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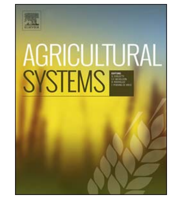

Grazing supplementation and crop diversification benefits for southern Brazil beef: A case study

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ABSTRACT

Profitability and environmental benefits of beef cattle raised on natural pasture or combined with soybean in tropical biomes need to be better evaluated. The objective of this research was to simulate and evaluate three common pastured beef grazing systems in southern Brazil, estimating profitability and the environmental impacts of carbon footprint (CF) measured as kg of CO_2 equivalent per kg of body weight produced (BWP), water footprint (kg of water used/kg of BWP) and energy footprint (MJ of energy used/kg of BWP) using the Integrated Farm System Model version 4.2. Simulations were run for Angus beef cattle raised on natural pasture (NP), natural pasture with low levels of grain supplementation (NPS), and NPS combined with soybean production (NPSC). Net animal weight produced (kg/ha/year) increased 7.9% for NPS and NPSC when compared with the NP system. Natural pasture production costs per hectare were lower (US$ 114) than that of NPS (US$ 126) and NPSC (US$ 233), while NP had a net return per hectare only 2% greater than NPS. Even though the gross income from animal sales was 5% higher in NPS than NP, the elevated cost of purchased feeds reduced net return per hectare. While costs were higher for NPSC, diversifying with soybean production, a high value commodity for cash sale, was profitable resulting in 44% and 47% greater net return per hectare than NP and NPS, respectively. Natural pasture with low supplementation (NPS) decreased CF by 2% when compared with NP due to faster weight gain from supplementation despite higher emissions from feed production. Furthermore, CF was also 6% lower for natural pasture combined with soybeans (NPSC) compared with NPS. However, the energy and water footprints and erosion increased with the greater use of both purchased feed and inputs required for feed and cash crop production. It can be challenging to increase beef cattle productivity and diversification to lower GHG emissions while minimizing water and energy use and soil erosion.

1. Introduction

Beef cattle production is one of the most important agricultural systems in Brazil with 212 million head (IBGE, 2014) distributed over an estimated total pasture area of 174 million ha, mostly in extensive pasture. Due to its potential to produce food, the United Nations (FAO, 2010) indicates that Brazil is one of the countries with the greatest potential to meet 70% more global food demand by 2050.

The Brazilian beef industry is under pressure to mitigate climate change, particularly from cattle production which is responsible for ~25% of Brazil's greenhouse gas (GHG) emissions including methane (CH_4), nitrous oxide (N_2O) and other relevant gases (Cardoso et al., 2016). However assessing the environmental sustainability of a production system should not be evaluated solely by GHG per kg of meat or product produced, but also other impacts such as water and energy use (Ridoutt et al., 2014). Furthermore, for an agricultural production system to be considered sustainable, profitability is of paramount importance.

In the southern Brazil state of Rio Grande do Sul, beef production takes place on natural pasture in one of the six Brazilian biomes, the Pampa Biome, which extends to Argentina and Uruguay. Rio Grande do Sul has 14.3 million cattle, which is approximately 8% of Brazil's herd (IBGE, 2009). Pampa Biome beef production involves an extensive farming system that has about 450 grass species and > 150 legume

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species (Boldrini, 1997) characterized by high nutritional quality in spring and summer and low nutritional quality in autumn and winter. Therefore, it is important to determine the relationship between environmental impact, beef and crop productivity and net return or profit for different beef production systems in southern Brazil.

The objective of this research was to use a whole-farm modelling approach using the Integrated Farm System Model (IFSM) software (Rotz et al., 2015b) to assess the profitability and evaluate environmental impacts of three beef production systems in Rio Grande do Sul state in southern Brazil. This is the first time IFSM has been used to model beef production in Brazil. All three systems modeled involve beef cattle raised on natural pasture. The baseline system, using just natural pasture, is compared to two systems using low grain supplementation. While the second system involves no row crop production, the third system includes soybean production solely for cash crop sales.

2. Material and methods

Three beef production systems in Rio Grande do Sul state were simulated using the Integrated Farm System Model, version 4.2 (Rotz et al., 2015b). IFSM simulates pasture and crop growth, feed production and use, animal growth, and the deposition of manure nutrients from cattle to the land to predict the environmental impacts, production costs and profit of agricultural production systems (Rotz et al., 2005, 2013, 2015a,b). Animal care and use committee approval was not obtained for this study because no animals were used.

2.1. Collaborating farm

This simulation study was performed based on a farm located in the central region of Rio Grande do Sul state, in southern Brazil (S 30° 26′ 454″ W 53° 11′ 024″). The climate is subtropical humid "Cfa", according to the Köppen classification. Farm performance was simulated over 25 years (1988 to 2013) of observed weather data collected at the experimental station farm of Universidade Federal do Rio Grande do Sul (UFRGS) in Eldorado do Sul, located in the same central region, 151 km from the cooperating farm. The average maximum and minimum temperatures over these 25 years were 24.7 °C and 13.5 °C respectively, precipitation averaged 1545 mm/year, humidity 81.4%, global radiation was 15.1 MJ/m^2, and average annual wind speed was 1.7 m/s.

The cooperating farm has an Angus beef cattle production system including cow-calf, growing and finished cattle raised on natural pasture, winter pasture (*Lolium perenne* Lam), supplemented on pasture, and natural pasture with diversified rotation with row crops for cash sales. Five year average (2009–2013) production and financial data from this representative farm were used to set up three simulated production systems commonly used in this region. Although the cooperating farm is classified as large (> 500 animals) and beef farms of this size in Rio Grande do Sul make up only 1% of the ~346,000 beef farms in the state (De Sousa e Silva et al., 2014), the cooperating farm had the most comprehensive availability of the myriad of livestock and crop production and management data required to calibrate the IFSM model.

2.2. Simulated production systems

The three systems simulated were: natural pasture (NP), natural pasture with low supplementation of grain (NPS), and NPS combined with appended soybeans for cash sales, not used internally as feed (NPSC). Profits, carbon footprint measured as kg of CO_2 equivalent (eq) per kg of body weight produced (BWP), water footprint (kg of water used/kg BWP) and energy footprint (MJ of energy used/kg BWP) were evaluated for these three representative production systems.

The breed simulated was Angus with a herd composition of 921 cows (30% in first lactation), 193 replacement heifers, 698 stocker cattle, and 171 finished cattle. The number of animals was the same across all three simulations to reduce undesired variability during system comparisons. However, the days required for each animal to reach final live weight (450 kg; Table 1) was different under the three scenarios due to the differences in nutritional quality of diets. IFSM was set up for zero-forage balance to insure accurate comparison, i.e. pasture areas were set to provide no buying or selling of forage on average over the 25-year simulation period.

Table 1
Land area, growing period goals, forage to grain ratio, and level of supplementation for three simulated beef production systems in Rio Grande do Sul State, Brazil.

	Production systems		
	NP	NPS	NPSC
Land area (ha)			
Native pasture	2100	2100	2100
Soybean	–	–	442
Growing period goals (months)			
Age of weaning	7	7	7
Stocker period	11	9	9
Finishing period	11	2	2
Forage to grain ratio	High	High	High
Supplementation level	No	Low	Low
Protein supplementation (% of recommended)[a]	0	95	95
Weight (kg)			
Body weight entering finish period	360	380	380
Final finish body weight	450	450	450

[a] Percent of that recommended to meet requirements of each animal group (NRC, 2016).

The NP simulation used 2100 ha of natural pasture with a pasture utilization efficiency of 60%. The animals were fed with essentially no protein or energy supplementation (Table 1). The growing periods were: age of weaning (7 months), stocker period (11 months), and finishing period (11 months). Fertilizer was not used on pasture. The tractor used for the model farm has 108 hp. (80 kW) at a price of US$ 73,350. The initial investment of perimeter fence was US$ 53,000 with temporary fence valued at US$ 1462. Simulations assumed a machine shed valued at US$ 50,000 and a feed storage shed at US$ 40,000. All other important costs and economic parameters are summarized (Table 2).

NPS also used 2100 ha of natural pasture with a pasture utilization efficiency of 60%. Cows, heifers, stockers, and finished cattle were fed at a supplementation level to meet 95% of recommended protein requirements (NRC, 2016; Table 1) and the weaning period was the same as NP with the stocker and finishing periods reduced to 9 months and 2 months, respectively. Grazing management, initial capital (equipment and building) costs, input costs, commodity prices, capital depreciation schedules and fertilizer prices were the same as the other systems (Table 2).

The NPSC system used the same cattle management, pasture operations and supplementation as the NPS system, however, 442 ha of soybeans were cultivated for cash sales as grain for a total area of 2542 ha. The crop land was rotated with the pasture providing some additional fixed N for pasture growth.

Soybean was planted on or soon after October 25th with a 12-row planter (9.1 m; initial cost US$ 53,100) and the same tractor used in NP and NPS. Fertilizer and chemicals were applied on 15-Oct, 14-Nov, 4-Dec, 20-Dec and 13-Jan. The sprayer with a 9.1 m wide boom (US$ 5850) was attached to the same tractor used for the other operations. Soybean harvest was March 10th using a small, 6-row combine (US$ 240,000). The macro-nutrient fertilizer cost (US$/ha) were lowest for nitrogen (US$ 14.49/kg at 15 kg/ha), highest for phosphorus (P_2O_5) (US$ 91.43/kg at 90 kg/ha) and intermediate for potassium (K_2O) (US$ 34.12/kg at 45 kg/ha). The lime cost was US$ 142.91/ha (3693 kg of $CaCO_3$/ha every 3 years). Seed and chemicals were US$ 128.80/ha. Other financial parameters are summarized in Table 2.

The soil used for all systems was a chromic luvisol with a low

Table 2
General costs, livestock expenses/year (US$/head), commodity prices (US$/t dry matter - DM), cattle prices, useful life of capital (years), salvage value (% of initial), interest rate (%) and fertilizer prices (US$/kg) used for three beef production systems in Rio Grande do Sul State, Brazil.

Item	Variables
General	
Diesel fuel (US$/liter)	0.82
Electricity (US$/kWh)	0.12
Labor wage (US$/hour)	2.50
Property tax (% of assessed value)	0.50
Veterinary and medicine (US$/head)	7.31
Fixed time insemination (US$/head)	15.70
Commodity	
Buying prices (US$/t of DM)	
Soybean meal 44%	339.00
Corn grain	132.00
Minerals	104.00
Selling price of soybeans (US$/t of DM)	328.00
Cattle prices	
Finished cattle 29 month of age (US$/kg of live weight)	1.21
Finished cattle 18 month of age (US$/kg of live weight)	1.31
Cull cow (US$/kg of live weight)	1.06
Bred heifer (US$/animal)	630.00
Feeder cattle (US$/kg of live weight)	1.26
Useful life of capital (years)	
Machinery	12.00
Structure	30.00
Salvage value (% of initial cost)	
Machinery	10.00
Structure	2.50
Interest rate (% per year)	
Medium term	6.50
Long term	6.50
Fertilizer prices	
Nitrogen (US$/kg N)	0.97
Phosphate (US$/kg P_2O_5)	1.02
Potash (US$/kg K_2O)	0.76
Lime (US$/t)	38.70

Table 3
Soil characteristics for the representative farm simulated in Rio Grande do Sul, Brazil.

Soil attributes	Value
Soil type (Mekonnen and Hoekstra)	Chromic luvisol
Available water holding capacity (mm)	300.00
Fraction of available water when stress begins	0.45
Bare soil albedo	0.20
Soil evaporation coefficient (mm)	6.00
Moist bulk density of soil (g/cm^3)	1.50
Organic carbon concentration (%)	1.80
Silt content (%)	22.00
Clay content (%)	31.00
Sand content (%)	47.00
Runoff curve number w/row crops	85.00
Whole profile drainage rate coefficient	0.35
pH	7.00
Exchangeable acidity	3.50

phosphorus level (< 30 ppm) and gently sloping (3–8%) topography (Table 3). The natural pasture used in these scenarios (Table 4) was composed of 77% C_4 grass species (predominantly *Paspalum notatum* and *Axonopus affinis* in inferior strata and *Andropogon lateralis* in the superior), 20% C3 grasses (Briza spp. and Stipa spp.), and 3% legumes (predominantly *Desmodium incanum*). Nutritional contents of the pasture and supplemental feeds used for all production systems are specified in Table 5.

2.3. Integrated Farm System Model

IFSM is a process-level farm simulation model that includes crop and pasture growth, feed production and use, animal growth, and manure nutrient cycling to predict the environmental impacts and profitability of agriculture production systems (Rotz et al., 2005, 2013, 2015a,b). Crop and pasture growth and yield are predicted daily based on soil characteristics, water and nutrient availability, temperature, and solar radiation. Growth of each pasture species in the sward is predicted from emergence to the end date of vegetative growth using functions from the GRASIM model developed by Mohtar et al. (1997).

Table 4
Sward species characteristics for the representative farm simulated in Rio Grande do Sul, Brazil.

Sward species characteristics	C4 grass	C3 grass	C3 legume
Species content (% of total sward dry matter)	77	20	3
Specific leaf area (m^2/kg leaf DM)	15	20	14
Maximum photosynthetic temperature (°C)	32	28	32
Optimum photosynthetic temperature (°C)	30	23	24
Minimum photosynthetic temperature (°C)	0	0	0
Base photosynthetic rate (μmol CO_2/m^2/s)	33.7	28.06	35.64
Temperature effect photosynthesis (μmol CO_2/m^2/s/°C)	3.14	2.95	3.50
Light extinction coefficient	0.60	0.46	0.50
Radiation-use coefficient (g/MJ total radiation)	4.50	5	4.77
Proportion growth sent to shoot	0.5	0.7	0.6
Leaf transmission coefficient	0.1	0.1	0.1
Maximum rooting depth (cm)	100	80	80
Maximum nitrogen concentration (%)	3.60	4.80	3.84

Energy, protein, and mineral requirements for each animal group are determined using relationships from the Cornell Net Carbohydrate and Protein System, level 1 (Fox et al., 2004). The quantity and nutrient contents of the manure produced are a function of the feeds consumed and herd characteristics (Rotz et al., 2015b). If feed quality or availability limit growth, average daily gain (ADG) is decreased, and the length of the growing or finishing period is extended (Rotz et al., 2005).

Total production cost is subtracted from the total income received from crop and/or culled and finished animal sales to determine the net return to management for the production system. The performance of the entire system is weather dependent; therefore, farms are simulated over a 25-yr sample of recent historical weather (Rotz et al., 2015b) to represent long term performance, environmental impacts and profits.

IFSM software simulates carbon, nitrogen (N), and phosphorus (P) dynamics through annual cycles (Rotz et al., 2015b). A cradle-to-farm gate Life Cycle Assessment (LCA) in IFSM integrates emissions from primary and secondary GHG sources. Carbon footprint is determined as the total GHG emission, expressed in CO_2 eq units, associated with the animal weight produced. The conversion to CO_2 eq is done using the global warming potential (GWP) of each gas. GWP values used for CH_4 and N_2O were 25 and 298 CO_2 eq/kg, respectively. A carbon footprint per unit of beef output is determined by totaling the annual GHG emissions and dividing by annual production in kg of body weight produced (Rotz et al., 2015b).

The major water requirement is for the production of feed crops with other uses including drinking water and water used for animal cooling. The water footprint is determined by summing the estimates for each of these uses, removing water allocated to other co-products (soybeans when produced), and dividing by the mass of all cattle sold from the farm. Another important consideration in the evaluation of the sustainability of production systems is the energy footprint. This is defined as the total energy required to produce feed and animals, not including solar energy captured by growing crops. Total energy includes all fuel and electricity directly used in the production system as well as the secondary energy used in the production of resources used on the farm (Rotz et al., 2015b). Soil erosion is estimated using the Modified Universal Soil Loss Equation.

Table 5
Composition of pasture and feed type (crude protein (CP), degradable protein (DP), neutral detergent fiber (NDF) and total nutrient digestive (TDN)) of the evaluated scenarios in Rio Grande do Sul State, Brazil.

	Feed type				Pasture			
	Corn	Soybean meal 48%	Urea	Mineral	Spring	Summer	Autumn	Winter
CP (% DM)	9	49	283	–	13.5	11	10	9
DP (% CP)	48	70	100	–	80.5	70	65	65
NDF (% DM)	14	15	–	–	63	65	65	65
TDN (% DM)	86	81	–	–	64.5	62	60	59

Table 6
Supplemental feed consumed (t DM/year) for natural pasture (NP), natural pasture with low supplementation (NPS) and NPS diversified with soybeans (NPSC) for beef production in Rio Grande do Sul State, Brazil.

Production system	Feed types			
	Corn	Soybean meal 48%	Urea	Mineral
NP	0	0	0	38
NPS	474	4	14	31
NPSC	474	4	14	31

3. Results

3.1. Production performance

Supplemental feed consumption simulated by IFSM for each production system is shown in Table 6. Only minerals were fed in the NP system, while supplemental grain and protein were fed with minerals in the other two systems to promote faster animal growth. Total forage produced (t of DM/ha/year) and consumed (t of DM/ha/year) were 4.88 and 2.34 for NP, 4.88 and 2.14 for NPS and 4.94 and 2.06 for NPSC, respectively. Total feed intake per year was 5068 t DM for NP and 4533 t DM for NPS and NPSC. Total forage consumed in the NPS and NPSC systems was lower due to the more rapid growth (less time on pasture) enabled through grain supplementation.

The average forage produced across the three system simulations was 4.91 t of DM/ha/year, which is similar to the average forage produced annually in Rio Grande do Sul (4–4.5 t of DM/ha/year) on natural pasture (Carvalho et al., 2006). Total average daily gain was 476 g/day for NPS and NPSC cattle and 441 g/day for cattle in the NP system. Thus, the annual net animal mass sold per hectare from both the NPS and NPSC systems (164 kg/ha/year) was 7.9% greater than that for NP (152 kg/ha/year) corresponding to medium animal productivity with no pasture fertilization. The average stocking rate for NP, NPS and NPSC was 0.76 animal units per hectare (1 animal unit or AU = 450 kg) which was similar to the Rio Grande do Sul state average of 0.7 AU/ha (Nabinger et al., 2009). The 25 year average soybean yield for NPSC was 2.66 t DM/ha, similar to the Rio Grande do Sul state average of 2.9 t DM/ha (Emater, 2015).

3.2. Profitability

In all simulated systems (NP, NPS and NPSC), after the cost of crop inputs (US$ 2, US$23 and US$104/animal respectively), livestock expenses including semen and breeding (US$ 15.70/animal) and veterinary and medicine (US$ 7.31/animal) most affected production costs. When supplementation was performed in both NPS and NPSC systems, purchased feed for supplementation was the third most costly item. Oaigen et al. (2008), evaluating the variables that most affect production costs on cow-calf-finish beef production systems in southern Brazil, found a similar ranking in production costs with the greatest costs from labor (13%), followed by semen and breeding (11.6%) and feed supplementation (10.5%).

Table 7
Livestock and crop production costs, farm revenue, and net return for natural pasture (NP), natural pasture with low supplementation (NPS) and NPS with a soybean-livestock diversified system (NPSC) for beef cattle production in Rio Grande do Sul, Brazil.

	Models		
	NP	NPS	NPSC
Farm revenues (US$/year)			
Gross income from animal sales	450,389	473,206	473,206
Gross income from grain sales	0	0	384,931
Farm revenues (US$/ha)	214.47	225.34	337.58
Production costs (US$/year)			
Equipment	51,655	51,655	110,343
Facilities	7516	7516	7516
Energy	15,047	14,200	17,426
Labor	20,008	20,548	21,149
Seed, fertilizer and chemicals	0	0	162,286
Purchased feeds	4010	45,902	44,270
Livestock expenses	127,033	112,218	112,218
Property tax	13,068	13,068	13,068
Total cost	238,557	265,107	488,276
Total cost (US$/ha)	113.49	126.24	192.08
Net return (US$/year)	212,052	208,099	369,861
Net return (US$/ha)	100.98	99.09	145.50
Net return (US$/head of finish cattle)	1240.08	1216.95	2162.93

Natural pasture production cost per hectare was lower (US$ 113) than NPS (US$ 126) and NPSC (US$ 192). Also, NP had a net return per hectare 2% greater than that of NPS (Table 7). Even though the gross income from animal sales was 5% higher in NPS than NP, the greater cost of purchased feeds reduced the net return per hectare. Furthermore, the NPSC system had 44% and 47% greater net return per hectare than NP and NPS, respectively (Table 7). While costs were higher for NPSC, soybean production for cash sale was very profitable resulting in greater net returns per hectare than the other two systems.

3.3. Environmental impacts

For all systems evaluated, the major GHG emission sources were enteric animal emissions, feed production, and the production of resource inputs (fertilizers, chemicals, grain and minerals). The NPSC scenario had a 7% and 5% lower carbon footprint per kg of beef than NP and NPS, respectively. NPS had a 2% lower carbon footprint when compared to NP (Table 8). Also, the total GHG (kg CO_2 eq) per hectare was lower for NPSC (2357) than NP (2453) and NPS (2591) (Table 8).

NPS and NPSC had 4% lower methane emissions (kg CO_2 eq/ha) and 3% lower manure emissions (kg CO_2 eq/ha), when compared to NP. The GHG emissions during feed production (kg CO_2 eq/ha) represents the N_2O emissions from cropland, with NPSC having a lower amount (704 kg CO_2 eq/ha) compared to NPS (1081) and NP (937). This was due to NPSC having lower nitrogen losses by denitrification (7.7 kg/ha) when compared to NP (12 kg/ha) and NPS (10.6 kg/ha). On the other hand, NP as a low input system, had 73% and 85% lower emissions from the production of resources used compared with NPS and NPSC, respectively (Table 8).

Sources that contribute to water and energy footprint are shown in

Table 8
Average annual greenhouse gas (GHG) emissions ± one standard deviation, resource use, and soil erosion for natural pasture (NP), natural pasture with low supplementation (NPS) and NPS with cash crop soybean production (NPSC) over 25 years of weather in Rio Grande do Sul State, Brazil.

Emission source	Production system		
	NP	NPS	NPSC
Greenhouse gas emissions - CO_2 eq (kg/ha)			
Animal emissions[a]	1457 ± 4.6	1397 ± 2.6	1397 ± 2.7
Manure emissions	21.1 ± 0.1	20.2 ± 0.1	20.4 ± 0.2
Emission during feed production[b]	937 ± 225	1081 ± 267	704 ± 159
Anthropogenic carbon dioxide emission[c]	18.2 ± 0.0	18.2 ± 0.0	99.5 ± 2.9
Production of resource inputs[d]	19.7 ± 0.1	74.4 ± 2.4	136 ± 3.2
Total GHG	2453 ± 590	2591 ± 689	2357 ± 538
Carbon footprint, soybeans (kg CO_2 eq/kg DM)	–	–	0.76 ± 0.14
Carbon footprint (kg of CO_2 eq/kg BWP)[e]	16.1 ± 3.9	15.8 ± 4.2	14.9 ± 3.4
Water use (Mg/ha)			
Feed production, rainfall	5278 ± 1044	5280 ± 1047	4398 ± 663
Drinking	5.0 ± 0.1	5.3 ± 0.3	5.7 ± 0.5
Production of purchased feed and inputs	0.2 ± 0.0	0.2 ± 0.0	25.4 ± 0.7
Water footprint without rainfall (kg/kg BWP)	35.0 ± 0.0	34.0 ± 0.0	190 ± 0.0
Energy use (MJ/ha)			
Feed production	253 ± 0.0	253 ± 0.0	246 ± 8.1
Animal feeding	10.8 ± 0.0	10.8 ± 0.0	8.5 ± 0.0
Animal housing ventilation and lighting	38.4 ± 0.0	26.3 ± 0.0	26.3 ± 0.0
Production of resource inputs	242 ± 1.4	505 ± 12.3	2522 ± 63.8
Energy footprint (MJ/kg BWP)	3.5 ± 0.0	4.8 ± 0.0	17.1 ± 0.4
Soil erosion loss (kg/ha)	675 ± 308	811 ± 375	3558 ± 1515

[a] Emissions from enteric fermentation.
[b] N_2O emissions from pasture and cropland.
[c] Fuel combustion and that emitted from lime applied to soybean.
[d] Emission factors described in IFSM manual are used to predict the emissions from feed and fertilizer production.
[e] Total GHG emission per unit of animal mass produced and sold from the farm.

Table 8. Water consumed by animals was similar among systems. Water use for production of purchased feed and inputs was greater for NPSC (25.4 Mg) compared to NP and NPS (0.2 Mg), resulting in a greater water footprint for NPSC (190 kg of water/kg BWP) than NPS and NP (34 to 35 kg of water/kg BWP). The energy footprint (MJ/kg BWP) increased with the greater use of purchased inputs for supplementation (NPS and NPSC) and fertilizers (NPSC), with values increasing from 3.5 (NP) to 4.8 (NPS) to 17.7 (NPSC) MJ/kg BWP. Soil erosion was greater for NPSC due to cultivating soybeans and not just raising pastured beef.

3.4. Carbon footprint versus animal production

Natural pasture supplemented with grain combined with soybean production had slightly lower GHG emissions both per ha and per unit of beef produced than the NP system. The NPS system had slightly lower CF than NP, but greater total GHG/ha. Carbon footprint was inversely proportional to the net animal mass produced per hectare (Fig. 1). Decreased days from birth to slaughter (Table 1) and greater animal gain per hectare provide greater production efficiency through the use of supplemental feed for both the NPS and NPSC production systems.

4. Discussion

Because of their perceived large contribution to global GHG emissions, the beef cattle industry is under pressure to reduce production or implement strategies to reduce emissions per unit of beef produced (Gianezini et al., 2014; Ruviaro et al., 2015). At the same time, the global demand for beef is increasing. This is creating the need for increasing animal productivity per unit of land while decreasing GHG emissions, energy use, water use and other negative impacts of cattle production. For our NPSC system, it is expected that GHG emissions are lower and energy and water use are higher per unit area (ha) due to the additional land base available to accommodate emissions and the added resources used to produce soybeans.

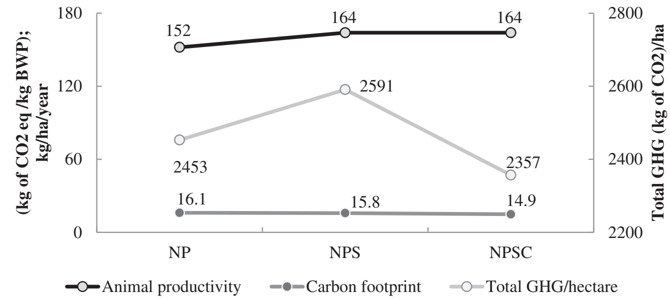

Fig. 1. Net animal gain (kg/ha/year), carbon footprint (kg CO_2 eq/kg BWP) and total annual greenhouse gas (GHG) emission (kg CO_2 eq/ha) for beef systems.

4.1. Model productivity and profitability

Beef productivity on natural pasture in southern Brazil in this analysis ranged from 152 to 164 kg/ha/year, while in other studies average net animal gain was 60–70 kg/ha/year (Carvalho et al., 2011a, 2006). Such productivity could increase by 228% with better management of natural pasture by controlling the stocking rate. It could also increase by 1328% with fertilization of natural pastures and by introducing cultivated pastures (Nabinger et al., 2009). There is great potential to improve the productivity of grazing livestock systems in southern Brazil by improving grazing management without additional inputs. These improvements have the potential to increase productivity, reduce environmental impacts, conserve biodiversity and reduce GHG emissions (Carvalho et al., 2011b).

Bueno et al. (2011) reported potential benefits of diversified systems in economies of scope (cost reduction associated with producing multiple outputs) or in the risk-reducing effects of diversification. Furthermore, there may be lower yield variability and overall higher yields. However, decision making toward diversified agricultural systems must be made based on relative crop and livestock prices. By contrast, low productivity in extensive beef production systems results in low net returns, a low index of employment and reduced development of the region (Reis, 2009). Like in our analysis, Ruviaro et al. (2016) found southern Brazilian beef cattle raised on natural pasture (NP) had the lowest production cost per animal and higher GHG emissions per kg of beef when compared with supplemented cattle. In southern Brazil, diversifying into cash crop production has brought greater financial returns to the producer and has further developed this region. However, cattle grazed in this area are seen as an important conservation tool to keep the fauna and flora diverse (Brandão et al., 2012). Thus, it is necessary to improve the efficiency of the beef production system through improved pasture management.

4.2. Greenhouse gas emissions

Our estimated CF ranged from 14.9 (NPSC) to 16.1 (NP) kg of CO_2 eq/kg BWP which was less than some past estimates in Brazil. Ruviaro et al. (2015) and Ruviaro et al. (2016) simulated Angus beef cattle in southern Brazil on natural, cultivated and improved pasture, which ranged from 18.30 to 39.3 kg CO_2 eq/kg BWP for a complete beef cattle system, including the contributions of cows, calves, and steers. Kamali et al. (2016) estimated CF of 18.7 to 29.3 kg CO_2 eq/kg BWP for southern Brazil beef cattle. Carbon footprint for Nelore (*Bos taurus*) pure and cross breeds finished earlier on extensive pasture were estimated by Cardoso et al. (2016) to be comparable (15.1 kg CO_2 eq/kg BWP) to the Angus (*Bos taurus*) used in our analyses, while Nelore on extensive pasture and slaughtered at 3 to 4 years was comparable (29.7 kg CO_2 eq/kg BWP) to the prior studies mentioned.

Soybean production may have a role in lowering CF and improving farm profitability as observed in NPSC compared to our other simulations. This was due to the allocation of a portion of the total GHG emissions of the farm to the co-product produced as cash crop soybeans. Kamali et al. (2016) estimated slightly lower CF for an integrated system with cattle fed on soybean residues (26.8 kg CO_2 eq/kg liveweight or LW) versus just on natural pasture (27.3 kg CO_2 eq/kg LW). This system involving feeding on soybean crop residues also was the most profitable compared to natural pasture, feedlot finishing, and improved pasture.

Increased animal performance is suggested as one of the most effective mitigation strategies to decrease greenhouse gas emissions from livestock production (Capper and Hayes, 2012). Some authors (Pelletier et al., 2010; White et al., 2014; Ruviaro et al., 2015) found that pasture production improvement and intensification by feeding grain, decreased the time required to slaughter an animal, and consequently decreased GHG emissions. Our NPS and NPSC systems support this increased animal performance argument with lower CF through improved animal productivity where the age at slaughter was reduced from 29 (NP) to 18 months of age (NPS/NPSC) using grain supplementation. Low level grain supplementation as demonstrated by our NPS system (Table 6) can be used without increasing CF. As expected, the NPS system has higher GHG per ha as well as higher water and energy use from grain fed compared to NP.

Cardoso et al. (2016) reported that beef cattle in Brazil raised on pasture and finished in confinement had a 19.6% lower carbon footprint per kg of beef compared to cattle grazed on improved pastures and supplemented for growing and fattening. Vergé et al. (2008) estimated GHG emissions from Canadian agriculture decreased 37% (16.6 to 10.4 kg CO_2 eq/kg BWP) from 1981 to 2001. This was due to a change from a more extensive production system to intensive confinement systems. This was primarily driven by the reduction in enteric CH_4 emissions by feeding a low forage and high concentrate diet (Aguerre et al., 2011). In our research, animal methane emissions were the greatest contributor to carbon footprint with greater total GHG emissions for NPS than for NP due to higher emissions from the production of feed and resource inputs offsetting lower emissions from enteric fermentation (Table 8).

While GHG emissions per kg of beef output can be lower for more grain intensive beef feeding systems due to the greater productivity per unit time, carbon footprint per ha of land base can actually be higher for these more intensive systems due to higher livestock densities in feedlots as well as GHG emissions from feed crop production, transport and processing. For example, Cardoso et al. (2016) found CF per ha to be 68% to 259% more for improved pasture and feedlot finishing compared to a native pasture baseline. While our CF per ha (2591 kg CO_2 eq) for NPS was slightly less than Cardoso et al.'s minimal supplementation and/or improved pasture models (3057 to 4158 kg CO_2 eq/ha), our NPS low supplementation model's CF/ha was 5.6% more than our NP baseline.

Past studies cited emphasize GHG emissions per kg of beef. High-intensity beef systems can have greater total and per hectare GHG emissions than low-intensity systems. However due to greater beef production per unit time for these high-intensity systems, they can have lower CF per kg of BWP as demonstrated by Stackhouse-Lawson et al. (2012) for U.S. conventional beef. Here CF for the terminal feedlot segment of the Angus beef production chain is only 10–14% of total carbon emissions compared to the stocker and/or cow-calf segments (86–90%). This results in U.S. Angus having a lower average CF (12.1 kg CO_2 eq/kg BWP) compared to our RS results for Angus on NP (15.1 kg CO_2 eq/kg BWP). Our low supplementation model had higher total CF from supplemental feed production even though enteric fermentation was reduced (Table 8). However increased beef productivity gains from low supplementation reduced CF per kg of beef BWP which is consistent with past studies.

4.3. Other environmental impacts

Our analysis does not take into account the implications of land use change (natural pasture to soybean) and the loss in biodiversity that comes with this change in un-degraded RS pastures with up to 600 species (Boldrini, 1997). It is necessary to not only evaluate GHG emissions, but to consider the impact of land use change and resulting impacts (Castanheira and Freire, 2013). In Europe for example, the replacement of traditional production systems (low-input until the 1950s) by intensive production systems has been identified as being responsible for environmental problems such as pollution of water resources, decline in biodiversity and increased erosion (Baldock et al., 2002; Buckwell and Armstrong, 2004).

When assessing the environmental sustainability of a production system, GHG emissions should not be considered alone (Ridoutt et al., 2014). Studies have shown that intensified production systems have lower carbon footprint per kg of output (Cardoso et al., 2016; Ruviaro et al., 2015; Vergé et al., 2008), yet have a larger water footprint (Mekonnen and Hoekstra, 2010, 2012) due to greater "input" into the system, such as irrigation. This may also lead to greater energy input (Nasca et al., 2015). Our results were consistent with this where NPSC involving row cropping had larger water and energy footprints (Table 8) than NP and NPS.

Mekonnen and Hoekstra (2010) reported that most of the total volume of water (98%) in a farm's water footprint (kg H_2O/kg BWP) is from the feed offered to the animal, and water consumed and other services amounts to only 2%. According to Chapagain and Hoekstra (2003), the water footprint of livestock activities vary widely among countries, production systems and geographical distribution. Therefore, it is possible to find water footprint values of 564 to 1083 L H_2O/kg BWP for confinement operations in the USA (Rotz et al., 2013) and 41 to 46 L H_2O/kg BWP for Australian cattle production (Ridoutt et al., 2014). Australian system values are similar to those of the present study in southern Brazil (34 to 35 L H_2O/kg BWP), because both production systems are centered on grazing natural grasslands without irrigation.

Regarding energy use of cattle production systems, Ridoutt et al. (2014) observed that fossil energy consumption in grazing systems was nine times lower than that of intensive feeding systems for beef production in southern Australia. Peters et al. (2010) documented Australian primary energy use (MJ/kg of HSCW) for organic beef systems as 41% of that for conventional feedlots. Kamali et al.'s (2016) feeding on soybean crop residues (CR) system had a lower energy footprint (0.7 MJ/kg LW) compared to both feedlot finishing (7.3) and improved pasture (19.3). However their CR system had an identical energy footprint as natural pasture since soybeans eaten in-field by beef cattle were not mechanically harvested. While our study did not model these specific intensive systems documented in the literature, energy footprint for the NPSC system growing soybeans, a concentrated feed crop used in highly intensive feeding systems, was about 6 times greater than the NP system.

4.4. Beef quality

Intensifying beef systems by finishing with grain (versus pasture) can increase tenderness and value, but can lower beneficial essential fatty acids (CLA) and vitamin E content (Poulson et al., 2004; Van Elswyk and McNeill, 2014). Patino et al. (2015) showed low levels of grain supplementation similar to those used in our models had no significant impact on lowering CLA content. Our results suggest that low-intensity grain supplementation used in conjunction with properly managed pasture-based systems may decrease GHG emissions per kg of beef while maintaining nutritional quality of essential fats for consumers.

4.5. Policy recommendations

While low intensity supplemental feeding decreased CF, NPS had increased water and energy use and was also the least profitable system due to higher costs associated with feeding grain. Higher costs of alternative beef production systems have been cited as one of the major challenges to improving the sustainability of Brazil's beef herd. Other factors in addition to cost are the current lack of technical support (Kamali et al., 2016) as well as beef producers' perceptions of the effectiveness of pasture improvement and the degree of support from family and cattle traders for adopting these alternative systems (Borges et al., 2016). Government policies could encourage more beef producers to transition to semi-intensive finishing.

Recent Brazilian government policies targeted at beef and soybean producers have penalized those that illegally deforest, decreasing Amazon deforestation rates and GHG emissions (Nepstad et al., 2014). To further reduce emissions, carbon taxes could help subsidize semi-intensive ranching (Cohn et al., 2014), pasture re-seeding during integration with soybeans (Gil et al., 2015), and genetic improvement of cattle and development of feed additives (Cottle and Eckard, 2014). However agricultural carbon taxes and cap and trade have not historically been used in Brazilian agriculture to regulate GHG's (Personal communication, Fernando Sampaio, MT State Government), nor have agricultural subsidies of technologies reducing carbon emissions been favored (Personal communication, Amando de Oliveira Filho, ACRIMAT). While Brazil's "Low Carbon Agriculture (ABC) Program" offers loans to food and bio-refinery producers to invest in low-carbon technologies, participation dropped after producers switched to other lines of financial credit with lower interest rates (Newton et al., 2016).

Unlike the U.S., recent surveyed beef consumption in Sao Paulo has not declined (Carvalho et al., 2014), however Brazilian consumers in Curitiba support sustainable beef (Hall, 2012). This suggests shifting Brazilian consumption to more sustainable beef may be more feasible than reducing consumption of such a culturally popular food. Public or private sector eco-labels could support greater consumer willingness to pay for beef with lower CF due to low-grain supplementation as well as greater sequestration of carbon by integrating beef systems with agroforestry (Figueiredo et al., 2017). Price premiums paid for beef in the U.S. with reduced environmental impacts range from 4% to 19% (White et al., 2014). Hall (2012) sampled beef consumers in Curitiba, Brazil, who were willing to pay a 12.8% premium for sustainably ranched beef. Assuming this 12.8% premium is representative of all Brazil beef consumers, it would be possible to initially cover the entirety of the 11% higher cost of the NPS compared to the NP system, but only 15% of the 87% higher cost of the NPSC compared to the NP system.

Although the reduction in GHG emissions per kg of beef from low-grain supplementation (NPS) relative to natural pasture (NP) is small (~2%), the current market value of reduced emissions (social cost of carbon or SCC) is 21% of the added cost of the NPS system assuming carbon is valued at $242/t of CO_2 which assumes declines in economic growth due to climate change (Moore and Diaz, 2015). Assuming this SCC can be transferred to NPS beef producers from consumers willing to pay more for semi-intensive beef, then NPS is about $10/head more profitable than NP (−$23/head lower net return for NPS versus NP + $33/head SCC). This SCC of $33/head of beef is only ~10% of the aforementioned 12.8% price premium for sustainable beef. In addition to consumers, beef processors could encourage NPS systems by paying producers more than is currently done for cattle slaughtered at 2–3 years (semi-intensive) compared to cattle slaughtered at 3–4 years (extensive).

While the NPSC system diversified with soybeans reduced carbon footprint (CF) and was more profitable, energy and particularly water use and erosion were greater. For climates like Rio Grande do Sul (RS) state in Brazil which has consistent rainfall, agricultural systems with higher water demand may not be as much of a problem compared to the Brazilian Midwest which has a seasonal rainfall pattern. Soybeans are planted at the start of the rainy season there in October which can be subject to production risk from inconsistent rainfall (Personal communication, Dr. Daniel Abreu, Universidade Federal de Mato Grosso, Campus Sinop). Our lower CF yet greater soil erosion support criticism of ecological footprints (including carbon footprint) not accurately reflecting erosion where lower footprints were not significantly associated with reduced erosion (Fiala, 2008). There is room for increased public and private support for diversification by more favorably insuring such production risk as well as covering costs associated with diversifying beef systems with soybeans.

In RS, government support for such diversification may not be necessary due to the relative profitability of adding soybeans as demonstrated by our results. However in areas like Mato Grosso (MT) in the Brazilian Midwest where beef and soybean producers are more specialized and spatially separated, reducing the management and transaction costs associated with diversifying beef systems may be required. For example, 98.5% of all agricultural land MT is associated with a lack of crop-livestock integration, while 24% of the agricultural land is used to produce soybeans (Gil et al., 2015). Such specialized agricultural systems can result in soil and resource degradation as highlighted historically by Brazilian soybeans (Fearnside, 2001) and in specialized livestock industries where commodity feeds like Brazilian soybeans are fed (e.g. North Carolina, USA). These specialized systems can accumulate nutrients resulting in watershed eutrophication (Edwards and Driscoll, 2008) because there is no adjacent cropping industry to uptake manure nutrients (Magdoff et al., 1997).

5. Conclusions

Increased human population and global demand for food will increase the necessity to have greater productivity per hectare which could decrease carbon footprint by intensifying ruminant livestock production. Supplemental grain feeding (NPS) increased GHG emissions per hectare, but decreased the GHG emissions per kg of beef produced and was less profitable due to higher feed costs compared to the native pasture (NP) baseline model so incentives may be required to entice producers to adopt supplemental feeding.

Net animal gain evaluated with the IFSM software increased for NPS and NPSC when compared with NP due to greater animal productivity per hectare and fewer days to slaughter. However, the advantage of the NP system is that it is self-sustaining, depending on very few external resources imported into the system, making it more profitable than the NPS system that received greater supplementation. However, when supplementation was combined with soybean production, the net return per hectare was much higher. Low-grain supplementation and adding a soybean cash crop lowered GHG emissions per kg of beef, but increased energy and water footprints in addition to soil erosion. For better assessment of the environmental impact of these natural pasture systems, it will be necessary in the future to estimate the impact of land use change (e.g. natural pasture converted to soybean) and related effects on biodiversity.

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