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THE EFFECT OF HARVEST RESIDUE MANAGEMENT INPUTS ON SOIL RESPIRATION AND CROP PRODUCTIVITY OF SUGARCANE

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ABSTRACT

Improper burning of harvest residue results in environmental and societal insults and success with mechanical removal of residue to row furrows is countered by slow degradation and potential impediments to drainage and cultivation from the concentrated residue bulk. There is a need to identify effective alternatives to these two industry-employed approaches. The objective of this research was to determine the effect of various management treatments of sugarcane harvest residue on soil respiration (SR)/ residue decomposition rate and crop productivity. Averaged over two years, compared to normal residue size from the harvester, further shredding of the residue resulted in significantly higher SR and stalk population. All other yield parameters were not affected by reducing residue particle size *per se*. Adjuvant treatment with non-ionic surfactant was not effective in enhancing SR, but adjuvant application of 66 kg slow release N ha^{-1} did increase SR. Both adjuvant treatments decreased plant population slightly compared to similar plots where residue was not treated with the adjuvant. Soil incorporation of residue when contrasted with all other treatments across two years produced higher stalk population, higher cane yield, higher CRS, and higher sugar yield than non-incorporation treatments. The combination of reducing particle size and soil incorporation resulted in faster degradation (higher SR), but additional residue shredding was not necessary for higher yield when residue was soil incorporated.

INTRODUCTION

Burning combine-harvest residue can affect the air quality of nearby communities. This problem will increase as production agriculture interfaces with more and more suburban communities. Moreover, removing the crop residue by burning eliminates any potential for build-up of organic matter and the improved soil quality that would result from that. Lastly, burning the residue results in a soil covered in flocculent residue ash. This condition would be susceptible to particle and nutrient loss from both soil and ash during rainfall events. With the arrival of the combine (chopper) harvester to the Louisiana sugar industry in 1993, burning at any point during the harvest process became an option instead of a necessity as opposed to the case of heap row burning with whole stalk harvesting. Positive affects of retaining the residue would come from retained nutrients that may otherwise be oxidized/ vaporized by burning, depending on fire temperature (Bell-Coelho et al., 1993). Yet data exist that indicate retaining the residue by not removing it through burning or other means can reduce crop yield (Richard, 2001). Leaving the residue intact can slow soil warming in the spring (Richard, 2001) or produce allelopathic/autotoxic effects (Viator et al., 2005), both of which can reduce crop growth rates.

Machinery has been developed to remove the residue from the top of the cane row, thus eliminating negative effects of a residue ‘mat’ covering the area where the sugarcane will subsequently emerge. However, moving and concentrating harvest residue measured as high as 6 Mg ha^{-1} or more to row middles can cause problems for water drainage and cultivation. Other methods should be considered as ways to hasten the decomposition rate or at least ameliorate the negative effects of retaining the residue in the field.

Possible alternatives to burning include treating the residue with a chemical adjuvant, reducing the residue particle size with additional shredding, and/or incorporating the residue into the soil. Treatment with an adjuvant to microbial activity would include a wide assortment of chemicals. Among them, non-ionic surfactants could allow better penetration of moisture and microbes within residue tissue (Hall et al., 1982). The application of N to hasten mineralization of organic C and N has been tried with other residue with mixed results. In some cases, it has been found to hasten mineralization of both constituents (Jones et al., 2002; Sturgis, 1938), but it has also been found to hasten N mineralization at the expense of C mineralization (Sanomiya et al., 2006). Additional shredding of the combine-harvest residue would make the particle size smaller, increasing the surface area from which microbes could degrade the residue. Results of shredding crop residue have generally hastened the degradation rate as indicated by increased C and N mineralization (Ambus and Jensen, 1997; Angers and Recous, 1997), altered the peak respiration time (Bending and Turner, 1999), or did not affect respiration (Vestergaard et al., 2001). Soil incorporation of harvest residue would also increase the amount of residue surface that would come in contact with soil microbes and thus should hasten decomposition. This has generally been found to be effective for other crop residues. Kushawa et al. (2000) found higher amounts of soil microbial biomass and more mineralized N when barley harvest residue was incorporated into soil. When corn residue was soil incorporated, higher respiration rate occurred indicating a higher decomposition rate compared to leaving the residue on the soil surface (Crews et al., 1998). In sugarcane, Sturgis (1938) found the timing of incorporation was important for adequate decomposition and mineralization. It was the objective of this experiment to evaluate the effect of several residue management inputs on soil respiration in late winter/early spring and on subsequent yield and yield components of ratoon crops of 'LCP 85-384' (Milligan et al., 1994).

MATERIALS AND METHODS

The variety LCP 85-384 was hand planted at a rate of two overlapping stalks in August 2002 in a Commerce silt loam (Fine-silty, mixed, superactive, nonacid, thermic Fluvaquentic Endoaquepts). The plant cane crop was harvested in December 2003 and the experiment was initiated when treatments were imposed on its residue in January 2004. Following the collection of first ratoon harvest data in December 2004, treatments were again imposed on that residue in the same plots in January 2005. The second ratoon harvest was in late November 2005. The treatments were as follows: 1) residue burned; 2) residue swept to the row furrows using a Gravois brush implement; 3) residue left undisturbed; 4) residue treated with an adjuvant chemical; 5) residue soil-incorporated using a 3-row disc cultivator; 6) residue particle size reduced using a tractor-mounted Bearcat model 70554 chipper-shredder; 7) shredded residue treated with an adjuvant chemical; 8) shredded residue soil-incorporated using a 3-row disc cultivator. The adjuvant used in 2004 was Triton x-100, a non-ionic surfactant, used at a rate of 2 l ha^{-1}. In 2005, 66 kg Nha^{-1} of a slow release N fertilizer (Nitamin™) was used as the adjuvant instead of the surfactant. The chipper-shredder reduced the harvest residue particle size by about

85%, and the resultant shredded material was manually redistributed back on the row (Figure1). The depth of soil incorporation was estimated to range from 0 – 7 cm (Figure 1). Plot dimensions were 3 rows, 1.8 m wide by 15.2 m long. Fertilizer was applied at the rate of 112-45-90, N-P_2O_5-K_2O, kg ha^{-1} in the spring each year. All additional cultural practices were as prescribed by LSU Ag Center recommendations (Legendre, 2001).

Figure 1. Four, physical forms of residue management. A. Residue undisturbed after exit from the combine; B. Residue with additional shredding; C. Harvest residue soil incorporated; D. Shredded residue soil incorporated.

Soil respiration (SR) was determined using a Li-Cor 6400 infrared gas analyzer (IRGA) coupled to a Li-Cor respiration chamber. One 10 cm ID soil collar was placed to a depth of 2.5 cm in each plot a few hours before measurements were made. Measurements were made between noon and 4 PM. The CO_2 efflux rate was determined by placing the respiration chamber on the soil collar and measuring CO_2 build up beginning from 10 µmoles CO_2 below ambient to10 µmoles CO_2 above ambient. This was repeated three times in succession and the average efflux was converted to kg C removed ha^{-1} d^{-1} according to the method of Parkin et al. (1996). Soil temperature was determined to a depth of ~3cm at the time CO_2 flux measurements were made. An estimate of combine- harvest residue degradation separate from total organic carbon degradation was accomplished by normalizing all CO_2 flux rates to 25°C and then subtracting the flux rate of the treatment with a bare soil surface on the top of the cane bed; in our case the swept treatment. Measurements were taken on three occasions in 2004 at weekly intervals in March. In 2005, measurements were taken on four occasions at about biweekly intervals beginning in mid February. The averages of these measurements were used to determine average C loss during this period of time.

Millable stalk counts were made in August of each year on the entire inside row of each 3-row plot. Plots were harvested by combine and weight was determined by a harvest wagon fitted with three load cells. Ten whole stalks were taken from each plot and stripped of leaves and tops for stalk weight determination and sugar analysis. Brix was determined by refractometry and sucrose by polarimetry. Commercially recoverable sugar (CRS) was determined using a standard formula (Legendre, 1992). Sugar yield was determined as the product of CRS and cane yield. The experimental design was a randomized complete block with four replications. Combined year analysis used a replicated year randomized block design using the general linear models procedure (SAS Institute, 1985). The orthogonal contrast method was used to compare shredding the residue vs. not shredding the residue and soil-incorporation of residue vs. all other treatments.

RESULTS AND DISCUSSION

There was no statistically significant ($P \leq 0.10$) treatment by year interaction for any measured variable in the combined year analysis. Therefore, two-year averages were used in the presentation of data along with selected orthogonal contrasts of those data.

The amount of carbon removed by SR averaged about 24 kg ha^{-1} d^{-1} among all treatments. Additional shredding of residue and subsequent soil incorporation was the only single treatment that had significantly higher SR than the rest of the treatments (Figure 2). Based on orthogonal contrasts, shredding the residue, in general, did result in a higher rate of C loss from the soil surface than not shredding the residue (Figure 2). This was also the case when soil incorporation treatments were contrasted with all other treatments (Figure 2).

Separating the harvest residue fraction from total carbon loss resulted in more differences among treatments (Figure 3). Untreated residue had the lowest rate of decomposition; resulting in about 4 kg less carbon removed ha^{-1} d^{-1} than shredded residue. Soil incorporation of shredded residue resulted in 7 or more kg carbon removed ha^{-1} d^{-1} than any other treatment, which was about a 3-fold increase in activity. Orthogonal contrasts showed that treatments with shredded residue had about 5 fold more residue decomposition activity than similar treatments with untreated residue. Orthogonal contrasts of tillage treatments vs. all others also resulted in about a 4-fold increase in residue decomposition. The treatment combining additional shredding and soil incorporation was the major contributor to this result. Improved mixing of soil and residue and greater surface area of the residue due to shredding was probably the main reason for this enhanced activity. When harvest residue is reduced in particle size and /or soil incorporated the more rapid decomposition rate that occurs may be beneficial to the subsequent crop. The potential for autotoxicity may be reduced if the decomposition rate is hastened and phytotoxic compounds are produced (and dissipate) earlier than much of early-season crop growth. Moreover, a faster decomposition rate may reduce the potential effect of N immobilization. In effect, the faster the residue decomposes the sooner soil N contained in the microbial fraction will be mineralized and released for plant uptake.

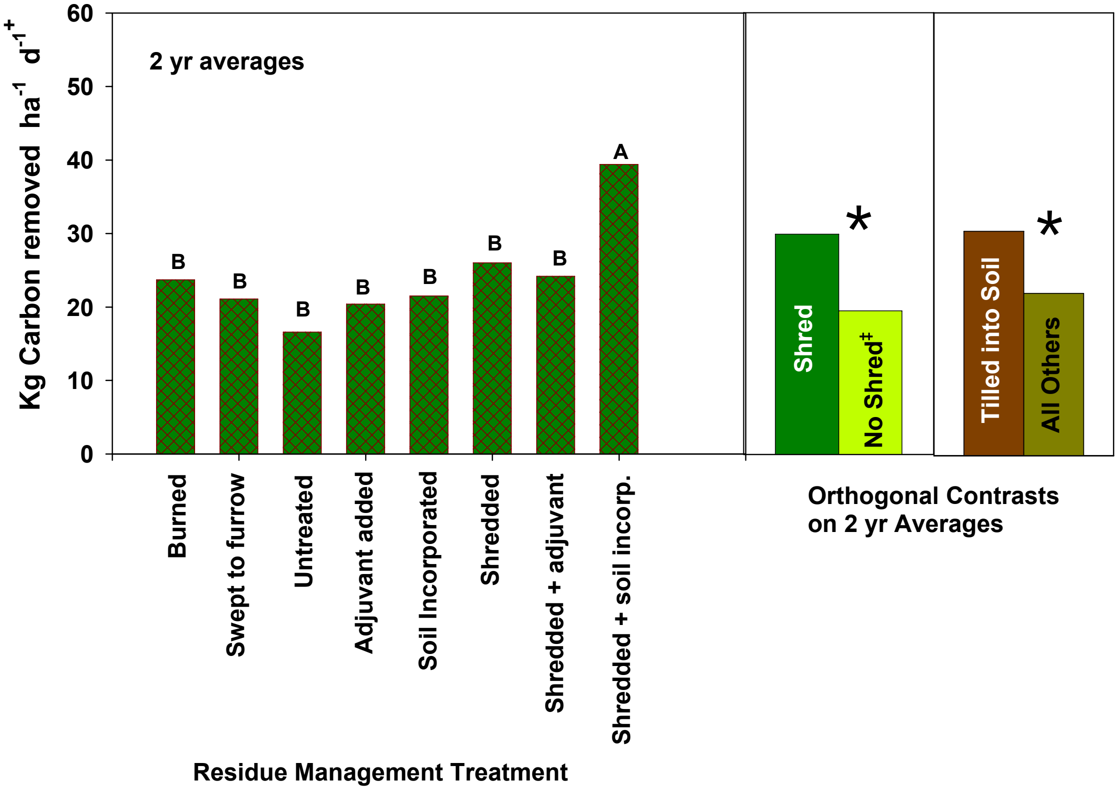

Figure 2. The effect of harvest residue management on the amount of carbon removed by soil microbial respiration during late winter. Bars attended by the same letter are NS at $P \leq 0.05$. All plots were maintained in the same place for two years.

+ Based on 3-4 measurements/plot during late February and March.

*** significantly different at $P \leq 0.05$.**

‡ 'No Shred' did not include Burned or Swept treatments.

Stalk population is dependent upon tillering and changes in early tillering/stalk population would be among the first yield components to respond to negative processes rendered by harvest residue. Maintaining or increasing the level of tillering would suggest an abatement of any negative process. We found a small increase in stalk population due primarily to shredding the harvest residue, but also to soil incorporation of residue, whether shredded or intact (Figure 4). Stalk population is an important component of yield, as is stalk weight. However, we did not find difference among treatments for stalk weight (data not presented).Regardless, additional shredding of the residue did not result in any significant improvement in yields or CRS (Figures 5-7). Once spring tillage occurred, any surface residue shredded or not, would have a similar effect on the crop due to some soil/residue mixing.

The adjuvants we selected for enhancing microbial activity had mixed effects. Non-ionic surfactants generally have not been found to affect self-regulated biological processes (Bayer and Foy, 1982), but higher concentrations (> 1% w/v) have produced phytotoxicity (Parr, 1982). The concentration of nonionic surfactant in the study exceeded 1% w/v and, thus had the potential for phytotoxicity. Orthogonal contrasts of adjuvant treatments in 2004 vs. similar treatments without adjuvant added indicated Triton X-100 had no significant effect on SR. The span of time between application and crops growth was a minimum of 60 d and we suspect the surfactant had not degraded appreciably during this time based on general response from previous surfactant research (Bayer and Foy, 1982). This potential for phytotoxicity may have been the reason for a significantly ($P \leq 0.1$) lower stalk population as indicated by the same orthogonal contrasts (data not presented).

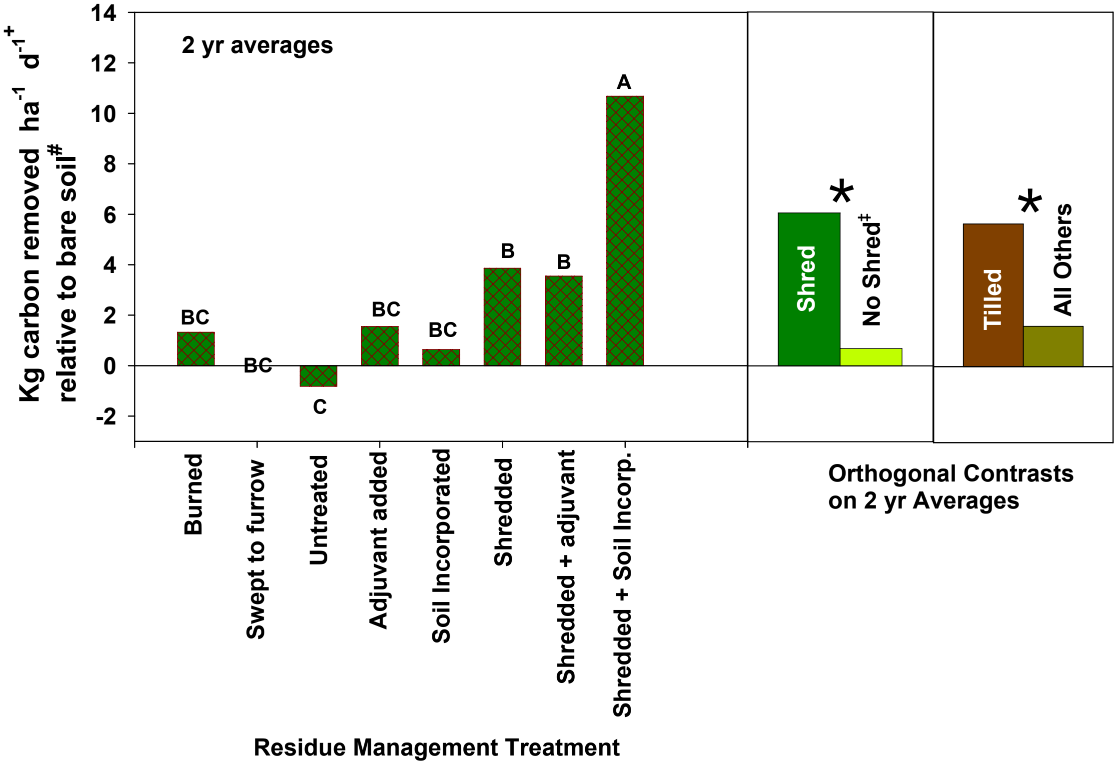

Figure 3. The effect of harvest residue management on the amount of harvest residue carbon removed by soil microbial respiration during late winter relative to bare soil. Bars attended by the same letter are NS at $P \leq 0.05$. All plots were maintained in the same place for two years.

+ Based on 3-4 measurements/plot during late February and March.

*** significantly different at $P \leq 0.05$.**

‡ 'No Shred' did not include Burned or Swept treatments.

 # All values were normalized to activity at 25°C and bare soil (Swept) activity was subtracted to estimate decomposition of residue.

When contrasted orthogonally with non-adjuvant counterparts in 2005, the application of 66 kg N/ha as a slow release N fertilizer had a slight positive effect on C loss ($P \leq 0.01$). One would expect adding N to harvest residue would lower the C: N ratio and thus improve degradation rate and subsequent mineralization. Enhancement of crop productivity with this adjuvant did not subsequently occur, however. As with the non-ionic surfactant, stalk population tended to be suppressed slightly by this application relative to other treatments ($P \leq 0.06$) (data not presented).

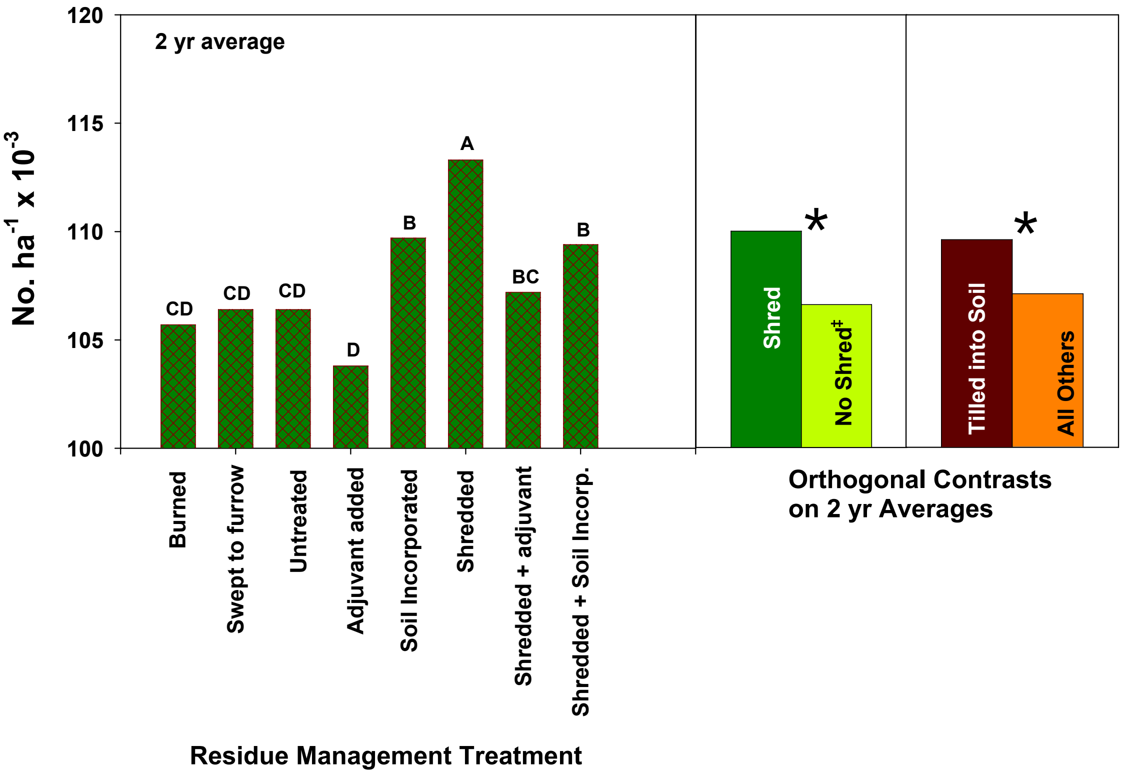

Figure 4. The effect of harvest residue management inputs on millable stalk population of ratoon LCP85-384. Bars attended by the same letter are NS at $P \leq 0.05$. All plots were maintained in the same place for two years.

*** significantly different at $P \leq 0.05$.**

‡ 'No Shred' did not include Burned or Swept treatments.

Orthogonal contrasts indicated soil incorporation produced superior yields to other treatments in this study. Soil incorporation resulted in a 5.7% increase in cane yield compared to all other treatments (Figure 5). Commercially recoverable sugar was about 3 % higher when residue was previously incorporated into the soil (Figure 6). Sugar yield was improved by about 8% above all other treatments combined due to residue incorporation into soil during January each year (Figure 7). It is difficult to ascribe a specific reason for improved yields due to this input. Soil incorporation of residue did improve yield although its effect on early-season C loss (decomposition) was primarily associated with the incorporation of shredded residue and not untreated residue (Figures 2, 3). Harvest residue incorporated into soil certainly would lead to faster decomposition pending good residue contact with soil and adequate soil moisture. Shredded residue incorporated better than regular combine-harvest residue as evidenced by more gaps and air pockets in the latter than the former (personal observation)(Figure 1). This latter condition may have diminished the rate of decomposition of normal residue early in the season, but was still better than leaving the residue on the surface in the long term. A reduction in phytotoxic chemicals, an increase in nutrients cycled from the vegetative residue or some other factor, could have been reasons for the improvement in yield by soil incorporation, but we did not measure those parameters.

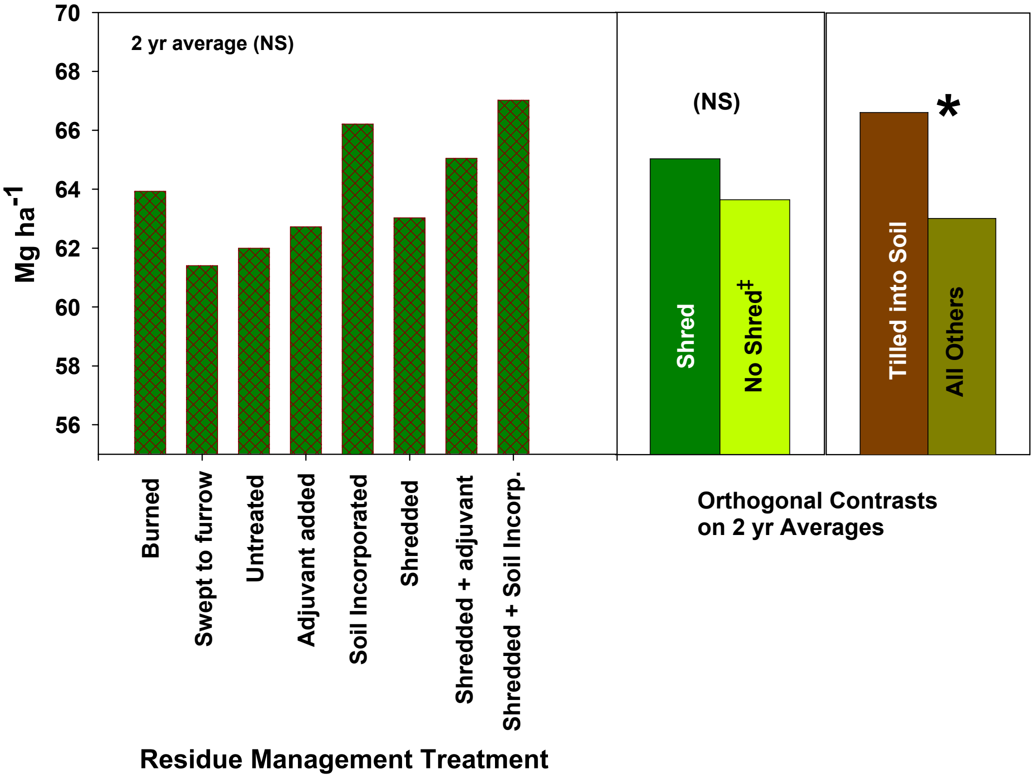

Figure 5. The effect of harvest residue management inputs on cane yield of ratoon LCP85-384. All plots were maintained in the same place for two years.

*** significantly different at P ≤ 0.05.**

‡ 'No Shred' did not include Burned or Swept treatments.

Regardless of the reason, soil incorporation of combine-harvest residue possibly with additional shredding through the extractor fan assembly could be the initial input in a reduced tillage system. This initial tillage would establish the row profile as early as possible after harvest. No further tillage would be employed until, possibly, lay-by. Such a program would reduce production costs by reducing excessive tillage in the spring. With this system sediment run-off would be more likely to occur earlier in the season when temperatures are cooler and biological problems in surface streams are less likely to occur because of this than with spring cultivations. It would also conserve soil moisture. This system would be similar to the "stale seedbed" system used with annual row crops. A problem with such a system would be wet soil conditions prohibiting entrance to fields during the fall and winter for timely soil incorporation of the residue. Late harvested plant cane fields would be most impacted by wet field conditions that might preclude tillage incorporation, but harvest residue from earlier harvest ratoon crops could, in most years, be incorporated during the normally dry fall conditions.

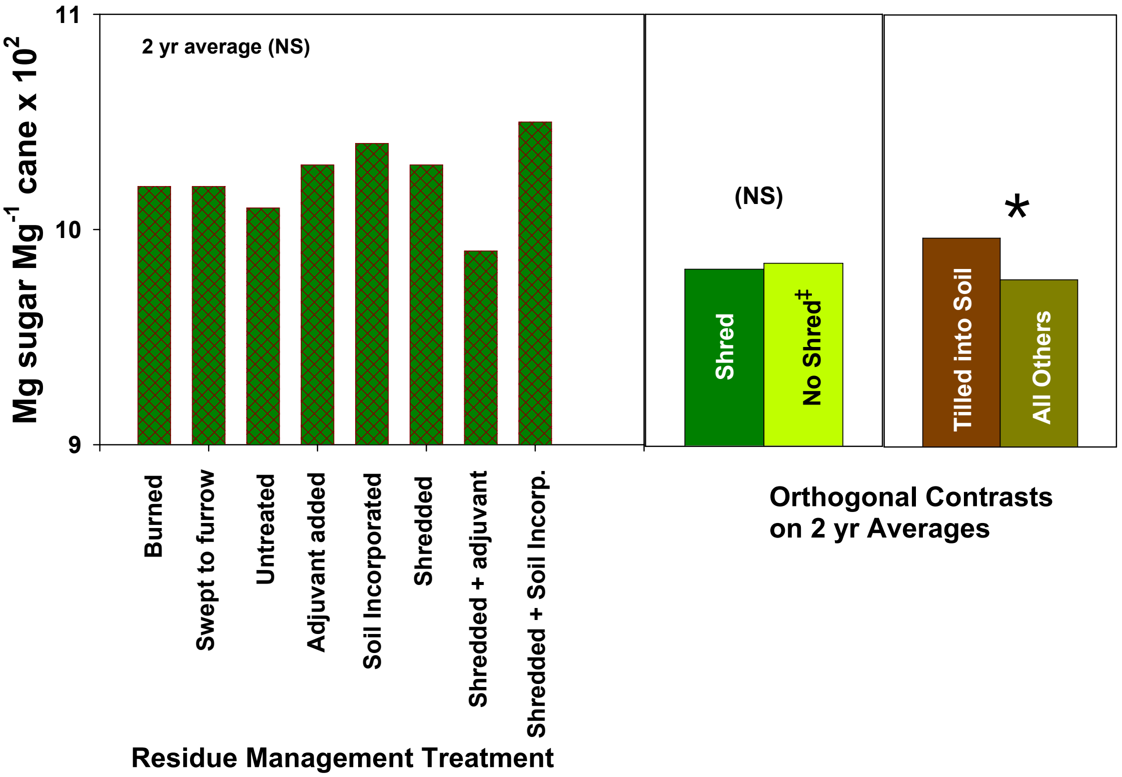

Figure 6. The effect of harvest residue management inputs on commercially recoverable sugar of ratoon LCP85-384. All plots were maintained in the same place for two years.

*** significantly different at $P \leq 0.05$.**

‡ 'No Shred' did not include Burned or Swept treatments.

CONCLUSIONS

Both the additional shredding of combine-harvest residue and soil incorporation of the residue resulted in a higher decomposition rate as expressed by soil respiration. Both inputs also resulted in slightly higher populations of millable stalks, but only soil incorporation improved yield. Soil incorporation of shredded residue could be an integral component of non-burn, reduced tillage, stale bed systems.

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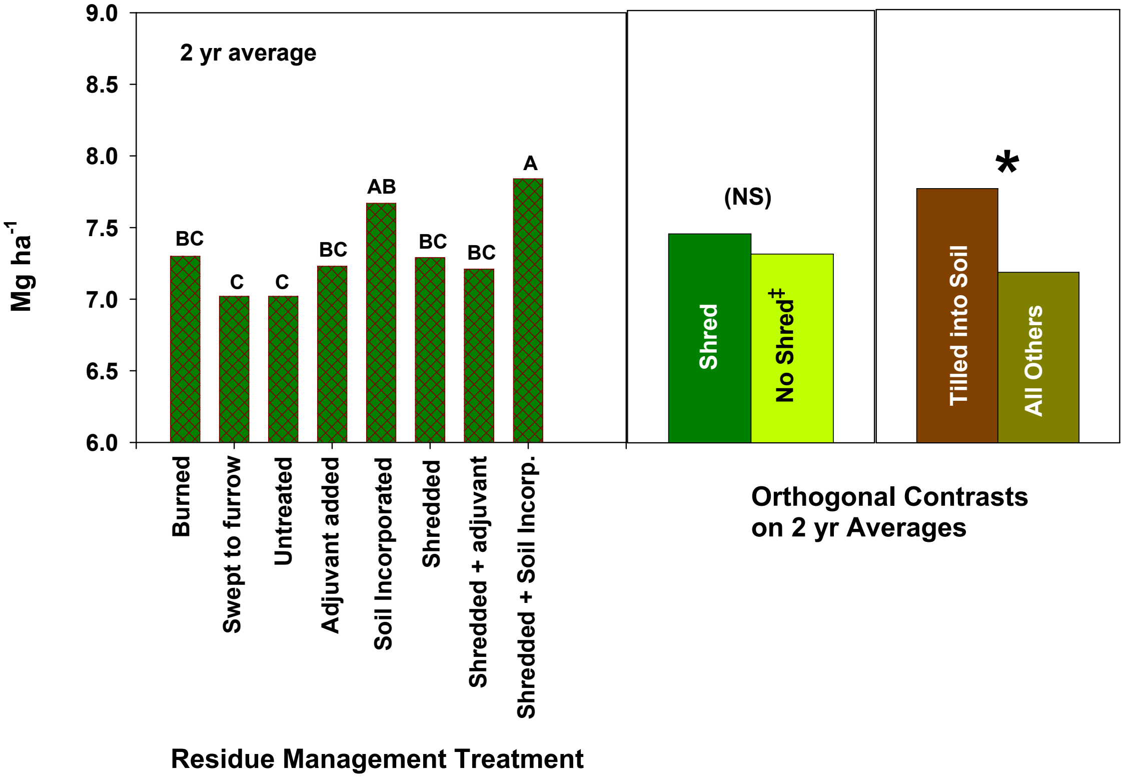

Figure 7. The effect of harvest residue management inputs on sugar yield of ratoon LCP85-384. Bars attended by the same letter are NS at P ≤ 0.10. All plots were maintained in the same place for two years.

*** significantly different at P ≤ 0.05.**

‡ 'No Shred' did not include Burned or Swept treatments.

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