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Linking measured carbon dioxide exchange by sugarcane crops and biomass production

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CARBON TRADING and the growing interest in biofuel production from sugarcane necessitate the ability to measure gains and losses of soil organic C which may occur as a result. Modelling and soil sampling suggest that changes in soil C are likely to be < 1 t C/ha/y. Published accounts indicate that confirming such small changes by traditional soil sampling is error-prone and requires investigations of > 10 years. The paper explores the possibility of calculating soil gains or losses by subtracting the carbon stored in the crop biomass from the carbon gained by the crop through the uptake of carbon dioxide supplied by the atmosphere and processes in the soil. Although uptake and storage very nearly balanced each other in one–year measurements in each of two sugarcane crops for which carbon turnover differed by a factor of 2, it was concluded that errors and uncertainties in the measurements and calculations were presently too large to detect the small differences in the gain or loss of soil C claimed for different management practices or predicted by modelling, at least in the short term.

Keywords

linking, crops, measured, biomass, production, carbon, dioxide, exchange, sugarcane, GeoQUEST

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LINKING MEASURED CARBON DIOXIDE EXCHANGE BY SUGARCANE CROPS AND BIOMASS PRODUCTION

By

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KEYWORDS: Carbon Dioxide Fluxes, Carbon Balance, Modelling, Eddy Covariance, Chambers.

Abstract

CARBON TRADING and the growing interest in biofuel production from sugarcane necessitate the ability to measure gains and losses of soil organic C which may occur as a result. Modelling and soil sampling suggest that changes in soil C are likely to be < 1 t C/ha/y. Published accounts indicate that confirming such small changes by traditional soil sampling is error-prone and requires investigations of > 10 years. The paper explores the possibility of calculating soil gains or losses by subtracting the carbon stored in the crop biomass from the carbon gained by the crop through the uptake of carbon dioxide supplied by the atmosphere and processes in the soil. Although uptake and storage very nearly balanced each other in one–year measurements in each of two sugarcane crops for which carbon turnover differed by a factor of 2, it was concluded that errors and uncertainties in the measurements and calculations were presently too large to detect the small differences in the gain or loss of soil C claimed for different management practices or predicted by modelling, at least in the short term.

Introduction

The possibility of carbon trading and the growing interest in biofuel production highlight the need to document the carbon balances of Australia's cropping systems, particularly sugarcane production.

The adoption of green cane harvesting in much of the sugar belt is significant in this context as one of its suggested advantages is the possible sequestering of carbon (C) into the soil through the breakdown of the trash mulch left on the soil surface and the incorporation of some of the C into soil organic matter, while harvesting the whole crop for biofuel production is likely to lead to a depletion of soil organic C (Vallis *et al.*, 1996). To confirm this by soil sampling is a lengthy and painstaking task since the suggested annual changes in soil organic C are likely to be < 1 t C/ha (Vallis *et al.*, 1996). Vallis *et al.* (1996) adapted the Century model to predict changes in soil organic C in sugarcane production systems employing burnt and unburnt trash management.

Apparently steady state levels of soil C were predicted for annual trash burning, but increases of 2 to 4 t C/ha were predicted for a system of trash blanketing in which five successive ratoon crops were grown after the plant crop. After five years, the cane was ploughed out and the sequence repeated.

A sharp decrease in soil C was predicted after the fifth ratoon was ploughed out. Simulations using 91 years of rainfall and temperature from Ingham and soil properties from two sites in the Ingham district indicated a net annual gain over a period of 60–70 years of approximately 0.2 t C/ha/y with gains of about twice that magnitude in the first 20 years of trash retention. However, field measurements of soil C could not confirm the gains; large yearly fluctuations, which Vallis *et al.* (1996) attributed to the inherent difficulties in accurately sampling and measuring soil C in large field plots, obscured the trends.

In a Brazilian field experiment extending over 16 years, in which changes in soil C were calculated from soil sampling at the beginning and end of the period, Resende *et al.* (2006) found an annual gain in soil C of 0.16 t C/ha in trash blanketed plots, which, however, was not statistically significant.

Coefficients of variation for the determination of soil C were between 13 and 30%. The indications are that changes in soil C are small and difficult to detect by soil sampling in the short term. In this paper, we examine a new approach based on the C balance of the crop.

The carbon assimilated by crops derives from atmospheric carbon dioxide (CO_2) and CO_2 emitted at the soil surface from leaf litter decomposition and soil and root respiration. Measurement of these two exchanges thus permits the C balance of crops to be assessed in a non-destructive way.

Denmead *et al.* (2009) measured large differences in the CO_2 derived from both atmospheric and soil sources between sugarcane crops at Mackay and Murwillumbah. The questions arise as to what extent these differences are reflected in biomass production and can a comparison of the measured C uptake and the C stored in the biomass indicate the probable extent of C sequestration to or loss from soil in cane crops. This paper compares the measured uptake of CO_2 by the two crops with biomass production calculated from mill data, field sampling and some literature values.

Methods

Sites and crop management

As reported in Denmead *et al.* (2009), the measurements at Mackay were made in a block of trash-blanketed 5th ratoon cane on a farm in the Racecourse Mill District. The soil is a sandy loam (Chromosol) with 1.7% organic C and a pH of 4.7

in the top 0.3 m. It is described locally as a Pioneer non-calcic brown soil. Fertiliser was applied at 150 kg N/ha on 19 November 2006. The CO_2 exchange measurements commenced on 8 November 2006 and continued for 292 days until 7 September 2007. Rainfall over the measurement period totalled 2142 mm and the mean air temperature was 22.4 ^oC.

The measurements at Murwillumbah were made on a farm at Blacks Drain within the Condong Mill District. The soils on the farm that are used for cane production are classified as acid sulfate soils.

They are characterised by a surface organic horizon 0.2–0.3 m deep (a clay loam with a porosity of 60%, an organic C content of 9.8% and a pH ~ 5), a strongly acidic A2 horizon (pH < 4) extending to around 0.5 m, a reduced B horizon and often, a water table at depths of 0.5–0.7 m.

The measurements were made in a block of 1^{st} ratoon cane that had been burnt before harvest. Carbon dioxide exchange measurements commenced on 14 October 2005 just prior to the application of urea fertiliser at a rate of 160 kg N/ha on 18 October and continued for 342 days until 20 September 2006. Rainfall for the period was 1859 mm and the mean air temperature was 19.3 ^oC.

A synopsis of the microclimate at each site was provided by Denmead *et al.* (2009). During our studies, the Mackay site was warmer and more humid, and despite the shorter growing season, received more solar radiation and more rain than the site at Murwillumbah.

One significant difference between the sites was the higher soil moisture content at Murwillumbah, due to the very high porosity of the surface soil, reduced evaporation during the winter months and perhaps the presence of a near-surface water table

CO_2 exchange

The measurement techniques employed in these studies have been described by Denmead *et al.* (2007, 2009) and Wang *et al.* (2008). The aims at both sites were to measure the average fluxes of CO_2 between crop and atmosphere in continuous 30-min runs by a micrometeorological eddy covariance technique, and to measure fluxes of CO_2 from the soil surface using chamber techniques.

Dynamic automatic chambers operating continuously through the growing season were employed at Mackay and static manual chambers, sampled less frequently, were used at Murwillumbah.

Fluxes during periods when the eddy covariance technique could not be applied because of unfavourable weather conditions (rain, dew, light winds, low turbulence) or when instrument or power failure prevented the operation of automatic chambers were inferred by interpolation or linear regression techniques as described in Denmead *et al*. (2007, 2009).

For comparing with biomass data, CO_2 fluxes have been converted to equivalent fluxes of C by multiplying the former by the ratio of the relevant molecular weights, 12/44.

Biomass data for Mackay

All biomass data are reported as t C/ha.

Harvested biomass was determined from mill data on the tonnage of cane delivered to the mill, assuming typical values for water content of 60 or 70% and, following Vallis *et al.* (1996), a value of 46% for the C content of the dry matter.

Trash biomass after harvest was assumed to be the same as that determined by field sampling at the start of the measurement period (Wang *et al.*, 2008), with the same C content as the harvested biomass.

Root biomass was estimated as 32% of the harvested biomass based on figures contained in Table 1 of Chapman *et al.* (1994).

We observe that the modelling of Vallis *et al.* (1996) would predict an annual gain of soil organic C of around 0.7 t /ha for this system.

Biomass data for Murwillumbah

A complication for Murwillumbah is that the measurements of CO_2 exchange were made in 2005–2006, but the crop was allowed to grow on and was harvested as 2-year old cane in August 2007. This necessitated various assumptions in order to compare CO_2 and biomass.

Harvested cane was estimated as that for the previous year on the same block, with the same assumptions about water and C contents as for Mackay.

Trash biomass on the ground was assumed to be the same as that at the start of the study period as determined by Wang *et al.* (2008)

Root biomass was estimated as 32% of the assumed harvested biomass based on figures contained in Table 1 of Chapman *et al.* (1994).

Burnt biomass was estimated as 0.65 times the mass of harvested cane based on data in Table 1 of Chapman *et al.* (1994).

The modelling of Vallis *et al.* (1996) would predict an annual loss of soil organic C under this burnt cane system of around 0.1 t/ha.

Results and discussion

Fluxes of C from atmosphere and soil for both crops are shown in Figure 1 where it can be seen that the contributions from both sources were much larger for the Murwillumbah crop, 26 t C/ha from the atmosphere and 10 t C/ha from the soil compared with 14 and 3 t C /ha from the Mackay crop.

It is difficult to calculate the precise errors in the measured fluxes given their diurnal and seasonal variation and their spatial variability, but a coefficient of variation of around 10% can be expected for such measurements.

In the present case, this would amount to 1.7 t C/ha for the estimated net gain of CO_2 at Mackay and 3.6 t C/ha at Murwillumbah.

Nevertheless, the 2 to 1 difference between the CO_2 fluxes for both crops provided an acceptably wide range for the comparison with biomass production.

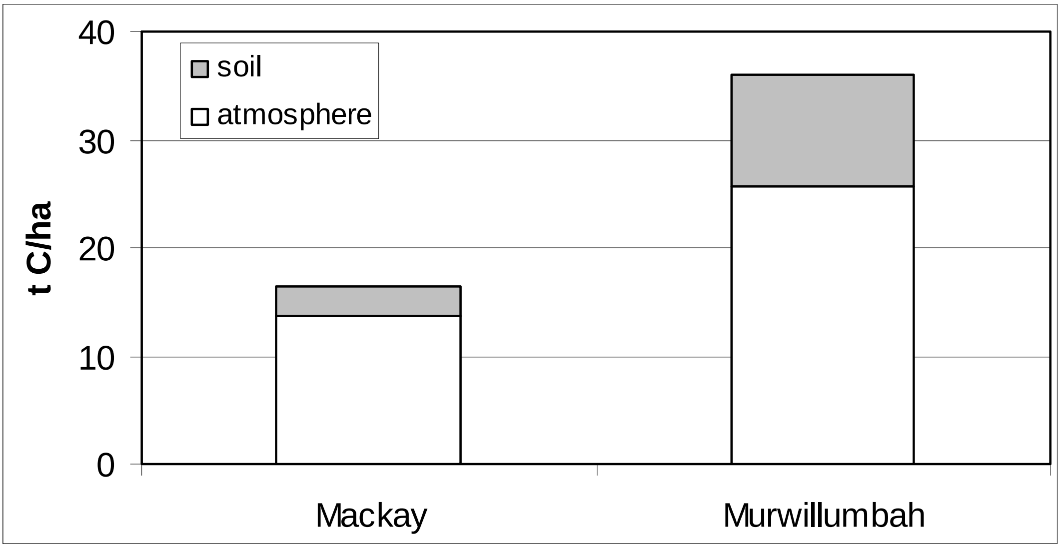

Fig. 1—Fluxes of CO_2–C from the atmosphere and the soil, measured by eddy covariance above the crop and chambers at the soil surface.

The total fluxes of CO_2–C from atmosphere and soil along with the measured and estimated components of biomass–C for both crops are given in Table 1. Some of the components depend on the moisture content of the harvested biomass and the table gives values for moisture contents of 60% and 70%.

Table 1—Net gain of C as CO_2 from atmosphere and soil and C content of biomass in units of t C/ha assuming biomass moisture contents of 60% and 70%.

	Mackay		Murwillumbah	
Net gain of CO_2	17		36	
Biomass components	60%	70%	60%	70%
Harvested cane	11	8	18	14
Trash	4	4	1	1
Roots	4	3	6	4
Burnt			12	9
Total biomass	19	15	37	28

It is evident from Table 1 that the moisture content of the cane as delivered to the mill has a significant influence on estimated biomass production. An increase from 60% to 70% reduced the estimates of total biomass by 23%. Another uncertainty in the calculation is the burnt component.

Weier (1998) assumed a typical loss by burning of 15 t dry matter/ha, equivalent to 7 t C/ha. The figures in Table 1 are based on assuming a ratio of 0.65 between the dry matter in tops and trash to that in the harvested cane, derived from

Table 1 of Chapman *et al.* (1994)., although recent research by Inman-Bamber *et al.* (2009) shows that there can be differences of around 10% in the stalk fractions of the total biomass. Such a difference could effect a change of approximately 1 t C/ha in the total biomass estimates for Murwillumbah. A third uncertainty is the C content of the biomass.

Table 1 assumes a C content of 46% after Vallis *et al.* (1996). G. Kingston (pers. comm., 2010) measured an average biomass C content of 43.3% in two crop years with very little variation. Adopting that value would reduce total biomass estimates by approximately 1 t C/ha for Mackay and 2 t C/ha for Murwillumbah.

The biggest uncertainty in the calculations in Table 1 is the mass of harvested cane for the Murwillumbah crop. As stated in the methods section, this was assumed to be the same as in the previous year because the crop was allowed to grow on for another year after the CO_2 exchange measurements were made.

The mass of harvested cane after the 2-year growing period was 1.63 times that assumed in Table 1.

Given the measurement errors and assumptions discussed above, the near balance between measured CO_2 exchange and estimated biomass production evident in Table 1 can only be regarded as somewhat fortuitous, even discounting the Murwillumbah results.

Further, it is obvious that the combined approach to measuring gains or losses of soil C suggested in the Introduction, which requires subtraction of biomass-C from the accumulated gain of C through above-ground exchanges of CO_2, will not be able to detect the small changes of < 1 t C/ha predicted by the modelling of Vallis *et al.* (1996) or indicated by direct measurements such as those of Resende *et al.* (2006).

The measurement errors on a field scale are presently too large; the errors in each of the terms in the calculation are at least equal to and mostly greater than the expected change in soil C.

The combined approach may be more successful over terms of 5 to 20 years, but this would require maintaining continuous measurements over impossibly long periods. For the present, it seems that verifying predicted or claimed changes in soil C stocks in the short term is beyond our measurement capabilities.

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