

# CARBON ENHANCING MANAGEMENT SYSTEMS (CEMS)

## Residue Management for Sustained Soil and Crop Productivity in Ghana



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June 2008



# **CARBON ENHANCING MANAGEMENT SYSTEMS (CEMS)**

## **Residue Management for Sustained Soil and Crop Productivity in Ghana**

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**June 2008**

This study and brochure were made possible by the generous support of the American people through the United States Agency for International Development (USAID). The contents are the responsibility of the Soil Management CRSP (Grant No. LAG-G-00-97-00002-00) of the University of Florida and do not necessarily reflect the views of the USAID or the United States Government.

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## OVERVIEW

For many centuries, agriculture in the West African tropics, including Ghana, has relied on the practice of shifting cultivation – an agricultural system in which the land is cultivated for a few years and then abandoned after becoming inadequate for crop production. Typically, new land is cultivated for one to three years, then left to regenerate, with fallow periods ranging from 10 to 18 years before re-cultivation. This system was sustainable until population pressure reduced fallow periods to between five and ten years. This shortening of the fallow period triggered a soil degradation spiral because there was insufficient time for the land to re-generate before re-cultivation. Without needed fertilizer inputs soil productivity declined, leading to low crop output under long-term cultivation. Further land pressures resulted in continuous cropping with 0 to one year fallow periods, and where no inputs were applied, the land productivity was drastically reduced within five years of cultivation.

Soil productivity decline can be linked to decreasing soil organic matter (SOM), which serves as a reservoir for soil nutrients and provides energy and a “food” source for micro-organisms that bring about essential processes in the soil to release nutrients for crop growth. SOM benefits the soil in several other ways, including soil aggregate formation and improvement of its structure, which influences water retention and aeration and reduces soil erosion.

SOM is also a major sink for carbon. What this means is when plants die, the residue they produce from using CO<sub>2</sub> via photosynthesis is returned to the soil and converted to SOM. When the SOM decomposes, CO<sub>2</sub> is released back into the atmosphere. Current climate changes, including global warming, are attributed to increased CO<sub>2</sub> loading of the atmosphere. Many scientists, therefore, believe that increasing SOM is one way of mitigating the rising atmospheric CO<sub>2</sub> and reducing global warming. Thus, using agricultural practices that increase or maintain SOM may also benefit the Earth’s climate.

When new land is cleared, SOM that took a long time to accumulate decomposes quickly under the high tropical temperature conditions of West Africa, releasing nutrients that can support crop growth for only about three to four years. A continuous input of residues during fallow periods is thus necessary to rebuild the SOM. Shortening these fallow periods or continuous cropping reduces residue input and often

results in the formation of only a small amount of SOM. This combination of shortened fallow periods, residue removal by burning (Figure 1) or grazing and the non-application of fertilizer inputs can result in a rapid and drastic decline in SOM and, as a consequence, a decrease in soil productivity.

The way residues and fertilizers are managed has implications for the soil and for agricultural productivity.



*Figure 1. Farmers practice of residue burning as a method of land clearing.*

## OBJECTIVE

Research studies were carried out in two farming zones in Ghana, Kpeve and Wa. The objective was to determine better ways to manage residues for sustained agricultural productivity, especially under continuous cropping systems. This technical bulletin presents the main findings from those studies in order to assist in formulating extension advice for sustained soil and crop productivity in Ghana.

## SITE DESCRIPTIONS

Kpeve (Volta Region) and Wa (Upper West) lie in two contrasting ecological zones of Ghana (Figure 2). The annual rainfall at Kpeve is 1200 mm distributed in two seasons: May to July (major season) and September to November (minor season). The major season receives about 66 percent of the annual rainfall. The vegetation is savanna-forest transition and the soil (Typic Haplustalf) is coarse textured with abundant gravel beyond 50 cm depth. The clay (low activity) content is about 20 percent. Due to the two rainfall seasons at Kpeve, vegetation grows year round but there are two cropping seasons in the year.

Annual rainfall at Wa is about 1100 mm but is concentrated in only one season from May to October.



**Figure 2. Map of Ghana showing sites.**

Much of the vegetation growth is restricted to the rainy months only. The vegetation is Guinea-savannah. Like Kpeve, the soil (Oxic Haplustalf) is coarse textured with abundant gravel with depth and has very low clay content (8 percent).

Elephant grass, which commonly grows at both Kpeve and Wa as fallow vegetation, produces about 15 to 20 ton/ha of residue per year at Kpeve but only half this amount (7 to 10 ton/ha per year) at Wa. Residue returned to the soil is often constrained by frequent bush fires at both sites. Animal grazing, which is more common at Wa than at Kpeve, further reduces the amount of residue returned to the soil at Wa. Consequently, the SOM at Kpeve in fallowed soils is much higher (3.1 to 4.1 percent) than that at Wa (0.43 and 1.1 percent). It is very important, therefore, that the design of residue management systems for sustained agricultural productivity take these site differences into consideration.

### Site Studies - Kpeve

Maize is a common crop grown at Kpeve. Production normally begins with land clearing, usually by slashing and burning, before hoeing. But about 15 percent of farmers also hire tractors to plough their lands. Maize for the major rainy season is planted in May/June and is harvested in August. Typical farmer yields range from 0.3 to 2 ton/ha but the average is about 0.5 ton/ha. Minor season production is limited. Maize is often intercropped with cassava or rotated with bush fallow and, to some extent, with legumes such as cowpea. Fallow periods are between two and four years.

How does residue management affect the SOM and maize productivity within the savanna-forest zones of Ghana?

To answer this question a four-year study (2003 to 2006) was carried out at Kpeve to investigate the changes in SOM and maize yields under different residue management treatments in a maize-fallow rotation experiment. Maize was grown during the major season. The minor season was used to produce residue with the goal of maintaining soil organic matter and maize yields in the major season.

### Treatments

The study treatments were as follows:

- Treatment T1 = maize-bush fallow rotation with the fallow residue burned just before maize planting in late May or early June (similar to farmer practice),
- Treatment T2 = maize-bush fallow rotation with the fallow residue incorporated just before maize planting (similar to tractor ploughing),
- Treatment T3 = maize-pigeon-pea rotation with the pigeon pea residue slashed and applied to the soil surface as mulch before maize planting (improved fallow),
- Treatment T4 = maize-bare fallow rotation with the total removal of maize stover after grain harvest and weed-free fallow period until the next maize planting,
- Treatment T5 = maize-cowpea rotation with the cowpea residue slashed and surface-applied as mulch before maize planting (improved fallow),
- Treatment T6 = maize-mucuna rotation with the mucuna residue slashed and surface-applied as mulch before maize planting (improved fallow), and
- Treatment T7 = maize-bush rotation with 61 kg N/ha, 16 kg P/ha and 31 kg K/ha applied to the maize and the bush residue slashed and surface applied as mulch.

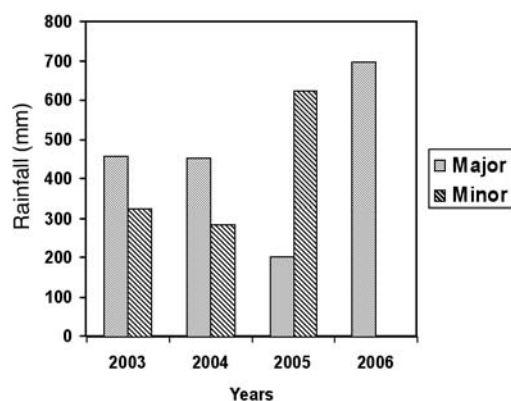
The seven treatments were repeated for four years.

Rainfall varied from year to year during the four years with 2005 major season receiving a very low amount (Figure 3).

The total residue produced by the maize stover and fallow vegetation and returned to the soil varied with treatments (Table 1). Treatment T7 returned the highest residue of 18 ton/ha per year to the soil whereas treatment T4 returned the least (2.5 ton/ha/yr).

Even though treatments T1 and T2 produced about the same amount of residue, burning residue in T1 reduced





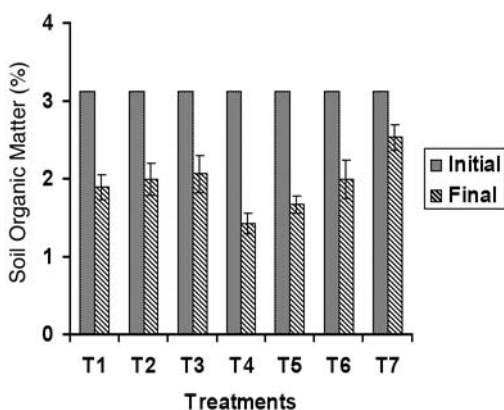
**Figure 3.** Seasonal rainfall during the research years.

the actual amounts returned to the soil. Generally, the legume fallow plants produced less residue biomass than the bush, but among the legumes, the pigeon pea returned the largest residue biomass to the soil (T3).

**Table 1.** Average residue production and return by the different treatments per year.

Treatment	Residue (t/ha/yr)	
	Produced	Returned
T1	12.7	7.2
T2	13.5	13.5
T3	13.0	13.0
T4	2.5	2.5
T5	10.5	10.5
T6	10.9	10.9
T7	18.3	18.3

The amount of residue returned and the way the residue was managed affected the build up of SOM. As Figure 4 shows, the SOM decreased in all treatments after the four years, relative to its initial amount of over



**Figure 4.** Soil organic matter under the different treatments at the end of the four-year study at Kpeve, Ghana.



**Figure 5.** Bare fallow in which all the residue is removed.

3.0 percent. However, some management treatments led to more drastic reduction. For example, treatment T4, in which all the maize stover residue was removed (Figure 5) and no fallow vegetation was allowed to grow resulted in more than 55 percent loss of the SOM after four years (Figure 6). On the contrary, treatments T3 and T7 minimized SOM loss.



**Figure 6.** Maize growth following bare fallow shown in Figure 5.

Even though treatments that returned high amounts of residues minimized the loss of SOM, it is worth noting that the effects of treatments T1 and T2 on the SOM were not different. Despite the larger residue return under T2, the incorporation method was not an effective way of maintaining the SOM.

Maize yields also varied with year and with residue management treatments (Table 2). The year-to-year variations could be attributed to rainfall variation (Figure 3). For example, maize yields were particularly low in 2005 when the major seasonal rainfall was also very low. In all cases, treatment T7 consistently produced the highest yields whereas the T4 maize failed from 2005 onwards.

**Table 2. Maize yields (t/ha) under the different treatments at Kpeve.**

Treatment	Years			
	2003	2004	2005	2006
T1	2.0	2.4	0.5	1.0
T2	1.8	2.2	0.4	1.3
T3	1.2	2.3	0.7	1.5
T4	1.4	1.8	0.0	0.1
T5	1.6	2.5	0.5	1.0
T6	1.9	1.9	1.0	1.8
T7	2.5	3.2	1.3	2.4

### Lessons Learned

1. Residue removal is generally detrimental to soil and crop productivity. The return of residues to the soil and the application of the residues as mulch are effective ways of minimizing SOM losses in continuous cropping systems.
2. The incorporation or burning of residues is not beneficial to SOM build up.
3. As much as possible, the soil must be covered by vegetation during the fallow period. In this respect, we found the pigeon pea as a hardy and woody legume that provided both aerial and contact cover for the soil and returned relatively large residue biomass to the soil (Figure 7).
4. With modest fertilizer application to maize and sound residue management, it is possible to achieve an average maize yield above 2 ton/ha from the major season alone, about four times average farmer yields.



**Figure 7.**  
*Pigeon pea becoming a small “forest.” Note the leaf litter that covers the soil surface.*

### Site Studies - Wa

Two sets of studies were carried out at Wa to investigate (i) the effect of crop rotation on residue production, SOM and maize yields and (ii) the effect of nitrogen and phosphorus fertilizer application on residue

production and the impact of retaining the residue on SOM and maize productivity.

### Study I

In the first study, a five-year crop rotation experiment was conducted with the following treatments:

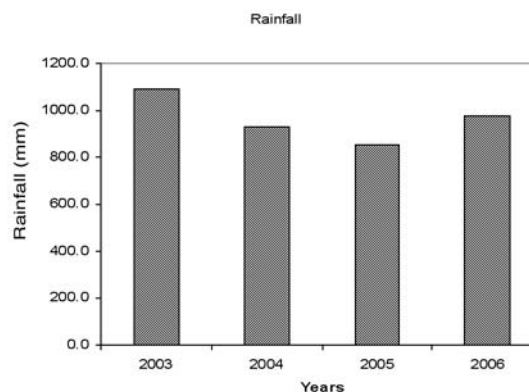
- Treatment T1 = continuous maize with 40 kg N/ha,
- Treatment T2 = continuous maize with 80 kg N/ha,
- Treatment T3 = maize-bush fallow rotation (T5) with one year fallow between maize years,
- Treatment T4 = maize-mucuna rotation, and
- Treatment T5 = maize-groundnut rotation.

In treatments T3 to T5 (Figure 8), 40 kg/ha of N was applied to the maize crop. Unlike Kpeve, the rotations were on annual cycles because Wa has only one growing season per year. At the end of each cropping season, the residues from each treatment were left on the soil surface as mulch until the next growing season when it was incorporated into the soil by hand hoeing. Soil organic matter was measured each year except in 2004.

During the study rainfall varied from year to year with 2005 receiving the lowest (Figure 9).



**Figure 8.** *Mucuna, peanut and bush fallow plots in alternate years.*



**Figure 9.** *Year-to-year rainfall at Wa from May to October.*



Figure 10 shows the average residue returned to the soil over four years. Average residue returned to the soil was about the same (4.1 t/ha) for T2, T3, T4 and T5 whereas T1 returned the least residues (3.0 t/ha).

Soil organic matter decreased under all cropping systems except under the maize-bush fallow rotation treatment (T3) where there was no change (Figure 11).

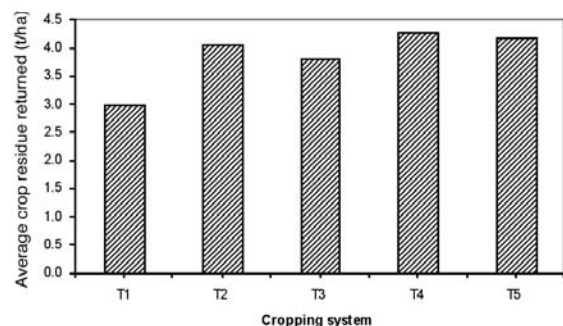


Figure 10. Total residues (average of four replicates) produced and returned to the soil over four years at Wa.

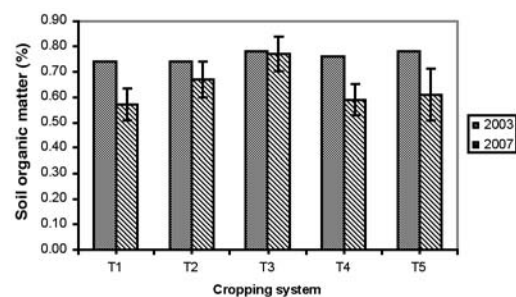


Figure 11. Soil organic matter at the beginning and end of the study period at Wa, Ghana.

Averaged across years, maize grain yield was highest in maize following groundnut (T5) and least in continuous maize without fertilizer (T1). Grain yields for T2, T3 and T4 were 2.8, 2.5 and 2.3 t/ha respectively (Table 3).

Table 3. Effect of cropping system and N fertilizer application (kg/ha) on maize grain yield (t/ha) at Wa.

Treatment	N-rate	Year		Mean
		2004	2006	
Maize-maize	40	2.5	1.1	1.8
Maize-maize	80	3.7	2.0	2.8
Maize-bush	40	2.7	2.3	2.5
Maize-mucuna	40	3.0	1.6	2.3
Maize-peanut	40	3.6	3.0	3.3

### Study II

In the second study, three levels of N (0, 60, and 120 kg N/ha) and three levels of phosphorus (0, 60 and 90 kg P<sub>2</sub>O<sub>5</sub>) were applied in continuous maize production system and the study was repeated for four years.

Unlike the first study, crop residues were left as mulch on the field with no tillage.

The total maize residue returned to the soil over four years was least (11.1 t/ha) for the treatment that received no fertilizer application (NOP0), whereas treatments that received N and P application returned total residue biomass of more than 30 ton/ha after four years (Figure 12).

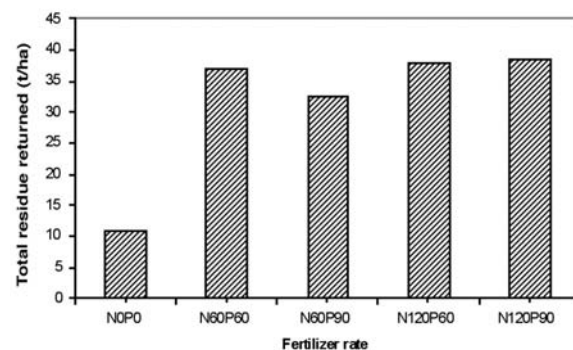


Figure 12. Total residues (average of four replicates) returned to soil by the end of four years.

The low amount of residue produced as a result of no fertilizer application (NOP0) resulted in a decrease in soil organic matter after four years (Table 4), while the other treatments that received fertilizer and high residue retention showed increased SOM.

Table 4. Effect of N and P fertilization on soil organic matter (%) at Wa, Ghana.

Treatment	Year		Change
	2003	2007	
NOP0	0.67	0.57	-0.10
N60P60	0.64	0.79	0.15
N60P90	0.64	0.81	0.17
N120P60	0.71	0.86	0.15
N120P90	0.67	0.79	0.12

Maize grain yield was on average lower without fertilizer than when N and P fertilizer was applied (Table 5). Averaged across years, maize grain yield was 0.53 t/ha without fertilizer application and ranged from 2.5 to 3.7 t/ha with application of N and P fertilizer.

Table 5. Effect of N and P (kg/ha) application on maize grain yield (t/ha) at Wa.

Trt	Year				Mean
	2003	2004	2005	2006	
NOP0	0.60	0.60	0.30	0.60	0.53
N60P60	3.40	2.50	2.30	2.60	2.56
N60P90	3.20	2.20	2.20	2.50	2.51
N120P60	4.90	3.90	2.60	3.40	3.73
N120P90	4.70	4.20	2.50	3.20	3.67

## Lessons Learned

### In Study I:

1. High maize grain yields can be obtained when maize is rotated with groundnut probably because of N contribution from the groundnut.
2. Although the amount of residue returned was high under high fertilizer application treatments, the SOM decreased in these systems probably because of faster decomposition of the nutrient-rich residues compared to the bush fallow which might have a high C:N ratio.
3. Maize-bush fallow rotation with modest N application was necessary to sustain the SOM and maize yields.
4. However, for continuous maize production, higher N and P application rates are necessary to sustain maize yields.

### In Study II:

5. Without organic or mineral fertilizer, maize growth and biomass production was limited (Figure 13), resulting in low amounts of residue returned to the soil and a decline in soil organic matter.
6. N and P fertilizer applications to maize resulted in vigorous growth, increased the amount of crop residue production and return to the soil and supported the build up of SOM over time (Figure 14).
7. No or reduced tillage practices led to increased SOM whereas residue incorporation in the first study led to decreased SOM.



**Figure 13. Maize without fertilizer showing poor growth and biomass production.**



**Figure 14. Fertilized maize crop showing good growth and biomass production.**

The findings from these studies show that high residue production and its management are important for sustained crop production in the tropics. Whereas residue production at Kpeve could occur year round, production at Wa is constrained by a single growing season per year.

## GENERAL FINDINGS AND CHALLENGES

Residue removal by burning is generally not beneficial to soil and crop productivity. Even though some nutrients may be returned to the soil in the ash, the practice often led to low soil and crop productivity at Kpeve (Figures 15 & 16).

Complete residue removal from the field led to rapid soil degradation (Figures 5 & 6) but residue retention as mulch and a modest fertilizer application to maize led to vigorous maize growth.



**Figure 15. Farmers practice fallow residue burning before planting.**





**Figure 16. Maize growth following residue burning shown in Figure 15.**

At Wa, the rotation of maize with legumes and/or other high biomass vegetation and the addition of modest to high fertilizer application were required to maintain good maize growth and yield.

The current tillage practice whereby residues are slashed, piled up, burnt and roots removed results in poor maize growth.

The studies also showed that even though the SOM was generally higher at Kpeve than at Wa, there is rapid decline in SOM at both sites, once the land is cleared and cultivated. Generally, residue retention and its management as mulch are preferred to other management systems (Figures 17 & 18).



**Figure 17. Elephant grass residue left as mulch on soil surface.**



**Figure 18. Maize residue left as mulch on the soil surface.**

Alternative feed sources for animals must be developed to minimize the use of crop residues for grazing.

The management of residue for sustained soil and crop productivity may have some implications for farm operations. Simple technologies and machinery would be required to slash and “hide” residues in the soil from competitors. In the case where residue is applied as mulch, equipment is required to plant seeds directly through the mulch.

## CONCLUSIONS

Overall, we conclude that the maintenance of the SOM is essential for sustained soil and crop productivity. The SOM is the “life blood” of the soil and every effort must be made to conserve it within the Ghanaian agriculture system. Organic matter is derived from added residue, and sound residue management practices that increase residue production and retention in cropped fields, similar to those described in this bulletin, must be encouraged. At the least, modest fertilizer application is required for sustained crop productivity, and as much as possible, the soil must always be covered by either fallow plants or residues.

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