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A life cycle assessment of annual, N fertilised perennial and non-N fertilised perennial pastures, South-Western Australia

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Abstract : This research aims to assess the emissions of greenhouse gases (GHGs) from one kilogram of live weight cattle production from annual pastures, nitrogen (N) fertilised perennial pastures and non-N fertilised perennial pastures in Western Australia for different farming practices. Using Streamlined life cycle assessment (SLCA) methodology, it was estimated that approximately 14.30 kg, 12.09 kg and 11.0 kg of CO_2-e of GHG emissions will be emitted from the production of one kilogram of live weight cattle from annual, non-N fertilised and N fertilised perennial pastures respectively. Enteric emissions account for a significant portion of GHG emissions (85% from annual pasture and around 95% from perennial pastures). Live weight yields from annual pasture emit more GHG emissions than do N fertilised and non-N fertilised perennial pastures. Although the inclusion of liming produces additional GHG emissions, the increase in productivity associated with these activities can actually offset GHG emissions when considered on a per kilogram basis.

Keywords: Life cycle assessment, GHGs, pasture, live weight, streamlined LCA, Western Australia

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1 Introduction

Agriculture is a significant contributor to global emissions due to its greenhouse gas emissions. Livestock production is responsible for approximately 70% of agricultural sector emissions and 11% of the total GHG emissions from Australian agriculture (Peters et al. 2010). These figures highlight the significant contribution of the livestock industry to Australia's GHG emissions and they point to the necessity of reducing these emissions.

Pasture production underpins Australia's $21 billion grazing industry (Hughes, 2009). Currently, there is strong interest in perennial pastures, due to the growing realisation that farming systems based solely on annual crops and pastures are not economically sustainable in many regions of south-western Australia (Moore et al., 2006). Ongoing research is being conducted into the development of new pasture varieties that can cope with more extreme weather conditions and water shortages. The research is also investigating the use of new perennials for improved livestock production such as the use of plant species to assist with carbon balance and provide groundcover to safeguard soils from continuing climatic pressures and environmental degradation (Howden and Reyenga, 1999; Restrepo et al., 2011).

The Australian pasture industry must look to managing the future effects of climate change, along with balancing the management requirements of a carbon-constrained world economy. Sixty-six per cent of Australian agricultural emissions are released as methane (CH4) from the digestive tracts of livestock (Eckard, 2007). These enteric emissions are part of the normal fermentation-based digestive process in the rumen of sheep and cattle (Hegarty, 2009). In the event that the livestock industry is included in Australian emissions accounting regulations, efforts may have to be directed towards a more effective livestock diet and towards improved pasture management.

Among the GHGs emitted from the livestock industry, CH_4 and nitrous oxide (N_2O) predominate. These emissions contain 25 and 298 times (respectively) more potential for global warming than does carbon dioxide (CO_2) (IPCC, 2006a). Nationally, agriculture is the dominant source of CH_4 (59%) and N_2O (84%) emissions (Department of Climate Change, 2008). Other than emissions from the paddock (Animal pasture farmland areas in Australia and New Zealand are known as paddocks), pre-farm operations (for example, production of fertilisers and pesticides) and on-farm operations (seeding, ploughing, harvesting) emit a significant portion of GHG emissions during the life cycle of livestock production (Peters et al. 2010; Biswas et al. 2010). While the life cycle of GHG emissions from livestock products in Victoria and NSW (New South Wales) has been studied, to date no study in Western Australia (WA) has determined the life cycle of GHG emissions from live weight gain in grazed annual pastures, nitrogen (N) fertilised perennial pastures and non-N fertilised perennial pastures. This current research differs from other studies in that it focuses on

Western Australia, where clay has been introduced into the sandy soil of the N fertilised pastures under examination. In addition, the current life cycle assessment (LCA) study investigates the impact of liming on the GHG emissions of live weight cattle production from the aforementioned pasture systems.

In order to achieve optimal environmental outcomes and to target management interventions, managers and policy-makers require performance information that contains a holistic life cycle perspective and is based on best-practice data acquisition and analysis. The LCA is a form of cradle-to-grave system analysis that attempts to quantify the major detrimental effects on the environment of all processes involved in a production system. The current project is a comparative study of the life cycle of GHG emissions from annual, N fertilised perennial and non-N fertilised perennial pastures on a farm in the Denbarker area, on the south coast of WA.

2 Methodology

This section presents the LCA methodology used for determining the GHG emissions from a pasture system in Denbarker, in the southern part of Western Australia, where about half of the total beef of the state is produced (DAFWA, 2015a). The general average stocking rates (i.e. number of cattle per hectare per year) for annual (N fertilised), N fertilised perennial and non-N fertilised perennial pastures in this study were 1, 2 and 1 respectively. The stock rate in N fertilized annual pasture (i.e. pasture requires renewal every year) is lower than that in N fertilized perennial pasture due to lower rate of herbage biomass production of the former as a result of the initial establishment period in a year.

Whilst the carrying capacity for the annual and non-fertilised perennial scenarios was the same, annual pastures require on-site supplementary feeding to maintain this stocking rate

(H.Brockman, Department of Agriculture and Food Western Australia (DAFWA), pers. comm.). On the other hand, perennial pastures require rotational grazing as they are inclined to thin out over time (DAFWA, 2015b). The pasture termed non-N fertilised perennial pasture received other fertilisers such as phosphate, but not urea; with the nitrogen provided by legumes.

The life cycle assessment analysis was carried out on three farm management practices (annual pasture, N-fertilised perennial pasture and non-N fertilised perennial pasture) in the same paddock (or farmland area). Modelling was undertaken on the assumption that a 50 hectare paddock (in the N fertilised perennial pasture scenario) was sandy. Annual pastures consist of Ryegrass and clover at the ratio of 50:50, whereas perennial pastures consist of a mixture of Kikuyu grass, temperate perennial grasses (Ryegrass), Tall Fescue and Phalaris and annual pasture. In summer, Kikuyu dominates the mixture, with a ratio of 60:17:23. In winter, the ratio is 17:60:23 with temperate perennial grasses dominating (H. Brockman, DAFWA, pers. comm.).

Using the LCA methodology, four steps from the ISO 14040:2006 guidelines were followed: goal and scope definition, life cycle inventory (LCI) development, life cycle impact assessment (LCIA) and interpretation of the results (ISO, 2006). This particular LCA is best termed ‘streamlined LCA’ as it does not take into account downstream activities (Todd and Curran, 1999). The LCA analysis considered all activities up to the production of live weight, not including the processing and storage of beef in the retail outlet and the conversion of live weight into different food items (e.g. steak, sausages). In addition it did not consider the domestic consumption stage (e.g. use of refrigerator at home) and the disposal of waste (e.g. ‘leftovers’) into landfill, where there is the possibility of methane emissions.

2.1 Goal and scope

The goal of this LCA analysis was to compare the GHG emissions from three pasture systems associated with the live weight gain of beef. The LCA analysis included GHG emissions resulting from both pre-farm and on-farm stages (Figure 1). By establishing the functional units, system boundaries and data requirements, the goals and scope were able to be established. A functional unit is the life cycle of GHG emissions (CO_2, CH_4, N_2O) associated with the production of one kilogram (kg) of live weight beef production in three separate pasture systems. It is important to note that in the scope of this study, the system boundaries did not include emissions from the transportation to abattoir stage, or from the slaughtering itself.

The pre-farm stage included GHG emissions from the production and transportation of farm inputs, such as farm machinery, energy and chemicals, supplementary feed and the emissions from claying (claying was just introduced to N fertilised pasture only). On-farm stage emissions included farm-based activities (application of lime, fertiliser and herbicide), soil-based emissions (for example N_2O from urea fertiliser) and the emissions from grazing and feedlot cattle (enteric emissions and emissions from the decomposition of manure). In the pre-farm stage, emission values for herbicide were not available in Australian databases. Therefore, an equivalent value was taken from the herbicide ‘Roundup’.

The information for this LCA analysis was based on the data in Denbarker Western Australia (34° 46' 11" S , 117° 22' 32" E, altitude, 154m), on a shallow sandy duplexes soil (25%-50%) (DAFWA 2015c). This is a high rainfall zone with an annual rainfall of >550mm making southern part of Western Australia the most perfect place for pasture industries . (Evergraze, 2013; BoM, 2015).

2.2 Life cycle inventory

As part of the life cycle inventory (LCI), the inputs and outputs for each of the stages were quantified. Pre-farm stage GHG emissions included those resulting from the production and use of farm machinery and chemicals, the transportation of the chemicals from point of origin to the paddock, and those from claying (for N fertilised pasture only). GHG emissions associated with the farm machinery used for chemical applications, and from soil-based emissions (e.g., N_2O and CO_2) were emitted in the on-farm stage. Methane (CH_4) emissions from the soil and/or soil uptake of CH4 were also not included due to the absence of data for rain-fed crops in semi-arid regions. Generally, CH_4 emissions/uptake from fertilised agricultural soils can be expected to be low (Suwanwaree and Robertson 2005; Biswas et al. 2008). The input data was collected from the companies that produced and distributed the chemicals used. The data on farm machinery operations and enteric emissions was obtained from DAFWA (H. Brockman, DAFWA, pers. comm.). The soil emissions (or output) values from the farm operations were considered once urea and lime had been applied to the soil.

Tables 1–3 show the calculated input and output data for the energy and chemicals used per hectare per year. This data was used to develop an inventory for the LCA of one kilogram of live weight cattle. The average live weight taken from all pastures in the study was approximately 210 kg (H. Brockman, DAFWA, 2012, pers. comm.). Using yearly per-hectare data, GHG emissions produced during the cattle-life were estimated. The total emissions were then divided by the average live weight of one animal (e.g., 210 kg) in order to determine the GHG emissions produced by one kilogram of live weight.

Pre-farm stage: In Table 1, input values for the production and use of chemicals in the pre-farm stage are given for annual, N fertilised perennial and non-N fertilised perennial pastures.

The units are given as kilograms per hectare per year (kg/ha/yr). Where liquids were used, the volume was converted to kilograms by dividing the volume by the density of the liquid, using the information obtained from the product material safety data sheets (MSDS). It should be noted that the LCA considers not only the emissions from the production of active ingredients, but also the emissions from inactive ingredients which are combined with the active ingredients to form inputs for the production of one kilogram of live weight.

The input values for the transportation of the chemicals used in the pre-farm stage are shown in Table 1.

Urea is imported by sea to Australia from Asia and then transported by truck to Denbarker via Albany. All other chemicals are manufactured or formulated in Australia and are transported via Albany to Denbarker using articulated trucks of varying capacities. The units used are the tonnage of chemicals transported for each kilometre travelled (tkm). As an illustration, the tkm for transporting one litre of Roundup-equivalent (Roundup- E) 467 km from Kwinana to Denbarker in an articulated truck is 0.633 tkm. By applying the emissions factors for transportation in a truck within Australia, namely 8.68, 8.61 x 10–5 and 9.96 x 10–3 for CO_2, N_2O and CH_4 respectively, the carbon dioxide equivalents (CO_2-e) may then be calculated for each GHG.

The costs involved in the production of farm machinery and the costs of fuel consumption are shown in Table 1. This data was obtained from DAFWA and various farm machinery dealers. The cost of the machinery is expressed in USD for each hectare of pasture (USD/ha). Fuel use is quantified in litres of fuel used per hectare (litres/hour/hectare).

Since the application of clay is cost-effective for N fertilised perennial pasture, this activity was incorporated into N-fertilised perennial pasture analysis only, in order to increase the nutrient content and water-holding capacity of the soil. The GHG emissions from claying included emissions originating from the machinery used for the removal of the topsoil, scalping, transportation, tipping, spreading and incorporation of the clay.

The analysis was conducted using clayed versus non-clayed soils. The clay was obtained by removing 500 cm of topsoil with a 220 HP D7 bulldozer from pits measuring 50 m x 36 m x 4 m. The exposed clay was then 'scalped' using a 185 HP carry grader and it was then transported 1.5 km to the paddock in a 30-tonne dump truck (H. Brockman, DAFWA, pers. comm.). The clay was emptied onto the paddock and then spread using a Lehman scraper and an 88 kW tractor. Finally the clay was incorporated into the paddock soil with a spading machine (57 series) pulled by a 170 kW tractor. GHG emissions resulting from the manufacture of the machinery along with the fuel-based emissions created were quantified in this stage.

The data required for the LCI inputs for claying was supplied by DAFWA, (Table 2). Data on the cost of machinery and fuel consumption was supplied by farm machinery dealers. The calculated values for the manufacture of the machinery were in United States dollars (USD) per hectare per year. Fuel use inputs were calculated in litres per hour per hectare (l/hr/ha).

The information on supplementary feed for cattle grazed on Western Australian annual pasture was obtained from DAFWA (2008). Half a tonne of supplementary feed over six months was required for 210kg; the average live weight of one animal.

On-farm stage: For the calculation of GHG emissions from farm machinery operations, emission factors for light duty agricultural machinery (RMIT, 2008) were considered.

Emissions data for all three pasture types from the paddock can be found in Table 3. The analysis used the default Australian data provided in the Australian Methodology for the Estimation of Greenhouse Gas Emissions and Sinks 2006: Agriculture (Department of Climate Change, 2007)

According to this methodology, an average N_2O-N emission factor for Western Australian non-irrigated fertilised farm land can be considered as 0.1% of N application, which is three times less than the average Australian value for non-irrigated farm land. Although N fertilizer was not applied to non N fertilized perennial pasture, there is an existence of natural N in soil, some of which are released to atmosphere through denitrifying bacteria. Since no local data on N_2O-N emissions from non-N fertilised farm land was available, these emissions values were estimated following the method published in Nitrous Oxide and Climate Change (Smith, 2010).

The results concerning CO_2 as carbon (CO_2-C) were derived from the urea hydrolysis IPCC (Intergovernmental Penal for Climate Change) guidelines (IPCC, 2006a). Average enteric emissions (CH_4-C), were provided by the local agricultural department, DAFWA. CH_4-C emissions from manure were determined by following Biswas et al. (2010), and Meat and Livestock Australia (MLA) (2011). Following the consultation with DAFWA (H. Brockman, DAFWA, pers. comm.) and the review of Barton et al. (2014), lime has been assumed to be dissolve in five years, which means that it was applied once in five years.

Indirect N_2O emissions from leaching and ammonia volatilisation were taken into account in this LCA analysis. The IPCC methodology predicts that leaching will only occur when Et/P is between 0.8 and 1 (IPCC, 2006b). N_2O emissions from leaching were considered to be zero, as the ratio of mean annual evapotranspiration (Et=700 mm) to annual precipitation (P=929 mm) was 0.75 for the field site in Denbarker (Bureau of Meteorology, 2005; Bureau of Meteorology, 2012). N_2O-N emissions from the volatilisation of ammonia (NH_3) due to fertiliser application were calculated using the IPCC default value (IPCC, 2006b), as this value was not determined at the research site. Furthermore, this IPCC default value is currently used in the Australian GHG inventory (Department of Climate Change, 2007). The IPCC methodology assumes that 10% of N fertiliser applied will be emitted as NH_3 via ammonia volatilisation, with 1% of the NH_3-N then emitted as N_2O-N following atmospheric deposition. The value of N_2O-N is multiplied by 44/12 to convert N_2O-N to N_2O.

Sequestration of CO_2 by Kikuyu in perennial pastures is approximately 0.9 tonne/ha/yr (CSIRO, 2012; Sanderman et al. 2014)). Since the Kikuyu dominates with a ratio of 60:17:23 respectively in summer, and a ratio of 17:60:23 in winter, with temperate perennials dominating, these proportions were used to calculate the amount of CO2 sequestration by perennial pastures. Since Kikuyu has the longer survival time and a greater biomass compared to annual pastures of Ryegrass and clover, there is significant interest in the carbon storage capability of this species of grass (Murphy, 2012).

2.3 Life cycle impact assessment

The life cycle impact assessment (LCIA) was initiated after compiling the LCI. The first step of LCIA is classification, where CO_2, N_2O, and CH_4 emissions associated with the production of inputs have been multiplied by the corresponding inputs (Tables 1–3) to obtain the emissions of CO_2, N_2O, and CH_4. . Then Forster et al.'s (2007) method was applied, to convert the values of CO_2, N_2O, and CH_4 to CO_2-equivalents (CO_2-e) by multiplying by 1 for CO_2, 298 for N_2O and 25 for CH_4, which is known as characterisation.

Finally the CO_2-e values were totalled for one hectare of pasture land. These hectare-wise GHG emission values were divided by the amount of live weight gain per hectare to determine the kg CO_2–e of GHG emissions per kilogram of live weight beef production.

Emission factors for chemicals and supplementary feed : Emission factors for CO_2, N_2O and CH_4 of urea, superphosphate and lime were obtained from the Australian LCA database (RMIT, 2008). It should be noted that the emissions factor for urea production does not exclude the amount of fossil-derived CO_2 for urea production; this amount of CO_2 was therefore excluded from that particular emission factor prior to conducting the current analysis. The generic emission factor for supplementary feed was obtained from FSA Consulting (S.Wiedemann, FSA Consulting, Toowoomba, Queensland, pers. comm.).

No data was available with regard to Roundup. It was therefore converted to an equivalent of glyphosate with the values for each herbicide obtained from DAFWA (A. Hashem, DAFWA, pers. comm.). Thereafter, emission factors from the Australian LCA database were used to calculate the emissions resulting from the use of glyphosate.

Emission factors for transportation:The emission factor for the transportation of the chemicals to the Denbarker pastures was taken from the Australian LCA database (RMIT, 2008). This emission factor was then used to calculate the GHG emissions for road transportation of chemicals in a 50-tonne articulated truck. The capacity of the vehicle used was obtained from the supplier and a single journey was assumed. Where sea transportation was used (for urea), the port closest to the manufacturer was identified, distances determined and a single sea journey on a ship assumed.

Emission factors for farm machinery: The emission factors for farm machinery are available in US dollars (i.e., kg CO_2–e produced per USD equivalent of farm machinery production). Therefore, emission factors were sourced from the USA input/output database for 1998 (Suh, 2004) in assessing the GHGs emitted from the manufacturing of farm machinery. The information on the operational lifetime of farm machinery and its costs was known in determining the cost per hectare. The current price of farm machinery was deflated to a 1998 price (in Australian dollars) at 3% per year. This allowed for the 1998 Australian price of the machinery to be converted to a 1998 US dollar price.

Emission factors for farm machinery operation: The operation of machinery requires the use of fuel and this depends on the number of passes the machine must make over the paddock, along with the size of the paddock. Using both fuel consumption and emissions factors, the GHG emissions for the operation of each machine were calculated. The emissions factors for the operation of farm machinery were obtained from the RMIT LCA database (RMIT, 2008).

3 Results and discussions

3.1 Existing scenario

Table 4 shows the life cycle of GHG emissions per kilogram of live weight cattle for annual, N fertilised perennial and non N fertilised perennial pastures, excluding the activities of claying and liming. Both non-N (unfertilised) and N fertilised perennial pastures contributed 23% and 15% (respectively) fewer emissions than did annual pasture (14.30 kg CO_2-e/kg of beef live weight). This is mainly because of the fact that the emissions from the production of supplementary feed produced additional emissions from live weight production in an annual pasture. Secondly, the carbon sequestration was not considered for this pasture due to the loss of vegetation annually for seeding. Thirdly, the input requirements for annual pasture were also higher than those for perennial pastures. Enteric emissions for live weight gain from annual pasture (12 kg CO_2-e/kg of live weight) were same as those for N fertilised and non-N fertilised perennial pastures as same enteric emission factor was considered for all pastures and are accounted for significant portion (84%-95%) of the total GHGs . However, GHG emissions from the production of inputs for annual pasture were higher than those for both N fertilised and non-N fertilised perennial pastures. In the case of N fertilised perennial pasture, GHG emissions per kilogram of live weight gain were reduced due to the benefits associated with the increase in productivity. The avoidance of GHG emissions from the production, transportation and application of urea significantly reduced the GHG emissions of live weight gain from the non-N fertilised perennial pasture. These perennial pastures sequester CO_2, but the annual pasture does not. It should be noted that the sequestration benefit associated with Kikuyu in non-N fertilised pasture was twice as much as that of N fertilised perennial pasture. This is due to the stock rate on fertilised plots being doubled, which in turn doubles the consumption rate of the pasture's species.

As can be seen from Figure 2, during the life cycle of live weight gain from annual, N fertilised perennial and non-N fertilised perennial pastures, the on-farm stage contributed significantly higher GHG emissions than those found for the pre-farm stage. GHG emissions from pre-farm and on-farm stages of live weight gain from annual pasture accounted for 13% and 87% of total GHG emissions, respectively. Similarly, the pre-farm and on-farm stages accounted for 5% and 95% of the total GHG emissions for N-fertilised perennial pasture, and 4% and 96% for non–N fertilised perennial pasture. CH_4 emissions from belching, and decomposition of animal excreta during the on-farm stage accounted for a significant proportion (85% for annual pasture and 94% and 95% for N fertilised and non-N fertilised perennial pastures, respectively) of total GHG emissions.

3.2 GHG emission-implications of claying N fertilised perennial pasture

The investment in the claying of N fertilised pasture has been found to be more cost-effective than for the other two pasture systems studied. This is due to evidence that an increase in pasture growth of 10% - 20% is possible (Bell et al. 2012; CSIRO, 2012). In the current analysis, live weight increase is also deemed to have the same percentage potential with regard to pasture growth. While claying improves productivity, GHG emissions from claying activities (i.e., emissions originating from the machinery used for the removal of the topsoil, scalping, transportation, tipping, spreading and incorporation of the clay) could increase the overall GHG emissions. The increase in the productivity of live weight gain associated with claying could also affect the life cycle of GHG emissions. Thus, the impact of the claying of pasture on GHG emissions from live weight gain was investigated for the N fertilised perennial pasture system only (Table 5). GHG emissions varied from 12.09 kg to 12.98 kg of CO_2–e for pasture growth increases of 10% and 20%, respectively. The GHG emissions increase from claying increased by more than 7.4% for a pasture growth increase of 10%, and by 3.3% for a pasture growth increase of 20%. It appears that productivity increases associated with claying do not result in carbon energy savings.

3.3 Impact of liming on GHG emissions of live weight production

The impact of liming on GHG emissions from live weight beef production was investigated for annual pasture, N fertilised perennial pasture and non-N fertilised perennial pasture (Table 6). The lime dissolution rate (or the rate at which lime will dissolve) has been reported as being 20% per year, and the pasture growth increase associated with liming application has been reported as varying from 10% to 20% (Bell et al. 2012). Although the production, transportation and application of lime produces additional GHG emissions, lime application in annual pasture, N fertilised perennial pasture and non-N fertilised perennial pasture has been found to reduce the GHG emissions of live weight gain on a per kilogram basis. The application of lime to annual pasture can reduce GHG emissions by 0.8% and 12.14.2% for annual pasture growth increases of 10% and 20%, respectively. Similarly, GHG emissions can be reduced by between 3.7% and 6.9% by the liming of N fertilised perennial pasture, and by between 1.0% and 4.5% by the liming of non-N fertilised perennial pasture, for pasture growth increases of 10% and 20% respectively.

3.4 Comparison with other similar Australian LCA and International studies

Life cycle GHG emissions from one kilogram of live weight production in WA have been compared with one kilogram of live weight produced in NSW (Peters et al. 2010). The total GHG emissions from live weight gain for WA (Table 4) are higher than those associated with live weight production in NSW (10 kg CO_2- e/kg live weight). This difference may be due to the fact that the NSW study excluded soil emissions from leguminous pastures from their calculations (Peters et al. 2010). In addition, the difference in the stocking rates in these two States may have caused this disparity in GHG emissions per kilogram. For example, the stocking rate for cattle in NSW is less than 1 animal per hectare expressed for a total farm area, with 69% reporting a stocking rate of less than 0.5 cattle/ha (FFI-CRC, 2010), while this study considered 1 animal per hectare for annual and non-N fertilised pastures and 2 cattle per hectare for N fertilised perennial pasture. The total GHG emissions from the production per kilogram of live weight in this current analysis was of similar magnitude to other values reported from live weight gain in North America (13.04 kg CO_2-e/kg), Japan (14.6 kg CO_2-e) and Europe (15 kg CO_2-e/kg) (Beauchemin et al. 2010; Ogino et al. 2007; Mogensen et al. 2009)).

4 Conclusion

An estimated 14.30 kg, 12.09 kg and 11.0 kg of CO_2-e of GHG emissions would be emitted from the production of one kilogram of live beef weight produced from annual, non-N fertilised and N fertilised perennial pastures, respectively. During the life cycle of live weight gain, the on-farm stage contributes significantly higher GHG emissions than do the other stages. Enteric GHG emissions account for a large proportion (85% - 96%) of the GHG emissions produced during the life cycle of beef production. Claying, liming and fertiliser production, which involves heavy machinery diesel fuel combustion, contribute a relatively lower amount of GHG emissions compared to enteric emissions.

Therefore, strategies for reducing enteric emissions need to be considered. These include the improvement of forage quality, improvements to feed efficiency, an increase in the use of condensed tannins in the diet of livestock, animal vaccinations, and the use of suitable feed additives (Davidson 2000 and Hegarty 2009). Finally, the use of liming for soil amendment purposes can increase carbon savings by 1% to 6%. However, the use of clay does not provide any carbon saving benefits as it is a more carbon-intensive activity than liming.

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References

Barton, L., Thamo, T., Engelbrecht, D. and W. K. Biswas (2014). 'Does growing grain legumes or applying lime cost effectively lower greenhouse gas emissions from wheat production in a semi-arid climate?'. *Journal of Cleaner Production* Vol. 83 pp.194.

Beauchemin, K.A., Janzen, H.H., Little, S.M., McAllister, T.A.and McGinn, S.M. (2010). 'Life Cycle Assessment of Greenhouse Gas Emissions from Beef Production in Western

Canada: A Case Study', *Agricultural Systems*, Vol.103, No 6, pp. 371– 379. doi : 10.1016/j.agsy.2010.03.008

Bell, M.J., Cullen, B.R. and Eckard, R.J.(2012) 'The Influence of Climate, Soil and Pasture Type on Productivity and Greenhouse Gas Emissions Intensity of Modeled Beef Cow-Calf Grazing Systems in Southern Australia‘, *Animals,* Vol. 2, pp. 540-558. doi:10.3390/ani2040540

Biswas, W.K., Barton, L. and Carter, D. (2008) 'Global Warming Potential of Wheat Production in South Western Australia: A Life Cycle Assessment.', *Journal of Water and Environmental Management,* Vol. 22, pp. 206 – 216. doi: 10.1111/j.1747-6593.2008.00127.x

Biswas, W.K., Barton, L.and Carter, D. (2011) 'Biodiesel production in a semiarid environment: a life assessment approach‘, *Environmental Science & Technology*, Vol. 45, No 7, pp.3069–74.doi: 10.1021/es1031807

Biswas, W.K., Graham, J., Kelly, K. and John, M.B. (2010) 'Global Warming Contributions from Wheat, Sheep Meat and Wool Production in Victoria, Australia- A life cycle assessment‘. *Journal of Cleaner Production,* Vol. 18, pp. 1386-1392. doi:10.1016/j.jclepro.2010.05.003

Bureau of Meteorology (2005) *Annual Actual Areal Evapo-Transpiration*. Australian Government, Melbourne.

Bureau of Meteorology (2010) *Climate Statistics for Australian Locations*. Australian Government, Melbourne.

Bureau of Meteorology (2015) Montly rainfall data, Dembarton, Australian Government, Melbourne.

CSIRO (2012) *Kikuyu Over Carbon*. Australian Science, Asutralia's Future. http://www.csiro.au/ruralpress/77

DAFWA (2008) Supplementary feeding : keeping livestock healthy during summer, Small Landholder Series, NW10.https://www.agric.wa.gov.au/supplementary-feeding-during-summer.

DAFWA (2015a) Beef cattle, Government of Western Australia, https://www.agric.wa.gov.au/livestock-animals/livestock-species/beef-cattle

DAFWA (2015b) Productive pasture management for small landholders, Government of Western Australia, https://www.agric.wa.gov.au/pasture-management/productive-pasture-management-small-landholders?page=0%2C1

DAFWA (2015c) My soil, Government of Western Australia, https://www.agric.wa.gov.au/mysoil

Davidson, S. (2000) ‘Bad Breath‘, *Ecos* Vol 103, pp. 10-11.

Department of Climate Change (2007) *Australian Methodology for the Estimation of Greenhouse Gas Emissions and Sinks 2006*: Agriculture. Department of Climate Change Commonwealth of Australia, Canberra.

Department of Climate Change (2008) *Agricultural Sector Greenhouse Gas Emissions Projections. Strategies and Coordination Division*, Department of Climate Change, Canberra.

Eckard. R. (2007) *Australian Agricultural Contributions to Greenhouse Gases*, Australian Fertilizer Industry Conference, 6-9 August 2007 Hamilton Island, Queensland.

Evergraze (2013) South Coast Sandplain WA – Pastures, EverGraze website, Future Farm Industries CRC, http://www.evergraze.com.au/library-content/south-coast-sand-plain-wa-pastures/

FFI-CRC (Future Farm Industries CRC) (2010) *A Survey of the Use of Perennial Pastures as Part of the Pasture Crop Rotation in the Mixed Farming Zone of Southern New South Wales*, The University of Western Australia, Crawley, WA 6009, Australia.

Forster, P., Ramaswamy, V., Artaxo, P., Berntsen, T., Betts, R., Fahey, D.W., Haywood, J., Lean, J., Lowe, D.C., Myhre, G., Nganga, J., Prinn, R., Raga, G., Schulz, M., and Dorland, R.V. (2007) ‘Changes in Atmospheric Constituents and in Radiative Forcing’, in: Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., M.Tignor, Miller, H.L. (Eds.): *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Hegarty, R. (2009) *Seeking Low Methane Sheep*, CRC for Sheep Industry Innovation. Commonwealth Government’s Cooperative Research Centre’s Program, Australia.

Howden, S.M. and Reyenga, P.J. (1999) ‘Methane Emissions from Australian Livestock: Implications of the Kyoto Protocol‘, *Australian Journal of Agricultural Research,* Vol. 50, pp. 1285–1292. doi:10.1071/ AR99002.

Hughes, S. (2009) *Bird-proof Cage Keeps Research Under Wraps*. South Australia Research and Development Institute. http://www.futurefarmonline.com.au/images/publications/Bird-proof cage keeps research under wraps.pdf.

IPCC (Intergovernmental Panel on Climate Change) (2006a) *N_2O Emissions from Managed Soils, and CO_2 Emissions from Lime and Urea Application*, Chapter 11, IPCC Guidelines for National Greenhouse Gas Inventories. Geneva 2, Switzerland, The Intergovernmental Panel for Climate Change, p 11.1.

IPCC (2006b) *IPCC Guidelines for National Greenhouse Gas Inventories 2006,* IPCC, Geneva.

http://www.ipccggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_11_Ch11_N2O&CO2.pdf.

ISO (International Standard Organization) (2006) *ISO 14040-44 Life Cycle Assessment – Principles and Framework. Environmental Management,* International Organization for Standardization. Geneva.

MLA (Meat and Livestock Australia) (2014) *Feedlot Mass Balance and Greenhouse Gas Emissions – A Literature Review,* Meat & Livestock Australia, Locked Bag 991, North Sydney NSW 2059

Mogensen, L., Hermansen, J.E., Halberg, N., Dalgaard, R., Vis, J.C. and Smith, B.G., 2009. Life Cycle Assessment Across the Food Supply Chain. In Baldwin, C.J. (Ed): *Sustainability in the Food Industry,* pp 115-145, Wiley-Blackwell.

Moore, G., Sanford, P. and Wiley, T(2006) 'Perennial pastures for WA',*Proceedings of the 13th Australian Agronomy Conference*, 10-14 September 2006 Perth, Western Australia.

Murphy, D. (2012) 'Carbon accumulation potential in WA soils', *Crop Updates,* 28 February 2012, Perth WA.

Ogino, A., Orito, H., Shimada, K. and Hirooka, H. (2007) 'Evaluating Environmental Impacts of the Japanese Beef Cow–Calf System by the Life Cycle Assessment Method', *Animal Science Journal*, Vol. **78**, pp. 424–42. doi: 10.1111/j.1740- 0929.2007.00457.x.

Peters, G., Rowley, H., Wiedemann, S., Tucker, R., Short, M.D. and Schulz, M. (2010) 'Red Meat Production in Australia: Life Cycle Assessment and Comparison with Overseas Studies', *Environmental Science and Technology,* Vol. 44, pp.1327-1332.doi: 10.1021/es901131e.

Restrepo, C., Ramirez, X., Li, D.Z., Vercoe, P., Gardiner, C., O'Neil, C., Coates, D, and Chamley, E. (2011). 'Assessment of tropical Legumes to reduce methane emissions from pastoral systems using in vitro fermentation and near infrared reflectance spectroscopy methodologies', *Proceeings of the Greenhouse 2011 Conference: the Science of Climate*

Change. *Greenhouse 2011 Conference: the Science of Climate Change*, 4-8 April 2011, Cairns, QLD, Australia.

RMIT (2008) *Australian Database 2008*, Centre for Design, Royal Melbourne Institute of Technology (RMIT) University, Melbourne.

Sanderman, J., Fillery, I.R.P., Jongepier, R., Massalsky, A., Roper, M.M.L., Macdonald, M., Maddern, T., Murphy, D.V., Wilson, B.R.and Baldock, J.A. (2014) 'Carbon sequestration under subtropical perennial pastures I: Overall trends", *Soil Research*, Vol. 51, No. 8, pp.760-770. http://dx.doi.org/10.1071/SR13111

Smith, K. (2010) *Nitrous oxide and climate change*. Earthscan Ltd, UK.

Suh, S.(2004) *Material and Energy Flows in Industry and Ecosystem Network*. Centre for Environmental Science, University of Leiden, The Netherlands.

Suwanwaree, P. and Robertson, G.P. (2005) 'Methane oxidation in forest, successional, and no-till agricultural ecosystems: effects of nitrogen and soil disturbance', *American Journal of Soil Science Society,* Vol.69, pp. 1722 – 1729. doi:10.2136/sssaj2004.0223

Todd, J.A. and Curran, M.A. (1999) *Streamlined Life-Cycle Assessment: A Final Report from the SETAC North America Streamlined LCA Workgroup*. Society of Environmental Toxicology and Chemistry and SETAC Foundation for Environmental Education, Pensacola, FL 32501-3370, USA.

List of figures

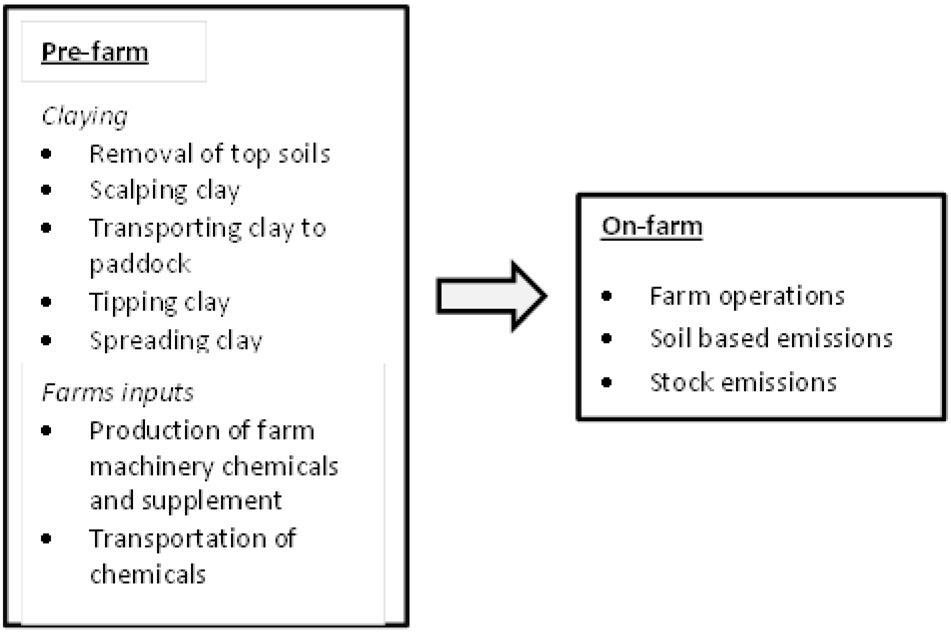
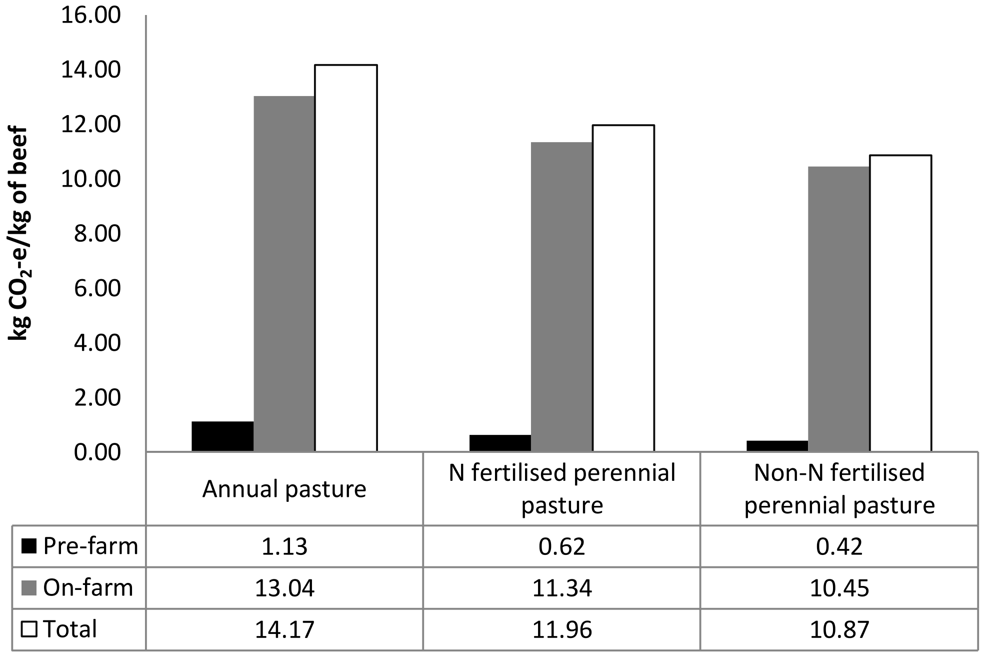


Figure 1 System boundaries of pasture LCA



	Annual pasture	N fertilised perennial pasture	Non-N fertilised perennial pasture
■ Pre-farm	1.13	0.62	0.42
▨ On-farm	13.04	11.34	10.45
☐ Total	14.17	11.96	10.87

Figure 2 GHG emissions (kg CO_2-e/kg beef) during pre-farm, and on-farm activities

List of tables

Table 1 Input values for life cycle inventory of pre-farm stage (annual basis)

Inputs		Units	Annual fertilised pasture	N fertilised Perennial pasture	Non-N fertilised Perennial pasture
Production and use of chemicals					
Fertilisers	Superphosphate	kg/ha/yr	200	150	150
	Urea[a]	kg/ha/yr	100	100	0
Herbicide	Roundup-E	kg/ha/yr	1.4	1.4	1.4
Lime		kg/ha/yr	500	500	500
Transportation of chemicals					
Fertilisers	Superphosphate	tkm/ha	93	70	70
	Urea*	tkm/ha	1052	1052	0.00
Herbicide	Roundup-E	tkm/ha	0.63	0.63	0.63
Lime		tkm/ha	297	297	297
Cost to produce farm machinery and fuel use					
Spraying Herbicide	Cost of spraying machinery (1998 price)	USD/ha	3.58	3.58	3.58
	Fuel use	l/hr/ha	1.000	1.000	1.000
Top dressing	Cost of top dressing machinery (1998 price)	USD/ha	111.90	111.90	111.90
	Fuel use	l/hr/ha	2.00	2.00	2.00
Liming	Cost of liming machinery (1998 price)	USD/ha	1.20	1.91	1.91
	Fuel use[b]	l/hr/ha	0.72	1.16	1.16

[a] The application rate of urea in leguminous pasture is the same as the rate applied to non-leguminous pasture even though the presence of legume species reduces the requirement for the addition of urea. The same rate of urea was applied to leguminous pasture in order to increase the productivity and hence the associated cost effectiveness (H. Brockman, DAFWA, 2012, pers. comm.).

[b] Since the speed of the lime spreader on annual pasture (8 km/hour) is higher than that on perennial pasture (5 km/hour), fuel consumption in lime spreading on annual pasture is lower than on perennial pasture.

Table 2 Input values for LCA from claying on an annual basis

Activity	Unit	Inputs
Removal of topsoil	USD/ha	0.029
	l/hour/ha	2.95
Scalping clay	USD/ha	0.67
	l/hour/ha	1.48
Transporting clay to paddock	USD/ha	0.01
	l/hour/ha	37.50
Tipping the clay	USD/ha	0.00
	l/hour/ha	8.33
Spreading the clay	USD/ha	0.05
	l/hour/ha	5.56
Incorporation of the clay	USD/ha	0.14
	l/hour/ha	17.00

Table 3 Output values for life cycle inventory for emissions from paddocks for the on-farm stage on an annual basis

Outputs	Units	Annual pasture	N fertilised Perennial pasture	Non-N fertilised Perennial pasture
N_2O-N	kg/ha/yr	$4.54 \text{x} 10^{-2}$	$4.54 \text{x} 10^{-2}$	$2.01 \text{ x} 10^{-2}$
CO_2-$C_{ureahydrolysis}$	kg/ha/yr	5.52	5.52	
CH_4-C_{manure}	kg/ha/yr	$1.3 \text{ x} 10^{-2}$	$1.7 \text{ x} 10^{-2}$	$1.7 \text{ x} 10^{-2}$
CH_4-$C_{enteric}$	kg/ha/yr	90	180	90
CO_2-C	kg/ha/yr	60	60	60
$CO_{2\ sequestration}$	kg/ha/yr	0	-346.5[a]	-346.5[a]

[a] equalised by additional CH_4 produced plus increased consumption of biomass leading to less C-sequestering

Table 4 GHG emissions of beef production (kg CO_2-e/kg beef) from annual pasture, N fertilised perennial pasture and non-N fertilised perennial pasture systems

Activities	Annual pasture	N fertilised Perennial pasture	Non-N fertilised Perennial pasture
Production of farm inputs	1.03	0.58	0.39
Transportation of farm inputs	0.10	0.04	0.03
Farm machinery operation	0.06	0.06	0.05
Soil emissions from urea application (CO_2 and N_2O)	0.20	0.10	0.04
Indirect emissions from leaching and NH3 volatilisation	0.01	0.004	0.004
Emissions from belching	12.00	12.00	12.00
Emissions from manure digestions	0.13	0.13	0.13
CO_2 sequestration		-0.83	-1.65
Production of supplementary feed	0.77		
Total	14.30	12.09	11.00

Table 5 Impact of claying of pasture on GHG emissions (kg CO_2–e/kg of beef) from beef production from N fertilised perennial pasture

Claying activities	Claying - with 10% increase in pasture growth	Claying - with 20% increase in pasture growth	No claying
Production of farm inputs	0.56	0.54	0.58
Claying	1.32	1.23	0.00
Transportation of farm inputs	0.04	0.04	0.04
Farm machinery operation	0.06	0.06	0.06
Soil emissions from urea application (CO_2 and N_2O)	0.10	0.09	0.10
Indirect emissions from leaching and NH3 volatilisation	0.004	0.004	0.004
Emissions from belching and manure digestion	11.69	11.29	12.13
CO2 sequestration	-0.80	-0.77	-0.83
Total	12.98	12.48	12.09

Table 6

Impact of liming on GHG emissions from annual, N fertilised perennial and non-N fertilised perennial pastures

Activities	Annual pasture			N fertilised perennial pasture			Non N fertilised perennial pasture		
	No liming	Liming - 10% pasture growth	Liming - 20% pasture growth	No liming	Liming - 10% pasture growth	Liming - 20% pasture growth	No liming -	Liming - 10% pasture growth	Liming -20% pasture growth
Production of farm inputs	1.03	1.04	1.00	0.58	0.37	0.36	0.39	0.37	0.36
Transportation of farm inputs	0.10	0.24	0.23	0.04	0.11	0.11	0.03	0.10	0.10
Farm machinery operation	0.06	0.07	0.07	0.06	0.07	0.07	0.05	0.06	0.06
Soil emissions from urea application	0.20	0.19	0.18	0.10	0.10	0.09	0.04	0.04	0.04
Indirect emissions	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Emissions from animal	12.13	11.69	11.29	12.13	11.69	11.29	12.13	11.69	11.29
CO2 emissions from liming	0.00	0.20	0.20	0.00	0.10	0.10	0.00	0.20	0.20
CO2 sequestration	0.00	0.00	0.00	-0.83	-0.80	-0.77	-1.65	-1.59	-1.54
Production of supplementary feed	0.77	0.74	0.72						
Total	14.30	14.18	13.69	12.09	11.65	11.25	11.00	10.89	10.51