

# Management Protocols for Soil Carbon Sequestration in San Joaquin Valley Agroecosystems

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## Summary

Conservation tillage (CT) and cover cropping are sustainable agricultural practices that may provide solutions for California's declining environmental quality. This study investigates how CT and cover cropping affect soil organic matter dynamics in a cotton-tomato (*Gossypium hirsutum*, *Lycopersicon esculentum*) rotation in California's San Joaquin Valley. After five years of treatments, the top 30 cm of soil in the CT with CC system had 4,500 kg C ha<sup>-1</sup> more C, while C increased by 3,800 kg C ha<sup>-1</sup> in standard tillage with cover crop. In CT, the increase occurred in the surface 15 cm; while in standard tillage, it was distributed throughout the top 30 cm. In the treatments without cover crops, soil C was unchanged in the 0-30 cm depth. To refine our understanding of aggregate-protected C dynamics in CT systems, we labeled cotton with <sup>13</sup>C in the field and followed the decomposition of both the roots and the shoots through three physical fractions: light fraction (LF) which tends to turnover quickly and two relatively stable C pools: intra-aggregate LF (iLF) and mineral-associated C (m). CT treatments retained more of the cotton residue-derived C in LF and iLF initially. However, these differences disappear after a year of residue decomposition in the field. During the study, more shoot C was retained and recovered than root C. In California's Mediterranean climate, conservation tillage does not accumulate or stabilize more C than standard tillage, and the addition of biomass as a cover crop is more important for total soil C accumulation than tillage practice.

*Keywords: conservation tillage, soil carbon, minimum tillage, carbon sequestration*

## Objectives

The objectives of this proposed research have been to:

- compare reduced tillage and conventional tillage practices in a crop rotation common to California's San Joaquin Valley in terms of soil carbon sequestration, crop productivity, and profitability

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- determine the effect of these tillage treatments on the fate of crop residue carbon and its influence on soil and residue nitrogen availability, and
- disseminate widely information related to the background, goals and outcomes of the proposed project.

These objectives have been met during the course of this project, however, new questions have indeed surfaced.

## Approach and Procedures

Four experimental tillage/cover crop management treatments: conservation tillage no cover crop (CTNO), conservation tillage with cover crop (CTCC), standard tillage no cover crop (STNO), and standard tillage with cover crop (STCC) were established in a field study at the University of California West Side Research and Extension Center in Five Points, CA, where the soil type is Panoche clay loam (fine-loamy, mixed superactive, thermic Typic Haplocambids). Each treatment was replicated four times and distributed randomly across the field. The field was divided in half. Each year, cotton (*Gossypium hirsutum*) is grown on one side of the field and tomato (*Lycopersicon esculentum*) on the other, and the next year the sides are switched. The winter cover crop is a cereal/legume mix of triticale (*Triticosecale*), rye (*Secale cereale* L.) and vetch (*Vicia sativa* L.). The treatments were fertilized and irrigated according to the established management practices of the region (see Baker et al. 2005 for further details). In the summer of 2003, we established 16 cotton microplots (four replicates of each treatment type) to determine aggregate protected C dynamics.  $^{13}\text{CO}_2$  was applied to cotton plants every two weeks during the growing season. At the end of the growing season, labeled aboveground portions of cotton plants were removed, cotton bolls were harvested by hand, and the remaining shoot residue was cut into 5- to 15-cm pieces, combined and distributed evenly among 16 new plots adjacent to those where the  $^{13}\text{C}$  labeled cotton roots remained. This allowed us to follow the decomposition of root and shoot residues individually. The shoot material was analyzed for initial  $^{13}\text{C}$  content and root  $^{13}\text{C}$  content was assumed to be the same as the shoot material. After the shoots and roots plots were established, post harvest tillage in the standard tillage plots was simulated using a rototiller. However, after the first season, the standard tillage microplots were exposed to the usual large-scale tillage practices of the long-term trial. One of the root/shoot treatment pairs was lost after the first season because it was disked in before the plot locations were recorded. A physical procedure was used to determine light organic fractions. Specifics of this procedure and more experimental details on this study are available in the University of California, Davis, master's thesis of Jessica Veenstra and in a soon-to-be published issue of *California Agriculture*.

## Results

Fossil fuel consumption and land use changes have led to rising greenhouse gas concentrations in the atmosphere. Scientists project that these increases could result in worldwide climate change that would impact the productivity of agricultural and natural systems. For these reasons, scientists and policy makers are devoting increasing efforts to developing methods that reduce greenhouse gas emissions and identify potential C sinks. By increasing organic matter contents, soils could serve as a C sink (Lal 2001b). Reducing tillage of agricultural soils is one method

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that may sequester soil C. Reduced tillage or conservation tillage (CT) has been extensively studied in other parts of the country, but there has been very little CT research in California. Because of California's unique climate, soils, and cropping systems, its agricultural soils may or may not have similar C sequestration potential as the agricultural systems that have been studied elsewhere.

Soil C storage potential is dependent on a number of factors, including climate and parent material. Adding more C as an input usually increases soil organic matter (SOM), but soils tend to reach a point where they do not stabilize more carbon, despite added C inputs. Because the capacity for C storage in soil is finite, soil C sequestration is only an interim solution to the problem of rising greenhouse gas concentrations.

This research investigated the potential for both CT and cover cropping to sequester carbon in California by accumulating and stabilizing soil organic matter. To achieve long-term soil C sequestration, it is ineffective to increase the labile pools, which are likely to be mineralized quickly. Instead, we must increase the C stock in the stable pools. In spite of this, some studies have suggested that increasing the labile fraction may lead to increased OM stabilization. Through organic matter cycling and the incorporation of labile fractions into aggregates, the C from the labile organic matter moves into the stabilized pools (Powlson et al. 1987; Gregorich and Bettany 1995; Needelman et al. 1999; Six et al. 2001). We looked at accumulation and stabilization of soil C by looking at changes in total soil C (accumulation) and changes in the concentrations of C in the light fraction (LF) and two stable fractions of soil organic matter: intra-aggregate light fraction (iLF) and mineral-associated C (m) (stabilization). These pools are physically separated by density floatation and disruption of aggregates with sonification. The idea behind this method is to use a relatively simple physical separation to identify three pools with different levels of stability, and as described by Gaunt et al. (2001). By floating the LF on a dense liquid as opposed to using sieving methods, the active pool of organic matter can be isolated with minimal mineral contamination.

We expected that CT would increase organic matter stabilization by increasing the amount of C stored within iLF. Many researchers have shown that CT increases particulate organic matter or light fraction organic matter, an unstable, transitory C pool (Fabrizzi et al. 2003; Liebig et al. 2004; Schwenke et al. 2002). This pool of C is considered a nucleus of aggregate formation and is central to aggregate stability (Tisdall and Oades 1982; Cambardella and Elliott 1993; Rees et al. 2001). It helps form organomineral complexes that bind mineral particles together and stabilize aggregates (Lal et al. 1998). The lower decomposition rate of physically or chemically protected iLF suggests that it is more resistant to decomposition and is protected from microbial attack (Gale and Cambardella 2000; Lutzow et al. 2002). So by increasing this labile light fraction organic matter pool, CT may foster aggregate formation, and thus stabilize more organic matter within aggregates, than standard tillage systems.

By adding  $^{13}\text{C}$  labeled cotton residue to an existing CT system, we followed the decomposition of new crop residue to determine if CT stabilizes more new C in aggregates than standard tillage systems. To further understand organic matter stabilization and soil C dynamics, we used the  $^{13}\text{C}$  tracer to differentiate between root and shoot C inputs, expecting that more root C than shoot C would be stabilized within aggregates. Root-associated C may be stabilized and incorporated into aggregates more than shoot C (Gale and Cambardella, 2000; Wander and Yang

2000; Puget and Drinkwater 2001; Schwenke et al. 2002) because live plant roots exert pressure on soil particles and exude polysaccharides, affecting soil aggregation (Kooistra and van Noordwijk 1996). Also, as dead roots and hyphae are decomposed, they become a direct input of organic matter within aggregates (Jastrow and Miller 1998).

With this study, our objective was to determine whether CT in California would effectively sequester C by accumulating and stabilizing soil C. We also sought to clarify our understanding of some of the mechanisms of soil C stabilization, determining if more root C is stabilized than shoot C and if CT stabilizes more C within aggregates than standard tillage systems.

### **Total Soil C and Total Soil N**

After five years, total C in the 0- to 30-cm depth increased in the two cover crop treatments. The CTCC treatment accumulated the most C at the surface (+4504 kg C ha<sup>-1</sup>), while in the STCC treatment the C increase was distributed throughout the two depths (+2035 kg C ha<sup>-1</sup> in 0-15 cm depth, +1799 kg C ha<sup>-1</sup> in 15-30 cm depth). In the STNO treatment, neither depth showed changes in total C, while in the CTNO treatment, the C quantity in the surface 15 cm increased (+1768 kg C ha<sup>-1</sup>), but the lower 15 cm was depleted in C (-2131 kg C ha<sup>-1</sup>), resulting in no overall change in total C content (*fig. 1.1, table 1.2*). Many studies have shown increased total C in CT systems, especially no-till (Cannell and Hawes 1994; Buschiazzo et al. 1999; Needelman et al. 1999; Yang and Kay 2001; Dominy and Haynes 2002; Hernanz et al. 2002; Puget and Lal, 2005). However, these increases often occur only in the surface few centimeters. If one looks at the whole profile and include changes in bulk density, often there are no significant differences in C stocks with conservation tillage. Only a few studies show overall increases in total profile C (Mrabet 2002; Zibilske et al. 2002). In a review of 56 no-till studies Puget and Lal (2005) found that only 10 out of 56 studies reported significant SOC increases when looking at the whole profile.

In this study, C redistributed toward the surface, in both the CT treatments with and without cover crops (*fig. 1.1*). The aboveground biomass retained on the soil surface in the CT system was about 10 times greater than that found in the standard tillage system (*table 1.5*). In standard tillage systems, crop residue is incorporated into the soil where it is exposed to microorganisms and quickly decomposed. Reduced tillage practices leave crop residues on the surface, which usually reduces decomposition, and as a result, organic matter and nutrients accumulate at the surface (Bakermans and de Wit 1970; Schomberg et al. 1994).

In this experiment, the lack of disturbance with CT contributed to C redistribution, not overall C accumulation, which is often true, but CT has been reported to increase C concentrations, in parts of Brazil, Australia, Argentina, North America and the tropics (Lal 2001a). The rate and degree of organic matter accumulation associated with surface residues vary widely because of climate, soil type and residue quality (Schomberg et al. 1994). Temperature and soil water content strongly affect decomposition rates (Scharpenseel and Pfeiffer 1997), and decomposition is more rapid in warm wet environments, so the best locations for increasing soil C storage would be in soils originally high in C levels such as those found in cool moist regions (Karlen and Cambardella 1996; Liebig et al. 2004). Therefore, California's hot and dry climate may be limiting C accumulation in CT systems here.

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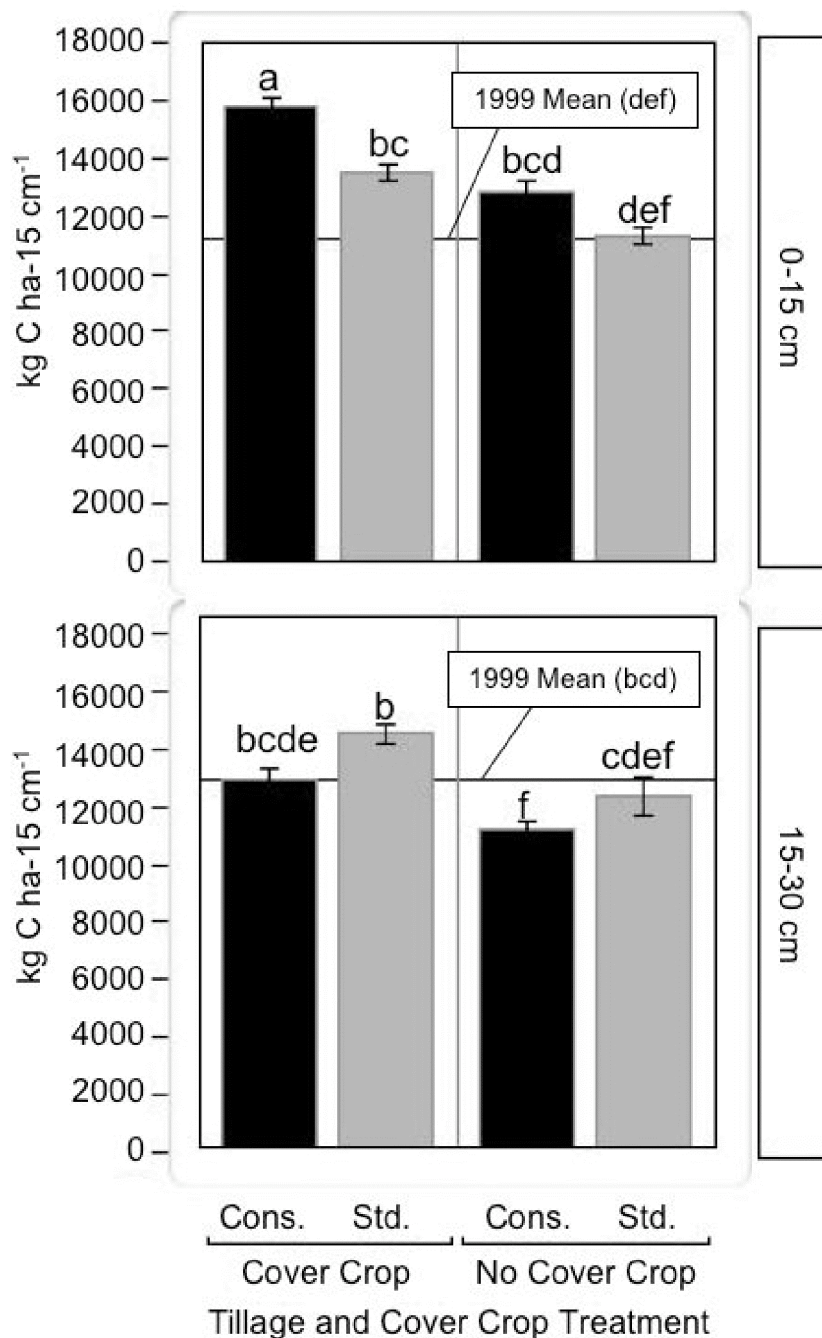
**Table 1.1.** Description of tillage practices for each treatment, standard tillage with cover crop (STCC), standard tillage no cover crop (STNO), conservation tillage with cover crop (CTCC) and conservation tillage no cover crop (CTNO). Cover crop treatments include more tractor passes for mowing in CT and mowing and incorporation in standard tillage.

<b>Treatment</b>	<b>STCC</b>	<b>STNO</b>	<b>CTCC</b>	<b>CTNO</b>
# of tractor passes	21	18	13	12
<i>Tillage after tomato:</i>	Disk twice Ripping Level List beds		None	
<i>Tillage after cotton:</i>	All of the above plus Shred cotton Undercut cotton Incorporate/shape beds Cultivate Roll beds		Clean furrows Shredder/Bedder Cultivate	

**Table 1.2.** Overall change in total soil C from 1999 to 2004, average annual cover crop C inputs, the aboveground residue remaining on the soil surface after tillage and the C:N ratio of that remaining residue for all tillage and cover crop treatments, standard tillage with cover crop (STCC), standard tillage no cover crop (STNO), conservation tillage with cover crop (CTCC) and conservation tillage no cover crop (CTNO). The difference in cover crop yield between tillage treatments accounts for the differences in total soil C after five years between CTCC and STCC.

<b>Treatment</b>	<b>Overall Change in Total Soil C</b> <i>kg C ha<sup>-1</sup></i>	<b>Aboveground Cover Crop C Input</b> <i>kg C ha<sup>-1</sup> yr<sup>-1</sup></i>	<b>Surface Residue</b> <i>g m<sup>-2</sup></i>	<b>C:N Ratio</b>
STCC	3834*	1833	76	50
STNO	-149		58	40
CTCC	4504*	2343	754	33
CTNO	-364		621	32

\*Values that represent a statistically different change from 1999,  $p=0.05$ .



**Figure 1.1.** Total C in the 0- to 15-cm and 15- to 30-cm depths for each tillage and cover cropping treatment. Background lines represent the 1999 mean total C from across the field for each depth. Error bars represent standard error of the mean (n =8). Bars not associated with the same letter are significantly different  $p=0.05$ .

This study was conducted on the west side of the San Joaquin Valley, a semi-arid Mediterranean environment. Few studies have looked at the potential for CT to store C in semi-

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arid conditions, and those that have reveal inconsistent results. Some studies of CT systems in arid regions found small C increases (Mrabet 2002; Hernanz et al. 2002). Cole et al. (1993) and Scharpenseel and Pfeiffer (1997) estimated that semiarid soils have a C sequestration potential of  $0.5 \text{ kg m}^{-2} \text{ y}^{-1}$ . However, other studies have shown that under hot, semi-arid conditions no SOC accumulation occurs (Buschiazzo et al. 1999; Chan et al. 2001). In semiarid conditions with low precipitation and high temperature, crop residue decomposition is limited by water content (Hajabbasi and Hemmat 2000; Mrabet 2002; Bronson et al. 2004). However, irrigation adds water during the warm growing season, and therefore can greatly increase mineralization potential. CT may actually further increase mineralization potential by retaining surface residues and thereby reducing surface evaporation (Unger et al. 1997) and thus increasing surface decomposition rates. In California’s climate, with furrow irrigation, CT may actually increase mineralization rates rather than improve C storage.

**Table 1.3.** Soil bulk density ( $\text{g cm}^{-3}$ ) after four years of different tillage treatments standard tillage with cover crop (STCC), standard tillage no cover crop (STNO), conservation tillage with cover crop (CTCC) and conservation tillage no cover crop (CTNO).

Treatment	STCC	STNO	CTCC	CTNO
<b>0-15 cm</b>				
Mean	1.28 <i>c</i>	1.24 <i>bc</i>	1.20 <i>b</i>	1.05 <i>a</i>
Std. Error	0.034	0.021	0.036	0.015
<b>15-30 cm</b>				
Mean	1.37 <i>e</i>	1.35 <i>d</i>	1.42 <i>e</i>	1.36 <i>e</i>
Std. Error	0.041	0.026	0.057	0.030

Values not followed by the same letter are significantly different  $p=0.05$ .

Usually the studies that have shown C accumulation with reduced tillage have used no-till systems, which eliminate all tillage and soil disturbance and plant directly into the previous crop’s residue. Conservation tillage, in this experiment, was a reduction in tillage practices, not the complete elimination of tillage. Cotton was planted directly into the tomato residue, but after cotton harvest the cotton roots were undercut to meet county requirements for pink bollworm outbreak prevention, and some cultivation and furrow maintenance was also required for the following year’s tomatoes. Even though this conservation tillage system greatly reduced tillage and soil disturbance, perhaps, it was not reduced enough to really begin to show C accumulation and stabilization as expected.

In spite of the lack of C accumulation in conservation tillage systems, both treatments that included cover crops show an overall increase in total C. The CTCC treatment has a larger increase ( $4504 \text{ kg C ha}^{-1}$ ) than STCC ( $3834 \text{ kg C ha}^{-1}$ ) because CTCC had a larger average yearly cover crop yield than STCC (table 1.2). In their model, Karlen and Cambardella (1996) found similar results; only cover crop treatments showed overall gains in total C when looking at overall changes in the one-meter depth. By adding a cover crop, we are adding more total biomass to the system, and therefore more C. Consequently, in this experiment, total C increases only with the addition of more biomass C, not with a reduction in tillage.

*Table 1.4. Average root and shoot cotton biomass applied per plot in grams.*

Shoots			Roots		
Stalks	Bolls	Leaves	Depth	Coarse Roots	Fine Roots
20.31	44.81	21.81	0-15 cm	62.51	9.81
			15-30 cm	25.53	15.92
<b>Total Shoot Biomass</b>			<b>Total Root Biomass</b>		
	<b>86.94</b>			<b>113.77</b>	

### **Soil Bulk Density**

Soil bulk density is an important factor that affects the interpretation of total soil C. Often total soil C is measured on a mass percent basis; if two different soils had 1% carbon, it would seem that they had the same total C content. But if their bulk densities were different, the soil with the higher bulk density would actually have a larger total C stock. In this study, soil bulk density was much lower in the CTNO treatment (1.05 g cm<sup>-3</sup>) compared to the other treatments, and the STCC treatment had the highest bulk density (1.28 g cm<sup>-3</sup>) (table 1.6). On a mass percent basis, the CTNO treatment had a higher total C concentration than the STNO plots, but considering the changes in bulk density the two treatments have similar total C contents on a volume basis.

### **Free Light Fraction and Aggregate-associated Light Fraction**

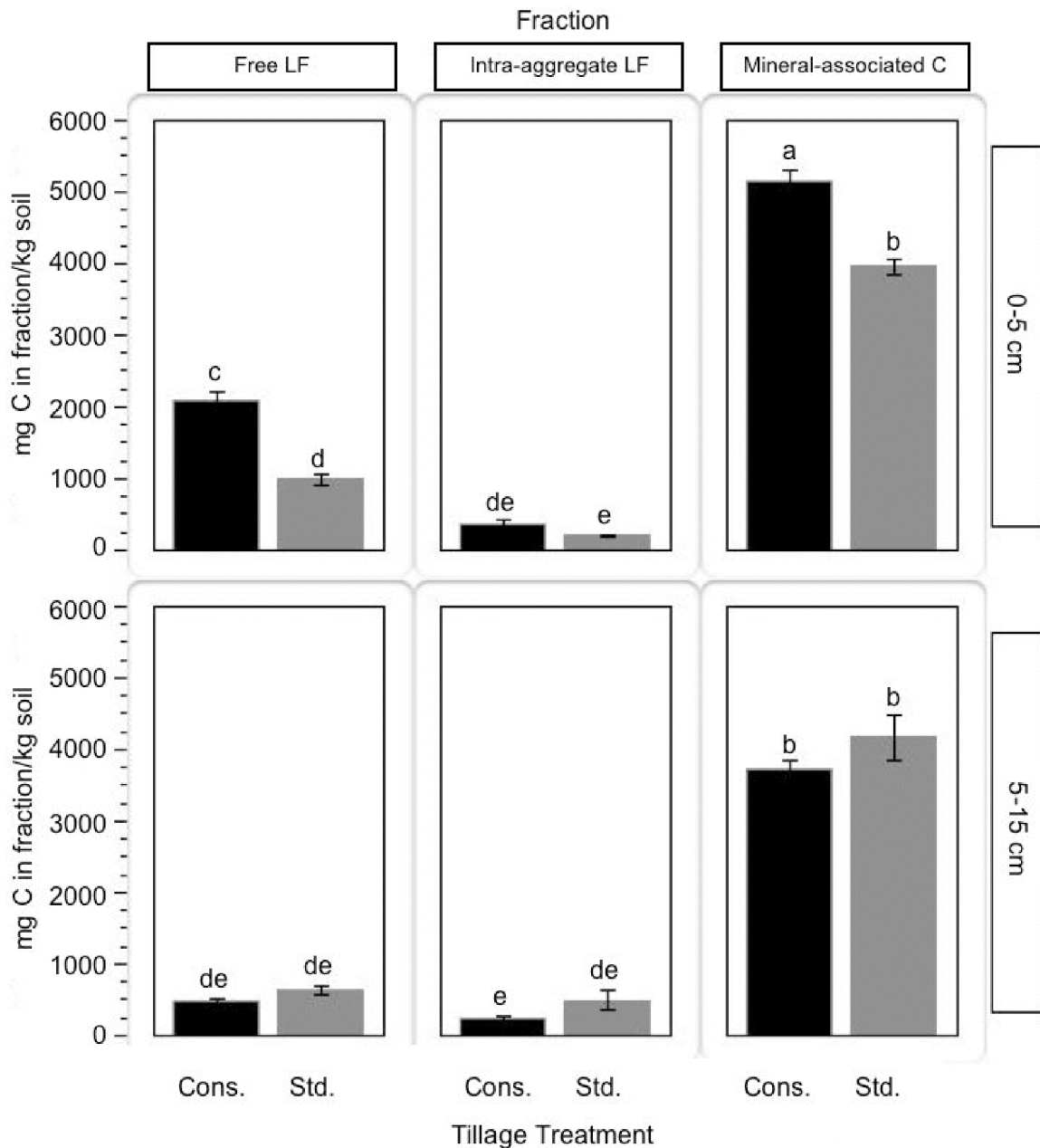
#### **Mass of C in LF, iLF and mineral fractions**

Often when total C increases in conservation tillage systems, those differences appear after as long as 10-20 years of CT practice (Mrabet 2002; Liebig et al. 2004). This study examined changes in soil C after five years, so over the longer term those changes may be different than what we have found here. Even though CT systems may not exhibit an overall C accumulation, the proportion of C in stable C pools may increase as an indicator of future total C increases (Six et al. 2002). To see if C distribution among pools changed with tillage, we analyzed total C distribution among free light fraction (LF), intra-aggregate light fraction (iLF) and mineral-associated C (m). In the 0- to 5-cm depth, CT treatments had significantly more LF-C and mineral C than the control (fig. 1.2). There were no differences in 5- to 15-cm depth. Conservation tillage, by reducing soil disturbance, tends to redistribute total C and increase LF in the surface 0-5 cm (Needelman et al. 1999; Mrabet 2002; Fabrizzi et al. 2003).

Yang and Kay (2001) also observed that decreased tillage led to greater C in LF and iLF. They found that less than 30% of the surface C increase was accounted for by the LF, while more than 60% of the C increase was actually mineral related. In this study, however, the surface C increases in the CT treatments were attributed primarily to LF, not mineral C. We observed increased mineral-associated C but only in 0- to 5-cm depth with C depletion in the 5- to 15-cm depth. This result reiterates the general redistribution of C towards the surface in CT systems. It appears that CT promotes the transition of C into LF, a less stabilized C form, not a transition to more stable C pool such as iLF or m. Gregorich and Janzen (1996) found similar



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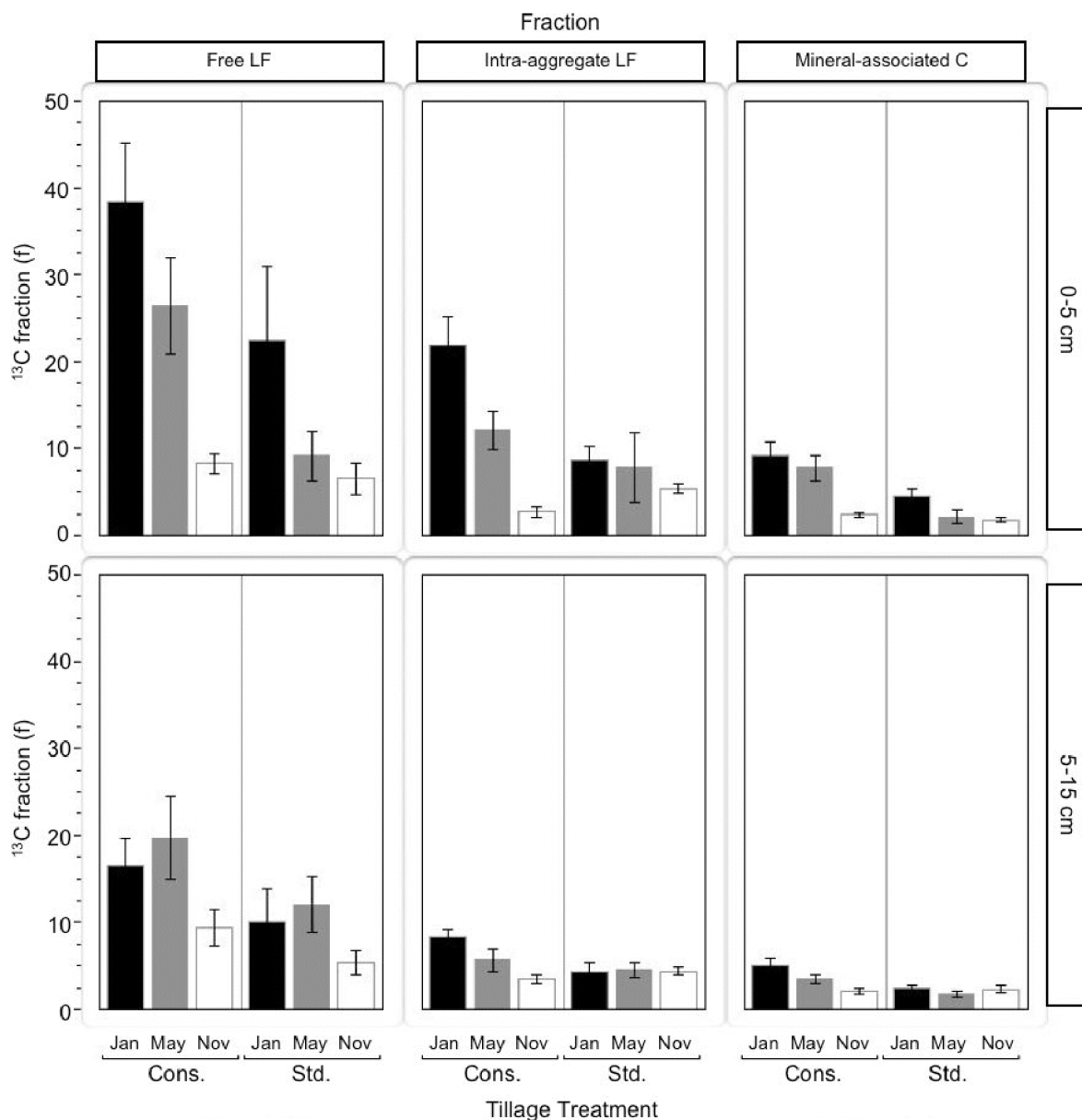


**Figure 1.2.** Total mass of C in each organic matter fraction after five years of treatments. Error bars represent standard error of the mean (n =8). Bars not associated with the same letter are significantly different  $p=0.05$ .

results; demonstrating that while total C remained constant, LF was 7% of total C in standard tillage and 19% of total C in CT. LF organic matter tends to be very sensitive to changes in tillage, crop inputs and management practices (Schwenke et al. 2002; Fabrizzi et al. 2003; Liebigh et al. 2004). LF accounts for the majority of SOM initially lost after cultivation (Cambardella and Elliott 1993; Gregorich and Janzen 1996), and with the transition from standard tillage to CT, the proportion of total C that is found in the LF increases rather than the overall quantity of total

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C (Gregorich and Janzen 1996; Schwenke et al. 2002). The increased proportion of LF in SOM and reduced soil disturbance may be the reasons that aggregate stability often increases with CT, regardless of whether or not there are overall increases in total SOM (Cannell and Hawes 1994; Hao et al. 2000; Chan et al. 2001; Hernanz et al. 2002).



**Figure 1.3.** The amount of added <sup>13</sup>C derived from new cotton residue as a fraction of total C in each organic matter fraction, light fraction (LF), intra-aggregate light fraction (iLF) and mineral associated C (m), with respect to tillage treatment and soil depth. Error bars represent standard error of the mean (n =8).

We expected that increased LF organic matter would contribute to aggregate formation, by providing a nucleus for mineral particle association and aggregate formation (Tisdall and Oades

1982; Gaunt et al. 2001; Six et al. 2002). However, after five years of CT, there were no significant differences in iLF-C in this study. The increased LF does not seem to contribute to the iLF pool. There was more total C in the mineral fraction of the 0- to 5-cm depth in the CT systems. Perhaps, aggregate turnover was high, and added LF was quickly incorporated into aggregates, decomposed and became associated with mineral materials to form organo-mineral complexes. Alternatively, the fresh organic matter could have rapidly formed organomineral complexes and was not incorporated into aggregates as LF. In order to determine if new organic matter additions are incorporated into aggregates as LF or if the material forms organomineral complexes directly, we added  $^{13}\text{C}$  labeled cotton residue and observed its decomposition and incorporation into the different organic matter fractions with time. The analysis of that experiment is discussed below.

### ***Tracking Cotton Crop Residue Decomposition: $^{13}\text{C}$ Analysis***

#### **Effects of Conservation Tillage**

Three months after the addition of  $^{13}\text{C}$  labeled cotton residue, more new cotton-derived C was found in the LF, iLF and m fractions in the CT treatments than in the ST treatments (*fig. 1.3*). One year after treatment, CT has more cotton-residue-derived C in LF in the 0- to 5-cm depth, but CT and standard tillage have the same levels of cotton-derived C in the rest of the fractions and depths.

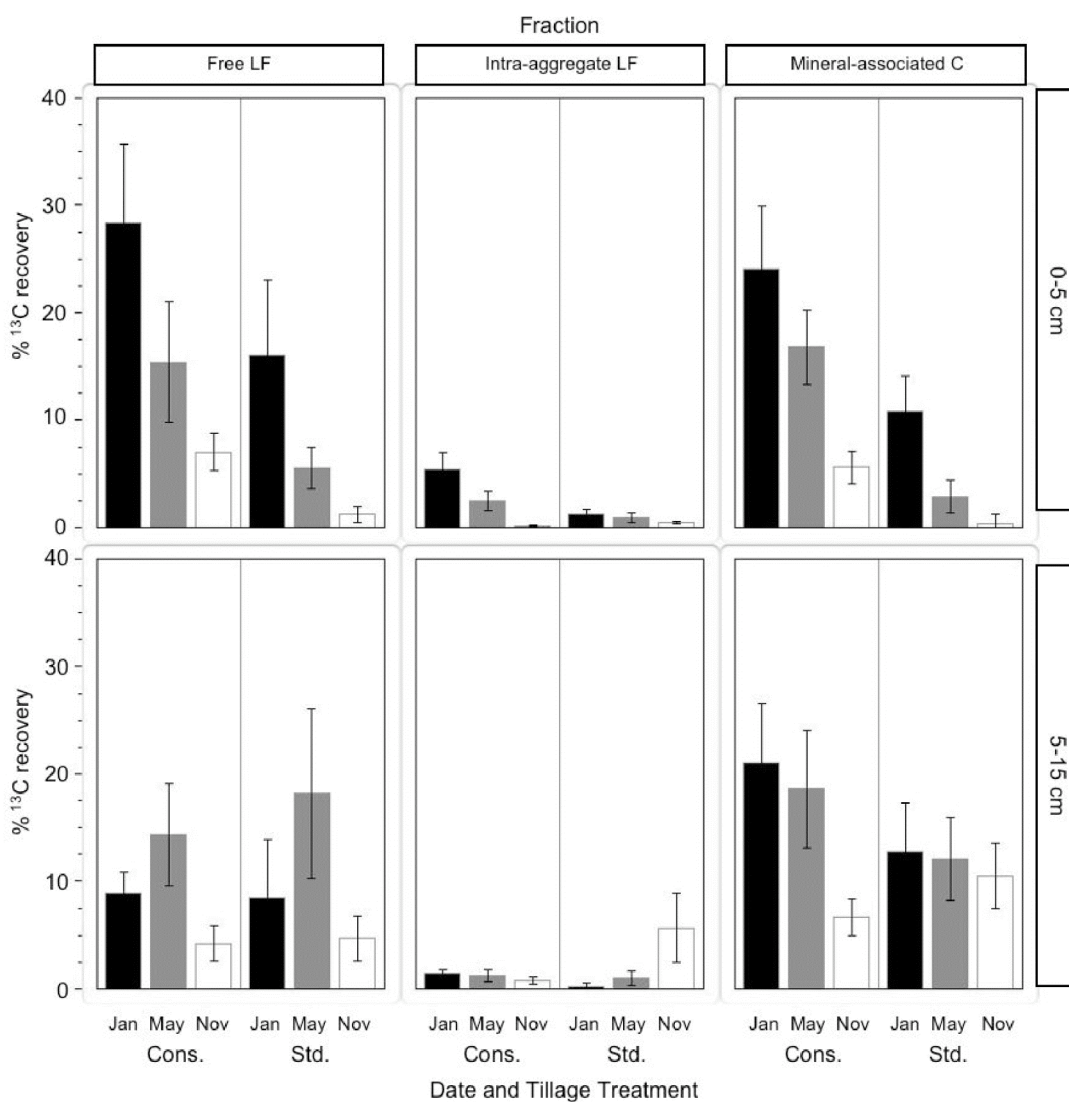
In January, samples from the 0- to 5-cm depth, 21% of the C found in the iLF was derived from the  $^{13}\text{C}$  labeled cotton in CT (*fig. 1.4*). Between November ( $^{13}\text{C}$  residue incorporation date) and January (first sampling), the cotton-derived LF was already occluded within aggregates. The rapid incorporation of LF into aggregates implied a much quicker turnover rate than expected. Studies in the Midwest reported that LF incorporation into aggregates occurs within a year (Wander and Yang 2000). The faster rate of organic matter association within aggregates found in our study may result from higher decomposition rates, which are influenced by California's Mediterranean climate in combination with irrigation water additions.

In standard tillage, however, only 7% of the C in iLF was derived from the new cotton C in the 0- to 5-cm depth in January (*fig. 1.4*), and with time the quantity of new residue derived C within that fraction decreased. With regular soil disruption in standard tillage, iLF turnover appears to be even faster than in the CT systems. Alternatively, in standard tillage systems, rather than first being occluded into aggregates as LF and then being decomposed, more of the residue inputs are being mineralized directly because the organic matter is incorporated and exposed to microbial attack. To clarify whether the LF is mineralized directly or if it is occluded within aggregates and then decomposed quickly would require sampling directly after labeled residue incorporation and continuing to sample frequently thereafter.

CT appears to slow LF decomposition and occlude more LF within aggregates initially, but this effect diminishes within a year. In this cropping system and climate, LF rapidly cycles through the aggregates rather than being stabilized. This rapid LF turnover within aggregates supports a model where aggregates require a continuously decomposing core of organic matter to maintain the microbial polysaccharide inputs that promote aggregate stability (Jastrow and

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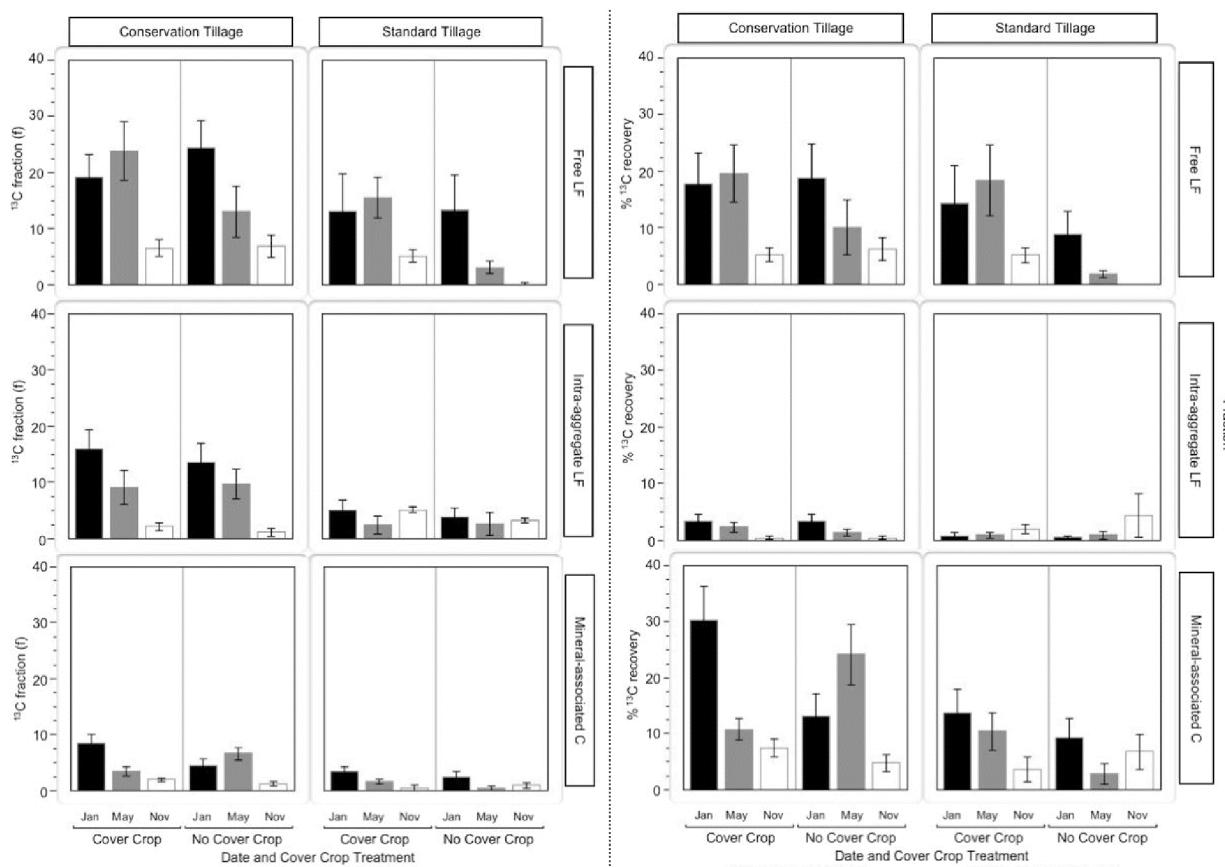
Miller 1998). Gregorich and Janzen (1996) also found that iLF is more decomposed than the free fraction. This evidence supports a model proposed by Golchin et al. (1994) for microaggregate formation where microaggregates are made up of mineral particles surrounding a continuously decomposing organic matter core. Microorganisms decompose the organic matter core simultaneously forming mucilages and extracellular polysaccharides that bind mineral particles to the LF. As the microorganisms decompose the organic matter, more and more resistant materials are leftover. Decomposition then begins to slow, the production of the mucilages slows, and the aggregates begin to fall apart releasing the recalcitrant organic matter. Thus in this model, stable aggregates are not necessarily protecting the organic matter within, instead microaggregate stability is dependent upon the continuous decomposition of its organic matter core.



**Figure 1.4.** Percent of added cotton C (<sup>13</sup>C) recovered in each organic matter fraction, light fraction (LF), intra-aggregate light fraction (iLF) and mineral associated C (m), by tillage treatment and depth. Error bars represent standard error of the mean (n =8).

## Effects of Conservation Tillage and Cover Cropping

The addition of a cover crop slowed the mineralization of the cotton-residue derived LF-C. In both tillage treatments, the amount of cotton-residue derived C in LF remains steady through the January and May sampling dates, whereas in the treatments without cover crops, there was less cotton-derived LF found in samples collected in May (*fig. 1.5*). This is most likely a substitution effect. Because the cover crop systems have more C inputs into the system overall, less of the cotton-derived C is decomposed initially, but this effect diminishes by the November sampling date.

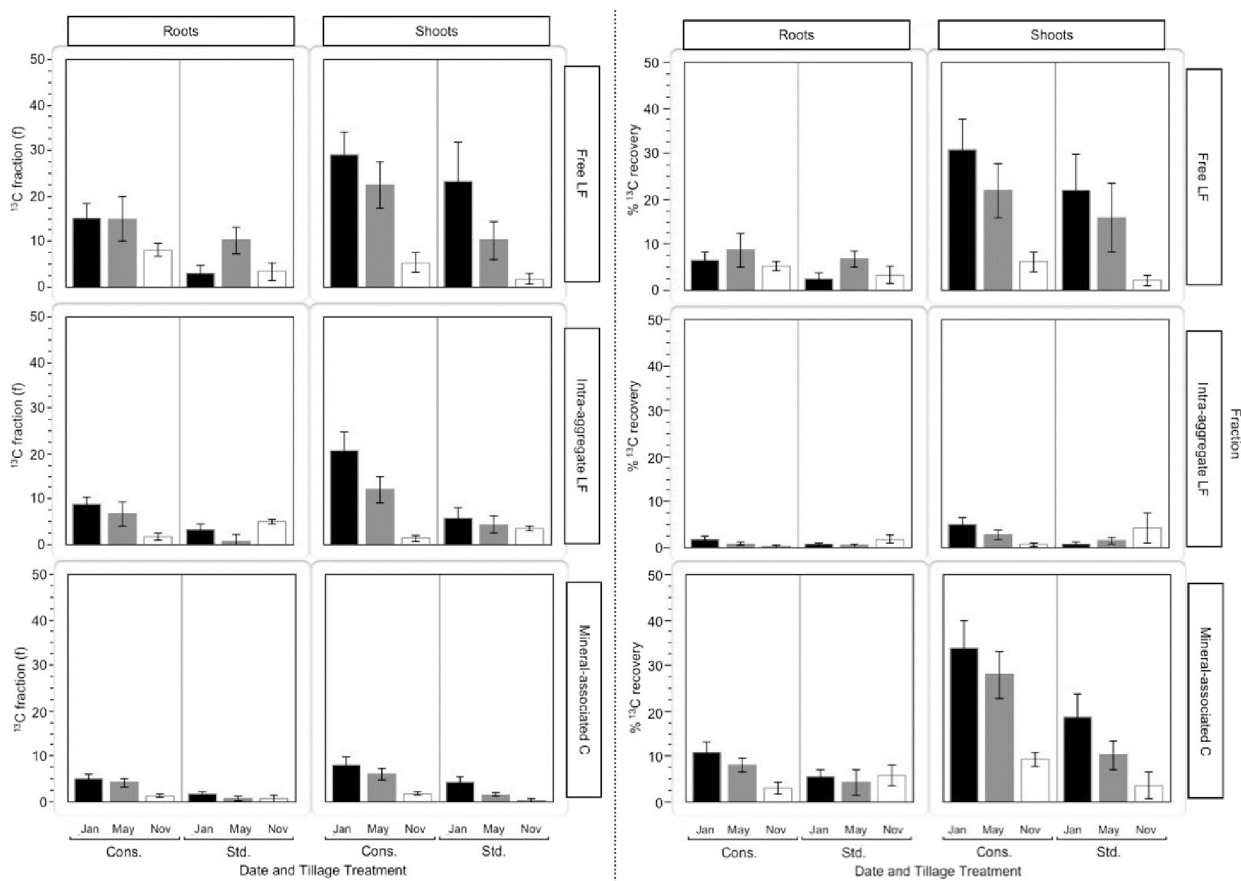


**Figure 1.5.** Amount of new cotton C ( $^{13}\text{C}$ ) as a fraction of total C found in each organic matter fraction and percent of added  $^{13}\text{C}$  that was recovered, by date, tillage and cover crop treatment. Error bars represent standard error of the mean (n =8).

There were no significant differences in iLF-C between the cover crop and no cover crop treatments. In the mineral-associated C fraction, however, there was more cotton-residue derived C recovered in the January sampling date in the CT with cover crop treatment, while there was more cotton-residue derived C recovered in the May sampling date in the CT without cover crop treatment. This difference in recovery is difficult to explain. There were no significant differences in the fraction of  $^{13}\text{C}$  within the mineral fraction, only differences in percent recovery.

## Root vs. Shoot Dynamics

We found no significant differences in the fraction of cotton root carbon recovered between any of the fractions, dates, or depths (*fig. 1.6*). This is unusual because in other studies root-derived carbon tends to be retained longer and is more likely to be incorporated into aggregates (Elliott 1986; Gale and Cambardella 2000; Wander and Yang 2000; Puget and Drinkwater 2001). Usually, roots make a large contribution to intra-aggregate organic matter. As roots and hyphae die and are broken down by soil fauna and fungi, they create a direct input of organic matter into aggregates (Jastrow and Miller 1998). However, these studies were conducted in the Midwest in a temperate climate. This study takes place in California in an arid irrigated environment with wet, warm winters and a different cropping system.



**Figure 1.6.** Root and shoot carbon dynamics. Amount of new cotton C ( $^{13}\text{C}$ ) as a fraction of total C found and percent of added  $^{13}\text{C}$  recovered in each organic matter fraction, light fraction (LF), intra-aggregate light fraction (iLF) and mineral associated C (m), by date, tillage and root/shoot treatment. Error bars represent standard error of the mean (n=8).

Other studies have focused on the root vs. shoot dynamics of corn, vetch and rye; all of these plants have fairly large branching root systems whereas cotton root distribution is much different. Cotton plants have one long, woody taproot, with few fine roots branching out from the main root. Crops with more root production will contribute more to LF, soil structural stability and possibly SOM (Schwenke et al. 2002). Most of the root biomass C in cotton is concentrated in

the taproot, and therefore cotton root carbon may have less of an effect on light fraction organic matter and aggregate stability.

However, we found significant differences in the cotton-shoot-derived C among the different tillage treatments. In the CT trials, new shoot-derived C remains in the LF longer; the levels of shoot carbon are higher in January and May in the LF and iLF (*fig. 1.6*). But by the November sampling date, the fractions of shoot-derived carbon in LF in the tillage treatments are not significantly different from each other, and the values are very close to the background values. In January, we also found cotton-shoot-derived C in the iLF in the CT trials. But by May, there was no significant difference in the amount of cotton shoot-derived C in the iLF. So again, turnover from LF to iLF may be much more rapid than we expected. Turnover is high but there is no overall C accumulation or C stabilization within the fractions and treatments after one year.

## **Conclusions**

### ***Aggregate-protected Organic Matter Dynamics in California Conservation Tillage Systems***

After five years of CT and cover crop treatments, overall aggregate-protected organic matter dynamics seem to change very little. Both CT and cover cropping merely slow the rate of LF incorporation and turnover, but neither stabilizes more C within aggregates. Added <sup>13</sup>C labeled residue C was cycled rapidly through aggregates and mineralized. This C turnover occurred in less than a year's time, which was much more rapidly than expected. Although we expected that more root C would be incorporated into aggregates, very little root carbon was recovered. Instead, much more shoot C was recovered in all three organic matter fractions, LF, iLF and m. This difference is most likely related to cotton root architecture where most of the carbon is concentrated in a long woody taproot.

### ***Conservation Tillage, Cover Cropping and Carbon Sequestration***

Conservation tillage is often purported to be a potentially effective method to sequester excess atmospheric carbon by accumulating and stabilizing soil carbon. However in this experiment after five years of CT, total C did not change. The only treatments that exhibited overall C increases were the systems with cover crop additions. However, the additional C found in the cover crop systems was not stabilized. Therefore the additional cover crop C was not effectively sequestered, but it did improve soil organic matter content, and additional organic matter tends to improve soil quality and could be beneficial for many other reasons.

Conservation tillage does not necessarily stabilize more C than standard tillage. Within the LF, iLF and m organic matter fractions, LF and m increase in the surface 5 cm of CT, but this is further evidence of C redistribution as opposed to C accumulation or stabilization. There was no evidence of increased organic matter stabilization within aggregates with reduced tillage. In fact, when looking at <sup>13</sup>C labeled residue decomposition, occlusion of C within aggregates is rapid, but the C turns over quickly, resulting in no net increase in aggregate-associated C stabilization. At this point it appears that reduced tillage in a cotton-tomato rotation in California's Mediterranean climate does not effectively sequester more C than standard tillage systems.

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