SIZE AND ACTIVITY OF THE SOIL MICROBIAL BIOMASS IN THE ROW AND INTER-ROW OF A SUGARCANE FIELD UNDER BURNING AND GREEN CANE HARVESTING

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Abstract

The size and activity of the soil microbial biomass was studied in the plant row and in the inter-row of a sugarcane field under burning or green cane harvesting. The sites sampled were on the long-term trash management trial situated at Mount Edgecombe. Soils were sampled to 30 cm depth in (i) the centre of the plant row, (ii) 30 cm out from the row centre and (iii) 60 cm out from the row centre (i.e. the middle of the inter-row area). Under burning, the only substantial input of organic matter to the soil was from root turnover in the row area where the root biomass was concentrated. As a consequence, the size (microbial biomass C) and activity (basal respiration) of the soil microbial community were concentrated in the row. However, under green cane harvesting there was a large input of organic matter in the inter-row area in the form of the trash blanket itself and through turnover of crop roots that were concentrated in the surface 10 cm of soil below the trash blanket. As a result, soil microbial activity was considerably higher in the inter-row area under green cane harvesting than under burning. Such results highlight the benefit of green cane harvesting to soil quality under sugarcane production.

Keywords: sugarcane, organic matter, burning, green cane harvesting, microbial biomass

Introduction

Loss of soil organic matter under sugarcane subjected to pre-harvest burning is believed to be a major factor contributing to soil degradation in the South African sugar industry (Meyer *et al*., 1996; Haynes and Hamilton, 1999). When studies on soil degradation are carried out, generally soil from the inter-row space is sampled (Graham *et al*., 1999, 2000; Dominy *et al*., 2001). Under pre-harvest burning, the inter-row space is effectively fallow and inputs of organic material are minimal. When green cane harvesting is employed, the C input to the inter-row area is greatly increased because it is covered with a blanket of trash. Organic matter content and structural stability of soil in the inter-row space is, therefore, greatly increased under green cane harvesting.

Dominy and Haynes (2002) recently suggested that the organic matter content could differ greatly between soil below the row and that in the inter-row space. This is because sugarcane is a perennial crop and can commonly remain in the ground for up to 10 years (i.e. one planted crop and nine ratoon crops). Under a burning regime the main organic matter input to the soil would occur via rhizodeposition and would be concentrated in the root zone below the sugarcane rows. For this reason, soil in the rows would have a higher organic matter content than that in the inter-row space. In agreement with this suggestion, Hartemink (1998a) observed that soil organic C concentrations tended to be larger in the row than in the inter-row of sugarcane fields in Papua New Guinea. If such gradients were pronounced then measurement of the organic matter content of the inter-row would underestimate the total quantity of organic matter present in a sugarcane field. In addition, such gradients would be expected to result in similar, or even more pronounced, gradients in soil microbial activity and structural stability. The existence of such gradients has, however, not yet been investigated.

The purpose of this study was to investigate the changes in soil organic matter status, microbial activity and aggregate stability that occur within a sugarcane field at increasing distances out from the centre of the plant row. These changes were investigated under pre-harvest burning and green cane harvesting using the long-term trash management trial at SASEX.

Materials and Methods

The trial (designated BT1) is situated at Mount Edgecombe on a vertisol (Arcadia form, Lonehill family; Soil Classification Working Group, 1991) with an ‘A’ horizon of about 500 mm. Mean annual precipitation at the site (longitude 31°04'29'' and latitude 29°43'20'') is about 950 mm.

The main experimental treatments are: (i) green cane harvested with retention of a trash blanket (100% cover) (T), (ii) burning prior to harvest with tops left scattered on plots (67% cover) (Bt) and (iii) burning prior to harvest with all tops raked of plots (Bto). The treatments are either (a) unfertilised (Fo) or (b) fertilised annually with 140 kg N/ha, 20 kg P/ha and 140 kg K/ha (F). The experiment is replicated four times in a randomized split-plot design. Three replicates of the TF and BtoF treatments were sampled for this study.

At the site, sugarcane is planted in rows 1.4 m apart. Soils were sampled in (i) the centre of the plant row, (ii) 30 cm out from the row centre (30 cm) and (iii) 60 cm out from the row centre (60 cm) (i.e. the middle of the inter-row area). This procedure was carried out in three randomly chosen areas of each plot; soils were sampled to a depth of 30 cm, sectioned into the 0-10, 10-20 and 20-30 cm layers, and samples from each layer were bulked.

Within 48 hours of collection, bulk field-moist samples were thoroughly mixed and split into three sub-samples. One sub-sample was sieved (> 2 mm) and stored at 2°C prior to biological analysis. Another sub-sample was air-dried, sieved (< 2 mm) and ground (< 0.5 mm) for subsequent analysis of organic C. The third sub-sample was sieved and the 2-6 mm diameter aggregates were collected and air-dried for subsequent analysis of aggregate stability.

Soil organic C (C_{org}) content was determined by the Walkley and Black dichromate oxidation method (Blackmore *et al.*, 1972). Microbial biomass C (C_{mic}) was estimated by the fumigation-extraction method based on the difference between C extracted with 0.5 M K_2SO_4 from chloroform fumigated and unfumigated soil samples using a K_c factor of 0.38 (Vance *et al.*, 1987). The microbial quotient (C_{mic}/C_{org}) was calculated by expressing microbial biomass C as a percentage of total organic C. Basal respiration was determined by placing 30 g oven-dry equivalent of field moist soil in a 50 ml beaker and incubating the sample in the dark at 25°C in a 1 L air-tight sealed jar along with 10 mL of 1 M NaOH. The CO_2-C evolved was determined after 2, 5 and 10 days by titration (Anderson, 1982). The metabolic quotient (qCO_2) was calculated as basal respiration (µg CO_2-C day^{-1}) mg^{-1} of C_{mic}.

Aggregate stability was measured using a wet sieving technique (Haynes, 1993). Thirty grams of air-dried 2-6 mm soil aggregates were transferred to a wet sieving apparatus (sieve aperture = 2 mm). The water level was adjusted so that aggregates on the sieve were just submerged at the highest point of oscillation. The oscillation rate was 25 cycles min^{-1}, the amplitude of sieving action was 35 mm and the period of wet sieving was 15 min. The results were expressed as mean weight diameter (mm), which is the sum of the fraction of soil remaining on each sieve after sieving multiplied by the mean diameter of the inter-sieve aperture.

Root samples were collected using the core technique (Fehrenbacher and Alexander, 1955; Kücke *et al*., 1995). A stainless steel pipe with a 37.5 mm inside diameter was driven into the soil with a motorized hammer. The samples were extracted from the soil after each 10 cm penetration to remove the sample. Samples were sectioned into 0-10, 10-20 and 20-30 cm layers.

Samples were immediately washed free of soil before being stored in a freezer until root length could be determined. Samples collected from soil with a high clay content were soaked in Calgon solution (20.0 g sodium hexametaphosphate + 8.0 g sodium carbonate per liter of water) for at least 24 hours before the roots were separated from the soil. Root length was determined by the line intersect method (Newman, 1966) as modified by Rowse and Phillips (1974). After root length determination, samples were oven-dried and total weight was determined.

In order to calculate the quantities of organic matter in the soil profile to 30 cm, per unit area, concentrations were first converted to a volumetric basis. For this purpose, bulk density was measured in quadruplicate using the core method in the 0-10, 10-20 and 20-30 cm layers. Bulk density samples were taken in the row centre and 30 and 60 cm from the row centre. The quantities of organic matter in the soil profile to 30 cm were calculated for each area. In order to calculate the C loads across the entire field, the proportion that each area (i.e. row, 30 cm and 60 cm) contributed to the field was estimated.

The statistical significance of experimental treatments was determined by subjecting the data to Analysis of Variance and Least Significant Differences (LSD) were calculated at the 5 % level.

Results

Both root mass and length density tended to decrease with increasing distance from the plant row (Table 1). In the surface 10 cm, the burnt treatment had a greater root length density than the trash treatment at each distance from the row centre (Table 1). However, although root mass density was greater under burning than trashing below the row, values were similar at 30 cm and, in fact greater under trashing at 60 cm (Table 1). Root mass density decreased to a depth of 30 cm (Table 1). In the row, significant increases in the root mass density were observed to a depth of 30 cm in response to burning. By contrast, in the inter-row, trash retention resulted in significant increases in root mass density only in the top 10 cm. The inter-row area contributed the largest proportion of the field as a result the root mass, calculated across the field, showed no significant difference between the two treatments (Table 2).

Table 1. Root mass and length and density in the row, 30 cm and 60 cm at each depth.

Depth (cm)	Treat-ment	Root mass density (x 0.001 g cm^{-3})				Root length density (cm cm^{-3})			
		Row	30 cm	60 cm	LSD ($P \leq 0.05$)	Row	30 cm	60cm	LSD ($P \leq 0.05$)
0-10	BtoF	0.832	0.366	0.120	0.08	1.046	0.608	0.395	0.04
	TF	0.397	0.235	0.242		0.408	0.286	0.268	
10-20	BtoF	0.398	0.071	0.032	0.01	0.392	0.164	0.149	0.03
	TF	0.223	0.065	0.069		0.216	0.119	0.113	
20-30	BtoF	0.208	0.097	0.026	0.01	0.298	0.103	0.100	0.02
	TF	0.067	0.051	0.027		0.164	0.111	0.093	

T = green cane harvesting with a trash blanket left at the soil surface.
Bto = burnt with harvest residues removed
F = fertilised annually with N, P and K.

Table 2. Quantities of root biomass and C, organic C, microbial biomass C and K_2SO_4-extractable C in the surface 30 cm of soil in the row, inter-row (60 cm) and across the field respectively.

	Root mass kg m^{-2}		Root biomass C Mg ha^{-1}		Organic C Mg ha^{-1}		Microbial biomass C kg ha^{-1}	
Area	TF	BtoF	TF	BtoF	TF	BtoF	TF	BtoF
Row	85.8	124	411	594	136	129	2284	1107
Inter-row	39.7	19.4	190	92	134	128	1045	527
Field	50.8	47.6	245	249	135	129	1459	795
LSD ($P \leq 0.05$)	23.6	19.8	113	147	2.87	1.56	136	128

T = green cane harvesting with a trash blanket left at the soil surface
Bto = burnt with harvest residues removed
F = fertilised annually with N, P and K.

In the surface 10 cm, concentrations of C_{org} and C_{mic} (Figure 1) decreased, with increasing distance from the row centre (i.e. Row > 30 cm > 60 cm) and were higher under trash retention than burning. Since C_{mic} was considerably more influenced by treatments than C_{org}, the microbial quotient also decreased with increasing distance for the row centre and was higher under trashing (Figure 1). Significant increases in C_{org} due to trash retention were observed only in the surface 10 cm of soil in the inter-row, but to a depth of 20 cm in the row (Figure 2). By contrast, significant increases in C_{mic} (Figure 2) were observed to a depth of 30 cm in response to trash retention in the row centre as well as in the inter-row. The microbial quotient decreased with increasing soil depth but was higher under trash retention at all depths (Figure 2).

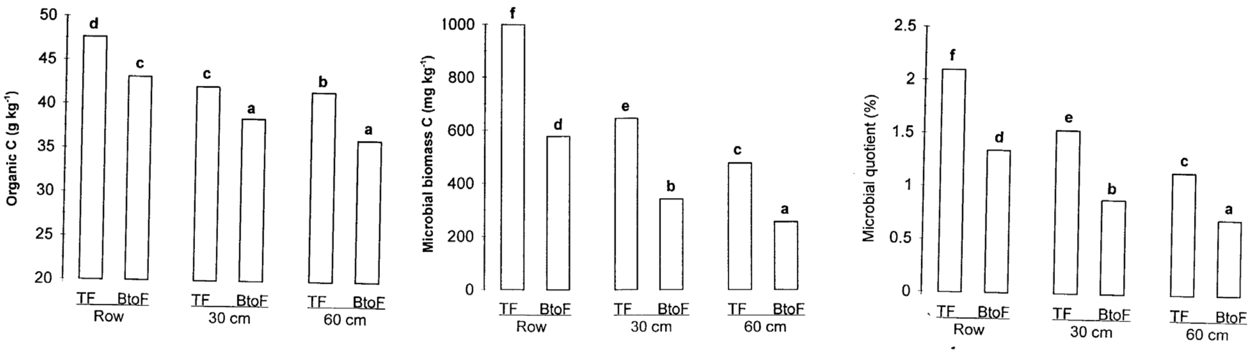

Figure 1. Organic C, microbial biomass C and microbial quotient in the 0-10 cm soil layer with increasing distance from the row centre (row, 30 cm and 60 cm) for both TF and BtoF treatments. T = green cane harvested with trash retention; Bto = burnt with harvest residues removed;F = fertilized annually with N, P and K. Means associated with the same letter are not significantly different (based on LSD $P \leq 0.05$).

Basal respiration in the surface 10 cm followed the same trends as that of C_{mic} (Figure 3) and as a result the qCO_2 increased with increasing distance from the row and was higher under burning than trashing (Figure 3). Basal respiration decreased with increasing soil depth whilst qCO_2 tended to increase (data not presented).

Although concentrations of organic C were lower in the inter-row than the row, the bulk density was considerably higher in the inter-row. As a result, when quantities of C_{org} under both trashed and burnt treatments were calculated on a per-hectare basis to a depth of 30 cm, there were no significant differences between values for the row, inter-row or on a field basis (Table 2). For C_{mic} values were highest in the row, lowest in the inter-row and intermediate when calculated on a field basis (Table 2). Trashing resulted in larger quantities of C_{mic} and to a lesser extent C_{org}, on a per hectare basis, in the row, inter-row and per field.

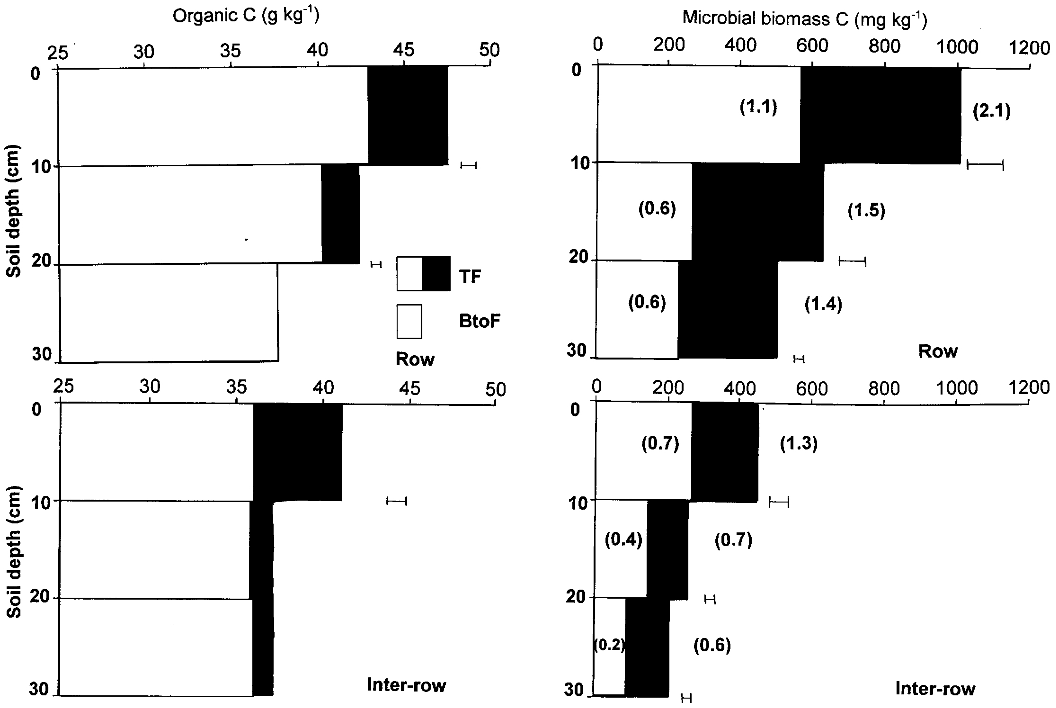

Figure 2. Effects of burning and green cane harvesting on soil organic C and microbial biomass C content in the soil profile in the row and inter-row. Values for the microbial quotient at each depth are shown in brackets. T = green cane harvested with trash retention; Bto = burnt with harvest residues removed; F = fertilised annually with N, P and K. LSD ($P \leq 0.05$) for comparison between treatments.

The size distribution of aggregates following wet sieving of samples from the 0-10 cm layer is shown in Figure 4. The percentage of sample remaining in the 2-6 mm class and the mean weight diameter was greatest for the trashed treatment, decreasing with increasing distance from the row centre. In the row area, aggregate stability was significantly increased to a depth of 30 cm in response to trash retention, however this effect was only statistically significant in the top 10 cm of inter-row area (data not shown).

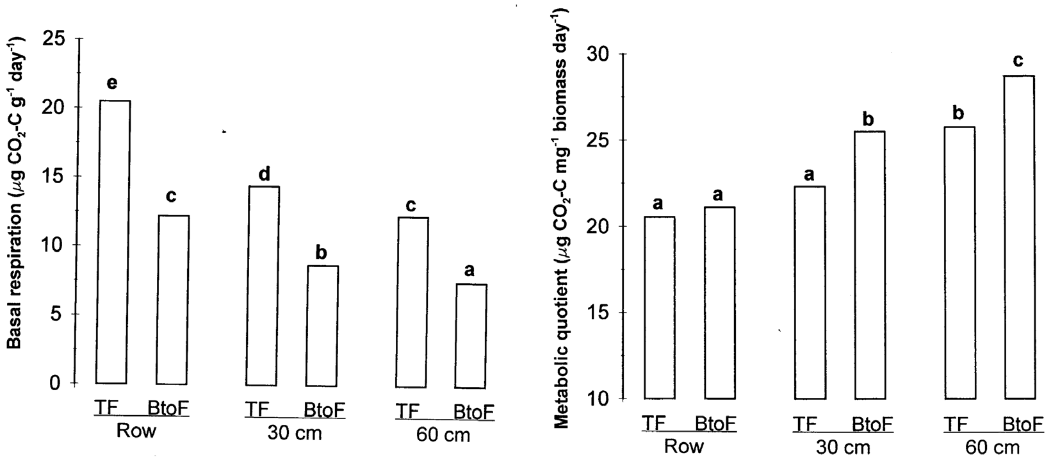

Figure 3. Basal respiration and metabolic quotient in the 0 - 10 cm soil layer with increasing distance from the row centre (row, 30 cm and 60 cm) for both TF and BtoF treatments. T = green cane harvested with trash retention; Bto = burnt with harvest residues removed; F = fertilised annually with N, P and K. Means associated with the same letter are not significantly different (based on LSD, $P \leq 0.05$).

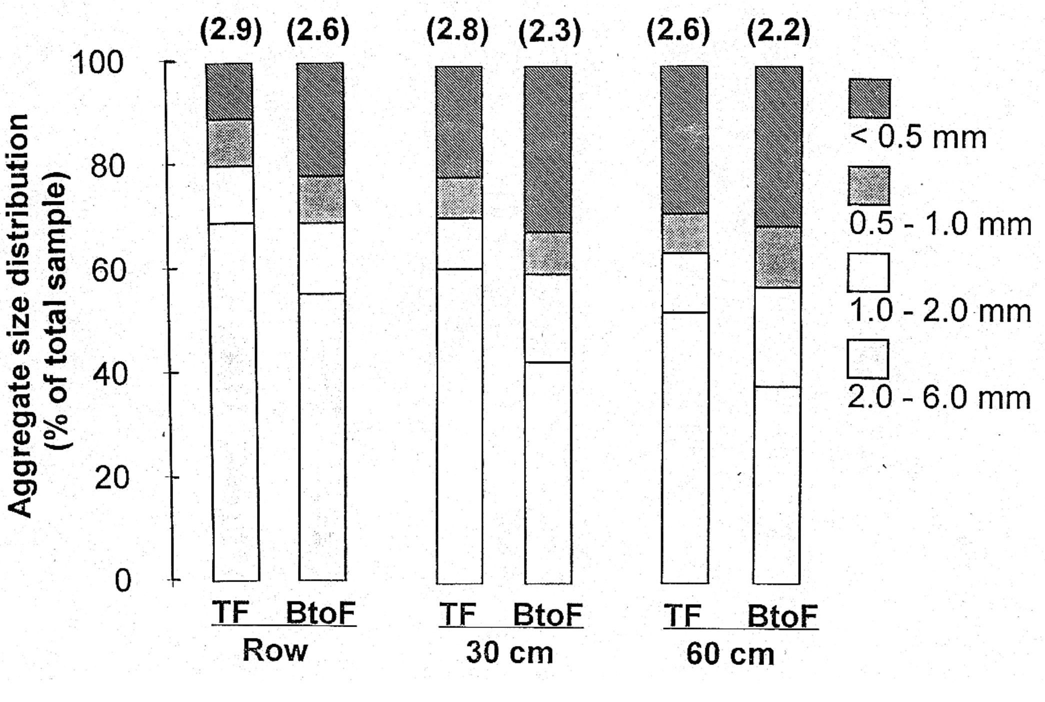

Figure 4. Size distribution of aggregates following wet sieving in the 0-10 cm soil layer with increasing distance from the row centre (row, 30 cm, 60 cm) for both TF and BtoF treatments. Values for the MWD (mm) are shown in brackets. T = green cane harvested with trash retention; Bto = burnt with harvest residues removed; F = fertilised annually with N, P and K.

Discussion

Under pre-harvest burning, the main C inputs to the soil are in the form of turnover of sugarcane roots. It is clear that under burning sugarcane roots are concentrated in the row below the stem clump. This has also been observed by other workers (Ball-Coelho *et al*., 1992; Hartemink, 1998b) and, as shown here, this is translated into a concentration of organic matter and microbial activity in the soil below the plant rows.

Root biomass contributes large amounts of organic matter to the soil. Rhizodeposition of organic material occurs in several ways including exudation of mucilaginous material which is dominantly polysaccharides (Morel *et al*., 1991). Input of root tissue also occurs from sloughing of root tissues during root senescence, conversion of very fine roots to those with secondary thickening (autolysis of cortical tissues) releasing epidermal and cortical tissue, senescence of woody or fine roots, and root tissue loss or damage due to faunal grazing or microbial root diseases (Haynes and Beare, 1996). However, it is root mortality that generally contributes most to the formation of soil organic matter (Clarke *et al*., 1967). This C supply from the roots encourages microbial proliferation in the rhizosphere and as a result, microbial activity was significantly increased in the row area. Indeed, the microbial quotient was considerably higher in the row (mean 1.22) than the inter-row (mean 0.65) (Figure 1). As noted previously (Graham *et al*., 1999), the microbial quotient is notably low in the inter-row since values normally range from 1-2 % (Sparling, 1997).

Factors such as soil compaction within the inter-row also contribute to poor root proliferation in the inter-row area. For example, wheeled traffic during harvesting and other field operations causes considerable compaction especially during wet harvesting seasons (Haynes and Hamilton, 1999). As a result, the bulk density and penetration resistance increases and pore space decrease causing poor root proliferation in the inter-row (Hartemink, 1998a).

The much larger root length and mass in the row under burning than trashing is probably related to the lack of a surface mulch and thus a shortage of soil water in the burnt treatments. Water stress often stimulates root growth resulting in longer, finer roots which are able to explore the soil volume for water more effectively (Sharp and Davies, 1979). Indeed, at all three sampling positions, the root length density was greater under burning.

Despite the smaller root mass, C_{org} was significantly increased in the row to 20 cm in response to trash retention. Large amounts of leaves and tops are returned annually to the soil with green cane harvesting, covering the soil surface in both the row and the inter-row. This explains the accumulation of organic matter in the row. Earthworm communities tend to be concentrated in the row area of sugarcane fields (Spain *et al*., 1990) and they could contribute to downward movement of organic material to 20 cm. Earthworms are actively involved in the redistribution of particulate organic matter fractions within the profile. They can ingest/collect the decaying plant material from the soil surface and redistribute it within their burrows. Earthworm casts frequently have a higher organic matter content than bulk soil (Haynes and Beare, 1996).

Return of trash to the soil surface has been shown to have a positive effect on various soil chemical (Graham *et al*., 2000), biological (Graham *et al*., 1999) and physical (Graham *et al*., 2000) properties. Surface mulches also result in water conservation by reducing runoff, increasing infiltration and reducing losses by evaporation. The moist soil conditions below the mulch stimulated root proliferation in the 0-10 cm layer of the inter-row under trashing. The redistribution of roots into the inter-row is also favoured by the large amounts of nutrients leaching from the trash blanket (Graham *et al*., 2000). Similarly Ball-Coelho *et al*. (1992) reported a concentration of roots at the soil surface and in the litter layer of mulch treatments. Although the root biomass was greater in the inter-row under trashing, there was no significant difference in total root biomass between the two treatments. Nevertheless, the redistribution of roots towards the inter-row under trashing will result in more rhizodeposition of C in the inter-row. This will contribute to the greater organic matter, higher biological activity and greater aggregate stability in the inter-row under trashing.

When sugarcane is burnt very little above ground plant material is returned to the soil and the inter-rows are left fallow. The metabolic quotient was considerably higher in the inter-row of burnt than trashed treatments. An increase in the metabolic quotient has been interpreted as a response by soil microflora to adverse environmental conditions (either environmental stress or disturbance) (Wardle and Ghani, 1995). In the inter-row of the burnt treatment the main stresses are likely to have been a sparsity of labile C, water stress and possibly, also compaction.

The relative decrease in C_{mic} in response to both burning and increasing distance away from the row was much greater than that for C_{org} (Figure 1). As a result, the microbial quotient was higher in the row than inter-row and higher under trashing than burning. A similar trend was also evident for basal respiration (Figure 3). Thus, as noted by a number of other workers (Gregorich *et al*., 1994) the effects of agricultural practice on organic matter status are more obvious, and noticed first, when measuring the size and activity of C_{mic} rather than simply measuring C_{org}.

Changes in C_{org} and C_{mic} play a major role in soil aggregation (Haynes and Beare, 1996). The major organic binding agents in soil are humic molecules and polysaccharides. These molecules can strongly bind to the mineral components of soils, and to each other, and are therefore of central importance in relation to binding aggregates together. The microbial biomass is also important due to its production of polysaccharide binding agents (mucilages) and the binding ability of fungal hyphae. Thus, the smaller C_{org} and C_{mic} concentrations in the surface soil under burning resulted in a substantially lower aggregate stability than under trashing. This means that soil in the inter-row of the burnt treatment is predisposed to structural breakdown and compaction. Such compaction occurs commonly in sugarcane inter-rows, and along with poor aggregation, tends to decrease infiltration and increase surface runoff (Wood, 1985; Prove *et al*., 1995).

The higher aggregate stability in the row than inter-row is likely to be not only because of the larger C_{org} and C_{mic} but also due to the direct and indirect effects of the presence of crop roots. Roots exert a stabilizing influence on soil structure partially through mucilage produced by the microbial population of the rhizosphere and by exudation of mucigel from the root (Russell, 1973). Roots and root hairs of plants, as well as associated mycorrhizal hyphae, can act as aggregating and temporary binding agents. They have been shown to enmesh fine particles of soil into aggregates (Clarke *et al*., 1967; Coughlan *et al*., 1973; Haynes and Beare, 1996).

Although C_{org} concentrations were less in the inter-row than row, bulk density was greater in the inter-row. As a result, when calculated on a per hectare basis, C_{org} values based on samples taken from the inter-row did not underestimate the C reserves in the field. Nonetheless, the equivalent values for C_{mic} were clear underestimates (Table 2). Where C reserves are being compared under various land uses, sampling randomly over the entire fields rather than between the row is obviously an important consideration.

However, from an agronomic viewpoint, the soil organic matter status and soil physical conditions in the inter-row are of great importance. The inter-row space represents about 60 % of the surface area of a sugarcane field and it is the main area where surface runoff, erosion and compaction occurs. Indeed, on the rolling topography of the South African sugar belt, losses of soil through water erosion are common. An increase in organic matter, microbial activity and aggregate stability in the inter-row space induced by green cane harvesting is therefore of considerable significance.

Conclusion

It is clear that under burning, the roots of sugarcane are concentrated below the stem clump down the plant rows. This results in a large gradient in organic matter content, soil microbial activity and aggregate stability across the fields with values being greatest below the rows and least in the middle of the inter-rows. Conversion to green cane harvesting results in redistribution of root mass and a concentration of roots in the surface soil in the inter-row space below the trash mulch. As a result of the large organic matter inputs via the trash itself, and in the form of root turnover, the organic matter status, size and activity of the microbial community and aggregate stability are all appreciably increased in the inter-row space under green cane harvesting. The likely results of these changes include stabilization of the surface soil, increased infiltration, a greater rate of nutrient turnover and reduced runoff and erosion and thus conservation of the soil resource in the sugar belt.

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