The Effect of Long-term Changes in Plant Inputs on Soil Carbon Stocks

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ABSTRACT

Soil organic carbon (SOC) is the one of the largest terrestrial reservoirs of carbon. The main source of SOC is plant input such as dead leaves and root exudates. Yet, the processes that dictate the response of SOC to changes in C inputs are still poorly understood and inadequately represented in predictive models. Here we explore the response of soil organic carbon (SOC) to long-term changes in plant C inputs across a range of biomes and soil types. We synthesize and analyze data from long-term litter manipulation field experiments, and focus our meta-analysis on changes to total SOC stocks and explore the relative contribution of above- versus belowground C inputs. Our cross-site data comparison reveals that divergent SOC responses are observed between forest sites, particularly for treatments that increase C inputs to the soil. We explore trends among key variables (e.g., biome, vegetation, temperature, precipitation) that inform soil C model representations. The assembled dataset is an important benchmark for evaluating process-based hypotheses and validating divergent model formulations.

KEYWORDS

soil carbon, environmental influences, land restoration, meta-analysis, ANOVA test

INTRODUCTION

Soil is the largest terrestrial pool of actively-cycling carbon, containing at least three times as much carbon as is found in vegetation or the atmosphere (Schmidt et al. 2011). The amount of organic carbon in the soil is often used as an indicator of soil health and fertility. Soil organic matter provides nutrients for plant growth, promotes the biological and physical health of soil(i.e high resistance to erosion), and acts as a buffer against harmful substances such as chemicals from pesticides. Soil carbon dynamics are also fundamental for maintaining the balance of atmospheric CO_2 concentrations (Denman et al. n.d.). Plants absorb CO_2 from the atmosphere via photosynthesis, and the subsequent decomposition of plant litter transforms this carbon into soil organic matter. Microorganisms in the soil digest plant-derived carbon and release a fraction of it back to the atmosphere. Increasing soil carbon sequestration has the potential to mitigate rising atmospheric CO_2 concentrations, and thus, motivates the need to better understand the drivers of soil carbon formation and sequestration.

Plant litter is the most significant source of organic inputs to the soil and plays a crucial role in driving the soil carbon cycle. Plant inputs to the soil are derived from both aboveground sources, such as leaf and woody litter input (Hieber and Gessner 2002, Romaní et al. 2006), and from belowground sources, such as root exudates and root biomass (Fierer et al. 2009). Annually, nearly 75 Gigatons of C are added to the soil via inputs of dead plant biomass and root deposits (Lajtha et al. 2014b). Despite the importance of plant litter in maintaining soil carbon stocks, land use change and unsustainable forest management practices lead to loss of forests and grasslands, with large implications for soil carbon stocks. On the other hand, to combat the increasing level of CO_2 in the atmosphere, sustainable forest management practices have a large potential to sequester additional atmospheric C (Lal 2005). Climate and land cover change can also affect the amount of plant C inputs that enter the soil through changes in plant productivity, allocation, and rooting depth. Understanding the response of soil carbon to changes in plant inputs is essential for elucidating carbon pool dynamics. As a dynamic pool, the levels of soil organic matter are determined by many factors, such as soil mineralogy (e.g., soil texture), climate, type and amount of plant organic matter, and microbial activity (Johnston et al. 2009). It is broadly agreed that a deep understanding of soil biogeochemistry is critical to the stewardship of ecosystem services offered by soils, such as soil fertility, water quality and retention, and erosion prevention, among others contributions (Schmidt et al. 2011)

Over the past century, scientists have designed and implemented many experiments to study the effect of long-term changes in plant inputs on soil carbon cycling and storage. Two outstanding types of experiments have been established at field sites around the world, namely, the Long-Term Bare Fallow (LTBF) and the Detritus Input and Removal Treatment (DIRT) experiments. The goal is to elucidate how soil content changes in response to different types of plant removal/addition manipulations. Recent studies suggest that altering above- and belowground inputs may also have complex effects on the soil carbon pool due to changes in factors such as microbial activity and decomposition rates (Lajtha et al. 2014a). Indeed, diverse responses have been observed among different sites. For example, the experimental plot at the Bousson site – established in a temperate deciduous forest – has shown nearly an 8% decrease in soil carbon concentration after 20 years of litter addition (Bowden et al. 2014). In contrast, the Harvard Forest site, also a temperate deciduous forest, has shown a 15% increase after 5 years litter removal (no aboveground and below ground litter) and a slight decrease after 5 years litter addition (Rousk and Frey 2015). Grassland sites, on the other hand, demonstrate different trends than forests. The plots in Curtis prairie, under 45 years of aboveground litter removal treatment, show a slight increase of soil carbon concentration (Lajtha et al. 2014b). Environmental factors and biological processes that control the interaction between soil carbon and the mineral matrix affect how carbon is stabilized in the soil (Sollins et al. 2009, Schmidt et al. 2011). In light of these diverse responses, a quantitative review of soil carbon studies that manipulate the plant inputs entering soil is needed for improving and benchmarking biogeochemical models, and for future predictive capability to inform land management.

In this study, we synthesized data from published literature and conducted a meta-analysis, leveraging a range of methods including data visualization and linear mixed effect modeling, to explore the response of soil organic carbon to long-term changes in plant litter across different environments. The main goal of our study was to explore the environmental factors that drive variation of soil carbon responses to changes of plant input and to propose a predictive statistical model. We addressed 2 primary questions in our analysis: (1) What factors drive variance in soil carbon response? (2) Do factors that influence soil carbon response change between short-term and long-term treatments?

METHODS

Brief introduction of the long-term bare fallow (LTBF) and detritus input removal treatment (DIRT) experiments

The Long-term Bare Fallow (LTBF) and Detritus Input Removal Treatment (DIRT) are two major types of experiments that have been established at many experimental sites to study the effect of long-term plant input changes on soil carbon cycling. The DIRT experiment consists of four treatments in addition to a control plot: no litter (NL), double litter (DL), no roots (NR), and no inputs (NI). Control plots receive normal above- and below- ground inputs. In NL and NI plots, aboveground litter was excluded using a plastic mesh fabric placed on the plots. Litter collected from either NL or NI plots is transferred to DL plots. Living roots entering the NR and NI treatments are removed manually at the start of the experiment. Plastic barriers are then inserted into the trench to thwart roots from reentering the plots (Bowden et al. 2014). The LTBF is a long-term experiment (most sites surpassing 20 years) of litter removal. With the elimination of plant litter, the LTBF experiment is a straightforward way to explore how labile carbon decays in the soil by stopping all carbon inputs (Brant et al. 2006).

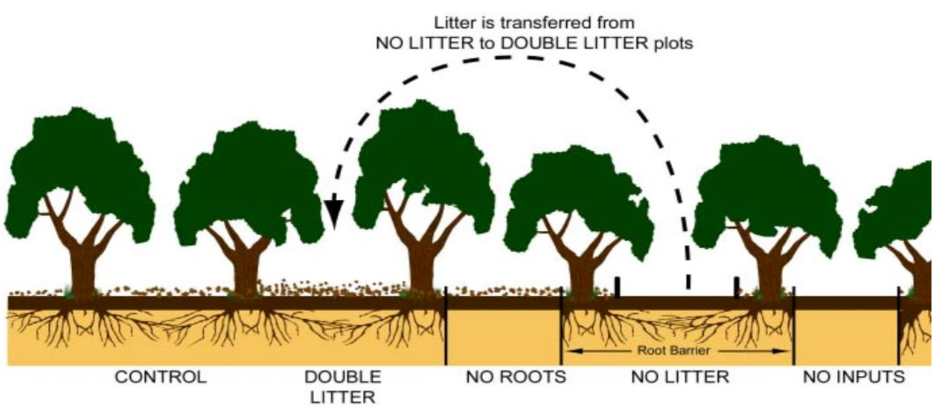

Fig 1. Litter manipulations in LTBF and DIRT Experiments.

Literature searching and criteria inclusion

We conducted a meta-analysis following the method of (Nave et al. 2011). We used online databases (namely, Google Scholar and the UC Berkeley Library Database) to find peer-reviewed papers. Keywords of our literature search included: litter manipulation, soil organic carbon, plant input, and bare fallow. We found 23 publications that met our criteria of inclusion. Specifically, to be included in our meta-analysis, a study must have: (1) reported soil organic carbon (SOC) data of both control and treatment plots, and (2) followed the standard procedure of DIRT and LTBF treatment. From the literature, we collected the SOC concentration at 0-20 cm depth of soil (excluding the O horizon). For data from the DIRT experiments, we used SOC data from the control plots as the undisturbed (control) condition. For data from the LTBF experiments, where no control plot was established, we used the data point from year 0 (initial) as our control condition.

We extracted auxiliary variables and metadata as potentially useful predictor variables from each paper (Table 1). Continuous predictors include mean annual temperature, mean precipitation, soil pH, % of clay in the soil, % of silt in the soil, and % of sand in the soil. Categorical predictors include biome type, vegetation, climate region, and soil taxonomic order. Biome type includes categories: temperate deciduous forest, temperate grassland, tropical rain forest, and tropical grassland. Vegetation includes categories: grassland and forest. Climate region includes categories: temperate and tropical. Soil taxonomic order is in USDA standard, which includes 11 different orders such as Alfisols, Mollisols, and Inceptisols. Soil information (such as soil taxonomic order and composition of clay, sand, and silt) was extracted from peer-reviewed papers and the ISRIC (International Soil Reference and Information Centre) database.

Table 1. Predictor variables tested using ANOVA

Factors	Level
Biome	tropical rain forest; temperate grassland; temperate deciduous forest; subtropical coniferous forest
Vegetation	forest; grassland
Soil taxonomic order	Alfisol; Mollisol; Entisol; Inceptisol
Treatment	Double litter (2X); aboveground litter removal (0X); belowground litter removal (NR); total litter removal (NI)
Latitude	continuous
Longitude	continuous
Mean annual temperature	continuous
Mean annual precipitation	continuous
% clay	continuous
%silt	continuous
% sand	continuous
Soil pH	continuous

Statistical analysis: linear regression modeling

To analyze the effect of experimental duration on changes in soil carbon stock, we performed a linear regression fitted by least squares using the R statistical program. We used percentage change of SOC to estimate the degree of response:

$$\frac{SOC_{treatment} - SOC_{control}}{SOC_{control}} \cdot 100\%$$

where $SOC_{treatment}$ is the SOC concentration in the treatment plots and $SOC_{control}$ is the SOC concentration in the control plots. In statistics, linear regression is an approach to model the linear relationship between a scalar dependent variable, in our case % change SOC, and one explanatory variable, in our case duration. We applied a linear regression on data from two distinct treatments: double litter addition (2X) and no inputs/bare-fallow (NI). If duration of treatment is important, a conspicuous increasing/decreasing trend line is expected. We chose a linear regression because the result is straightforward and gives one straight trend line, especially when only having one explanatory variable. We did acknowledge that duration was not the only factor that affects the soil carbon change, and therefore, the linear regression result may not be useful for predicting soil carbon change, but it is an effective way to show the effect of duration alone.

Statistical analysis: ANOVA F test

To explore what factors drive variation of soil carbon responses to changes in plant input, we conducted ANOVA (Analysis of Variance) with our dataset using R (R Core Team, Vienna, Austria). ANOVA test is a useful method to identify factors that drive variation of observation. Factors we analyzed consisted of two types: continuous and categorical (Table 1). For categorical factors, ANOVA partitions the total variance into within- and between-group components, according to each categorical factor we analyzed (Nave et al. 2011). For each predictor (e.g., biome) ANOVA computes the mean and variance of data from each group belonging to that predictor (e.g., temperate zones, tropics). With the null hypothesis stating that all groups have the same effect, ANOVA calculates the significance level (F value) to reject or accept the null hypothesis. Rejecting the null hypothesis means that the differences in observed effects between treatment groups is unlikely to be due to random chance. Larger values of F indicate strong evidence to reject the null hypothesis. ANOVA test with continuous predictors is similar to a linear regression. The best predictor should have the largest F value, which means that the variation of SOC change has a strong relation with the predictor. Hypothesizing that the environmental factors that affect the response of soil carbon to changes in plant inputs may change with treatment duration (e.g., short- to long-term driving mechanisms), we have divided the dataset into three time intervals: short-term (<20 years), intermediate (20-40 years), and long-term (>40 years). We conducted an ANOVA test on data from each interval and compared the predictors that were significant in each test.

RESULTS

Linear regression of the % change in SOC versus years of treatment

Our meta-analysis of data from the literature showed that the duration of litter manipulations has a significant effect on the percent change of SOC. The percent change of SOC is positively correlated (k=0.596) with time in the litter addition (2X) treatment (Figure 2a) and negatively correlated (k=-0.867) with time in the total input removal (NI) treatment (Figure 2b). The absolute value of the slope in each linear regression also indicates the degree of impact of each treatment on SOC. We noted that the absolute value of the slope in Fig. 1b is larger than that in Fig. 1a, which may suggest that input removal has a stronger effect on SOC than litter addition.

(a) **(b)**

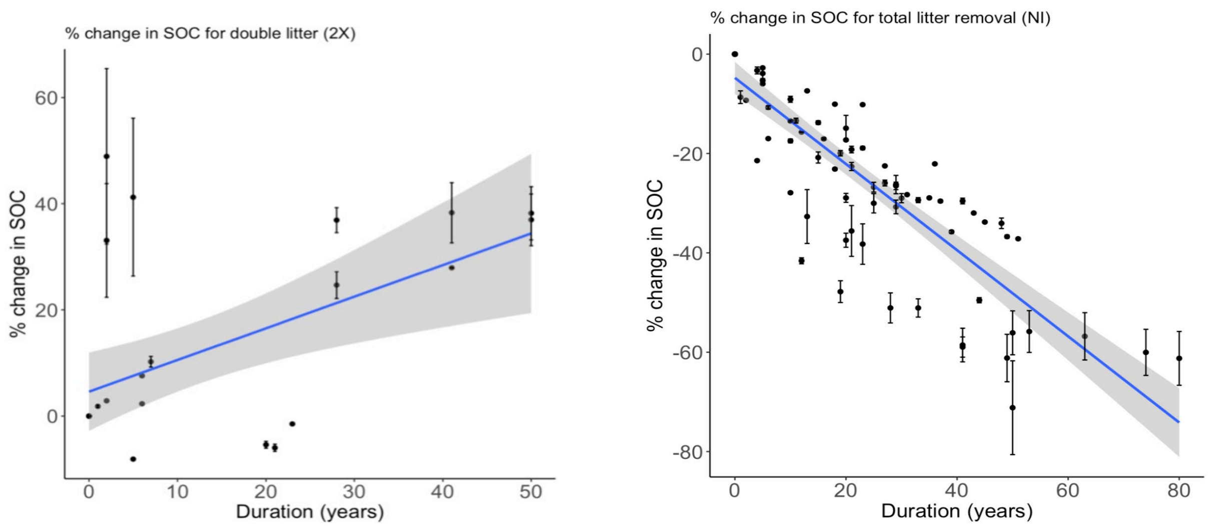

Fig 2a/b. Percent (%) change in SOC for doubled litter (Fig 1a) and total litter removal (Fig 1b). We fit a linear regression (blue line) to our data and calculate the 95% confidence interval (shaded gray area) of the regression.

ANOVA Result of Predictor Variables

The ANOVA results (Table 2) showed different significant factors in each time interval we tested. In the short-term (<20 yr) time interval, there are predictor variables that are statistically significant and differ from the other two time intervals. Besides the treatment effect, mean annual temperature (MAP) and vegetation are second-tier factors that drive variation in soil carbon responses to litter manipulation. Biome, along with latitude and longitude, also has a considerable impact on SOC responses. It was unexpected to find that soil pH also drove variation in percent change of SOC under litter manipulation. This may be due to the fact that soil pH can affect the level of microbial activity in the soil, which in turn affects the soil carbon dynamics. In the 20-40 yr time interval, predictors that are identified as significant in the short-term interval no longer remain their significance, with the exception of treatment type. In contrast, in the long-term (>40 yr) time interval, soil properties such as % clay and % silt play an important role in soil carbon responses. It is apparent that treatment type is the only factor that plays major roles in all of the time intervals.

Table 2. Significance of predictor variables tested in ANOVA

Time Interval: 0-20 years				Time Interval: 20-40 years				Time Interval: > 40 years			
Predictors	**F value**	**Pr(>F)**		**Predictors**	**F_value**	**Pr(>F)**		**Predictors**	**F value**	**Pr(>F)**	
Biome	3.2209	0.02635	*	Biome	1.1623	0.2876		Biome	4.0778	0.05312	
Vegetation	8.81	0.003809	**	Vegetation	1.1623	0.2876		Vegetation	4.0778	0.05312	
Soil order	1.0016	0.4219		Soil order	0.2794	0.7578		Soil order	0.0012	0.9988	
Treatment	7.2203	1.03E-05	***	Treatment	21.017	5.22E-09	***	Treatment	24.929	8.18E-08	***
Latitude	6.7809	0.01073	*	Latitude	0.7809	0.3823		Latitude	1.1589	0.2909	
Longitude	5.4594	0.02161	*	Longitude	1.594	0.2143		Longitude	3.7025	0.06455	
MAT (°C)	3.8059	0.05408		MAT (°C)	0.0408	0.8411		MAT (°C)	1.2734	0.2687	
MAP (mm)	7.3211	0.008107	**	MAP (mm)	0.6288	0.4326		MAP (mm)	2.831	0.1036	
% clay	0.1364	0.7138		% clay	0.4441	0.5113		% clay	34.485	0.0001073	***
% silt	2.4402	0.1266		% silt	1.5761	0.2209		% silt	39.737	5.81E-05	***
% sand	0.7558	0.3901		% sand	1.1728	0.2892		% sand	0.0129	0.9116	
pH	5.7072	0.02	*	pH	0.2976	0.59		pH	3.5661	0.07165	
Significance level: *** = 0.999; ** = 0.99; * = 0.95											

The Role of Treatment, Biome, and Time Interval on the % Change in SOC

In support of the ANOVA results showing that treatment drives variance in SOC, we provided a box plot of % change in SOC versus the 4 types of treatments (Fig. 3) that gave a clear visualization of the result. We used the latest data point from each site to avoid a larger contribution from sites with more frequent measurements. Above the zero line, we observed the double litter treatment, showing a positive average change (+20.53%) in SOC. As for the three litter removal treatments, complete input removal (NI) had the largest impact (-38.01%)on SOC, followed by aboveground litter removal (0X) and belowground litter removal (NR),with percentage change as -23.98% and -17.54%. In Fig. 4, we visualized the absolute % change in SOC from different biomes. Temperate grasslands showed the largest absolute % change in SOC (+37.55%), followed by temperate deciduous forest (+26.66%), tropical rain forest (+26.02%) and subtropical coniferous forest (+4.85%). Time interval (i.e., duration of treatment) reinforces the effect of plant litter on soil organic carbon (Fig. 5). Long-term (>40 year) litter manipulation treatments have the largest absolute % change in SOC (+42.7%), followed by 20-40 year treatments (+24.92%) and short-term (<20 years) treatments (+17.62%).

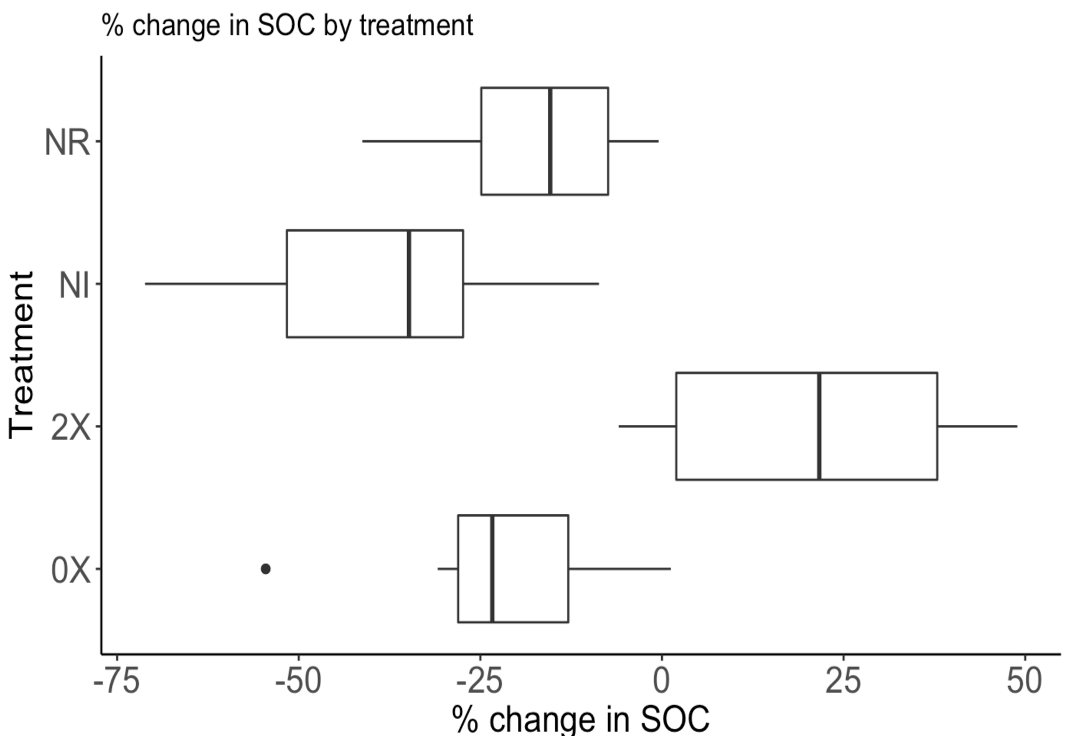

Fig. 3. Percent (%) change in SOC in different treatments. Only the latest data point from each site is taken to prevent a bias from sites that sample more frequently.

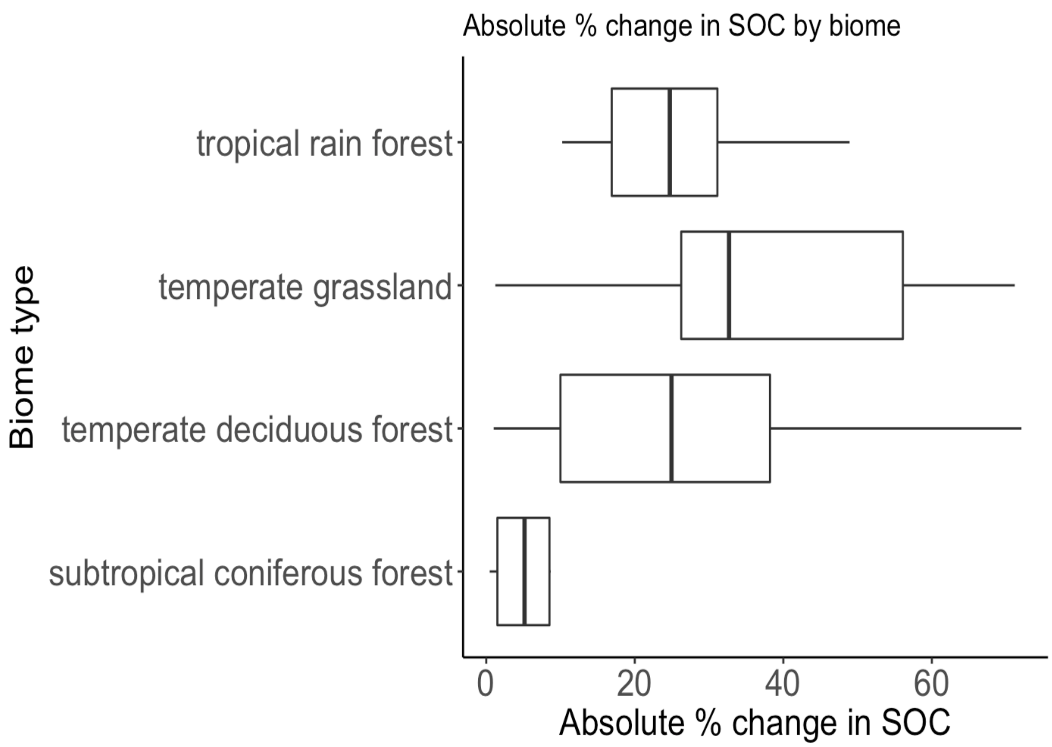

Fig. 4. Absolute percent (%) change in SOC by biome. Only the latest data point from each site is taken.

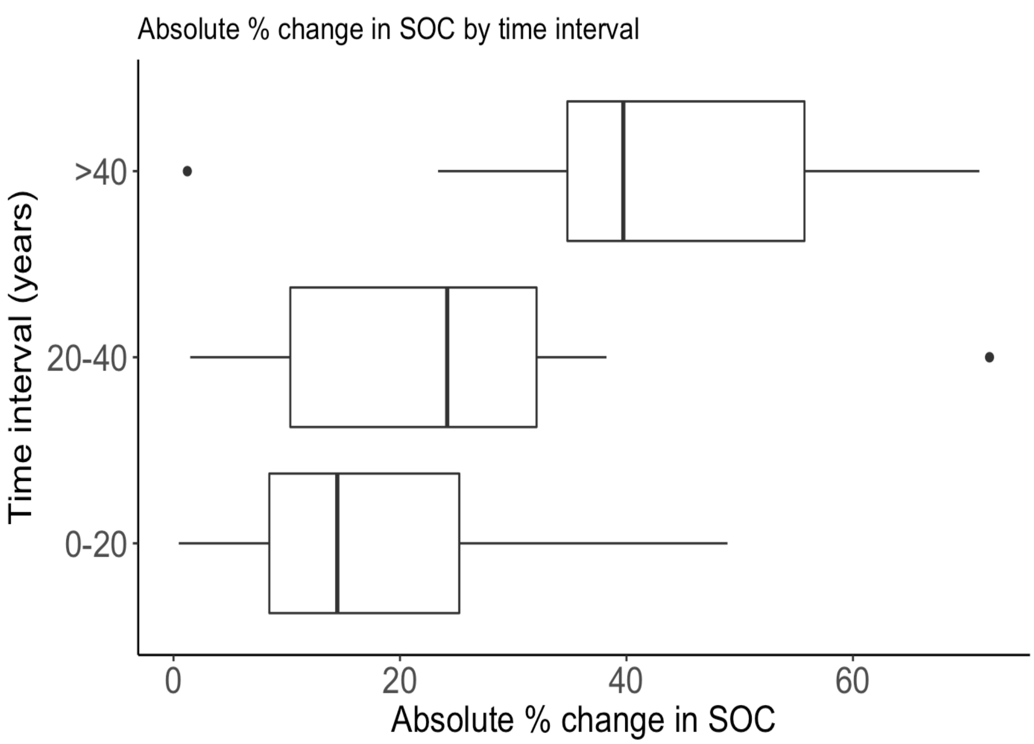

Fig. 5. Absolute percent (%) change in SOC by biome. Only the latest data point from each site is taken.

The Relationship Between Initial SOC Stocks and the Absolute Change of SOC

In the double litter experiment, the regression line of absolute change of SOC versus initial SOC stocks (Fig. 6a) showed that there was a slight positive correlation (k=0.07) between these two factors. When more carbon exists in the soil, the absolute increase in carbon from the litter addition can also be larger. However, the regression had a very large variance, which indicates that the data points are very spread out from the regression line. In the litter removal experiment, the regression line of absolute change of SOC versus initial SOC stocks (Fig. 6b) showed that there was a significant negative correlation (k=-0.14). Large carbon pools result in larger absolute losses of carbon in the litter removal experiments.

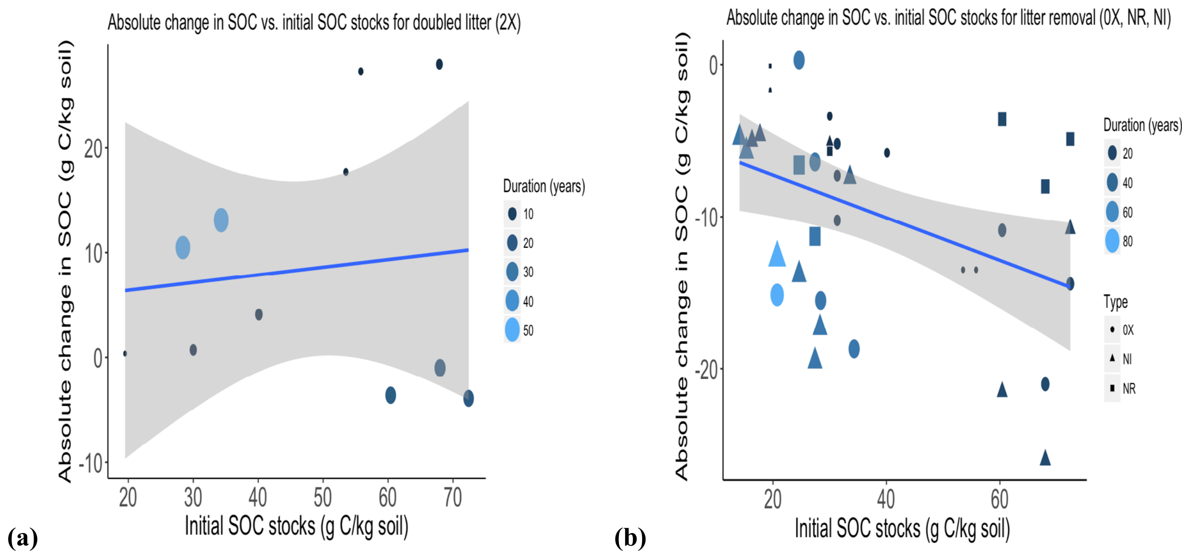

Fig 6a/b. Absolute change in SOC for double litter (Fig 5a) and litter removal experiments (Fig 5b). We fit a linear regression (blue line) to our data and calculate the 95% confidence interval (shaded gray area) of the regression. The size of the points represents the experiment duration from which data is taken.

DISCUSSION

Overview: effect of environmental factors on soil carbon dynamics

Our meta-analysis indicated that plant inputs had a significant impact on soil carbon stocks, especially at 0-20 cm depth. Changes in plant inputs can alter the amount of labile carbon (which has light density) in the soil within a relatively short period of time. The result of long-term (over 50 years) treatments showed that the rate of change of soil carbon slowed as the treatment time increased, which may indicate an approach towards equilibrium in soil carbon dynamics. Environmental factors, such as biome, mean annual temperature, and mean annual precipitation, had effects on short-term soil carbon responses to changes in plant input. For long-term treatments, soil properties seemed to be the main factors that drove variation in carbon changes. Microbial measurements were sparse among the experiments and, therefore, we ignored the potential contribution of microbial activity in this study. However, many of the unusual trends in soil carbon response can be the direct result of changes in microbial activity. Due to the limited observations of microbial biomass carbon in these experiments, we were not able to statistically prove the explicit relationship between soil carbon stock changes and the intensity of microbial activity. Considering the applicability of our results to soil restoration efforts, short-term restoration plans are required to consider the location of the restoration, since soil carbon responses can differ under different environments in short time periods of soil treatment. For long-term interventions, our results showed that at least within 40 years of treatment, changes in plant inputs affect “free” carbon that is not bound to minerals. The “protected” carbon, which exists mostly in deep soil, does not change significantly in our testing period(Lajtha et al. 2014b).

Litter addition, litter removal and soil carbon equilibrium

We found that soil carbon changes are in strong linear relationship with treatment duration and the level of effect from plant input is different between litter addition plot and litter removal plot. (Lajtha et al. 2014b) stated that a 50 year time period was still too short to see the saturation or depletion of the mineral-associated carbon pool. Our linear regression model showed that carbon seems not to reach equilibrium, where the carbon pool did not change with plants input. This corroborates the conclusion made by Lajtha et al. (2014b). From the slope of our linear regression, we also found that litter removal had a stronger effect on soil carbon stock than does litter addition. One possible explanation is the priming effect. Introducing more labile carbon can disproportionately increase microbial respiration rates, known as positive priming (Lajtha et al. 2014b). Many studies have shown that soil priming occurs in response to added labile carbon (Kuzyakov et al. 2000, Brant et al. 2006, Cleveland et al. 2007). It is possible that increasing rates of microbial activity in litter addition plots counteract the effect of incoming plant inputs and, as a result, more carbon is decomposed than is added to the soil. However, soil priming is often only a short-term change of microbial activity (Luo et al. 2011). After several years the rate of microbial activity may return to normal despite the ongoing litter addition. Therefore, priming itself does not sufficiently explain the different impact between litter removal and addition. Another explanation is the role of plant roots in stabilizing soil carbon. There are studies suggesting that roots may make a greater contribution to stable C pools than aboveground litter (e.g., Rasse et al. 2005, Clemmensen et al. 2013). In litter removal plots, with the absence of plant roots, carbon can be less stable than litter addition plots and therefore have less resilience to environmental changes.

Soil carbon response in different biomes

We found that each biome type responded differently to plant input changes, with temperate grassland having the highest percentage change, followed by temperate deciduous forests, and tropical rainforest. Sub-tropical coniferous forests had the lowest percentage change. Studies have shown that soil carbon from grasslands is usually more sensitive to changes in plant inputs (Barré et al. 2010, Lajtha et al. 2014b). This result was unexpected since the root system of grasslands is more extensive than of forest. Root-derived carbon is expected to have a higher resistance to decomposition (Crow et al. 2009). The extensive root system of grasslands can potentially make the soil contain more decomposition resistant carbon, causing less change in litter removal treatment. The opposite result may indicate other factors, other than root development, such as water retention and soil properties that potentially affect the soil response. Tropical rainforests and temperate deciduous forests had similar soil responses to plant changes. This suggested that microbial activity between tropical biome and temperate biome were similar. Tropical soil with more moisture clearly did not exhibit stronger priming effects based on our data visualization. (Frey et al. 2004) found that the soil of coniferous forests often is more fungal dominated than that of deciduous forests. Fungal dominance in soil will lead to a faster mineralization of carbon (Rousk and Frey 2015). Coniferous forests therefore may have more mineralized carbon, which is stable carbon, and demonstrate higher resilience to plant input changes than any other type of forests.

Aboveground litter versus underground litter

From our data visualization we found that soil lost more carbon in complete litter removal than it gained from litter addition and aboveground litter removal had a greater impact on soil carbon stock than belowground litter removal. Aboveground organic carbon sources include leaves, twigs, seeds, and coarse woody debris. Belowground inputs are from roots, root exudations of C compounds, and organic matter from the rhizospheric microbial community (Ekberg et al. 2007). Studies have shown that root and rhizosphere-derived carbon are equally or more important to stable soil C than is aboveground litter (Lajtha et al. 2014a). We thus expected to see more changes from plots with belowground litter removal than with aboveground litter removal, given the importance of roots in controlling carbon as compared to leaves (Bowden et al. 2014) However, our data analysis suggested the opposite outcome. One possible reason is due to the incomplete root elimination process (Bowden et al. 2014). Roots may reenter the plots and generate belowground carbon, making the result less negative.

Soil carbon sensitivity in different time intervals

Our ANOVA analysis indicated that in short-term treatment (0 to 20 years), soil carbon was more sensitive to environmental factors such as biome, vegetation, and geographic coordinate (longitude and latitude), while in long-term treatment, SOC responses become independent of environmental factors except the soil properties (% clay and % silt). Litter manipulation at short-term periods changes the amount of labile carbon in the soil, which is young carbon existing in the surface layer (Lajtha et al. 2014b). The dynamics of labile carbon vary in different environments (Schmidt et al. 2011). Levels of soil organic matter are determined by factors such as soil texture, climate, inputs of organic material, its subsequent rate of decomposition, and the rate at which native SOM decomposes (Johnston et al. 2009). As such factors affect soil organic matter in the short term, the long-term ability of soils to sequester C is not well understood (Nadelhoffer et al., 2004), as C stored in biomass or transferred to the forest floor does not necessarily lead to long-term changes in soil C storage (Sulzman et al. 2005). In fact, the size of intermediate carbon pool is strongly related to soil texture, especially sand particle and nitrogen availability (Tian et al. 2016).

Effect of microbial activities on soil carbon changes in different environment

As the ecosystem's net primary productivity (NPP) and litter fall changes, the alteration of microbial carbon and activity are expected (Frey et al. 2004). Heterotrophic microorganisms utilize the carbon of either plant, animal, or microbial origin as a substrate for metabolism, retaining some carbon in their biomass and releasing the rest as metabolites or as CO_2 back to the atmosphere (Gougoulias et al. 2014). Changes of microbial activity affect the rate of carbon decomposition in the soil. Increased microbial activities accelerate the loss of soil carbon via microbes' respiration and metabolism. Soil organic carbon quality, temperature, and fungal to bacteria ratio have been suggested by several studies as potential influencing factors of microbial activities. However, (Rousk and Frey 2015) found no evidence supporting the hypothesis that a positive relationship exists between the relative dominance of bacteria and high SOC quality. Research by (Potthoff et al. 2006) also disapproves the fact that microbial communities differ in restored grassland and undisturbed grassland. Factors affecting the microbial communities and their decomposition rate remain unclear.

Limitations and future directions

Although we tried our best to find as many data as possible from published literature, the number of valuable data is still limited. It makes sense since soil carbon data is costly due to intensive lab requirements, and it can take several years of continuous treatment to observe differences in the large soil carbon stocks. However, the accuracy of our models is sacrificed with the limited data I can use. Overall, we synthesized 186 data points with 123 observations from litter removal and 63 observations from litter addition experiments. The uneven data distribution across treatments may cause a potential bias in analysis. Moreover, most of the LTBF treatments are done in temperate regions. The data collected from tropical regions is far less than those from temperate regions. We clearly need more soil treatment data from tropical regions in order to have a more precise conclusion on how climate affects the soil carbon cycle. Third, we contend that microbial activity plays an important role in carbon dynamics. However, experimental sites with SOC data often do not measure MBC (microbial biomass carbon) as well. The absence of MBC data makes explanations of the trend of soil carbon difficult.

In our opinion, to better understand the soil carbon cycle, scientists in the future should focus on the following things: (1) establish more experiment sites in tropical regions, (2) collect more MBC data from litter manipulation experiments, and (3) establish an online database of soil treatment results.

Conclusions

Our study found that changes in plant input significantly changed the labile soil carbon stocks. The degree of impact is determined by the duration of treatment as well as environmental factors such as climate and soil composition. Microbial activity plays an important role in soil carbon cycling, however, more studies are required to determine the specific role. Even though humans can interfere with soil carbon in diverse ways such as agriculture and soil restorations, our findings suggest that soil carbon may remain persistent to changes of plant input in the long term. The amount of protected carbon in the soil signifies how much persistence the soil has on land changes, which I may consider as a way to measure soil health. In the short-term, the variation of soil carbon responses to plant inputs indicates that the result of soil restoration may differ substantially depending on the geographical region. Regions where soils are less sensitive to plant inputs may be hard to recover from depletion.

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