12th Asian Maize Conference and Expert Consultation on

Maize for Food, Feed, Nutrition and Environmental Security

30 October – 1 November 2014
Bangkok, Thailand

Extended Summaries

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Effect of Fertilizer Management and Cropping System on Soil Quality, Greenhouse Gas Emission and Maize Productivity

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Introduction

There are many factors to be managed for improving maize productivity, such as the selection of suitable production area, proper planning of the planting date (especially due to climate change), use of high-yielding varieties which are suitable for each area, and soil and fertilizer management based on soil fertility and crop's requirement. However, the survey data shows that Thai farmers lack necessary skills for precision-nutrient management. Attanandana et al. (2011) reported that about 64.9 percent of maize farmers applied chemical fertilizers at 63-125 kg ha-I, while some farmers applied fertilizers at 131-188 kg ha-I. About 54.4 percent of farmers applied fertilizers twice, initially using a chemical fertilizer grade of 16- 20-0, and then urea, whereas about 55 percent of farmers applied chemical fertilizer grade of 16-20-0 only once at the time of planting. Additionally, Kanchanalai et al. (2009) reported that most farmers applied organic fertilizers at about 188-625 kg ha-I for maize production which was insufficient for improving soil productivity.

Soil and fertilizer management not only affects soil fertility and maize production but also greenhouse gas emission or mitigation. Jansson *et al*. (2010) reported that the carbon in the soil is mostly derived from vegetation through photosynthesis process. After the plant is incorporated into the soil and decomposed by micro-organisms, the absorbed carbon in the plant residues will accumulate in the soil as humus which is a stable form of carbon. Then, the carbon is stored in the soil for many years as called this process as "carbon sequestration" (Lal, 2004; Lal et al., 2007). Matsumoto *et al*. (2008) reported that about 1,700 kg C ha^{-1} was input to the soil through incorporation of maize residues which was grown on sandy soil with sufficient fertilizer application. The increase of soil organic carbon is significantly related to carbon addition through crop residues incorporation and organic fertilizer application. However, there is not much data on greenhouse gas emission from maize production areas under different soil and fertilizer management in Thailand. Therefore, this study aims to evaluate the long-term effects of fertilizer management and maize cropping systems on alteration of soil quality, maize productivity as well as greenhouse gas emissions in Thailand.

Materials and methods

This experiment was conducted on Samo Thod Soils (very fine, smectitic, isohyperthermic, *Chromic Haplusterts*) as a long-term (since 1981), semi- demonstration plot. It consists of three cropping systems with maize as the main crop, and sorghum, mungbean and lablab bean as second crops. Among those three cropping systems, there were four levels of fertilizer management for maize which are: l) without fertilization, 2) chemical fertilizer application, 3) chicken manure application, and 4) application of combination of chemical fertilizer and chicken manure. The three-cropping systems are laid as strip across with four-levels of fertilizer management without replication. Dimension of each plot is 18 x 40 m

During the period from 1981-1989, Suwan-1 (SW1), a popular open-pollinated maize variety, was planted with chemical fertilizer application at a rate of 62.5-62.5-0 kg N-P_2O_5-K_2O ha^{-1}. Then, during the period from 1990 to 2010 the maize variety was changed to another open-pollinated variety (OPV) named Nakhon Sawan-1 (NS1) and fertilizer applied: 62.5-31.3-0 kg N-P_2O_5-K_2O ha^{-1} during 1990 to1993; 62.5-31.25-31.25 kg N-P_2O_5-K_2O ha^{-1} during 1994 to 2005; and without application during 2006 to 2010. During the period from 2011 to 2014, Nakhon Sawan-3 (NS3) hybrid maize was planted and fertilizer applied at the rate of 62.5-31.25-31.25 kg N-P_2O_5-K_2O ha^{-1} Chicken manure was incorporated into the soil a week before maize planting at a rate of 6.25 t ha^{-1} based on dry-matter. The chicken manure contained a moisture-level of about 9.98 percent and its pH was likely to be and its carbon, nitrogen, neutral (about 6.7), and its carbon , nitrogen, phosphorus, and potassium contents were 35.0 percent, 2.6 percent, 3.2 percent, and 2.1 percent, respectively. Chemical fertilizer was applied twice; initially using a half-rate of nitrogen fertilizer and full-rates of phosphate and potash fertilizers, and then using another half-rate of nitrogen fertilizer.

Maize was planted during the early rainy season in May of every year, with spacing between rows and plants of 0.75 x 0.20 m. Maize harvesting is carried out with four replication of 3x3 m harvesting area. Then, the second crops, such as sorghum, mungbean and lablab bean, were planted without a fertilizer application. Sorghum was planted with a spacing of 0.60 x 0.10 m whereas mungbean and lablab bean were planted with a spacing of 0.50 x 0.10 m. The second crops were planted without fertilizer application, similar to the farmers' practice. Sorghum, mungbean, and lablab bean were harvested with four replications of 3x3 m harvesting area of each plot. Carbon dioxide emission was trapped by IN sodium hydroxide (Anderson, 1982) for 24 hours every two-weeks from March, 2013 to March, 2014. Soil samples were taken at depth before planting for chemical analysis (such as pH) by using the soil- to-water ratio of 1:1; soil organic carbon was determined by wet digestion using the method of Walkley and Black (Allison, 1965), available Phosphorus by Bray II extraction followed by colorimetric method, and molybdenum blue exchangeable potassium by 1*N* ammonium acetate extraction followed by measurement using the flame photometer.

Results and discussion

Effect Of fertilizer management and maize cropping system on soil fertilit

Maize cultivation without fertilizer application continuously for 32 years drastically depleted soil organic carbon to about 297 kg C $ha^{-1}y^{-1}$ and the soil organic carbon content reduced from 13.45 g kg^{-1} to 10.39 g kg^{-1} (Table 1 and Figure l). This was caused by less biomass production of the crops under non-fertilization and subsequently less carbon returned to the Soil (Table 2). Application Of chemical fertilizer at a rate of 62.5-31.25-31.25 kg $N\text{-}P_2O_5\text{-}K_2O$ ha^{-1} lowered the depletion of soil organic carbon because the fertilizer provides nutrients to enhance biomass production of the crops higher than non-fertilization (Table 2). However, the soil organic carbon still decreased by about 13.4 percent and the rate of soil carbon loss was accounted for 175 kg C $ha^{-1}y^{-1}$ (Table l). Application of 6.25 t ha^{-1} of chicken manure was efficient to maintain the level of soil organic carbon because it provided about 2.19 t C to the soil. In addition, it also increased crop growth and biomass production which the crop residues later returned to the soil. Long-term application of chicken manure significantly increased phosphorus and potassium accumulation in the soil to the highest levels of 174 mg P kg^{-1} and 274 mg K kg^{-1}, respectively (Figures 2 and 3). Fertilizer management affected to soil fertility more than the cropping system. However, the maize-lablab bean cropping system caused soil carbon loss at 108 kg C $ha^{-1}y^{-1}$ less than the Other Systems (Table l).

Table 1. Change of soil carbon within 0.20 m depth through fertilizer management and cropping system under maize production for 32 years.

Treatments	Average SOC in 1982-1987 (g C m^{-2})	Average SOC in 2011-2014 (g C m^{-2})	Rate of SOC loss (kg C ha^{-1} y^{-1})	Changes of SOC (percent)[1/]
Cropping system				
1. Maize-Sorghum	4075	3577	156	-12.2
2. Maize- Mung bean	4068	3556	160	-12.6
3. Maize-Lablab bean	4375	4028	108	-7.9
Fertilizer management				
1. No fertilizer	4215	3265	297	-22.5
2. Chemical fertilizer	4177	3617	175	-13.4
3. Chicken manure	3931	3901	9	-0.8
4. Chemical fertilizer + chicken manure	4368	4098	84	-6.2

[1/] Negative values mean decreasing of SOC, SOC: soil organic carbon

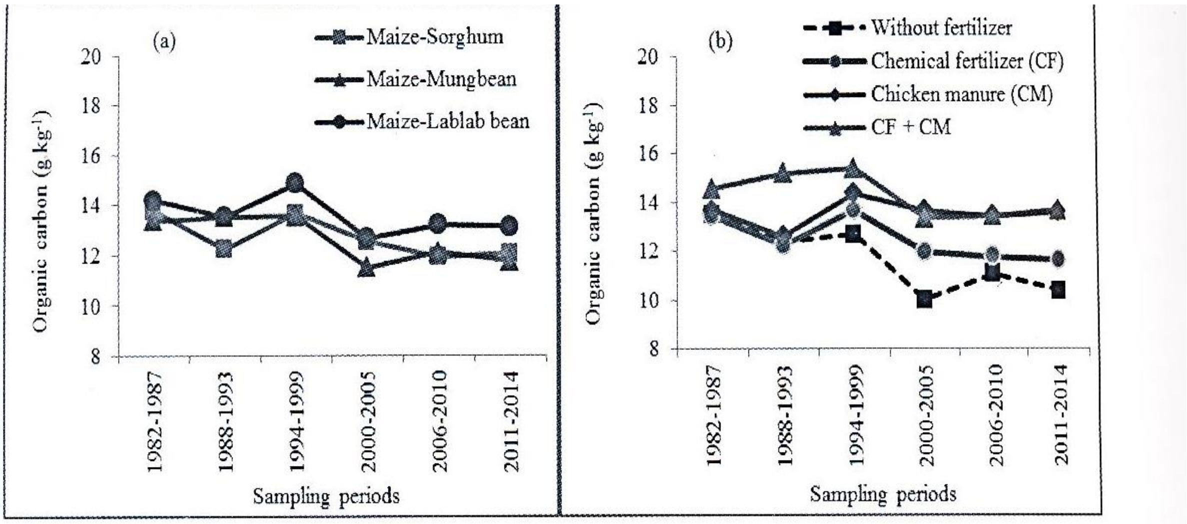

Figure 1. Changes of soil organic carbon, as affected by (a) cropping system; and (b) fertilizer management.

Table 2. Quantity of carbon incorporation into the soil through crop residues

Treatments	Maize residue (kg C ha^{-1})	Sorghum residue (kg C ha^{-1})	Mungbean residue (kg C ha^{-1})	Lablab bean residue (kg C ha^{-1})
No fertilizer	2,763	783	284	408
Chemical fertilizer	4,631	795	602	1,094
Chicken manure	5,994	1,366	512	1,628
Chemical fertilizer + chicken manure	7,163	1,484	689	1,610

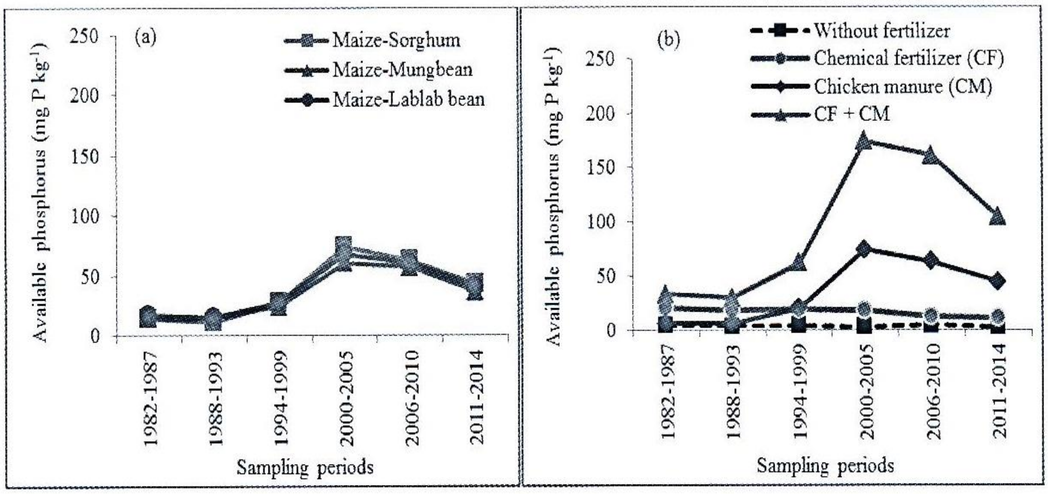

Figure 2. Changes of available phosphorus, as affected by (a) cropping system; and (b) fertilizer management.

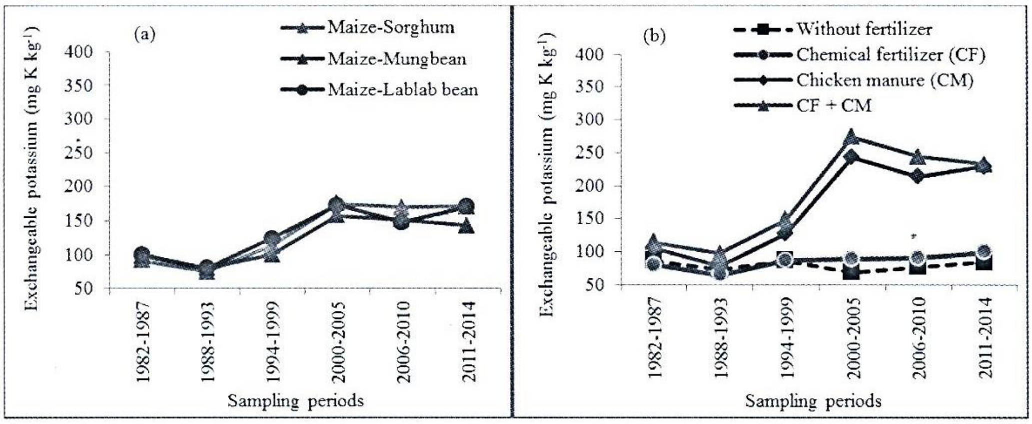

Figure 3. Changes of exchangeable potassium, as affected by (a) cropping system (b) fertilizer management.

Effect of fertilizer management and maize cropping system on maize productivity

The study showed that fertilizer management significantly affected maize productivity more than e effect of cropping system. The combination plication of chicken manure and chemical fertilizer the most effective fertilizer management for improving maize yields. This is because the chicken Manure also provides nutrients to enhance maize growth and productivity. The sole application of 6.25 t ha^{-1} of chicken manure was effective for maize productivity, where the productivity was as high as the chemical fertilizer application. However, maize production without fertilization resulted in low-productivity due to insufficient nutrient supply for maize (Figure 4).

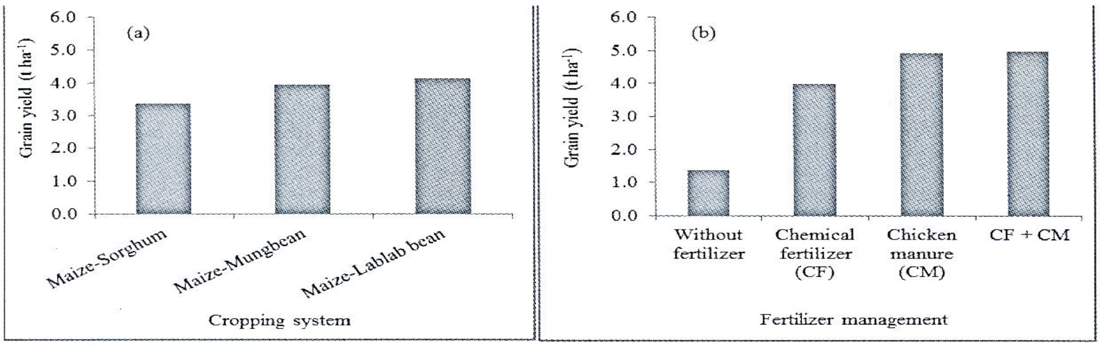

Figure 4. Maize productivity in 2013 as affected by (a) cropping system, and (b) fertilizer management.

Carbon dioxide emission

Carbon dioxide emission from the soil surface showed similar trends between different fertilizer management and cropping systems (Table 3; Figures 5 and 6). The CO_2 emission from the soil surface under the maize cropping system was high at 32-74 kg CO_2 $ha^{-1}d^{-1}$ during the rainy season (May to October) and decreased to 26 to 30 kg CO_2 ha^{-1} d^{-1} during dry season (November to February) (Figures 5 and 6). This result conformed with Matsumoto *et al*. (2008) who found that the CO_2 emission under the maize cropping system in sandy soil was high (at 30-80 kg CO_2 $ha^{-1}d^{-1}$) from March to October and reduced (to 10 to 30 kg CO_2 $ha^{-1}d^{-1}$) during the period from November to February. The CO_2 emission of bare soil outside the cropping area also showed the same pattern as that under crop cultivation. However, the bare soil sometimes showed higher CO_2 emission than was observed under crop cultivation because it was exposed to sunlight directly, without shading of any crop, which might cause higher-activity of microorganisms in the soil including crop root respiration and decomposition of organic matter in the soil. The total annual CO_2 emission was highest (at 17.76-18.18 t CO_2 $ha^{-1}y^{-1}$) in the chicken manure treatments and lowest (at 14.56 t CO_2 $ha^{-1}y^{-1}$) in the chemical fertilizer treatments. The plot without fertilization showed the lowest-total annual CO_2 emission (at 13.44 t CO_2 ha^{-1} y^{-1}) (Table 3.)

Table 3. Annual carbon dioxide emission from the soil surface as affected by fertilizer management and cropping system

Treatments	Annual CO_2 emission from soil surface ($t\ C\ ha^{-1}\ y^{-1}$)
Bare soil	16.34
Cropping system	
1. Maize-Sorghum	16.16
2. Maize- Mung bean	15.40
3. Maize-Lablab bean	16.39
Fertilizer management	
1. No fertilizer	13.44
2. Chemical fertilizer	14.56
3. Chicken manure	18.18
4. Chemical fertilizer + chicken manure	17.76

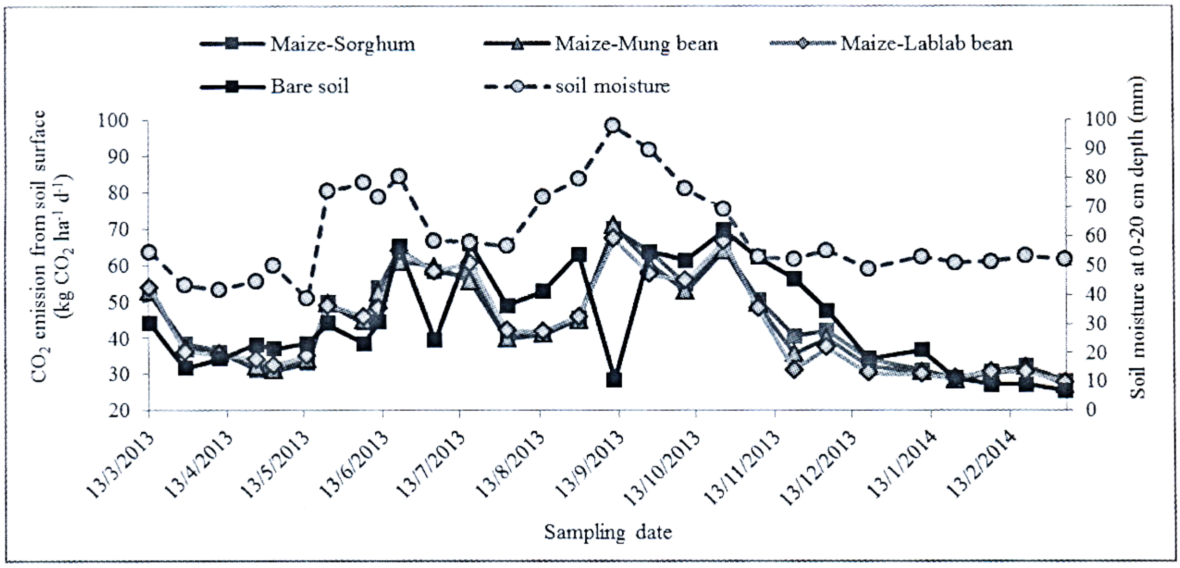

Figure 5. CO_2 emission from the soil surface as affected by cropping system.

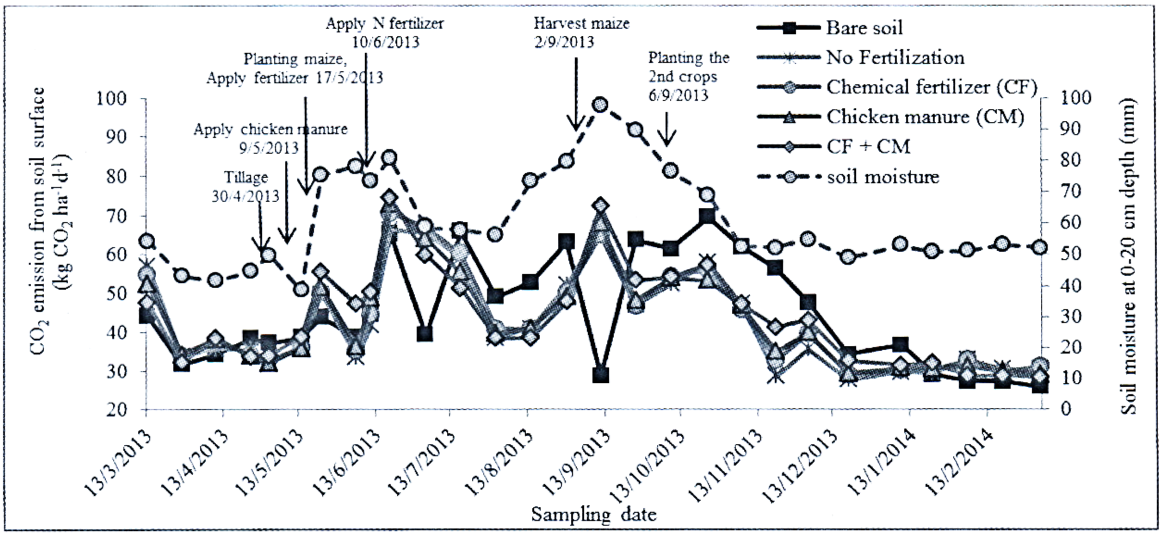

Figure 6. CO_2 emission from the soil surface as affected by fertilizer management.

Economic return

The economic return was analyzed using the value-to-cost ratio (VCR). It was found that the maize- mungbean cropping system was the most profitable system with VCR value of 2.57 (Table 4). Application of chicken manure for maize production revealed the highest-economic return with a VCR value of 2.11, followed by the treatment of chemical fertilizer application and the combination application of chicken manure and chemical fertilizer (Table 4).

Table 4. Analysis of economic return of maize cropping systems under different fertilizer management

Treatments	Maize yield t ha^{-1}	2nd crop yield t ha^{-1}	Cost for maize USD ha^{-1}	Cost for 2nd crop USD ha^{-1}	Income for maize USD ha^{-1}	Income for 2nd crop USD ha^{-1}	Gross return USD ha^{-1}	Value to cost ratio
Cropping systems								
1. Maize-Sorghum	3.363	2.042	423	104	633	384	490	0.93
2. Maize-Mungbean	3.945	1.425	434	126	744	1258	1442	2.57
3. Maize-Lablab bean	4.136	0.533	438	0	779	0	341	0.78
Fertilizer management								
1. Without fertilization	1.365	0.723	214	77	257	267	234	0.81
2. Chemical fertilizer	3.990	1.165	450	77	751	519	744	1.41
3. Chicken manure	4.925	1.715	438	77	928	674	1087	2.11
4. Chemical fertilizer + chicken manure	4.979	1.731	626	77	938	730	965	1.38

Conclusion

Maize-sorghum, maize-mungbean and maize-lablab bean cropping systems affected soil fertility, maize productivity, and greenhouse gas emission. However, the maize-mungbean cropping system was considered to be the most cost-effective system. Among the different fertilizer management treatments, application of chicken manure at a rate of 6.25 t ha^{-1} was the most valuable as it was able to maintain soil fertility and enhance maize productivity, though the greenhouse gas emission was high compared to chemical fertilizer application and the treatment "without fertilization."

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