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Harvest management effects on sugarcane growth, yield and nutrient cycling in Florida and Costa Rica

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ABSTRACT

The literature on harvest management in Australia, Brazil and Louisiana indicates positive effects of harvest residue on sugarcane (*Saccharum* spp. hybrid) growth in well-drained soils with dry climate or high slopes, but negative effects in wet climates and heavy soils with little relief. There is limited information available on harvest management effects in Florida and Costa Rica. Therefore, sugarcane harvest management effects were studied on plant cane and two ratoon crops grown on organic Histosols in Florida and plant cane and three ratoon crops grown on clay loam soils in Costa Rica. The harvest systems included burnt cane harvest (Burnt), green cane harvest (Green), and green cane harvest with residue management. Residue management included either raking residues from the cane rows into the inter-row spaces (Rake; in Florida) or manual removal from the field (Remove; in Costa Rica) immediately after harvest. Sub-treatments were early (Nov.–Dec.) or late (Feb.–Mar.) harvest in Florida. Our results showed a negative effect from maintaining the harvest residue layer on late (> 120 days after harvest, DAH) tillering and mid-season (150–200 DAH) leaf area index (LAI) in early harvested cane in Florida. However, the harvest system effects on early to mid season growth were not observed in final sugarcane yield (tons of cane per hectare, TCH), sucrose concentration (commercially recoverable sucrose, CRS) and sugar yield (tons of sugar per hectare, TSH) in Florida. In Costa Rica, TCH and TSH were greater in burnt than remove treatment with no difference between burnt and green. These results indicate that keeping harvest residue on soil surface after green cane harvest may have neutral effects on sugarcane yields in Florida and Costa Rica.

1. Introduction

Sugarcane (*Saccharum* spp. hybrid) is harvested either burnt or green. The cane tops and leafy residue are burnt before harvesting in burnt cane harvest (Burnt). In green cane harvest (no burn event; Green), harvester primary extractor fans blow leafy residues (harvest residue) back onto the soil surface, resulting in a thick layer of plant material. Sugarcane undergoes multiple annual harvests before replanting similar to other perennial grasses. Re-growth of sugarcane after each harvest is called ratoon cane. The harvest method (Burnt or Green) and post-harvest residue management may have either positive or negative effects on the emergence and growth of ratoon cane and soil quality. The positive effects of retaining harvest residue include increased soil C (Cerri et al., 2011), conservation of soil moisture (Ball-Coelho et al., 1993; De Beer et al., 1995), reduced weed growth (Ball-Coelho et al., 1993), improved air quality (Le Blond et al., 2008), reduced greenhouse gas emissions (Coelho et al., 2008), minimized soil erosion, reduced herbicide use and water runoff (Prove et al., 1986), improved soil quality and nutrient recycling (Barzegar et al., 2000; Graham et al., 2002) and cultural control against some soil insects such as lesser cornstalk borer, *Elasmopalpus lignosellus* (Zeller) (Sandhu et al., 2011). Reported negative effects of harvest residue include increased harvesting costs as a consequence of reduced harvesting and loading rates (De Beer et al., 1995), increased volume of trash delivered to the mill (Eiland and Clayton, 1983; Núñez and Spaans, 2008), slower post-harvest sugarcane growth and lower yields due to decreased soil

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temperatures (Ridge, 1997; Kingston et al., 2002; Sandhu et al., 2013), excessive soil moisture retention in wet climates and poorly drained flat soils (Wood, 1991), and increased loss of ammonia from the urea applied on harvest residue (Meyer et al., 1961; Bacon and Freney, 1989)

Reduced soil temperature under harvest residue can reduce the early growth rates of ratoon cane. Harvest residue in green cane harvest systems promote reduced soil temperature in both organic soils of Florida and clay loam soils of Costa Rica (Sandhu et al., 2013). The difference in maximum soil temperature in green versus burnt cane harvested in April was 3–4 °C in Florida's organic soil and 7–8 °C in Costa Rica's clay loam soil (Sandhu et al., 2013). Slow initial growth and reduced tillering due to lower soil temperature under a residue layer were also reported in similar studies (Morandini et al., 2005; Viator et al., 2005). Also, lower air temperature near the plant canopy in Green versus Burnt during freeze or near-freeze events increases the vulnerability of young sugarcane regrowth to frost damage in green cane harvest systems and can have a negative effect on early-season sugarcane growth in Florida (Sandhu et al., 2013). Allelopathic effects from phenolic compounds leached from fresh crop residues have also been proposed as a mechanism for slow or poor ratooning performance in the presence of green cane harvest residues (Cock et al., 1997; Francis, 1998; Kingston et al., 2002).

The sugarcane harvest residue layer may also affect important sugarcane growth parameters such as tillering and leaf area index (LAI). Tillering is considered to be the key factor in profitable sugarcane cropping (Matsuoka and Stolf, 2012). Harvest residue had either negative (Monzon, 1956; Olivier and Singels, 2012) or no effect (Ball-Coelho et al., 1993; Viator et al., 2005) on tillering in previous studies. Sugarcane has high photosynthetic efficiency and high LAI (Bassham, 1978) which is directly related to determination of sugarcane yield (Teruel et al., 1997). There is a high correlation between LAI and sugarcane yield (Sandhu et al., 2012) and LAI is also used as an important adjustment factor in many sugarcane growth and yield models (O'Leary, 2000). Therefore, both tillering and LAI are important factors in evaluating the effect of harvest residue on sugarcane regrowth.

The effects of harvest residue on sugarcane yield differ with soil type and climate. For example, green cane harvest yield exceeded burnt cane yield on well-drained dry soil, with no yield differences reported for poorly-drained wet soil in Australia (Wood, 1991). This study suggested that green cane harvest residue improved soil moisture conservation in well-drained dry soils which in turn supported improved yield responses. Use of harvest residues as mulch supported improved sugarcane yields in Brazil (Ball-Coelho et al., 1993) and South Africa (Van Antwerpen et al., 2001). Raking of harvest residue from the cane rows into the inter-row space after harvest improved sugarcane ratoon yields in Louisiana (Viator et al., 2005). Sugar yield is improved by post-harvest removal of harvest residue through burning or mechanical means, but the residue should be removed soon after harvesting (Viator et al., 2009). Harvest residue retention after green cane harvest significantly reduced cane and sugar yields in long-term studies in temperate and humid environments of Louisiana (Viator and Wang, 2011).

Sugarcane harvest residue supplies nutrients back to the soil. Vitti et al. (2010) reported 9.8–23% recovery of N from harvest residue in Brazil. However, most of this N was assimilated by the second ratoon crop, with only 4% assimilated in the first ratoon crop. Similarly, Ng Kee Kwong et al. (1987) reported that plants use $<$ 10% harvest residue N compared to 45% fertilizer N after 18 months of sugarcane growth in pots. Núñez and Spaans (2008) reported that the harvest residue left after green cane harvest had greater N content (0.85% N) than burnt cane harvest (0.55% N) in Ecuador. They calculated 118 kg N, 14.6 kg P and 164 kg K ha^{-1} were recycled in green cane compared to only 17.5, 3.3 and 37.5 kg ha^{-1} of N, P, and K, respectively, in burnt cane.

Sugarcane is a major crop in Florida and Costa Rica, and currently almost all sugarcane is harvested after pre-harvest burning in both environments. Increased environmental pressure and grower's interest in green cane harvest may result in switching from burnt cane to green cane harvest in the future. Despite the wealth of global green cane harvest literature, the unique soils and climatic conditions in Florida and Costa Rica might result in different harvest management impacts on sugarcane growth compared to other regions of the world. Investigating the effect of harvest timing (early during the fall or later during the cooler winter) is important in Florida since young ratoon regrowth is particularly vulnerable under green cane harvest residue when freeze or frost weather events occur. We further hypothesised that the strategic management of harvest residue left after green harvest events will support increased sugarcane yields through nutrient cycling. The objectives of this study were to determine the effect of green cane harvest, post-harvest residue management, and time of harvest on sugarcane growth, yield and nutrient cycling compared to traditional burnt cane harvest on Histosols (Florida) and clay loam soils (Costa Rica).

2. Materials and methods

2.1. Site characteristics

A 3-year trial was conducted during one multi-year crop cycle (plant cane, first and second ratoon) in Belle Glade, Florida (26°39′N, 80°38′W) to determine the effect of sugarcane harvest method, post-harvest residue management and timing of harvest on sugarcane regrowth, yield and nutrient cycling in plant cane and two ratoon crops. Similarly, a 4-year trial was conducted in Azucarera El Viejo Mill, Costa Rica (10°25′N, 85°24′W) to determine the effects of sugarcane harvest method and post-harvest residue management on sugarcane yield and nutrient cycling in plant cane and three ratoon crops. The characteristics of each site are provided in Table 1. Soil samples were collected at 0–15 cm soil depth to measure soil physical and chemical parameters reported in this table. Each soil sample was mixed thoroughly, placed in aluminum drying pans, air-dried in a forced-air drying room at 31 °C, and sieved through a 2-mm screen before analysis. Soil $pH_{(water)}$ was determined for all samples in 1:2 soil/water ratio (15 cm^3 soil/30 mL water). Soil samples were allowed to stand in the extractant overnight and then were shaken for 50 min before filtering for P analysis. Mehlich 3 extractant (0.2 *M* CH_3COOH, 0.25 *M* NH_4NO_3, 0.015 *M* NH_4F, 0.013 *M* HNO_3, and 0.001 *M* EDTA) was used in a 2.5 cm^3 soil/25 mL extractant ratio with a 5-min shaking time immediately after adding the extractant to soil samples and then samples were filtered for analysis. Phosphorus concentrations were determined with a discrete analyzer

Table 1
Site characterization for the field trials in Florida and Costa Rica.

Characteristic	Florida	Costa Rica
Soil type	Organic soil (Histosols)	Clay loam soil
Soil series	*Euic, hyperthermic lithic haplosaprist*	*Fluventic ustropept*
Sand: silt: clay%	Negligible	20–33: 41–42: 26–38
Bulk density (g cm^{-3})	0.2–0.5	1.25
Elevation (m)	3–4	10
pH	7.0	6.4
N (%)	2–4	0.14
P (g m^{-3})	33	16.5
K (g m^{-3})	51	0.18
Ca (g m^{-3})	2886	11.5
Mg (g m^{-3})	402	5.8
Na (g m^{-3})	23	—
Si (g m^{-3})	13	—
Fe (g m^{-3})	—	241
Cu (g m^{-3})	—	9.8
Zn (g m^{-3})	—	5.9
Mn (g m^{-3})	—	118

— nutrients not tested; Soil test analysis is based on the soil samples collected at 0–15 cm soil depth before sugarcane planting in each trial.