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Improving greenhouse gas emissions intensities of subtropical and tropical beef farming systems using *Leucaena leucocephala*

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ABSTRACT

Leucaena leucocephala (leucaena) is a perennial legume shrub of subtropical regions that has forage characteristics favourable for livestock production, often delivering ruminant liveweight gains that are superior to most other forage systems. Recent work suggests that leucaena mitigates ruminant enteric methane emissions, implying that the shrub may also reduce greenhouse gas (GHG) emissions at the whole farm level. However, the high crude protein content of leucaena relative to endemic grasses can increase livestock urine nitrogen concentration and may increase soil nitrous oxide emissions, potentially offsetting benefits of enteric methane mitigation.

Here we examine the effects of leucaena on emissions, production and profitability at the whole farm level by modelling a property in northern Australia, assuming enterprises that specialise in cattle breeding and finishing. To contrast leucaena with a baseline property with Rhodes grass, we modelled three equivalent leucaena scenarios by matching (1) annual average stocking rate, (2) total liveweight production or (3) net farm emissions with that of the baseline, assuming all animals had access to leucaena.

To maintain average annual stocking rate or liveweight production, scenarios 1 and 2 carried 5% and 12% less cattle than the baseline because animals on leucaena grew faster and had greater liveweight. In contrast, the number of animals carried and liveweight production in scenario 3 increased by 15% and 31% relative to the baseline, respectively, due to enteric methane abatement and greater liveweight gains. Grazing of leucaena increased soil nitrous oxide emissions by more than 38% in all scenarios, but this did not substantially offset net emissions abatement because nitrous oxide constituted a far smaller proportion of emissions than did methane (<10% and >90%, respectively). In all scenarios, emissions intensity (net farm emissions per unit liveweight sold) caused by grazing leucaena was reduced by more than 23% relative to baseline emissions intensities.

This work shows that whilst income from carbon offsets associated with grazing leucaena is small, leucaena has significant potential to increase both animal production and gross margin, whilst reducing emissions intensity. Provided net farm emissions are maintained or reduced, these results suggest that leucaena is conducive to sustainable intensification of beef production in subtropical grazing systems.

1. Introduction

Leucaena leucocephala (leucaena) is a large perennial legume shrub that typically grows with companion pasture grasses in subtropical and tropical regions (Larsen et al., 1998; Radrizzani et al., 2010). Leucaena is long-lived, drought-tolerant and recognised as high value fodder for ruminant livestock due to its palatability and nutritional characteristics, including high crude protein and non-bloating attributes (Jones and Bunch, 2000; Kennedy and Charmley, 2012; McSweeney et al., 2011; Radrizzani et al., 2010). Together these traits deliver ruminant weight gains that are superior to most other tropical forage systems (Aregheore, 1999), and in combination with tropical grasses leucaena pastures are conducive to productive and sustainable livestock farming systems (Shelton and Dalzell, 2007). In northern Australia, there are more than 120,000 animal equivalents (one AE = 450 kg steer/year) grazing 250,000–300,000 ha of leucaena-grass pastures (Michael Burgis, pers. comm., 2015). At the current rates of adoption, the area planted is expected to exceed 500,000 ha by 2017 (Shelton and Dalzell, 2007).

Research indicates there is significant potential for reducing cattle enteric methane emissions as the proportion of leucaena in tropical grass–legume mixtures increases (Kennedy and Charmley, 2012). Suppression of enteric methanogenesis is thought to be the mechanism underlying lower methane emissions and may redirect rumen

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fermentation towards other more useful end products (Ouwerkerk et al., 2008), potentially increasing the proportion of energy available for growth or lactation. Together with enhanced liveweight gains these findings suggest a reduction in greenhouse gas (GHG) emissions per unit beef produced (emissions intensity) and sustainable intensification of subtropical beef farming systems.

Most previous work on methane mitigation has concentrated on emissions of individual animals, often using measurements from respiration chambers or from *in vitro* incubations using donor rumen fluid (Kennedy and Charmley, 2012; Meale et al., 2012). There is less information on the effects of leucaena on the emissions intensity of beef production at the whole farm level, particularly when animals are grazing representative mixtures of leucaena and grass pastures, and when animals are considered in realistic cattle breeding and trading scenarios. Indeed, enterprise-scale analyses can reveal important trade-offs caused by management interventions that are not apparent when studied at the animal level. For example, simulations indicate that improving genetic feed-use efficiency (dry matter consumed per unit liveweight gain) can reduce emissions per unit intake and emissions intensity at the animal level, but the feed conserved can facilitate higher stocking rates such that net farm emissions also increase if livestock numbers are increased (Harrison et al., 2014a, 2014b).

Analyses at the whole farm level also account for GHGs other than enteric methane, which may form a significant proportion of farm emissions. This is particularly important for leguminous fodder such as leucaena, which can have crude protein contents greater than 25% (Agbede and Aletor, 2004; Bassala et al., 1991; Liu et al., 2010). Since ruminants excrete 75–95% of nitrogen ingested, a high crude protein diet often leads to increased urine nitrogen concentration and, under conditions conducive to denitrification (de Klein and Eckard, 2008), can result in greater soil nitrous oxide emissions (Eckard et al., 2010).

The objective of this study was to determine the effects of leucaena on whole farm production, emissions and emissions intensity of a number of trading scenarios for a cattle farming enterprise typical of north central Australia. We also conducted an economic analysis to contrast the relative profitability of leucaena enterprises to those with only pasture grasses, since interventions to livestock farming systems that reduce whole farm emissions intensity may not necessarily reduce economic risk (Ho et al., 2014), and since greater productivity may not translate into greater profitability (Alcock et al., 2014).

2. Materials and methods

2.1. Overview

This study used temporal measurements of liveweight (LW) and methane emissions from steers grazing pastures dominated by Rhodes grass (*Chloris gayana*) or leucaena (*L. leucocephala*) at two experimental research sites in Queensland, Australia. Pasture nutritional characteristics and livestock diet composition from these experiments were measured using wet chemistry and faecal near infra-red spectroscopy (F.NIRS), respectively. A modelling approach was used to scale measured animal data to the whole farm level in two steps. The first step used measured data from individual animals to generate herd characteristics using an enterprise model, which was then used to parameterise a greenhouse gas (GHG) emissions model. Together these data were used to estimate the net farm emissions of a representative beef enterprise in central Queensland assuming pastures consisting of either Rhodes grass or leucaena hedgerows with interspersed Rhodes grass, consistent with field experiments. The second step examined three scenarios to determine the effects of leucaena on animal productivity, emissions, farm gross margin and the emissions intensity of beef produced and sold.

2.2. Measurement of pasture nutritional characteristics, animal diet composition, liveweight and methane emissions: field studies

Measured liveweight and methane emissions as well as pasture nutritive characteristics were adopted from field experiments conducted at Belmont Research Station (23.22°S, 150.38°E) near Rockhampton in Queensland, Australia. A concurrent experiment at Brian Pastures (25.64°S, 151.72°E) near Gayndah was used to provide additional data on nutritive characteristics. Field experimentation began in summer 2012/13. At each site, and to coincide with methane measurements, grass pastures were assessed for total available biomass by cutting up to 12×0.25 m^2 quadrats and species composition determined. Collected grass material was dried at 65 °C to constant weight then ground, bulked and sub-sampled for proximate analysis of dry matter (DM), organic matter (OM), crude protein (CP), and acid- and neutral-detergent fibre content (ADF, NDF). Pluck samples of leucaena leaf and stem (diameter <5 mm) were randomly sampled across each plantation at both sites and dried under similar conditions prior to analysis. Leucaena DM was further sub-sampled and placed onto dry ice, stored at –80 °C and freeze dried for measurement of condensed tannins. Faecal samples from each animal were collected to coincide with methane measurement periods throughout the project at both sites to estimate animal diet composition. Digestibility measures, the proportion of leucaena in the diet and the nutritive quality of the forage consumed were estimated using F.NIRS analysis.

Leucaena and grass forage had similar DM and OM content throughout 2013, but the leucaena forage had greater nitrogen and lower fibre concentration compared with the pasture grasses during the dry season (Table 1). Differences in nutritional characteristics were mitigated when diet composition was considered, because diets in the leucaena treatment included both leucaena and grass forage. Over the three sampled periods, the apparent crude protein and *in vivo* dry matter digestibility of animals grazing leucaena was 2.9–4.3% and 2.6–3.6% greater than that measured for the grass-pastured animals, respectively (Table 1). Values in Table 1 were used to parameterise pasture nutritive characteristics and diet composition coefficients in the models for simulating whole farm production and emissions (described below).

On Belmont Research Station *Bos indicus* cross steers ($n = 60$, initial mean ± SEM LW of 325 ± 7 kg) were allocated to one of two management groups ($n = 30$); leucaena or grass fed. Animals were transferred to either paddocks of approximately 7 ha containing double rows of *L. leucocephala* (cv. Cunningham) at 4 m spacing, or paddocks of approximately 6.8 ha dominated by Rhodes grass (*C. gayana*). At approximately 14 day intervals animals were rotated into adjacent leucaena or Rhodes grass paddocks, respectively, to ensure *ad libitum* grazing intakes. Grazing of leucaena and Rhodes grass pastures by each group of steers and LW measurements commenced in November 2012 when animals reached 400 days old. Mean daily liveweight gains slowed over time, with the leucaena and grass-fed steers averaging 0.95 and 0.75 kg/head/day respectively for the first 100 days, and 0.59 and 0.46 kg/head/day over 500 days, respectively (Fig. 1). On Brian Pastures *B. indicus* composite steers ($n = 60$, initial mean ± SEM LW 237 ± 3.4 kg) were allocated to one of two management groups; leucaena or grass pastures. Animals were transferred to either paddocks containing double rows of leucaena (cv. Cunningham), 4 ha at 3 m spacing, or approximately 15 ha Native Blue grass (*Dicanthium* spp.) pastures. On 28 day intervals, animals were rotated into adjacent leucaena or grass paddocks, respectively, to ensure *ad libitum* grazing intakes. Differences in stocking rates across sites reflected regional variation associated with climate and soil characteristics.

Open path lasers (GasFinder Boreal Laser Inc., Canada) were used to determine methane emissions at the herd scale for cattle grazing leucaena and grass-pastured groups. This approach measured the