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# Management practice effects on spatial variability characteristics of surface mineralizable C

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**Abstract**

Information on spatial variability of different C pools and fractions is important for site-specific monitoring the changes in soil carbon (C) on a farm-scale basis. The objectives of this study were to compare the effects of 16 years of implementation of conventional chisel-plowed management practice (CT) and organic cover crop based practice (CT-cover) on spatial variability of C mineralized in a 210-day incubation; and to study the effects of topography, texture, plant biomass input, and total soil C on mineralizable C. For each management practice we collected more than 350 soil samples at 0–5 cm depth in well-drained Typic Hapludalfs in southwest Michigan. The spatial continuity of $CO_2$ respired C was found to be relatively weak with the variability at distances < 1 m constituting more than 65% of the overall variability. In either treatment, only a small portion of variability in $CO_2$ respired C (11–16%) was explained by multiple regression models with topography (WI), soil texture (clay + silt content), main crop biomass, and total C. There was a positive direct effect of total C and a negative direct effect of clay + silt on $CO_2$ respired C. The practical implication of these findings for modeling soil C processes on a farm scale is that in soils similar to those of this study producing site specific maps of labile C inputs using either spatial auto-correlation or auxiliary variables will likely not be feasible.


*Keywords:* $CO_2$ respired soil C; Soil texture; Wetness index; Total C; Spatial variability

## 1. Introduction

Information on spatial variability in soil carbon (C) across diverse terrain under different agricultural management practices is one of the important components in development and implementation of an accurate and effective system of C credits in future carbon trading markets. Farmers, as potential sellers of C credits, might be interested in taking full advantage of the soil diversity in their fields/farms by using site-specific approaches to calculating C sequestration potentials and site-specific management strategies for maximizing C sequestration. Implementations of such strategies will require better understanding of the dynamic of the soil and ecosystem processes leading to C sequestration not just on a research experimental site but on a farm or landscape scale level with sufficient amount of spatial details at acceptable resolution. Information on soil C variability is important from ecological perspective as well, since it allows assessing contribution of soil diversity to enhancement of ecosystem productivity and to maintenance of species diversity (Knapp et al., 1993; Ozinga et al., 1997).

Because of spatial variability of soil organic matter it is believed that C sequestration capabilities of different land use and land management practices may vary across the landscape (Lal et al., 1995; Bruland and Richardson, 2005). A substantial amount of information exists on spatial variability of soil organic matter (e.g., McBratney and Pringle, 1999; Walter et al., 2003; Bruland and Richardson, 2005; Minasny et al., 2006). However information on how different types of land use or land management might affect soil C variability is sparser. The few studies that assessed not only the differences in mean C levels but also the differences in spatial variability patterns were primarily focused on comparing soils under agricultural cultivation with those under native vegetation or under native vegetation restorations projects (Robertson et al., 1993; Boerner et al., 1998; Paz-Gonzalez et al., 2000; Lane and BassiriRad, 2005). In a comparison between agricultural management

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practices, such as conventional tillage, no-till, and organic management practice with cover crops, Kravchenko et al. (2006) demonstrated that the spatial distribution of total C under conservational practices has become more spatially continuous and structured.

Soil C sequestration is a complex multi-stage process, of which total C is just one of characteristics. The dynamic processes that govern the rates and potentials for C sequestration are reflected in C pools of different stability. Active C is an essential input component of computer models simulating soil C processes (e.g. Parton et al., 1987). Since dynamic process-based modeling is one of the primary methods for predicting and monitoring changes in soil C (e.g., Bricklemyer et al., 2007), information on spatial variability of active C is particularly important for successful modeling applications in site-specific context. However, only limited information is currently available on spatial variability of active C pool indicators and on how various factors, including topography, management practice, crops, etc., affect such variability on a scale of an agricultural field or farm. Likewise, there is no information on whether the spatial variability pattern might be affected by type of agricultural management.

The first objective of this study is to compare the effects of a conventional agricultural management practice and an organic cover crop based management practice on spatial variability characteristics of C mineralized in a long-term incubation. The second objective is to study the effects of topography, texture, plant biomass input, and total soil C on mineralizable soil C in conventional and organic management practices.

## 2. Materials and methods

### 2.1. Data collection

Data were collected at the Long Term Ecological Research site (LTER), Kellogg Biological Station, in southwest Michigan, USA (42° 24’ N, 85° 24’ W). The soils of the studied site developed on glacial outwash and are classified as well-drained, Typic Hapludalfs either fine-loamy, mixed mesic (Kalamazoo series) or coarse-loamy, mixed, mesic (Oshtemo series). The experimental site was established in 1988. The treatment design is a randomized complete block with seven treatments and six blocks. The experimental plots are approximately 80 by 100 m. The two treatments used in this study are conventional tillage (chisel plowed) with conventional chemical inputs (CT) and conventional tillage with legume winter cover crops and no chemical inputs (CT-cover). Detailed information on the experimental site and on the studied treatments is presented by Robertson et al. (1997) and Hao and Kravchenko (2007). Descriptions of the treatment management protocols and history are provided at the LTER website (Kellogg Biological Station, 2007). Soil incubation measurements were conducted using soil samples collected from two plots of each treatment, from experimental blocks 5 and 6, referred to from now on as Rep 5 and Rep 6 (Fig. 1). Reps 5 and 6 were selected out of the 6 replications of the experiment to achieve the largest possible gradient in both soil texture and topography, since Rep 5 represents the highest elevations of the studied site and relatively fine textured soils, while Rep 6 is of lower elevation and with the most coarse-textured soils of the LTER site. Since assessment of spatial variability was the primary goal of this study the sampling effort was concentrated on intensive sampling within individual experimental plots in order to produce reliable sample variograms. In each plot, we collected approximately 100 geo-referenced soil samples in May of 2004 from 0- to 5-cm depth. Sampling locations are shown on Fig. 1 and the detailed description of how the sampling locations were selected is provided by Kravchenko et al. (2006).

At each sampling location, a composite sample consisting of five 2.5-cm diameter cores was taken within a 0.2-m-radius circle. The samples were air-dried and cleaned of visible plant residues and stones. Smaller visible plant material was removed by gentle air blowing and the sample was ground to pass a 2-mm sieve. Then, three subsamples were taken for measurements from each soil sample. The first sub-sample was used to determine total C via a Carlo–Erba C–N analyzer (Carlo Erba Instruments, Milan, Italy). The second sub-sample was used to determine soil sand content by wet sieving the dispersed sample through a 53-µm sieve. Our previous results indicated that for the studied LTER site sand content had stronger correlation with total C than either clay or silt content (Hao and Kravchenko, 2007). Based on these results as well as on the notion that clay+silt content (100%-% of sand) is a functional input in some widely applied soil C models, e.g., CENTURY (Parton et al.,

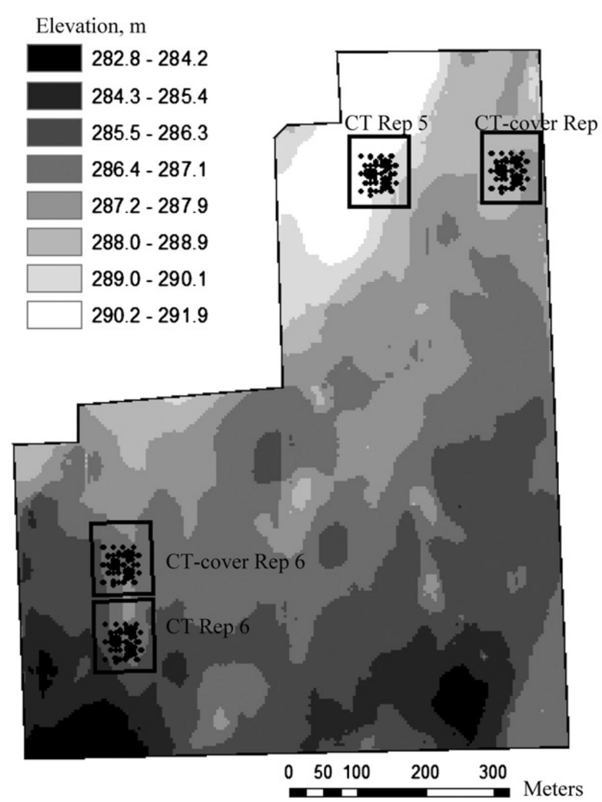


Fig. 1. KBS LTER site with soil sample locations (black dots) in the four studied plots overlaying the elevation map.

1987) we decided to use clay + silt content as the only textural variable for this study.

The third subsample was used for the incubation experiment. The incubation was based on the procedures described by Robertson et al. (1999). Briefly, soil samples were packed in 25 ml scintillation vials, and water content was adjusted to 60% (v/v) water-filled pore space. Soil pore space was estimated by measuring the volume of soil samples in vials and assuming the particle density of 2.65 g $cm^{-3}$. The vials were placed in 240 ml mason jars containing 3 ml water at the bottom to maintain humidity inside the jars. The incubation jars then were placed in a 25 °C constant temperature room. The incubation lasted about 210 days, and $CO_2$ respiration rates were determined weekly during the first month of the incubation and then approximately every two months till the end of the incubation period. At each sampling time, incubation jars were first flushed with $CO_2$-free air for about 10 min. The air stream was humidified by bubbling it through water-filled syringes. The respiration rate at the sampling time was obtained by measuring change of head-space $CO_2$ concentration in each jar over an incubation period.

Headspace $CO_2$ was measured using an infra-red gas analyzer (LICOR-6252; LICOR, Lincoln, NE, USA).

We conducted comparisons between the treatments in cumulative $CO_2$ respired C for all the incubation measurement dates. But the detailed data analyses were performed only for the cumulative $CO_2$ respired C by 7 (Cday7) and 210 (Cday210) days of incubation. Besides comparisons between the treatment means, these data were subjected to regression and spatial analyses. The total C data of Rep 6 used in this study were reported previously by Kravchenko et al. (2006) as part of the total C analyses. The total C data of Rep 5 and Rep 6 are shown here to facilitate interpretation of the $CO_2$ respired C results of this study.

The elevation measurements were collected every 2 m in rows 5 m apart. The elevation measurements were converted into a cell-based terrain map on a 4 × 4 m grid (ArcGIS 9.0 Spatial Analyst, ESRI, 2004). Based on the elevation map we have derived a map of wetness index (WI) values as described in Huang et al. (2007). Wetness index reflects both the information on the terrain slope for the particular map cell and on the size of the upslope area for the cell, and as such was used as an index representing topography.

Crop grain yields were collected with a combine equipped with yield monitor. The raw yield data were converted into 4 × 4 m cell-based maps (Kravchenko et al., 2005). The data from 1996 (the first year of yield monitor use at LTER) to 2003 (the year prior to soil sample collection) were considered for use in this study. We converted the grain yields into above ground main crop biomass. The conversions were done based on the seed and stover biomass data collected every year prior to harvest by the LTER research team from 5 sampling stations within each plot. The sampling protocols are reported on the LTER website (Kellogg Biological Station, 2007). We calculated ratios between seed and stover biomass for each of the data points within each plot individually and then averaged them for each crop in each treatment in each year. The average ratios for each treatment in each year, thus, are based on 10 data points available from 5 sampling stations in each of the two plots (Reps 5 and 6). Then we used the average ratios to estimate site-specific above-ground biomass, based on site-specific yield monitor grain yield data. After conversion we calculated the cumulative above ground main crop biomass inputs for each cell. Unfortunately, in some plots in 1996 and 1997 (the first years of yield monitoring) the yield monitor data were missing, thus we only calculated the cumulative above-ground main crop biomass, bio, based on the 1998–2003 data, which were the years when the grain yield data were available for each studied plot. We also considered separately the above-ground main biomass from 2003, bio2003, the year directly preceding soil sampling. There are multiple factors affecting the harvest index (ratio between grain weight and total above ground biomass weight) which is at the basis of this conversion (Johnson et al., 2006). It this study, we viewed the conversion not as an accurate representation of the biomass amounts but rather as a way of converting the site-specific grain yield data into common-unit measures suitable for comparing and combining data from different years and crops, measures that would be meaningful for C processes.

### 2.2. Data analysis

Comparisons between the means of the two studied treatments were conducted using PROC MIXED in SAS (SAS Inc., 2002). The statistical model consisted of treatment as a fixed factor and block and block by treatment interaction (error term for testing treatment effect) as random factors. Sample variograms were calculated and fitted with variogram models by weighted least-squares method using SAS procedures PROC VARIOGRAM and PROC NLIN, respectively (Kravchenko et al., 2006).

Relationships between $CO_2$ respired C with topography, soil texture, and total C were evaluated using multiple regression. To facilitate interpretations the multiple regression equations were considered within a framework of path analysis approach (Pedhazur, 1997; Kline, 1998). We used the conceptual path diagram shown on Fig. 2 to represent the relationships between the potential influences, such as total C, biomass, texture, and topography, and the $CO_2$ respired C.

The diagram reflects what is generally understood about topography, soil texture and soil organic matter relationships within landscape. Wetness index (WI), representing topographical influences, affects all the other studied variables. Soil

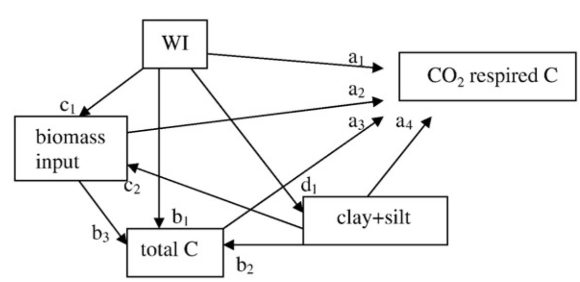


Fig. 2. Path diagram representing relationships between $CO_2$ respired C (either Cday7 or Cday210) and wetness index (WI), clay + silt content, above-ground main crop biomass input (either bio or bio2003) and total C. Letters identify the path coefficients, estimates of which are shown in Table 4.

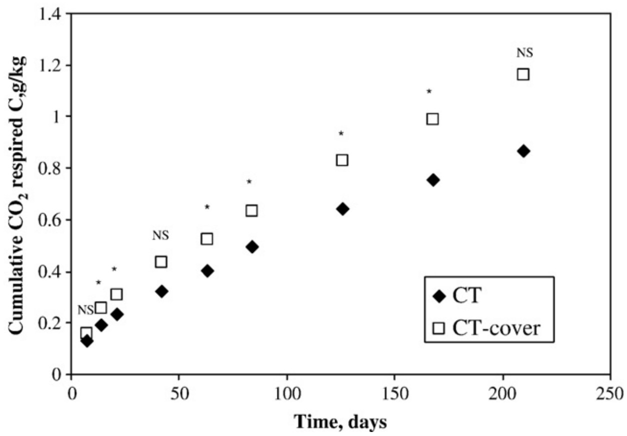


Fig. 3. Average cumulative respiration curves for the CT and CT-cover treatments. Stars (*) indicate the dates where $p$-values for comparison between the two treatments was <0.05, NS indicate $p$-values >0.05.

texture (clay+silt) is affected by topography, i.e. WI. Texture affects soil C, total as well as $CO_2$ respired. It also affects plant growth and through it biomass production (either bio or bio2003). Above-ground main crop biomass either contributes to soil organic matter directly (as in CT-cover where only grain is harvested and the rest of the plant is returned to soil) or serves as an indicator of the biomass contributions via plant roots. The relationships between plant biomass and total C could not be estimated in our study in all its complexity of reciprocal causations. Since separating the components of these relationships was not among our objectives we included in our model only unidirectional effects of biomass input on soil C variables. This simplification did not affect the direct effects of the studied variables on the $CO_2$ respired C, estimation of which was among our primary objectives. It allowed us to pursue the main study objective, that is, assessment of the factors affecting $CO_2$ respired C, in a straightforward manner using multiple regression techniques. The effects on texture are represented by the linear regression with WI. The effects on biomass inputs are represented via multiple regression with WI and clay+silt as independent variables. The effects on total C are represented via a model with WI, clay+silt and biomass input as independent variables, and the effects on $CO_2$ respired C are represented by a multiple regression with all four independent variables (WI, clay+silt, total C, and biomass inputs).

These sets of multiple regressions were conducted using PROC MIXED. As described earlier, the statistical model, first, included fixed effect of treatments and random effects of blocks and block by treatment interaction. Second, the model included linear effects of the continuous independent variables with separate regression coefficients for each treatment. Based on examinations of plots of residuals versus independent variables it was decided that no higher order terms were required in any of the studied regression models.

Unstandardized path coefficients from the multiple regressions and the correlation coefficients are reported. The coefficients from multiple regression equations represent direct effects of the independent variables. In multiple regression terms, these are the contributions of the individual independent variables when the other variables are being controlled for. Reported correlation coefficients represent combined effects of the studied independent variables on $CO_2$ respired C. Correlation coefficient with WI represents a combination of its direct effect and its indirect effects through texture, biomass input and total C. Correlation coefficient with clay+silt is a combination of its direct effect, the indirect effect through total C and biomass input, and the spurious effect due to the fact that both clay+silt and $CO_2$ respired C share a common cause–topography, expressed through WI. Likewise, correlation coefficients with biomass input and total C represent combinations of their direct, indirect, and spurious effects.

## 3. Results and discussion

### 3.1. Mean C values of CT and CT-cover

Mean cumulative $CO_2$ respired C for CT-cover tended to be higher than that of CT during all studied time periods (Fig. 3). However, the $p$-values for $CO_2$ respired C comparisons were relatively high (0.1–0.15) for 3 sampling times (Table 1 and Fig. 3).

Total C of CT-cover was significantly higher than that of CT ($p$=0.03) (Table 1). Higher soil carbon values in management practices with cover crops were reported in a number of studies (e.g., Kuo et al., 1997; Villamil et al., 2006; Franzleubbers and Brock, 2007). Franzleubbers and Brock (2007) observed statistically significant differences in soil organic C and no significant differences for mineralizable C characteristics. Several other studies reported differences in mineralizable C and not in total C (Janzen et al., 1998; Mendes et al., 1999; Schutter and Dick, 2002; Sainju et al., 2003). These inconsistencies probably are reflecting a wide diversity in the reported cover crop experiments in terms of environmental, soil, management, cover crop specie, experiment duration, and other conditions.

Table 1
Means, standard errors, and results of comparisons between CT and CT-cover treatments for the $CO_2$ respired C by 7 day (Cday7) and by the end of 210 day incubation (Cday210) and for the independent variables used in the study

| Variable | Means/standard errors for | | $p$-value from comparing CT and CT-cover |
|---|---|---|---|
| | CT | CT-cover | |
| WI† | 6.5/0.35 | 7.1/0.35 | 0.11 |
| Clay+silt, g/kg | 467/147 | 564/147 | 0.14 |
| bio‡, Mg/ha | 36.7/1.5 | 32.2/1.5 | >0.2 |
| bio2003§, Mg/ha | 3.2/0.26 | 2.6/0.26 | >0.2 |
| Total C, g/kg | 6.8/0.71 | 9.5/0.71 | 0.03 |
| Cday7 | | | |
| C–$CO_2$, g/kg | 0.13/0.0043 | 0.16/0.0046 | 0.14 |
| % of total C | 2.0/0.22 | 1.7/0.22 | 0.11 |
| Cday210 | | | |
| C–$CO_2$, g/kg | 0.87/0.042 | 1.16/0.042 | 0.13 |
| % of total C | 13.1/1.37 | 12.5/1.37 | >0.5 |

The numbers of observations used in the data analyses are 196–199 for CT and 165–170 for CT-cover.
†WI is the wetness index.
‡Bio is the cumulative above-ground main crop biomass 1998–2003.
§Bio2003 is the above-ground main crop biomass of 2003.

Table 2
Parameters of the variogram models fitted to the sample variograms of the $CO_2$ respired C by 7 day (Cday7) and by the end of 210 day incubation (Cday210) in CT and CT-cover treatments

| Variable | Treatment | Variogram model | Nugget | Sill | Range, m | Nugget/Sill, % |
|---|---|---|---|---|---|---|
| Cday7 | CT | Gaussian | 0.00031 | 0.00035 | 19 | 89% |
| | CT-cover | Gaussian | 0.00067 | 0.0010 | 55 | 67% |
| Cday210 | CT | Gaussian | 0.017 | 0.027 | 60 | 65% |
| | CT-cover | Gaussian | 0.024 | 0.031 | 60 | 78% |
| Total C | CT | Spherical | 0.40 | 1.19 | 43 | 34% |
| | CT-cover | Gaussian | 0.43 | 2.22 | 30 | 19% |

Moreover, even within the same experiment the differences between the treatments with and without cover crops were found to vary annually and seasonally (Mendes et al., 1999; Schutter and Dick, 2002).

In both CT and CT-cover the cumulative amount of $CO_2$ respired C by the end of 7 day incubation (Cday7) constituted ~1.8% of the total C. The cumulative amount of $CO_2$ respired C by the end of 210 day incubation (Cday210) constituted ~13.0% of the total C.

### 3.2. Spatial variability characteristics

For both treatments the variogram shapes of $CO_2$ respired C showed only weak spatial structure (Table 2). The nugget to sill ratios exceeded 65% indicating that most of the variability occurred at distances less than the smallest sampling distance (1 m). There was overall higher variability in Cday7 data in CT-cover than in CT (Fig. 4). The difference between the variograms for Cday210 data was much smaller.

Consistently with the findings of Kravchenko et al. (2006), in the two blocks used in this study (Reps 5 and 6) the variability of total C in CT-cover was more spatially structured with lower nugget to sill ratio than those of CT, pointing to more continuous patterns of total C distribution in the CT-cover (Fig. 4). This trend was present in the combined data as well as in data from Reps 5 and 6 individually (not shown). Similar to our observations Yanai et al. (2005) found strong spatial correlation in total C, while much lower spatial structuring for mineralizable C data in a study of Khazakhstan Chernozem soils.

The patterns observed in the total C variograms appear to be similar to the pattern in biomass variograms (Fig. 5a). The biomass inputs in organic management can be expected to be more spatially variable than those of the management with conventional chemical inputs. Greater spatial continuity is a result of greater field-scale variability in availability of plant nutrients under organic management. Greater variability of crop yield in CT-cover was observed in the study of 1996–2001 years of georeferenced crop grain yields from KBS LTER (Kravchenko et al., 2005). The 1998–2003 biomass data, bio, from Reps 5 and 6 used in this study were a part of the data set reported by Kravchenko et al. (2005).

However, for the biomass data of 2003 the trend was reversed with greater variability and greater spatial structure observed in CT than in CT-cover (Fig. 5b). The growing season of 2003 was characterized by very wet May and dry June and overall soybean yields in CT-cover were substantially lower than that in CT. The lack of difference in variograms of CT and CT-cover for Cday210 could be reflecting the change of the variability pattern of biomass in 2003 compared to the 6-year biomass variability trend. That is, the Cday210 spatial pattern reflects a combination of the 6-year biomass variability pattern, where CT-cover was more variable than CT, and the pattern of the most recent main crop biomass input of 2003, where CT was more variable than CT-cover. Probably, a mixture of the longer-term and the preceding year patterns resulted in small differences in variograms of Cday210, which reflected both last year as well as somewhat older C inputs. Interesting that greater variability of Cday7 in CT-cover was consistent with the 6-year biomass variograms trend not reflecting the variability pattern of the most recent main crop. One possible speculative explanation could be the contribution of weeds grown in the organic

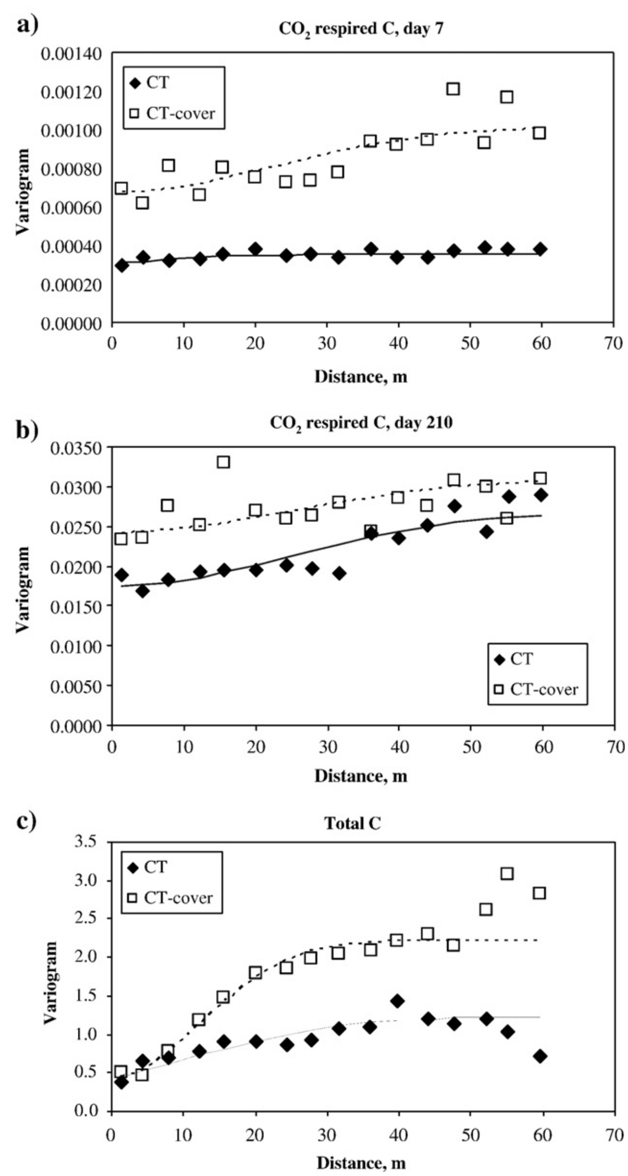


Fig. 4. Sample variograms (dots) and variogram models (lines) calculated based on combined data from Reps 5 and 6 for a) Cday7, b) Cday210, and c) total C. Variogram model parameters are shown in Table 2.

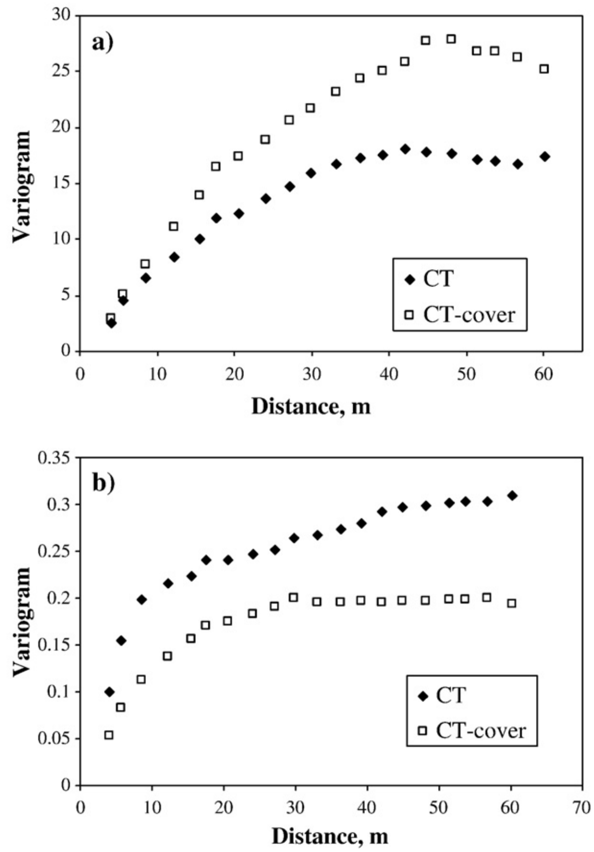


Fig. 5. Variograms of the biomass input data for a) cumulative above-ground main crop biomass from 1998–2003; and b) above-ground main crop biomass from 2003, the growing season preceding soil sampling collection.

CT-cover treatment in fall and spring prior to sampling. Spatial patterns in weed growth in fall 2003/spring 2004 could be following the same pattern as that of the long-term biomass. Unfortunately, no data on spatial variability of weeds have been collected in the studied site.

### 3.3. Relationships with topography, texture, and biomass inputs

Overall, the models with topography, texture, biomass, and total C explained only very modest portion of variability in $CO_2$ respired C. For Cday7 combined effects of 6-year main crop above ground biomass (bio), WI, clay+silt and total C explained only 13% of its variability in CT and only 12% in CT-cover treatment. The explained variabilities for Cday210 were 11% and 16% for CT and CT-cover, respectively. The amount of the variability that was explained is comparable to what can be regarded as spatially structured variability of $CO_2$ respired C data. As indicated by the variograms, for $CO_2$ respired C more than 65% of variability occurred at distances less than 1 m (the smallest sampling distance). Thus it could not be explained by the variables that were measured at the same (total C and texture) or larger (WI and biomass) spatial resolution. The topographical, biomass and texture effects explained much more substantial part of variability in total C. The explained variability was 56% in CT and 41% in CT-cover.

Combined effect of WI on Cday210 as reflected in the correlation coefficients (Table 3) was positive in CT-cover, but not in CT. However, direct effects of WI on Cday210 as well as on Cday7 were not statistically significant in both treatments (Table 4). Initially, we hypothesized that there would be a non-negligible direct effect of WI, which would reflect a contribution of topography to C processes via variations in soil moisture and temperature conditions affecting variations in mineralization rates. We believed that such a contribution would be noticeable besides what is already reflected in plant growth, textural, and total C variations. However, the data indicated that direct topographical influences were completely encompassed by these other contributions.

Biomass (1998–2003) had significant positive combined (direct, indirect and spurious) effects on Cday210, with correlation coefficient for CT-cover and CT 0.32 and 0.20, respectively (Table 2). The correlation with bio2003 was positive in CT-cover while not significant in CT. For both day 7 and day 210, direct contribution of both bio and bio2003 tended to be positive in CT-cover, while not significant in CT. The bio data of CT-cover were much better explained by WI and texture than those of CT, with substantially higher percent of explained variability (34% and 1%, respectively). The reverse was true for bio2003, where the 20% of variability was explained in CT and only 9% in CT-cover. The data indicated that mineralizable pools were only weakly related to the amounts of above-ground main crop biomass inputs.

Texture, as expressed by clay+silt, had negative correlation with Cday7 in CT-cover and negative direct effect on Cday7 in

Table 3
Correlation coefficients for the $CO_2$ respired C by 7 day (Cday7) and by the end of 210 day incubation (Cday210) and total C with biomass inputs, wetness index and clay+silt content

| | Bio‡ | | Bio2003§ | | WI† | | Clay+silt | | Total C | |
|---|---|---|---|---|---|---|---|---|---|---|
| | CT | CT-cover | CT | CT-cover | CT | CT-cover | CT | CT-cover | CT | CT-cover |
| Cday7 | NS¶ | NS | NS | NS | NS | NS | NS | −0.19* | 0.30** | NS |
| Cday210 | 0.20** | 0.32** | NS | 0.18* | NS | 0.17* | NS | 0.36** | 0.14($p$=0.06) | 0.34** |
| Total C | 0.18* | 0.51** | −0.19** | NS | 0.25** | 0.52** | 0.71** | 0.55** | | |

†WI is the wetness index.
‡bio is the cumulative above-ground main crop biomass 1998–2003.
§bio2003 is the above-ground main crop biomass of 2003.
¶$p$-value > 0.1.
*p < 0.05.
**p < 0.01.

Table 4
Multiple regression results representing unstandardized coefficients in the path analysis specifying functional relationships between the studied variables

| Response variable | Analysis with 6-year biomass input, bio‡ | | | | | Analysis with 2003 biomass input, bio2003§ | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | ID | Independent variable | Treatment | | *p*-value¶ | ID | Independent variable | Treatment | | *p*-value |
| | | | CT | CT-cover | | | | CT | CT-cover | |
| Cday7 | $a_1$ | WI† | | | NS | $a_1$ | WI | | | NS |
| | $a_2$ | Clay+silt | −0.00003# | −0.00008 | <0.001 | $a_2$ | Clay+silt | −0.00004 | −0.00008 | <0.001 |
| | $a_3$ | bio | | 0.0012 ($p$=0.055) | NS | $a_3$ | bio2003 | | | NS |
| | $a_4$ | Total C | 0.0069 | 0.0046 | <0.001 | $a_4$ | Total C | 0.0077 | 0.0062 | <0.001 |
| Cday210 | $a_1$ | WI | | | NS | $a_1$ | WI | | | NS |
| | $a_2$ | Clay+silt | −0.0003 | 0.0002($p$=0.06) | <0.001 | $a_2$ | Clay+silt | | | NS |
| | $a_3$ | bio | | 0.007($p$=0.08) | 0.07 | $a_3$ | bio2003 | | | NS |
| | $a_4$ | Total C | 0.040 | 0.020($p$=0.09) | <0.001 | $a_4$ | Total C | 0.048 | 0.028 | <0.001 |
| Total C | $b_1$ | WI | | 0.33 | <0.001 | $b_1$ | WI | | 0.38 | <0.001 |
| | $b_2$ | Clay+silt | 0.0088 | 0.012 | <0.001 | $b_2$ | Clay+silt | 0.011 | 0.013 | <0.001 |
| | $b_3$ | bio | 0.066 | | <0.001 | $b_3$ | bio2003 | | | NS |
| Biomass input | $c_1$ | WI | | 0.65 | 0.05 | $c_1$ | WI | | | NS |
| | $c_2$ | Clay+silt | 0.032 | 0.037 | <0.001 | $c_2$ | Clay+silt | 0.0011 | 0.0017 | <0.05 |
| Clay+silt | $d_1$ | WI | | 0.014 | <0.001 | | | | | |

Letters are used as IDs for the coefficients on the path diagram shown on Fig. 2.
†WI is the wetness index.
‡bio is the cumulative above-ground main crop biomass 1998–2003.
§bio2003 is the above-ground main crop biomass of 2003.
¶*p*-value for comparison between the regression coefficients of CT and CT-cover (interaction with the treatments).
#Coefficients that were not significantly different from zero ($p$>0.1) are not shown. Coefficients not followed by a specified *p*-value were significant at 0.05 level.

both treatments (Table 4). It had positive correlation with Cday210 and no significant direct effects in CT-cover, while negative direct effect in CT. Weak and inconsistent correlations observed in this study are comparable with those reported in literature. Other studies have reported either weak relationships, negative as well as positive, or no relationships between $CO_2$ respired C and textural variables, e.g., clay content (Franzleubbers et al., 1996; Muller and Hoper, 2004; McLauchlan, 2006). Cote et al. (2000) observed significant negative correlation between C mineralizable at the end of more than 280 day incubation and clay in mineral soil. Wang et al. (2003) observed a negative coefficient for clay in the multiple regression with $CO_2$ respiration as a response after reaching equilibrium length of incubation. Positive combined effect of clay+silt reflects indirect positive contributions of clay+silt to $CO_2$ respired C through greater total C and higher biomass inputs. They are a part of overall better plant growth conditions due to higher moisture availability and higher contents of plant nutrients, especially for CT-cover, in areas with finer texture, often corresponding to lower topography with higher WI values. The negative direct contributions of clay+silt content to the $CO_2$ respired C are reasonable to expect in support of the general conception of more protection for labile C offered by finer textured soils (Hassink, 1994). That is, with everything else, that is total C, biomass, and WI, held constant, $CO_2$ respiration is lower in finer-textured soils.

## 4. Conclusions

$CO_2$ respired C tended to be higher in the organic CT-cover treatment than in conventional CT treatment. The structure of its spatial distributions was relatively weak with variogram values of CT-cover tending to be higher than those of CT. In either treatment, only a small portion of variability in $CO_2$ respired C (11–16%) was explained by multiple regression models that included topography (WI), soil texture (clay+silt content), above-ground main crop biomass, and total C as independent variables. There were positive direct effect of total C and negative direct effect of clay+silt, while no significant direct effects of either WI or biomass on $CO_2$ respired C.

The practical implication of these findings for modeling soil C processes on agricultural field/farm scale is that in soils similar to those of this study it is sufficient to have model input information on labile C sources as field averages. That is, attempts to produce site specific maps of labile C input information using either spatial auto-correlation information or measurements of auxiliary variables, such as topographical, soil texture or site-specific biomass input information might not be feasible. On the other hand, obtaining site-specific inputs on total C most likely will be practical and may potentially produce more accurate C modeling results for field/farm scales.

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