Evaluation of the Use of Green Manure Soybean Grown in Rotation with Sugarcane in a Sub-tropical Environment

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ABSTRACT

Soybeans [Glycine max (L.) Merr] is the most commonly grown crop during the fallow period of sugarcane (Saccharum sp.) production cycles in Louisiana. The majority use of soybean in Louisiana sugarcane production systems is for harvest as a grain crop but it also has been used as a green manure crop for almost a century. The objective of a series of three experiments was to determine the influence of soybean green manure grown during the fallow period on the sugar and cane yields of plant-cane. A secondary objective was to associate the levels of soil nitrate (NO₃⁻-N) and ammonium (NH₄⁺-N) at fertilization time in the spring with plant cane yields following both a conventional fallow period and the incorporation of soybean manure grown immediately prior to planting the next cycle of sugarcane production. Treatments compared at experimental sites 1 and 2 included plant-cane grown both with and without N fertilizer after a conventional fallow period and plant-cane grown both with and without N fertilizer after the incorporation of soybean green manure. At experimental site 3 the effects of fallowing and soybean green manuring were evaluated using only N-fertilized plant-cane. Neither plant-cane yields (cane and sugar) nor theoretical recoverable sugar (TRS) levels were significantly affected by the addition of soybean biomass to the soil in the fall. Also, the additive effect of the combination of incorporation of green manure and additional fertilizer N did not result in higher plant-cane yield or TRS compared to the unfertilized plant-cane after fallow. While there were site differences for soil NH₄⁺-N and NO₃⁻-N concentrations, differences between treatments within sites for soil inorganic N levels were not significant except for NO₃⁻-N at site 3. It seems justified to conclude that soil N was not a limiting factor for plant-cane growth and development, as there was a slight tendency at two sites for the unfertilized plant-cane following a conventional fallow period, expected to be the least N-rich environment, to yield the highest. Failure of sugarcane to respond to applied N indicates the capability of the fallow period to make N readily available in quantities sufficient for plant-cane growth.

INTRODUCTION

The practice of growing soybeans during the fallow period between sugarcane production cycles dates to the early part of the 20th century in Louisiana, when soybean was grown for hay production or ploughed down as green manure (Arceneaux et al. 1932). With the more recent advent of glyphosate-resistant soybean, sugarcane growers aggressively embraced the opportunity for economic returns from the harvest of soybean as a cash crop (Griffin et al. 2006). Growers may also benefit from the “rotation effect”, which may include improvements in
organic matter, soil fertility and water-holding capacity and also may aid in the disruption of pest cycles and the reduction in soil erosion. The utilization of legumes in rotation with sugarcane in tropical growing regions has been investigated for the assignment of N credits (Garside and Bell 2001; Hemwong et al. 2009; Hue et al. 2000; Park et al. 2010; Shoko et al. 2009) and for providing a break in monoculture production for the avoidance of yield decline (Garside et. al. 2000; Pankhurst et al. 2003). The efficacy of utilizing legumes inter-row planted with sugarcane has also been evaluated in the tropics (de Resende et al. 2003). Similar field studies, however, for sub-tropical/temperate environments are uncommon. In Florida on sandy soil plant-cane produced higher yield following a green manure soybean crop than a fallow period (Gilbert et al. 2008). They suggested that a well-managed legume crop could provide fertilizer credits equivalent to the recommended fertilizer rates for plant-cane. Wiedenfeld (1998) studied the effects of previous crops on the response of sugarcane to N fertilization in the sub-tropical environment of Texas. He found that sugarcane following a grain soybean crop failed to respond to N fertilizer application. He also observed that residual N in the soil following grain soybean appeared to be less available for subsequent crops than for sorghum, corn and cotton.

In Louisiana, turning under a green manure soybean crop did not satisfy the N requirements of even the plant-cane crop of a multi-crop production cycle (Arceneaux 1943). He found that conventionally fertilized plant-cane consistently produced greater cane and sugar yield than did plant-cane benefitting from only incorporated soybean green manure. Golden (1982) concluded that plant-cane following a grain soybean crop required recommended rates of fertilizer nitrogen to achieve yield comparable to conventionally fertilized plant-cane. He also measured lower leaf nitrogen content for unfertilized plant-cane grown after soybean harvest. White et al. (2011), however, concluded from studies with harvested soybeans grown during the fallow period in Louisiana that the legume did not reduce cane yield, TRS, or sugar yield. They also calculated the half-life of soybean residue to be 75 days, based on a first order carbon mineralization model (Gilmore et al. 1998). They stated that it is plausible that synchrony would not exist between sugarcane demand for N in the spring and N release from incorporated grain soybean residue the previous fall/winter.

The primary objective of these experiments was to determine the influence of soybean grown as a green manure (no grain harvest) during the fallow period on the sugar and cane yield of plant-cane. A secondary objective was to associate the levels of soil nitrate (NO₃⁻-N) and ammonium (NH₄⁺-N) at fertilization time in the spring with plant cane yields following both a conventional fallow period and the incorporation of soybean manure grown during the fallow period.

**MATERIALS AND METHODS**

Three sites near Jeanerette, LA (site 1 is a Fine-silty, mixed, superactive, thermic Aeric Epiaqualfs soil at 29° 54’ 16.00” N, 91° 44’ 19.46” W; site 2 is a Fine-silty, mixed, active, hyperthermic Glossaquic Hapludalfs soil at 29° 55’ 28.08”N, 91° 42’ 35.19” W; and site 3 is a Fine, smectitic, hyperthermic Chromic Vertic Haplqualfs soil at 29° 57’ 39.05”N, 91° 43’ 02.52” W) were selected to conduct a series of experiments. Experiments were conducted in 1992-93 at site 1, in 1994-95 at site 2 and in 2010-11 at site 3. Treatments compared at sites 1 and 2 included plant-cane grown both with and without N fertilizer after a conventional fallow period.
and plant-cane grown both with and without N fertilizer after the incorporation of soybean green manure grown during the fallow period. At site 3 the effects of fallowing and soybean green manuring were evaluated using only N-fertilized plant-cane. Pertinent dates for cultural, planting and harvesting events are shown in Table 1. Table 1 also includes soil series and organic matter and cultivar identification. For each test adapted early maturing soybean was double drilled in the spring using 38-cm spacing on raised sugarcane beds spaced 1.84 m apart.

Standard cultural practices (fertilization and both in-crop and fallow weed control) for sites 1 and 2 were the responsibility of growers on whose land the tests were conducted. For site 3 glyphosate was applied to soybean plots twice at the rate of 1,402 g a.i. ha$^{-1}$ for weed control. Sugarcane weed control was accomplished by applying a pre-plant tank-mixture of atrazine (3700 g a.i. ha$^{-1}$) and pendimethalin (3053 g a.i. ha$^{-1}$) followed by an early spring application of a tank mixture of atrazine (3364 g a.i. ha$^{-1}$), pendimethalin (1850 g a.i. ha$^{-1}$), and 2,4-D (1065 g a.i. ha$^{-1}$). Plant-cane plots scheduled to be fertilized with N according to the experimental design received 134 kg ha$^{-1}$ of N and all plots received 67 kg ha$^{-1}$ of P$_2$O$_5$, and 112 kg ha$^{-1}$ of K$_2$O, in keeping with recommend fertilizer rates (Johnson et al. 2008).

Table 1. Soil type, soil organic matter, dates for soybean plantings, green manure soil incorporation, and sugarcane plantings and harvests for the three experiments.

<table>
<thead>
<tr>
<th>Soil series</th>
<th>Site 1</th>
<th>Site 2</th>
<th>Site 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patoutville silt loam</td>
<td></td>
<td>Coteau silt loam</td>
<td>Baldwin silt loam</td>
</tr>
<tr>
<td>Soil organic matter at initiation of study</td>
<td>10.8 mg g$^{-1}$</td>
<td>12.5 mg g$^{-1}$</td>
<td>19.9 mg g$^{-1}$</td>
</tr>
<tr>
<td>Soybean variety and planting date</td>
<td>‘Riverside 499’</td>
<td>‘Dyna-Gro 3495’</td>
<td>‘Croplan 4455’</td>
</tr>
<tr>
<td>Sugarcane variety and planting date</td>
<td>December 7, 1993</td>
<td>November 28, 1995</td>
<td>November 16, 2011</td>
</tr>
</tbody>
</table>

$^1$Soybean dry matter was not determined for all plots at all sites. Randomly selected areas sampled immediately prior to anticipated plough down ranged in dry matter from 7,778 to 8,664 kg ha$^{-1}$.

Plot size (8, 1.83 m wide rows x 61 m in length) at site 1 was chosen to be sufficiently large to accommodate the 9 Mg capacity field wagons used to transport sugarcane to a commercial sugarcane mill for processing. Plot sizes for sites 2 and 3 were 3, 1.83 m wide rows x 21 m in length and 3, 1.83 m wide rows x 30.5 m in length, respectively. For sites 1 and 2, stalks of sugarcane in each plot were mechanically harvested with a two-row soldier harvester (J&L, Jeanerette, LA, USA). Plots weights at site 1 were determined using Enterprise sugar mill scales and for site 2 plots were weighed with tractor-mounted electronic load cells. Cane yield
for site 3 was determined by harvesting one middle row with a single-row combine (John Deere, Thibodeaux, LA, USA) in each plot and weighing with a weigh wagon instrumented with electronic load cells. For all sites, ten stalks were randomly selected from each plot for determination of stalk weight and juice quality analysis. Different methods were used to analyze for juice quality in this experiment. Prior to 2007, juice was extracted using a 3-roller sample mill. Brix was measured with a Model RFM110 Bellingham & Stanley Refractometer (Lawrenceville, GA) and pol was measured using an Autopol 880 Rudolph Research Saccharimeter (Flanders, NJ). For site 3, stalks were shredded by a Dedini shredder and scanned using a Spectracane 200 NIR (Lower Hutt, New Zealand). Comparison of the methods resulted in an $r^2$ value for Brix of 0.96 and for Pol ($Z^o$) of 0.93 (K. Gravois, pers. comm., February 21, 2011). Sugar yield was estimated as the product of cane yield and theoretical recoverable sugar (TRS).

**Soil inorganic nitrogen procedures**

For soil inorganic N analysis, compositing cores to a depth of 30 cm from all plots were taken just prior to spring fertilization. Total inorganic N (ammonium – NH$_4^+$-N, and nitrate – NO$_3^-$-N) was quantified based on the principle described by Carlson (1978, 1986) using an Alltech ammonia analyzer (Alltech Associates, Deerfield, IL). Soil extracts using a 1:5 soil:1N KCl ratio extraction procedure were passed through a diffusion membrane cell system coupled with electrical conductivity measurements. The NH$_4^+$ fraction was measured by pumping the sample extracts mixed with caustic solution into the membrane cell (permeable only to gases). The resulting solution has a pH high enough to convert all NH$_4^+$-N ions to dissolved ammonia gas. The solution which contained the ammonia gas was mixed with a buffered (absorbing) solution converting back the ammonia to ammonium. The change in electrical conductance of the absorbing solution during this process was measured by a conductivity cell. The total inorganic N was determined to quantify NO$_3^-$-N by difference method. Similar procedure was done except that the extract has to pass first a zinc reduction cartridge to reduce nitrate and nitrite ions to ammonium.

**Experimental design and statistical procedures**

For each site the experimental design was a randomized complete block with three replications for sites 1 and 2 and six replications for site 3. Sugar and cane yield, TRS and soil inorganic N parameters were analyzed using PROC MIXED, SAS 9.3 Program for Windows® (SAS, 2009). Replication was considered a random effect and treatment and site were included as fixed effects. Comparison of treatment means was accomplished using the PDIF option at the $P=0.05$ level. Because experiments at sites 1 and 2 contained the same treatments and number of replications the analysis of variance for those sites was combined for sugar and cane yields and TRS but kept separate for soil inorganic N parameters.

**RESULTS AND DISCUSSION**

**Soil Inorganic N**

Soil inorganic N was generally greater in the soybean green manure plots, but only soil NO$_3^-$-N at site 3 was the difference statistically significant at $P=0.05$ (Table 2). Since soil samples were collected before N fertilization, differences in KCl-extractable NO$_3^-$-N and NH$_4^+$-N values may only be associated with fallow-period and green manure treatments. It appears that NH$_4^+$-N level was more a function of site, perhaps because of the differences in soil texture or organic matter content. Site 3 having a heavy texture suggests that higher NH$_4^+$-N was
associated with the soil’s cation exchange capacity, which was greater than for sites 1 and 2. Similar interpretation was presented by Obeemea et al. (1988) who observed that larger loss of ammonium via ammonia volatilization, leaching and seepage on a light-textured soil (than a heavy-textured soil) was associated with its low capacity to hold NH$_4^+$-N on exchange sites. The terms native and artificial NH$_4^+$-N described as the amount of ammonium fixed during soil formation and application of ammonium fertilizer, respectively, were found to vary with soil type (Dalal 1977; Dorame and Evans 1983; Breitenbeck and Paramasivam 1995). The differences in soil properties could also explain the differences in inherent yield potential of the soils; thus, reflecting significant differences in cane yield across sites rather than between fallow-period and green manure-treated soils. Soil NO$_3^-$-N concentration varied considerably less than NH$_4^+$-N across sites. An earlier study conducted by Olness et al. (2001) reported that predictions of soil NO$_3^-$-N concentrations requires six factors including soil clay content, bulk density, organic matter content, pH, temperature and rainfall implying the influence of both soil and specific weather conditions. Levels of NO$_3^-$ -N and NH$_4^+$-N in our study were similar to that measured by Wiedenfeld (1998) in the Texas sub-tropical environment. He reported, however, higher soil inorganic N concentrations for fallow land than for land previous cropped with grain soybean for two years. Hipp and Gerard (1971) also measured more NO$_3^-$-N in the soil profile in fallowed plots compared to cropped plots in south Texas. They observed that mineralization of N occurs even in the fall and winter at their latitude. While a N-richer environment following green manure plough down is consistent with expectations, the difference in measured inorganic N between the green manure and fallow plots in this study was modest and points to adequate N availability in the fallow plots prior to spring fertilization, as confirmed by treatment yields in Table 3.

Table 2. Levels of NO$_3^-$-N and NH$_4^+$-N Prior to Sugarcane Fertilization

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Patoutville silt loam Site 1</th>
<th>Coteau silt loam Site 2</th>
<th>Baldwin silty clay loam Site 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NO$_3^-$-N (kg ha$^{-1}$)</td>
<td>NH$_4^+$-N</td>
<td>NO$_3^-$-N</td>
</tr>
<tr>
<td>Soybean for green manure</td>
<td>5.66</td>
<td>10.73</td>
<td>8.13</td>
</tr>
<tr>
<td>Fallow</td>
<td>5.34</td>
<td>8.33</td>
<td>8.57</td>
</tr>
<tr>
<td>P-value</td>
<td>0.8153</td>
<td>0.0846</td>
<td>0.2507</td>
</tr>
</tbody>
</table>

Yield Data

The combined analysis of variance for sites 1 and 2 indicated that the only statistical significance among variables and their interactions were site differences for cane yield and TRS.
There was no statistical difference in either cane yield, TRS or sugar yield between the treatments at site 3 (Table 3).

There was no plant-cane response to the addition of N, either from green manure or fertilizer application or both for any yield components at sites 1 and 2 (Table 3). Indeed, the presumably least N-abundant treatment, the unfertilized plant-cane grown subsequent to the conventional fallow period, produced the numerically greatest yields for sites 1 and 2. Unlike Gilbert et al. (2008) who showed on low- CEC sandy soil in Florida that the combination of soybean green manure and spring-applied fertilizer yielded 35% more than green manure alone, our results did not show such an additive effect. Failure of the plant-cane benefitting from both ploughed-down green manure and applied inorganic fertilizer to produce greater yields than the plant-cane exposed to only soil-residual N strongly suggests that N was not a limiting growth factor for this specific study, but rather was in the adequacy range for all treatments. Comparable TRS level among treatments is further evidence that N was sufficient and not excessive, as excessive N levels typically delay maturity and/or reduce TRS (Borden 1946; Lakshmikantham 1974). Levels of soil inorganic N for the green manure and fallow treatments prior to spring fertilization (Table 2) provides empirical evidence to account for the capability of unfertilized plant-cane following a conventional fallow period to yield comparable to unfertilized plant-cane following green manuring.

Unexpected, however, was the lack of a yield disparity between plant-cane profiting from both fertilizer and green manure residue and the unfertilized plant-cane after fallowing. These results are analogous to that of both Hipp and Gerard (1971) and Wiedenfeld (1998), who measured no yield response to applied N for crops following a fallow period. Wiedenfeld (1998) stated that soil testing has invariably failed to predict the ability of the soils in the sub-tropics to provide N to subsequent cropping systems. He postulated that immobilization of N in crop residue or microbial biomass accounts for the unpredictability of soil testing for N content and availability. In contrast, Arceneaux (1943) observed that soybean green manuring produced significantly less cane and sugar compared to plant-cane receiving the conventional application of 45 kg N ha⁻¹. In his study, the entire experimental area was planted to soybean, which did not allow for a true fallow but only a simulated fallow for which vines were removed and below-ground soybean residue remained. Unfortunately, his methodology prevents a direct comparison with the results of our experiment. White et al. (2011) found that plant-cane following a grain soybean crop produced marginally greater yields than sugarcane after a fallow period. They conjectured based on a first order carbon mineralization model that readily available soil N from decomposition of the residue from a grain soybean crop would not coincide with the needs of the plant-cane crop. They stated that decomposition of the residue would be largely complete prior to the initiation of spring sugarcane growth. The minimal difference in soil inorganic N levels between the treatments at spring fertilization time in our study also implies a lack of synchrony between plant-cane need for N in the spring and N released from incorporated soybean residue the previous year.
Table 3. Effects of fallow-period treatment on plant cane yield (Mg ha\(^{-1}\)), TRS (g kg\(^{-1}\)) and sugar yield (Mg ha\(^{-1}\)) for sites 1 and 2 combined and site 3.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Sites 1 and 2 Combined - Variety ‘CP 70-321’</th>
<th>Site 3 - Variety ‘L 99-226’</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soybean green manure with plant-cane fertilizer</td>
<td>Cane yield 62</td>
<td>Cane yield 105</td>
</tr>
<tr>
<td>Soybean green manure with no plant-cane fertilizer</td>
<td>TRS 99</td>
<td>TRS 117</td>
</tr>
<tr>
<td>Fallow with plant-cane fertilizer</td>
<td>Sugar yield 6.0</td>
<td>Sugar yield 13.1</td>
</tr>
<tr>
<td>Fallow with no plant-cane fertilizer</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*P*-value for Site (S)

<0.0001 (Site 1 and 2) 0.0006 (Site 3) 0.7173 (Site 3)
*Treatment (T) 0.1912 (Site 1 and 2) 0.5597 (Site 3) 0.1985 (Site 3)
*S*T 0.1660 (Site 1 and 2) 0.6905 (Site 3) 0.3455 (Site 3)

**CONCLUSIONS**

The results of this study dispute the presumption of the assignment of a N fertilizer credit for sugarcane following a soybean green manure crop in the humid sub-tropical environment of Louisiana. Neither soil inorganic N nor plant-cane yield levels were meaningfully influenced by the addition of soybean biomass to the soil in the fall prior to resumption of cane growth in the spring. Also, the additive effect of the combination of incorporation of green manure and additional fertilizer N did not result in higher plant-cane yield. On the contrary, there was a slight tendency (*P*=0.19) at two sites utilized in the study for the unfertilized plant-cane following a conventional fallow period to yield the highest. Louisiana’s temperate winters certainly accounts for a lack of synchrony between crop demand and N release from soybean residue. The cold-temperature induced dormancy intervening between the incorporation of soybean residue and the resumption of plant-cane growth the following spring, a period typically totaling approximately seven months, makes Louisiana sugarcane growing conditions unique.
Fertilizer N application protocol studies for sugarcane often reveal no statistical differences among N rates (Thomas et al. 1985 and Johnson et al. 2008). This insensitivity to applied N is likely related to adequacy of soil-available N, a metric which, heretofore, has not associated well with sugarcane growth and development. Typically in the Gulf Coast region measurements of soil NO₃⁻N and NH₄⁺-N do not reflect the capability of soil to release N tied up in organic sources. To what extent this well-documented insensitivity of plant-cane to applied N played a role in this study is, of course, unknown.

Another factor that may influence the dynamics of a soybean/sugarcane rotation is the possible occurrence of allelopathic compounds influencing sugarcane germination (Viator et al. 2006). The authors have observed poor fall shoot emergence when sugarcane was planted in the decomposing residue of a ploughed-down soybean green manure crop (unpublished data). Stalk counts for this study (data not shown), however, between treatments were comparable and not indicative of unsatisfactory emergence.

Non-N rotation effects were not an objective of this study. Interruption of the sugarcane monoculture by occupation of fallow-land with a legume crop can affect pest cycles, change the physical soil properties, protect against soil erosion and allow for control of grass species of weeds with selective herbicides. These phenomena can influence subsequent sugarcane growth and production and may have had positive effects in this study, but were not quantified.

The findings of this study are sufficient to question the presumption of a N fertilizer replacement value of green manure soybeans for sugarcane and warrants its re-evaluation for the humid sub-tropical environment of Louisiana.

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REFERENCES


Hemwong, S., B. Toomsan, G. Cadish, V. Limpinuntana, P. Vityakon, and A. Pantanothai. 2009. Sugarcane residue management and grain legume crop effects on N dynamics, N


Shoko, M.D., M. Zhou and P.J. Pieterse. 2009. The use of soybean (Glycine max) as a break crop affect the cane and sugar yield of sugarcane (Saccharum officinarum) variety CP 72-2086 in Zimbabwe. World J. Agric. Sci. 5:567-571

