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Agronomic Responses in the Short-Term to Some Management Options for Sugarcane Top Residue

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ABSTRACT

Agronomic responses in the short-term to various management options for the discarded tops of harvested sugarcane (interspecific hybrids of Saccharum spp.) are largely unknown. This greenhouse study examined the effects of four simulated sugarcane harvest managements on the soil chemical properties of an Acrudoxic Hydrudand and growth of two tropical maize (Zea mays L.) varieties (‘Hawaiian Supersweet #9’ [HS] and ‘Tex-Cuban’ white flint [TC]). Simulated harvest managements consisted of removing the tops (leaves, sheaths, and immature cane-i.e., above the growing point of the millable stalk) from the field (control), burning the tops (10,0000 kg ha^{-1}) with ash returned to the soil (burnt tops), returning chopped tops (10,000 kg ha^{-1}) to the soil as a mulch (mulched tops), or removing tops from the field with replacement of the K contained in the tops (145 kg ha^{-1}) as KCl fertilizer (K replacement). The mulched tops management increased soil oxidizable C but decreased soil available inorganic N relative to the other managements. However, it was estimated that about 73% of the immobilized N in this management could eventually be replaced via an increase in the pool of mineralizable organic N. Both the mulched and burnt tops managements slightly increased modified-Truog extractable P. About a third of the K in the mulched tops was not immediately available. This K pool was slowly released with the greatest increase in exchangeable K concentration occurring between 60 and 90 d after sugarcane top incorporation into the soil. The slow release nature of a third of the K in the mulched tops management resulted in lower maize seedling K concentrations (30 d after emergence) than observed for the burnt tops and K replacement managements. The HS maize variety appeared to have a greater internal plant K concentration requirement than TC. Future research should explore the feasibility of composting sugarcane tops possibly in combination with other by-products of the sugar industry in order to decrease the C/N ratio and thereby potential for N immobilization.

INTRODUCTION

A mature crop of sugarcane produces about 10,000 kg ha^{-1} of crop residue at harvest in the form of tops (Evensen *et al*., 1997; Mendoza and Samson, 1999). Potential long-term agronomic and environmental benefits of “green-harvesting” sugarcane where the tops are returned to the field as a chopped mulch during harvest rather than burning them before or after harvesting the cane stalks has only recently become well-documented (Wood *et al*., 1991; Haynes and Hamilton, 1999; Mendoza and Samson, 1999; Mendoza *et al*., 2001; Rivacoba and Morín, 2002). These benefits often include increased yields resulting from better maintenance of soil organic matter and associated improvements in nutrient recycling, retention of fertilizer nutrients against leaching, soil physical conditions such as aggregation, resistance to erosion, water holding capacity, and more favorable conditions for beneficial soil organisms and overall soil health (Lal, 1995). Furthermore, air pollution from burning is eliminated. In other operations the tops are removed from the field when separation from stalks in the field is not considered practical or when tops are used for animal feed (Rivacoba and Morín, 2002). Tops are also removed from the field when volunteer sugarcane in abandoned fields is pushed to the field edge in preparation for planting alternative crops. Burning sugarcane tops in piles without spreading the ash throughout the field can also have an agronomic effect similar to complete removal of the tops from most of the field (Mendoza and Samson, 1999; Mendoza *et al*., 2001). Recent work with volcanic ash soils (Udands) in Hawaii suggests that 50 to 90 yr of mechanized sugarcane cultivation with burning of the crop residues at harvest has resulted in net carbon losses of about 30% in the top 20 cm of soil and perhaps as much as 10 to 25% for the top meter (Osher *et al*., 2003).

Sugarcane is often grown in rotation (Corpus *et al*., 1987; Garside *et al*., 1999; Glaz and Ulloa, 1994) or occasionally intercropped (Mulkins *et al*., 2000) with maize in many parts of the world. Research in India and Nigeria has demonstrated that mulching with crop residues can increase maize yield and available soil K (Lal, 1995; Ogban *et al*., 2001). Soil K is depleted more rapidly in systems where crop residues are not returned to the soil because they account for ≥ 50% of K in crop output (Sundara, 1993; Lal, 1995). Little research has been conducted to simultaneously document the effects of the various sugarcane harvest managements on agronomic responses in the short-term (Srivastava and Prakash, 1990). In a greenhouse experiment, Srivastava and Prakash (1990) compared the effects of burning and different amounts and fineness of chopped sugarcane residue mulch on soil nutrient availability and the growth of maize. Increasing the amount or finely grinding sugarcane residue (wide C/N ratio) decreased available soil N via microbial immobilization compared to burning the residues. However, these researchers also suggested that K may release more slowly from mulched than burnt sugarcane residue and that the release of nutrients in the short-term needs to be further investigated. The present research was conducted under greenhouse conditions with the following objectives: 1) to study the effects of four simulated sugarcane harvest managements on soil chemical properties in the short-term, and 2) to study the effects of these managements on shoot dry matter (DM) yield and chemical composition of two internationally grown, open-pollinated, tropical maize varieties.

MATERIALS AND METHODS

The Ap1 horizon (0- to 15-cm depth) of a Honokaa silty clay loam (hydrous, ferrihydritic, isothermic Acrudoxic Hydrudands) and the tops of mature volunteer sugarcane growing on this soil were collected near Honokaa on the island of Hawaii (20° N lat.). The recently abandoned site had been cropped to sugarcane for over 50 yr but appeared to have good physical properties compared to the degradation observed for some nearby former sugarcane lands (Osher *et al*., 2003). The mineralogy of this soil consists of approximately 20% allophane, 15% goethite, 10-15% ferrihydrite, 10-15% micas/illite, 5% kaolin minerals, and 5% gibbsite. Selected properties of the Honokaa soil determined by the methods outlined by Hue *et al*. (2000) and Bower (1975) are presented in Table 1. These properties are similar to those reported for Udands used for sugarcane production in the Philippines and Latin America (Silva, 1985). The low exchangeable K concentration likely reflects the very high demand of sugarcane for K (Sundara, 1993; Haynes and Hamilton, 1999) coupled with a limited capacity of most Hydrudands to replenish exchangeable K (Bower, 1977). The Honokaa soil also has a very limited capacity to strongly retain or "fix" fertilizer K which had not been applied for several years (Table 1).

The sugarcane tops were chopped to ≤ 2.5 cm with a Promark chopper (Gravely Corp., Clemmons, NC) and oven-dried at 60°C for 1 wk. A subsample of the oven-dried tops was prepared for chemical analysis by grinding to pass a 1-mm stainless steel screen, using a Wiley mill (Arthur H. Thomas Company, Philadelphia, PA). Selected chemical properties of the sugarcane tops are are presented in Table 2. Analyses of the sugarcane tops for pH; organic matter; C, N, and S (ECS 4010 C/N/S analyzer, Costech Analytical Technologies, Valencia, CA); and P, K, Ca, Mg, S, Fe, and Mn (tissue digest analysis by inductively coupled plasma emission spectroscopy, ICPES) were performed as described by Hue *et al*. (2000)

while Si, hemicellulose, lignin, were determined as outlined by Allen (1989). Water soluble K was determined by ICPES analysis of a 1:40 chopped tops/deionized H_2O suspension that had been allowed to sit overnight prior to shaking for 1 h and filtering through a Whatman no. 42 filter paper. *In vitro* digestible organic matter (IVDOM) concentration in the sugarcane tops was determined by the modified two-stage procedure of Moore and Mott (1974). The IVDOM has been suggested as an index of that portion of a crop residue or green manure that is likely to readily degrade in the soil within about six months or less (Chesson, 1997). In order to simulate the effects of field burning a 10.0 g subsample of the chopped sugarcane tops was placed in porcelain evaporating dish that was gradually heated to a maximum temperature of 265^{o}C (Ball-Coelho *et al.*, 1993) for 1 h in a muffle furnace. The pH of the ash, water soluble K, and volatile losses of C, N, and S (Table 2) were determined using the same analytical procedures described above and were within the ranges expected under field conditions (Ball-Coelho *et al.*, 1993).

In order to approximate field bulk density (Table 1) thirty-two 6-L (22.5 cm diam.) pots lined with polyethylene bags were filled with 3.6 kg (oven-dry equivalent) of field-moist Honokaa soil that had been screened to pass a 4-mm sieve. All amendments and fertilizers were applied on a surface area basis with 4.00 mg pot^{-1} (1.11 mg kg^{-1} soil) corresponding to a surface area based application rate of 1 kg ha^{-1}. The experiment was designed as a completely randomized factorial combination of four managements of sugarcane tops and two internationally grown, open-pollinated, tropical maize varieties (‘Hawaiian Supersweet #9’ [HS; Brewbaker, 2003] and ‘Tex-Cuban’ white flint [TC; Florida Foundation Seed Producers, Greenwood, FL]), with four replications. The sugarcane top managements were:

i) Control (no addition of sugarcane tops representing complete removal from the field at harvest)

ii) Burnt tops where the equivalent of 10,000 kg ha^{-1} of chopped sugarcane tops that had been burned in a muffle furnace as described previously is added to the soil

iii) Mulched tops where the equivalent of 10,000 kg ha^{-1} (1.1% by weight) of chopped sugarcane tops is added to the soil

iv) K replacement where there is no addition of sugarcane tops but muriate of potash (KCl) fertilizer is added to the soil at a rate equivalent to the K contained in the sugarcane tops (145 kg K ha^{-1} or 161 mg K kg^{-1} soil)

Despite the very low initial exchangeable K concentration (Table 1) it was decided not to supplement the managements with additional K as fertilizer in order to best assess the impact of management on plant and soil K. As simulation for a possible field cultivation practice in preparation for planting (Glaz and Ulloa, 1994; Robertson and Thorburn, 2000) the burnt tops and mulched tops amendments were thoroughly mixed with the soil in each pot. The pots were then allowed to incubate in the greenhouse for 7 wk at a moisture content maintained at 90 to 100 percent of field capacity by addition of deionized water. Based on Brewbaker (2003), the soil was then fertilized with 210 kg N ha^{-1} (233 mg N kg^{-1} soil) as $(NH_4)_2SO_4$ and the maize varieties were planted in separate pots (four replications for each) at the rate of five seeds per pot. The plants were thinned to two per pot 8 days after planting and harvested by cutting 1 cm above the ground 30 d after emergence.

After harvest the soil in each pot was thoroughly mixed again and analyzed moist. All extraction procedures were conducted on an oven-dry equivalent (100^{o}C) basis. The soil samples were analyzed for pH (1:2 soil/solution paste), 1 *M* KCl extractable NH_4-N and NO_3-N (phenate and cadmium reduction colorimetric procedures), modified-Truog extractable P (molybdenum-blue colorimetric procedure), and 1 *M* NH_4OAc exchangeable Ca, Mg, and K (atomic absorption procedure) as described by Hue *et al.* (2000). Readily mineralizable organic N was determined by the 40°C incubation procedure outlined by Rowell (1994) while biologically active soil C was estimated by the 0.02 *M* $KMnO_4$-oxidizable C procedure of Weil *et al.* (2003). Labile 0.5 *M* $NaHCO_3$ extractable organic P was determined by the method of Tiessen and Moir (1993).

The whole tops of maize were dried at 60°C for 72 h, weighed, and ground to pass a 1 mm screen using a Wiley mill. These samples were analyzed for N by a micro-Kjeldahl procedure (Hue *et al.*, 2000) while P, K, Ca, Mg, S, Fe, and Mn were determined as described previously for the sugarcane tops.

A second completely randomized pot experiment was conducted with the chopped sugarcane tops alone to assess K release and recovery percentage from the tops as a function of time. In this experiment the equivalent of 10,000 kg ha^{-1} chopped sugarcane tops were thoroughly mixed with the Honokaa soil and allowed to incubate in the greenhouse for 15, 30, 60, 90, or 120 d. There were four replications per incubation period and after the allocated time the soil in each pot was analyzed for exchangeable K as described previously.

Statistical analysis consisted of analysis of variance (ANOVA), Fisher's *F*-test protected least significant difference (LSD) test for mean separation, and regression using the statistical analysis system (SAS, 1989). Main effects and interactions with P values ≤ 0.10 were considered significant.

RESULTS AND DISCUSSION

Plant Responses

There were management ($P < 0.001$), variety ($P < 0.001$), and management x variety interaction ($P = 0.05$) effects for shoot DM yield. The control management had the lowest yield for both maize varieties (Table 3). Interaction occurred because HS yields for the burnt and mulched tops managements were intermediate between the K replacement and control managements while TC yields did not differ among the K replacement, burnt tops, and mulched tops managements. Depending on the management TC out yielded HS by 1.2 to 1.5 fold. This was expected because TC was breed primarily for total biomass yield and adaptability to lower soil fertility (FFSP, 2002). As will be discussed later it also appeared that HS was more sensitive to K nutritional stress than TC.

There were management effects on maize shoot concentrations of N, K, Ca, Mg, and Mn (Table 4); variety effects ($P < 0.005$) for N, P, and K; and a management x variety interaction ($P = 0.007$) for P. There were no management or variety effects ($P > 0.28$) for S (mean = 2.1 g kg^{-1}; SE = 0.1) or Fe (mean = 187 mg kg^{-1}; SE = 28) and both of these minerals were well within the sufficiency ranges reported by Mills and Jones (1996). With the exception of K (discussed separately below), the management effects can be attributed primarily to nutrient dilution in greater shoot yields for managements other than the control. Likewise, variety effects can be attributed to nutrient dilution in the greater shoot yields for TC than HS.

Shoot N concentrations were greatest for the control management and did not differ among the other managements (Table 4). Relatively similar management response patterns were observed for Ca, Mg, and Mn (Table 4) and these minerals were sufficient regardless of treatment according to the ranges provided by Mills and Jones (1996). Incorporation of sugarcane residues into soils at rates ≤ 2.5% by soil weight is not likely to significantly effect soil redox potential and therefore bioavailabililty of Mn and Fe (Asghar and Kanehiro, 1977). This explains why the mulched tops management did not result in increased plant concentrations of these nutrients. The variety effect for N occurred because HS averaged slightly greater in N across managements (mean = 31.9 g kg^{-1}) than TC (mean = 28.0 g kg^{-1}).

Interaction occurred for shoot P concentration because P concentration for HS was greater ($P < 0.05$; SE = 0.2) for the control (mean = 3.7 g kg^{-1}) than the burnt tops (mean = 2.6 g kg^{-1}), mulched tops

(2.6 g kg^{-1}), and K replacement (mean = 2.7 g kg^{-1}) managements, while management had no effect on shoot P concentrations for TC ($P = 0.54$; mean = 2.5 g kg^{-1}; SE = 0.2). Regardless of management the P concentrations were within the sufficiency range of 2.2 to 5.0 g P kg^{-1} for maize 30 to 60 cm tall (Reuter and Robinson, 1986; Mills and Jones, 1996).

Shoot K concentrations followed a management response pattern of K-replacement > burnt tops > mulched tops > control (Table 4) while K concentration across managements was greater for HS (mean = 18.5) than TC (mean = 15.7). When the management data for shoot K concentration is considered in relation to yield it is obvious that the shoot K concentrations reflect shoot K uptake patterns or K bioavailability. Shoot K concentrations of < 2.5 g kg^{-1} are considered deficient (Mills and Jones, 1996) but visual symptoms are only obvious at lower concentrations. Visually, the control was extremely K deficient (Brewbaker, 2003) with yellowing/bronzing of leaf edges and premature withering of older leaves throughout most of the study period following germination. In contrast, the mulched tops management readily showed K deficiency symptoms during the middle of the growing period but improved somewhat in appearance during the last two weeks of growth. This was likely due to additional K release from the decomposing tops as will be discussed later. The burnt tops management was showing some K stress by the end of the study period, but none was apparent for the K-replacement management. If plants lack K they are less efficient at photosynthesis and transpiration, and also at moving sugars and other organic compounds within the plant (Clements, 1980). This is partly because their leaves work less efficiently, particularly the stomata.

Soil Responses

There were no significant management x variety interactions ($P > 0.12$) for any of the soil nutrients. Management effects were observed for soil pH, extractable NO_3-N, mineralizable organic N, modified-Truog extractable P, exchangeable K and Mg, and 0.02 *M* $KMnO_4$ oxidizable C (Table 5). Variety effects were also observed ($P < 0.04$) for modified Truog extractable P and exchangeable K. There were no management or variety effects ($P > 0.17$) for extractable NH_4-N (mean = 7 mg kg^{-1}; SE = 1), exchangeable Ca (mean = 1836 mg kg^{-1}; SE = 28), or labile 0.5 *M* $NaHCO_3$ extractable organic P (mean = 20 mg kg^{-1}; SE = 1).

The mulched tops management increased soil pH relative to all other managements while the burnt tops management increased soil pH relative to the control and K replacement managements (Table 5). The increase in soil pH observed for the burnt tops management can be attributed to ash alkalinity while the increase for the mulched tops can be attributed to exchange reactions with base cations, protonation of added organic anions, proton consumption during microbial decarboxylation of organic complexes with base cations, and hydroxyl displacement from hydrous oxides by soluble organic anions (Asghar and Kanehiro, 1977; Marschner and Noble, 2000). In the mulched tops management, immobilization of some of the NH_4-N from the $(NH_4)_2SO_4$ fertilizer (discussed below) may have also decreased the amount of acidity contributed by nitrification (Recous and Mary, 1990).

The mulched tops management had the lowest concentration of soil NO_3-N while the control had the greatest concentration followed by intermediate values for the burnt tops and K replacement managements (Table 5). The high soil NO_3-N concentration for the control can be attributed to the low shoot DM yield for this management and thereby lower total N uptake. The mulched tops management likely had the lowest NO_3-N concentration because of microbial immobilization of some of the NH_4 from the $(NH_4)_2SO_4$ fertilizer, thereby decreasing the amount available for the relatively rapid process of nitrification (Asghar and Kanehiro, 1976; Recous and Mary, 1990). The breakpoint C/N ratio between net N immobilization and mineralization is thought to be < 30 (Rowell, 1994) and the sugarcane tops had an initial ratio of 41 (Table 2). Therefore, during the decomposition process crop residues containing about 10 g N kg^{-1} (C/N ratio ≈40) such as corn stalks or the sugarcane tops in the present study may be expected to tie up at least 4 kg N Mg^{-1} crop residue (Brewbaker, 2003). Because of the low bulk density of Andisols the NO_3-N requirement during rapid growth of maize and sugarcane on these soils is approximately 50 mg kg^{-1} or about twice that of other mineral soils (Fox, 1976). This suggests that unless N contributed from the soil organic matter, the mulched tops, and immobilized fertilizer N could have been mineralized in synchrony with crop demand during the next few weeks following the end of the experiment, the mulched tops management may have become N deficient relative to the other managements as suggested by Asghar and Kanehiro (1976) and Robertson and Thorburn (2000).

Composting of sugarcane tops should be explored in order to narrow the C/N ratio and thereby decrease the potential for N immobilization in the field (Rivacoba and Morín, 2002). This would be particularly feasible in mechanically harvested operations where sugarcane tops are removed at the mill and could be mixed with soil residue washed from the millable sugarcane stalks (cane wash) and possibly other mill waste by-products for the composting process (Stoffella and Graetz, 2000). Analysis of such a material will be the subject of a future study by the authors.

In contrast to the soil NO_3-N data, the mulched tops management had the greatest concentration of mineralizable organic N while there were no differences for this parameter among the other managements (Table 5). Considering that the shoot DM yield (Table 3) and N concentration (Table 4) responses were similar for the mulched and burnt tops managements it is interesting to note that 73% (32 mg kg^{-1}) of the 44 mg kg^{-1} (40 kg ha^{-1}) difference between these managements for extractable NO_3-N could potentially be made up for by their difference in mineralizable organic N. A study would have to be conducted with ^{15}N labeled fertilizer in order to determine the portion of mineralizable N coming from immobilized fertilizer N vs. the cane tops and soil organic matter (Rowell, 1994). Because of limited potential for denitrification and ammonia volatilization (Asghar and Kanehiro, 1976; 1977), the remaining difference between the mulched and burnt tops managements was probably due to fertilizer N immobilized in forms that are not readily mineralized.

A variety effect for modified-Truog extractable P occurred because HS averaged slightly greater across managements (mean = 45 mg kg^{-1}) than TC (mean = 42 mg kg^{-1}). This can be primarily attributed to increased shoot P uptake associated with the greater TC yields. Both the mulched ($P < 0.10$) and burnt ($P < 0.05$) tops managements increased modified-Truog extractable P by 4 to 6 mg kg^{-1} relative to the control and K replacement managements (Table 5). This can be attributed to P release directly from the mulched and burnt top inputs. While working with a Lihue silty clay (very-fine ferruginous, isohyperthermic Rhodic Eutrustox) Lai and Rajan (1972) suggested that increased soil P availability in response to the incorporation of sugarcane leaves resulted from the dissolution of Fe/Al bound P or competition for soil P-retention sites by low molecular weight organic acids (citrate and oxalate) released from the decomposing leaves. In the present study, the similar responses for the mulched and burnt tops managements do not support this suggestion. Guppy *et al.* (2005) concluded that reported decreases in P retention in response to organic matter additions are not related to reactions involving the organic decomposition products, but are the result of P release from the organic matter that was not accounted for when calculating P retention.

A variety effect for exchangeable K occurred because HS averaged 11 ± 6 mg kg^{-1} greater across managements than TC (data not shown). This can be primarily attributed to increased shoot K uptake associated with the greater TC yields. As expected, the exchangeable K concentration for all managements (Table 5) was very low as the critical K concentration for Andisols is generally between 100 and 140 mg kg^{-1} (Pérez and Melgar, 2000) or occasionally more (Clements, 1980). However, the exchangeable K data is particularly interesting because except for the control which had the lowest concentration, the concentrations follow an inverse pattern of that observed for shoot K concentration (Table 4). These data suggest that K added as KCl fertilizer in the K replacement management was readily available for uptake while that added in burnt and particularly mulched tops was more slowly available. While fertilizer KCl is 100% water soluble, the K in chopped tops and burnt tops was 70 and 89% water soluble at the start of the experiment (Table 2). Srivastava and Prakash (1990) previously suggested that a portion of the K in mulched sugarcane residues is slowly released as they breakdown. This was confirmed by the exchangeable K data for the mulched tops incubation experiment (Fig. 1) and is likely due to K trapped within intact cells and attraction of K to organic matter functional groups (Playne *et al*., 1978). Even a 12 h incubation in rumen fluid followed by a 20 min H_2O extraction solubilized only 74 and 82% of the K in the tropical forage grasses purpletop chloris [*Chloris barbata* (L.) Swartz.] and speargrass [*Heteropogon contortus* (L.) Palisot de Beauvois ex Roemer & Schultes] that had been ground to pass a 2 mm sieve (Playne *et al*., 1982). Most of the K in the burnt tops would be expected to be present as readily soluble potassium carbonate (K_2CO_3) or other K salts.

While the burnt and mulched tops managements did not differ from the control in exchangeable Mg they had greater Mg concentrations than the K replacement management (Table 5). This can be attributed to Mg inputs from the mulched and burnt tops coupled with differences in total shoot Mg uptake between the K-replacement management and the control that produced 50% less DM.

The mulched tops management increased 0.02 *M* $KMnO_4$-oxidizable C by 1.17 g kg^{-1} compared to the control (Table 5). This indicates that about 24% of the C added via the sugarcane tops was contributing to the biologically active soil C pool by the end of this short term study (Weil *et al*., 2003). Weil *et al* (2003) found that 0.02 *M* $KMnO_4$-oxidizable C provided good relationships to common measures of soil microbial activity (respiration, biomass, etc.), soluble carbohydrate C, and was intimately associated with the stability of macroaggregates. Despite their high soil organic C concentrations even Andisols are susceptible to structural deterioration when tilled repeatedly for annual crops with limited inputs of readily oxidizable C (Osher *et al*., 2003). This is because most soil organic C is recalcitrant (Weil *et al*., 2003). Therefore, rotations of annual crops with 'green harvested' sugarcane where the tops are returned to the field as a mulch has been increasingly promoted in several countries.

CONCLUSIONS

Mulching with sugarcane tops is beneficial to increase oxidizable or "active" soil organic C and recycle nutrients. However, it can immobilize substantial inorganic N in the short-term and should be considered a very slow release source of mineralizable N. This N immobilization may necessitate increases in N fertilization. Future research should explore the composting of sugarcane tops where feasible in order to decrease the C/N ratio and thereby potential for N immobilization. While two thirds of the K in sugarcane tops is readily soluble the remainder is only slowly made available as the tops breakdown.

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Table 1. Selected properties of the Honokaa soil (0- to 15-cm depth)[a].

pH (1:2 soil/solution paste)	
H_2O	5.9
1 *M* KCl	5.0
Bulk density, organic C and total N	
Bulk density (core method), g cm^{-3}	0.6
C, g kg^{-1}	115.6
N, g kg^{-1}	7.5
Exchangeable cation concentrations and K^+ fixation	
Ca^{2+}, mg kg^{-1}	1900
Mg^{2+}, mg kg^{-1}	268
K^+, mg kg^{-1}	26
Na^+, mg kg^{-1}	40
K^+ fixation, %[b]	8.3
Extractable P, NH_4-N, and NO_3-N	
Modified-Truog extractable P, mg kg^{-1}	49
1 *M* KCl extractable NH_4-N, mg kg^{-1}	9
1 *M* KCl extractable NO_3-N, mg kg^{-1}	24

[a] The subsoil at the sampling site was also very low in exchangeable K ranging from 18 to 39 mg kg^{-1} for samples collected at 15 cm increments to a depth of 75 cm.

[b] Determined from a 120 d equilibration of 161 mg K kg^{-1} applied as KCl and thoroughly mixed with soil maintained at field capacity water content.

Table 2. Selected chemical properties of the sugarcane tops and the effect of burning the tops on pH of the resulting ash and the percentage loss of C, N, and S.

Sugarcane tops	
pH (1:8 ground tops/deionized H_2O suspension)	5.7
Organic matter, g kg^{-1}	952.0
C, g kg^{-1}	437.4
N, g kg^{-1}	10.6
C/N ratio	41.3
P, g kg^{-1}	1.7
K, g kg^{-1}	14.5
Percentage of K soluble in a 1:40 chopped tops/deionized H_2O suspension	69.7
Ca, g kg^{-1}	2.6
Mg, g kg^{-1}	1.3
S, g kg^{-1}	1.2
Mn, mg kg^{-1}	34.0
Fe, mg kg^{-1}	77.5
Si, g kg^{-1}	8.2
Cellulose, g kg^{-1}	351.4
Hemicellulose, g kg^{-1}	348.0
Lignin	45.2
In vitro digestible organic matter (IVDOM), g kg^{-1}	506.0

Burnt sugarcane tops	
pH (1:8 ash/deionized water suspension)	9.3
Percentage of total K soluble in a 1:40 burnt tops/deionized H_2O suspension	89.0
Dry matter (DM) loss, % of initial	86.2
C loss, % of initial	85.7
N loss, % of initial	78.3
S loss, % of initial	60.4

Table 3. Effect of sugarcane tops management and variety on shoot dry matter yield of Hawaiian Supersweet #9 (HS) and Tex-Cuban white flint (TC) maize 30 d after germination[a].

	Variety	
Management	HS (g pot^{-1})	TC (g pot^{-1})
Control	6.8c	10.0b
Burnt tops	13.2b	19.4a
Mulched tops	12.1b	18.4a
K replacement	16.1a	19.3a
SE[b]	0.6	0.8

[a] Means in the same column not followed by the same letter are different at $P < 0.05$ using Fisher's F-test protected LSD test.
[b] Standard error of a management mean.

Table 4. Effect of sugarcane tops management on concentrations of N, K, Ca, Mg, and Mn in the shoots of maize averaged across varieties 30 d after germination[a].

Management	N (g kg^{-1})	K (g kg^{-1})	Ca (g kg^{-1})[b]	Mg (g kg^{-1})	Mn (mg kg^{-1})
Control	35.7a	6.8d	4.7a	8.9a	31a
Burnt tops	28.8b	20.4b	4.2b	5.4b	24bc
Mulched tops	27.1b	17.9c	4.4ab	5.7b	23c
K replacement	28.2b	23.4a	4.1b	5.2b	27b
SE[c]	0.7	0.6	0.2	0.3	1

[a] Means in the same column not followed by the same letter are different at $P < 0.05$ using Fisher's F-test protected LSD test unless otherwise noted.
[b] Means for Ca not followed by the same letter are different at $P < 0.10$ using Fisher's F-test protected LSD test.
[c] Standard error of a management mean.

Table 5. Effect of sugarcane tops management on soil pH, 1 *M* KCl extractable NO_3-N, mineralizable organic N, modified-Truog extractable P, 1 *M* NH_4OAc exchangeable K and Mg, and 0.02 *M* $KMnO_4$-oxidizable C[a].

Management	pH (mg kg^{-1})	NO_3-N (mg kg^{-1})	Mineralizable-N (mg kg^{-1})	P (mg kg^{-1})	K (mg kg^{-1})	Mg (mg kg^{-1})	Oxidizable C (g kg^{-1})
Control	5.8c	119a	15b	41b[b]	5d	234ab	5.42b
Burnt tops	6.0b	92b	14b	47a	35b	243a	5.42b
Mulched tops	6.1a	48c	46a	45ab[b]	50a	245a	6.59a
K replacement	5.8c	74b	16b	41b[b]	21c	219b	5.34b
SE[c]	__	9	2	1	2	5	0.18

[a] Means in the same column not followed by the same letter are different at $P < 0.05$ using Fisher's F-test protected LSD test.

[b] Extractable P for the mulched tops management differs from the control and K replacement managements at $P < 0.10$.

[c] Standard error of a management mean.

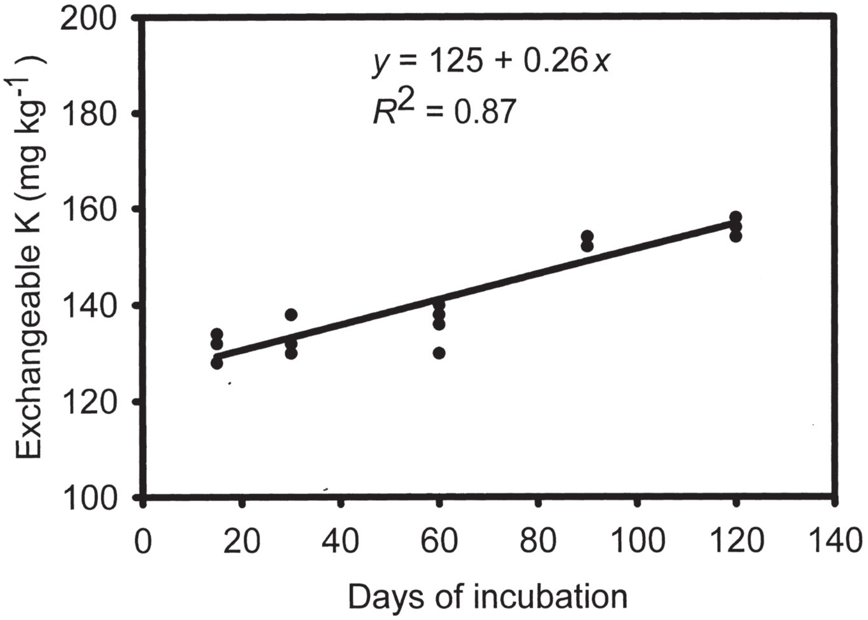

Figure 1. Soil exchangeable K concentration as a function of time after the addition of chopped sugarcane tops. Initial exchangeable K concentration was 26 mg kg^{-1} (Table 1). The recovery percentages of K added in the tops after 15, 30, 60, 90, and 120 days were 65, 66, 68, 78, and 81%.