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# Mulched and soil-incorporated sugarcane greenchop residue and compost: effects on selected soil components, sugarcane nutrients, Mexican rice borer injury, and yield

Allan T. Showler*

**Abstract**

Burning sugarcane, *Saccharum* spp., fields to remove leaves before harvest is a routine practice in many sugarcane production areas, including the United States. The method is environmentally deleterious and has been discontinued in some parts of the world. Alternatively, excised preharvest leaf residue, or greenchop, is used as mulch. This field study examined the effects of greenchop, applied in several ways to sugarcane soil, on soil fertility, selected sugarcane plant physiochemicals, injury inflicted by the Mexican rice borer, *Eoreuma loftini* (Dyar) (Lepidoptera: Crambidae), and sugarcane yield parameters, compared to plots augmented by soil-incorporated compost and a nontreated control. The compost amended soil had elevated concentrations of many nutrients, and in sugarcane leaves, heightened concentrations of certain sugars and free amino acids. None of the greenchop treatments affected soil and sugarcane leaf nutrients. During the first year of the study, *E. loftini* injury to sugarcane stalks during the first season, however, was generally greater in the greenchop and compost treatments than in the control. In the second growing season, the compost treatment was the only treatment associated with heightened *E. loftini* infestations. Relationships between soils augmented with organic amendments and *E. loftini* injury to sugarcane are discussed in terms of mediation through physiochemical changes induced by the amendments.

**Keywords** Compost, *Eoreuma loftini*, Leaf residue, Mulch, Organic matter

## Introduction

In addition to the air pollution and adverse health effects associated with routine burning to remove sugarcane, *Saccharum* spp., leaves from the stalks before harvest (Lara et al. 2005; Cançado et al. 2006; Arbex et al. 2007), the practice can also cause deterioration of soil structure and loss of organic matter and nutrients (Juo and Lal 1977; Biederbeck et al. 1980) from high-temperature volatilization (Raison et al. 1985), fly ash, and water runoff (Smith and Bowes 1974; Tulaphitak et al. 1985). As an example, in Brazil 2600 kg of C, 17 kg of N, and 1 kg of P were estimated lost per hectare of sugarcane from volatilization alone (Ball-Coelho et al. 1993). Alternatively, leaves can be mechanically stripped from the stalks (often cut into small pieces) and left as a 15–20-metric ton/ha mat of "greenchop" on the soil surface (Wood 1991) 8–10 cm deep (Hall et al. 2006). Greenchop mulching is particularly common in Brazil (Basanta et al. 2003) and New Zealand (Hall et al. 2006). Advantages can include stabilized soil temperature, reduced erosion, and soil moisture conservation (Eavis and Cumberbatch 1977; Spain et al. 1990; Yadav et al. 1986; Wood 1991). Decomposition of greenchop occurs through rapid leaching followed by earthworm-induced soil mixing (Spain

*Correspondence:
Allan T. Showler
allan.showler@usda.gov
USDA-ARS KBUSLIRL, 2700 Fredericksburg Road, Kerrville, TX 78028, USA

et al. 1990; Spain and Hodgen 1994), releasing nutrients for sugarcane growth (Patriquin 1982; Ng et al. 1987; Hill and Patriquin 1988; Wood 1991; Yadav 1995). While greenchop mulch and compost have improved sugarcane yield (Cumberbatch 1969; Eavis and Cumberbatch 1977; Sandhu et al. 1980; Yadav et al. 1986; Ball-Coelho et al. 1993; Showler 2015), greenchop can also reduce availability of some nutrients (White and Ayoub 1983; Ng et al. 1987) and inhibit growth and yield under certain conditions.

Organic soil amendments, by affecting plant physiochemistry, can influence the susceptibility of sugarcane to lepidopteran pests. The eldana borer, *Eldana saccharina* Walker, damage to sugarcane increases where soil N is abundant (Nuss and Atkinson 1983; Turner et al. 1991). In sugarcane mulched with greenchop, cutworm, *Agrostis* sp., populations increased (Stirling and Eden 2008). In South Texas, the Mexican rice borer, *Eoreuma loftini* (Dyar) (Lepidoptera: Crambidae), originally from Mexico, became the key pest of sugarcane since its first detection there in 1980 (Legaspi et al. 1999). The pest prefers to lay eggs, and it inflicts more damage, on sugarcane grown on compost-amended soil than on non-augmented soil because the plant is more nutritious to *E. loftini* (Showler 2015). While on one hand it is possible that the water retentive capacity of soil amended with greenchop under the relatively dry conditions of South Texas could make the crop less attractive to female *E. loftini* (Reay-Jones et al. 2005; Showler and Castro 2010a,b) enhanced soil N associated with decomposed sugarcane leaf tissue might have the opposite effect.

The purpose of this study was to examine the effects of greenchop used as mulch, and as a soil incorporated amendment, on sugarcane soil fertility, concentrations of selected sugarcane physiochemicals, injury caused by *E. loftini*, and sugarcane yield parameters. This study is important because it demonstrates how an alternative to a polluting leaf removal method affects soil nutrition, associated changes in sugarcane nutrient uptake and assimilation, and the effects of nutrient uptake and leaf detritus on infestation of sugarcane by *E. loftini*.

## Materials and methods

### Study site and treatments

The study occurred at the United States Department of Agriculture – Agricultural Research Service's laboratory in Weslaco, Hidalgo Co., Texas, from 6 Oct 2009 (planting) to 2 Nov 2011 (second-year harvest). The area, on Hidalgo sandy clay loam, was divided into 30 plots, each plot six rows (1.52-m row spacing) wide by 20 m long, arranged into six blocks, each block comprised of five plots. Blocks were separated from one another by ≈3 m of bare ground. Each block had a plot where sugarcane greenchop was left (during the first year, greenchop was brought in from a harvested sugarcane field elsewhere and manually spread on the soil surface as a mulch in each of the three greenchop treatments) in early Dec 2009 and 2010. The three greenchop treatments were: greenchop left on the soil surface, greenchop tractor-tilled into the soil up to 30 cm deep on 21 Jan 2010 and 14 Jan 2011, and, on the same dates, greenchop sprayed to runoff with 100 L of compost extract immediately before soil incorporation. The compost extract was obtained by extracting 50 g of compost per 3.8 L water for 3 h; the process was completed 2 h before the extract was sprayed, using a hand-held Greenlawn hand-pumped sprayer (Gilmour, Peoria, Illinois, USA) on the corresponding treatment. A 0.25 $m^2$ metal quadrat thrown in each mulched plot was used for collecting and weighing the sugarcane leaf residue within. Mulch depth was measured at two randomly selected locations within each plot. The fourth treatment in each block had ≈227 kg of composted sugar mill mud, fly ash, and bottom ash from the mill fire box, and yard waste (Natural Solutions, Mission, Texas) rototilled into the top 30 cm of soil on 4 March 2009 (8 mo before sugarcane was planted), and the fifth treatment was a non-treated control. One kg of the compost was sent to the Texas Plant and Soil Lab (Edinburg, Texas) for analysis of N, P, K, Na, Mg, Zn, Fe, Mn, Cu, B, S, and organic matter content. Sugarcane (var. CP70-321), stalks were planted 6 Oct 2009. All of the plots were side-dressed by tractor-pulled knives on 4 Mar 2010 and 19 Jan 2011 with nitrogen fertilizer at 282 L/ha, providing 119 kg N/ha because sugarcane has a high N requirement. Furrows were flood irrigated on 14 Oct and 23 Nov 2009, and on 11 Mar and 6 May 2010; during the summer months, rainfall was sufficient without the need for flood irrigation. Irrigation was applied on 15 Dec 2010, and 22 Feb, 29 Mar, 29 Apr, 2 May, 9 Jun, 10 and 29 Aug, and 12 and 26 Sept 2011 during the second growing season. Weeds were hand-rogued throughout the growing season, and no pesticides were applied for control of insects and pathogens.

### Soil measurements

All samples used to determine sugarcane and insect injury to the crop were randomly taken from the four inner rows of each plot. Six soil probe samples, each 15 cm deep, were randomly collected and mixed from within each plot on 29 Oct and 28 Jul 2010, and on 20 Jan and 22 Jul 2011. The soil samples were analyzed at the Texas A&M AgriLife Extension Service Soil, Water and Forage Testing Laboratory (College Station, Texas) for conductivity (Rhoades 1982), pH (Schofield and Taylor 1955), nitrate (Keeney and Nelson 1982), P, K, Mg, Ca, Na, Zn, S, Cu, Fe, Mn (Lindsay and Norvell 1978, Mehlich 1978), and percentage organic matter (Storer

1984; McGeehan and Naylor 1988; Schulte and Hopkins 1996).

#### Sugarcane measurements

Six leaves from the topmost three fully expanded leaves, each leaf from a separate stalk, were collected from each plot on 27 Jul 2010 and on 22 Jul 2011, oven dried at 38 °C for 48 h, and delivered to the Texas A&M AgriLife Extension Service Soil, Water and Forage Testing Laboratory for quantifying N (%) (Nelson and Sommers 1973; Sheldrick 1986; McGeehan and Naylor 1988; Sweeney 1989), P, K, Ca, Mg, Na, Zn, Fe, Cu, and Mn (Isaac and Johnson 1975, Mavlin and Soltanpour 1989). On 3 Mar 2010, sugarcane stools were counted along two 3-m-long randomly selected sections of row per plot, and on 28 Oct 2010, 24 Feb and 27 Oct 2011 stools, mature sugarcane stalks, "watersprouts" (newly-forming stalks at the base of the stools), were counted. Stalks were not counted until the end of the first season due to initial uneven stalk emergence, and 2009 and 2011 winter freezes caused initial dieback of some young sprouts. Dry leaves were counted on five stalks in each plot on 21 Jul 2010 and 25 Jul 2011. Leaves were considered to be dry when 50% of the leaf was dead and brittle. Photosynthetic leaf activity was determine using the third uppermost fully expanded leaf on five sugarcane plants in each plot with a chlorophyll meter (SPAD-502, Konica Minolta, Plainfield, Illinois) on 21 Jul 2010 and 16 Jul 2011. Percent brix measurements were taken from the 4th internode from the bottom of each of three stalks in each plot on 5 Nov 2010 and 3 Nov 2011 using a digital PDX-95 refractometer (VEE GEE Scientific, Kirkland, Washington). On 9 Nov and 2 Nov 2011, 15 stalks per plot were cut at the basal internode, stripped of leaves, and the weight of each 15-stalk sample was recorded as well as numbers of internodes and stalk lengths.

On 21 Jul 2010 and 23 Jul 2011, three fully developed uppermost leaves, each from a separate stalk within the same plot, were excised and promptly placed in dry ice until storage at − 80 °C 5 min later. The single leaf sample from each plot was mashed into powder with mortar and pestle, kept frozen using liquid nitrogen, which assisted with grinding. A gram of ground leaf material was homogenized using 10 ml of 0.1 N HCl in a Virtishear homogenizer (Virtis, Gardiner, New York). Five grams of homogenate from the different samples were placed in separate 10-ml tubes then centrifuged for 30 min at 10,000 rpm. A ml supernatant aliquot from each sample was pushed through a 0.5-µm filter in a 5-ml syringe. Samples were analyzed for free amino acid concentrations using a reversed-phase high-performance liquid chromatograph (HPLC) (1100 Series Agilent Technologies, Atlanta, Georgia). The binary pump delivered solvent A [500 ml purified HPLC grade water + 1.36 g sodium acetate trihydrate + 90 µl triethylamine + sufficient acetic acid to adjust pH to 7.2] and solvent B [100 ml purified HPLC grade water + 1.36 g sodium acetate trihydrate + (acetic acid used to adjust pH to 7.2) 200 ml methanol + 200 ml acetonitrile] at 100 and 1.0 ml/min using a Zorbax Eclipse AAA4.6 × 150 mm 3.5 µ Agilent Technologies column. Absorbances, 262 and 338 nm, were monitored for 26 min/sample with a variable wavelength detector. The HPLC's autosampler mixed 6 µl sodium borate buffer (0.4 N, 10.2 pH in water), and 1 µl ophthalaldehyde derivitizing and 1 µl 9-fluorenylmethylchloroformate agents + 2 µl of sample, and injected 2 µl of the mixture for chromatographic separation of free amino acids. Quantification of 17 derivitized free amino acids (aspartic acid, glycine, histidine, leucine, lysine, arginine, methionine, phenylalanine, cysteine, proline, serine, isoleucine, threonine, alanine, valine, tyrosine, glutamic acid, and tyrosine) was accomplished through calibration using a standard amino acid mixture. Agilent software was used to enhance manual determination of peak integration accuracy.

Three whole leaf samples for soluble sugar analysis were collected on 21 Jul 2010 from each plot, and the three leaves were pooled within each plot. Samples were kept on dry ice for 5 min until placed in a − 80° C freezer. The samples, for 48 h, were lyophilized and thoroughly macerated in a Wiley grinding mill (Thomas Scientific, Swedesboro, New Jersey, Model 4, mesh size 20). Extraction of soluble sugars from samples that were freeze-dried by creating a suspension from 0.5 g of sample in 5 ml of 80% ethanol at 80 °C, then homogenized using a Polytron PT10-35 homogenizer (Kinematica AG USA, Bohemia, New York). After incubation for 5 min, 80 °C, the samples were filtered and the extract tubes were rinsed using 2 ml hot 80% ethanol added onto the filter. Each filtrate diminished to 0.5 ml under nitrogen, then reconstituted to 1 ml using distilled water. Twenty µl of extract per sample was run through an Agilent 1100 Series RDIdetector programmed to 55 °C and a 280 nm wavelength using a 300 × 7.8 mm Bio Rad Aminex HPX 87C (Bio-Rad, Hercules, California) for carbohydrate analysis at 80 °C and a Milton Roy ConstaMetric III pump (LDC Analytical, Riviera Beach, Florida) using a 0.5 ml/min flow rate. We used distilled water that had been sparged with He for an hour prior. Two- to 20-fold extract dilutions were prepared to enhance the accuracy of peak integration. Fructose, glucose, and sucrose retention times were compared to sugar standards (Sigma, St. Louis, Missouri) for preparing curves to determine concentrations (mg/ml) of extract sugars from which mg/g dry weight was calculated. The freeze-dried sugar samples collected in 2011 were analyzed before grinding them in a Wiley

mini-mill fitted with a 20-mesh screen; 0.26 g of ground leaf tissue was extracted using 2 ml of 80% (v/v) aqueous ethanol, held at 60 °C for an hour, then centrifuged for 15 min, 450 × g. Supernatants were decanted and extraction was repeated two more times. The resulting residues were passed through a Whatman GF-A glass fiber filter. The extracts were combined, and concentrations of fructose, glucose, and sucrose determined by high pressure ion chromatography using a Dionex CarboPac 20 guard in tandem wtih analytical columns using 50 mM of KOH eluent. Each of the three sugars were found with a pulsed aperometric detector, concentrations determined by comparing against standards.

### Stalk borer injury

Numbers of *E. loftini* entry and exit holes, and injured internodes were recorded for 15 stalks per plot. Injured internodes were determined by longitudinally slicing internodes using a knife to observe presence or absence of *E. loftini* larval tunneling.

### Statistical analyses

Treatment differences were detected using two-way ANOVA with treatment and block effects, and treatment × block interaction; means were separated by Tukey's honestly significant differences (Analytical Software 2008). Homogeneity and normality assumptions were observed, hence, data did not undergo transformation. Percentages were arcsine-square root-transformed for ANOVA. Where treatment differences were not detected, means and standard errors were calculated using pooled data from all of the plots.

## Results

### Soil measurements

The compost contained 26.3% organic matter with an 11.8:1 C:N ratio, and concentrations of each tested constituent were determined (Table 1). Greenchop on the soil surface in December 2009 and 2010 weighed 1.45 ± 0.04 and 1.53 ± 0.04 kg/m$^2$, respectively, and the mulch layer was 11.3 ± 1.0 and 12.6 ± 0.9 cm thick in December of each respective year.

Soil analysis of samples collected early in the growing season, before application of the greenchop treatments and in July of both years, when sugarcane stalks had grown > 1.5 m tall, did not detect treatment differences for pH and conductivity (a measure of salinity) (Table 2). Percentage organic matter was 1.4- to 1.7-fold greater in the compost treatment than in the other treatments and the control on the two sampling dates of each year (Table 2).

The early season (October) soil samples for the first year had greater percentage nitrate–N and ppm P, K, Ca, Mg, and Zn by ≥ 1.9-, ≥ 4.6-, ≥ 1.2-, ≥ 1.3-, ≥ 1.1-, and ≥ 2.3-fold, respectively, in the compost treatment than in any of the greenchop treatments and the control, and by mid season (July), P, K, S, MG, and Zn were ≥ 5.1-, ≥ 1.1-, ≥ 1.7-, ≥ 1.1-, and ≥ 3.5-fold more abundant in the compost treatment (Table 2). By mid season, Ca was more concentrated in the compost treatment only in relation to the compost extract-treated soil-incorporated greenchop treatment, by 1.5-fold (Table 2). During the second year, treatment effects were not detected for nitrate–N, K, Na, Fe, and Mn, but the compost treatment had ≥ 6.1-, ≥ 1.3-, and ≥ twofold more P, Ca, and Zn than the other treatments, and Mg, S, and Cu were ≥ 1.1-, ≥ 2.1-, and ≥ 1.3-fold more abundant only in the mid-season soil samples (Table 2).

**Table 1** Selected constituents of the compost based on dry weight

| *Constituent* | *Quantity* |
|---|---|
| %N | 1.1 |
| Nitrate, ppm | 3320 |
| % P | 2.0 |
| % K | 1.1 |
| % Na | 0.2 |
| % Ca | 4.9 |
| % Mg | 0.6 |
| Zn, ppm | 265 |
| Fe, ppm | 11,600 |
| Cu, ppm | 65 |
| % S | 0.2 |
| Mn, ppm | 484 |

### Sugarcane measurements

Sugarcane stools on 3 Mar 2010 and on 2 Nov 2010 averaged 4.6 ± 0.2 and 4.7 ± 0.3 per 3 m of row, and were not affected by the treatments. Similarly, treatment effects were not detected for numbers of mature stalks and water sprouts on 28 Oct 2010, averaging 42.9 ± 2.9 and 15.0 ± 1.9, respectively, per 3 m of row. Dry leaves averaged 4.2 ± 0.2 and 4.4 ± 0.3 per stalk on 21 Jul 2010 and 25 Jul 2011, respectively, without differences between treatments.

Leaf photosynthetic activity also did not differ between treatments on 21 Jul 2010 and on 24 Jul 2011, averaging 41.9 ± 1.4 and 42.1 ± 1.3 SPAD units, respectively. Analysis of leaf tissue samples taken on 27 Jul 2010 and 22 Jul 2011 did not detect treatment differences for any of the nutrients measured. Of the 17 detectable free amino acids, we found 14 in our sugarcane samples,; none of them were affected by the treatments in 2010, but in 2011, free histidine and free lysine were 57.4–93.3% and

**Table 2** Mean (± SE) concentrations of nutrients in sugarcane (before and during the two growing seasons) soil amended with compost, and greenchop that was mulched, soil incorporated, and sprayed with compost extract before soil incorporation, and a non-amended control, based on 15 stalks/plot ($n = 6$ plots), Hidalgo Co., Texas, 2009–2011 ($n = 6$ replications); significant differences ($P < 0.05$) are given in bold.

| Treatment[a] | Sampling date[b] | Nitrate N (ppm) | P (ppm) | K (ppm) | Ca (ppm) | Mg (ppm) | S (ppm) | Na (ppm) | Fe (ppm) | Zn (ppm) | Mn (ppm) | Cu (ppm) | % organic matter |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Control | Oct 2009 | 7 ± 1 b | 65 ± 4 b | 402 ± 18 b | 1737 ± 100 b | 305 ± 19 b | 22 ± 3 | 124 ± 22 | 7 ± 0.3 | 0.6 ± 0.1 b | 10 ± 1 | 0.7 ± 0.1 | 0.7 ± 0.2 b[b] |
| Compost | | 19 ± 3 a | 296 ± 58 a | 478 ± 14 a | 2403 ± 234 a | 368 ± 20 a | 28 ± 4 | 138 ± 18 | 7 ± 0.6 | 1.4 ± 0.2 a | 12 ± 1 | 0.9 ± 0.1 | 1.0 ± 0.1 a |
| Gchop mulch | | 6 ± 1 b | 60 ± 4 b | 408 ± 8 b | 1712 ± 92 b | 326 ± 16 b | 20 ± 2 | 100 ± 10 | 8 ± 0.6 | 0.5 ± 0.1 b | 10 ± 1 | 0.8 ± 0.1 | 0.7 ± 0.1 b |
| Gchop incorp | | 8 ± 1 b | 57 ± 2 b | 403 ± 24 b | 1882 ± 175 b | 299 ± 23 b | 22 ± 3 | 129 ± 23 | 7 ± 0.5 | 0.5 ± 0.1 b | 10 ± 1 | 0.8 ± 0.1 | 0.6 ± 0 b |
| Gchop + tea incorp | | 10 ± 2 b | 57 ± 4 b | 403 ± 18 b | 1718 ± 149 b | 309 ± 24 b | 20 ± 2 | 105 ± 9 | 8 ± 0.4 | 0.6 ± 0.1 b | 11 ± 1 | 0.8 ± 0.1 | 0.7 ± 0.1 b |
| *F*[c] | | 12.18 | 15.50 | 2.99 | 5.83 | 3.78 | 2.67 | 2.82 | 1.24 | 11.81 | 2.14 | 2.55 | 4.88 |
| *P* | | **< 0.0001** | **< 0.0001** | **0.0438** | **0.0028** | **0.0191** | 0.0619 | 0.0524 | 0.3263 | **< 0.0001** | 0.1129 | 0.0712 | **0.0065** |
| Control | Jul 2010 | 3 ± 0.7 | 73 ± 7 b | 373 ± 26 b | 1746 ± 95 ab | 318 ± 22 b | 6 ± 1 b | 62 ± 13 | 5 ± 0.3 | 0.4 ± 0.1 b | 4 ± 1 | 0.6 ± 0.1 | 0.6 ± 0.1 b |
| Compost | | 3 ± 0.5 | 374 ± 55 a | 438 ± 32 a | 2644 ± 251 a | 381 ± 25 a | 12 ± 1 a | 66 ± 9 | 6 ± 0.5 | 1.4 ± 0.2 a | 4 ± 1 | 0.7 ± 0.1 | 1.1 ± 0.1 a |
| Gchop mulch | | 3 ± 0.6 | 69 ± 4 b | 374 ± 24 b | 1706 ± 83 ab | 335 ± 21 b | 6 ± 1 b | 67 ± 14 | 5 ± 0.9 | 0.4 ± 0.1b | 4 ± 1 | 0.7 ± 0.1 | 0.7 ± 0.1 b |
| Gchop incorp | | 3 ± 0.7 | 69 ± 4 b | 393 ± 33 b | 1914 ± 157 ab | 326 ± 35 b | 7 ± 1 b | 64 ± 11 | 5 ± 0.4 | 0.4 ± 0.1 b | 4 ± 1 | 0.6 ± 0.1 | 0.8 ± 0.1 b |
| Gchop + tea incorp | | 2 ± 0.6 | 66 ± 6 b | 352 ± 30 b | 1739 ± 167 b | 316 ± 30 b | 6 ± 1 b | 73 ± 15 | 5 ± 0.5 | 0.4 ± 0.1 b | 4 ± 1 | 0.6 ± 0.1 | 0.7 ± 0.1 b |
| *F*[c] | | 2.62 | 12.06 | 29.54 | 3.45 | 3.63 | 23.8 | 0.41 | 0.93 | 21.16 | 1.41 | 2.25 | 9.74 |
| *P* | | 0.0660 | **< 0.0001** | **< 0.0001** | **0.0268** | **0.0221** | **< 0.0001** | 0.7982 | 0.4648 | **< 0.0001** | 0.2671 | 0.0999 | **0.0002** |
| Control | Jan 2011 | 1 ± 0.2 | 76 ± 5 b | 425 ± 28 | 1186 ± 117 b | 340 ± 20 | 41 ± 2 | 109 ± 11 | 6 ± 0.2 | 0.5 ± 0.1 b | 5 ± 1 | 0.7 ± 0.1 | 0.6 ± 0.1 b |
| Compost | | 2 ± 0.8 | 346 ± 29 a | 346 ± 25 | 2.542 ± 243 a | 370 ± 22 | 46 ± 4 | 120 ± 5 | 6 ± 0.5 | 1.0 ± 0.1 a | 5 ± 1 | 0.7 ± 0.1 | 1.1 ± 0.1 a |
| Gchop mulch | | 1 ± 0.1 | 62 ± 4 b | 411 ± 20 | 1900 ± 181 b | 348 ± 19 | 35 ± 5 | 105 ± 5 | 7 ± 0.5 | 0.4 ± 0.1 b | 5 ± 1 | 0.8 ± 0.1 | 0.7 ± 0.1 b |
| Gchop incorp | | 1 ± 0.2 | 68 ± 4 b | 430 ± 16 | 1960 ± 136 b | 325 ± 20 | 33 ± 3 | 104 ± 9 | 5 ± 0.3 | 0.3 ± 0.1 b | 4 ± 1 | 0.6 ± 0.1 | 0.7 ± 0.1 b |
| Gchop + tea incorp | | 1 ± 0.2 | 67 ± 5 b | 434 ± 28 | 1850 ± 115 b | 342 ± 27 | 37 ± 4 | 117 ± 7 | 6 ± 0.5 | 0.4 ± 0.1 b | 4 ± 1 | 0.7 ± 0.1 | 0.7 ± 0.1 b |
| *F*[c] | | 1.16 | 83.59 | 0.48 | 2.91 ± | 0.91 | 2.16 | 0.95 | 1.28 | 10.05 | 1.00 | 1.00 | 5.85 |
| *P* | | 0.3570 | **< 0.0001** | 0.7508 | **0.0475** | 0.4777 | 0.1112 | 0.4585 | 0.3126 | **0.0001** | 0.4291 | 0.4291 | **0.0028** |
| Control | Jul 2011 | 1 ± 0.2 | 66 ± 7 b | 443 ± 11 | 1692 ± 105 b | 334 ± 25 b | 8 ± 2 b | 57 ± 9 | 6 ± 0.3 | 0.4 ± 0.1 b | 5 ± 1 | 0.6 ± 0.1 b | 0.6 ± 0.5 b |
| Compost | | 1 ± 0.2 | 422 ± 50 a | 502 ± 12 | 2580 ± 195 a | 386 ± 29 a | 17 ± 2 a | 74 ± 6 | 7 ± 0.5 | 1.6 ± 0.2 a | 6 ± 1 | 0.8 ± 0.1 a | 1.3 ± 0.1 a |
| Gchop mulch | | 1 ± 0.3 | 60 ± 6 b | 443 ± 15 | 1600 ± 134 b | 340 ± 30 b | 7 ± 1 b | 64 ± 7 | 7 ± 0.2 | 0.7 ± 0.1 b | 8 ± 1 | 0.6 ± 0.1 b | 0.8 ± 0.1 b |
| Gchop incorp | | 1 ± 0.2 | 65 ± 6 b | 434 ± 34 | 1829 ± 138 b | 340 ± 26 b | 7 ± 1 b | 57 ± 8 | 6 ± 0.4 | 0.4 ± 0.1 b | 6 ± 1 | 0.6 ± 0.1 b | 0.7 ± 0.1 b |
| Gchop + tea incorp | | 1 ± 0.2 | 69 ± 6 b | 463 ± 22 | 1679 ± 146 b | 327 ± 146 b | 7 ± 1 b | 65 ± 6 | 6 ± 0.4 | 0.5 ± 0.1b | 6 ± 1 | 0.6 ± 0.1 b | 0.8 ± 0.1 b |
| *F*[c] | | 1.50 | 50.95 | 1.75 | 13.50 | 4.08 | 9.15 | 1.18 | 2.79 | 20.46 | 1.51 | 21.74 | 16.08 |
| *P* | | 0.2412 | **< 0.0001** | 0.1784 | **< 0.0001** | **0.0140** | **0.0002** | 0.3507 | 0.0544 | **< 0.0001** | 0.2359 | **< 0.0001** | **< 0.0001** |

Means in the same column and within the same sampling date followed by different letters are different ($P > 0.05$, Tukey's HSD)

[a] Control, no amendments; compost, compost soil incorporated; gchop mulch, greenchop left on soil surface; gchop incorp., greenchop soil incorporated; gchop + tea incorp., greenchop sprayed with compost tea then immediately soil incorporated

[b] 26 October 2009, 29 July 2010, 12 January and 22 July 2011

[c] df = 4, 29

**Table 3** Mean (± SE) concentrations of selected free amino acids in sugarcane leaf tissue (nanomoles/10 µl) from field plots amended with compost (605 kg/0.11-ha plot), greenchop mulch, greenchop that was soil-incorporated, and greenchop that was sprayed with compost tea then soil incorporated, and from control plots (all treatments received 119 kg/ha N fertilizer), Hidalgo Co. Texas, 2010 and 2011 (n = 6 replicates); free amino acids are given in bold were significantly ($P < 0.05$) affected

| Free amino acids[a] | Year[b] | Treatment | | | | | F[c] | P |
|---|---|---|---|---|---|---|---|---|
| | | Control | Compost | Greenchop mulch | Greenchop soil incorporated | Greenchop + compost tea soil incorporated | | |
| Alanine | 2010 | 622 ± 82 | 562 ± 95 | 564 ± 129 | 618 ± 73 | 635 ± 82 | 0.13 | 0.9707 |
| Arginine | | 194 ± 20 | 183 ± 18 | 167 ± 16 | 184 ± 28 | 198 ± 16 | 0.39 | 0.8147 |
| Aspartic acid | | 492 ± 61 | 463 ± 47 | 420 ± 56 | 428 ± 69 | 453 ± 66 | 0.37 | 0.8270 |
| Glutamic acid | | 651 ± 52 | 653 ± 75 | 632 ± 88 | 610 ± 85 | 615 ± 84 | 0.10 | 0.9827 |
| Glycine | | 99 ± 32 | 179 ± 59 | 218 ± 38 | 134 ± 31 | 166 ± 27 | 1.48 | 0.2465 |
| Histidine | | 210 ± 24 | 178 ± 19 | 155 ± 23 | 174 ± 21 | 184 ± 17 | 1.15 | 0.3602 |
| Isoleucine | | 54 ± 18 | 38 ± 18 | 61 ± 23 | 48 ± 22 | 31 ± 20 | 0.42 | 0.7915 |
| Leucine | | 117 ± 17 | 114 ± 15 | 134 ± 20 | 114 ± 16 | 116 ± 15 | 0.34 | 0.8446 |
| Lysine | | 33 ± 15 | 27 ± 13 | 47 ± 10 | 30 ± 19 | 43 ± 15 | 0.58 | 0.6827 |
| Methionine | | 0 | 0 | 0 | 0 | 0 | – | – |
| Phenylalanine | | 25 ± 16 | 20 ± 20 | 34 ± 15 | 21 ± 13 | 17 ± 17 | 0.25 | 0.9081 |
| Proline | | 0 | 0 | 0 | 0 | 0 | – | – |
| Serine | | 348 ± 68 | 336 ± 98 | 361 ± 67 | 234 ± 56 | 302 ± 72 | 0.90 | 0.4843 |
| Threonine | | 351 ± 36 | 289 ± 33 | 292 ± 21 | 278 ± 38 | 325 ± 72 | 2.52 | 0.0737 |
| Tyrosine | | 114 ± 27 | 148 ± 17 | 137 ± 12 | 130 ± 13 | 141 ± 20 | 0.42 | 0.7905 |
| Valine | | 159 ± 26 | 124 ± 19 | 148 ± 17 | 135 ± 22 | 142 ± 25 | 0.52 | 0.7200 |
| Free essentials[d] | | 1141 ± 145 | 974 ± 143 | 1,038 ± 118 | 984 ± 160 | 1057 ± 131 | 0.39 | 0.8109 |
| Total | | 3468 ± 296 | 3317 ± 377 | 3372 ± 300 | 3139 ± 465 | 3369 ± 434 | 0.20 | 0.9339 |
| Alanine | 2011 | 583 ± 78 | 603 ± 88 | 579 ± 102 | 631 ± 97 | 649 ± 125 | 1.49 | 0.2388 |
| Arginine | | 209 ± 23 | 207 ± 20 | 216 ± 18 | 204 ± 17 | 226 ± 21 | 0.52 | 0.7263 |
| Aspartic acid | | 438 ± 55 | 422 ± 47 | 401 ± 41 | 431 ± 62 | 429 ± 53 | 0.39 | 0.8145 |
| Glutamic acid | | 722 ± 98 | 693 ± 84 | 736 ± 102 | 717 ± 79 | 728 ± 82 | 0.73 | 0.5811 |
| Glycine | | 151 ± 35 | 189 ± 47 | 173 ± 37 | 199 ± 44 | 165 ± 38 | 1.13 | 0.2663 |
| **Histidine** | | 183 ± 26 b | 288 ± 33 a | 179 ± 22 b | 162 ± 26 b | 149 ± 21 b | 16.44 | < 0.0001 |
| Isoleucine | | 63 ± 25 | 59 ± 22 | 67 ± 22 | 71 ± 25 | 71 ± 23 | 0.23 | 0.9174 |
| Leucine | | 129 ± 16 | 114 ± 21 | 121 ± 18 | 130 ± 14 | 118 ± 13 | 0.55 | 0.7323 |
| **Lysine** | | 26 ± 9 b | 71 ± 11 a | 24 ± 8 b | 21 ± 8 b | 30 ± 8 b | 28.63 | < 0.0001 |
| Methionine | | 0 | 0 | 0 | 0 | 0 | – | – |
| Phenylalanine | | 17 ± 7 | 12 ± 5 | 18 ± 6 | 13 ± 4 | 19 ± 6 | 0.21 | 0.9226 |
| Proline | | 21 ± 4 | 17 ± 4 | 23 ± 5 | 16 ± 3 | 20 ± 4 | 0.62 | 0.6596 |
| Serine | | 313 ± 54 | 286 ± 51 | 324 ± 61 | 316 ± 58 | 301 ± 50 | 1.01 | 0.4281 |
| Threonine | | 275 ± 39 | 302 ± 48 | 286 ± 36 | 289 ± 40 | 308 ± 46 | 1.25 | 0.3226 |
| Tyrosine | | 137 ± 18 | 145 ± 14 | 132 ± 16 | 137 ± 14 | 151 ± 20 | 0.47 | 0.7518 |
| Valine | | 144 ± 19 | 153 ± 18 | 139 ± 16 | 155 ± 16 | 149 ± 16 | 0.44 | 0.7693 |
| Free essentials[d] | | 1046 ± 139 | 1206 ± 127 | 1050 ± 119 | 1045 ± 144 | 1070 ± 147 | 0.23 | 0.9136 |
| Total | | 3411 ± 288 | 3561 ± 406 | 3418 ± 381 | 3492 ± 352 | 3513 ± 337 | 0.18 | 0.9314 |

Means followed by different letters are significantly different ($P < 0.05$, two-way ANOVA, Tukey's HSD)

[a] Cystine was detectable but not found in the samples; methionine and proline were also not detected, but they are included in this table because methionine is an essential amino acid, and proline levels are indicative of drought stress

[b] 21 July 2010 and 23 July 2011

[c] df = 4, 29

[d] Total amounts of free arginine, histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, and valine

136.7–238.1%, respectively, more abundant in the compost treatment than in any of the other treatments and the control (Table 3). Analysis of sugars in leaf tissue did not detect treatment differences during 2010; pooled concentrations were 1.39 ± 0.14 mg of glucose per g dry leaf tissue, 0.40 ± 0.03 of fructose, and 20.45 ± 2.27 of sucrose. In 2011, pooled concentrations of glucose and sucrose were 1.41 ± 0.23 and 19.81 ± 1.63, respectively, but fructose was ≥ twofold more abundant in the compost treatment than in any of the other treatments and the control (pooled 0.40 ± 0.03) ($F = 5.89$, df = 4, 29, $P = 0.0027$).

At harvest, treatment differences were not found for stalk weights during 2010, averaging 15.1 ± 0.7 kg and 16.1 ± 1,3 kg per bundle of 15 stalks in 2010 and 2011, respectively. Stalk lengths, averaging 225.1 ± 8.5 cm, were not affected by the treatments in 2010, but in 2011, stalks in the greenchop + compost extract treatment were 1.2-fold longer than in the compost treatment ($F = 4.78$, df = 4, 29, $P = 0.0072$) and numbers of internodes per stalk, averaging 17.6 ± 0.5 and 16.5 ± 0.6, were not affected by the treatments in 2010 and 2011, respectively, nor was percentage brix, which averaged 20.3 ± 0.6 in 2010 and 18.9 ± 0.6 in 2011.

### Stalk borer injury

The harvested sugarcane stalks in 2010 had 2.6-, 2.3-, and 2.8-fold more *E. loftini* entry holes per stalk in the compost, greenchop mulch, and soil-incorporated greenchop treatments, respectively, than in the control ($F = 4.36$, df = 4, 29, $P = 0.0107$), but no differences were detected involving the compost extract-sprayed, soil-incorporated greenchop treatment, nor were treatment effects found for numbers of adult *E. loftini* exit holes per stalk (Fig. 1A). In 2011, entry holes were ≥ fourfold more numerous in the compost treatment than any other treatment and the control ($F = 43.10$, df = 4, 29, $P < 0.0001$) (Fig. 1B). Percentages of *E. loftini*-injured internodes per stalk in 2010 were 2.8-, 2.3-, 2.6-, and 2.1-fold higher in the compost, greenchop mulch, and soil-incorporated and compost extract-sprayed, soil-incorporated greenchop treatments, respectively, than in the control ($F = 3.93$, df = 4, 29, $P = 0.0164$) (Fig. 2). In 2011, the percentage of bored internodes was ≥ 2.4-fold greater in the compost treatment than in greenchop-treated plots and the control ($F = 32.25$, df = 4, 29, $P < 0.0001$) (Fig. 2). Percentages of *E. loftini*-injured stalks were 1.6-, 1.6-, and 1.4-fold greater in the compost, and in the soil-incorporated and compost extract-sprayed, soil-incorporated greenchop treatments, respectively, than in the control ($F = 3.94$, df = 4, 29, $P = 0.0162$), but differences with the greenchop mulch treatment were not detected (Fig. 3). In 2011, all of the stalks were injured where compost was

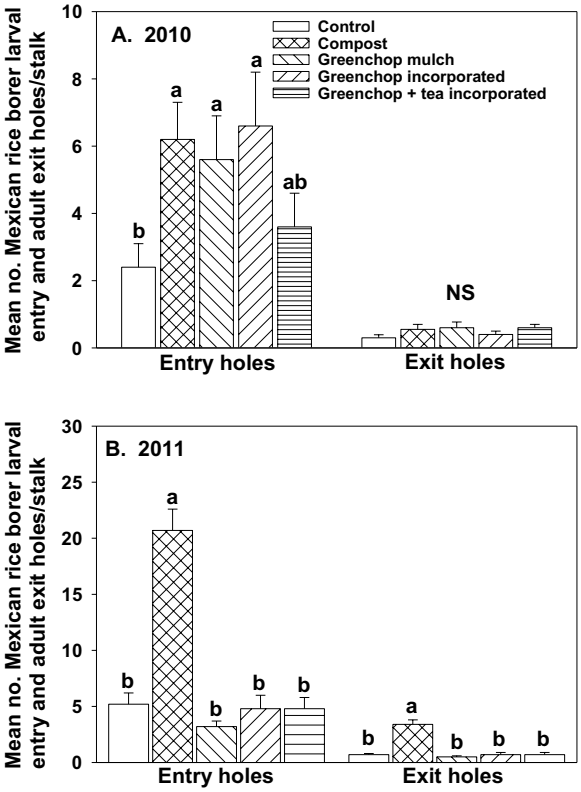


**Fig. 1** Mean (± SE) numbers of *E. loftini* entry and exit holes per stalk from field plot soil amended with compost, and greenchop that was mulched, soil incorporated, and sprayed with compost extract before soil incorporation, and a non-amended control, based on 15 stalks/plot ($n = 6$ plots), Hidalgo Co., Texas; A, 2010; B, 2011

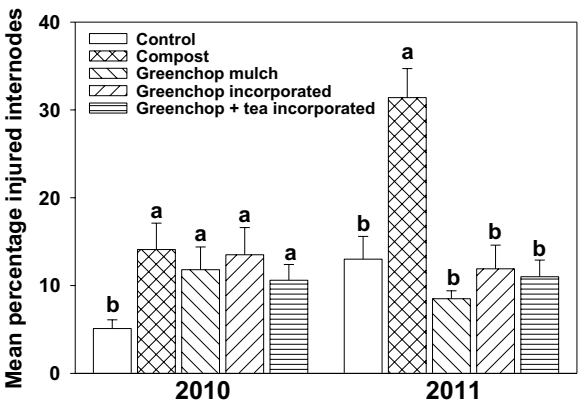


**Fig. 2** Mean (± SE) percentages of internodes per sugarcane stalk injured by *E. loftini* larval tunneling, based on 15 stalks/plot from field plot soil amended with compost, and greenchop that was mulched, soil incorporated, and sprayed with compost extract before soil incorporation, and a non-amended control, ($n = 6$ plots), Hidalgo Co., Texas; 2010, 2011

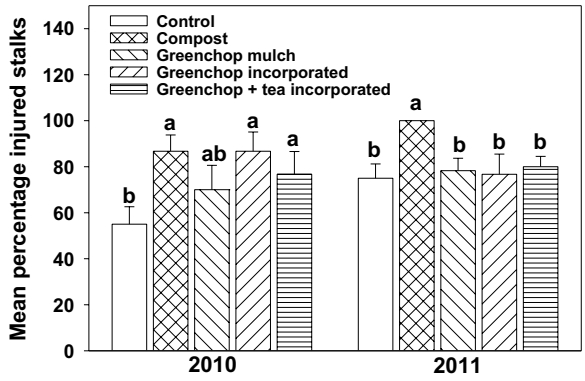


**Fig. 3** Mean (± SE) percentages of sugarcane stalks injured by *E. loftini* tunneling field plots with soil amended with compost, and greenchop that was mulched, soil incorporated, and sprayed with compost extract before soil incorporation, and a non-amended control, ($n = 6$ plots), Hidalgo Co., Texas; 2010, 2011

applied, ≥ 1.2-fold more than in the greenchop-treated plots and the control (Fig. 3).

## Discussion

Although a higher rate of the same compost in an earlier sugarcane study reduced soil pH and increased conductivity (Showler 2015), the rate used in our study did not affect those soil parameters. Compost-amended soil had the greatest amounts of available N, but midway through the growing season, available N was substantially depleted. Greenchop did not provide much measurable organic matter and N to the soil because it decomposes gradually; 19% of its initial mass remains after ≈11 mo (Spain and Hodgen 1994). Once mixed into the soil (Spain et al. 1990; Spain and Hodgen 1994), further decomposition for organic matter releases nutrients and, at a late stage, provides sites for N fixation (Patriquin 1982; Hill and Patriquin 1988), explaining why soil N levels take ≈75 d to increase (Spain and Hodgen 1994). The gradual decomposition of greenchop indicates that N and other nutrients accumulate to measurable levels after one or more seasons (Wood 1991; Ng et al. 1987; Yadav 1995; Graham and Haynes 2006). Soil incorporation of greenchop, and finely chopping or grinding the leaf residue, can eventually enhance degradation, soil ash content, nitrate–N, S, and water retention (Basanta et al. 2003; Hall et al. 2006). Compost-amended soil, on the other hand, is also enriched by P, K, Ca, Fe, Zn, and Mn (Stamatiadis et al. 1999; Showler 2015). Composts, however, can be made of many materials, and different composts can have different effects on soil nutrition and tilth, and on crop growth (Showler 2022).

The compost and the greenchop treatments did not increase numbers of harvestable sugarcane stalks (a three-fold rate of the same compost, however, heightened stalk production by ≈18.5% because N levels were ≥ 30% higher [Showler 2015]). Sugarcane growth does not strongly respond to substantial increases in levels of P (Kelley et al. 2001, 2005; Showler 2015) and in the P-rich compost-amended plots of the present study. The failure of most compost-associated nutrient (other than N) increases to improve yield parameters (e.g., stalk production, weight, length, and percentage brix) indicates that the principal nutritional factor for enhancing yield is available N (Weidenfield 1995; Baldani et al. 2002; Gopalasundaram et al. 2012; Otto et al. 2014; Yang et al. 2019).

While organic matter can retain soil moisture (Hudson 1994; Hall et al. 2006), and water availability results in relatively few dry sugarcane leaves on the plant (Showler and Castro 2010a), the absence of treatment differences in terms of numbers of dry leaves and relatively low free proline concentrations (elevated in sugarcane under conditions of water deficit [Reay-Jones et al. 2005, Showler and Castro 2010a]) suggest that the plants were not water deficit stressed because rainfall and irrigation were adequate when leaf tissue samples were collected (free amino acid concentrations in plants can change in response to changes in water availability within hours [Showler et al. 2007]). Quantities of dry leaves and drought-associated accumulations of free amino acids are both associated with *E. loftini* oviposition preference (Showler and Castro 2010a,b), hence, the greater numbers of larval entry holes, injured internodes per sugarcane stalk, and injured stalks in the greenchop treated plots during the first growing season, and in the compost treatment during both seasons, than in the control were elicited by factors other than water deficit.

Host plant selection among lepidopterans, including stalk borers, involves visual (Renwicke and Radke 1988, Renwicke and Chew 1994, Showler and Castro 2010b) and chemical cues (Munakata and Okamoto 1967; Saito and Munakata 1970; Schur and Holdaway 1970; Waladde 1983; Udayagiri and Mason 1995; Showler 2001). Various weed and crop host plant species exhibit different degrees of attractiveness to *E. loftini* in positive association with accumulations of free histidine and fructose (Showler and Moran 2014). Nitrogen concentration in foliage is a determinant of neonate *E. loftini* performance (Mattson 1980; Showler 2001; Showler and Moran 2003; Moran and Showler 2005; Chen et al. 2008), and the eldana borer inflicts more damage to sugarcane where soil N is abundant (Nuss and Atkinson 1983; Atkinson and Nuss 1989; Turner et al. 1991). Moderately higher amounts of available soil N in the compost-amended treatment were not reflected by leaf tissue N, free amino acids, and sugars (e.g., fructose [Showler and Moran 2014]). Free amino

acid concentrations were unaffected by the treatments and therefore did not underlie the heightened *E. loftini* injury to sugarcane observed in the 2010 growing season, but in 2011 elevated levels of free histidine and lysine in the compost treatment were associated with greater *E. loftini* injury. Because of the association of sugarcane free amino acid accumulations with the compost, *E. loftini* injury levels were likely mediated by soil fertility particularly during 2011 (Showler 2015).

*Eoreuma loftini* is attracted to dry folded host plant leaf tissue for ovipositing (Showler and Castro 2010a,b). Greenchop, as opposed to compost, is comprised of dry sugarcane leaf tissue which might of itself attract *E. loftini* (Showler and Castro 2010b). It is possible that *E. loftini* inflicted more injury to sugarcane in the greenchop-amended plots during the first growing season than in the second because the dry leaf material might have attracted the pest into those plots. The relatively low damage to sugarcane in the second-season greenchop treatments, however, suggests that attraction to leaf residue is not as important as compost-mediated changes to host plant nutritional quality.

In regions where *E. loftini* does not occur, compost increases sugarcane yield parameters, including sugar content (Turner et al. 1991; Chudhry and Ullah 2001; Graham and Haynes 2005). In South Texas, however, advantages to the addition of compost are offset by associated elevated injury from *E. loftini* (Showler 2015). The compost amendment, a one-time operation intended to last many years, cost ≈$1,500/ha in addition to other economic and logistical considerations. Expense can make amending soil with compost impractical, a problem largely avoided where greenchop is used. In addition to accelerating decomposition, soil incorporation of greenchop increases soil microbial biomass N and activity (Graham and Haynes 2005; Hall et al. 2006) in contrast to preharvest burning (Hemwong et al. 2008). Soil incorporation of greenchop before planting is not difficult, but for ratoons it is challenging because of established root systems, and incorporation into furrows is less efficient than on flat pre-bedded soil (Graham and Haynes 2006). Greenchop left as mulch is not associated with those technical obstacles and input costs, and in greenchop-mulched furrows, organic matter content and the microbial and physical status of the soil can improve (Graham and Haynes 2006).

Use of greenchop mulch in regions where *E. loftini* does not exist has resulted in sugarcane yield increases (Cumberbatch 1969; Yadav et al. 1986; Ball-Coelho et al. 1993) of up to 13.8% (Sandhu et al. 1980), as well as soil enrichment, reduced erosion, and conservation of soil moisture (Eavis and Cumberbatch 1977; Yadav et al. 1986; Spain et al. 1990; Wood 1991). Other benefits of greenchop mulch include reduction of weed growth by denying light penetration to the soil surface (Hall et al. 2006) and release of *trans*-ferulic, *cis*-ferulic, vanillic, and syringic acids which inhibit root growth of several weed species (Sampietro et al. 2006). Despite the greater injury to sugarcane stalks in all of the treatments than in the control during the first growing season, the lack of differences in adult exit holes indicates that greenchop and the compost treatment do not necessarily contribute to increased next generation populations of the next generation. The reason for the relatively low development to adulthood, however, is not clear. At a higher rate of the compost successive generations increase (Showler 2015). Disadvantages to greenchop mulching include inhibition of sugarcane tillering, yield reductions, and increased damage from the fall armyworm and sugarcane borer, *Diatraea saccharalis* F. (Kumar and Mihm 2002), in addition to the first growing season's elevated *E. loftini* infestation in the present study. As pre-harvest sugarcane leaf burning comes under further scrutiny because of environmental concerns, greenchop might become increasingly prevalent; hence, its contribution to enhancing crop productivity will require further study to maximize advantages and minimize negative aspects. Use of leaf residue is less environmentally polluting than burning it, and it poses lower risk from *E. loftini* infestations than where soil is augmented by high N amendments.

In summary, while the compost elevated concentrations of many macro- and micronutrients, especially P, Ca, and Zn (and % organic matter), in the soil, concentrations of the nutrients in the leaves were not affected. Only the free amino acides histidine and lysine were present in greater concentrations in sugarcane grown in compost-augmented plots. Sugarcane plant growth parameters were not consistently affected by the compost and greenchop treatments, indicating that greenchop was not detrimental to crop production. Incidence of *E. loftini* injury, however, was greater in the composted plots, demonstrating that greenchop is more benign than the compost in terms of that pest's incidence. This study shows that, while the compost increased some soil nutrients, it was also associated with greater *E. loftini* injury than the other treatments. Greenchop, in comparison, had no detrimental effects relative to the control, and use of greenchop should be considered more seriously in the United States (and other countries that still burn leaf residue) as an alternative to the polluting and soil-degrading pre-harvest burning method.

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**Author contributions**
ATS planned, conducted, and analyzed the study, interpreted the results, and wrote the manuscript. All authors read and approved the final manuscript.

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**Availability of data and materials**
All data generated or analyzed during this study are included in this published article.

## Declarations

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This article does not contain any studies involving humans and animals other than crop pests.

**Consent for publication**
Consent given.

**Competing interests**
The author declares that there was no conflict of interest.

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