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ANALYSIS OF PASTURE SYSTEMS TO MAXIMIZE THE PROFITABILITY AND SUSTAINABILITY OF GRASS-FED BEEF PRODUCTION

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Abstract. Pasture systems for grass-fed beef production in the Gulf Coast region were evaluated for profitability and sustainability over the period 2009/2010 to 2011/2012. May-weaned steers were divided into groups and randomly placed into different pasture systems. Data on input usage, output quantities, and carbon emissions were recorded and analyzed. The least complex grazing system yielded higher profit than the most complex, but the most complex produced the lowest greenhouse gas impact. A trade-off was found between profitability and greenhouse gas impact among the systems.

Keywords. Bermuda grass, carbon emissions, Dallis grass, grass-fed beef, ryegrass

JEL Classifications. Q12, Q15, Q16

1. Introduction

A wide range of forage management systems can be used to produce grass-fed beef (GFB), with each system resulting in potentially different productivity, profitability, and sustainability outcomes. The U.S. Department of Agriculture

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(USDA) defines GFB as beef from cattle whose lifetime diet consists of only grass and other forage, with the exception of milk consumed prior to weaning; no grains are fed (USDA Agriculture Marketing Service, Grass Fed Marketing Claim Standards, 2007). Although GFB preceded grain-fed beef production as a practice of raising cattle, grain supplementation has been standard practice in cattle production since the 1950s (Schupp et al., 1979). Today, the share of GFB production is <1% of the total beef produced in the United States (Pelletier, Pirog, and Rasmussen, 2010). Lack of knowledge of appropriate production practices has been cited as one of the reasons for the relative low production of GFB (Gwin, 2009). With increased interest in GFB production in recent years, potential GFB farmers are asking questions about the most profitable production methods.

Over the past 50 years, studies have reported favorable carcass characteristics for grain-fed beef such as juiciness, tenderness, and marbling (Aberle et al., 1981; Fishell et al., 1985; Oltjen, Rumsey, and Putnam, 1971; Young and Kauffman, 1978). Recently, however, with consumer concerns about human health, the environment, and animal welfare, GBF is experiencing increased demand (McCluskey et al., 2005; Mills, 2003; Wright, 2005). Umberger et al. (2002) found that 23% of U.S. consumers were willing to pay a \$3.00/kg premium for GFB, and Cox et al. (2006) reported that 33% preferred GFB and were willing to pay premiums of \$2.38 to \$5.63/kg. Prevatt, Kerth, and Fields (2006) also reported that a segment of U.S. consumers preferred GFB.

Forage quality can impact beef productivity and quality; thus, it plays a crucial role in animal development and beef production (Gerrish, 2006). Various studies have compared different grazing systems for beef production, many focusing on stocking density (Anderson, 1988; Bertelsen et al., 1993; Lewis et al., 1990) and some also analyzing the economics of those systems (Comerford et al., 2005; Gillespie et al., 2008). Few, however, have focused on GFB production. Surveys of GFB producers have been conducted by Lozier, Rayburn, and Shaw (2005) and Steinberg and Comerford (2009). According to the latter study, the major expenses associated with GFB production were steers, land, feed, equipment, and wintering (hay or silage), the latter four of which are related primarily to forage production. Knowledge of the most profitable forage production systems would greatly benefit GFB producers.

In addition to the selection of an appropriate forage production technology for productivity and profitability, there is a need to investigate the comparative ecological sustainability of forage production systems. Greenhouse gas (GHG) emissions from agricultural land play a role in total global warming potential (GWP). Pasture, as the largest land resource in the United States, plays an important role in carbon cycling and sequestration (Follett and Reed, 2010). Since the Kyoto Protocol of 1997, studies have evaluated the feasibility of carbon sequestration from agricultural and forest land (Antle and McCarl, 2002; Liebig et al., 2010). A wide range of compensation cost for producers for shifting their land use to the conservation reserve program ($12 to $500 per metric ton) was found in eastern Montana depending on the type of land, crop, and cropping intensity (Antle et al., 2001). Zeuli and Skees (2000) analyzed the challenges and opportunities for southern U.S. agriculture to play a role in the carbon market and discussed a wide range of carbon value estimates, which were similar in range to those found by Antle and McCarl (2002). Liebig et al. (2010) evaluated the GHG impacts of different grazing strategies in terms of their contributions to GWP. Limited efforts, however, have been made to evaluate agricultural management strategies in terms of profitability and GHG emissions (Nalley, Popp, and Fortin, 2011; Nalley, Popp, and Niederman, 2013; Williams et al. 2004). For example, McFadden, Nalley, and Popp (2011) and Lyman and Nalley (2013) evaluated rice varieties in Arkansas to maximize profit and minimize GHG emissions. Despite these various efforts, development of a carbon market remains largely in the discussion stage. The present study has implications for what the development of a carbon market might do in encouraging more sustainable agricultural systems.

In this context, we evaluated the profitability and ecological sustainability of three GFB production pasture systems with different levels of management intensity and use of resources. The specific objectives of this study are to determine, for GFB pasture systems, (1) the most profitable system, (2) the system with the lowest GHG emissions, and (3) the potential trade-off between economic profitability and GHG emission reduction. This study is unique not only because it compares the profitability of specific pasture combinations for GFB production, but also because it evaluates carbon emissions related to each of three systems throughout the study period. Trade-offs between profitability and GHG emissions are estimated for the pasture systems. Thus, this study integrates three distinct disciplines of agricultural science: agricultural economics (expenses and returns and trade-offs between GHG impact and economic profitability), animal science (pasture management and rearing of beef cattle), and soil science (analysis of carbon emissions on pasture land).

2. Analytical Techniques

This study was based on the following experimental design. Three treatments used in a field experiment at the Iberia Research Station (IRS) in Jeanerette, Louisiana, from 2009/2010 to 2011/2012 represented forage systems with different degrees of management complexity. The three forage systems are as follows:

1. Forage system 1: Bermuda grass as summer pasture; ryegrass as winter pasture.
2. Forage system 2: Bermuda grass as summer pasture; Dallis grass and clover mix as fall and winter pastures; and annual ryegrass, rye, and clover mix (berseem, red, and white clovers) as winter pastures.

3. Forage system 3: Bermuda grass, sorghum-Sudan hybrid, and forage soybean as summer pastures; Dallis grass and clover mix as fall and winter pastures; and annual ryegrass, rye, and clover mix (berseem, red, and white clovers) as winter pastures.

These systems were chosen as representative of the types of systems currently being used for GFB production in the U.S. Gulf Coast region. The least complex and relatively common system in the Gulf Coast region is represented by system 1, which consists of perennial summer and winter pasture. System 2 consists of clover mixtures and Dallis grass as an addition to the winter pasture in system 1. This would help to extend the grazing period and reduce the requirement of hay feeding. Sorghum-Sudan hybrid and soybean are added in system 3 as summer pasture in addition to system 2, which would help to satisfy the nutritive requirements of steers. Thus, system 1 is the least complex system, and system 3 is the most complex system.

The same pastures were used for each treatment each year. The experimental year began in May and ended by the end of April the following year. The three forage systems were managed in different subpaddocks at the IRS, rotated among the subpaddocks based on forage availability. Annually, 54 fall-born steers (7–8 months old) were assigned to one of the three forage systems immediately after weaning and remained until time of harvest at age 17–19 months. The steers were blocked at weaning by weight into nine groups (6 steers/group). Each group was randomly assigned to one of the three treatments, each of which was replicated three times. During the transition period when forage availability was low (mid-November to December), animals were fed hay produced in the paddocks allocated to the system/replication group. Records were kept on the amount of hay fed to each group. Constructed portable shades were made available for the animals in each group. They were moved along with the animals when rotated. Water and mineral mix were available at all times. The stocking rate was 1 hectare per animal for each entire system. Although this may seem to be a relatively low stocking rate at first glance, unpublished survey results of a mail survey we sent to all identified southern U.S. GFB producers show that it is not uncommon to have a stocking rate in this range considering the lowest forage production period in the year.

Detailed cost and input records were kept for each pasture by year, with sheets on which the records were to be kept developed by the authors. These records detailed the agronomic operations, labor activity, and input usage in each pasture, recorded in a field book. These records were used to develop detailed cost and return estimates for each treatment/replication. Budgets included returns, direct expenses, fixed expenses, and land rent. The expenses of seed, fertilizer, pesticide, minerals, medication, twine, fuel, purchased weaned steers, repair and maintenance of machinery, and interest on operating capital were included in the direct expenses. Depreciation and interest on machinery (trucks, tractors, and

Table 1. Prices of Inputs and Outputs for the Experimental Years

		Price in US$		
Inputs/Outputs	Units	2009	2010	2011
Urea	Kilogram	0.40	0.35	0.42
Gramoxone Max	Liter	10.57	11.54	11.54
Grazon P+D	Liter	8.47	10.44	8.18
Roundup Original Max	Liter	13.86	15.32	12.85
Outrider	Liter	676.28	N/A	N/A
Platoon	Liter	N/A	N/A	3.70
Malathion	Liter	N/A	8.98	8.94
Sevin 80WP	Kilogram	13.51	15.01	16.20
Bovishield	Dose	2.50	2.50	2.50
One Shut	Shut	2.50	2.50	2.50
Sweetilix	Bag	18.00	18.00	18.00
Ultrabac 8	Dose	0.40	0.40	0.40
Vigortone 3V2	Bag	26.20	26.20	26.20
Vigortone 3V5	Bag	17.13	17.13	17.13
Weanling calf	Kilogram	2.17	2.51	2.51
Twine	Ton	0.75	0.75	0.75
Berseem clover seed	Kilogram	4.72	4.74	7.72
Red clover seed	Kilogram	5.51	6.61	2.65
White clover seed	Kilogram	5.51	7.05	6.83
Rye seed	Kilogram	0.49	0.97	0.99
Ryegrass seed	Kilogram	1.34	1.54	1.10
Soybean seed	Kilogram	1.23	1.17	1.32
Sorghum-Sudan seed	Pound	0.47	0.80	0.80
Hay[a]	Bale	45.00	40.00	82.50
Steers at harvest[a]	Kilogram	2.56	2.93	3.11
Diesel fuel	Liter	0.58	0.61	0.73

[a] Although the prices of hay and steer at harvest were tabulated as 2009, 2010, and 2011, those were based on U.S. Department of Agriculture prices in the following years (2010, 2011, and 2012) because the harvesting and selling of hay and steers was in the second calendar year of the experiment.
Note: N/A indicates data not available.

other implements), permanent fencing, and temporary fencing were included in the fixed expenses. The opportunity cost of land rental was included.

Table 1 includes annual prices of inputs and outputs. Most of the input prices are those used by Boucher and Gillespie (2009, 2010, 2011) for cost and return estimates for cattle and forage production. Weaned calf prices from *Louisiana Agricultural Statistics 2011* were used (LSU Agricultural Center, USDA-NASS, 2012). We used calf prices from the second quarter of each year from 2009 to 2011 because animals entered the experiment in May. Hay prices were determined based on those listed in the *Weekly Texas Hay Report* (USDA–Texas Department of Agricultural Marketing News, 2010, 2011, and 2012) for fair quality hay, assuming any leftover hay was sold in April after harvest of the animals. The grass-fed steer price was based on USDA Economic Research

Table 2. Prices of Fixed Inputs, Machinery, and Equipment

Fixed Input Annual Costs in US$

	Units	Repair and Maintenance	Fixed Costs
Fence electric	Kilometer	23.61	156.19
Fence 5 wire	Kilometer	130.49	302.30
Hay rack	Each	9.04	26.27
Shade structure	Each	3.48	72.65
Shade cloth	Each	5.30	64.25
Water tank and pump	Each	40.00	132.50

Machinery and Equipment Costs in US$

Machinery/Equipment	Direct Costs/Hour	Fixed Costs/Hour
Mower conditioner	10.79	12.89
Hay rake	2.43	3.16
Hay tedder	2.45	3.67
Hay fork	0.09	0.22
Baler round	13.98	18.56
Mower drum	4.68	5.59
Boom sprayer	2.35	3.12
Tractor (40–59 hp)	6.48	4.42
Tractor (60–89 hp)	10.05	7.81
Tractor (90–115 hp)	14.31	12.52

Service (Johnson 2012) published prices for fed steers in the second quarter of each year and adjusted by adding $0.44/kg to the fed steer price, as suggested by a manager of one of the larger GFB production firms. As the records were kept by group for each year, there were 9 sets of records per year, for a total of 27 sets of records and 27 resulting cost and returns estimates for the 3 years.

Table 2 shows fixed inputs with their annual fixed and repair and maintenance costs. These costs were calculated according to their useful life as the costs of capital and depreciation. Similarly, the fixed expenses of machinery and equipment were estimated as depreciation and opportunity cost of capital (interest) by hours of use, assuming a useful life of a fixed number of hours as shown in Boucher and Gillespie (2011).

Differences in fixed expenses, variable expenses, gross returns, and net returns among treatments were determined using a mixed model with fixed treatments, and years as fixed repeated measures effects. The Kenward-Roger degrees of freedom method was used (Kenward and Roger 1997).

Because the cost and returns analysis is based on 27 observations, we used simulation and dominance techniques to strengthen the results of this research. Based on historical data (10 years, 2002–2011) on prices of inputs (fertilizer, fuel, and calf) and outputs (hay and steer), 1,000 randomly simulated values were developed using Simetar, a commercial mathematical simulation software package (Richardson, Schumann, and Feldman, 2008). Similarly, hay yield was estimated based on 10 years of historical rainfall data at the IRS, and 1,000 randomly simulated values were developed. Other input prices and quantities and steer yield were taken as constant because we did not observe significant variation in these input and output prices and quantities over the course of the experiment. Based on these simulated values and constant values, 1,000 net returns for each of the systems were developed.

Using the 1,000 simulated net returns, we estimated certainty equivalents (CEs) assuming different risk aversion coefficients for each system according to the relationship outlined by Hardaker et al. (2004). The CE is the net return value held with certainty at which the decision maker is indifferent to a risky distribution of net return values. Estimation of the CE depends on the utility function of the decision maker. Equation (1) gives the relationship between the utility function $U(w)$ and the absolute risk aversion coefficient $r_a(w)$,

$$U(w) = -\exp[-r_a(w)], \tag{1}$$

where w is the wealth or income associated with the choice. The absolute risk aversion coefficient is defined as the negative ratio of the second and first derivatives of the utility function as shown in equation (2).

$$r_a(w) = -\frac{u''(w)}{u'(w)} \tag{2}$$

The relationship between the absolute risk aversion coefficient and the relative risk aversion coefficient, $r_r(w)$, is expressed as follows:

$$r_a(w) = \frac{r_r(w)}{w}. \tag{3}$$

The CE for a random sample of size n from risky alternatives w is estimated as follows, as shown by Hardaker et al. (2004):

$$\mathrm{CE}[w, r_a(w)] = \ln\left(\left\{\frac{1}{n}\sum_{i}^{n}\exp[-r_a(w)w_i]\right\}^{-1/r_a(w)}\right) \tag{4}$$

As Anderson and Dillon (1992) have proposed, a general classification of relative risk aversion coefficients falls in the range of 0 for risk neutral to 4 for highly risk averse. Absolute risk aversion coefficients were obtained by dividing a range of relative risk aversion coefficients (0 to 4) by the estimated mean net return of system 3. This gives the maximum absolute risk aversion coefficient of 0.0024, which is used in a stochastic efficiency with respect to function (SERF) analysis. SERF is a means to evaluate the risky alternatives in terms of CEs for a specified range of absolute risk aversion coefficients. It is superior to stochastic dominance with respect to function because the latter only makes the pairwise comparison (Hardaker et al., 2004). The result is graphed to analyze the dominance by system. We used a similar method to that of Hardaker et al. (2004) to analyze the SERF among the systems.

2.1. *Estimating Carbon Emissions*

Soil carbon emission data and soil samples were collected and analyzed within the three pasture systems. There were seven different forage categories. For each category, gas sampling for carbon dioxide (CO_2) and atmospheric methane (CH_4) flux was carried out. Four chambers (replicates) were placed in pastures for each forage category. Samples were taken monthly throughout the experiment. Chamber gas samples at each location were taken at regular intervals of 0, 30, and 60 minutes. These samples were analyzed by gas chromatography equipped with a methanizer and flame ionization detector. The CO_2 and CH_4 fluxes were computed from the rate of change in chamber concentration, chamber volume, and soil surface area. We were, thus, able to compute the annual average CO_2 equivalent carbon emissions by pasture system. Because CO_2 equivalent carbon emissions from the atmospheric CO_2 flux, CH_4 flux, and nitrous oxide (N_2O) flux data were collected based on different pasture types, not from the individual subpaddocks, we could not develop 27 separate sets of data for CO_2 emissions specific to a system. Therefore, we could not apply statistical analysis on CO_2 emissions, so only the arithmetic means for each system were compared for the analysis.

The net GWP in kilograms of CO_2 equivalent in each system was determined by summing the emitted CO_2 equivalents from seven factors as shown in the following equation used by Liebig et al. (2010), with modification:

$$\mathrm{GWP} = \mathrm{NP} + \mathrm{EF} + \mathrm{CO_2\ flux} + \mathrm{N_2O\ flux} + \mathrm{CH_4\ flux} + \mathrm{DU} + \mathrm{PP}, \tag{5}$$

where GWP is measured in kilograms of CO_2 equivalent emissions summing from different sources; NP is the CO_2 equivalent emission by nitrogen fertilizer production; EF is the CO_2 equivalent emission via thorough enteric fermentation; CO_2 flux is the CO_2 equivalent emission through atmospheric CO_2 surrounding the pasture; N_2O flux is the CO_2 equivalent emission through atmospheric N_2O flux; CH_4 flux is the CO_2 equivalent emission through CH_4 flux; DU is the CO_2 equivalent emission by diesel use, which includes diesel used in fertilizer and pesticide application, tillage, and hay operations; and PP is the CO_2 equivalent emission by pesticide production.

Equation (5) was modified from Liebig et al. (2010) by replacing the change in soil organic carbon with CO_2 flux, as the change in soil carbon as measured in the study through soil sampling was barely noticeable over the 3-year period of our study. A much longer period of soil sampling would have been required to begin to detect differences in soil carbon, presenting challenges for the collection of such data in most studies of this type. Additionally, in Liebig et al. (2010), NP consists of two parts (i.e., nitrogen production and application). In our study, the application portion is included in DU. Because Liebig et al. (2010) did not apply any pesticides or include any field operations, DU and PP were not included in their equations.

Nitrogen fertilizer used in each system was aggregated based on annual use in the respective pasture systems; CO_2 equivalent emission from NP was computed as in Liebig et al. (2010). Similarly, CO_2 equivalent emission from EF was computed as in Liebig et al. (2010), in which they assumed similar CO_2 equivalent emissions from EF per animal among different systems. Atmospheric CO_2-C flux, N_2O-N flux, and CH_4-C flux were calculated based on laboratory analysis of field samples. The conversion of CO_2-C flux to CO_2 equivalent emission was conducted by multiplying by the conversion factor 3.667, and the conversions of N_2O-N flux and CH_4-C flux were conducted by multiplying by conversion factors of 298 and 25, respectively, as in Liebig et al. (2010). The carbon equivalent emission from DU was estimated by multiplying the conversion factor of 0.94 kg carbon equivalent per kg of diesel as in Lal (2004), which was further converted to CO_2 equivalent emission by multiplying by the conversion factor, 3.667. Pesticide used in each system was aggregated based on annual use. Then the carbon equivalent emission from PP was calculated by summing the carbon equivalents from different pesticides used as in Lal (2004)[1] and further converted into CO_2 equivalent emission by multiplying by the conversion factor 3.667. As the conversion factors in Lal (2004) are based on kilograms of active ingredients, liquid formulations were converted to quantities by using the specific gravity of the pesticides in solution as a multiplying factor (Table A1 in the Appendix). Because we could not find the specific conversion factors for picloram, sulfosulfuran, and dimethylamine salt of 2,4-D to estimate CO_2 equivalent emission, the general conversion factor for herbicides, 4.4, was used as estimated in West and Marland (2002). Because these three active ingredients of herbicides contributed <1% of the total pesticides used for this experiment, they would have minimal impact on the CO_2 equivalent emission.

Equation (5) is further modified by subtracting the CO_2 equivalent carbon sequestration from hay surplus (HS) as follows:

$$GWP = NP + EF + CO_2\,\text{flux} + N_2O\,\text{flux} + CH_4\,\text{flux} + DU + PP - HS. \tag{6}$$

HS is the quantity of hay biomass remaining after consumption by the animals in the respective pasture systems. Carbon sequestered in this HS is calculated by subtracting the 12% moisture from hay biomass and multiplying by the conversion factor 0.475. This is then converted into CO_2 equivalent by multiplying by the conversion factor 3.667. Because HS fixed atmospheric carbon, it would negatively affect the net GWP. Therefore, it has a negative sign in equation (6). Ultimately, this carbon sequestered in the HS would likely

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[1] Carbon equivalent conversion factors for different active ingredients as per Lal (2004) are as follows: 1.7 for 2,4-D, 9.1 for glyphosate, 9.2 for paraquat, 4.6 for malathion, and 9.1 for carbaryl.

be released to the atmosphere because the HS will be used for consumption by animals. Therefore, we calculated the GWP with and without including HS.

The value of carbon that would entice farmers to switch management practices (treatments) was determined. The value of carbon emissions was determined by comparing the total amount of CO_2 equivalent GWP and economic profit per animal per year among the systems, as in equation (7),

$$\pi_k = \pi_l + C, \tag{7}$$

where π_k is the profit associated with system k (without placing economic value for CO_2 equivalent carbon emissions); π_l is the profit associated with system l (without placing economic value for CO_2 equivalent emissions); and C is the value of reduced CO_2 equivalent carbon emissions that would induce a change from system k to system l.

3. Results and Discussion

3.1. Economic Profitability by System

Return, expense, and profit estimates for the three systems are presented in Table 3. Results are reported on a per steer basis. Because the stocking density is 1 steer per hectare, this can be taken as a per hectare basis as well. Differences in steer income were not found among the treatments in this experiment because the animal weights at the time of harvest did not differ significantly among the systems. Mean weights of finished animals were 462 kg, 458 kg, and 459 kg for systems 1, 2, and 3, respectively (Table 4). Hay income differed significantly among the systems (i.e., greatest in system 1 and least in system 3) because hay production was more extensive in Bermuda grass and ryegrass pastures than in other pastures. System 1 had greater proportions of Bermuda grass and ryegrass pasture than system 3. Little hay was made with clovers, sorghum-Sudan hybrid, soybean, and so forth, as there was little excess forage to be harvested in those crops. Average gross returns per steer were \$2,129, \$1,984, and \$1,772, for systems 1, 2, and 3, respectively, noninclusive of any partial carbon sequestration benefits. Each differed significantly from the others. The gross return was highest in system 1 and lowest in system 3 due primarily to the differences in hay income among these systems.

Fertilizer expense for system 1 was significantly greater than for systems 2 and 3. This was due to higher usage of nitrogen-fixing legumes in systems 2 and 3, which substituted for commercial nitrogen fertilizer. Pesticide expense did not differ significantly among the systems, although it was numerically slightly greater in system 3 due to higher use of Outrider, which was not used in system 1. Livestock expense did not differ among the systems because equal-weight weaned animals were used across the treatments. Twine expense was greater in system 1 than in systems 2 and 3 because it was used on more bales of hay produced. Seed expense differed among the three systems, with the lowest in system 1

Table 3. Revenue, Expenses, and Profit per Treatment (US$ per Animal)

Item	System 1	System 2	System 3
Income			
Steer income	1,324.41	1,330.17	1,311.61
Hay income	804.20[bc]	653.37[ca]	460.31[ab]
Total income	2,128.61[bc]	1,983.56[ca]	1,771.94[ab]
Expenses			
Fertilizer	238.37[bc]	173.50[ac]	145.52[ab]
Pesticide	48.54	45.65	52.82
Livestock	620.98	622.93	623.35
Twine	3.96[bc]	2.91[a]	2.41[a]
Seed	68.52[bc]	142.37[ac]	201.89[ab]
Minerals, medication	22.17[bc]	22.69[a]	22.65[a]
Diesel expense	74.96[bc]	56.46[a]	48.03[a]
Repair and maintenance	64.96[bc]	51.76[a]	48.06[a]
Interest on operating capital	47.22	48.07	46.56
Total direct expense (D)	1,190.28	1,161.93	1,192.02
Return over total direct expense	938.26[c]	816.57[c]	579.87[ab]
Fixed expense (F)	214.48[bc]	170.04[ac]	147.24[ab]
Total expenditure (D + F)	1,404.78	1,337.07	1,339.39
Return over specified expenses	723.44[c]	646.44[c]	432.50[ab]
Residual return	641.33[c]	572.17[c]	360.39[ab]
Residual returns per labor hour	33.65	35.35	25.04
Residual returns with labor	452.35[c]	411.30[c]	217.43[ab]

Notes: Residual Return = Total Income − Direct Expense − Fixed Expense − Land Rent. System 1 represents the simplest pasture system including Bermuda grass and ryegrass. System 2 includes a clover mix in addition to grasses in system 1, and system 3 includes sorghum-Sudan hybrid and soybean in addition to the forage in system 2.

[a] Means differ significantly from system 1 within rows at $P < 0.05$.

[b] Means differ significantly from system 2 within rows at $P < 0.05$.

[c] Means differ significantly from system 3 within rows at $P < 0.05$.

and the highest in system 3. This was due to the greater diversity of pastures in system 3 compared with only Bermuda grass and ryegrass in system 1, the former of which is a permanent (perennial) pasture. Instead of including variable expenses for seeding Bermuda grass pastures (assuming these had been previously established as permanent pastures), the establishment expense for Bermuda grass was included as a fixed expense as in Boucher and Gillespie (2009, 2010, 2011). Minerals and medication expenses were greater in systems 2 and 3 than in system 1. This was due to the use of Sweetlix to control bloat in systems 2 and 3 with legume pastures, but not in system 1. Diesel expense was greater in system 1 than systems 2 and 3, primarily because of the greater use of machinery for hay cutting and baling in system 1. Similarly, repair and maintenance expense was also greater in system 1 than systems 2 and 3 because of greater use of machinery for hay cutting and baling.

Table 4. Steer and Hay Measures

	Average Weight per Steer in Kilograms		Number of Hay Bales	
System	Initial	Final	Produced	Fed
System 1 average	259	462	96	6
2009	255	461	54	7
2010	247	459	148	4
2011	273	466	86	6
System 2 average	260	458	80	5
2009	258	445	81	7
2010	246	469	101	3
2011	275	459	58	4
System 3 average	260	459	59	5
2009	256	440	64	6
2010	247	463	73	5
2011	275	474	40	5

Notes: System 1 represents the simplest pasture system including Bermuda grass and ryegrass. System 2 includes a clover mix in addition to grasses in system 1, and system 3 includes sorghum-Sudan hybrid and soybean in addition to the forage in system 2.

In total, direct expenses did not differ significantly among the systems, the major reason being relatively high fertilizer and diesel expenses in system 1 and higher seed expenses in system 3. The return over direct expenses was higher for systems 1 and 2 than for system 3. Fixed expense differed among the systems. Assuming 50 animals on the farm, system 1 consisted of 4.18 kilometers of permanent fencing and 0.89 kilometers of temporary fencing. System 2 included 3.99 kilometers of permanent and 0.47 kilometers of temporary fencing. System 3 included 4.25 kilometers of permanent fencing only. Fixed cost was highest for system 1 due primarily to the greater use of machinery for hay harvesting and baling and the fixed expense associated with establishing Bermuda grass pastures. Altogether, total specified expenses per steer were $1,405, $1,337, and $1,339 for systems 1, 2, and 3, respectively.

Net returns per steer were $641, $572, and $360 for systems 1, 2, and 3, respectively, with the net profit of systems 1 and 2 being significantly greater than that of system 3. The net return estimates are in the range of magnitudes found by Steinberg and Comerford (2009), −$198 ± 1,596.90 per steer. The average labor hours required for systems 1, 2, and 3 were 19.1, 16.2, and 14.4, respectively, and returns per labor hour were $34, $35, and $25 for systems 1, 2, and 3, respectively. When we considered the labor and management expenses from the residual returns, returns per steer were $452, $411, and $217 for systems 1, 2, and 3, respectively (Table 3).

Results of the SERF analysis are presented in Figure 1. The results show that systems 1 and 2 clearly dominate system 3 and confirm the findings of the cost and returns analysis. Due to the stochastic nature of hay production in system 1,

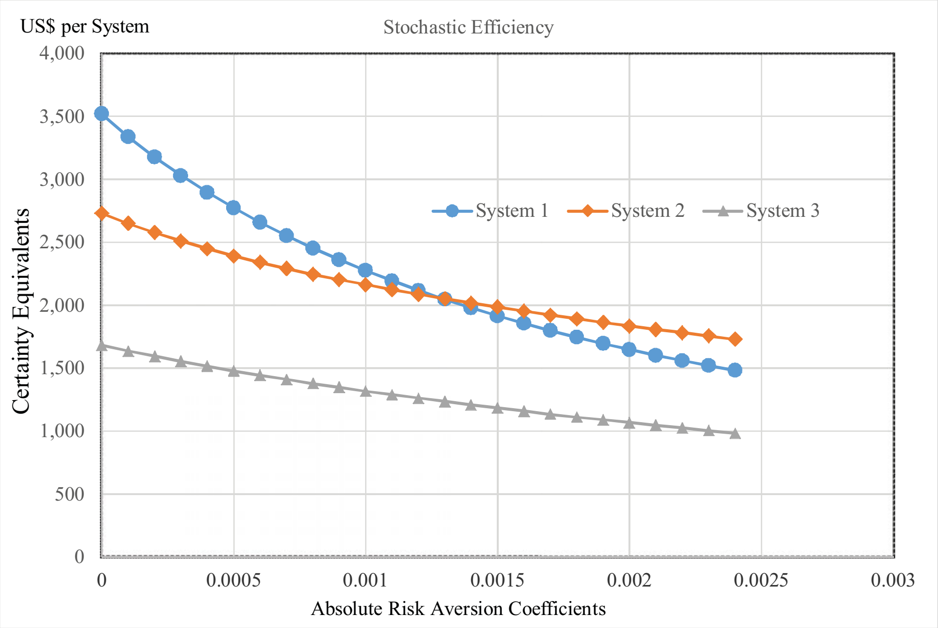

Figure 1. Stochastic Efficiency with Respect to a Function among the Systems

decision makers with risk aversion coefficients of 0.0013 or less would choose system 1 over system 2, whereas decision makers having risk aversion coefficients greater than 0.0013 would choose system 2 over system 1. Thus, the results show that more risk averse producers would choose system 2, whereas less risk averse producers would choose system 1. System 2 had associated net returns that were less variable than in system 1 due to higher variability of hay production in system 1.

3.2. Greenhouse Gas Emissions

Annual CO_2 emissions data were collected by pasture type and aggregated for each pasture system. Estimated CO_2 equivalent emissions from NP; EF; CH_4, N_2O, and CO_2 fluxes; DU; and PP per system as well as CO_2 equivalent fixation by HS per system are presented in Table 5, as are the net annual GWP with and without HS per system and per animal per year. Because HS from each system was sold and income due to hay sale was included in economic profit measures, GWP per steer per year was also estimated without subtracting HS as in equation (5). Although the amount of GWP per steer per year was slightly higher in each system without HS, the difference was not great.

System 3 produced the lowest annual GWP per steer, 52,281 kg of CO_2 equivalent GWP, whereas system 1 produced the highest, 68,556 kg of CO_2 equivalent GWP. On average, 3,735 kg, 2,721 kg, and 2,475 kg total of nitrogen

Table 5. Global Warming Potential (GWP) as Kilograms CO_2 Equivalent per Year among Systems with and without Hay Surplus per Treatment per Animal

	Kilograms CO_2 Equivalent per Year from Different Sources								GWP with HS		GWP without HS	
System	NP	EF	CH_4 F	N_2O F	CO_2 F	HS	DU	PP	GWP	GWP/Animal	GWP	GWP/Animal
System 1	5,319	29,401	2,276	120,970	253,994	3,389	2,121	644	411,336	68,556	414,725	69,120
System 2	3,875	29,401	819	33,164	276,142	2,827	1,606	523	342,702	57,117	345,528	57,588
System 3	3,525	29,401	2,007	36,520	242,364	2,023	1,383	507	313,684	52,281	315,707	52,618

Notes: System 1 represents the simplest pasture system including Bermuda grass and ryegrass. System 2 includes a clover mix in addition to grasses in system 1, and system 3 includes sorghum-Sudan hybrid and soybean in addition to the forage in system 2. CH_4 F, kilograms of CO_2 equivalent of emissions from atmospheric CH_4 flux; CO_2 F, kilograms of CO_2 equivalent of emissions from atmospheric CO_2 flux; DU, kilograms of CO_2 equivalent emissions from diesel used; EF, kilograms of CO_2 equivalent of emissions from enteric fermentation; HS, kilograms of CO_2 equivalent of emissions from the hay surplus; N_2O F, kilograms of CO_2 equivalent of emissions from atmospheric N_2O flux; NP, kilograms of CO_2 equivalent of emissions from the nitrogen fertilizer production; PP, kilograms of CO_2 equivalent of emissions due to pesticide production.

Table 6. Annual Average Use of Pesticides by System, per Replication (~6 Hectares or 6 Animals)

System	Liters						Kilograms
	Roundup Original	Grazon P+D	Outrider	Gramoxone	Platoon	Malathion	Sevin 80WP
System 1	22.73	3.12	0.00	0.00	0.00	10.76	1.46
System 2	18.18	4.61	0.03	0.63	0.58	6.94	1.02
System 3	19.56	3.77	0.03	0.84	0.26	3.47	0.21

Notes: System 1 represents the simplest pasture system including Bermuda grass and ryegrass. System 2 includes a clover mix in addition to grasses in system 1, and system 3 includes sorghum-Sudan hybrid and soybean in addition to the forage in system 2.

fertilizer were used annually for systems 1, 2, and 3, respectively. Due to the higher use of nitrogen fertilizer in system 1, CO_2 produced through NP, CH_4 flux, and N_2O flux was highest in that system, which contributed to the highest GWP relative to the other pasture systems. Diesel consumption was highest in system 1 and lowest in system 3 due to higher machinery use for hay harvesting and nitrogen fertilizer application. On average, 724 liters, 548 liters, and 472 total liters of diesel were used annually for systems 1, 2, and 3, respectively. Therefore, CO_2 equivalent emission due to the use of diesel was highest in system 1 and lowest in system 3.

Four herbicides and two insecticides were used in the experiment. Annual average use of these pesticides per system is presented in the Table 6. The most heavily used pesticide was Roundup Original. On average, 23 liters, 18 liters, and 20 liters of Roundup Original were used in systems 1, 2, and 3, respectively. Outrider, Gramoxone, and Platoon were not used in system 1. Higher quantities of pesticides were used in system 1 than in systems 2 or 3. CO_2 equivalent emission from PP was greater in system 1 than in systems 2 and 3, due to greater pesticide use in system 1. Liebig et al. (2010) studied the impact of different grazing management strategies on GWP with three different grazing systems and found that heavily grazed and moderately grazed pastures had negative net GWP. Only the crested wheatgrass pasture had positive net GWP that differed significantly from two other systems. We cannot compare our results directly with theirs because they examined differences in soil organic carbon over a 50-year period.

Comparing profitability and GHG emissions, the following trade-offs are shown and presented in Table 7. System 3 had \$235 including labor expense (\$281 excluding labor expense) lower net profit per steer and 16,275 kg lower CO_2 equivalent GWP per steer than system 1. Thus, if reduced CO_2 equivalent emissions were valued at \$0.014/kg including labor expense (or \$0.017/kg excluding labor expense), then systems 1 and 3 would be economically

Table 7. Trade-Offs between the Three Systems, per Animal

Comparison among Systems	System 3 versus System 1	System 3 versus System 2	System 2 versus System 1
Difference in profit (without labor expense)	−\$281[a]	−\$212[a]	−\$69
Difference in profit (including labor expense)	−\$235[a]	−\$194[a]	−\$41
Difference in GWP CO_2 equivalent	−16,275 kg	−4,836 kg	−11,439 kg
Value of CO_2 to trade-off (without labor expense)	\$0.017/kg	\$0.044/kg	\$0.006/kg
Value of CO_2 to trade-off (including labor expense)	\$0.014/kg	\$0.040/kg	\$0.004/kg

[a] Statistically significant at $P < 0.05$.

Notes: System 1 represents the simplest pasture system including Bermuda grass and ryegrass. System 2 includes a clover mix in addition to grasses in system 1, and system 3 includes sorghum-Sudan hybrid and soybean in addition to the forage in system 2. Currency amounts are in US\$.

equivalent. Similarly, system 3 had \$194 including labor expense (\$212 excluding labor expense) lower net profit per steer and 4,836 kg lower CO_2 equivalent GWP per steer than system 2. Therefore, if reduced CO_2 equivalent emissions were valued at \$0.040/kg including labor expense (\$0.044/kg excluding labor expense), then systems 2 and 3 would be economically equivalent. System 2 had \$41 including labor expense (\$69 excluding labor expense) lower economic profit per steer than system 1, which was not statistically different, and 11,439 kg lower CO_2 equivalent GWP per steer than system 1. Thus, system 2 appears to dominate system 1 because it produced statistically equivalent economic profit but had lower GWP than system 1.

4. Conclusions

From a cost and returns point of view, placing no economic value on carbon emissions, the least complex GFB production systems in this study, systems 1 and 2, are more profitable than system 3. Under this scenario, there is no conclusive evidence that Bermuda grass and ryegrass combinations differ in profitability from the Bermuda grass, ryegrass, rye, Dallis grass, and clover mix (berseem, red, and white clovers) system. These two systems were found to be more profitable than the more complex system 3 with Bermuda grass/ryegrass, rye, Dallis grass and clover mix, soybean, and sorghum-Sudan hybrid. From a risk preference perspective, the more risk averse producers would choose system 2, whereas the less risk averse producers would choose system 1.

From an ecological view point considering GWP, the most complex system, system 3, is the most favorable because it produced less CO_2 equivalent GWP than the other two systems. System 1 produced the greatest CO_2 equivalent GWP. This is based on the arithmetic average of CO_2 equivalent emissions. Based on these results, the following trade-offs can be ascertained. If reduced CO_2 equivalent emissions were valued at $0.014/kg including labor expense (or $0.017/kg excluding labor expense), then systems 1 and 3 would be economically equivalent. Similarly, if reduced CO_2 equivalent emissions were valued at $0.040/kg including labor expense ($0.044/kg excluding labor expense), then systems 2 and 3 would be economically equivalent. System 2 may dominate system 1 because it produced statistically equivalent net profit and had numerically lower GWP than system 1. Similar valuations of carbon credits were conducted by Williams et al. (2004) to compare no-tillage with conventional tillage operations for 10 years. They estimated carbon credit values in the range of $0.0086/kg to $0.065/kg to make no-till and conventional tillage operations economically equivalent. Together, these results suggest that carbon credit values of >$0.014/kg would have the potential to entice significant change in the use of agricultural production practices.

When choosing a forage system, both profitability and GHG impacts can be considered. The findings of this study would be helpful in selecting appropriate pasture systems to fulfill the increasing demand for GFB. To understand the net carbon emissions of pasture management more thoroughly, further studies are suggested over longer time periods. Economic, social, and ecological sustainability aspects should be taken into consideration when implementing extension programs for GFB production. To draw final conclusions about the selection of appropriate pasture systems, farmers must consider the complexity of management at the farm level with additional fencing and labor requirements. Because this is an experimental study within a research station, additional study at the farm level would be appropriate to evaluate its widespread applicability. Further, a working paper by Torrico et al. (2014) found for some groups (but not others) higher sensory scores for meat produced in our most complex system, system 3. Here the higher sensory scores mean they liked system 3 beef better. This raises the question, if over time system 3 is shown to produce consistently higher sensory scores, will consumers be willing to pay premium prices for that beef such that the price for carbon would not have to be as high for producers to select system 3? This raises a rather complex question if the meats do not differ visually and do not grade differently and should be dealt with in further research.

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Appendix

Table A1. Specific Gravity and Active Ingredient of Pesticides

Pesticides	Specific Gravity	Active Ingredient	Percentage Active Ingredient
Roundup Original	1.36	Glyphosate	49
Grazon P+D	1.143	2,4-D + picloram	39.6 + 10.2
Gramoxone	1.13	Paraquat	43.8
Outrider	1.55	Sulfosulfuran	75
Platoon	1.161	Dimethylamine salt of 2,4-D	47.3
Malathion 57EC	1.0768	Malathion	57
Sevin 80WP	—	Carbaryl	80

Note: Specific gravity and percentage of active ingredient contained in pesticides are as per the material safety data sheets of the respective pesticides.