Exploring patterns amongst soil characteristics and soil respiration in an agricultural field in the Sacramento Valley, CA

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Introduction

The ability of soil to sequester carbon is dependant upon biogeochemical interactions between plant, soil, and microbial niches, and external driving forces such as climate and tillage. For instance, soil respiration is an indicator of C exchange between terrestrial and atmospheric reservoirs and has been shown to depend on soil organic carbon (SOC),[1] moisture,[2] temperature,[3] and to be effected by tillage.[4]

Presented is an analysis of field-scale soil characteristics and soil respiration dynamics in an agriculture field. Total C and percent clay were sampled while the field was under no-till wheat production (8/03). Soil respiration, temperature and water content were sampled during a maize growing season, following the division of the field into a standard and minimum tillage system (6-9/04). Bulk density was sampled before tillage division (8/03) and following maize harvest (10/04).

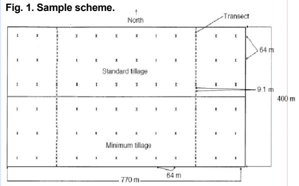
A variety of analytical techniques have been employed to explore the patterns amongst variables. A simple analysis of variance is presented as a starting point to determine independent correlations. Spatial trends within the field are presented from two methods: variogram models to determine the spatial structure of clay content, total C, and bulk density; and median polish (an exploratory data analysis technique) for analyzing median trends of soil respiration and temperature across tillage treatments. Lastly, the temporal persistence of soil respiration is viewed in terms of the Spearman rank correlation coefficient and the relative difference from the sampled mean, at given time and location, compared over several sampling events.

Site Description

Our samples were collected in a 30 hectare CA agricultural system, from 140 sites across the field (Fig. 1). 72 of these sites are spread in a grid across the entire field and the remaining 68 sites are in two transects running N-S. Soil respiration, temperature, and water content are sampled along columns 1, 3, 7, 10, 12 (running west-east, Fig. 1), all other variables are sampled at each noted sample location in the main grid.

From August 2002 to July 2003 the entire field was under minimum till wheat production, sown directly into maize stubble requiring no tillage. In October 2003 the field was divided into two treatments to represent the farmer's standard (ST) and minimum tillage (MT) practices The northern half of the field is managed under ST and the southern half under MT. Maize was sown into both treatments in April, and harvested in September, 2004.

Fig. 1. Sample scheme.



Sample Depths and Variable Units :

Total Carbon (0-15cm, μg/cm³), Clay (0-15cm, %), Soil Respiration (510 cm², CO2 - μg/m²/s), Bulk Density (0-15cm, g/cm³), soil temperature (0-15 cm, °C), Soil water content (o-15cm, %)

Pearson Correlation Coefficient

Table 1. Pearson correlation coefficient (r) among soil variables (7/04)

	BD	% Clay	Total C	SR	swc	Tsoil
BD	1.000	-0.458	0.010	0.000	-0.365	-0.029
% clay		1.000	0.230	0.025	0.536	0.024
Total C			1.000	-0.085	0.327	-0.080
SR				1.000	0.053	0.442
swc					1.000	0.011
Tsoil						1.000

$P<0.05$ (red), $P<0.10$ (blue)

Pearson Statistical Summary

-% clay positively linked to soil water content and negatively correlated with soil BD, across tillage treatments.

- Soil water content positively related total C, but total C not related to % clay, due to the varying clay spectrum across the field site (see figure 2).

-Soil respiration positively correlated to soil temperature (see figure 6).

-No statistical significance found between soil respiration, % clay, and/or total C, at the field scale.

-Importantly, above summary statistics assume independence, and a week stationarity, between variables. However, particularly with clay content, this assumption is false (see AutoCorrelation).

AutoCorrelation

Ordinary Kriging (Fig. 2) and an anisotropic variogram model (Fig. 3) of percent clay show nicely clay's field-scale non-stationarity $\{E(Z_{t+h} - Z_t) \neq 0\}$ across tillage treatments .

Ordinary Kriging (Fig. 4) of total C reveals by observation similar trends as with % clay in the eastern half of the field. By linear regression, total C is significantly correlated to (r^2= 0.50) clay in the eastern half of the field, yet no correlation exists between the variables on the western half. As a result, total C is better predicted alone than with clay as covariate at this field site.

Bulk density shows no spatial structure at our scale of measurement (Fig. 1) , before or after tillage, as shown by the 'nugget effect' in the bulk density variogram model (Fig. 5), sampled post-tillage.

Fig 3.

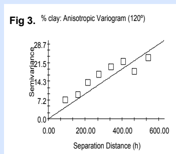


Fig. 5.

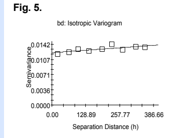


Figure 2. % Clay from O.K., "X's" represent sampling locations.

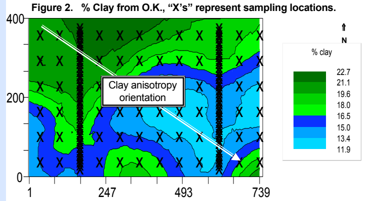
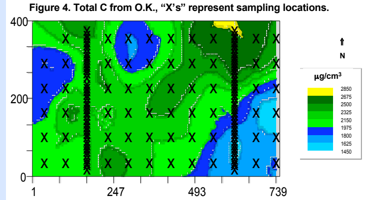


Figure 4. Total C from O.K., "X's" represent sampling locations.



Median Polish

Median polish (MP) is an exploratory data analysis technique[5] used to find an additive fit to two-way tables, and illuminate spatial trends in data sets. Because MP uses medians instead of means, it is robust to outliers. The assumptions;

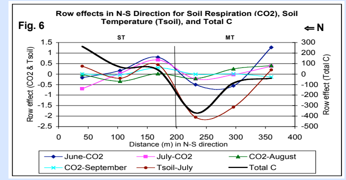
Data $\mathbf{Z}=(Z(s_1),\ldots,Z(s_n))$ observed at known spatial locations $\{s_1,\ldots,s_n\} \in D$ are a *realization* from a spatial process $Z= \{Z(s): s \in D\}$ and can be represented as $Z(s) = \mu(s) + \delta(s)$, where

$\mu(s)$ = large-scale spatial mean component, and $\delta(s)$ = small scale stochastic residual component.

Thus, median Polish models $\mu_{ij}(s)$ as linear combination of an overall effect (a), a row effect (r_i), and a column effect (c_j) **{ $\mu(s) = a + r + c$ }**, which are found by subtracting row and column medians from a two-way table while keeping track of the additive median 'effects' from each subtraction. In our case, the two-way table is the field scale grid (figure 1).

Figure 6 shows the row effects (r_i) of soil respiration (June-Sept), soil temperature (July), and total C (8/03) in the N-S direction, across tillage treatments.

Fig. 6 Row effects in N-S Direction for Soil Respiration (CO2), Soil Temperature (Tsoil), and Total C



MP Summary

As viewed from MP row effects (Fig. 6), soil respiration, total C, and soil temperature behave with similar spatio-temporal patterns across tillage treatments. There are generally higher row medians in the middle of the ST treatment and lower row median in the middle of the MT treatment between the variables.

Interestingly, percent clay shows similar median value trends across tillage treatments (Fig. 2), and total C was sampled before tillage yet its median distribution remains similar to soil respiration and temperature after tillage.

References:

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Spearman Rank Coefficient and Mean Relative Difference

Two techniques to test the temporal persistence of variables are:

1) Spearman rank correlation[6] (r_s), defined by $r_s = 1 - \{6\sum(R_{xt} - R_{x,t'})^2 * (n(n^2-1))^{-1}\}$

Where $R_{x,t}$ is the rank of the variable $S_{x,t}$ observed at location x on date t, $R_{x,t'}$ is the rank of the same variable, at the same location, but on date t', and n is the sample number. Therefore, r_s = 1 corresponds to equal rank for any site, or perfect time stability between sampling dates t and t.'

2) Relative difference[7] ($\delta_{x,t}$) from mean variable, defined by $\delta_{x,t} = (S_{x,t} - \underline{S}_t)/\underline{S}_t$

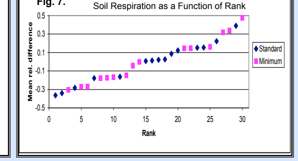
Where $S_{x,t}$ is an individual variable at location x and time t and $\underline{S}_t$ is the variable's mean at that same time. Thus, if $S_{x,t} = \underline{S}_t$, $\delta_{x,t} = 0$

Table 2. Spearman rank correlation coefficients between soil respiration values.

Date (2004)	June	Early July	Late July	August	September
r_s	1.00	0.51	0.32	0.52	-0.04

Significant at the 0.5% level of a one tailed test.[5] (red)
Significant at the 5.0% level of a one tailed test.[5] (blue)
(n=27)

Fig. 7. Temporal Mean of Relative Difference (δ_t) for Soil Respiration as a Function of Rank



Temporal Persistence of Soil Respiration

The Spearman rank correlation coefficient for soil respiration (SR) reveals, relative to June, significant temporal stability between early and late July and August sampling events (Table 2). However, there was no correlation between the rank of June and September SR values across the field, possibly relating to soil water status or the harvesting of maize before the September sampling event.

A plot of the time average value (δ_x) of any soil respiration (SR) sample location over the growing season (June-Sept.) versus its rank shows the temporal mean behavior of the spatial SR pattern (Fig. 7, where each data value represents a singular sampling location within the field site). As seen by MP (Fig. 6) there is a grouping of SR values in the ST treatment above, and a grouping of SR values in the MT below, the temporal field mean (median for MP). However, no clear separation in SR values between tillage treatments is apparent.

Conclusions

Assuming independence between variables, and using the Pearson correlation coefficient (Table 1), significant relations were found between soil characteristics and soil respiration (SR), such as a positive correlation between SR and soil temperature. However, the assumption of sample independence is mostly false in our in case, and further investigation is needed to determine spatial coherence between variables within the landscape.

For instance, a Krigged map of clay content shows the non-stationarity, and thus directional dependency, of clay's mean structure (Fig. 2,3). This non-stationarity can confound comparisons on the averaged effects of tillage and C sequestration if clay content turns out to be a greater influence on C dynamics than short term tillage reductions. Preliminarily, total C is not statistically related to clay content at the field scale, but is correlated in regions of lower clay content (Fig. 4), and remnants of this pattern will most likely remain irregardless of tillage over next several years.

There was no statistical difference between SR or bulk density between standard (ST) and minimum (MT) tillage treatments. However, spatial patterns orthogonal to the tillage divide generally show higher SR values in the middle of ST, and lower SR values in the middle of MT. Soil temperature, percent clay (fig 2), and total C (before tillage) show similar median value spatial trends as does SR. Thus, during the first year of reduced tillage, field-scale percent clay and initial total soil C (before tillage) seem to have a greater relation to soil respiration than reduced tillage.

Soil respiration (SR) was found to have statistically significant temporal persistence during 3 of the four months sampled (Table 2). However, the rank (or persistence) of September SR values did not correlate well with those of June, most likely due to maize harvest and changes in soil water status. The consistency in the rank of field-scale SR values over time could indicate a greater influence of spatially stable, versus transient, soil characteristics on C transformation.

In conclusion, an exploratory data analysis of field variables allows the researcher to better understand patterns occurring within the landscape that may otherwise be missed by traditional summary statistics, and thus is a valuable research tool to illuminate variable spatio-temporal trends within data sets.