Impacts of land use change on the assessment of water use in grazing systems and interactions with carbon sequestration

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ABSTRACT

The impact of land use change (LUC) and water use was investigated using a a case study of beef production from grazing land. LUC from grassland to forest (afforestation) reduced greenhouse gas (GHG) emissions as a result of carbon sequestration, but also decreased runoff and consumptive fresh water availability compared to pre-LUC conditions. During the transition (LUC period), annualized carbon sequestration (reported as negative emissions) were an estimated –4.9 t CO_2-e / ha.yr. By the end of the transition period (post LUC) run-off declined by 30% (0.1 ML / ha.yr) as tree growth modified soil moisture conditions. Per kilogram of beef, net emissions changed from 10.9 kg CO_2-e / kg live weight (LW) (pre-LUC) to -3.0 kg CO_2-e / kg LW (LUC period). Consumptive water use increased from 305 L / kg LW (pre-LUC) to 632.7 L / kg LW during the LUC period. In the post LUC period, net sequestration was minimal as trees reached maturity, but reduced runoff and higher consumptive water use remained as a permanent change.

Keywords: beef, grazing, LUC, water, carbon, GHG

1. Introduction

It is now widely accepted that land use change (LUC) can be an important contributor to greenhouse gas (GHG) emissions in food production supply chains and is a necessary inclusion for agricultural and food product life cycle assessment (LCA) and carbon footprinting (CF). Land use change can also lead to carbon sequestration (GHG removals) if afforestation occurs. In Australia, efforts have been made to promote tree planting in grazing areas to provide improved production and environmental outcomes (Youl et al. 2006). Afforestation has also been promoted as a means to sequester carbon under a government scheme known as the Carbon Farming Initiative or CFI (Department of the Environment 2014). Accounting for LUC GHG emissions has shown large impacts may be attributed to agricultural systems where LUC occurs, i.e. Cederberg et al. (2011). Other authors such as Schmidinger and Stehfest (2012) have extended the discussion to consider not only the emissions that may have occurred from deforestation, but also the ‘missed potential carbon sink’ associated with land occupation. This approach treats all land as having the potential to sequester carbon if returned to forest.

Land use change is known to have an effect on water availability (Mila i Canals et al. 2009) though few case studies have considered this. Research in the field of hydrology is unequivocal; increasing vegetation cover will reduce runoff (water yield) while decreasing vegetation cover will increase water yield (Bosch & Hewlett 1982, Brown et al. 2005). Thus, a trade-off exists between net LUC impacts on GHG (emissions or removals) and water yield, and methods proposed to account for the impact of land management on GHG flux (i.e. Schmidinger & Stehfest 2012) should consider broader impacts such as water availability to provide a holistic analysis. In the context of greater global demand for food (FAO 2009), the complex interactions between GHG flux, livestock (food) production and water resource availability require careful investigation to avoid unintended outcomes. Australian grazing land is predominantly classified as grazing of native vegetation (Lesslie & Mewett 2013) and in these systems, livestock graze partly forested pasture lands. In such systems, there is some flexibility to alter the proportion of trees and pasture by promoting seedling establishment from established trees or alternatively, by controlling seedling recruitment. This paper investigates the interaction between these three factors at the local scale for an Australian beef grazing farm where afforestation had taken place as a result of changed farm management, resulting in changed tree density.

2. Methods

2.1. Goal and scope

This study used actual production data from a cattle grazing farm in Queensland, Australia to investigate the impacts of partial afforestation of pasture land. The case study was located in the headwaters of the Murray Darling river catchment of Australia, which has a high degree of competition for water resources. This study examined the impacts of LUC on global warming using IPCC AR4 global warming potentials (GWP) – (IPCC 2007). Consumptive water use was assessed using water balance methods (Bayart et al. 2010). The system boundary included all processes associated with the production of beef up to the farm-gate. The functional unit (FU) was chosen as 'one kilogram of live weight at the farm gate' and results were also reported as totals for the whole farm.

2.2. Inventory data

Livestock production data were collected from farm records over a two year period and were confirmed via discussions with the farmer and site visits in the year 2010 (Table 1). Land use change was initiated on the farm in 2008 as a result of a change in grazing species (sheep to cattle) when the farm was purchased. This resulted in natural regrowth of native woody perennial trees (afforestation) to take place on a 235 ha section of the property. On other parts of the property, regrowth was controlled as part of routine management. The association between cattle grazing and woody thickening has been reported large parts of Australia (Burrows et al. 1998, Burrows et al. 2002). On the case study farm, woody thickening was the result of a change in grazing species from sheep, which graze young trees and limit growth, to cattle which don't graze young trees to the same extent. Grazing livestock were changed from sheep to cattle eight years before the assessment period (in the year 2000), resulting in wide spread establishment of native trees that were suppressed by sheep grazing but not by cattle. While attribution of the impacts of LUC to livestock is generally accepted where livestock are grazed following conversion of forest to pasture, attribution is less clear when changed grazing management results in increased tree growth and GHG removals. On the case study farm, the management change from sheep to cattle was deemed the causal factor enabling establishment of trees, providing a causal association between cattle grazing and changed GHG flux.

The system was assessed over three time periods, before (pre-LUC, prior to year 2008), the LUC period (2008-2037) and the post-LUC period (2037+). The impact of afforestation was modelled over a forward estimate period of 30 years to approximate the time taken for trees to reach maturity. The modelling periods did not account for other possible changes in climate or management over the forward estimate period. Over the reforested land area, livestock grazing was predicted to decline by 10%, corresponding to the decline in grass growth as trees approached maturity. This was predicted to result in an equivalent 10% decrease in livestock numbers and beef production for the farm in the absence of other management changes.

Table 1. Case study farm characteristics

Parameter	Units	Value
Average annual rainfall	mm	661
Land and grazing		
Farm size	ha	2 017
Total area of pasture	ha	1 967
Afforestation area	ha	235
Sheep	%	0
Cattle	%	100
Cropping	%	0
Herd size (cow no.)	No.	212
Water supply		
Farm dam	%	83
Bore	%	0
Creek	%	17
Total livestock drinking water	ML	5.27

Consumptive fresh water use

The water use inventory was developed in accordance with Bayart et al. (2010), covering all sources and losses associated with beef production both in foreground and background systems. Primary sources of consumptive fresh water use for beef cattle production were associated with livestock drinking water, drinking water supply losses, and irrigation. Drinking water for grazing cattle was predicted from feed intake, climate and feed characteristics for the farm using equations from Ridoutt et al. (2012). Losses from farm dams occurred from evaporation, and to a lesser extent seepage (Nathan & Lowe 2012). Losses associated with water supply from farm dams were modelled using farm dam water balances constructed from long term climate data for the farm. Dams and catchment areas were assessed during site visits and were later mapped using aerial imagery. The dam water balances were modelled using a daily time-step water balance using long term rainfall and evaporation data obtained for each region as Patched Point Datasets (DSITIA 2013, Jeffrey et al. 2001). The balance accounted for extractions, seepage and evaporation losses. The dam water balances were calibrated using records of filling and emptying events, determined through discussion with the farm owner. Catchment runoff and dam inflow was modelled using USDA-SCS KII curve numbers (USDA NRCS 2007), with appropriate values determined from site observations of soil type and farming practices. Water use was determined from the difference between water flows leaving the farm in the presence of absence of the farming system. Water modelling took into account the degree of forest cover in prior to LUC (pre-LUC), during afforestation (LUC period) and post-LUC. Runoff predictions were calibrated at the local scale using farmer knowledge of the frequency of runoff events, and against catchment yields for similar catchments. Catchment yields (runoff as a percentage of rainfall) were 6% in the pasture system, declining to 4% in the reforested system after 30 years which was a conservative estimate (Brown et al. 2005), and similar to the estimated whole catchment water yield of 5% (CSIRO 2007). This corresponded to an annualised decline in runoff across the whole farm of 25.4 ML per year over the LUC period and an absolute decline of 31 ML between the pre and post-LUC periods.

Greenhouse Gas Emissions

Greenhouse gas emissions from livestock were determined using methods based on the Australian National Greenhouse Gas Inventory (DCCEE 2012) with the exception of the enteric methane prediction equation, which was based on a regionally representative enteric methane prediction model (Kennedy & Charmley 2012). All impacts associated with energy demand were included, based in the inventory of farm purchases (data not shown). No additional energy use associated with afforestation because this occurred naturally. Hence, emissions intensity associated with livestock emissions and energy use remained the same. Net LUC emissions were determined from Fensham and Guymer (2009) for sub-humid, Eucalypt woodland, which was assumed to have a net sequestration 40 t C ha and a total sequestration of 34,466 t CO_2-e over the 30 year period. As an annualized rate, this resulted in sequestration of 1149 t CO_2-e per year for the farm.

3. Results

Total beef production and GHG emissions are presented for the three time periods in Table 2. Land use change resulted in net removals from sequestration of -14.4 kg CO_2-e / kg LW, which resulted in a net negative emission of -3.5 kg CO_2-e / kg LW for all beef sold from the farm over a thirty year period with all emission sources taken into account. However, after the forest reached maturity, estimated total beef production declined by 10% and estimated net emissions returned to levels similar to the pre LUC emissions.

Table 2. Greenhouse gas emissions and sequestration associated with land use change reported over three time periods

Time period	Beef production	GHG	LUC GHG	total GHG	Emissions intensity
	total kg LW	t CO2-e	t CO2-e	t CO2-e	kg CO2-e / kg LW
2008 (pre LUC)	88,649	966	-	966	10.9
2008-2037 (LUC period)	82,443	899	- 1,149	- 250	-3.0
2037+ (post LUC)	79,784	899	-	899	11.3

Consumptive water use over the same time period changed in response to changing livestock numbers and changed vegetation cover. This resulted in a net decline in direct consumptive water use of 2% during the LUC period and 3% after the LUC period ended. This change in direct consumptive water use was in response to lower drinking water requirements for the smaller herd. Importantly, the decline was not a linear response to reductions in livestock numbers and production. This non-linear response was because the reduction in drinking water requirements had a negligible impact on water supply system losses from farm dam evaporation. In the present case study, the farm manager did not respond to reduced livestock numbers by changing either the number or size of dams. This is to be expected, because changing the number or size of dams would require considerable capital expenditure without providing any benefit to the farm. Hence, the supply losses associated with farm dams occur despite changed livestock numbers.

The large changes in water were the result of changed runoff conditions, which may be termed an indirect water use for the system. When attributed to the livestock system, this resulted in an additional 308 L / kg LW. This additional indirect water use continued as a permanent change to local hydrology after the LUC period finished, resulting in a large, long-term increase in consumptive water use that would be reduced only after another LUC event to reduce vegetation.

Table 3. Change in consumptive water use in response to land use change reported over three time periods

Time period	Beef production	Consumptive water use	Change in runoff (LUC)	Total water	Water use / kg beef
	total kg LW	ML	ML	ML	L / kg LW
2008 (pre LUC)	88,649	27.1	-	27.1	305.2
2008-2037 (LUC period)	82,443	26.8	25.4	52.2	632.7
2037+ (post LUC)	79,784	26.2	31.1	57.3	718.4

4. Discussion

There is a global imperative to reduce greenhouse gas emissions from livestock production, and emissions from land use change are understood to be a substantial contributor to total emissions (Opio et al. 2013). One possible option is to promote afforestation of grazing areas. The environmental impacts from this type of land use change are likely to be improved in some instances (i.e. improved biodiversity outcomes) but there are other impacts that must be addressed, such as the decline in runoff. In water footprint terms, this amounts to a change in the proportion of green and blue water use within a system, because runoff (blue water) declines in response to increased vegetative cover and subsequent evapo-transpiration (green water). This relationship between vegetation and runoff is well established at the global level (Bosch & Hewlett 1982, Brown et al. 2005). Mila i Canals et al. (2009) identified the need to address changes in runoff caused by alterations in the balance of green and blue water within a system. However, the choice of reference system is debatable. In the present example, we chose the land cover in 2008 as the reference. At this time, the land was open pasture used for grazing. However, if the reference system was considered the natural vegetation at the site prior to land clearing (which occurred around the 1900's for this region) then afforestation has a very different effect on sequestration and net water use. Such matters are not semantic, they demonstrate the importance of such methodological choices on the interpretation of results. In Australia, the relationship between vegetation cover, runoff and subsequent water available for competitive users is carefully monitored, and programs promoting afforestation must account for the impact on reduced runoff (NWC 2011). It would be clearly beneficial for LCA research to address this rather than considering LUC in the context of GHG emissions only. The implications of this research on deforestation are also apparent; local scale deforestation will result in increased runoff and greater water availability (Bosch & Hewlett 1982, Brown et al. 2005). This relationship has been assessed as a means to increase runoff and alleviate localized water stress in Australia (Li et al. 2011). In the present case study, increasing carbon storage in vegetation had a relatively short term effect (30 years) but resulted in a permanent decrease in water availability and beef production. The negative impact of lower water availability in river systems impacts both the environment and competitive water users such as irrigators elsewhere in the river system. It is a legislated requirement that afforestation projects funded under the Australian government CFI program account for reduced runoff, possibly via acquisition of irrigation water licenses to account for water consumption (NWC 2011). This aligns with an approach that considers this water an additional consumptive use in the LCA context. The focus on this paper has been to consider the localized impacts of this change only, rather than a full scale consequential analysis. The study only took into account one additional impact, consumptive water use, and further study should incorporate the impact on a broader range of potential impacts, including soil degradation and water quality. A full system consequential analysis is also required to understand the impacts of changes in water availability and beef supply. For example, reduced beef production in Australia (one of the world's two largest beef exporters –FAO (2011) may induce beef production in other regions where deforestation is a risk. Secondly, reduced water yield will constrain water supply to local river systems, causing stress to aquatic ecosystems and reducing irrigation water supply, with the latter having ongoing impacts on food and fibre production.

5. Conclusion

Afforestation is a plausible LUC option to remove atmospheric carbon dioxide via carbon sequestration in woody perennials. In a mixed grazing system, GHG removals from afforestation may be triggered by beef grazing, and as a result could provide reduce net emissions from beef production. However, such improvements can only be sustained for a limited period of time until trees reach maturity. After this time, the production system was estimated to return to a net GHG source, with lower overall productive capacity. Importantly, LUC resulted in reduced water yield which may place additional stress on water catchments, compromising aquatic ecosystem function and reducing water supply for irrigation and food production. This highlights the important trade-offs that exist when assessing LUC, particularly with respect to GHG emissions and water yield, and consideration of a broader suite of impacts such as impacts on soil condition would be beneficial. Detailed consequential modelling is required to explore the broader implications of these findings, accounting for environmental impact and the effect on global food supply. In the context of greater global demand for food and the environmental challenges such as climate change, this research should be seen as a priority.

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