



Nitrous Oxide from Sugarcane Crops Methods for calculation

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1 INTRODUCTION

This specific method for agricultural land management (ALM) to reduce losses of nitrous oxides from crops forms one component of the Project Design Document (PDD), for the *Australian Wet Tropics Region Biocarbon Sequestration Project based on Regional Natural Resource Management* (Wet Tropics Project), which covers the Wet Tropics region of far north Queensland, Australia. The PDD was submitted to the Climate Community and Biodiversity Alliance (CCBA) as a project for public review and validation on 6th July 2008.

The method addresses the losses of nitrous oxide from the nitrification and denitrification of applied synthetic fertilizers and other practices, leading to volatilization of N₂O from the soil. Sources of N₂O emissions may include synthetic fertilizers, other direct emissions, such as organic fertilizers, applied urine and dung, crop residue, added soil organic matter, and leaching of nitrogen from the soil, and others identified in IPCC guidelines (IPCC 2006 2006, p4). These may be added as better data become available.

This method was prepared in order to document the methods we propose to use for calculating the gains made by reducing fertilizer application and therefore nitrous oxide (N₂O) emissions from sugarcane farming in the Wet Tropics region of Far North Queensland. It relies on the following methodologies:

- **2006 IPCC Guidelines for National Greenhouse Gas Inventories. Volume 4 AFOLU Chapter 11 - N₂O Emissions From Managed Soils, and CO₂ Emissions from Lime and Urea Application**
- **CDM Approved Methodology - Annex 16 A/R Methodological tool “Estimation of direct nitrous oxide emission from nitrogen fertilization” (Version 01) (EB 33 Report 16 Annex 16)**

1.1 Scope and Applicability

The method covers the application of fertilizers to soil and other practices for the growing of sugarcane in the Wet Tropics Project area, and addresses losses of nitrous oxide (N₂O) from volatilization through nitrification and denitrification only.

In accordance with the Clean Development Mechanism (CDM) EB decision (EB 26 para 50, <http://cdm.unfccc.int/EB/026/eb26rep.pdf>):

- (a) Only direct (e.g. volatilization), and not indirect (e.g. run-off), emissions of N₂O from application of fertilizers within the project boundary shall be accounted for in A/R project activities;
- (b) If the only source of N₂O emissions, which is located outside the project boundary is due to the application of fertilizer in nurseries supplying seedlings to the A/R project activity, then these N₂O emissions (either direct or indirect), may be considered as negligible (CDM-EB-26 *Executive Board Of The Clean Development Mechanism Twenty-Sixth Meeting Report*. 29 September 2006, para. 50).

The method has been prepared to comply with the CCB Standards First Edition, which rely on the Voluntary Carbon Standards (VCS) for methodological approaches, and on the 2006 IPCC Guidelines.

The method is presented as an outline method, which will be developed over the next period of the project. Data on sugarcane practices on individual properties in the region are not yet sufficiently advance to enable amounts of CO₂-e reductions to be calculated at this stage.

1.2 Eligibility

This component of the Wet Tropics Project, reduced application of nitrogenous fertilizers to sugarcane crops, complies with Voluntary Carbon Standard eligibility condition number 1 - Agricultural Land Management:

*Improved cropland management, including the adoption of practices that demonstrably reduce net GHG emissions from a defined land area by increasing soil carbon stocks, **reducing soil N₂O emissions**, and/or reducing CH₄ emissions.*

1.3 Sources of emissions & interactions

Principal sources of terrestrial N₂O emissions are agricultural soils (~80%), and the main sources of N₂O relating to soil and land-based activities include: N fertiliser use, soil disturbance and legume-based ley pastures, livestock excretory products (urine, faeces and manure), and grasslands and savanna burning (Dalal *et al.* 2003).

Over the past two decades, N fertilizer use in Australian sugarcane has increased substantially, as shown in Table 1. It is assumed that this rate has not decreased since 2000.

Table 1 Crop Fertilizer N use (kt N) (from Dalal *et al.* 2003)

| Year | 1987 | 1996 | 2000 |
|-----------|------|------|------|
| Sugarcane | 58 | 100 | 96 |

Nitrous oxide emission characteristics are complex. It was estimated that fertilizer use and crop/pasture soil disturbance contributed 32% and 38% of nitrous oxide to the atmosphere. Most N₂O emissions measurements are of very short duration and over a limited area, and therefore do not measure the total N₂O emissions from either fertiliser or soils accurately. When N₂O emissions have been measured for over a year, about 2% of nitrogen fertiliser applied appears as N₂O in temperate environments. No long-term N₂O emission measurements exist for the subtropical and tropical regions. N₂O emission rates in these regions are likely to be higher than for temperate regions (Dalal *et al.* 2003).

Direct emissions from measurable N fertilizer application are complicated by the management activities undertaken by the landholders and by natural environmental factors. The critical factors are summarised from Dalal *et al.* (2003) in Table 2 below.

Table 2 Factors affecting nitrification and denitrification in soil (from Dalal *et al.* 2003)

| Factors | Explanation |
|---|--|
| Moisture and aeration | Alternate wet and dry cycles stimulate N mineralisation from organic matter, promote NO ₃ ⁻ accumulation during the dry period, and increase N ₂ O production during the wet period as long as it does not get waterlogged |
| Temperature | Optimum soil temperature for nitrification is generally between 25°C and 35°C; As the soil temperature increases, N ₂ O emissions also increase, at least up to 37°C; The ratio of N ₂ O/N ₂ due to denitrification declines with increasing temperatures above 37°C Direct combustion remains the major source of trace gas emissions from biomass burning – Note: No burning of sugarcane occurs in the Wet Tropics Region |
| Soluble and Readily Decomposable Carbon | Soil denitrification capacity increases with increasing organic C content, especially water-soluble C content; incorporation of plant materials enhances the rate of denitrification; Soil disturbance such as drying-wetting can liberate more available C, and thus can greatly increase the rate of denitrification; the total amount of N ₂ O produced from denitrification may be enhanced by the addition of organic materials |
| | The relationship of organic C availability to nitrification is less straightforward. Addition of organic materials with high C/N ratios promotes microbial immobilisation of NH ₄ ⁺ and hence competes for this substrate against nitrification. If the organic materials have low C/N ratios, however, the rates of nitrification and hence N ₂ O production are increased by supplying more NH ₄ ⁺ from mineralisation. |

| Factors | Explanation |
|---|---|
| | Decomposable organic materials increase the respiration rate of microorganisms and may induce O ₂ -limitation, which enhances N ₂ O production from nitrification. In general, addition of degradable organic materials increases N ₂ O production in soils containing NO ₃ ⁻ or applied with fertiliser NO ₃ ⁻ . High amount of N ₂ O can also be produced if materials containing degradable organic N (e.g. animal and green manures) is applied |
| Soil and Fertiliser Nitrogen | Generally, the rate of denitrification increases with increasing NO ₃ ⁻ content in soil under conditions suitable for denitrification (e.g. high moisture). When other factors such as temperature and available organic C are limiting, however, changes in NO ₃ ⁻ content can have little effect on denitrification rate. Under most circumstances, the presence of NO ₃ ⁻ inhibits the rate of N ₂ O reduction to N ₂ which results in higher N ₂ O/N ₂ ratio at similar moisture and oxygen content; flushes of N ₂ O production are observed usually immediately after NO ₃ ⁻ addition. In a few hours or days, N ₂ O production decreases, and N ₂ production increases; rate of N ₂ O emission after fertiliser application is interactively influenced by the amount and type (e.g. NO ₃ ⁻ , NH ₄ ⁺) of fertiliser N, soil properties and the environmental conditions |
| Soil pH and Salinity | Soil pH is a secondary controller of denitrification by mainly affecting the nitrification process. Nitrification is sensitive to extremes in soil pH. High salinity inhibits both nitrification and denitrification |
| Limitation of Nutrients Other Than Nitrogen | Limitations of other essential nutrients, such as P, for plant growth limit the ability of plants to utilise ammonium and nitrate N and reduces the overall plant sink for mineral N absorption |

Emissions of N₂O from sugarcane crops are therefore difficult to calculate. Improved crop management practices such as sugarcane trash retention and no-till have improved the productivity of sugarcane soils and reduced environmental impacts. However, it may not have reduced the total N₂O emissions from the sugarcane lands (Dalal *et al.* 2003).

Responses of nitrous oxide emissions to different management practices have been summarised by Dalal *et al.* (2003). They include the following:

- Split application of N fertiliser may reduce rapid N₂O losses. Split application of urea and ammonium sulfate to sugarcane soil at 80% water-filled pore space (WFPS) and 100% WFPS results in lower N₂O emissions initially compared with full application of urea although total N₂O emissions over a given season are not significantly different;
- Application of sugarcane trash (10t/ha) to soil fertilised with KNO₃ or urea at the rate of 160 kg N/ha, and followed by 50 mm of irrigation, increased N₂O emissions, and CO₂ respiration, especially from KNO₃;
- Nitrous oxide emissions from N added to sugarcane soils of different texture differed. For example, more gaseous N was lost from a fine-textured soil than from a coarse-textured soil;
- In waterlogged or flooded soils, where aeration is restricted, less N₂O is emitted into the atmosphere because more N₂O is converted into N₂ through the denitrification process. Since mineral N content governs the N supply both to crops and the denitrifiers, increasing the efficiency of mineral N use to crops should result in lower amount of mineral N available for denitrification;
- Addition of nitrapyrin to soil after anhydrous ammonia application of 60-80 kg N/ha significantly reduced fertiliser-induced loss of nitrous oxide only in a calcareous soil, which accumulated nitrite in the fertiliser band;
- Wax-coated calcium carbide reduces significantly the rate of N₂O emission;
- Denitrification and N₂O losses of urea from flooded systems are further reduced when urea is deep placed as compared to surface broadcast application;

Strategies that increase the efficiency of N fertiliser use will reduce N₂O emissions. These strategies include: fertiliser form (reduce anhydrous ammonia use), rate and method of application, matching N supply with demand, supplying fertiliser in the irrigation water, applying fertiliser to the plant rather than the soil, and the use of slow-release fertilisers, and urease and nitrification inhibitors. Although these approaches enhance nitrogen use efficiency, they do not necessarily reduce N₂O emissions

significantly. However, newly developed urease and nitrification inhibitors and coated-urea have the capacity to prevent loss of N, including the loss as N₂O, as well as increase crop yields.

In arable systems, soil structure (soil texture), nitrate, soluble and readily available C, and water content appear to be major factors that affect the N₂O:N₂ balance between N₂O diffusion into the atmosphere and its further reduction to N₂ gas (Weier 1998, cited in Dalal *et al.* 2003). Nitrate concentration in the soil can be kept at low levels by applying N fertiliser to the crop when the crop needs it, split applications, and applying in drip irrigation. Further reductions in N₂O emissions may be achieved by the use of cover crops during the fallow period to remove residual nitrate from the soil profile.

The marginal cost of reducing greenhouse gases from Australian agriculture by 20% was estimated to be \$20/t of CO₂ equivalent, or \$4/t for nitrous oxide mitigation alone (Phipps and Hall 1994, cited in Dalal *et al.* 2003, 1994 prices). Increasing nitrogen use efficiency should reduce gaseous losses of N, including that of nitrous oxide.

Management practices which may improve nitrogen use efficiency and minimise N₂O emissions from nitrogen fertilisers include the following (from Dalal *et al.* 2003):

1. Apply fertiliser N at optimum rates by taking into account all N sources available to the crop/pasture from soil (ammonium and nitrate N in the soil at the time of crop sowing, and in-crop N mineralisation), and other N sources such as manure or waste;
2. Apply fertiliser N at the rate and time to meet crop/pasture needs, and when appropriate through split application;
3. Avoid fertiliser N application outside the crop/pasture growing season, and especially prior to a clean fallow period. Avoid fallow periods if season or availability of irrigation permits;
4. Provide fertiliser N application guide through crop/pasture monitoring and soil tests, and adjust fertiliser application rates and timing accordingly;
5. Apply other nutrients if required so that nutrients supply to crop/pasture is balanced and N utilisation is optimised;
6. Avoid surface application so that fertiliser N losses are minimised and plant utilisation maximised. Incorporate fertiliser N with soil; apply band placement or point placement close to the plant roots;
7. Monitor and adjust fertiliser application equipment to ensure the precision and amount of fertiliser applied, and control over appropriate spatial distribution (GPS/GIS) according to the information from yield monitors, crop/pasture monitors (including remote sensing), and soil tests;
8. Fertilizers should be in a form (such as granulated) that can be applied evenly, conveniently and cost-effectively. In irrigated agricultural systems, application in sprinkler/drip irrigation may be an effective option;
9. Fertilizer may be formulated with urease and/or nitrification inhibitors or physical coatings to synchronise fertiliser N release to that of crop/pasture growth needs so that at any given time minimum amount of mineral N (ammonium and nitrate) is present in soil;
10. Practice good crop/pasture management, disease control and good soil management to optimise crop/pasture growth and hence efficient fertiliser N utilisation. Avoid/or reduce cultivation early in the fallow period and retain plant residues to minimise mineralisation and nitrate accumulation during the fallow period;
11. Use cover crops to utilise the residual mineral N following N-fertilised main crops or mineral N accumulation following legume-leys.

Secondary considerations to reduce nitrous oxide emissions include:

- Oxygen supply/soil water content (waterfilled pore space <40% increases nitrification but reduces nitrous oxide loss, >90% increases denitrification as a nitrogen gas loss);
- Carbon substrate supply (readily available carbon) creates 'hot spots' of microbial growth, and hence nitrous oxide emissions; examples are addition or incorporation of biomass of high carbon: nitrogen ratio such as non-legumes rather than legume biomass.
- Soil organic matter management to manipulate carbon substrate and oxygen/water supply.

- Soil pH and salinity (salinity and alkaline pH enhance the nitrous oxide emissions due to the persistence of nitrites); soil amendments such as application of gypsum or crop residues of high carbon: nitrogen ratio reduces nitrous oxide emissions (Dalal *et al.* 2003).

These findings and recommendations in the report by Dalal *et al.* (2003) are discussed in the following section in relation to the management practices recommended for sugarcane in the Wet Tropics region. Some are in conflict, and need further investigation and analysis.

2 METHOD & PROCEDURE

2.1 Calculating emissions - IPCC N₂O Tier 1 default and Tier 2 values

The project has considered the choice of method for calculating losses of N₂O from sugarcane crop soils. Three choices are available, based on the IPCC Tier Structure. Definitions of the Tier structure are provided below in box 1.

| Box 1 - FRAMEWORK OF TIER STRUCTURE IN THE GOOD PRACTICE GUIDANCE (source: Table 3.1.1 from IPCC Good Practice Guideline for LULUCF, 2003) |
|---|
| The Tier 1 approach employs the basic method provided in the <i>IPCC Guidelines</i> (Workbook) and the default emission factors provided in the <i>IPCC Guidelines</i> (Workbook and Reference Manual) with updates in this chapter of the report. For some land uses and pools that were only mentioned in the <i>IPCC Guidelines</i> (i.e., the default was an assumed zero emissions or removals), updates are included in this report if new scientific information is available. Tier 1 methodologies usually use activity data that are spatially coarse, such as nationally or globally available estimates of deforestation rates, agricultural production statistics, and global land cover maps. |
| Tier 2 can use the same methodological approach as Tier 1 but applies emission factors and activity data which are defined by the country for the most important land uses/activities. Tier 2 can also apply stock change methodologies based on country-specific data. Country-defined emission factors/activity data are more appropriate for the climatic regions and land use systems in that country. Higher resolution activity data are typically used in Tier 2 to correspond with country-defined coefficients for specific regions and specialised land-use categories. |
| At Tier 3 , higher order methods are used including models and inventory measurement systems tailored to address national circumstances, repeated over time, and driven by high-resolution activity data and disaggregated at sub-national to fine grid scales. These higher order methods provide estimates of greater certainty than lower tiers and have a closer link between biomass and soil dynamics. Such systems may be GIS-based combinations of age, class/production data systems with connections to soil modules, integrating several types of monitoring. Pieces of land where a land-use change occurs can be tracked over time. In most cases these systems have a climate dependency, and thus provide source estimates with interannual variability. Models should undergo quality checks, audits, and validations. |

Direct emissions from N fertilizer application can be calculated from either IPCC 2006 default (Tier 1) values or from Australian Tier 2 values.

Tier 1 default values for direct N₂O emissions from managed soils reported in IPCC 2006 Guidelines for NGGI Volume 4 AFOLU-Chapter 11, are provided below in Table 3. Values derived from studies in Australia suggest that emissions are higher in Australia, at 0.016 (1.6 kg N₂O-N (100 kg N)⁻¹) (Dalal *et al.* 2003). More recently the National Greenhouse Gas Inventory (NGGI) for Australia has reported emission factor for sugarcane at **0.0125** (1.25 kg N₂O-N (100 kg N)⁻¹) (Department of Climate Change 2008; Table 6.17).

Emission factors for Organic fertilizers were reported in the NGGI for Australia also, and are shown in Table 3 (Department of Climate Change 2008; Table 6.18). The organic fertilizers are referred to as sourced from manure, so the emission factor may not be applicable to non-manure organic fertilizers, such as mill mud and mill ash, which are the residues from sugarcane processing. It is unclear how to account for the different emission factors for synthetic fertilizers and for organic fertilizers in equation 1.

Table 3 Emission Factors to Estimate Direct N₂O Emissions from Managed Soils (Source: IPCC 2006 Table 11.1; Dalal *et al.* 2003; Sugarcane - NGGI 2006 Vol 1)

| Emission factor | Default value | Uncertainty range |
|--|----------------------|--------------------------|
| Default EF ₁ for N additions from mineral fertilisers, organic amendments and crop residues, and N mineralised from mineral soil as a result of loss of soil carbon (kg N ₂ O-N (kg N) ⁻¹) | 0.01 | 0.003 - 0.03 |
| Australian EF ₁ for N addition | 0.016 | |
| Australian EF ₁ for N addition Sugarcane | 0.0125 | |
| Australian NGGI Organic (manure) fertilizer | 0.0156 | 0.0021 – 0.0331 |

IPCC (2006) allows the use of Tier 2 or Tier 3 values where they are known and published, using Equation 11.2 of IPCC 2006 (Vol 4 Ch 11, p11.10). As Australia has Tier 2 values for N₂O emissions, equation 11.2 is used for calculating the emissions from sugarcane soils in the Wet Tropics Project area.

Equation 1 (from equation 11.2 of IPCC 2006 Guidelines):

$$N_2O_{Direct-N} = \sum_i (F_{SN} + F_{ON})_i * EF_{1i} + (F_{CR} + F_{SOM}) * EF_1 + N_2O - N_{OS} + N_2O - N_{PRP}$$

Where:

N₂O_{Direct-N} = annual direct N₂O-N emissions produced from managed soils, kg N₂O-N yr⁻¹ (Emission of N₂O in units of Nitrogen – IPCC GPAUM, 2001, Chap 4 Agric, p4.67)

N₂O-N_{OS} = annual direct N₂O-N emissions from managed organic soils, kg N₂O-N yr⁻¹

N₂O-N_{PRP} = annual direct N₂O-N emissions from urine and dung inputs to grazed soils, kg N₂O-N yr⁻¹

F_{SN} = annual amount of synthetic fertiliser N applied to soils (adjusted to account for the amount that volatilises as NH₃ and NO_x – IPCC GPAUM, 2001, Chap 4 Agric, p4.54), kg N yr⁻¹

F_{ON} = annual amount of animal manure, compost, sewage sludge and other organic N additions applied to soils (Note: If including sewage sludge, cross-check with Waste Sector to ensure there is no double counting of N₂O emissions from the N in sewage sludge), kg N yr⁻¹

F_{CR} = annual amount of N in crop residues (above-ground and below-ground), including N-fixing crops, and from forage/pasture renewal, returned to soils, kg N yr⁻¹

F_{SOM} = annual amount of N in mineral soils that is mineralised, in association with loss of soil C from soil organic matter as a result of changes to land use or management, kg N yr⁻¹

F_{OS} = annual area of managed/drained organic soils, ha (Note: the subscripts CG, F, Temp, Trop, NR and NP refer to Cropland and Grassland, Forest Land, Temperate, Tropical, Nutrient Rich, and Nutrient Poor, respectively)

F_{PRP} = annual amount of urine and dung N deposited by grazing animals on pasture, range and paddock, kg N yr⁻¹ (Note: the subscripts CPP and SO refer to Cattle, Poultry and Pigs, and Sheep and Other animals, respectively)

EF₁ = emission factor for N₂O emissions from N inputs, kg N₂O-N (kg N input)⁻¹ (Table 11.1 of IPCC 2006)

EF_{1i} = emission factors developed for N₂O emissions from synthetic fertiliser and organic N application under conditions *i* (kg N₂O-N (kg N input)⁻¹); *i* = 1, ...n. (Table 11.1).

According to IPCC 2006 (p11.10), the above equation may be modified in a variety of ways to accommodate any combination of N source-, crop type-, management-, land use-, climate-, soil- or other condition-specific emission factors that a country may be able to obtain for each of the individual N input variables (F_{SN}, F_{ON}, F_{CR}, F_{SOM}, F_{OS}, F_{PRP}).

As an indication of the mass of N₂O emitted from sugarcane in the Wet Tropics, if we ignore the contributions from factors F_{OS} and F_{PRP} the equation can be modified to:

Equation 2 (modified from Equation 11.2 of IPCC 2006 Guidelines)

$$N_2O_{Direct-N} = \sum_i (F_{SN} + F_{ON})_i * EF_{1i} + (F_{CR} + F_{SOM}) * EF_1$$

This takes account of added synthetic and organic fertilizers, and crop residue and soil organic matter. Synthetic fertilizers are those sold commercially as mixed fertilizers, with differing proportions of nutrients, and the suppliers provide information on the ratios of N, P, K and other elements in the fertilizers. Organic fertilizers for sugarcane in the Wet Tropics Region include residues from sugarcane mills, including ‘mill mud’ and ‘mill ash’, on which data were not available at the time of publication. Crop residue in the form of legume crops has been modelled for N contribution. Soil organic matter in the form of organic carbon percentage is one of the analytes recommended for testing in soil tests of sugarcane soils.

In order to calculate the N₂O emissions accurately, some elements of Equation 2 need more specific data. These are discussed further in the following sections, and conclusions made in sections 2.3 to 3.

2.1.1 Conversion to N₂O & CO₂-equivalent

Conversion of N₂O–N emissions to N₂O emissions for reporting purposes is performed by using the following equation:

$$N_2O = N_2O-N \bullet 44/28$$

The Global Warming Potential for N₂O, kg-CO₂-e (kg-N₂O)⁻¹ is **310** (IPCC default = 310, valid for the first commitment period) (EB33 Report Annex 16).

2.1.2 Baseline Nitrous Oxide emissions from N fertilizer applications for FNQ region

The minimum baseline estimates for N₂O (and CH₄) emissions have to be based on verifiable management records (e.g. fertilizer purchase records, manure production estimates, livestock data) averaged over the 5 years prior to project establishment (VCS 2008 Tool for AFOLU Methodological Issues, section II, item 13, p6).

In 2001, the estimated usage of nitrogen fertilizers contributed about 4970 tonnes of N (as N fertilizer) to the Wet Tropics region (21,611 km²) and the rate of application of N fertilizers was calculated to be 2.3 kg/ha (McDonald & Weston 2004) on average for the region. Area under agriculture is around 2,399 km² (239882 ha) which is about 11% of the total. In 2004 there were about 182,355 hectares under sugarcane (McDonald & Weston 2004) (Terrain NRM (2004) Plan Vol 1, background). This averages to around 20.7 kg/ha as applied to the intensive agricultural areas, including sugarcane.

But the rate of application of N fertilizers to sugarcane in the Wet Tropics as estimated by Incitec Pivot Fertilizers (Sept 2008, unpublished data which is around 60-70% of the fertilizer sold in the region (Incitec Pivot, pers. comm.)), as shown in Table 4 below, is much higher than the regional average for agriculture.

Table 4 – Average N Rates (kg/ha) by Year – Wet Tropics (Tully to Mossman, including Atherton Tablelands) (Incitec Pivot data 2008, extrapolated from 70% estimated market share)

| Year | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 |
|---------|------|------|------|------|------|------|------|------|------|------|
| kg/ha N | 197 | 206 | 216 | 213 | 210 | 196 | 207 | 203 | 204 | 207 |

These figures are shown graphically in Figure 1 below.

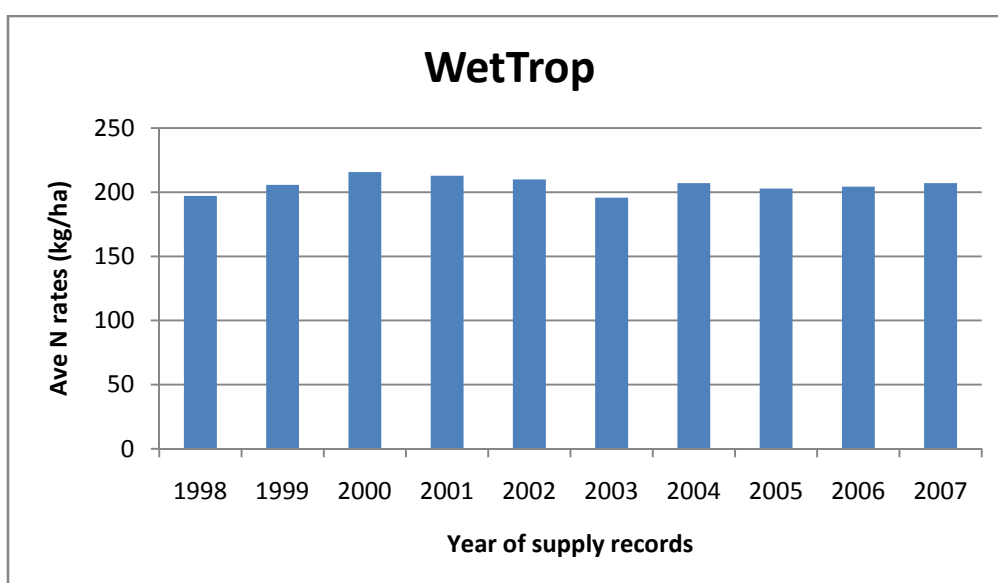


Figure 1 – Average N fertilizer application rates from fertilizer supply records (extrapolated from Incitec Pivot’s 70% market share data)

Nitrous oxide and CO₂-equivalent emissions from N fertilizer application to sugarcane crops for the region can be calculated from these figures, using Equation 2, and Australian Tier 2 emission factor of 0.016. As noted in section 2.1.1, the global warming potential of N₂O in CO₂-equivalent value is a

factor of **310**. Emission values for each year are shown in Table 5 below, and a graph of the trend over time has been provided in Figure 2.

Table 5 – Nitrous oxide and CO₂-equivalent emissions (in tonnes) from N fertilizer applied to sugarcane – Wet Tropics of FNQ

| Year | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 |
|--------------------------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| N ₂ O emissions (t) | 706 | 737 | 773 | 762 | 752 | 701 | 742 | 727 | 732 | 742 |
| CO ₂ equiv. (t) | 218910 | 228428 | 239532 | 236359 | 233186 | 217323 | 230014 | 225255 | 226841 | 230014 |

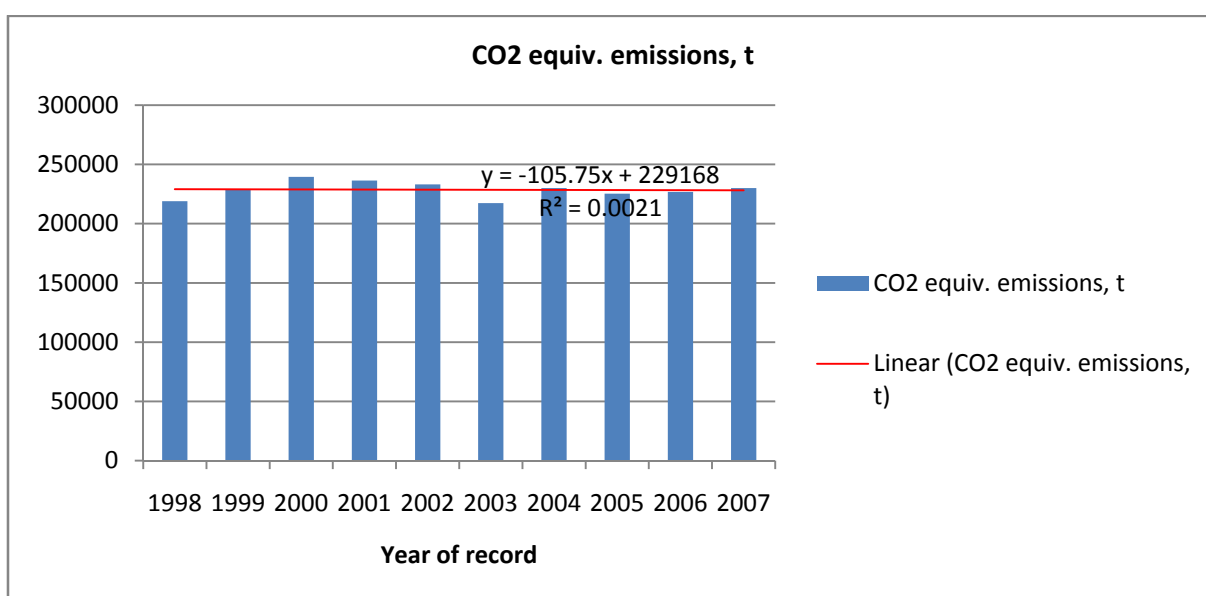


Figure 2 – 10-year trend in CO₂-equivalent emissions from N fertilizer application to sugarcane in Wet Tropics region (data from Incitec Pivot fertilizer company, 2008, extrapolated from 70% market share)

Figure 1 shows a very small decline in nitrous oxide emissions (as CO₂-equivalent emissions) from N fertilizer application to sugarcane in the Wet Tropics of Far North Queensland, supporting the earlier interpretation from Dalal *et al.* (2003) of no decline since 2000.

2.2 Six Easy Steps – Improving Nutrient Management Practices for Far North Queensland Sugarcane

The sugarcane industry in Queensland has been working for over a decade to improve management of soils used for sugarcane production. Positive environmental benefits have been one of the main focuses and outcomes of the improvements. Soil-specific management guidelines for catchments such as the Johnstone River catchment provide detailed recommendations for the analysis and assessment of on-farm soils so that the most appropriate management decisions can be made for crop and soil management (Schroeder *et al.* 2007). These guidelines were followed by a workbook ‘Accelerating the Adoption of Best Practice Nutrient Management: Best Practice’ (Schroeder *et al.* 2008) which is used as part of a training course, ‘Six Easy Steps’, for sugarcane farmers in the Wet Tropics. The six easy steps are:

1. Knowing and understanding our soils;
2. Understanding and managing nutrient processes and losses;
3. Soil testing regularly;
4. Adopting soil-specific fertiliser recommendations;
5. Using leaf analysis as a check on the adequacy of fertiliser inputs;
6. Keeping good records/modifying nutrient inputs when and where necessary.

These steps reflect the findings that analysis of nutrient requirements for sugarcane has been in need of improvement. Previous nutrient management recommendations have resulted in excessive addition of nutrients to soils, resulting in high levels of a range of elements (particularly P) in the soil, in runoff and in emissions to the atmosphere (Schroeder *et al.* 2008).

The guidelines and workbook recommend good analysis of soils and crops (by leaf analysis) in order that the correct applications of fertilizers with the best proportions of nutrients are made in conjunction with specific management practices. In summary, the following steps (Table 8) are recommended.

Table 6 – Recommendations for soil-specific nutrient management for sugarcane (Schroeder *et al.* 2008)

| Step | General parameters (see notes below table) |
|--|---|
| Knowing and understanding soils | Texture, colour, depth, structure, position in landscape |
| Understanding and managing nutrient processes and losses | Leaching, runoff, loading (accumulation), gaseous and erosive losses, mining (depletion of nutrients) |
| Soil testing regularly | Sampling & laboratory analysis |
| Adopting soil-specific fertiliser recommendations | District yield potential of sugarcane (t/ha), combined with soil N mineralisation index <ol style="list-style-type: none"> 1. Determine baseline N application rate from Organic C % 2. Calculate N contribution from legume crop 3. Determine N requirement for plant and ratoon crops from 1 & 2 4. Discount N application rates where mill by-products are used 5. Determine Phosphorus requirements from P Buffer Index & Organic C % & soil texture 6. Discount P requirements where mill by-products are used 7. Determine Potassium (K) requirements from exchangeable K and Nitric K analyses – based on regional maximum of 120 kg/ha K; assumes trash retained 8. Discount K rates if mill by-products applied 9. Determine S application rates 10. Discount S rates if mill by-products are applied 11. Determine lime requirements, as N fertilizers use Calcium (Ca) and acidify the soil 12. Discount lime rates if mill by-products have been applied 13. Determine Mg requirements 14. Determine gypsum or lime application rates if Sodium levels are above 5% exchangeable sodium percentage (ESP) 15. Determine Cu and Zn application rates 16. Determine Si application rates |
| Leaf analysis | Analyses of samples of leaves to test accuracy of nutrient application recommendations |
| Record keeping | good records of nutrient inputs and harvest data, and soil and leaf analyses |

Notes:

- Legume crops may contribute from 60 to 360 kg N/ha;
- Different rates are recommended for planting and for ratoon crops – suggested rates range between 100 and 160 kg N/ha, depending on the organic carbon percentage in the soil, and thus the N mineralisation rate;
- Mill mud & mill ash are applied at rates of 100-150 t/ha. Within that range, discounts of recommended N, P, K and S application rates are made. Data on the N, P, K and S content of mill mud and mill ash were not available;
- For organic matter, the workbook states that organic matter improves soil structure and is a source of N, P and S and trace elements, and that there is ‘*no optimum level of organic matter, but it is best to maintain it as high as possible*’ (Schroeder *et al.* 2008, p13). Trash conservation and use of fallow

green manure crops, as well as reduced tillage operations, preventing soil erosion and use of imported organic matter sources such as mill mud, mill ash and bagasse are recommended (Schroeder *et al.* 2007, p4);

- Fallow legume crops are recommended between crops to improve the amount of N in the soil available for the succeeding crop (Schroeder *et al.* 2007, p10).

The recommended rate of application to sugarcane in the Wet Tropics, at around 160 kg/ha, is based on the ‘district yield potential’ for sugarcane of 120 tonnes/ha. The method for calculating this is that, according to studies by CSIRO, sugarcane needs 1.4 kg N per tonne up to a yield of 100 tonnes/ha and 1 kg per tonne/ha thereafter (Schroeder *et al.* 2007). Adoption of these practices and recommendations would reduce the amount of N fertilizer added to sugarcane in the Wet Tropics region by around 20%, based on the fertilizer supply records provided in Table 4 above. This potential reduction is shown graphically in Figure 3 below.

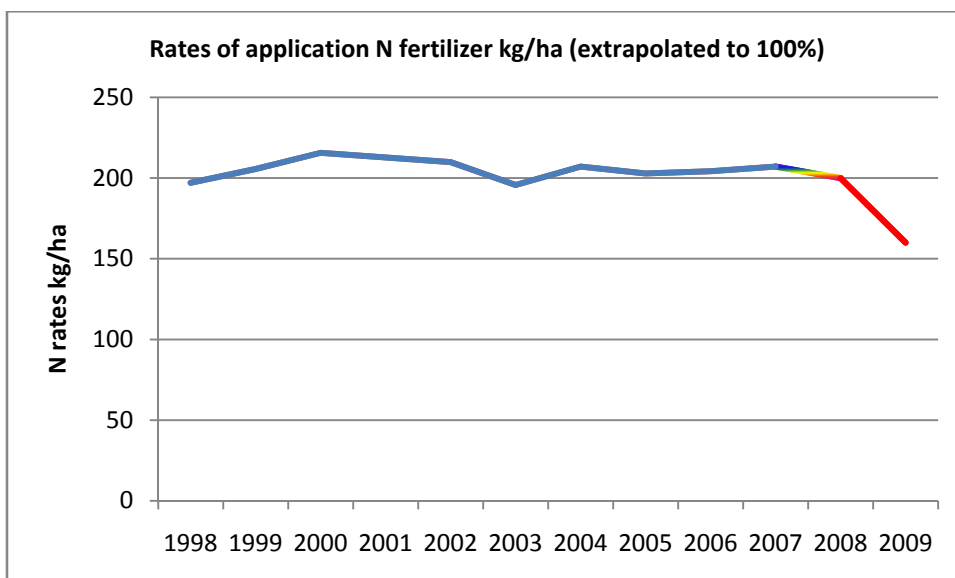


Figure 3 – Rates of application of N fertilizer in Wet Tropics Sugarcane crop over 10 years of records, and **potential** projected over one year if Six Easy Steps adopted.

According to BSES, adoption of these recommendations has been slow; few obtain soil analyses, and few keep good records of practices, cropping outcomes, fertilizers use and problems. Sugarcane farmers need incentives to adopt the practices. Rising costs of fertilizer are one incentive, but for them to adopt the more detailed nutrient management guidelines will require a higher level of incentive.

2.3 Requirements to enable trade of reduced N₂O emissions from sugarcane cropping

Credits from reduced N₂O emissions from better management of sugarcane nutrient inputs would be traded in the Voluntary market, which is regulated by the Voluntary Carbon Standards (VCS 2007.1). Under the VCS, the project crediting period is the period of time for which the net GHG emissions reductions or removals will be verified, which is equivalent to the project lifetime. The project must have a robust operating plan covering this period. The project crediting period for ALM projects focusing exclusively on emissions reductions of N₂O shall not exceed 10 years, renewable at most two times (Voluntary Carbon Standard – Guidance for Agriculture, Forestry and Other Land Use Projects (VCS 2007.1, 2008, p17, VCS Association)).

Minimum baseline estimates for N₂O emissions must be based on verifiable management records (e.g. fertilizer purchase records) averaged over the 5 years prior to project establishment according to the VCS (VCS 2007.1, 2008, Item 13, p19, VCS Association).

3 WET TROPICS SUGARCANE – PROGRESS TOWARDS ACCOUNTING FOR NITROUS OXIDES

3.1 Research needs

The BSES recommendations are generally in accordance with those recommended by Dalal *et al.* (2003) and summarised in section 1.3 above, but the project has a number of issues to resolve before the desired outcomes can be achieved. These include the general observations:

1. First, quantification of N in organic fertilizers in the form of mill mud and mill ash needs to be made. No data on the N content of these organic fertilizer additives were available at the time of publication;
2. Records from sugarcane properties of the amount of N fertilizer, organic matter additives such as mill mud, and legume crops used over the previous 5 years are required to establish historical patterns of use, and demonstrate reduction of N fertilizer.

Resolution of some contradictions between the known emission characteristics of different practices and those recommended in the ‘six easy steps’ is required. These differences are tabulated below in Table 7. Some of the questions will require research to resolve.

Table 7 - Factors affecting N nitrification and denitrification

| Factor | Process | BSES recommendations which need refinement to account for factors affecting N ₂ O emissions |
|---|--|---|
| Soluble and Readily Decomposable Carbon | Soil denitrification capacity increases with increasing organic C content | Legume crops increase soil N, but this needs further analysis in response to IPCC 2006 GPG (see Note 1 below) and to calculate F _{CR} – the BSES guidelines show that a fallow legume crop can add 3 to 4 times the required amount of N for sugarcane production, thus increasing N ₂ O emissions; BSES recommends keeping organic matter as high as possible; BSES recommends addition of mill mud or ash if available, but actual C content of mill mud and mill ash was not available. Analysis is required. |
| | Addition of organic materials with high C/N ratios promotes microbial immobilisation of NH ₄ ⁺ and hence competes for this substrate against nitrification. If the organic materials have low C/N ratios, however, the rates of nitrification and hence N ₂ O production are increased by supplying more NH ₄ ⁺ from mineralisation. In general, addition of degradable organic materials increases N ₂ O production in soils containing NO ₃ ⁻ or applied with fertiliser NO ₃ ⁻ . High amount of N ₂ O can also be produced if materials containing degradable organic N (e.g. animal and green manures) is applied | C/N ratio of mill mud and mill ash, and other organic materials added needs to be analysed to resolve this issue for calculating F _{ON} . Soil organic matter (SOM) can be calculated using Equation 2.25 from IPCC 2006 (Vol 4 Ch11 p2.30). The equation requires inputs of soil carbon mass per hectare for different soils and management practices, which is included in the BSES guidelines. Usage trends as a result of management practices need to be accounted for. |
| Soil and Fertiliser Nitrogen | rate of N ₂ O emission after fertiliser application is interactively influenced by the amount and type (e.g. NO ₃ ⁻ , NH ₄ ⁺) of fertiliser N, soil properties and the environmental conditions | Amount and type of fertiliser (e.g. NO ₃ ⁻ , NH ₄ ⁺) needs to be determined, or data obtained to resolve this. Specific formulae to calculate the differences need to be sourced or developed. |
| Soil pH and Salinity | Soil pH is a secondary controller of denitrification by mainly affecting the nitrification process. Nitrification is sensitive to extremes in soil | BSES recommendations include maintaining a relatively neutral pH through adding lime. |

| Factor | Process | BSES recommendations which need refinement to account for factors affecting N ₂ O emissions |
|---|---|--|
| | pH. High salinity inhibits both nitrification and denitrification | |
| Limitation of Nutrients Other Than Nitrogen | Limitations of other essential nutrients, such as P, for plant growth limit the ability of plants to utilise ammonium and nitrate N and reduces the overall plant sink for mineral N absorption | Guidelines to the appropriate rates of essential nutrients required, based on soil analyses, are accounted for in the BSES guidelines. |

Note 1: IPCC GPG 2006, V4, Ch 11, p11.6 Biological nitrogen fixation has been removed as a direct source of N₂O because of the lack of evidence of significant emissions arising from the fixation process itself (Rochette and Janzen, 2005). These authors concluded that the N₂O emissions induced by the growth of legume crops/forages may be estimated solely as a function of the above-ground and below-ground nitrogen inputs from crop/forage residue (the nitrogen residue from forages is only accounted for during pasture renewal). Conversely, the release of N by mineralisation of soil organic matter as a result of change of land use or management is now included as an additional source. These are significant adjustments to the methodology previously described in the *1996 IPCC Guidelines*.

Management recommendations suggested by Dalal *et al.* 2003 for agriculture are presented in relation to the guidelines by BSES (Schroeder *et al.* 2007) in Table 8. Most of the recommendations are adopted in the BSES guidelines.

Table 8 – Comparison of management recommendations to reduce N₂O emissions (Dalal et al. 2003) with BSES sugarcane recommendations

| Management guideline | BSES recommended practice equivalent |
|--|---|
| 1. Apply fertiliser N at optimum rates by taking into account all N sources available to the crop/pasture from soil (ammonium and nitrate N in the soil at the time of crop sowing, and in-crop N mineralisation), and other N sources such as manure or waste; | Accounts for all N sources |
| 2. Apply fertiliser N at the rate and time to meet crop/pasture needs, and when appropriate through split application; | Split application and appropriate timing of application recommended |
| 3. Avoid fertiliser N application outside the crop/pasture growing season, and especially prior to a clean fallow period. Avoid fallow periods if season or availability of irrigation permits; | Not mentioned |
| 4. Provide fertiliser N application guide through crop/pasture monitoring and soil tests, and adjust fertiliser application rates and timing accordingly; | Yes, forms the basis of the guidelines |
| 5. Apply other nutrients if required so that nutrients supply to crop/pasture is balanced and N utilisation is optimised; | Yes, fundamental to the guidelines |
| 6. Avoid surface application so that fertiliser N losses are minimised and plant utilisation maximised. Incorporate fertiliser N with soil; apply band placement or point placement close to the plant roots; | Placement under stools or green trash recommended |
| 7. Monitor and adjust fertiliser application equipment to ensure the precision and amount of fertiliser applied, and control over appropriate spatial distribution (GPS/GIS) according to the information from yield monitors, crop/pasture monitors (including remote sensing), and soil tests; | Not mentioned |
| 8. Fertilizers should be in a form (such as granulated) that can be applied evenly, conveniently and cost-effectively. In irrigated agricultural systems, application in sprinkler/drip irrigation may be an effective option; | Not mentioned |
| 9. Fertilizer may be formulated with urease and/or nitrification inhibitors or physical coatings to synchronise fertiliser N release to that of crop/pasture growth needs so that at any given time minimum amount of mineral N | Not mentioned |

| Management guideline | BSES recommended practice equivalent |
|--|--|
| (ammonium and nitrate) is present in soil; | |
| 10. Practice good crop/pasture management, disease control and good soil management to optimise crop/pasture growth and hence efficient fertiliser N utilisation. Avoid/or reduce cultivation early in the fallow period and retain plant residues to minimise mineralisation and nitrate accumulation during the fallow period; | Good crop management recommended, retaining plant residues (green trash) recommended |
| 11. Use cover crops to utilise the residual mineral N following N-fertilised main crops or mineral N accumulation following legume-leys. | Not recommended, but assumed cane will be grown immediately following legume crop |

3.2 Potential benefits to landholders – worked example

The potential for sugarcane farmers to gain a benefit through trading their reduced emissions is reasonably good, considering the area under sugarcane. An example is provided of a worked equation for a sugarcane ratoon crop in the Wet Tropics region, with soil test results as follows:

Organic C% = 1.30

Mill mud applied = nil

Crop residue from legume crop = nil

Soil organic matter (as C) = $3,000 \text{ m}^3 * 0.013 = 39 \text{ m}^3 = 39 \text{ t/ha}$ (assuming $3,000 \text{ m}^3$ of soil on 1 ha down to 30cm depth)

BSES recommended synthetic N application per ha = 130 kg/ha

For this particular property (which is a real property in the Innisfail district of far north Queensland on the coast) the previous fertilizer application was 200 kg N/ha.

The worked equation is as follows:

$$N_2O_{Direct-N} = (130 + 0) * 0.016 + (0 + 39000) * 0.016 \text{ (kg/ha)}$$

Results

| N Application | SN | ON | CR | SOM | EF | $N_2O_{Direct-N}$ |
|---------------|-----|----|----|-------|--------|-------------------|
| Previous | 200 | 0 | 0 | 39000 | 0.0125 | 490 |
| Recommended | 130 | 0 | 0 | 39000 | 0.0125 | 489 |

This converts to a saving of N_2O emissions as follows:

| Reduction in N_2O emissions (kg/ha) | Reduction in CO_2 equivalent emissions (t/ha) (GWP of N_2O is 310) |
|---------------------------------------|---|
| 0.875 | 0.27125 |

These reduced emissions spread over, say, 100 ha would reduce by 27 tonnes the CO_2 -equivalent of N_2O emissions over a year. As sugarcane crops are normally grown in the region as one planting year and 5 ratoon or repeat crops, this would result in around 162 tonnes of reduced emissions of CO_2 -equivalent.

If improved practices were implemented across the region, with 182,355 hectares under sugarcane, the reduced nitrous oxide emissions would be substantial.

3.3 Summary and conclusions

In order to fulfil the requirements of Equation 2 (which is repeated here), a number of factors need refinement.

Equation 2

$$N_2O_{Direct-N} = \sum_i (F_{SN} + F_{ON})_i * EF_{1i} + (F_{CR} + F_{SOM}) * EF_1$$

The factors which need to be further assessed and determined before the nitrous oxide emissions from sugarcane can be accounted for are summarised in Table 9. This summary is preliminary and based on the limited information available.

Table 9 – Assessments required for adequate inventory of nitrous oxide emissions from sugarcane.

| Factor | Assessment and data requirements |
|------------------|---|
| F _{SN} | Adequate knowledge and accuracy of data; requires at least 5 years of historical records to comply |
| F _{ON} | Nutrient content of mill mud and mill ash required to model N content and C/N ratio Actual mass of mill mud and mill ash applied to fields needs to be determined, and the uncertainties of variable application rates determined (i.e. 100-150 t/ha is considered in calculations, which is a wide range) Assess whether EF for non-manure organic fertilizers (specifically mill mud and mill ash) is different from EF for synthetic fertilizers |
| F _{CR} | N contribution from legume crop residue has been modelled (BSES 2007), but N contribution may be 3 times higher than required for sugarcane, resulting in increased losses of N ₂ O Estimates of actual mass of crop residue from green trash needs to be determined in order to determine N contribution |
| F _{SOM} | Soil organic matter in the form of organic C % is tested for in soil tests, forming the basis of the recommendations for N fertilizer application |

These questions need to be resolved before proper accounting of nitrous oxide emissions from improved nutrient management can be incorporated into the inventory for the project.

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