Long-term consequences of biological and biogeochemical changes in the Horseshoe Bend LTREB Agroecosystem, Athens, GA.

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Symposium on **"Revisiting the Crossroads of Ecology and Agriculture: a Tribute to Ben Stinner"**

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1. Introduction:

We thank Patrick Bohlen and the organizers for inviting us to participate in this publication honoring the life and work of Ben Stinner, who was an early alumnus of the Horseshoe Bend project, where he conducted the research leading to his Ph.D. degree in 1984.

The maintenance of soil organic matter (SOM) is considered a desirable goal in agroecosystems (Coleman et al. 1984, 1994; Bossuyt et al. 2002). SOM maintains soil structural stability, enhances water holding capacity, soil fertility and crop production, ensuring long-term agricultural ecosystem stability (Dick et al. 1997; Hassink et al. 1997; Denef et al. 2004). Soil is estimated to be the largest terrestrial pool of C, containing 1500 Pg, twice that of the atmosphere (Schlesinger 1997).

Agroecosystems that utilize conservation tillage or no-tillage techniques are promising alternatives to deep moldboard plowing, because they enhance agricultural sustainability, and reduce losses to erosion (Six et al. 1999). Tillage practices disrupt soil aggregates which may lead to increased aggregate turnover and increased decomposition of SOM (Six et al. 1998). Reduced aggregation leads to subsequent lower levels of SOM in conventional tillage (CT) than in no-tillage (NT) treatments (Paustian et al. 1998). Conversely, there is an increase in C content under NT which is attributed to a combination of slower litter decomposition and reduced soil disturbance under NT (Coleman et al. 1994; Paustian et al. 1997).

Six et al. (1999) developed a conceptual model of aggregate turnover, depicting organic C accumulation, mineral fraction, and particulate organic matter (POM). Faster macroaggregate turnover in CT than in NT results in: (1) fewer macroaggregates being maintained, with more free microaggregates being present in CT, and (2) less fine POM and new microaggregates formed in CT. By the end of the cycle, fewer microaggregates contain crop-derived C in CT than in NT (Six et al. 1999).

Several soil scientists have used the natural signal from C3-type vegetation (δ^{13}C ca. –26‰) in the indigenous soil organic matter, and then followed the change that occurs from growing C4-type vegetation (δ^{13}C ca. –12‰) in experimental fields (Balesdent et al. 1987; Balesdent and Balabane 1992). Our studies have used a modified approach, converting from a regime of C3 winter cover crops (wheat, rye, clover) and C4 summer maize or grain sorghum crops, to all C3 winter crops and summer (kenaf, cotton) crops. We are following changes in isotopic ratios of some soil C pools, measuring the long-term accretion of C in various soil fractions (Coleman et al. 1994; Six et al. 1998, 1999) in our agroecosystem. This research on a sub-tropical soil serves as a useful comparison and contrast to the results of Balesdent et al. (1987, 2000) in temperate soils and Cerri et al. (1995) in tropical soils. We expect that C stabilization (i.e., slower C turnover) will be more pronounced over the long-term in NT than in CT plots due to C protection within microaggregate fractions in the upper soil stratum of NT.

The studies presented here were conducted in the Horseshoe Bend Agroecosystem Long-term Research in Environmental Biology (LTREB) site, Athens, Georgia. Our objectives were: (1) to measure the peak standing crop biomass of our summer crops across decadal time spans, and to relate those trends to other aspects of tillage management and winter cover crop; (2) to determine the influence of both tillage methods (CT and NT) on water-stable aggregate distribution and SOM dynamics and (3) to investigate the changes in ^{13}C in both tillage practices. We hypothesized that the contrast between tillage treatments would change over time, with greater macroaggregation and organic matter fractions in NT vs. CT, and faster C turnover in both macro- and microaggregates in CT vs. NT.

2. Materials and Methods:

2.1. The Horseshoe Bend field site

Horseshoe Bend is a two ha. research site of the University of Georgia, situated in bottomland (fine loamy siliceous thermic Rhodic Kanhapludult in the Hiwassee series with 66% sand, 13% silt, and 21% clay) along the middle fork of the Oconee River, in Athens-Clarke County, GA. Mean annual precipitation is 1270mm., and annual mean minimum and maximum temperatures are 8.3 and 19.3^0 C. for Conventional Tillage (CT) and 9.5 and 17.5^0 C. for No-tillage (NT) plots (Hendrix et al. 2001). Soil pH is 6.0 in the surface 2 cm. and 5.7 at depths of 5-10 cm. Research has been conducted continuously at Horseshoe Bend since Odum et al. (1974) set up old fields in the mid-1960’s. From 1978 onward, four 0.1 ha plots have been managed with moldboard plowing (to 15 cm.) followed by disking (conventional tillage = CT), and another four 0.1 ha. plots have been managed using a no-tillage (NT) regime, with the only soil disturbance being direct seed drilling in these untilled plots. We sow winter cover crops of wheat and crimson clover, and various summer crops, including grain sorghum (*Sorghum bicolor*) corn (*Zea mays* L.), and beginning in 1999, cotton (*Gossypium hirsutum* L.), either engineered *Bt* (producing the *Cry1Ac* protein), or Non-*Bt*. In spring and summer, we make topical applications of Roundup herbicide to control C4 weeds, such as Johnson grass (*Sorghum halepense*) The NT plots have built up a significant organic layer near the soil surface, and tend to be dominated by fungal tissues in the top 1-2 cm (Beare et al. 1992, 1994a, b). In contrast, the CT plots have a more uniform distribution of the organic carbon in the soil profile in the top 15-cm. The tillage and Bt treatments are set up in a split-split plot design.

2.2. Sampling and analytical procedures

For net primary production aboveground, we sampled quadruplicate one-quarter meter samples in late October. Thus four each were taken from rye and clover winter cover crop sites of each management plot, for a total of 64 samples. The biomass samples were oven dried in a forced-air oven at 60^0 C. until fully dry, then weighed to determine total mass. At the time of sampling for crop biomass, samples for weeds and litter were taken in the same quadrats in some years, and also recorded.

For soil organic matter analyses, samples (5.8 cm. dia., 0-5 and 5-15 cm) were taken from CT and NT plots in quadruplicate for each 0.1 ha. plot. Samples were kept field moist at 4^0 C. for no more than 24 h., and processed for macro-and micro-aggregates using the wet sieving technique of Beare et al. (1994a, b). Delta ^{13}C values were determined on ground samples of micro- and macro-aggregates on a Finnigan MAT Isotope Ratio Spectrometer. All analyses were made in triplicate and analyzed by Analysis of Variance, or nonparametric statistics.

The distribution of aggregates was measured using a modified Yoder (1936) wet-sieving apparatus that was designed to handle larger masses of soil on stacked sieves (21.6 cm. dia.), which allowed for complete recovery of all particles from individual samples (Beare and Bruce 1993). Soil was air dried prior to sieving and suspended in distilled water at room temperature on the largest sieve 5 minutes before sieving. Each 50 g subsample was distributed on the surface of the top sieve of the 3-sieve stack (2000 μm above the 250 μm sieve). The soil was wet-sieved oscillating 21 x/min. for 5 min., through the three sieves to obtain four aggregate size fractions: (1) 2000 μm (large macroaggregates), (2) 250 to 2000 μm, (3) 53 to 250 μm (microaggregates) and (4) < 53 μm (silt- plus clay size particles). Following sieving, the sieves were lowered to the bottom of the stroke and the fresh OM from crop residue was aspirated from the surface before draining and placed into an aluminum cake pan. After wet sieving, the water columns were drained and the soil sieves were backwashed into cake pans and left to dry in a drying chamber (10^{o} C). Subsamples of soil were taken to enable calculation of sample weight to oven-dry weights. The 53 μm pan was removed from the bucket and a stirrer was used to mix the water in the bucket. After mixing, a 200 ml. subsample was taken and placed in its respective pan. Subsamples from each size fraction were ground and analyzed for total C and ^{13}C. Sub-samples were taken from the dry aggregate size fractions noted above to separate the POM associated and Mineral associated C and N. Details of this method are described by Cambardella and Elliott (1992). Subsamples of intact aggregates were mixed with sodium hexametaphosphate and shaken for 12 h on a reciprocal shaker. The dispersed organic matter plus sand was collected on a 53 μm mesh sieve; the water in the soil slurry was evaporated in a forced-air oven at 50^{0} C and the dried sample ground and analyzed by Dumas combustion on a Carlo/Erba analyzer. The difference between the C and N values for the evaporated soil slurry and those obtained from a non-dispersed soil sample was considered to be equal to the C or N retained in the sieve.

2.3. Isotope analysis:

Total carbon content and ^{13}C content of aggregate size fractions was measured on a Finnigan Delta C Mass Spectrometer coupled to a Carlo Erba NA 1500 CHN combustion analyzer via Finnigan's Conflo II interface. The ^{13}C/^{12}C ratios are then reported as _ ^{13}C values measured relative to a Peedee Belemnite (PDB) standard.

The fraction of new C was calculated using the equation:

$$F = (\delta t - \delta A) / (\delta B - \delta A)$$

where $\delta t = \delta^{13}C$ at time t, $\delta A = \delta^{13}C$ of the soil when a mix of C_3 and C_4 plants were grown (at time 0, 1997), δB = the average $\delta^{13}C$ of C_3 plants, and F = fraction of new C in the soil. F is used to estimate the turnover of soil C (Balesdent and Mariotti 1996).

2.4. Turnover and net inputs of organic carbon:

Skjemstad et al. (1990) used the assumption of exponential decay as a means for comparing relative decay rates and turnover times in micro and macro-aggregates. We determined the first order rate constants (k) as:

$$K = -\ln (Cmix_{cotton} / Cmix_{time\ 0})/t$$

Where Cmix cotton is the concentration of C from the mixture of C3 and C4 plants remaining in each size fraction from the soil at the present time, Cmix time 0 is the concentration of C from the mixture at time zero, before the switch to only C3 vegetation was made, and t is the time interval since that change took place (2005-1997 = 8 y). The net input rate was calculated as the concentration of new C in each size fraction divided by the length of time since only C3 plants had been planted.

2.5. Statistical analysis:

The experiment was analyzed as a nested split plot design, and analyzed by the SAS statistical package for analysis of variance (ANOVA-PROC GLM, SAS Institute, 1990). Tukey's HSD ($p<0.05$) was used for mean separation.

3. Results:

3.1. Crop Biomass

Crop biomass at Horseshoe Bend has been measured intermittently since 1984. The majority of variation in above-ground crop biomass is explained by the species of crop being grown. Biomass was greatest for corn, then kenaf, followed by sorghum and cotton ($F_{3,36}=101.40$, $p<0.001$, Figure 1). There are also some modest effects of cover crop, tillage, and year on crop biomass. For example, a clover cover crop provides a substantial boost to corn production, whereas its effects on other crops are negligible ($F_{3,36}=8.06$, $p=0.0003$, Figure 2). Likewise, tillage has its greatest impact on corn and sorghum production. In general, corn biomass was higher under conventional tillage than under no tillage, with the exception of the year 1996. In contrast sorghum biomass was higher under no tillage than conventional tillage ($F_{11,184}=3.64$, $p<0.0001$, Figure 3).

Overall, these data suggest that tillage and cover crop have relatively minor effects on crop biomass with the clear exception of corn. Corn biomass was favored by a cover crop of clover and conventional tillage.

3.2. Weed biomass

The above-ground biomass of weeds in the fall was estimated, starting in 1991. Again, the species of crop planted explained the greatest variation in the fall biomass of weeds ($F_{3,36}=133.78$, $p<0.0001$) with very low weed production under cotton (Figure 4). Weed biomass was generally higher under no tillage than under conventional tillage, with the greatest differences observed under corn production ($F_{7,131}$=2.74, p=0.0109, Figure 4) Overall, weed biomass under cotton was very low, although this was likely driven in part by significant drought during the cotton years. As expected, weed biomass was higher under no tillage.

3.3. Litter biomass

During 1991 (sorghum) and 1992 (corn), estimates were made of above-ground litter biomass during the fall sampling period. Litter biomass was greater under no tillage than under conventional tillage, with a larger effect of tillage on litter biomass under corn production ($F_{1,12}$=32.10, p=0.0001, Figure 5).

3.4. Changes in water-stable aggregates

Our hypothesis was that there will be more accumulation of carbon in aggregates in NT and hence more rapid loss and turnover of C in the CT treatments.

The distribution of water stable aggregates was influenced significantly by tillage management in both depths of soils (Fig. 6, a and b). Macroaggregates (>2000 μm) comprised the larges percentage of the total soil, and they were 1.6 time greater ($p < 0.001$) in NT than in CT. For aggregates of 250-2000, 53-250 and < 53 μm, the aggregates in CT plots were 1.3, 2.9 and 2.2 times greater than NT, respectively ($p<0.05$). At 5-15 cm. depth, the distribution of macroaggregates from NT was 1.2 times greater than in CT. There was no significant difference in the smaller WSA size classes.

Total C and N were significantly different by tillage, aggregate size and their interaction ($p< 0.01$, Fig. 7). Total sand free C and N in 0-5 cm soils were significantly higher for all aggregate size classes in NT than CT. In the 0-5 cm layer, sand-free C and N were highest in the 250-2000 µm aggregates, with total C and N being 1.6 and 1.5 times greater. In contrast, there were no significant differences in aggregate C and N in the 5-15 cm depths.

The differences in particulate organic matter (POM)-associated C and N were significantly affected by tillage and aggregate size class for all aggregate size classes in surface soils (N) and in aggregates >2000 µm and 250-2000 µm (C)(fig. 8). In general, the C/N ratios were much greater between size classes for the POM associated organic matter than for the Mineral Associated POM.

We compared total C within the same tillage practices for the three different sampling dates 1997, 2000 and 2005 (Fig. 9). Total C in NT surface soils showed a significant loss for aggregate size classes > 53 µm, and a constant concentration of C in the aggregates < 53 µm. The net loss of C from 1997 to 2005 was reduced and average of 1.6 times (40 g C kg^{-1}) of C concentration in the NT treatment. In contrast, surface soils of CT showed no significant differences in time for the > 53 µm size classes, but significantly different total C concentration in <53 µm aggregates.

3.5. Changes in delta ^{13}C in aggregates.

There were significant differences in ^{13}C ratios in time within tillage method (Fig. 10). Ratios for all aggregate size classes were shifting towards the ^{13} C ratios of C3 plants. The values for NT in the surface soils were generally lower (more negative) compared to CT. In both NT and CT, the aggregates >53 µm had the youngest age (most negative ^{13}C ratio) and the aggregate < 53 µm showed the oldest signature, being older in CT than NT. Both the 0-5 and 5-15 cm depths in CT were significantly more negative in the year 2000 than in 2005, and the 5-15 cm depth in NT was not significantly different in 1997 and 2000.

For surface soils there were similar values of new C in CT and NT (Table 1); in lower depths, the larger aggregates in CT had more new C incorporated than NT. The proportion of new C did not show a significant variation for both depths within the NT practice, with a similar behavior in CT except for the deeper soil profile.

Table 2 shows the average rate constant (*k*) for loss and turnover time (1/*k*) of the mixture of C4 and C3 -C and average net input rate of C3-C in aggregate size fractions as determined by ^{13}C natural abundance. The *k* was lower for microaggregates than for macroaggregates in both tillage treatments and the turnover was faster in CT than in NT for both surface and deep soil in most all of aggregate size fractions. The turnover of aggregate associated old C in microaggregates was 27.08 years for NT and 26.12 for CT (0-5 cm) and for the deeper soil profile the difference was greater (34.5 and 12 yr, respectively). In the 5-15 cm. depth the aggregates < 53 μm for both NT and CT had very little net input rate of new C. Furthermore, within tillage there was a difference of turnover within aggregate size fractions.

4. Discussion:

4.1. Aggregate distribution

Macroaggregates (> 2000 μm) from surface soils of NT were more abundant than those of CT soils, and the situation was reversed for smaller aggregates in the surface horizon. Several researchers found more macroaggregates in NT vs. CT soils (Beare et al. 1994a; Six et al. 2000; Bossuyt et al. 2002). Our results are similar to those obtained by Beare et al. (1994a), Hendrix et al. (1998) and Collins (2001) in the same field site. Tillage management changes soil conditions (aeration, temperature, moisture) and decomposition rates of litter (Cambardella and Elliott 1992). In NT, residue accumulates at the surface where litter decomposition rate is slowed due to drier conditions and reduced contact between soil microorganisms and litter (Salinas-Garcia et al. 1997). A greater proportion of the microbial biomass is composed of fungi, which contribute to macroaggregate formation and stabilization (Tisdall and Oades 1982; Beare et al. 1992). In CT, subsurface soil is brought to the surface and exposed to wet-dry, freeze-thaw cycles and raindrop impact (Beare et al. 1994; Paustian et al. 1997).

Higher microbial activity (e.g., in CT soils) depletes SOM, which eventually leads to decreased microbial biomass and activity and consequently a lower production of microbial-derived binding agents and a loss of aggregation (Jastrow et al. 1996; Six et al. 1998). Six et al. (1999) developed a conceptual model of aggregate turnover that shows the faster macroaggregate turnover in CT than in NT results in fewer macroaggregates being maintained, and more free microaggregates being present in CT than in NT soils. Our results (Fig. 1) support this model, with more macroaggregates existing in NT than in CT and more microaggregates in CT than in NT (0-5 cm).

4.2. Carbon and Nitrogen concentrations

The total sand-free concentrations of aggregate C and N were up to 1.6 and 1.5 times greater in the surface layers of NT than in CT (Fig. 7). With aggregate disruption, more organic substrates are made available for microbial attack, with ensuing increased SOM decomposition, and hence a decrease in C content. Beare et al. (1994a), Dick et al. (1997) and Six et al. (1999) also found higher C concentrations in surface samples of NT compared to CT soils.

POM-associated C and N values were greater in NT than in CT in all aggregate size classes in surface soils, and they were greater for larger than smaller aggregates (Fig. 8).

Thus aggregate formation and stabilization processes are directly related to the decomposition of root-residue and the dynamics of POM C in the soil (Gale et al. 2000). Beare et al. (1994a) noted that the differences in distributions of POM between depths in NT and CT may be a function of biological activity near the soil surface, including fungi (Doran, 1980), roots (Cheng et al. 1990) and soil fauna (Parmelee et al. 1990), that assist in incorporating POM within macroaggregates and to increase their stability. Examining surface soils in CT (Fig. 9) there were no significant differences in time for all of the larger size classes, but there was a significantly different concentration of total C for aggregates <53 µm, indicating that for CT and NT of this size class the C in this fraction is stabilized by intimate associations with mineral particles. Gregorich et al. (1995) also found that the most stable organic matter is associated with this small size fraction. For both depths the old C associated with microaggregates may be physically protected, as was observed also by Christensen (1992).

4.3. Carbon-13 concentrations and Carbon turnover

Carbon turnover for NT and CT soils was calculated over time, showing delta-^{13} C values from 1997 onward (Fig. 10). We observed significant differences in time within tillage method. Increased tillage intensity enhanced turnover of SOM and decreased soil aggregation (Six et al., 1998). Because the average annual inputs of aboveground crop plus weed residues to NT and CT are very similar in HSB (Beare et al. 1994a; this paper), we attribute the differences in SOM content to differences in assimilation and decomposition of SOM under both tillage treatments. However, in this study, total C was reduced in NT plots for 2005 compared to previous years (Fig. 9), which was not the case with CT. Perhaps there was an unusually large biomass of cotton that remained to decompose after being cut. Therefore the woody tissue was incorporated into the soil faster in CT than in NT.

The fraction of new C in the soil is a direct expression of carbon turnover (Table 1). The similar values of new C in CT and NT suggest that the increase of C was proportional in both tillage practices over time. Similar results were noted by Six et al. (1998). In lower depths (5-15 cm) more new C was incorporated into new C for the larger aggregates of CT vs. NT, again suggesting that new organic matter movement through the soil profile in CT. More details on this study of delta ^{13}C change in soil macro- and microaggregates are given in Arce-Flores and Coleman (2007).

Our research shows considerably increased mean residence time of SOM under NT vs. CT managements, similar to results measured by Paustian et al. (1997). Most of the aggregate size fractions experienced faster turnover in CT than in NT in both surface and deeper depths (Table 2). The turnover of aggregate-associated old C in microaggregates was 27.08 y for NT and 26.12 for CT (0-5 cm) and was greater for the 5-15 cm depth (34.5 and 12 y) for NT and CT, respectively. In the deeper profile the microaggregates < 53 um in both NT and CT had very little net input rate of new C. The measured turnover times for micro- and macroaggregates are in accord with the aggregate hierarchy concept of Oades and Waters (1991), and further demonstrate the mechanisms involved in the binding of micro- vs. macroaggregates (Tisdall and Oades 1982).

The net input rate of C3 pathway OM to aggregates increased from micro- to macroaggregates, which supports the concept that larger aggregates are bound together initially by root exudates and exfoliates and mycorrhizal hyphae. As they senesce and begin to undergo comminution, they are then incorporated into the intra-aggregate POM of larger macroaggregates first (Jastrow et al. 1996). The roles of mycorrhizal mycelia and their products are probably important in microaggregate formation, but little research has been carried out on this phenomenon yet (Rillig and Mummey 2006). In earlier studies at Horseshoe Bend, Bossuyt et al. (2002) measured more young C accumulated in the subsurface soil of CT than in NT, but it was not stabilized over the long term. They found, similar to our study, greater long-term stabilization of C in the surface layers of NT compared to CT.

Because the total C concentration in the three different sampling times between 1997 and 2005 remained relatively constant suggests that old C associated with microaggregates may be physically protected. As surface soils in CT are exposed to variable abiotic conditions, these factors contribute to the more frequent disruption of soil aggregates, releasing the aggregate protected SOM for mineralization (Beare et al. 1994b) and also to a lower production of aggregate stabilizing agents (Angers et al. 1993).

5. Conclusions

Long-term studies of soil detrital food webs and the dynamics of soil organic matter at Horseshoe Bend have been illustrative of several basic principles of ecology, and we feel that it has grown and matured with the influence of Ben Stinner and his colleagues who were so influential in establishing the studies nearly three decades ago.

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Figure Legends

Fig. 1. Above-ground biomass of crops measured during the fall at Horseshoe Bend.

Fig. 2. Effects of winter cover crop on crop biomass at Horseshoe Bend

Fig. 3. Yearly variation in the effects of tillage on crop biomass at Horseshoe Bend.

Fig. 4. Yearly variation in the effects of tillage on weed biomass at Horseshoe Bend.

Fig. 5. The effects of tillage on litter biomass at Horseshoe Bend

Fig. 6. Distribution of water-stable aggregates from conventional and no tillage soils at 0-5 (a) and 5-15 (b) depth. Bars are means ± S.E. Asterisks indicate significant differences ($P<0.05$, Tukey's HSD) between tillage treatments within size class; $n=32$.

Fig. 7. Total C and N (g kg^{-1}; normalized to a sand-free basis) in water-stable aggregates from conventional and no tillage soils at 0-5 and 5-15 depth. Bars are means ± S.E. Asterisks indicate significant differences ($P<0.05$, Tukey's HSD) between tillage treatments within size class; $n=32$.

Fig. 8. Particulate Organic Matter-Associated Carbon and Nitrogen (g kg^{-1}; normalized to a sand-free basis) in water-stable aggregates from conventional and no tillage soils at 0-5 and 5-15 depth. Bars are means ± S.E. Asterisks indicate significant differences ($P<0.05$, Tukey's HSD) between tillage treatments within size class; $n=32$.

Fig. 9. Total Carbon concentration in time for No Tillage and Conventional Tillage in different depths (0-5 and 5-15 cm) and aggregate size fractions.

Fig. 10. ^{13}C ratios of No tillage and Conventional Tillage in time in different depths (0-5 and 5-15 cm) and aggregate size fractions

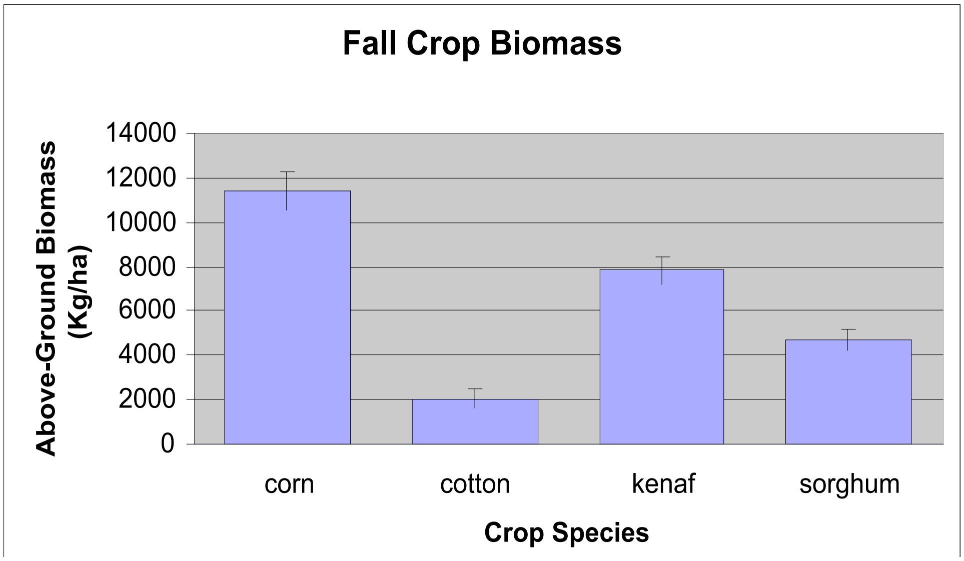
Fall Crop Biomass
Above-Ground Biomass (Kg/ha)
14000
12000
10000
8000
6000
4000
2000
0
corn
cotton
kenaf
sorghum
Crop Species

Figure 1.

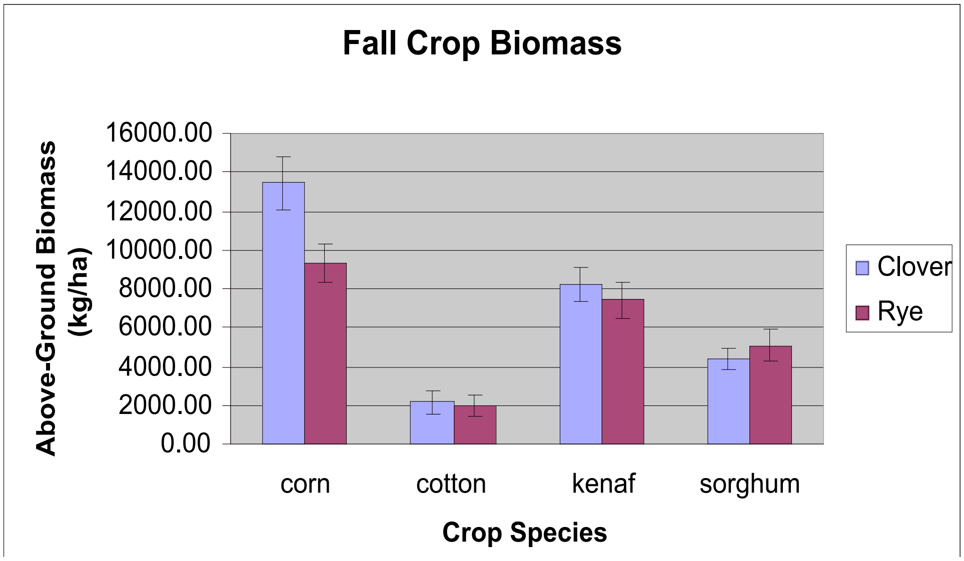
Fall Crop Biomass
Above-Ground Biomass (kg/ha)
16000.00
14000.00
12000.00
10000.00
8000.00
6000.00
4000.00
2000.00
0.00
corn
cotton
kenaf
sorghum
Crop Species
Clover
Rye

Figure 2.

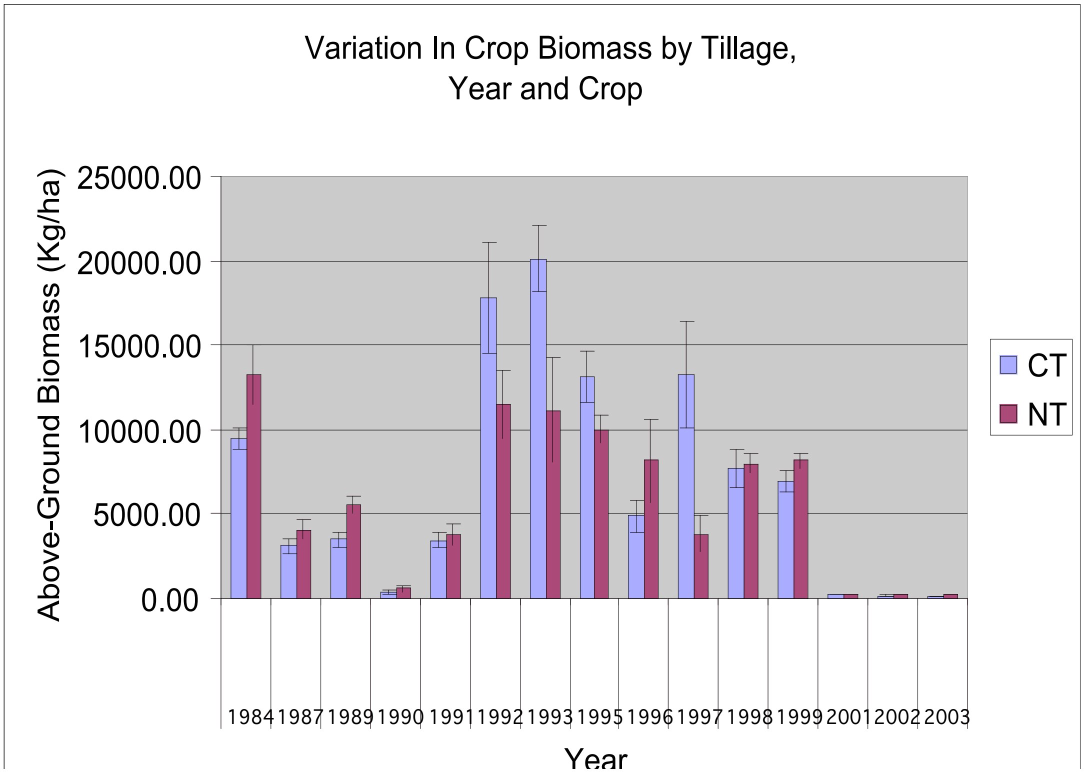
Variation In Crop Biomass by Tillage,
Year and Crop
Above-Ground Biomass (Kg/ha)
25000.00
20000.00
15000.00
10000.00
5000.00
0.00
1984
1987
1989
1990
1991
1992
1993
1995
1996
1997
1998
1999
2001
2002
2003
Year
CT
NT

Figure 3.

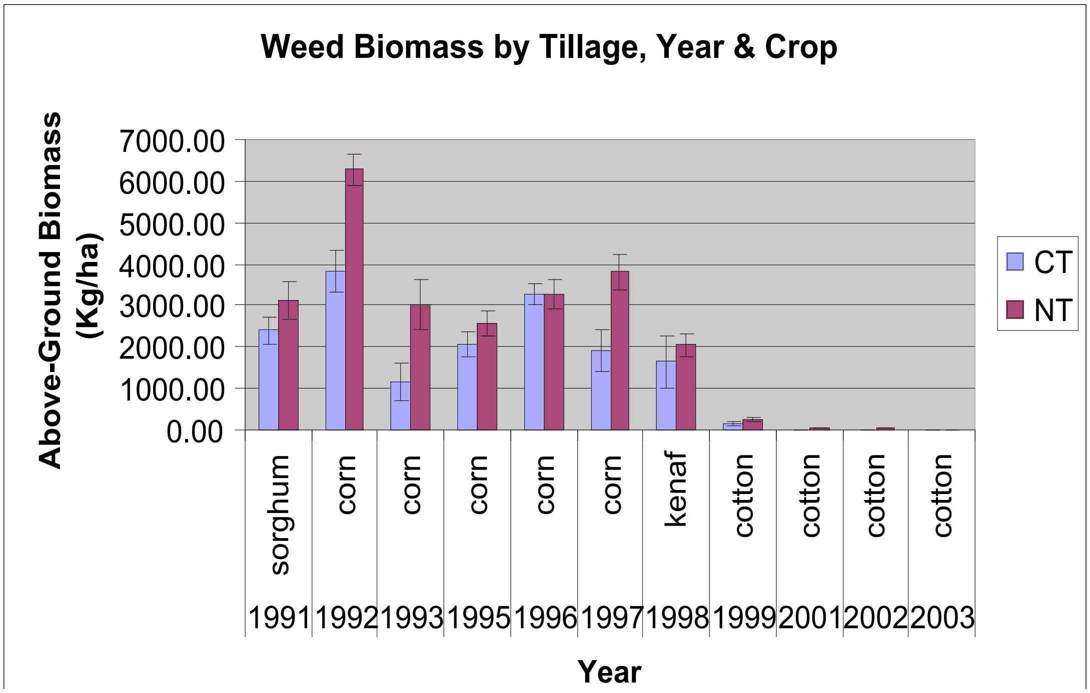
Weed Biomass by Tillage, Year & Crop
Above-Ground Biomass (Kg/ha)
7000.00
6000.00
5000.00
4000.00
3000.00
2000.00
1000.00
0.00
CT
NT
sorghum
corn
corn
corn
corn
corn
kenaf
cotton
cotton
cotton
cotton
1991
1992
1993
1995
1996
1997
1998
1999
2001
2002
2003
Year

Figure 4.

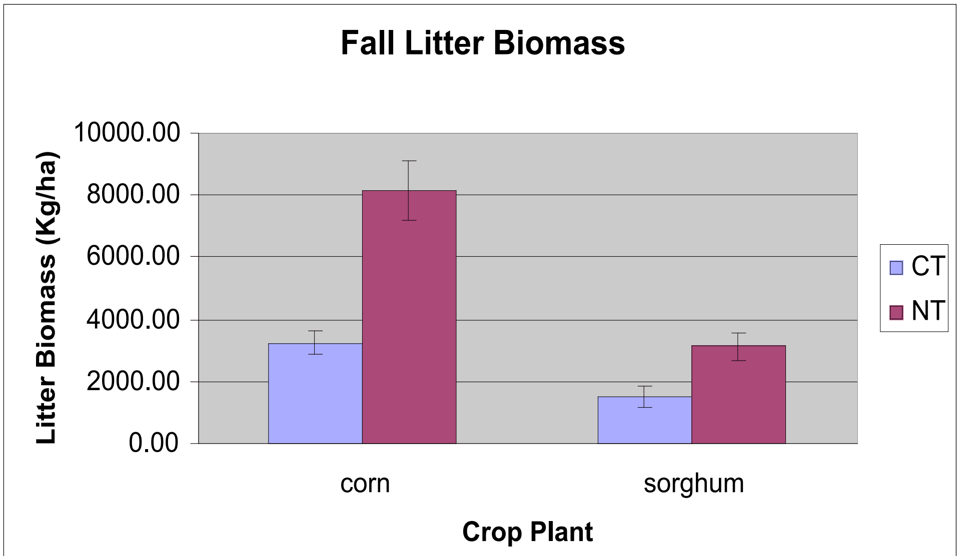
Fall Litter Biomass
Litter Biomass (Kg/ha)
10000.00
8000.00
6000.00
4000.00
2000.00
0.00
corn
sorghum
Crop Plant
CT
NT

Figure 5.

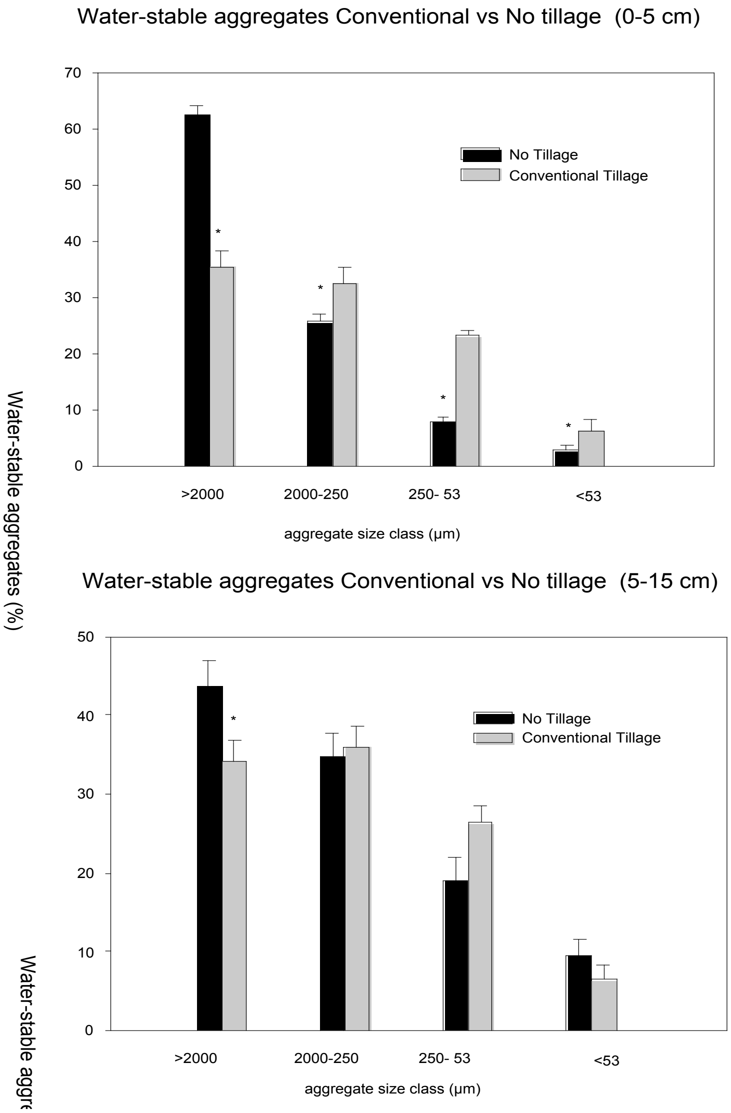
Water-stable aggregates Conventional vs No tillage (0-5 cm)
70
60
50
40
30
20
10
0
No Tillage
Conventional Tillage
*
*
*
*
>2000
2000-250
250- 53
<53
aggregate size class (µm)
Water-stable aggregates (%)
Water-stable aggregates Conventional vs No tillage (5-15 cm)
50
40
30
20
10
0
No Tillage
Conventional Tillage
*
>2000
2000-250
250- 53
<53
aggregate size class (µm)
Water-stable aggre

Fig 6.

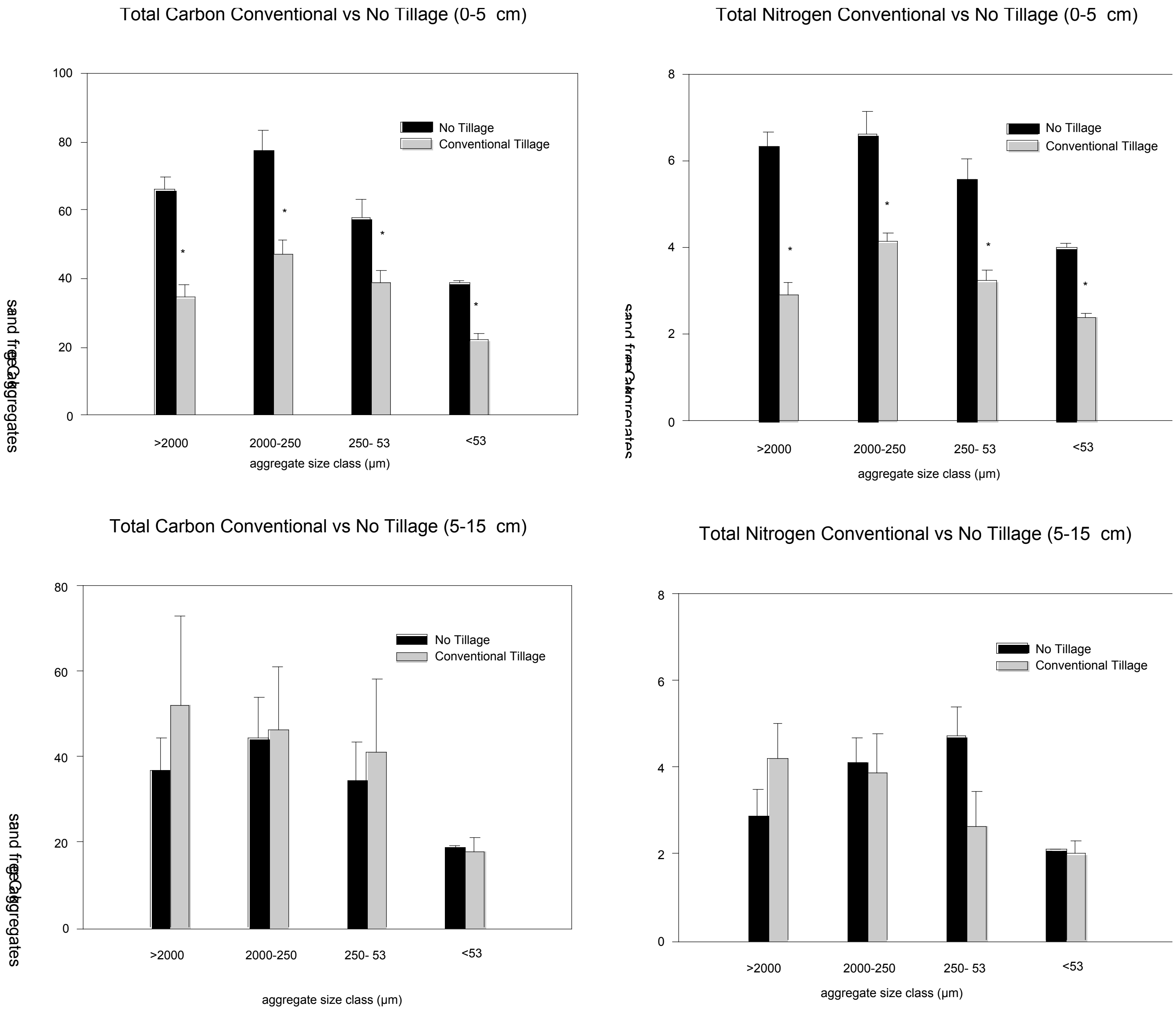
Total Carbon Conventional vs No Tillage (0-5 cm)
Total Nitrogen Conventional vs No Tillage (0-5 cm)
Total Carbon Conventional vs No Tillage (5-15 cm)
Total Nitrogen Conventional vs No Tillage (5-15 cm)
No Tillage
Conventional Tillage
sand free aggregates
0
20
40
60
80
100
0
2
4
6
8
*
>2000
2000-250
250- 53
<53
aggregate size class (µm)

Fig 7.

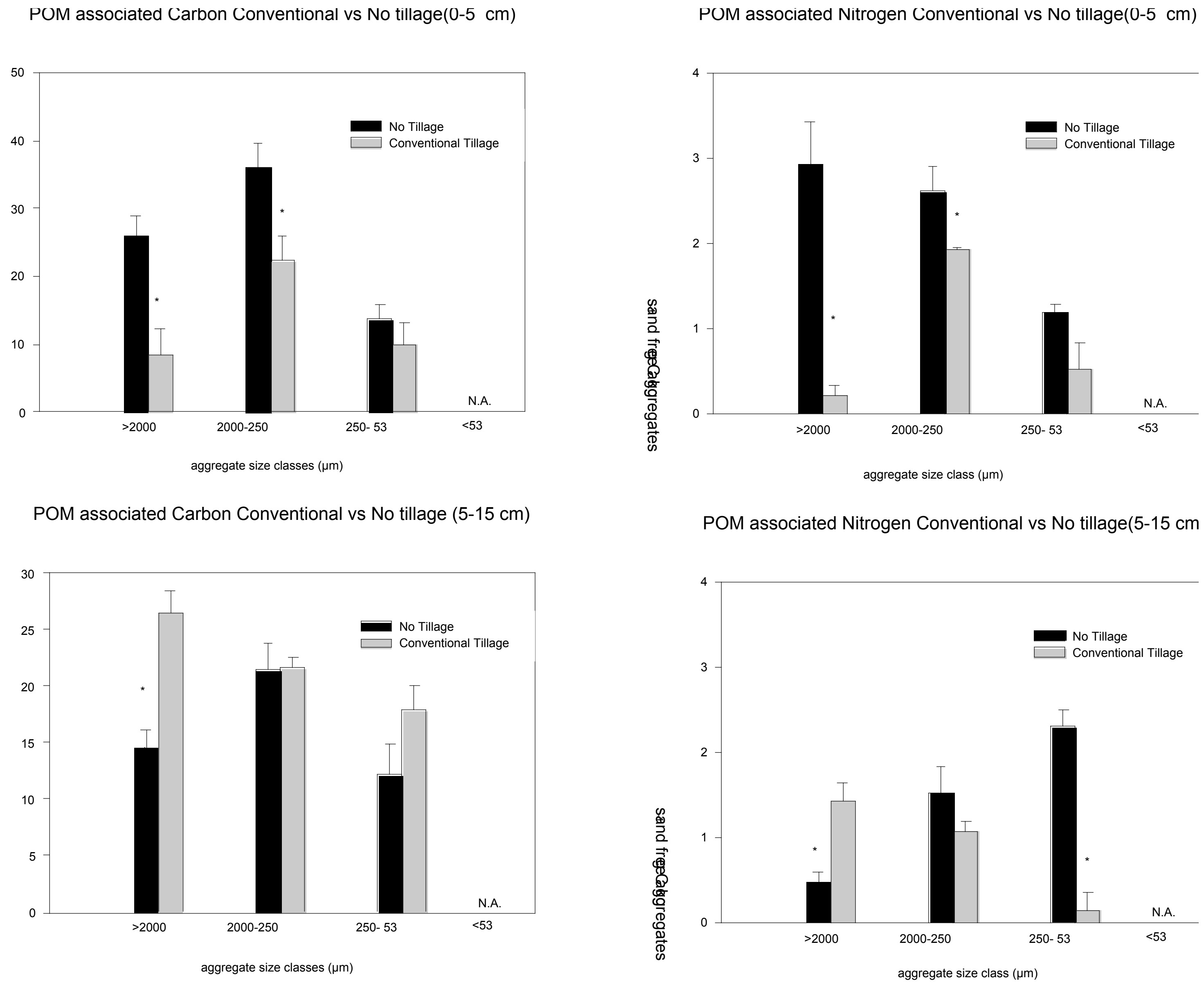
POM associated Carbon Conventional vs No tillage(0-5 cm)
50
40
30
20
10
0
No Tillage
Conventional Tillage
*
*
N.A.
>2000
2000-250
250- 53
<53
aggregate size classes (µm)
POM associated Nitrogen Conventional vs No tillage(0-5 cm)
4
3
2
1
0
sand free aggregates
*
*
N.A.
>2000
2000-250
250- 53
<53
aggregate size class (µm)
POM associated Carbon Conventional vs No tillage (5-15 cm)
30
25
20
15
10
5
0
*
N.A.
>2000
2000-250
250- 53
<53
aggregate size classes (µm)
POM associated Nitrogen Conventional vs No tillage(5-15 cm
4
3
2
1
0
sand free aggregates
*
*
N.A.
>2000
2000-250
250- 53
<53
aggregate size class (µm)

Fig 8.

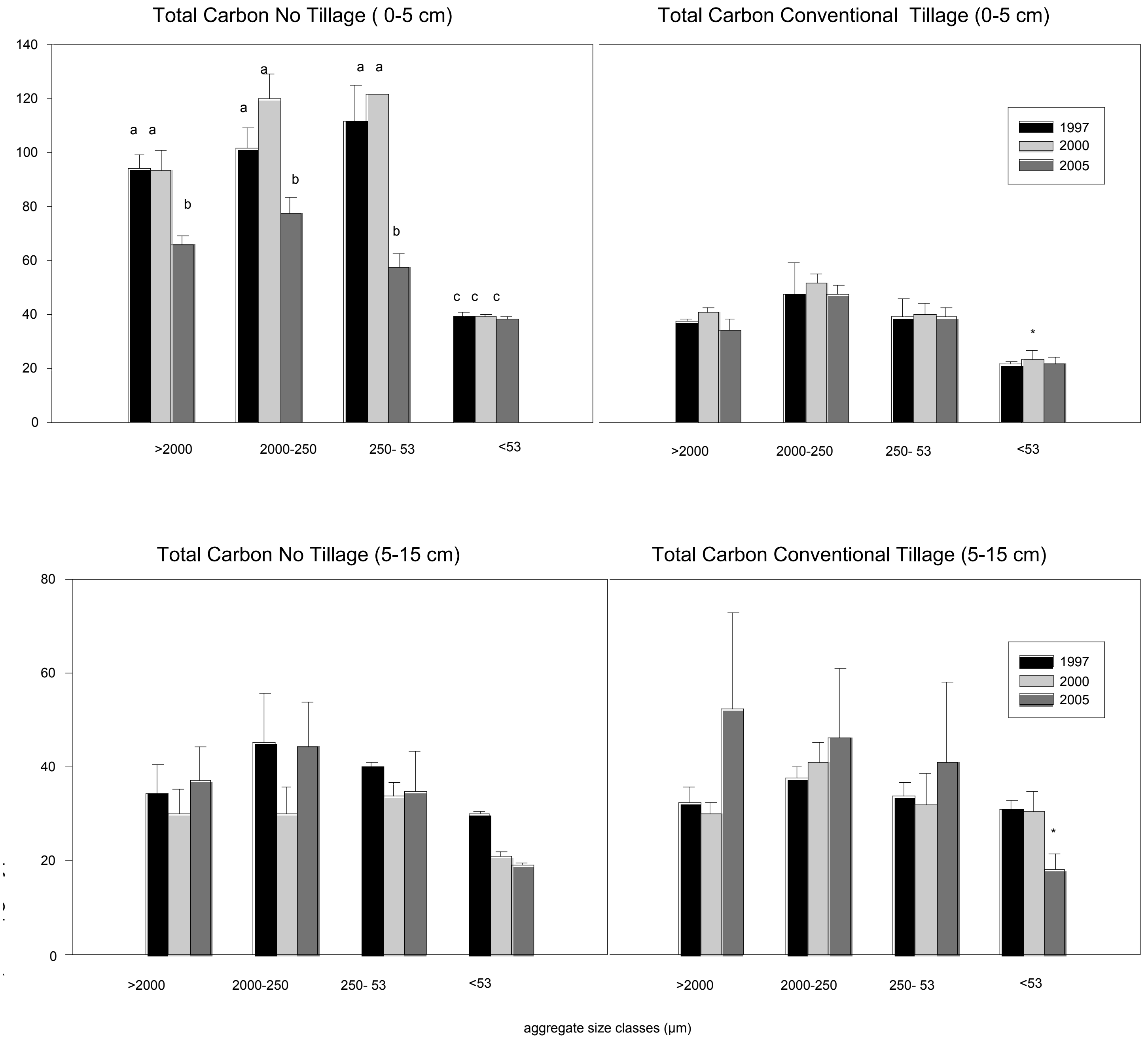
Total Carbon No Tillage (0-5 cm)
Total Carbon Conventional Tillage (0-5 cm)
140
120
100
80
60
40
20
0
a a b
a a b
a a b
c c c
*
1997
2000
2005
>2000
2000-250
250- 53
<53
Total Carbon No Tillage (5-15 cm)
Total Carbon Conventional Tillage (5-15 cm)
80
60
40
20
0
*
aggregate size classes (µm)

Fig. 9.

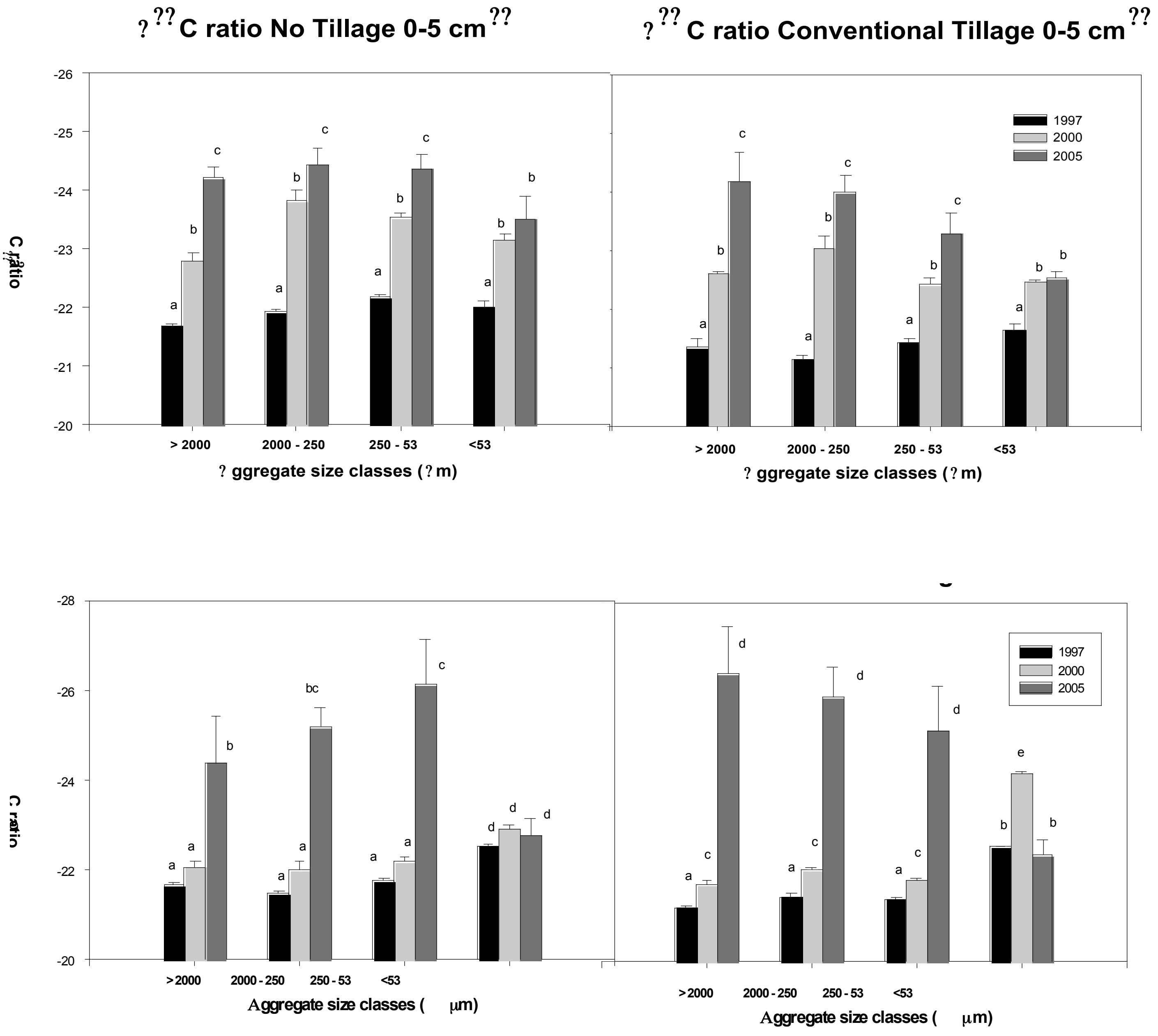
? ?? C ratio No Tillage 0-5 cm ??
? ?? C ratio Conventional Tillage 0-5 cm ??
C ratio
-26
-25
-24
-23
-22
-21
-20
-28
1997
2000
2005
a
b
c
bc
d
e
> 2000
2000 - 250
250 - 53
<53
? ggregate size classes (? m)
Aggregate size classes (µm)

Fig 10.

Table 1. Fraction of new carbon in 2000 and 2005 compared to 1997 at two depths, 0-5 and 5-15 cm. at Horseshoe Bend, Athens, GA.

Aggregate size	No Tillage (0-5 cm)		Conventional Tillage (0-5 cm)	
(µm)	2000	2005	2000	2005
>2000	0.18	0.40	0.18	0.43
2000-250	0.31	0.41	0.27	0.41
250-53	0.23	0.38	0.15	0.28
<53	0.19	0.25	0.10	0.13
	No Tillage (5-15 cm)		Conventional Tillage (5-15 cm)	
	2000	2005	2000	2005
>2000	0.07	0.43	0.07	0.77
2000-250	0.08	0.57	0.09	0.67
250-53	0.07	0.70	0.06	0.56
<53	0.07	0.04	0.30	0.001

Table 2. Average rate constant (*k*) for loss and turnover time (1/*k*) of the mixture of C_4 and C_3 Carbon and average net input rate of C_3-C in aggregate size fractions at 0-5 and 5-15 cm. depths as determined by ^{13}C natural abundance.

	No Tillage (0-5 cm)			Conventional Tillage (0-5 cm)		
Aggregate size	*k*	1/ *k*	Net input rate	*k*	1/ *k*	Net input rate
(µm)	yr^{-1}	yr	g kg^{-1} fraction yr^{-1}	yr^{-1}	yr	g kg^{-1} fraction yr^{-1}
>2000	0.08	12.51	3.30	0.12	8.58	1.86
2000-250	0.10	10.25	3.98	0.10	10.43	2.42
250-53	0.12	8.66	2.74	0.10	10.49	1.36
<53	0.04	27.08	1.21	0.04	26.12	0.36
	No Tillage (5-15 cm)			Conventional Tillage (5-15 cm)		
Aggregate size	*k*	1/ *k*	Net input rate	*k*	1/ *k*	Net input rate
(µm)	yr^{-1}	yr	g kg^{-1} fraction yr^{-1}	yr^{-1}	yr	g kg^{-1} fraction yr^{-1}
>2000	0.06	15.89	2.00	0.13	7.49	5.03
2000-250	0.08	13.17	3.16	0.10	9.69	3.89
250-53	0.15	6.58	3.03	0.08	12.18	2.89
<53	0.03	34.50	0.10	0.08	12.01	0.001