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Application of the Crop Carbon Progress Calculator in a ‘farm to ship’ cotton production case study in Australia

Francois Visser [b,*], Paul Dargusch [a], Carl Smith [b], Peter R. Grace [c]

[a] School of Geography Planning and Environmental Management, University of Queensland, QLD 4072, Australia
[b] School of Agriculture and Food Sciences, University of Queensland, QLD 4343, Australia
[c] Institute for Future Environments, Queensland University of Technology, 2 St George St, Brisbane, QLD 4000, Australia

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A B S T R A C T

The various initiatives in the market place to quantify the sustainability levels of products are putting pressure on farmers to demonstrate a reduction in the environmental impacts of their crop management practices, and in particular with the lowering of the carbon footprints of their crops. At present there is no internationally accredited common method or carbon footprint model which generates site specific and LCA aligned emission estimates. The application of the Crop Carbon Progress Calculator (CCAP) is demonstrated for an irrigated cotton ‘farm to ship’ case study in Australia where we determine that the progress made in the 2011 crop against a 2002 crop base year amounts to 44% reduction in GHG emission levels.

We estimate that for this particular case study the total carbon footprint of producing a bale of cotton up to ship's side or point of export is 323 kg CO_2e. This includes 182 kg CO_2e from the farm production phase, 73.1 kg CO_2e from the gin to port supply chain, and 68.1 kg CO_2e that results from emission from the stock piled gin trash at the gins. It appears that a feasible option to avoid these trash emissions is to incorporate the waste at farm level. Our analysis shows that this could generate an emissions credit of 48.8 kg CO_2e per bale at farm level, which will amount to a 27% reduction in the farm emissions footprint and a 15% reduction in the whole farm to ship carbon footprint. Due to a number of site specific environmental and crop management factors, there can be significant variances in crop carbon footprint outcomes.

1. Introduction

With an increased emphasis from major brands and retailers in the textile industry to communicate the environmental credentials of their products, cotton exporting countries are under increased pressure to reduce the carbon footprint (CFP) levels of their products (Brock et al., 2012). At present there is no internationally accredited common method or CFP model whereby this can be done which is Life Cycle Assessment (LCA) aligned. The ability to distinguish between irrigated and dryland cotton is also a necessity as more than half of the world's cotton is grown under rain fed conditions (ICAC, 2012). In order to address the need for such an industry level tool, the following requirements were taken into consideration in the development of the Crop Carbon Progress Calculator (CCAP): industry friendliness and easily accessible by farmers and various supply chain participants; the ability to quantify the improvement (reduction) of CFP levels over time or against a base year; market oriented and meet the requirements of industry initiatives (e.g. the Higg Index from the Sustainable Apparel Coalition); compliant with international product carbon footprint standards (e.g. the LCA based Greenhouse Gas (GHG) Protocol; and ideally assess environmental sustainability apart from just GHG emissions.

The tool should also capture site and crop specific data suitable for Intergovernmental Panel for Climate Change (IPCC) Tier 1 or Tier 2 analysis of greenhouse gas emissions, in particular nitrous oxide (N_2O) emissions; and enable the inclusion of basic farm level data without the need to involve third parties; and be based on the best science in terms of methodology and compliance.

To this end, the Crop Carbon Progress Calculator (CCAP) is applied to a cotton case study where the CFP of a bale of irrigated cotton is calculated through the supply chain from a farm in the Darling Downs region of Queensland, Australia, to ship side in the nearest major port of Brisbane.

* Corresponding author. Tel.: +61 (7) 5460157; fax: +61 (7) 54601324.
E-mail address: f.visser@uqconnect.edu.au (F. Visser).

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The methodology of the model is based on the guidelines of the international product CFP standard, GHG Protocol, which is based on the Life Cycle Assessment (LCA) method. Accordingly both the direct and indirect GHG emissions resulting from the manufacturing of a product throughout its entire life cycle need to be accounted for when determining CFPs (Stechemesser and Guenther, 2012). Direct GHG emissions are emissions from sources that are owned or controlled by the reporting entity, typically on-farm emissions and also reported as Scope 1 emissions. Indirect GHG emissions are emissions that are a consequence of the activities of the reporting entity, but occur at sources owned or controlled by another entity, and reported as Scope 3 emissions; typically off-farm emissions emanating higher up or lower down in the supply chain. Scope 2 emissions are specifically from the consumption of purchased electricity, heat or steam (Greenhouse Gas Protocol, 2012).

This application is not a specific LCA case study with the normal use of LCA software (e.g. SimaPro), but a demonstration of an LCA aligned, industry friendly CFP model with the use of site specific data. The LCA methodology or software programs are typically too complex and involved to serve as an industry level tool for individual growers or members of the supply chain to calculate a crop's CFP. The study does not cover the complete life cycle of cotton and should be regarded as a part LCA, from cradle to point of export (Stechemesser and Guenther, 2012).

The focus of the CCAP model is to serve as a management tool whereby the user can evaluate the impacts of different management practices on crop CFP levels as well as monitor progress made against a previous or base year. In this case the progress of the CFP of the 2010/11 crop year is compared against the 2001/2002 base year.

The study also includes cotton gin waste emissions and a carbon credit assessment for the incorporation of gin waste into cotton soils. This is compared to the common practice at gins to stock pile the waste or send it to landfill. We also aim to show that a crop CFP calculation could potentially be a suitable proxy for crop environmental sustainability assessments, including inputs required by the Higg Index from the Sustainable Apparel Coalition (SAC, 2012).

2. Material and methods

The case study was conducted on an established irrigated cotton production farm in the Dalby district of the Darling Downs region in the state of Queensland, Australia. The farm produces irrigated cotton on a continuous or back-to-back basis, and the case study is better able to provide reliable estimates of soil emissions due to consistent agronomic management. The farm data is presented in Appendix A.

We adopt the same emissions framework developed by Visser et al. (2014), except that for this crop manure and anhydrous ammonia (AA) were also used as additional fertilizer sources, and we also consider a potential carbon credit generated through the incorporation of gin trash. The Product Life Cycle Accounting and Reporting Standard of the Greenhouse Gas Protocol standard stipulates which emission sources need to be included for a CFP calculation. For specific formulations and emission factors the model relies on the Australian National Greenhouse Accounts National Inventory Report (NIR) (Australian Government, 2011) which is largely based on the IPCC guidelines, which also formed the basis for the GHG Protocol Standard (Greenhouse Gas Protocol, 2012).

Whilst this is not strictly an LCA case study, it is anticipated that some of the methods that have been developed in the model could assist in LCA calculations to provide more site specific outcomes; in particular the N_2O ABOM model, the chemical emissions model and the gin trash carbon credit model.

2.1. Direct farm emissions

The study employs the same NIR based formulation for fuel use for production and irrigation as in Visser et al. (2014). No electricity was used for irrigation.

2.1.1. Soil nitrous oxide emissions

Nitrous oxide emissions from soil are the dominant emission source in the CFP calculation. In this case study, the 3 nitrogen sources applied to the irrigated crop per hectare were 150 kg N urea, 60 kg N Anhydrous ammonia and 5 tonnes of non-composted feedlot manure. In calculating the indirect N_2O emissions of atmospheric deposition and leaching or runoff, we applied the same formulations based on the NIR guidelines as outlined in Visser et al. (2014).

Direct emissions of N_2O from the crop can be calculated by applying the common applied N-based emission factor (EF) method, or employing complex computer simulation models to generate estimates or actual *in situ* chamber measurements. The latter are more accurate but too costly and time consuming for individual growers to undertake over a typical crop cycle. A range of environmental factors that also influence the rate of N_2O emissions in soils apart from the quantity of N applied, in particular soil temperature, moisture and timing of irrigation, soil mineral N content, type of crop and the type of fertiliser applied (Scheer et al., 2009; Smith et al., 2000; Liu et al.,2010). For specific crop GHG estimates, site specific variations need to be taken into consideration as far as possible and it will be inappropriate to apply a common emission factor over different sites or regions as N_2O emissions is such a dominant GHG emission source in cropping.

The only N_2O model that takes these factors into consideration is the Bouwman model where relative indices (positive or negative) have been developed for the different factors (Bouwman et al., 2002). Unfortunately only limited parameters are available to make a distinction between the different impact levels, and the two factors that warrant further discussion are 'Climate type' and 'Soil drainage'. In the case of climate type we select 'sub-tropical' above 'temperate' as most of the irrigated cotton in Australia is grown in the hotter and dryer westerns parts of the New South Wales and Queensland states, including the case study farm (Roth, 2010). With reference to soil drainage we select 'poor' above 'good' as a heavy vertosol with a high clay content is the most prevalent soil type in these cotton producing regions, coupled with flood irrigation as the common irrigation method which is also conducive to poorer drainage (Roth, 2010). This is also in line with the case study farm with a clay content of 54% and a flood irrigation system. However, due to the uncertainty involved and the considerable impact that these two above factors can have on the results it was decided to incorporate them at 50% of the indicated table value.

Bouwman et al. (2002) shows that there is an increasing non-linear relationship between N applications and corresponding N_2O emission levels (Fig. 1 in paper). This is supported by a number of studies that show that N_2O flux typically increases exponentially in relation to increasing N rates, in particular where N rates exceeded the N uptake capacities of the crop and soil (Grant et al., 2006; FAO – United Nations, 2001; McSwiney and Robertson, 2005; Hoben et al., 2011; Kim et al., 2013). However, in Table 1 in Bouwman et al. (2002) the authors only provide a single emission factor per type of fertiliser without parameter ranges/results as was done with the other site specific factors (see Tables 1 and 2 below). Therefore for the CCAP model we adopt the ABOM N_2O model developed by Visser et al. (2014) that applies a combined linear/non-linear (above optimum yield levels) emission factor data set, as shown below in Table 1 and Fig. 1. Studies have shown that the