6.90	6.74
10	$C_0F_0f_0$	C_0	36.7	38.8	37.6	37.7	31.7	31.9	32.4	31.9
		C_1	42.4	43.1	44.0	43.2	24.8	23.3	22.4	23.5
		C_2	36.7	37.6	35.7	36.7	30.9	30.7	29.8	30.5
		C_3	35.5	36.4	37.2	36.3	36.7	34.0	33.6	34.8
	$C_0F_0f_1$	C_0	84.3	87.1	80.7	84.0	53.6	53.8	55.5	54.3
		C_1	101.2	103.8	105.4	103.5	43.8	43.8	42.8	43.5
		C_2	92.3	92.4	100.4	95.1	39.5	39.5	45.7	41.6
		C_3	86.2	85.9	79.7	83.9	48.1	50.5	50.7	49.7
	$C_3F_0f_0$	C_0	33.6	34.3	30.0	32.6	41.7	43.6	48.1	44.4
		C_1	25.7	20.7	28.8	25.1	50.9	58.1	48.6	52.5
		C_2	32.4	28.1	35.7	32.1	45.7	40.9	45.7	44.1
		C_3	41.7	42.1	41.4	41.7	44.0	38.1	40.2	40.8
	$C_3F_0f_1$	C_0	82.3	75.2	74.3	77.3	45.0	52.8	55.0	50.9
		C_1	95.9	94.0	96.2	95.4	62.8	56.9	53.1	57.6
		C_2	75.4	65.7	66.2	69.1	65.2	60.5	64.3	63.3
		C_3	84.5	83.3	82.8	83.5	64.7	53.8	55.2	57.9
20	$C_0F_0f_0$	C_0	2.62	2.62	2.14	2.46	69.0	64.7	66.6	66.8
		C_1	5.95	4.05	4.52	4.84	62.4	65.7	65.0	64.3
		C_2	9.28	8.33	10.5	9.36	64.0	73.3	54.3	63.9
		C_3	3.57	4.52	3.33	3.81	66.6	70.9	80.4	72.7
	$C_0F_0f_1$	C_0	19.5	20.5	22.1	20.7	114.7	116.4	111.9	114.3
		C_1	20.9	34.3	20.5	25.2	107.1	100.0	107.1	104.7
		C_2	21.4	27.1	23.6	24.0	91.4	104.7	102.3	99.5
		C_3	26.2	22.6	24.3	24.4	114.5	113.1	111.9	113.1

Appendix Table 21 (Continued)

Incubation period (days)	Tr.	Compost	Ammonium (NH_4^+) (mg kg^{-1})				Nitrate (NO_3^-) (mg kg^{-1})			
			Rep 1	Rep 2	Rep 3	Avg	Rep 1	Rep 2	Rep 3	Avg
	$C_3F_0f_0$	C_0	0.48	0.48	0.72	0.56	71.4	64.3	73.3	69.7
		C_1	2.38	3.09	2.62	2.70	66.6	63.8	68.5	66.3
		C_2	0.48	0.71	0.24	0.48	68.8	65.7	72.8	69.1
		C_3	0.48	0.24	0.48	0.5	66.6	66.6	70.2	67.8
	$C_3F_0f_1$	C_0	18.1	14.8	14.5	15.8	129.5	109.5	111.4	116.8
		C_1	17.9	15.2	17.4	16.8	106.1	106.9	108.1	107.0
		C_2	1.90	3.33	2.38	2.54	127.6	112.3	130.4	123.4
		C_3	3.33	4.28	3.09	3.57	123.3	128.0	120.9	124.1
40	$C_0F_0f_0$	C_0	6.19	9.04	9.28	8.17	75.9	76.9	76.9	76.6
		C_1	9.76	6.43	10.23	8.81	83.3	77.6	90.9	83.9
		C_2	4.76	2.86	2.38	3.33	85.7	75.2	73.8	78.2
		C_3	8.09	7.14	6.19	7.14	83.3	85.7	80.9	83.3
	$C_0F_0f_1$	C_0	3.81	4.05	9.52	5.79	145.2	134.7	110.4	130.1
		C_1	9.04	10.00	9.76	9.60	144.5	138.8	140.9	141.4
		C_2	7.62	8.57	9.04	8.41	154.0	130.9	126.6	137.2
		C_3	6.19	7.85	7.14	7.06	145.7	150.9	144.2	146.9
	$C_3F_0f_0$	C_0	2.62	4.76	2.86	3.41	72.4	76.6	75.2	74.7
		C_1	4.52	3.33	9.04	5.63	76.6	68.5	77.1	74.1
		C_2	3.57	2.38	5.24	3.73	81.4	79.5	85.9	82.3
		C_3	8.33	8.09	6.19	7.54	90.9	85.2	87.1	87.7
	$C_3F_0f_1$	C_0	9.04	9.76	11.4	10.1	131.4	131.9	144.9	136.1
		C_1	5.2	10.5	10.9	8.89	140.4	129.7	136.1	135.4
		C_2	16.2	10.0	16.2	14.1	142.8	161.4	143.3	149.2
		C_3	8.57	6.90	9.76	8.41	140.9	157.1	140.9	146.3

Appendix Table 22 Extractable P (mg kg^{-1}) in incubation experiment.

Incubation period (days)	Treatments	Compost	Extractable P (mg kg^{-1})			
			Rep 1	Rep 2	Rep 3	Avg.
0	$C_0F_0f_0$	C_0	3.12	3.21	3.27	3.20
		C_1	4.24	3.58	4.10	3.97
		C_2	4.44	4.47	4.42	4.44
		C_3	7.27	7.21	7.07	7.18
	$C_0F_0f_1$	C_0	15.7	14.8	15.7	15.4
		C_1	15.7	16.4	15.4	15.8
		C_2	14.3	14.0	14.1	14.1
		C_3	17.9	15.9	16.9	16.9
	$C_3F_0f_0$	C_0	3.13	3.09	3.12	3.11
		C_1	3.40	3.27	3.40	3.36
		C_2	4.14	4.24	4.01	4.13
		C_3	5.68	5.26	6.69	5.87
	$C_3F_0f_1$	C_0	13.0	14.1	14.2	13.8
		C_1	15.6	14.8	16.4	15.6
		C_2	11.7	12.2	14.1	12.7
		C_3	14.5	13.6	13.6	13.9
10	$C_0F_0f_0$	C_0	3.64	3.93	3.77	3.78
		C_1	4.57	4.69	3.93	4.39
		C_2	4.55	4.71	4.55	4.60
		C_3	7.77	8.73	7.14	7.88
	$C_0F_0f_1$	C_0	14.1	13.3	13.3	13.6
		C_1	13.7	13.3	13.3	13.4
		C_2	14.9	13.3	12.5	13.6
		C_3	14.8	15.3	15.4	15.2
	$C_3F_0f_0$	C_0	5.55	4.34	4.22	4.70
		C_1	5.32	5.53	5.60	5.49
		C_2	6.02	6.35	6.29	6.22
		C_3	11.8	12.7	11.1	11.9
	$C_3F_0f_1$	C_0	14.1	14.1	13.3	13.8
		C_1	13.3	15.8	14.1	14.4
		C_2	16.6	16.6	13.0	15.4
		C_3	16.2	15.3	17.5	16.3
20	$C_0F_0f_0$	C_0	2.70	2.80	2.68	2.73
		C_1	2.91	2.96	2.85	2.91
		C_2	3.45	3.26	3.02	3.24
		C_3	4.65	4.24	5.06	4.65
	$C_0F_0f_1$	C_0	8.86	8.34	8.81	8.67
		C_1	8.81	9.39	10.4	9.53
		C_2	10.5	10.7	10.2	10.5
		C_3	9.61	10.5	9.66	9.91

Appendix Table 22 (Continued)

Incubation period (days)	Treatments	Compost	Extractable P (mg kg^{-1})			
			Rep 1	Rep 2	Rep 3	Avg.
	$C_3F_0f_0$	C_0	3.41	3.84	3.56	3.60
		C_1	3.72	3.88	3.61	3.74
		C_2	4.04	3.93	3.71	3.89
		C_3	7.31	6.79	7.26	7.12
	$C_3F_0f_1$	C_0	9.61	9.89	9.34	9.61
		C_1	9.34	10.74	9.89	9.99
		C_2	11.3	9.9	10.5	10.6
		C_3	11.3	12.3	12.6	12.1
40	$C_0F_0f_0$	C_0	2.28	2.23	2.26	2.26
		C_1	2.50	2.48	2.51	2.50
		C_2	2.45	2.61	2.56	2.54
		C_3	3.52	3.59	3.47	3.53
	$C_0F_0f_1$	C_0	3.07	4.07	3.86	3.67
		C_1	3.66	4.58	3.33	3.86
		C_2	4.58	4.28	4.58	4.49
		C_3	2.61	2.73	3.40	2.91
	$C_3F_0f_0$	C_0	2.50	2.07	2.37	2.31
		C_1	3.32	2.96	3.02	3.10
		C_2	3.46	3.47	3.49	3.47
		C_3	3.21	3.32	2.96	3.16
	$C_3F_0f_1$	C_0	3.52	3.52	2.96	3.34
		C_1	4.58	2.90	3.14	3.54
		C_2	4.74	4.40	3.98	4.38
		C_3	4.98	5.32	4.66	4.99

Appendix Table 23 Height (cm) of maize plant at 30 DAP of pot experiment.

Soil type	Treatments	Rep 1	Rep 2	Rep 3	Rep 4	Rep 5	Avg.
Kt	ctrl	12.6	15.6	14.3	16.0	12.7	14.2
	F	19.1	20.6	21.0	20.5	18.8	20.0
	ch-A	17.9	15.6	19.8	18.8	19.0	18.2
	ch-B	20.8	18.8	18.8	19.7	20.9	19.8
	ch-C	18.3	19.4	23.9	23.3	22.7	21.5
	cph-A	13.3	13.9	14.8	14.6	13.8	14.1
	cph-B	14.9	12.8	16.6	15.2	13.6	14.6
	cph-C	16.8	15.8	16.2	17.3	15.5	16.3
	cpl-A	14.3	12.8	15.4	15.8	14.8	14.6
	cpl-B	14.4	15.8	15.9	15.8	14.8	15.4
	cpl-C	15.0	18.4	19.2	18.8	13.9	17.1
Pc soil with high %OM	ctrl	12.0	11.3	11.3	11.4	11.8	11.6
	F	14.0	11.5	13.6	11.8	16.1	13.4
	ch-A	11.5	11.2	12.0	12.8	12.9	12.1
	ch-B	9.6	14.3	14.5	10.2	12.4	12.2
	ch-C	12.8	12.5	12.6	13.7	13.8	13.1
	cph-A	10.3	10.2	12.0	9.1	10.3	10.4
	cph-B	12.2	9.0	10.4	10.0	9.6	10.2
	cph-C	11.6	11.8	12.3	11.4	12.3	11.9
	cpl-A	11.7	10.8	11.7	11.0	12.5	11.5
	cpl-B	10.1	9.4	11.0	11.5	10.6	10.5
	cpl-C	12.1	8.4	14.2	10.9	11.4	11.4
Pc soil with low %OM	ctrl	19.7	19.3	20.1	19.7	18.2	19.4
	F	22.3	21.6	23.3	20.9	19.3	21.5
	ch-A	20.0	20.9	20.7	18.4	17.0	19.4
	ch-B	22.5	22.1	21.8	20.8	21.2	21.7
	ch-C	19.2	23.3	25.5	24.1	22.7	22.9
	cph-A	21.0	21.3	19.1	17.7	18.2	19.4
	cph-B	19.7	20.6	20.3	19.1	19.3	19.8
	cph-C	18.9	19.9	21.8	20.1	17.3	19.6
	cpl-A	21.7	19.5	21.3	18.3	21.3	20.4
	cpl-B	20.4	20.7	17.9	17.8	21.5	19.7
	cpl-C	19.6	20.0	21.1	19.6	19.9	20.0

Appendix Table 24 Height (cm) of maize plant at 45 DAP of pot experiment.

Soil type	Treatments	Rep 1	Rep 2	Rep 3	Rep 4	Rep 5	Avg.
Kt	ctrl	24.0	26.6	24.9	26.8	26.2	25.7
	F	30.0	32.2	32.6	32.9	30.9	31.7
	ch-A	26.8	27.4	30.3	27.3	29.2	28.2
	ch-B	29.7	28.1	26.8	29.5	32.0	29.2
	ch-C	30.8	34.4	37.4	37.8	33.3	34.7
	cph-A	25.5	27.4	25.4	27.4	26.4	26.4
	cph-B	24.3	24.1	27.0	28.5	25.6	25.9
	cph-C	27.9	28.9	26.0	28.0	29.3	28.0
	cpl-A	27.1	24.7	27.4	25.7	28.6	26.7
	cpl-B	25.9	26.6	26.0	28.0	26.2	26.5
	cpl-C	25.2	29.8	28.4	29.9	27.0	28.1
Pc soil with high %OM	ctrl	26.1	21.3	23.3	24.6	25.5	24.2
	F	28.2	26.5	30.6	27.7	32.6	29.1
	ch-A	27.5	23.4	25.4	30.6	28.7	27.1
	ch-B	21.3	25.9	33.2	23.9	30.4	26.9
	ch-C	32.8	27.5	27.5	32.5	30.8	30.2
	cph-A	20.1	23.4	28.4	23.7	22.8	23.7
	cph-B	25.2	20.7	28.1	20.7	23.2	23.6
	cph-C	27.7	28.1	28.0	29.3	28.5	28.3
	cpl-A	25.7	20.0	26.3	26.8	26.5	25.0
	cpl-B	24.0	19.3	24.2	26.2	25.3	23.8
	cpl-C	29.2	17.6	30.3	24.9	31.5	26.7
Pc soil with low %OM	ctrl	30.1	32.8	31.3	31.3	31.8	31.5
	F	32.4	35.3	39.1	31.5	32.5	34.2
	ch-A	28.8	31.6	32.0	30.9	28.1	30.3
	ch-B	33.0	33.6	36.1	28.5	29.3	32.1
	ch-C	31.7	34.9	40.8	36.8	33.7	35.6
	cph-A	30.8	31.1	30.2	28.5	32.1	30.5
	cph-B	28.7	33.1	34.3	29.8	34.3	32.0
	cph-C	29.3	29.9	35.0	29.9	30.4	30.9
	cpl-A	32.9	31.0	31.3	29.7	33.3	31.6
	cpl-B	33.9	33.0	31.7	30.3	32.1	32.2
	cpl-C	32.5	31.9	32.4	30.2	30.8	31.6

Appendix Table 25 Dry weight of maize shoot (g pot^{-1}) of pot experiment.

Soil type	Treatments	Rep 1	Rep 2	Rep 3	Rep 4	Rep 5	Avg.
Kt	ctrl	20.2	19.6	19.9	17.6	19.89	19.3
	F	44.4	49.8	42.3	40.1	45.48	44.1
	ch-A	28.1	32.5	28.5	26.9	29.68	29.0
	ch-B	28.9	32.4	32.5	37.0	31.25	32.7
	ch-C	45.4	52.7	53.5	46.7	50.55	49.6
	cph-A	20.5	21.0	19.4	20.5	20.28	20.3
	cph-B	18.9	23.6	20.7	23.4	21.03	21.6
	cph-C	26.3	27.0	24.5	25.7	25.93	25.9
	cpl-A	17.4	23.5	16.9	20.4	19.25	19.5
	cpl-B	23.1	21.0	17.2	20.8	20.44	20.5
	cpl-C	28.0	25.0	22.5	20.7	25.20	24.1
Pc soil with high %OM	ctrl	30.4	31.4	39.4	28.4	33.74	32.4
	F	47.5	49.7	43.1	55.7	46.77	49.0
	ch-A	39.6	30.5	40.5	34.7	36.84	36.3
	ch-B	42.1	41.9	31.7	37.1	38.58	38.2
	ch-C	49.5	47.0	52.2	48.2	49.55	49.2
	cph-A	29.5	34.9	27.9	29.4	30.78	30.4
	cph-B	33.2	38.5	31.3	33.9	34.30	34.2
	cph-C	45.1	33.4	39.7	40.6	39.39	39.7
	cpl-A	29.7	32.9	31.6	37.6	31.38	32.9
	cpl-B	25.6	33.4	31.2	35.1	30.06	31.3
	cpl-C	28.9	33.4	30.9	30.9	31.07	31.0
Pc soil with low %OM	ctrl	36.4	39.9	28.8	36.9	35.00	35.5
	F	54.3	54.2	59.8	57.1	56.10	56.4
	ch-A	40.8	38.1	40.1	29.7	39.65	37.2
	ch-B	45.8	43.9	39.4	38.8	43.03	42.0
	ch-C	46.9	53.3	57.0	46.5	52.38	50.9
	cph-A	33.1	35.3	26.9	40.5	31.77	33.9
	cph-B	45.4	33.9	40.3	33.1	39.87	38.2
	cph-C	41.6	42.1	42.4	31.5	42.04	39.4
	cpl-A	37.8	35.2	27.9	38.0	33.61	34.7
	cpl-B	41.3	30.3	29.8	34.7	33.78	34.0
	cpl-C	44.7	33.2	31.3	40.1	36.40	37.3

Appendix Table 26 N uptake in maize shoot (g pot^{-1}) of pot experiment.

Soil type	Treatments	Rep 1	Rep 2	Rep 3	Rep 4	Rep 5	Avg.
Kt	ctrl	0.209	0.222	0.199	0.207	0.210	0.209
	F	0.395	0.446	0.402	0.399	0.414	0.410
	ch-A	0.307	0.236	0.267	0.266	0.270	0.269
	ch-B	0.273	0.286	0.275	0.316	0.278	0.287
	ch-C	0.454	0.509	0.483	0.396	0.482	0.461
	cph-A	0.202	0.210	0.190	0.260	0.201	0.216
	cph-B	0.210	0.211	0.208	0.223	0.210	0.213
	cph-C	0.291	0.271	0.219	0.297	0.260	0.269
	cpl-A	0.209	0.224	0.197	0.211	0.210	0.210
	cpl-B	0.236	0.203	0.172	0.208	0.204	0.205
	cpl-C	0.145	0.163	0.180	0.171	0.163	0.165
Pc soil with high %OM	ctrl	0.471	0.372	0.576	0.442	0.473	0.465
	F	0.861	0.763	0.881	0.769	0.835	0.818
	ch-A	0.499	0.527	0.510	0.433	0.512	0.492
	ch-B	0.589	0.520	0.484	0.538	0.531	0.533
	ch-C	0.762	0.602	0.716	0.634	0.693	0.678
	cph-A	0.430	0.491	0.426	0.433	0.449	0.445
	cph-B	0.576	0.320	0.451	0.484	0.449	0.458
	cph-C	0.669	0.439	0.575	0.489	0.561	0.543
	cpl-A	0.569	0.486	0.449	0.442	0.501	0.486
	cpl-B	0.509	0.512	0.489	0.538	0.503	0.512
	cpl-C	0.498	0.449	0.437	0.427	0.461	0.453
Pc soil with low %OM	ctrl	0.371	0.377	0.346	0.343	0.365	0.360
	F	0.571	0.486	0.548	0.592	0.535	0.549
	ch-A	0.431	0.336	0.377	0.361	0.381	0.376
	ch-B	0.327	0.424	0.369	0.499	0.373	0.405
	ch-C	0.489	0.518	0.566	0.474	0.525	0.512
	cph-A	0.348	0.344	0.261	0.402	0.318	0.339
	cph-B	0.420	0.389	0.414	0.367	0.408	0.397
	cph-C	0.443	0.401	0.452	0.331	0.432	0.406
	cpl-A	0.391	0.340	0.334	0.356	0.355	0.355
	cpl-B	0.341	0.341	0.338	0.357	0.340	0.344
	cpl-C	0.450	0.330	0.311	0.367	0.364	0.365

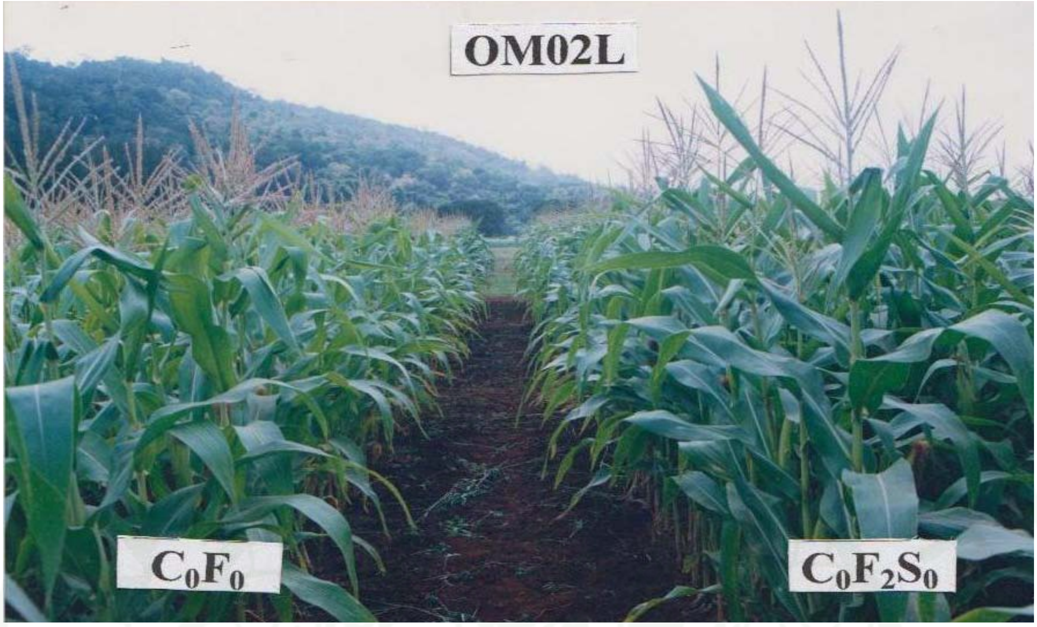
Appendix Table 27 P uptake in maize shoot (g pot^{-1}) of pot experiment.

Soil type	Treatments	Rep 1	Rep 2	Rep 3	Rep 4	Rep 5	Avg.
Kt	ctrl	0.0151	0.0131	0.0105	0.0128	0.0129	0.0123
	F	0.0325	0.0306	0.0242	0.0283	0.0291	0.0293
	ch-A	0.0307	0.0332	0.0265	0.0286	0.0301	0.0297
	ch-B	0.0436	0.0396	0.0338	0.0387	0.0390	0.0407
	ch-C	0.0645	0.0910	0.0831	0.0738	0.0795	0.0813
	cph-A	0.0036	0.0103	0.0126	0.0081	0.0088	0.0103
	cph-B	0.0136	0.0157	0.0135	0.0135	0.0143	0.0147
	cph-C	0.0214	0.0207	0.0207	0.0211	0.0209	0.0216
	cpl-A	0.0153	0.0146	0.0132	0.0142	0.0144	0.0145
	cpl-B	0.0181	0.0144	0.0128	0.0154	0.0151	0.0151
	cpl-C	0.0211	0.0204	0.0213	0.0212	0.0209	0.0202
Pc soil with high %OM	ctrl	0.0276	0.0299	0.0376	0.0326	0.0317	0.0317
	F	0.0455	0.0411	0.0386	0.0420	0.0417	0.0426
	ch-A	0.0350	0.0352	0.0382	0.0366	0.0361	0.0364
	ch-B	0.0421	0.0384	0.0386	0.0404	0.0397	0.0395
	ch-C	0.0659	0.0572	0.0613	0.0636	0.0615	0.0612
	cph-A	0.0313	0.0303	0.0295	0.0304	0.0303	0.0313
	cph-B	0.0370	0.0391	0.0332	0.0351	0.0364	0.0368
	cph-C	0.0443	0.0327	0.0427	0.0435	0.0399	0.0405
	cpl-A	0.0303	0.0334	0.0336	0.0320	0.0324	0.0334
	cpl-B	0.0353	0.0354	0.0376	0.0365	0.0361	0.0365
	cpl-C	0.0338	0.0338	0.0349	0.0344	0.0342	0.0349
Pc soil with low %OM	ctrl	0.0553	0.0567	0.0475	0.0514	0.0532	0.0536
	F	0.0576	0.0494	0.0558	0.0567	0.0543	0.0586
	ch-A	0.0620	0.0567	0.0587	0.0604	0.0592	0.0567
	ch-B	0.0733	0.0659	0.0707	0.0720	0.0700	0.0700
	ch-C	0.0763	0.0987	0.0969	0.0866	0.0907	0.0898
	cph-A	0.0547	0.0547	0.0455	0.0501	0.0516	0.0515
	cph-B	0.0625	0.0494	0.0552	0.0588	0.0557	0.0550
	cph-C	0.0556	0.0617	0.0532	0.0544	0.0568	0.0568
	cpl-A	0.0557	0.0513	0.0566	0.0562	0.0545	0.0565
	cpl-B	0.0633	0.0459	0.0493	0.0563	0.0528	0.0539
	cpl-C	0.0714	0.0514	0.0597	0.0656	0.0609	0.0610

Appendix Figure

Appendix Figure 1 Landscape of field experimental area in Suwan Farm before field trial start

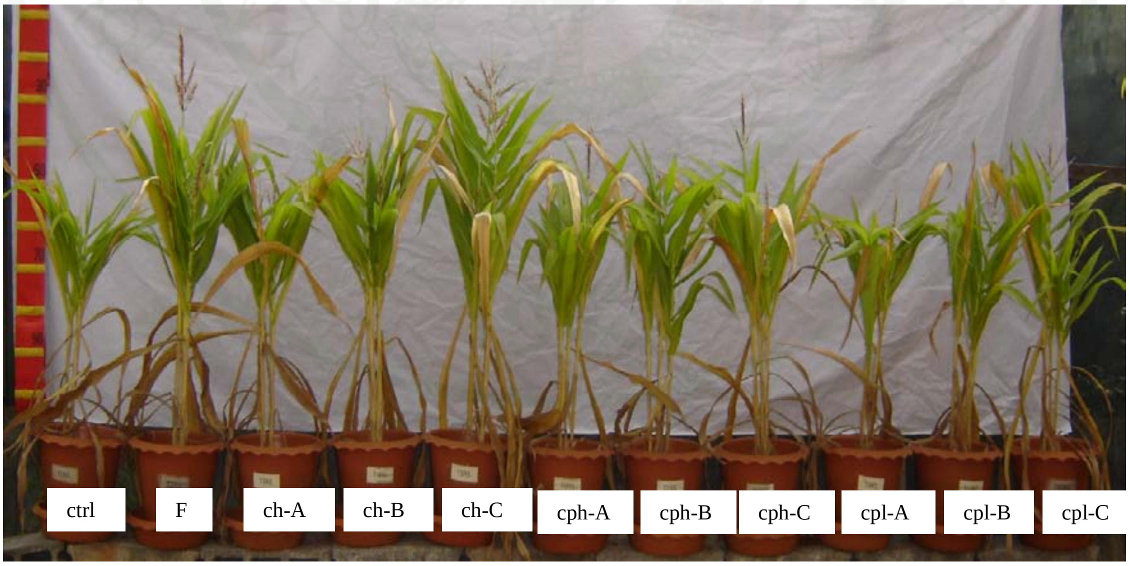
Appendix Figure 2 Maize height on plot receiving the highest NP rate (left hand side) comparing to plot receiving compost at the lowest rate (right hand side) in 2002



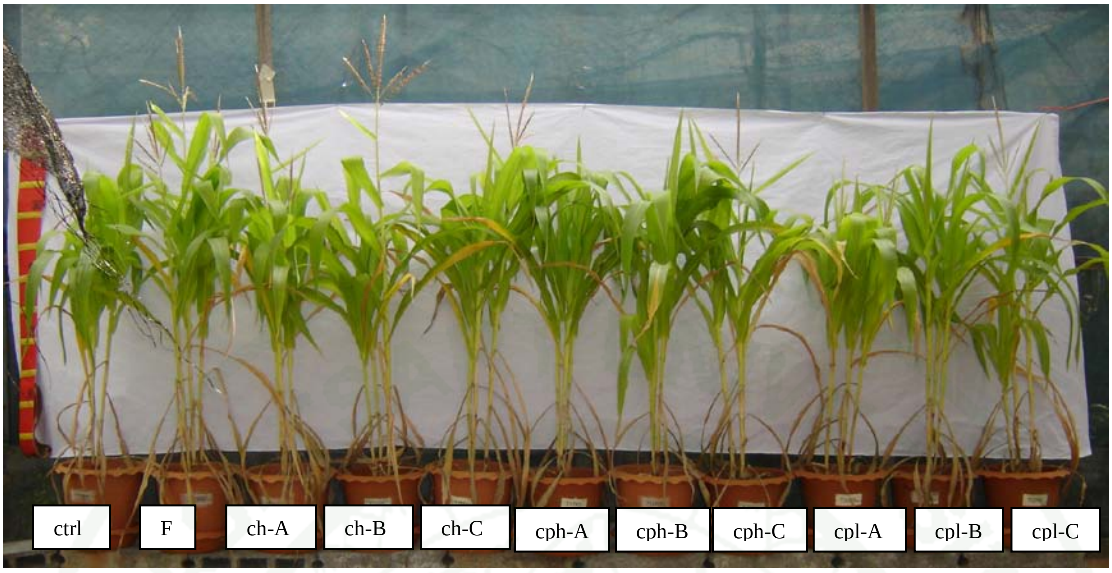
Appendix Figure 3 Maize height on plot receiving medium NP fertilizer rate (right hand side) comparing to control plot (left hand side) in 2002

Appendix Figure 4 Maize lodging in field experiment in 2005 from strong wind

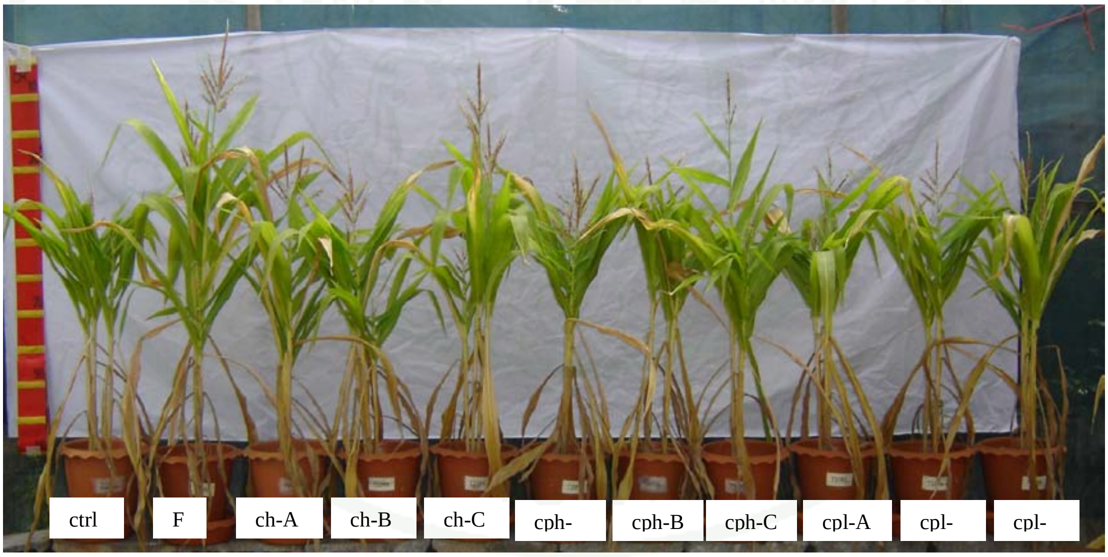
Appendix Figure 5 Setup for laboratory incubation experiment: (A) Soil samples in incubator; (B) Shaking soil samples; (C) Distillation apparatus for Nitrogen determination; and (D) Phosphorus determination by Bray II method



Appendix Figure 6 Maize heights of different treatments in pot experiment with Korat soil series



Appendix Figure 7 Maize heights of different treatment in pot experiment with Pak Chong soil series with high %OM



Appendix Figure 8 Maize heights of different treatment in pot experiment with Pak Chong soil series with low %OM

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PUBLICATIONS:

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