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COMPARISON OF COW-CALF PRODUCER NET RETURNS AND GREENHOUSE GAS EMISSIONS FROM CHANGES IN CALVING DISTRIBUTIONS IN THE SOUTHEAST TRANSITION ZONE

S. Aaron Smith, Ph.D. Student
Department of Agricultural Economics & Agribusiness
217 Agriculture Building, University of Arkansas
Fayetteville, AR 72701
Office: (479) 575-2530
Email: sas011@uark.edu

Michael Popp, Professor
Department of Agricultural Economics & Agribusiness
217 Agriculture Building, University of Arkansas
Fayetteville, AR 72701
Office: (479) 575-6838
Email: mpopp@uark.edu

D. Keeton, Masters Student
Department of Agricultural Economics & Agribusiness
217 Agriculture Building, University of Arkansas
Fayetteville, AR 72701
Office: (479) 575-6838
Email: drkeeton@email.uark.edu

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Abstract

A spreadsheet-based tool that tracks cow-calf producer net returns (*NR*) and greenhouse gas (*GHG*) emissions was used to determine the impact of calving season for three typical farm sizes and four fertilization strategies in Arkansas. Economic and environmental changes were examined for spring, fall, year-round, and profit-maximizing, monthly calving distributions.

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Introduction

Cow-calf industry stakeholders are under ongoing financial and political pressure to revise production methods to improve efficiencies both economically and environmentally. Volatile input and commodity prices combined with increased environmental regulations have created a need for improved farm-level decision aids to assist in evaluating different inputs and production methods. As such, a spreadsheet-based management decision tool was created for producers, extension agents, and educators to estimate the net return (*NR*) and greenhouse gas (*GHG*) emission changes for different cow-calf and forage management strategies and inputs. Since cow-calf and forage production methods vary dramatically by region, the tool was developed specifically for the Southeast transition zone of the United States, but parameters can be easily modified to represent forage and cow-calf production parameters for other regions. The tool uses a scan-level life-cycle-assessment (LCA) to determine interactions between various production parameters and inputs common to forage and cow-calf production in the region.

Producer responses to the 2012 University of Arkansas Cow-Calf Drought Survey (Smith et al., 2012a) revealed that cow-calf producers in Arkansas predominantly utilize four calving distributions: i) year-round; ii) fall; iii) spring; and iv) dual (spring and fall). Year-round calving is the most common strategy utilized by producers (50% of respondents) followed by dual (24%), spring (18%), and fall (7%). Year-round calving distributions do not result in the same percentage of calves born each month. Doye et al. (2008) reported the percentage of calves born in each month due to natural cycles for cow-calf operations using a year-round calving strategy (Table 1).

Modifying the forage species mix can lead to a seasonal forage growth distribution that more closely matches monthly animal nutritional requirements. Further, inclusion of nitrogen (N) fixing species can reduce commercial N fertilizer requirements (West and Waller, 2007). Hay and pasture species composition were assumed to consist of a combination of bermudagrass [Cynodon dactylon (L.) Pers.]), tall fescue (Lolium arundinaceum [Schreb.] Darbysh), and white clover (Trifolium repens L.). The specific species were selected to represent a warm-season grass, cool-season grass, and legume common to the Southeast transition zone. Crude protein (CP), total digestible nutrients (TDN), and dry matter (DM) production for the three forages were estimated from University of Arkansas Feedstuffs Database 20-Year Summary (UACES, 2009).

Cow-calf herd size in Arkansas varies dramatically from a few head to thousands. Land available to each operation is generally the limiting factor in cow-calf herd size. Purchasing hay and other feed supplements rather than growing one's own feedstuffs, can increase stocking rates, but is not considered a norm for the industry. Typical stocking rates in Arkansas are site and fertility-dependent and exhibit a large amount of variation. Producer responses to the 2012 the drought survey, for example, indicated stocking rates of 1.1 to 8.0 acres/cow with an average of 3.2 acres/cow (Smith et al., 2012a).

Using the *NR* and *GHG* emissions tool, the objectives of this analysis were to i) determine the *NR* maximizing calving distribution, hay and pasture species composition, and stocking rate for three operation sizes (small, medium, and large) using four fertilization strategies (lime only, low, medium, or high); and ii) compare the estimated *GHG* emissions from each *NR*-optimized scenario to operations of the same size and fertilization strategy using a fall (October), spring (April), and year-round calving distribution (Table 1).

Data and Methodology

Model Background

A tool was developed at the University of Arkansas to allow users to estimate *GHG* emissions and producer *NR* for cow-calf and forage operations in the Southeast transition zone. The tool allows producers, extension agents, and educators to enter operation-specific parameters to determine the *NR* and *GHG* emission changes from different input, management, agronomic, and economic variables. Additionally, the tool allows users to compare their operation to a benchmark farm of similar size, site characteristics, production methods, and inputs. Benchmark farms for each size were developed to assist with the comparison of a typical operation's performance with those of an operation where selected operating parameters were chosen using profit-maximizing, non-linear programming techniques available with expanded solver tools available via the Risk Solver Platform v9.5 spreadsheet addin to Excel® (Frontline Systems Inc, 2011).

Net Returns Maximization

This analysis maximizes enterprise *NR* by varying calving distribution, hay and pasture forage species composition, and stocking rate or number of bred cows grazed on the operation. Profit-maximizing scenarios (n) were estimated for three operation sizes using four fertilization strategies. Large, medium, and small operations were defined as containing 150, 60, and 0 acres of hay and 450, 180, and 120 acres of pasture, respectively. Annual fertilizer application was defined as: *Lime* – application of lime at pasture establishment prorated to an annual 0.1 tons/acre on pasture and hay land; *Low* – *Lime* + 0.5 and 0.25 tons/acre of poultry litter (3-2-3) on hay and pasture, respectively; $Medium - Lime$ + 1.0 tons/acre of poultry litter (3-2-3) and 100 lbs/acre ammonium nitrate (34-0-0) on hay and 0.50 tons/acre of poultry litter on pasture; and $High - Lime$ + 1.0 tons/acre of poultry litter (3-2-3), and 300 lbs/acre ammonium nitrate (34-0-0) on hay and 0.50 tons/acre of poultry litter, and 50 lbs/acre of ammonium nitrate (34-0-0) on pasture.

2011 prices (P) for commodities and inputs were assumed in the analysis. Cattle prices were the 2011 monthly average sale prices from sale barns in Arkansas for number one medium and large steer and heifer calves in 100 lb increments, breaking utility and commercial grade cull cows 75 to 80% lean, and yield grade 1-2, 1,000 to 2,100 lb bulls. Commercial fertilizer prices were the average farm price for selected fertilizers for 2011 (ammonium nitrate $479/ton, diammonium phosphate $703/ton, and potash $601/ton) reported by the United States Department of Agriculture Economic Research Service (USDA-ERS, 2012). Poultry litter prices were based on expert opinion and charged at $36/ton. Additional input prices are estimated from 2011 retail prices for Northwest Arkansas and expert opinion and shown as in the sample input screen of the tool presented in Figure 1.

Revenue streams resulted from five sources (Y); steer calves, heifer calves, culled cows, culled bulls, and excess hay. The quantities produced for each scenario were estimated using the default input quantities and production methods for the benchmark farm for each size and fertilization strategy with significant parameter values presented in the results. Costs (C) were estimated from default parameters and vary for each scenario. As such, the profit maximizing equation was as follows:

$$(1)\ \text{Maximize } NR_n = \sum_{i=1}^{5} P_{in} \cdot Y_{in} - C_n$$

Where:

NR_n	is the net returns for scenario n
P_{in}	is the 2011 average price for revenue source i (steer calf sales, heifer calf sales, culled cow sales, culled bull sales, and hay sales) for scenario n
Y_{in}	is the quantity produced in scenario n for each revenue source i
C_n	is the total cost for scenario n (total costs include direct costs, operating interest, and ownership charges)
n	is the scenario evaluated and ranges across three operation sizes each with four different fertilizer regimes discussed above

Subject to:

Number of Cows	$1 \leq$ Number of Cows $\leq 1{,}000$
Hay/Pasture Species Composition:	$0 \leq$ % Bermudagrass by area ≤ 70 $0 \leq$ % Fescue by area ≤ 70 $0 \leq$ % Clover by area ≤ 30 $\sum$ % Bermudagrass, Fescue, Clover ≤ 100
Calving distribution:	$0 \leq$ % calves each month ≤ 67 $\sum$ % calves by month $= 100$

Species composition was limited to a maximum of 70% fescue or bermudagrass and 30% clover as higher percentages in a typical pasture were deemed unrealistic by expert opinion. Integer constraints were added to eliminate solutions containing fractions of animals or species composition. Inputs and production decisions other than the choice variables were held constant for all scenarios.

GHG Emission Comparisons

GHG emissions for methane (CH_4), nitrous oxide (N_2O), and carbon dioxide (CO_2) produced from forage production, animals, and agricultural inputs were tracked in CO_2 equivalents (CO_2 eq). Methane and N_2O emissions were estimated in CO_2 eq. using their 100 year global warming potential (GWP) of 25 and 250 times that of CO_2 (IPCC, 2007). Sources of animal emissions (*j*) were: enteric fermentation (CH_4), respiration (CO_2) and urine and manure (N_2O). N_2O and CH_4 emissions were estimated using 2007 IPCC Tier II emission equations and CO_2 was estimated from Kirchgessner et al. (1991)(Appendix 1). Calculations for each animal group (cows, bulls, replacement heifers, steer calves, and heifer calves) are based on animal weight, crude protein, dry matter and energy intake by month. Emissions from forage production (*k*) on both pasture and hay acres are included. Agricultural input *GHG* emissions (*m*) are estimated from standard emission factors for fuel, fertilizer, N fertilizer N_2O emissions, and twine (Lal et al., 2004). As such, *GHG* emissions are estimated as:

$$(2)\ GHG_n = \sum_{j=1}^{3} GHGA_{jn} + \sum_{k=1}^{2} GHGF_{kn} + \sum_{m=1}^{4} GHGI_{mn}$$

where:

GHG_n	is the estimated CO_2 eq. GHG emissions from scenario *n*
$GHGA_{jn}$	is the CO_2 eq. GHG emissions produced from animals from source *j* for scenario *n*
$GHGF_{kn}$	is the CO_2 uptake of forages for photosynthesis by source *k* (hay or pasture) by scenario *n*
$GHGI_{mn}$	is the CO_2 eq. emissions produced from input *m* for scenario *n*

and the *GHG* emissions for the *n* scenarios were compared across the year-round, fall, and spring calving seasons, holding all other variables constant.

Results

Table 2 shows the profit-maximizing values for stocking rate, hay and pasture species composition, and calving distribution for the twelve farm size by fertilizer strategy combinations. Stocking rate (number of cows) increases for each operation size as the quantity of fertilizer applied to pasture and hay acres increases. Increased fertilizer applied results in greater forage production and consequently additional animal DMI requirements can be sustained on the same number of acres (acreage is held constant for each operation size).

Hay production was modeled on an annual time step and as such species were selected to maximize the annual DM production per acre. Hay species composition included bermudagrass, fescue, and clover that differed by fertilization strategy (Table 2). All scenarios contained the maximum allowable percentage of bermudagrass (70%). This result was anticipated as bermudagrass has the largest annual DM base production and N response of the forages modeled. Lime only and low fertilization scenarios maximized the allowable percentage of clover in the species composition as each percent of clover added one lb of N via nitrogen fixation which provided a sufficient increase in DM production from bermudagrass to crowd out fescue. At medium and high fertilizer application rates, however, the hay species composition replaced clover with fescue, as fescue produces greater quantities of DM compared to clover.

Pasture production was modeled on a monthly time step by breaking annual production into monthly intervals. Species composition was therefore selected not only to maximize monthly DM production but also to meet the DMI requirements for the cow-calf herd which would vary by calving distribution, weaning age, and animal group weights. The pasture species selection emphasizes the timing of species growth in addition to total DM production to meet periods of high DMI in the herd such as when cows are lactating or calves get closer to their weaning weight. As a result the species composition is more evenly distributed than the hay species composition as peak production by species varies by season. Clover percentage reaches a maximum (30%) for all scenarios except for high fertilizer strategies. Bermudagrss and fescue do not reach their maxima for any scenario. The mix of fescue and bermudagrass supports the notion that extending grazing periods through complementary warm and cool season forages provides improved *NR* to producers versus a pasture containing only one dominant species.

Selection of calving distribution for all scenarios was centered on a January /February calving period. The large farm with medium fertilizer application and small farm with high fertilizer application exhibited the possibility of a dual calving season (Table 2). Calving distribution and pasture species composition are closely linked as a change in one modifies the timing of grazing requirements which would influence pasture species composition.

Net returns for all operation sizes were greatest using the low-cost *Lime* fertilization strategy; \$19,347, \$4,029, and \$620 per farm for large, medium, and small operation sizes, respectively (Table 3). It is important to note that the results are specific to the default input parameters, site characteristics, and production methods and as such it should not be inferred that results are applicable to scenarios other than those specifically modeled. For large- and medium-sized operations the *High* fertilization strategy resulted in the next greatest *NR* per operation (\$14,898 and \$2,564), indicating high fertilizer costs were partially offset by increased hay and pasture production and increased stocking rates (increased cattle sales). Net returns per cow for each operation size decreased as fertilization strategy increased with the exception of medium size operations using the *Medium* (\$21/cow) and *High* (\$23/cow) fertilization strategies. Since total acres for each operation size was fixed, \$/acre produced the same scenario ordering as total operation returns.

Table 4 shows the source (calf sales, culled breeding stock, fertilizer, and hay purchased) of *NR* changes for each scenario. Fertilizer costs and animal sales revenue increase with fertilizer strategy due to increased quantity applied and increased stocking rate, respectively. In general hay purchases decreased as fertilization increased for medium and large operations. For small operations hay purchased increased as fertilizer strategy increased, as increased stocking rate resulted in additional hay purchases during periods when hay needed to be fed (no hay acres are estimated for small operations).

GHG emissions (total, lbs/cow, and lbs/acre) increased as fertilizer application and stocking rate increased (Table 3). In general, emissions per cow reduced as operation size increased, indicating improved production efficiency (e.g. greater average # of cows/bull given a limit of 30 cows/bull) with increasing operation size. Table 5 shows the percentage change in *NR* and *GHG* emissions from the profit maximizing solution shown in Tables 2 to 4 by changing only calving distribution. Moving calving distribution from the optimal to fall calving resulted in a greater decreases in *NR* and increases in *GHG* emissions than moving to a year-round or spring calving distribution for all 12 scenarios. Decreased *NR* and increased *GHG* emissions was due to a less efficient matching of grazed forage growth and animal DMI requirements. Of note, however, is that simulations did not account for the impact of fescue toxicosis which can adversely affect breeding failures and animal weight gains specifically in herds using a spring calving distribution (Smith et al.,2012b; Caldwell et al., 2012) . Also, a producer may modify their pasture species composition when switching calving season which would lessen the impact of calving season change.

Conclusions and Discussion

Results showcase the extent of variability in *GHG* emissions and *NR* estimated across operation size and fertilization strategy. Results suggest that fall calving is economically disadvantageous compared to spring and year-round calving and also leads to higher *GHG* emissions. These results are specific to the inputs, site characteristics, and production methods modeled. The spreadsheet tool was designed to allow for producer specific comparisons between benchmark and modified production practices on both economic and environmental tradeoffs. As modeled within, changing calving distribution in the southeastern United States has the potential to reduce the *GHG* emissions and improve producer *NR*.

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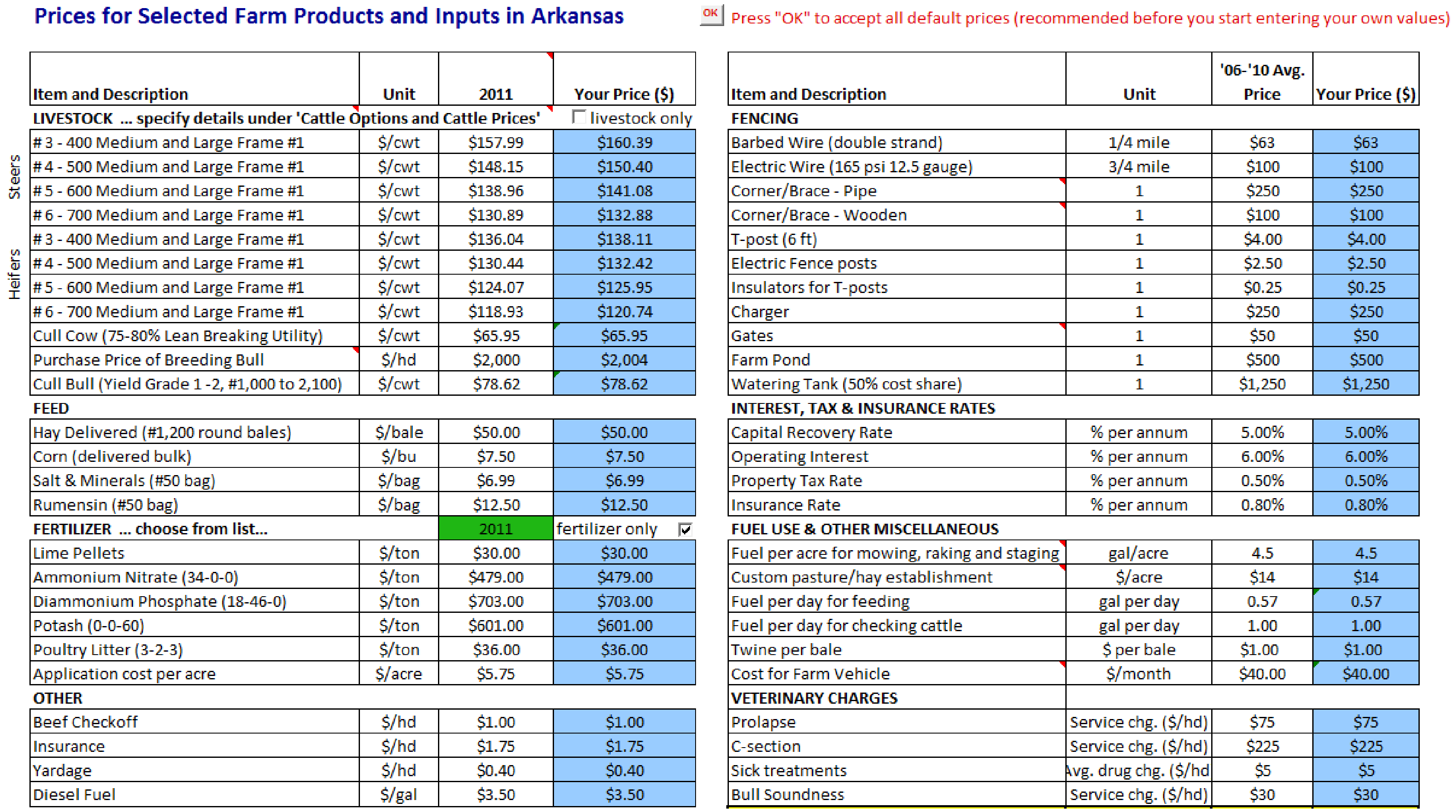
Figure 1. Input cost selection screen of the spreadsheet tool used for evaluating calving distribution differences.



Prices for Selected Farm Products and Inputs in Arkansas

OK Press "OK" to accept all default prices (recommended before you start entering your own values)

	Item and Description	Unit	2011	Your Price ($)
	LIVESTOCK ... specify details under 'Cattle Options and Cattle Prices'			☐ livestock only
Steers	# 3 - 400 Medium and Large Frame #1	$/cwt	$157.99	$160.39
	# 4 - 500 Medium and Large Frame #1	$/cwt	$148.15	$150.40
	# 5 - 600 Medium and Large Frame #1	$/cwt	$138.96	$141.08
	# 6 - 700 Medium and Large Frame #1	$/cwt	$130.89	$132.88
Heifers	# 3 - 400 Medium and Large Frame #1	$/cwt	$136.04	$138.11
	# 4 - 500 Medium and Large Frame #1	$/cwt	$130.44	$132.42
	# 5 - 600 Medium and Large Frame #1	$/cwt	$124.07	$125.95
	# 6 - 700 Medium and Large Frame #1	$/cwt	$118.93	$120.74
	Cull Cow (75-80% Lean Breaking Utility)	$/cwt	$65.95	$65.95
	Purchase Price of Breeding Bull	$/hd	$2,000	$2,004
	Cull Bull (Yield Grade 1 -2, #1,000 to 2,100)	$/cwt	$78.62	$78.62
	FEED			
	Hay Delivered (#1,200 round bales)	$/bale	$50.00	$50.00
	Corn (delivered bulk)	$/bu	$7.50	$7.50
	Salt & Minerals (#50 bag)	$/bag	$6.99	$6.99
	Rumensin (#50 bag)	$/bag	$12.50	$12.50
	FERTILIZER ... choose from list...		2011	fertilizer only ☑
	Lime Pellets	$/ton	$30.00	$30.00
	Ammonium Nitrate (34-0-0)	$/ton	$479.00	$479.00
	Diammonium Phosphate (18-46-0)	$/ton	$703.00	$703.00
	Potash (0-0-60)	$/ton	$601.00	$601.00
	Poultry Litter (3-2-3)	$/ton	$36.00	$36.00
	Application cost per acre	$/acre	$5.75	$5.75
	OTHER			
	Beef Checkoff	$/hd	$1.00	$1.00
	Insurance	$/hd	$1.75	$1.75
	Yardage	$/hd	$0.40	$0.40
	Diesel Fuel	$/gal	$3.50	$3.50

Item and Description	Unit	'06-'10 Avg. Price	Your Price ($)
FENCING			
Barbed Wire (double strand)	1/4 mile	$63	$63
Electric Wire (165 psi 12.5 gauge)	3/4 mile	$100	$100
Corner/Brace - Pipe	1	$250	$250
Corner/Brace - Wooden	1	$100	$100
T-post (6 ft)	1	$4.00	$4.00
Electric Fence posts	1	$2.50	$2.50
Insulators for T-posts	1	$0.25	$0.25
Charger	1	$250	$250
Gates	1	$50	$50
Farm Pond	1	$500	$500
Watering Tank (50% cost share)	1	$1,250	$1,250
INTEREST, TAX & INSURANCE RATES			
Capital Recovery Rate	% per annum	5.00%	5.00%
Operating Interest	% per annum	6.00%	6.00%
Property Tax Rate	% per annum	0.50%	0.50%
Insurance Rate	% per annum	0.80%	0.80%
FUEL USE & OTHER MISCELLANEOUS			
Fuel per acre for mowing, raking and staging	gal/acre	4.5	4.5
Custom pasture/hay establishment	$/acre	$14	$14
Fuel per day for feeding	gal per day	0.57	0.57
Fuel per day for checking cattle	gal per day	1.00	1.00
Twine per bale	$ per bale	$1.00	$1.00
Cost for Farm Vehicle	$/month	$40.00	$40.00
VETERINARY CHARGES			
Prolapse	Service chg. ($/hd)	$75	$75
C-section	Service chg. ($/hd)	$225	$225
Sick treatments	vg. drug chg. ($/hd	$5	$5
Bull Soundness	Service chg. ($/hd)	$30	$30

Table 1. Estimated year-round calving distribution by percentage of calves born in each month, adopted from Doye et al., 2008.

Month	Percentage of Calves Born
January	15
February	18
March	14
April	9
May	5
June	5
July	3
August	3
September	8
October	8
November	8
December	4

Table 2. Estimated, profit-maximizing number of cows, hay and pasture species composition and calving distribution across three operation sizes using four fertilization strategies in the Southeast transition zone.

			% Species Composition [c]													
			Hay			Pasture			Calving Distribution (%) [d]							
Size [a]	Fertilizer [b]	# cows	B	F	C	B	F	C	J	F	M	A	M	J	N	D
Large	Lime	180	70	-	30	39	31	30	28	67	-	-	-	-	-	5
	Low	197	70	-	30	41	29	30	34	66	-	-	-	-	-	-
	Medium	208	70	30	-	35	36	29	28	59	-	-	-	4	2	7
	High	270	70	30	-	38	62	-	26	67	5	-	2	-	-	-
Medium	Lime	75	70	-	30	45	25	30	38	62	-	-	-	-	-	-
	Low	78	70	-	30	37	33	30	33	67	-	-	-	-	-	-
	Medium	78	70	30	-	33	37	30	33	67	-	-	-	-	-	-
	High	112	70	30	-	37	63	-	67	29	-	-	-	-	-	4
Small	Lime	47	not applicable			38	32	30	33	67	-	-	-	-	-	-
	Low	58				49	21	30	38	62	-	-	-	-	-	-
	Medium	58				37	33	30	37	63	-	-	-	-	-	-
	High	78				41	59	-	40	47	1	7	-	1	3	1

[a] Farm sizes are estimated based on pasture and hay acres in each operation. Operation land bases are defined as follows: *Large* - 150 acres of hay and 450 acres of pasture; *Medium*- 60 acres of hay and 180 acres of pasture; and *Small* – 0 acres of hay and 120 acres of pasture.

[b] Fertilization strategies are defined as: *Lime* – application of lime at pasture establishment prorated to an annual 0.1 tons/acre on pasture and hay land; *Low* – *Lime* + 0.5 and 0.25 tons/acre of poultry litter (3-2-3) on hay and pasture, respectively; *Medium* – *Lime* + 1.0 tons/acre of poultry litter (3-2-3) and 100 lbs/acre ammonium nitrate (34-0-0) on hay and 0.50 tons/acre of poultry litter on pasture; and *High* – *Lime* + 1.0 tons/acre of poultry litter (3-2-3), and 300 lbs/acre ammonium nitrate (34-0-0) on hay and 0.50 tons/acre of poultry litter, and 50 lbs/acre of ammonium nitrate (34-0-0) on pasture.

[c] Species composition is the percentage of B-bermudagrass; F- tall fescue; and C- clover on pasture and hay acres by area. The three species should sum to 100% and do not account for volunteer species or weeds.

[d] Calving distribution is the percentage of total calves born in each month. July through September is not included as the optimum did not contain percentages in these months.

Table 3. Estimated, profit-maximizing net returns and GHG emissions across three operation sizes using four fertilization strategies in the Southeast transition zone, 2013.

		Net Returns(*NR*) [c]			GHG Emissions [d]			% Change [e]	
Size [a]	Fertilizer [b]	Total ($)	$/Cow	$/Acre	Total (Tons)	lbs/Cow	lbs/Acre	GHG	NR
Large	Lime	19,347	107	32	434	4,822	1,447	-	-
	Low	14,786	75	25	530	5,384	1,768	22	-24
	Medium	14,401	69	24	613	5,896	2,044	41	-26
	High	14,898	55	25	875	6,480	2,916	102	-23
Medium	Lime	4,029	54	17	190	5,055	1,580	-	-
	Low	2,207	28	9	211	5,421	1,762	12	-45
	Medium	1,602	21	7	226	5,785	1,880	19	-60
	High	2,564	23	11	384	6,862	3,202	103	-36
Small	Lime	620	13	5	131	5,574	2,183	-	-
	Low	(589)	(10)	(5)	180	6,193	2,993	37	-195
	Medium	(746)	(13)	(6)	185	6,365	3,076	41	-220
	High	(1,213)	(16)	(10)	272	6,971	4,531	108	-296

[a] Farm sizes are estimated based on pasture and hay acres in each operation. Operation land bases are defined as follows: *Large* - 150 acres of hay and 450 acres of pasture; *Medium*- 60 acres of hay and 180 acres of pasture; and *Small* – 0 acres of hay and 120 acres of pasture.

[b] Fertilization strategies are defined as: *Lime* – application of lime at pasture establishment prorated to an annual 0.1 tons/acre on pasture and hay land; *Low* – *Lime* + 0.5 and 0.25 tons/acre of poultry litter (3-2-3) on hay and pasture, respectively; *Medium* – *Lime* + 1.0 tons/acre of poultry litter (3-2-3) and 100 lbs/acre ammonium nitrate (34-0-0) on hay and 0.50 tons/acre of poultry litter on pasture; and *High* – *Lime* + 1.0 tons/acre of poultry litter (3-2-3), and 300 lbs/acre ammonium nitrate (34-0-0) on hay and 0.50 tons/acre of poultry litter, and 50 lbs/acre of ammonium nitrate (34-0-0) on pasture.

[c] Net returns are the estimated returns to land, management, owner's equity and labor for each operation size and fertilization strategy. Results are shown in total per operation, $/bred cow, and $/acre (pasture + hay acres).

[d] GHG emissions are estimated from animal emissions, forage production, and agricultural input use. Agricultural inputs include the upstream production of fertilizer and twine. Total emissions for the operation (tons), lbs/bred cow, and lbs/acre (hay + pasture acres) are shown.

[e] Percentage change in GHG and NR is the percentage change in net returns and GHG emissions from the lime only fertilizer option for each farm size.

Table 4. Estimated change in hay purchased (tons), calf sales ($), culled breeding stock ($), fertilizer cost ($), and hay purchased ($) across three operation sizes using four fertilization strategies in the Southeast transition zone, 2013.

				% Change [c]			
Size [a]	Fertilizer [b]	Stocking Rate (Cows/Acre)	Hay Purchased (Tons)	Calf Sales ($)	Culled Breeding Stock ($)	Fertilizer Cost ($)	Hay Purchased ($)
Large	Lime	0.40	170	-	-	-	-
	Low	0.44	177	9	11	383	4
	Medium	0.46	112	15	18	804	-34
	High	0.60	99	49	51	1710	-42
Medium	Lime	0.42	76	-	-	-	-
	Low	0.43	64	3	5	383	-16
	Medium	0.43	24	3	5	804	-68
	High	0.62	47	47	51	1710	-38
Small	Lime	0.39	87	-	-	-	-
	Low	0.48	121	24	14	332	38
	Medium	0.48	112	24	14	535	28
	High	0.65	150	66	54	1340	72

[a] Farm sizes are estimated based on pasture and hay acres in each operation. Operation land bases are defined as follows: *Large* - 150 acres of hay and 450 acres of pasture; *Medium*- 60 acres of hay and 180 acres of pasture; and *Small* – 0 acres of hay and 120 acres of pasture.

[b] Fertilization strategies are defined as: *Lime* – application of lime at pasture establishment prorated to an annual 0.1 tons/acre on pasture and hay land; *Low* – *Lime* + 0.5 and 0.25 tons/acre of poultry litter (3-2-3) on hay and pasture, respectively; *Medium* – *Lime* + 1.0 tons/acre of poultry litter (3-2-3) and 100 lbs/acre ammonium nitrate (34-0-0) on hay and 0.50 tons/acre of poultry litter on pasture; and *High* – *Lime* + 1.0 tons/acre of poultry litter (3-2-3), and 300 lbs/acre ammonium nitrate (34-0-0) on hay and 0.50 tons/acre of poultry litter, and 50 lbs/acre of ammonium nitrate (34-0-0) on pasture.

[c] Percentage change in calf sales and culled breeding stock sales are changes in gross revenue for each scenario from the lime only fertilizer option. Fertilizer cost and hay purchased are changes in expenses $ per operation from the lime only fertilizer option.

Table 5. Percentage change in net returns and GHG emissions from an estimated, profit-maximizing operation using optimum forage species and calving season across three operation sizes and four fertilization strategies.

Size [a]	Fertilizer [b]	Optimum Forage Species and Calving Season [c]		Deviation from Optimal with Modified Calving Season (in %) [d]					
				Year-round		*Spring*		*Fall*	
		NR ($)	GHG (Tons)	NR	GHG	NR	GHG	NR	GHG
Large	Lime	19,347	434	(5.6)	6.4	(5.3)	5.5	(13.6)	11.0
	Low	14,786	530	(8.0)	5.6	(10.6)	4.8	(23.8)	9.7
	Medium	14,401	613	(7.5)	4.4	(7.3)	3.7	(20.4)	8.2
	High	14,898	875	(11.0)	4.8	(14.4)	4.1	(32.7)	8.2
Medium	Lime	4,029	190	(10.5)	5.3	(14.0)	4.5	(32.0)	9.7
	Low	2,207	211	(19.7)	5.7	(19.4)	4.9	(42.7)	9.8
	Medium	1,602	226	(29.0)	5.3	(28.6)	4.6	(60.7)	9.2
	High	2,564	384	(22.0)	0.1	(32.9)	0.5	(70.2)	3.4
Low	Lime	620	131	(41.7)	5.5	(43.2)	4.8	(85.8)	9.5
	Low	(589)	180	(42.3)	4.4	(67.7)	3.7	(151.5)	8.0
	Medium	(746)	185	(42.8)	4.4	(43.3)	3.7	(94.7)	7.9
	High	(1,213)	272	(28.6)	2.6	(42.5)	2.0	(102.6)	5.8

[a] Farm sizes are estimated based on pasture and hay acres in each operation. Operation land bases are defined as follows: *Large* - 150 acres of hay and 450 acres of pasture; *Medium*- 60 acres of hay and 180 acres of pasture; and *Small* – 0 acres of hay and 120 acres of pasture.

[b] Fertilization strategies are defined as: *Lime* – application of lime at pasture establishment prorated to an annual 0.1 tons/acre on pasture and hay land; *Low* – *Lime* + 0.5 and 0.25 tons/acre of poultry litter (3-2-3) on hay and pasture, respectively; *Medium* – *Lime* + 1.0 tons/acre of poultry litter (3-2-3) and 100 lbs/acre ammonium nitrate (34-0-0) on hay and 0.50 tons/acre of poultry litter on pasture; and *High* – *Lime* + 1.0 tons/acre of poultry litter (3-2-3), and 300 lbs/acre ammonium nitrate (34-0-0) on hay and 0.50 tons/acre of poultry litter, and 50 lbs/acre of ammonium nitrate (34-0-0) on pasture.

[c] Optimum calving distribution and production parameters are shown in Table 2 and result in thousands of dollars and tons of GHG emissions per farm as in Table 3.

[d] Deviations from the profit-maximizing forage species and calving season production scenario when modifying calving distribution to *Year-round* as in Table 1, *Spring* – March born calves and *Fall* – October born calves and holding all other variables constant.

Appendix 1. GHG emissions equations used in estimating emissions from each herd for each operation size and fertilization strategy adapted from Kirchgessner et al. and IPCC.

Emissions from animal respiration:

$ECO_{2\ \text{animal}} = -1.4 + 0.42 \times M_{DMI} + 0.045 \times M_{BW}^{0.75}$

where:

$ECO_{2\ \text{animal}}$	is defined as emissions of CO_2 from animal respiration (kg CO_2 cow^{-1} day^{-1})
M_{DMI}	is defined as daily intake of feed dry matter for each animal (kg DM cow^{-1} day^{-1})
M_{BW}	is defined as the animal's body weight (kg)

Emissions from enteric fermentation:

$CH_{4\ E} = (NE_m \times Y_m \times \text{Number of days}) \div 55.65$

$NE_m = 0.322 \times M_{BW}^{0.75}$

where:

NE_m	is mega joules (MJ) of energy intake per day required to maintain the animal's weight
Y_m	is a constant of 0.06
55.65	is the MJ per kg of methane

Emissions from urine and manure:

$N_{ex} = N_{intake} \times (1 - N_{retention})$

$N_2O = CP_{intake} \times N_{CP} \times (1 - N_{retention}) \times N_2O_{Nex} \times M_{BW} \times \text{Number of Days}$

where:

N_{ex}	is defined as the N excretion rates per kg of live animal weight
N_{intake}	is defined as the N intake per kg of live animal weight
$N_{retention}$	is defined as the fraction of N retained by animal, assumed to be constant of 0.07 based on the IPCC constant for animal group
CP_{intake}	is defined as the crude protein intake required for each animal group
N_{CP}	is defined as the N intake as a percentage of crude protein, assumed to be a constant of 0.16
N_2O_{Nex}	is defined as the amount of N_2O per kg of N excreted, assumed to be a constant of 0.02

Total animal emissions for a representative herd:

$$CO_{2\ \text{animals}} = \sum_{i=1}^{12}\sum_{j=1}^{5}\sum_{n=1}^{4}\left(-1.4 + 0.42 \text{ x } M_{\text{DMI}} + 0.045 \text{ x } M_{\text{BW}} \wedge 0.75\right)$$

$$N_2O_{\text{animals}} = \sum_{i=1}^{12}\sum_{j=1}^{5}\sum_{n=1}^{4}\left(CP_{\text{intake}} \text{ x } N_{\text{CP}} \text{ x } (1 - N_{\text{retention}}) \text{ x } N_2O_{\text{Nex}} \text{ x } M_{\text{BW}} \text{ x } \#\text{Days}\right)$$

$$CH_{4\ \text{animals}} = \sum_{i=1}^{12}\sum_{j=1}^{5}\sum_{n=1}^{4}\left((NE_m \text{ x } Y_m \text{ x } \#\text{ days}) \div 55.65\right)$$

Net animal emissions $= CO_{2\ \text{animals}} + N_2O_{\text{ animals}} \text{ x } 298 + CH_{4\ \text{animals}} \text{ x } 25$