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Effect of land use types on decomposition of ^{14}C-labelled maize residue (*Zea mays* L.)

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ABSTRACT

The effect of three land use types on decomposition of ^{14}C-labelled maize (*Zea mays* L.) residues and soil organic matter were investigated under laboratory conditions. Samples of three Dystric Cambisols under plow tillage (PT), reduced tillage (RT) and grassland (GL) collected from the upper 5 cm of the soil profile were incubated for 159 days at 20 °C with or without ^{14}C-labelled maize residue. After 7 days cumulative CO_2 production was highest in GL and lowest in PT, reflecting differences in soil organic C (SOC) concentration among the three land use types and indicating that mineralized C is a sensitive indicator of the effects of land use regime on SOC. $^{14}CO_2$ efflux from maize residue decomposition was higher in GL than in PT, possibly due to higher SOC and microbial biomass C (MBC) in GL than in PT. $^{14}CO_2$ efflux dynamics from RT soil were different from those of PT and GL. RT had the lowest $^{14}CO_2$ efflux from days 2 to 14 and the highest from days 28 to 159. The lowest MBC in RT explained the delayed decomposition of residues at the beginning. A double exponential model gave a good fit to the mineralization of SOC and residue-^{14}C ($R^2 > 0.99$) and allowed estimation of decomposition rates as dependent on land use. Land use affected the decomposition of labile fractions of SOC and of maize residue, but had no effect on the decomposition of recalcitrant fractions. We conclude that land use affected the decomposition dynamics within the first 1.5 months mainly because of differences in soil microbial biomass but had low effect on cumulative decomposition of maize residues within 5 months.

1. Introduction

Concern over global warming and rising levels of atmospheric CO_2 has prompted renewed interest in increasing soil C sequestration. Much effort has been invested in identifying soil management practices and land uses that favour C sequestration. The use of conservation tillage (including no-till) and conversion from cropland to grassland are being encouraged as part of a strategy to reduce C loss from agricultural soils [24,26,36]. However, the relatively high background levels of soil C and their high temporal and spatial variability may often mask differences in soil C storage arising from land use and soil management changes [7,18]. Therefore, simple or short-term predictors must be explored to show the

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effects of soil management on potential changes in soil organic matter (SOM) long before such effects can be detected by measuring total SOM. The mineralizable C measured as CO_2 efflux by incubation has been suggested as an early indicator of future trends in total SOM as it provides a good measure of labile organic matter because it directly reflects recent SOM turnover [12]. The first aim of our study was therefore to compare mineralizable C as CO_2 efflux from three soils under different land use types.

The application of crop residues to soils is one of the main factors increasing organic matter and nutrient supply. Therefore it is important to understand the dynamics of crop residues decomposition in soils in order to predict the effect of land use on release of C from the remaining residues. ^{14}C-labelled plant residues have been useful in studying C flux in plant/soil systems [39]. The incorporation of ^{14}C-labelled plant residues to soils allows for the differentiation between residues-derived C and native soil organic carbon (SOC) and provides precise estimates of residues decomposition rates [13,38]. The second aim was therefore to evaluate how different land use types affect decomposition of plant residues.

Mathematical and statistical models are other suitable approaches to describe and predict C mineralization dynamics from SOM or plant residues. A double exponential model which assumes that organic matter pool can be divided into a labile and a resistant pool allows for estimation of the size, the decomposition rate and the turnover time of each pool [8]. The third aim was to unravel the effects of different land use types on decomposition kinetics of residues or SOC using a double exponential model formalized by our data.

To summarize, the objectives of this study were to evaluate the differences in decomposition of native SOM and crop residues in three contrast land use types, plow tillage (PT), reduced tillage (RT) and grassland (GL). ^{14}C-Labelled maize residues were used to differentiate and quantify the contribution of residues-derived C and soil organic matter-derived C. A double exponential model was used to characterize the decomposition kinetics of SOC and plant residues.

2. Materials and methods

This study was carried out at the Institute of Soil Science and Land Evaluation, University of Hohenheim, Stuttgart, Germany.

2.1. Soils

Soil samples were taken from GL, RT and PT at the Edelweiler site (8°33′ E, 48°32′ N) located in the Black Forest (Baden-Württemberg, southwest Germany), with a mean annual temperature 6.5 °C and mean annual precipitation of 1200 mm. Adjacent GL, RT and PT were carefully selected with similar soil forming factors. The soil type is a Dystric Cambisol according to the FAO soil classification (19.3% clay, 48.8% silt and 31.9% sand). GL has been managed for about 4 years with four cuttings annually. GL was not grazed and no fertilizer was applied. PT has been cultivated for 5 years at the time of sampling. The crop sequences in PT included oat (*Avena sativa* L.), summer barley (*Hordeum vulgare* L.), triticale and rapeseed (*Brassica napus* L.). PT tilled the soil with a mouldboard plow to a depth of 15 cm. RT had passed through 15 years. The crop rotations in RT were maize (*Zea mays* L.), winter wheat (*Triticum aestivum* L.) and winter triticale. RT consisted of stubble tillage to a depth of 8–10 cm. Soil samples were collected from the upper 5 cm of the three land use types in November 2004. The soil samples were air-dried at room temperature and sieved (2 mm mesh size). Plant residues and roots were removed by electrostatic forces induced by a plastic bottle being rubbed against wool according to Kuzyakov et al. [25]. Soil properties of the three land use types are presented in Table 1 [5].

2.2. Incubation

Laboratory incubation was conducted in closed vessels at 20 °C for 159 days. Twenty grams of air-dried soils were weighed into 250 ml Schott jars. There were six treatments with three replicates: (1) GL soil; (2) GL soil with residue; (3) RT soil; (4) RT soil with residue; (5) PT soil; (6) PT soil with residue. Eighty milligrams of ^{14}C-labelled maize residues ground with a ball mill (specific ^{14}C activity 5970 DPM mg^{-1} C, 36.5% C and 2.9% N) were added. ^{14}C-labelled maize residues were taken from a previous experiment in which maize shoots were labelled three times during 29 days of growth [46]. Labelled maize residues were thoroughly mixed with the soil prior to incubation. The soil or soil-residue mixtures were wetted to 80% of water holding capacity (WHC) and maintained at this level throughout the experiment. A small cap containing 4 ml of 1.0 M NaOH solution was placed in the jars to trap CO_2. The traps were exchanged 17 times on days 2, 7, 14, 21, 28, 36, 43, 49, 56, 63, 70, 84, 98, 112, 130, 144 and 159. The jars were aerated at sampling time to maintain adequate O_2 level. Additional triplicate jars containing only the caps with NaOH served as blanks to account for the CO_2 trapped from the air inside the vessels.

2.3. Analysis

The concentrations of total soil C and N were determined with a LECO CN2000 analyzer. As the soils are free of carbonates,

Table 1 – Selected characteristics of the soils studied (0–5 cm) from the Edelweiler site.

Land use[a]	PT	RT	GL
pH ($CaCl_2$)	5.31 ± 0.10[b]	4.60 ± 0.03	4.97 ± 0.07
SOC (%)	2.11 ± 0.004	2.62 ± 0.121	2.99 ± 0.107
Total N (%)	0.18 ± 0.002	0.22 ± 0.007	0.26 ± 0.009
BD (g cm^{-3})	1.19 ± 0.07	1.19 ± 0.07	1.16 ± 0.09
C/N	11.8 ± 0.1	11.7 ± 0.3	11.6 ± 0.2
WHC (%)	30.00	34.14	28.75
MBC (μg g^{-1})	372.0 ± 29.1	274.8 ± 30.5	564.9 ± 41.6
MBN (μg g^{-1})	54.8 ± 0.6	40.6 ± 4.8	76.0 ± 4.5
MBC/MBN	6.8 ± 0.5	6.8 ± 0.3	7.4 ± 0.3

SOC, soil organic carbon; WHC, water holding capacity; BD, bulk density; MBC, microbial biomass C; MBN, microbial biomass N.

a PT, plow tillage; RT, reduced tillage; GL, grassland.

b Values are means ± S.D.

total C was equivalent to SOC. Soil pH was measured using a 1:2.5 (w/v) soil to 0.01 M $CaCl_2$ ratio with a glass electrode. Soil texture was determined by the pipette method [16]. Microbial biomass C (MBC) and N (MBN) in soil samples before incubation were measured by the fumigation-extraction method [40]. Plant residues and roots were removed from soil samples for MBC and MBN measurements by hand. Each soil sample was divided into two equivalent portions, one of which was fumigated for 24 h with ethanol-free chloroform and the other was unfumigated as the control. Both fumigated and unfumigated soils were shaken for 30 min with 0.5 M K_2SO_4 (1:4 soil:extraction ratio), centrifuged and filtered. Extracts were analyzed for total organic C and total N on a Dimatoc-100 analyzer (Dimatec Co., Essen, Germany). A K_C value of 0.45 and a K_N of 0.54 were used to calculate the C and N contents of the microbial biomass [21, 22].

Total CO_2 absorbed in NaOH solution was measured by titration of an aliquot (1 ml) with 0.1 M HCl against phenolphthalein after addition of 0.5 M $BaCl_2$ solution. The ^{14}C activity in CO_2 trapped in NaOH solution was measured by adding 2 ml scintillation cocktail Rothiscint-22x (Roth Company, Germany) to 1 ml aliquot of NaOH solution after the decay of chemiluminescence. The ^{14}C counting efficiency was about 87%.

2.4. *Calculations and statistical analysis*

The cumulative CO_2 efflux from native SOM was fitted with a double exponential model [8]:

$$C_t = C_a * (1 - e^{-k*t}) + C_b * (1 - e^{-h*t}) \tag{1}$$

Where C_t is the cumulative CO_2-C mineralized (% of SOC) by time t; C_a and C_b are the sizes of labile and recalcitrant C pool (% of SOC; $C_a + C_b = 100\%$), respectively; k and h are the mineralization rate constants for each pool; and t is the period of incubation.

The decomposition of the ^{14}C-labelled residue was also estimated by the double exponential model (1), where C_t is the cumulative ^{14}C-CO_2 released (% of input ^{14}C) by time t and C_a, C_b, k, and h are the kinetic parameters for ^{14}C, as previously defined for C from SOM.

A non-linear least-squares regression analysis was used to calculate parameters from cumulative C mineralization data (Software STATISTICA 6.0, StatSoft Inc.). The comparison of model fits was evaluated by the coefficient of determination, R^2. The decomposition parameters were compared for the tested land use types.

The CO_2 efflux and C mineralization parameters from the double exponential model were subjected to one-way analysis of variance to test for significant differences between the treatments. Differences were considered significant at $P < 0.05$ level. The SAS statistical package was used for the statistical analysis [32].

3. Results

3.1. *Mineralization of the native SOC*

The initial soil characteristics of the three land use types are shown in Table 1. Land use types had significant effects on SOC and total N concentrations as well as MBC and MBN. Soil organic C concentration was in the order: GL > RT > PT, and total N followed a similar trend. Microbial biomass C was in the order: GL > PT > RT, and MBN followed the same sequence (Table 1).

To compare the CO_2 efflux rates from soils having initially different SOC contents, all results are presented as percentages of SOC. All soils showed an initial CO_2 release flush, accounting for 0.297%, 0.265% and 0.567% of SOC day^{-1} for PT, RT and GL, respectively after 2 days (Fig. 1a). Then the CO_2 evolution rates decreased rapidly and dropped to 0.042%, 0.061% and 0.066% of SOC day^{-1} for PT, RT and GL by day 36. Thereafter, the CO_2 evolution rates became lower and

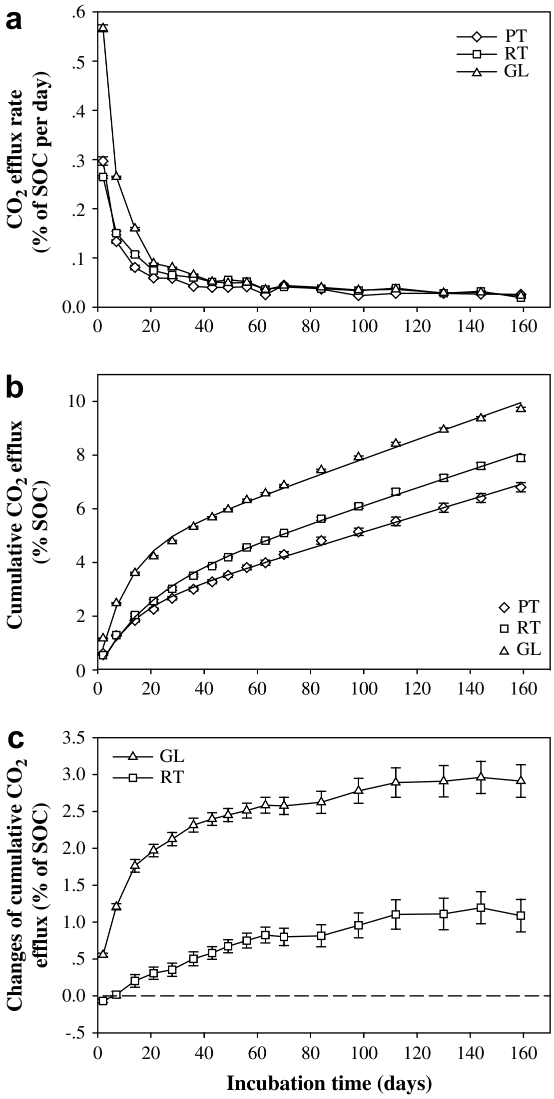

Fig. 1 – (a) Total CO_2 efflux rates from soils without plant residues. (b) Cumulative CO_2 efflux from soils without plant residues, the solid lines were fitted curves with $C_t = C_a * (1 - e^{-k*t}) + C_b * (1 - e^{-h*t})$, $C_a + C_b = 100\%$. Standard errors are indicated or are less than symbol size ($n = 3$) in (a) and (b). (c) Changes in cumulative CO_2 efflux (% of SOC) compared to PT. The vertical bars refer to the least significant differences ($P < 0.05$) of three replicates. PT, plow tillage; RT, reduced tillage; GL, grassland.

generally constant, and they were 0.026%, 0.019% and 0.023% of SOC day^{-1} for PT, RT and GL at the end of 159 days of incubation (Fig. 1a).

The cumulative CO_2 release was highest in GL comparing to the RT and PT with significant differences during the whole incubation period ($P < 0.05$, Fig. 1b and c). After the first 7 days, significantly more cumulative CO_2 production was released under RT than under PT ($P < 0.05$, Fig. 1b and c). At the end of the incubation the total mineralized C represented a small percentage of the SOC: 6.80%, 7.89% and 9.71% for PT, RT and GL respectively.

The cumulative CO_2 production over 159 days fitted very well to the double exponential model ($R^2 > 0.99$ for the three soils) (without the initial 0–2 day data) (Table 2). The estimated labile C pool (C_a) was highest in GL and higher in RT than in PT. The mineralization rates (k) of this labile organic C were 0.041, 0.032 and 0.054 day^{-1} for PT, RT and GL, corresponding to half-lives of 16.8, 22.2 and 12.8 days, respectively. The mineralization rates (h) ranged from 0.000289 to 0.000349 day^{-1}, with an average half-life of 6.1 years (Table 2).

3.2. *Total CO_2 efflux after plant residue addition*

Following the addition of plant residues, there was a significant increase in the cumulative CO_2 emission with respect to the soil unamended with plant residue over the entire incubation period for each of the three land use types ($P < 0.05$, Fig. 2). Where plant residues were added, the CO_2 efflux was in the order: GL > RT > PT from day 14 to the end of the incubation.

3.3. *Decomposition of ^{14}C-labelled maize residue*

The effects of GL, RT and PT on the mineralization of ^{14}C-labelled maize residue were compared. Mineralization of maize residue began immediately with the maximum rate occurring within 2 days, ranging from 4.72% to 5.80% of input ^{14}C per day. Over the first 14 days, labelled residue was rapidly mineralized in all soils, subsequent decomposition was slow, and at the end of the incubation the $^{14}CO_2$ evolution rates were 0.038%, 0.043% and 0.050% of input ^{14}C per day for GL, RT and PT respectively (Fig. 3a).

Table 2 – Native SOC mineralization parameters using a double exponential model: $C_t = C_a * (1 - e^{-k^*t}) + C_b * (11 - e^{-h^*t})$, $C_a + C_b = 100\%$.

Land use[a]	C_a (% SOC)	k (day^{-1})	$T_{1/2}$ of C_a (days)	h (day^{-1})	$T_{1/2}$ of C_b (years)	R^2
PT	1.80 c[b]	0.041 b	16.8 b	0.000289 b	6.6 a	0.9998
RT	2.83 b	0.032 c	22.2 a	0.000307 b	6.2 a	0.9998
GL	3.46 a	0.054 a	12.8 c	0.000349 a	5.4 b	0.9999

C_a and k = amount and decay rate of labile C pool; C_b and h = amount and decay rate of resistant C pool; t = time (d); $T_{1/2}$ = half life of C_a or C_b.

a PT, plow tillage; RT, reduced tillage; GL, grassland.

b Different letters indicate significant differences within each column ($P < 0.05$, $n = 3$).

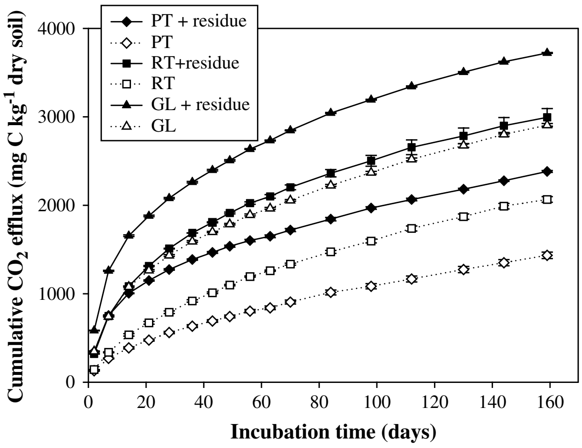

Fig. 2 – Effects of land use types and residues on cumulative CO_2 efflux. Standard errors are indicated or are less than symbol size ($n = 3$). PT, plow tillage; RT, reduced tillage; GL, grassland.

After 2 days of incubation, 10–12% of the input ^{14}C from the maize residue was mineralized. After the rapid initial decomposition phase, by day 14, 35–40% of the applied maize-^{14}C was released as $^{14}CO_2$. The soils differed significantly in their $^{14}CO_2$ evolution with time ($P < 0.05$, Fig. 3b and c). By day 2, PT and GL evolved more of $^{14}CO_2$ than RT.

From day 7 to 14 the release of $^{14}CO_2$ was highest from GL and was significantly higher from PT than from RT. However, after 28 days the cumulative $^{14}CO_2$ evolution was in the order: RT > GL > PT. At the end of the incubation the cumulative $^{14}CO_2$ evolved amounted to 61.6%, 57.7% and 56.4% of input ^{14}C for RT, GL and PT respectively (Fig. 3b and c).

The cumulative $^{14}CO_2$ release conformed well to the double exponential model ($R^2 > 0.99$ for the three soils) (Fig. 3b, Table 3). The sizes of C_a varied from 42.84% to 47.79% of input ^{14}C for the three different soil types. The decay rates (k) of C_a ranked in the order: GL > PT > RT, corresponding to half-lives of 4.7, 7.7 and 4.0 days respectively. The mineralization rates (h) of the recalcitrant C pool varied from 0.00186 to 0.00204 day^{-1}, with an average half-life of 347 days. The mineralization rates (h) and corresponding half-lives did not differ significantly among the three land use types (Table 3).

4. Discussion

4.1. *Mineralization of native SOC*

A significant effect of land use types on native SOC mineralization was found in our experiment. The cumulative CO_2 production was in the order: GL > RT > PT over the entire incubation period except the first few days (Fig. 1b and c). The higher mineralized C under grassland and reduced tillage indicates that more labile C had accumulated in these soil management systems than in the plowed tillage system. The build-up of higher mineralizable C in GL and RT was due to less disturbance and promotion and stabilization of aggregates compared to plowed soils in the last 4 (GL) to 15 (RT)

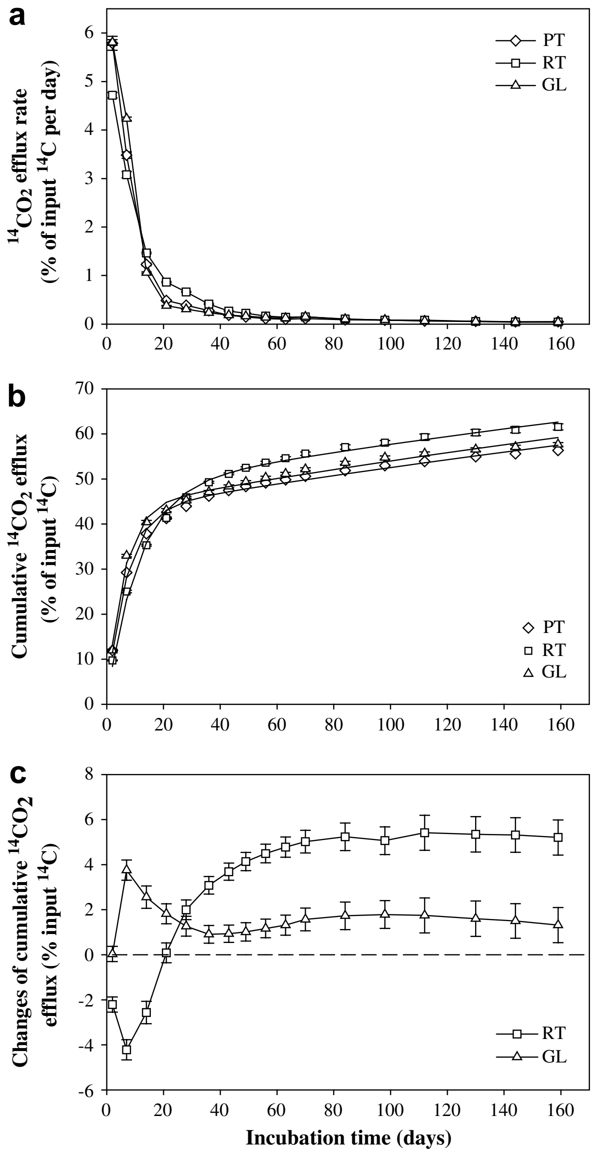

Fig. 3 – (a) $^{14}CO_2$ efflux rates. (b) Cumulative $^{14}CO_2$ efflux; The solid lines are curves fitted with $C_t = C_a * (1 - e^{-k*t}) + C_b * (1 - e^{-h*t})$, $C_a + C_b = 100\%$. Standard errors are indicated or are less than symbol size ($n = 3$) in (a) and (b). (c) Changes in cumulative $^{14}CO_2$ efflux (% of SOC) compared to PT. The vertical bars refer to the least significant difference ($P < 0.05$) of three replicates. PT, plow tillage; RT, reduced tillage; GL, grassland.

years. Tillage operations result in the mechanical breakdown of soil aggregates, enhance aggregate turnover and increase decomposition of SOM [34]. The total CO_2 respired was related to SOC concentration, with higher CO_2 production in land use types with higher SOC concentration. This indicates that mineralized C is a sensitive indicator of the effects of land use regime on the SOC. These results are consistent with the findings by Janzen et al. [20] and Bremer et al. [4], who suggested that mineralized C can be an early indicator to evaluate the effect of different soil management practices. Previous studies have shown higher mineralized C under zero (or reduced) tillage or grassland than under conventional tillage under laboratory conditions [1,10,19] as well as under field conditions [11,17].

Table 3 – ^{14}C-labelled maize residue mineralization parameters using a double exponential model: $C_t = C_a * (1 - e^{-k*t}) + C_b * (1 - e^{-h*t})$, $C_a + C_b = 100\%$.

Land use[a]	C_a (% added)	k (day^{-1})	$T_{1/2}$ of C_a (days)	h (day^{-1})	$T_{1/2}$ of C_b (days)	R^2
PT	42.84 b[b]	0.146 b	4.7 b	0.00186 a	372.6 a	0.9993
RT	47.79 a	0.090 c	7.7 a	0.00211 a	332.1 a	0.9993
GL	43.63 b	0.171 a	4.0 c	0.00204 a	337.3 a	0.9991

C_a and k = amount and decay rate of labile C pool; C_b and h = amount and decay rate of resistant C pool; t = time (days); $T_{1/2}$ = half life of C_a or C_b.

a PT, plow tillage; RT, reduced tillage; GL, grassland.

b Different letters indicate significant differences within each column ($P < 0.05$, $n = 3$).

An initial short CO_2 release flush was observed in the three soils. Similarly, other authors showed a stimulation of C mineralization during the first few days of incubation when dried soils were remoistened [3,30,37,45]. This was generally explained by mineralization of SOM released from physical disruption of soil aggregates [2,6] and/or from the release of microbial C [14] as reviewed by Miller et al. [27]. The drying-rewetting cycles frequently occurring in the plow layer could cause an increase in SOM decomposition and result in partial loss of labile carbon [31].

The high CO_2 evaluation rates from day 3 to day 36 indicate a rapid depletion of an easily mineralizable fraction (labile SOC) while the slow-steady phases in which mineralization declined to a fairly constant rate after 36 days indicate that the most active fraction was exhausted and the resistant and stable fraction of SOM was being mineralized [8,43]. The shoulder at approximately day 36 may be an indication of a change in substrate availability and also a change in the soil microbial communities responsible for decomposition [29].

4.2. *Maize residue mineralization*

The decomposition of plant residue was estimated by measuring the $^{14}CO_2$ release from the soil. Two distinctive phases were observed during the mineralization of the maize residues. In the first phase, plant substrates such as sugars and cellulose, readily available to microorganisms, were decomposed [1] and 35–40% of residues were decomposed by day 14. In the second phase, stable forms of plant C such as lignin were degraded. This slow and more stabilized phase indicates a decline in the quality of substrate with decomposition due to a progressive loss of the more biologically labile components and a concomitant increase in the proportion of more resistant components in the remaining material [44] and indicates that the maize residue had been specially incorporated in the humus compounds for each soil [3]. Land use had a small effect on cumulative decomposition of maize residue within 5 months. At the end of 159 days of incubation, 56.4–61.6% of input ^{14}C was evolved as $^{14}CO_2$, depending on the land use types (Fig. 3b). Similar levels of straw mineralization were found in other studies, e.g. Vanlauwe et al. [41] reported approximately 45% of the maize residue was mineralized within 28 days for incubation at 25 °C (44–46% of maize was decomposed in 28 days in our case).

The total $^{14}CO_2$ efflux showed interesting differences among the three land use types. The greater $^{14}CO_2$ emission from the GL soil than from the PT soil during the incubation could be attributable to higher SOC content and microbial biomass in GL than in PT. However, RT soil behaved differently from PT and GL. RT had lowest $^{14}CO_2$ efflux from day 2 to day 14 and thereafter it increased progressively and had the highest values of $^{14}CO_2$ efflux from day 28 to the end of the incubation (Fig. 3b and c). The lowest pH and MBC in RT may explain the delayed decomposition of maize residue at the beginning—a low start but later catching up. Xu et al. [47] reported that decomposition of plant residues was affected by the initial soil pH and upon addition of plant residues the peak respiration rates in Widjil soil (initial pH 3.87) were only half of those in Lancelin soil (initial pH 5.06). Low pH depresses microbial activities, changes microbial communities and decreases the decomposition of SOM [28]. In our study pH was likely to influence soil microbes and their activity in the RT soil as the MBC in the RT soil was smaller than in PT despite the higher SOC content in RT (Table 1).

4.3. *A double exponential C mineralization approach*

The double exponential model with three parameters (Eq. (1)) fitted the cumulative native SOC and maize residue-C mineralization data sufficiently well, with the multiple correlation coefficient ($R^2 > 0.99$) for all data series (Figs. 1b and 3b, Tables 2 and 3). This model describes the decomposition of two separate pools of substrates with different degradation rates, one labile pool (C_a) with high degradation rate (*k*) and the other resistant (C_b) to microbial attack with low decomposition rate (*h*). The rates (*k* and *h*) are important in estimating the half-life of mineralization listed in Tables 2 and 3. The overall mineralization is considered as the sum of the two pools. Such a model has been widely used to describe and predict C mineralization of SOM or plant materials [1,3,44].

Land use affected the decomposition of labile fraction of native SOC. The size of C_a was higher in the land use types with higher SOC and mineralized C. It seems reasonable to use this labile C pool (C_a) as a sensitive indicator of soil process affected by land use change. Its decay rate (*k*) was related to MBC, with higher *k* in land use types with higher soil MBC (Fig. 4). The slowly decomposing fraction (C_b) was the major part of the SOM, varying from 96.5% to 98.2% SOC (Table 2). Its decay rate (*h*) was about 142, 103 and 155 times lower than those (*k*) of labile C for PT, RT and GL, respectively (Table 2). The much lower decay rate (*k*) was generally explained by chemical recalcitrance or physical protection [9,15,23,33,42] and it appeared to be the cause of SOC accumulation.

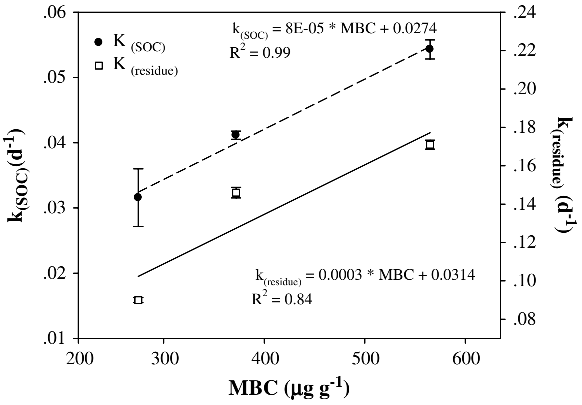

Fig. 4 – Relationships between microbial biomass C (MBC) and decay rates of labile SOC pool ($k_{(SOC)}$) and labile residue-C pool ($k_{(residue)}$). Standard errors are indicated or are less than symbol size ($n = 3$). SOC, soil organic C.

The decomposition rates (*k*) of labile residue-^{14}C were positively related to MBC, with higher *k* in land use types with higher soil MBC (Fig. 4), indicating that land use affected the decomposition of labile fraction of maize residue mainly because of differences in microbial biomass. Land use had no effect on the decomposition of recalcitrant fraction of maize residue. There were no significant difference in the decomposition rates (*h*) of resistant pool (C_b) and corresponding half-lives among the three land use types, indicating the decomposition of fraction C_b was essentially controlled by the quality of the residues. The *k* values were about 78, 43 and 84 times greater than *h* values for PT, RT and GL, respectively (Table 3). The lower decomposition rates (*h*) of resistant C pool may be associated with a more efficient storage of C, as soil microorganisms may respire less of the substrate as CO_2 [35].

5. Conclusions

The three land use types showed significantly different effects on decomposition of SOM and maize residues. The CO_2 efflux patterns during the 159-day incubation reflected SOC contents in soils under PT, RT and GL: higher CO_2 production occurred in land use types with higher SOC concentration. Higher $^{14}CO_2$ efflux in GL than PT was also reflected difference of SOC and MBC between GL and PT. The lowest MBC in RT delayed the residue decomposition in the early phase resulting in the lowest $^{14}CO_2$ efflux at the beginning but highest in the later phase compared to PT and GL. A double exponential model fitted the cumulative native SOC and maize residue-C mineralization data sufficiently well ($R^2 > 0.99$), showing that SOM and maize residue-C can be described as being composed of two pools, one labile and the other resistant. Land use affected the decomposition of labile fractions of SOC and of maize residue, but had little effect on the decomposition of recalcitrant fractions.

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