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REGULAR ARTICLE

Short-term effects of crop rotation, residue management, and soil water on carbon mineralization in a tropical cropping system

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Abstract The purpose of this study was to investigate the short-term effects of maize (*Zea mays*)-fallow rotation, residue management, and soil water on carbon mineralization in a tropical cropping system in Ghana. After 15 months of the trial, maize–legume rotation treatments had significantly (P<0.001) higher levels of potentially mineralizable carbon, C_0 (μg CO_2–C g ^{1}) than maize–elephant grass (*Pennisetum purpureum*) rotations. The C_0 for maize–grass rotation treatments was significantly related to the biomass input (r=0.95; P=0.05), but that for the maize–legume rotation was not. The soil carbon mineralization rate constant, k (per day), was also significantly related to the rotation treatments (P< 0.001). The k values for maize–grass and maize–legume rotation treatments were 0.025 and 0.036 day ^{1} respectively. The initial carbon mineralization rate, m_0 (μg CO_2–C g ^{1} day ^{1}), was significantly (P<0.001) related to the soil water content, θ. The m_0 ranged from 3.88 to 18.67 and from 2.30 to 15.35 μg CO_2–C g ^{1} day ^{1} for maize–legume and maize–grass rotation treatments, respectively, when the soil water varied from 28% to 95% field capacity (FC). A simple soil water content (θ)-based factor, f_w, formulated as: $f_w = \left[\frac{\theta\ \ \theta_d}{\theta_{FC}\ \ \theta_d}\right]$, where θ_d and θ_{FC} were the air-dry and field capacity soil water content, respectively, adequately described the variation of the m_0 with respect to soil water (R^2= 0.91; RMSE=1.6). Such a simple relationship could be useful for SOC modeling under variable soil water conditions.

Keywords Maize–fallow rotation · Residue management · Soil carbon mineralization · Soil water

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Introduction

Even though equilibrium soil organic carbon (SOC) in undisturbed tropical soils can attain values as high as 24.5 g kg ^{1} (Windmeijer and Andriese 1993), actual levels in cultivated lands are often very low. Prudencio (1993) observed equilibrium SOC levels of 2.0 and 11.0 g kg ^{1} for tropical bush fields and home gardens, respectively. Measures that minimize this gap would help to improve the productivity of tropical soils since the organic matter is both a source and sink for plant nutrients (Duxbury et. al. 1989). Increasing the SOC of tropical soils would require either consistently increased carbon inputs to the soil, decreased microbial decomposition of the SOC, or both. Noteworthy, however, is that current agricultural practices that rely heavily on bush burning for land clearing are ineffective in enhancing the build-up of SOC, as large amounts of carbon sources are lost in the process. Bush burning also leads to a decline in SOC, especially the fraction of <0.52 μm (Chan et. al. 2002). Current tropical agricultural systems are thus net SOC loss systems, with loss rates estimated at 4.7% annually for sandy soils under West African agricultural systems (Bationo et al. 2007). Furthermore, the introduction of conventional tillage to tropical agriculture has not been effective for SOC enhancement even though it returns large residue amounts to the soil. Residue incorporation generally reduces SOC (Parker 1962; Chivenge et al. 2007) because of increased contact between the residue and soil microbes, thereby accelerating the decomposition and loss of soil carbon. Chan et al. (2002) observed that tillage had a more detrimental effect on SOC than burning. Thus, residue management is an important factor for SOC build-up in soils.

Given that changes in and the equilibrium of SOC are management-dependent, investigating how different cropping practices would affect SOC dynamics is of great interest. Increased knowledge of this interaction would aid in the development of suitable cropping practices that would eventually increase the SOC of the depleted topical soil. The bulk of the literature indicates that, apart from residue management, crop rotation is another factor that determines the SOC and its dynamics. Medium to long term (14 years) continuous corn systems have been found to lead to higher SOC than continuous soybean systems (Huggins et al. 2007). Collins et al. (1992) observed that total SOC and microbial biomass C were significantly greater in annual wheat rotations than in wheat–pea rotations after 58 years. Such long-term studies are often lacking in the tropics, apparently due to the lack of resources to maintain them. Hence, inferences must also be made from short-term findings. A recent study from Mexico showed that significant increases in SOC occurred after only 2 years when crop rotation was combined with high application of cattle manure (Covaleda et al. 2006). In general, however, the effect of cropping practices on SOC and its dynamics in tropical regions has not been sufficiently investigated. The relevant question in this study is: How does crop rotation affect the dynamics of soil carbon in the short term? If tropical agricultural systems are to benefit from the general findings associated with SOC management, then further research is required to investigate how crop rotation and residue management could be used to enhance SOC.

Apart from cropping practice and residue management, SOC and its dynamics also depend on environmental factors such as temperature and moisture (Angle et al. 1984). In the tropics, moisture is more variable than temperature and, thus, it is conceivable that SOC changes over time may be associated with soil moisture variation. Amador and Jones (1997) found a significant relationship between the relative soil respiration and the soil water potential. Davidson et al. (2000) observed that CO_2 emissions from forest and cattle pastures in the Amazonia were negatively related to the logarithm of the soil water potential and also to the third power of the soil water content. In formulating the moisture factor for microbial-mediated residue decomposition, Andrén and Paustian (1987) proposed a moisture factor derived from a log-linear function of the soil water potential, which has been validated by other studies (Andrén et al. 1992; Henriksen and Breland 1999). In many tropical countries where data on the soil water potential are scant due to resource constraints, an alternative formulation of the moisture factor based on the easier-to-determine water content would be helpful for evaluating SOC changes under variable environmental conditions. The aims of this study were to (1) investigate the short-term effects of crop rotation and residue management on SOC and its dynamics and (2) derive a simple soil water content-based factor and compare its prediction performance with that based on the soil water potential approach.

Materials and methods

Maize–fallow management history

The soils used for the carbon mineralization studies were sampled from a medium-term trial designed to investigate the effect of seven maize–fallow rotation treatments on maize productivity and soil carbon accretion (Table 1). The trial began in 2003 at the experimental site of the Ministry of Food and Agriculture in Kpeve, Volta Region, Ghana (6°

Table 1 Description of maize fallow treatments

Treatment	Description (rotation)	Fertilizer application to maize (kg/ha)			Maize stover management after August	Fallow residue management in April
		N	P	K		
T1	Maize grass	0.0	0.0	0.0	Left standing on field	Burned
T2	Maize grass	0.0	0.0	0.0	Left standing on field	Incorporated into soil
T3	Maize pigeon pea	0.0	0.0	0.0	Hoed/left on field	Applied to soil surface
T4	Maize bare	0.0	0.0	0.0	Removed from field	Bare
T5	Maize cowpea	0.0	0.0	0.0	Hoed/left on field	Applied to soil surface
T6	Maize mucuna	0.0	0.0	0.0	Hoed/left on field	Applied to soil surface
T7	Maize grass	64.0	16.4	31.0	Left standing on field	Applied to soil surface

43.15′ N, 000° 20.45′ E). The annual rainfall at the site is about 1,200 mm and is distributed between two seasons: April/May to July (major season), receiving about 66% of the rain, and September to November (minor season), receiving the remaining 34%. Occasionally, rainfall occurred from December to March, in which case it is considered to be part of the minor season. The field previously lay fallow for over two years and carried vegetation that was composed largely of elephant grass. The soil, a sandy clay loam classified as Haplic Lixisol, had abundant coarse fractions below the depth of 50 cm.

Maize was planted during the major seasons (April/May to July/August), and the fallow period was from September to March of the following year. The first maize (variety *Obatanpa*) crop was sown on May 6, 2003, following ploughing of the field in April 2003. Within-row and between-row spacing was 40 and 80 cm, respectively, and the design was a randomized complete block with four replications. In this first sowing, treatments T1 to T6 were the same relative to the prior fallow period and crop management. Only treatment T7 consisted of the application of 37.5 kg N ha ^{1}, 16.4 kg P ha ^{1}, and 31.0 kg K ha ^{1} to maize on May 22, 2003 after the initial weeding on May 20, 2003, and a top dressing of 26.5 kg N ha ^{1} 6 weeks after planting (WAP). The maize cobs in all treatments were harvested at 12 WAP. The maize stover was left as standing biomass in treatments T1, T2, and T7, while those in treatments T3, T5 and T6 were hoed and left on the field plots to facilitate the planting of fallow legumes (Table 1). The maize stover of treatment T4 was removed from the field and the plots were kept bare during the entire fallow period.

The first fallow cycle began in September 2003, 4 weeks after the maize cob harvest. The grass in treatments T1, T2, and T7 began as weeds towards the end stages of the previous maize crop and were allowed continued, uninterrupted growth during the fallow period. Treatments T3, T5, and T6 were planted on September 9, 2003. Seeds of mucuna, cowpea, and pigeon pea were sown using 1.0 m× 1.0 m, 0.60 m×0.30 m, and 0.90 m×0.50 m spacing, respectively. The fallow treatments were terminated on March 30, 2004, after which the residues were burned (T1), incorporated (T2), or slashed and applied to the soil (T3, T5, T6 and T7).

The second maize sowing was on April 28, 2004, 4 weeks after the termination of the previous fallow treatments. The husbandry practices were the same as in the first maize sowing. For treatments that had residues applied to the soil surface (T3, T5, T6 and T7), the maize seeds were planted directly in the residue using planting sticks. The maize was harvested at 12 WAP. The total rainfall during the first maize crop, the intervening fallow, and the second maize crop were 460, 327, and 453 mm, respectively. The soils for the carbon mineralization studies reported here were sampled in September 2004 following the harvest of the second maize crop.

Carbon mineralization studies

Disturbed soil samples of about 5.0 kg were taken from the top 10 cm for each maize–fallow treatment, transported in an ice-chest to the Soil Science laboratory of the University of Ghana, and subsequently stored at 5°C in a refrigerator to minimize microbial activity. One kilogram of the refrigerated soil samples of each maize–fallow treatment was divided into four parts, and each part was moistened with different quantities of water to obtain 4 soil wetness conditions: W1=0.08 cm^3 cm$^{\ 3}$ (28% of field capacity, FC), W2=0.18 cm^3 cm$^{\ 3}$ (62% FC), W3=0.22 cm^3 cm$^{\ 3}$ (76% FC) and W4=0.28 cm^3 cm$^{\ 3}$ (95% FC). The soil moisture potential corresponding to W2, W3, and W4 were obtained using the pressure plate apparatus, and that for W1 was estimated by curve fitting. The moisture treatments corresponded to pF (the logarithm of soil water potential) values of 6.1, 3.4, 2.6, and 1.5, respectively. All the water-treated soil sub-samples were further stored in a refrigerator at 5°C for 2 days for equilibration.

Four replicates of 20 g (dry weight) sub-samples of the soils for each treatment and water level were placed in air-tight Mason jars containing NaOH vials (10 ml of 1.0 M NaOH) for trapping the respired CO_2. The trapping solution was changed at 14, 28, 42, 56, 70, 84, and 98 days, and the incubation studies were terminated on day 112. Four replicates of soil-free blank treatments were also run. Trapped CO_2 was measured by titrating the aliquot with 0.5 M HCl after precipitating the carbonates with a 1.5 M $BaCl_2$ solution. At each time of changing the trapping solution, the soil samples were quickly re-weighed and re-watered when necessary to restore the soil moisture to the initial level.

Model fitting and statistical analysis

Given the relatively short duration of the incubation studies and the fact that soils were sampled only 15 months after the start of the field trials, our analysis was limited to the dynamics of potentially mineralizable carbon, C_0. Hence, we fitted the first order kinetics model to the cumulative CO_2 production according to Stanford and Smith (1972) as follows:

$$C_{\mathrm{m}} = C_0\left(1 - e^{\ kt}\right) \tag{1}$$

where C_{m} is the cumulative carbon mineralized at time t and k is the first order rate constant. The parameters C_0 and k were determined using the non-linear regression routine of *Microcal Software ORIGIN* version 6 whereby initial estimates of C_0 and k were used as input and the software used the simplex algorithm to minimize the squared difference between the observed data and the fitted values. The model that gave the least squared error was chosen to be the best. The mean residence time, MRT, of the C_0 was derived as $1/k$. The initial carbon mineralization rate, m_0, was obtained by differentiating Eq. 1 with respect to time to yield:

$$\frac{d\,C_{\mathrm{m}}}{d\,t} = kC_0 e^{\ kt} \tag{2}$$

and setting t=0, reducing to $m_0 = k \times C_0$. The dependence of m_0 on soil water content was derived by regression analysis.

Formulation of the water factor

Assuming that the microbial-mediated processes of residue and soil carbon decomposition are similar, we can apply the moisture factor of Andrén and Paustian (1987) to describe the effect of soil water on carbon mineralization rate. The factor, f_{w}, is given as:

$$f_{\mathrm{w}} = 1 \quad \psi > \psi_{\max} \tag{3a}$$

$$f_{\mathrm{w}} = \log\left(\psi_{\min}/\psi\right) / \left(\log\left(\psi_{\min}/\psi_{\max}\right)\right) \tag{3b}$$

$$f_{\mathrm{w}} = 0 \quad \psi < \psi_{\min} \tag{3c}$$

with $\psi_{\min}$ and $\psi_{\max}$ given as −7.58 and −0.01 MPa, respectively (Andrén et. al. 1992). Equation 3c implies that microbial activity, and hence the mineralization process, would cease when the soil water potential is lower than −7.58 MPa.

Our alternative water content-based formulation relied on the premise that the mineralization process was rapid at field capacity (FC), but very slow when soil moisture declined below 40% field capacity (Meerle and Dick 2002). Hence, we used the water content at field capacity, θ_{FC}, as the maximum θ at which f_{w}=1. For most coarse textured soils such as that used in this study, van Keulen (1975) observed that the wilting point (WP) was about 30% FC. Hence, our water level, W1, would be somewhat below the WP. Since microbial activity could proceed below the WP, we used the air-dry water content, θ_{d}, as the minimum θ at which f_{w}=0. We hypothesized a linear decline of the decomposition rate between the FC and air-dry water contents so that the f_{w} may be expressed as:

$$f_{\mathrm{w}} = \left[\frac{\theta - \theta_{\mathrm{d}}}{\theta_{\mathrm{FC}} - \theta_{\mathrm{d}}}\right] \tag{4}$$

From this study, θ_{FC}=0.29 cm^3 cm$^{\ 3}$ and, according to Bloemen (1980), the average minimum volumetric soil water content for most soils is 6%. Hence, we set θ_d=0.06 cm^3 cm ^{3}.

Results

Biomass inputs

Biomass input frequency and amount differed among the maize–fallow treatments (Table 2). Even though the biomass of the fallow elephant grass prior to the start of the trials was not determined, we estimated it to be about 10 t ha ^{1} based on the annual grass production observed later during the trial. Since this grass was ploughed-in at the start of the maize–fallow trials, we assumed that all trials received an initial biomass input of 10 t ha ^{1} (Table 2). Thereafter, biomass residue was contributed by the maize stover after harvest in August 2003 and fallow vegetation after termination of the fallow period in April 2004. Only treatment T4 received no further aboveground biomass from either maize stover or fallow vegetation. Treatment T1 received biomass input from maize stover in August 2003, but no input from fallow vegetation in April 2004 because the residue was burned. Even though we lacked data for root biomass input, estimates were made according to Paul et al. (1999), based on the assumption that roots contribute 53% and 47%×aboveground residues for grass/cereals and legumes, respectively. The biomass from weed growth during the maize seasons was not quantified as it was visually far less than the maize biomass. Furthermore, because the soil for the SOC mineralization studies was sampled in September 2004 immediately following the harvest of the second maize crop, we assumed that biomass contribution by the maize stover in August 2004 to the SOC was negligible.

In 2003, all treatments except T4 received between 24 and 28 t ha ^{1} of biomass input. Even though treatment T4 received aboveground residue input only one time, the roots of the grass and maize contributed an additional 9 t ha ^{1}, so that the total input for the year was 19.11 t ha ^{1}. In 2004, treatment T7 received an additional 30.0 t ha ^{1}, while the other treatments received between 0.0 and 15.00. Thus, over 15 months, the fertilized maize–bush fallow (treatment T7) received the largest biomass input, and treatment T4 received the least.

Table 2 Residue and carbon inputs (t ha ^{1}) by the different maize fallow rotation treatments

Above ground			Root[a]		Total residue	Total C[b]
Treatment	Fallow	Maize	Fallow	Maize	Input	Input
	April	August	April	August		
2003						
T1	10.00[c]	6.55±0.62	5.30	3.47	25.32	10.13
T2	10.00[c]	6.23±0.64	5.30	3.31	24.83	9.93
T3	10.00[c]	6.62±0.21	5.30	3.51	25.4	10.17
T4	10.00[c]	0 (removed)	5.30	3.82	19.11	7.64
T5	10.00[c]	5.98±0.81	5.30	3.16	24.44	9.80
T6	10.00[c]	7.23±0.91	5.30	3.83	26.34	10.54
T7	10.00[c]	8.05±0.79	5.30	4.27	27.62	11.05
2004						
T1	0 (burned)	0.00	4.20	0.00	4.20	1.68
T2	10.05±2.10	0.00	5.32	0.00	15.38	6.15
T3	8.57±2.10	0.00	4.03	0.00	12.60	5.04
T4	0.00	0.00	0.00	0.00	0.00	0.00
T5	8.10±2.20	0.00	3.81	0.00	11.91	4.75
T6	7.74±2.20	0.00	3.64	0.00	11.38	4.55
T7	19.58±1.40	0.00	10.37	0.00	29.98	11.98

[a] Grass or maize root=0.53×aboveground biomass; legume root=0.47×aboveground residue

[b] Carbon input=0.4×total residue input

[c] Estimated fallow grass biomass input for the first year.

Crop rotation and residue management effects on carbon mineralization patterns

The CO_2–C evolution patterns observed for all treatments were well described by the first order kinetics equation, with the model fits giving R^2 values between 0.95 and 0.99. Crop rotation effects on carbon mineralization were not clear cut even though the maize–legume rotation treatments, especially T6, had higher C_0 than the maize–grass rotation treatments. Thus, even though the fertilized maize–grass rotation treatment (T7) received the largest biomass input of 57.6 t ha ^{1} during both years (Table 2), the largest C_0 was observed for treatment T6 (Table 3), which received a lower biomass input (38 t ha ^{1}) than T7. The lowest C_0 was observed for treatment T1, but it was not significantly different from that of T4. The increase in the C_0 was significantly related to the biomass input (r=0.98, P=0.05) for maize–grass rotation treatments, but not for maize–legume rotation treatments.

The effect of residue management on C_0 was also unclear, but the treatments that retained residues, such as T5, T6, and T7, tended to have larger C_0 than those in which the residue was removed (T1 and T4). It is worth noting that even though treatment T1 received relatively larger biomass input (30.00 t ha ^{1}) than T4 (19.00), the effects on C_0 were similar, suggesting that residue incorporation was not better than residue burning in terms of SOC accretion. The fraction of total SOC (C_t) that was mineralized, (C_0/C_t), was smallest for treatment T1 (2.2%) and largest for treatment T6 (3.3%). For the maize–grass rotation treatments, the C_0/C_t was significantly affected by residue input (P=0.05).

The soil carbon mineralization rate constant, k, ranged from 0.020 for treatment T4 to 0.036 day ^{1} for treatment T3 and was significantly affected by crop rotation treatment (P=0.022). The mean residence times (MRTs) ranged from 33 to 52 days, and were generally lower for residue retention treatments than for residue removal treatments. The higher MRTs observed for T1 and T4 suggest a higher resistance to carbon mineralization in these treatments compared to the others.

Soil water effects on carbon mineralization

The cumulative soil carbon mineralization amounts increased for all treatments (Fig. 1) between three and five fold when soil water content increased from 0.08 to 0.28 cm^3 cm ^{3}. A similar observation could also be made for initial carbon mineralization rates, m_0, (Table 4) with maize–legume rotations generally having higher values of m_0 than maize–grass rotations, excluding T7.

Generally, the m_0 for the different treatments were linearly related to the soil water content (Fig. 2), lending support to Eq. 4. Comparisons between the predicted and observed m_0 (Fig. 3) showed that both the water potential- and water content-based formulations of f_w adequately described the variation in m_0 with respect to soil moisture (R^2=0.91).

Discussion

Most studies examining crop rotation effects on SOC were derived from long term trials, and the findings

Table 3 Effect of residue management on carbon mineralization parameters under non limiting soil water conditions

Treatment	Mean ± SD					
	C_t (μg g ^{1})	C_0 (μg CO_2 C g ^{1})	C_0/C_t (%)	k (day ^{1})	MRT (day)	m_0 (μg CO_2 C g ^{1} day ^{1})
T1	17,800	389.75±58.44cd	2.19±0.33c	0.026±0.01b	41±8ab	9.83±1.7d
T2	18,400	450.00±58.74bc	2.44±0.32b	0.025±0.00b	42±6b	10.89±0.95d
T3	18,200	448.50±14.15b	2.46±0.08b	0.036±0.00a	28±3b	16.12±1.26ab
T4	17,800	397.75±44.55c	2.23±0.25c	0.020±0.01b	52±12a	7.90±1.11de
T5	18,000	467.75±56.00bc	2.60±0.31b	0.03±0.01a	35±8b	13.87±2.01c
T6	18,400	606.50±74.55a	3.30±0.41b	0.031±0.00a	33±4b	18.67±2.23a
T7	18,800	520.50±47.06b	2.77±0.25a	0.030±0.01a	36±12 b	15.35±3.25bc
P		0.000	0.010	0.022	0.020	0.000
LSD (P<0.05)		74.00	0.41	0.008	15.99	2.92

Within each column, means followed by the same letter or letters are not significantly different at the 0.05 probability level

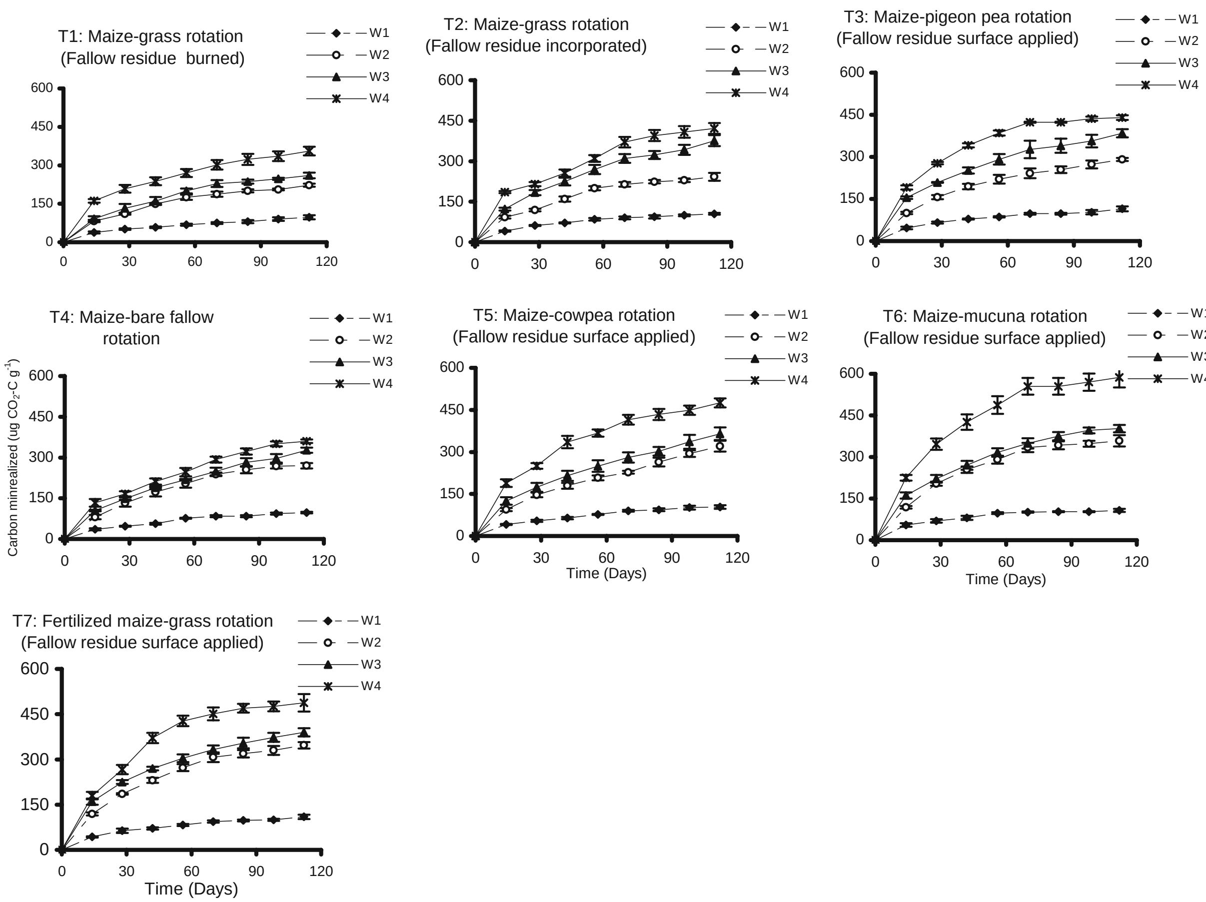

Fig. 1 Patterns of C release as CO_2 evolution for different maize fallow rotation and residue management treatments under variable soil water conditions

have not always been conclusive. Collins et al. (1992) observed that total SOC and microbial biomass C were significantly greater for annual wheat rotations than wheat–pea rotations after 58 years. In contrast, Al-Kaisi (2001) observed lower SOC for continuous corn than corn–oats–clover rotations. Our attention in the current study was focused on the short-term effects of crop rotation and residue management on

Table 4 Effect of soil water content on m_0 (microgram of CO_2 C per gram per day)

Treatment	Water treatment				P
	W1	W2	W3	W4	
Mean ± SD					
T1	2.38±0.35	5.84±0.50c	6.60±2.40c	9.83±1.67d	<0.001
T2	3.25±0.19b	6.49±0.85bc	9.38±1.50b	10.89±0.95d	<0.001
T3	3.69±1.50ab	7.97±1.75b	10.95±0.67a	16.12±1.26ab	<0.001
T4	2.33±0.46b	6.36±1.69bc	7.08±0.52bc	7.90±1.10de	<0.001
T5	2.93±0.32b	6.09±1.40c	7.96±1.70bc	13.87±2.01c	<0.001
T6	5.01±1.93a	10.53±1.10a	11.37±2.50a	18.67±2.23a	<0.001
T7	3.51±1.20b	9.51±0.64ab	12.03±1.44a	15.35±3.25bc	<0.001
LSD (P<0.05)	1.54	1.79	2.47	2.67	
P	< 0.05	< 0.001	< 0.001	< 0.001	

Within each column, means followed by the same letter or letters are not significantly different at the 0.05 probability level

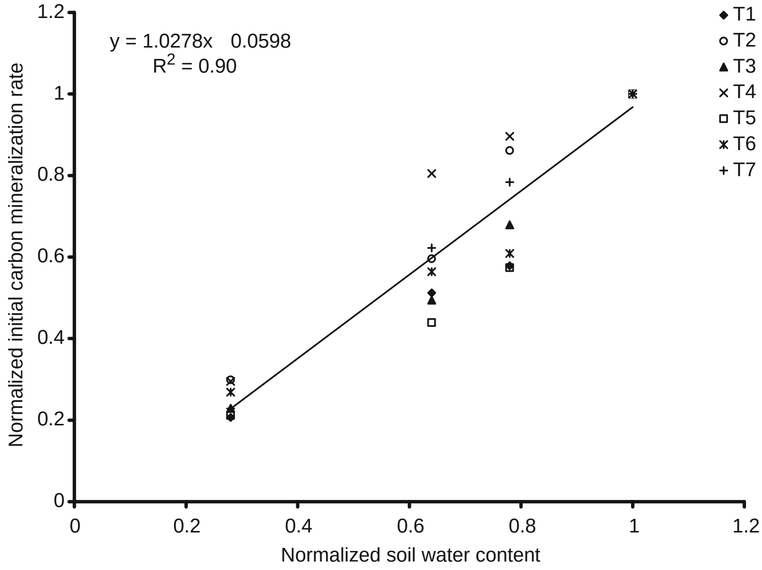

Fig. 2 Relative initial carbon mineralization rate as a function of the normalized soil water content

SOC changes, which, even though known to often be complex and variable (Al-Kaisi and Yin 2005), may be relevant to the design of SOC-enhancing cropping systems for tropical regions, especially regions where resource constraints limit long-term field trials. Short-term studies in Mexico showed that significant increases in SOC occurred (from 19.9 to 22.1 g/kg) after only 2 years when crop rotation was combined with high application of cattle manure (Covaleda et al. 2006), with an increased proportion of the C within the soil fraction >0.2 mm. In the traditional system combining crop rotation with low fertilizer input, SOC declined from 18.2 to 16.2 g/kg, with a decreased fraction of total SOC in the soil fraction >0.2 mm. These findings suggest that mineralizable carbon increased by the short-term addition of organic carbon input. Our observations, which indicated that the C_0 increased with biomass input, especially for maize–grass rotations, agree with those of Covaleda et al. (2006).

Crop rotation and residue management also affect SOC dynamics. Evidence, often from medium to long-term studies, indicates that the quality of soil carbon is derived from the quality of the added residue, and this affects the SOC mineralization rates. Huggins et al. (2007) observed that the SOC mineralization rates were higher for continuous soybean than for continuous corn cropping systems. Using the initial mineralization rate m_0 (=$k \times C_0$) as a measure of carbon dynamics (Murwira et al. 1990), we observed (Table 3) that treatments involving maize–legume rotations such as T3, T5, and T6 had significantly higher m_0 than those treatments that derived their biomass inputs solely from cereal and grass sources (e.g. T1 and T2). The relatively high m_0 for treatment T7 could be attributed to fertilizer application, leading to a lowering of the C/N ratio of the T7-grass (25:1; not shown) relative to that of T1 and T2 grass (30:1). As the m_0 is sensitive to the quality of soil carbon (Pascual et al. 1998), it could be concluded that the differences in residue quality affected the mineralization rates, even in the short-term. Apparently, the effects of crop rotation and residue management on SOC dynamics are rapid in tropical regions.

The increased mineralization response to increasing soil water could be generally attributed to the enhanced activity of aerobic microbes, a phenomenon that depends greatly on soil water content (Young and Ritz 2000). It is worth noting that carbon mineralization did not cease at water level, W1, even though the soil water content was very low. For most of the treatments, the final evolution at W1 was about 100 μg CO_2–C g ^{1}, while the m_0 ranged from 2.3 to 5.1 μg CO_2–C g ^{1} day ^{1}. It could be concluded that carbon mineralization may still proceed in dry soils, albeit slow, but over long time periods, the cumulative loss could be substantial. Furthermore, even though Eqs. 3a, b, c and 4 both described (R^2>0.90) the variation of the m_0 with respect to soil water (Fig. 3), setting ψ_{min} in Eqs. 3a, b, c to −7.58 MPa cut off the

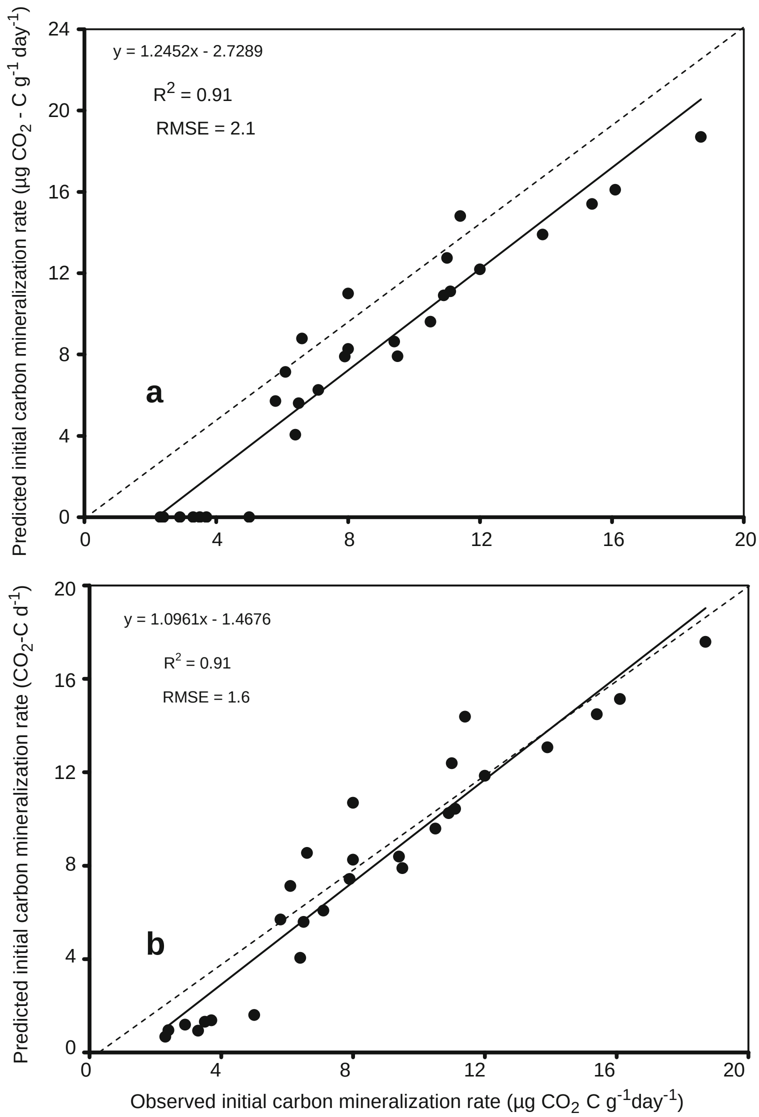

Fig. 3 Predicted vs. observed initial carbon mineralization rate (m_0) using the soil water potential based f_w (**a**) and soil water content based f_w (**b**)

carbon mineralization earlier than observed, while setting the air-dry moisture content to 6% in Eq. 4 enabled the prediction of carbon mineralization at very low soil water contents and improved the RMSE. In general, where soil water potential data are lacking, a simple water-content based f_w such as Eq. 4 could be useful in evaluating carbon mineralization under varying environmental conditions.

Conclusion

Overall, we conclude that the mineralization dynamics of SOC were significantly affected by crop rotation, residue management, and soil water content. Even though the short-term effects of crop rotation and residue management on SOC dynamics are often complex and variable (Al-Kaisi and Yin 2005), our observations of treatment effects demonstrated some emerging patterns after only 15 months. The potentially mineralizable carbon, C_0, was generally higher in maize–legume rotation treatments than in maize–grass rotations. For the maize–grass rotation treatments, increased biomass input generally led to higher C_0. The initial carbon mineralization rate increased with soil water, and the relationship could be adequately described by using either water-potential or water content-based equations. However, given that only a few laboratories in the tropical regions are equipped to determine the water potential, the water content-based equation could be easier to apply. Of all the maize–fallow rotation treatments, T7, which returned very high maize and grass biomass to the soil annually but had a slow carbon mineralization could be a promising technology for enhancing SOC under tropical conditions.

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