Climate change mitigation through intensified pasture management

Estimating greenhouse gas emissions on cattle farms in the Brazilian Amazon

Working Paper No. 188

CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS)

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Contact:
CCAFS Coordinating Unit - Faculty of Science, Department of Plant and Environmental Sciences, University of Copenhagen, Rolighedsvej 21, DK-1958 Frederiksberg C, Denmark. Tel: +45 35331046; Email: ccafs@cgiar.org

Abstract

Cattle ranching in Brazil is a key driver of deforestation and greenhouse gas (GHG) emissions. The Brazilian government plans to reduce national GHG emissions by at least 36%, partly by reducing emissions in the livestock sector through strategies such as intensification, pasture improvement, and rotational grazing. We surveyed 40 cattle ranchers located in the Brazilian Amazon biome to investigate how GHG emissions differed between farms participating in livestock sustainability programs with intensified production and farms not participating in these programs. We found that participating farms produced 8.3 kg of CO_2e/kg of beef than did non-participating farms, which represents 19% fewer emissions. Farms that had participated in a sustainability program for at least two years showed larger differences in emissions: 19.0 kg of CO_2e/kg of beef less for program farms compared with their counterparts, or 35.8% fewer emissions. Key drivers of the total CO_2e/kg of beef in all farms were enteric fermentation and manure management. This paper provides farm-level data supporting intensification as a possible strategy to reduce emissions per kilogram of beef produced, and suggests implications for policy and future research.

Keywords

Amazonia; beef; Brazil; cattle; certification; climate change; greenhouse gas emissions; intensification; livestock; mitigation; pasture improvement; rotational grazing; sustainability

About the authors

Meghan Bogaerts is a graduate student at the University of Michigan in the School of Natural Resources and Environment and the Gerald R. Ford School of Public Policy. She can be reached at mbogaerts@gmail.com.

Lora Cirhigiri is a graduate student at the University of Michigan in the Gerald R. Ford School of Public Policy. She can be reached at lora.nels@gmail.com.

Ian Robinson is a graduate student at the University of Michigan in the School of Natural Resources and Environment and the Stephen M. Ross School of Business. He can be reached at irobi@umich.edu.

Mikaela Rodkin is a graduate student at the University of Michigan in the School of Natural Resources and Environment and the Stephen M. Ross School of Business. She can be reached at marodkin@umich.edu.

Reem Hajjar was a postdoctoral fellow at the University of Michigan at the time of research. Currently, she is an Assistant Professor at Oregon State University, and can be reached at the Department of Forest Ecosystems and Society, College of Forestry, Oregon State University, Richardson Hall 350, Corvallis, Oregon 97333 USA, or reem.hajjar@oregonstate.edu.

Ciniro Costa Junior is a climate change and agriculture analyst at the Brazilian nongovernmental organization Instituto de Manejo e Certificação Florestal e Agrícola (Imaflora). He can be reached at Imaflora, Estrada Chico Mendes, 185. CEP: 13426 420. Piracicaba – SP, Brazil, or ciniro@imaflora.com.

Peter Newton is an Assistant Professor at University of Colorado, Boulder. He can be reached at Environmental Studies Program, Sustainability, Energy and Environment Complex, University of Colorado Boulder, UCB 397, 4001 Discovery Drive, Boulder, Colorado 80303 USA, or peter.newton@colorado.edu.

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Contents

Acronyms

CH_4	Methane
CO_2	Carbon dioxide
EX-ACT	EX-Ante Carbon Balance Tool
FAO	Food and Agriculture Organization of the United Nations
GHG	Greenhouse gas
IBGE	Instituto Brasileiro de Geografia e Estatística
IPCC	Intergovernmental Panel on Climate Change
MAPA	Ministério da Agricultura, Pecuária e Abastecimento
MCTI	Ministério de Ciência, Tecnologia e Inovação
N_2O	Nitrous oxide
PNMC	Politica Nacional Sobre Mudança do Clima
SAN	Sustainable Agriculture Network
WRI	World Resources Institute

1. Introduction

Brazil is the world's second largest producer of beef—9.68 million tonnes in 2013—and production is predicted to increase to 11.4 million tonnes by 2025 (FAOSTAT 2016; MAPA 2015). As the industry has risen in prominence and economic importance, modern pressures related to social and environmental sustainability have matched pace. In particular, Brazil faces major international pressure to reduce greenhouse gas (GHG) emissions, of which livestock production contributes roughly 18% to annual totals (Ruviaro et al. 2015; MCTI 2013). Linkages have also been made between the expansion of cattle ranching since the 1970s and increased deforestation. Brazilian cattle herds have nearly tripled since 1970 (IBGE 2016), in part as a result of policies promoting agricultural expansion and development activity in the Cerrado (Brazilian savannah) and Amazonian frontier (McAlpine et al. 2009). Though complex, the relationship between cattle ranching and deforestation has created further urgency in the industry to evolve in response. Recent commitments made by the Brazilian national government to reduce GHG emissions by 37% by 2025 (from 2005 levels) have further underscored the need to understand the relationship between cattle production and emissions, including emissions attributable both to deforestation and to production practices (Federated Republic of Brazil 2015; Cerri et al. 2010).

The economic potential of the cattle sector has also spurred desire for innovation in technologies and practices that will increase sophistication and competitiveness in the world market. Traditional cattle-raising practice in Brazil is low input, characterized by large open pastures that are often degraded by unchecked grazing (Cerri et al. 2016). Intensification of cattle production has gained traction as a potential solution to the problem of meeting both increased production and decreased emission goals for a reasonable cost (Palermo, d'Avignon, and Freitas 2014; Teixeira and Abreu da Silva 2007). Intensification in Brazil is generally understood to mean "moderate intensification," which uses a system that is still based primarily on pasture-fed cattle. Intensification in this context often includes two sets of strategies: (1) pasture management practices designed to increase quality and quantity of forage, typically using soil inputs and rotational grazing; and (2) the use of feed lots and supplements for the final stages of cattle's lives (Latawiec et al. 2014). The main goals of both strategies include increasing stocking rates and decreasing the age of slaughter, both of which typically yield higher profits for producers and have the potential to decrease emissions from both land use change and enteric fermentation (Dick, Silva, and Dewes 2015; Undersander 2014).

Cattle intensification strategies are therefore an attractive central component of several new livestock sustainability programs and certification options that were created to induce producers to increase productivity while decreasing environmental impacts. Sustainability programs have made inroads into other sectors such as coffee, Brazil nuts, and biofuels (Potts et al. 2014; Duchelle, Kainer, and Wadt 2014; Scarlatt and Dallemand 2011), yet progress in the cattle sector has lagged due to lack of market demand, little or no price premium, and the complexities of assessing livestock operations in comparison with annual crops. There is some evidence that this may be changing (Alves-Pinto, Newton, and Pinto 2013).

Limited empirical information is available to indicate how undertaking intensification practices affects the balance of GHG emissions at the farm level. This paper seeks to contribute to an emerging body of literature using farm-level data to relate individual producer practices to resultant emissions (Dick, Silva, and Dewes 2015; Cerri et al. 2016). Our paper complements and expands on recent work by relating drivers of emissions and resultant emission profiles to participation in a sustainability program. The objective of this study was to answer the question: Does the farm-level balance of GHG emissions related to raising cattle differ between farms that do and do not participate in a sustainability program or sustainability certification?

2. Methods

2.1 Description of sustainability programs

We identified sustainability programs that worked with farmers to adopt best management practices for beef cattle in the Amazon biome. We identified four sustainability programs and one sustainability certification program with specific criteria for beef cattle and active operations in the Brazilian Amazon region (table 1).

Common to all five programs was a focus on improving cattle productivity through increased stocking rates and lower slaughter age, as well as pasture management techniques such as pasture rehabilitation and rotational grazing. All programs provided technical assistance, though this varied widely by initiative. And although all programs were designed for cattle herds raised primarily on pasture, some participating farms also contained confined feeding operations for the finishing stage. Each program had differing requirements and recruitment strategies for identifying farms that would participate in the programs, though generally program staff worked through existing local relationships and networks. All programs supported avoiding further deforestation. All farmers changed their practices in response to program participation; but those who did not typically were already engaged in those practices before joining the program. Major changes in practices included rotational grazing, protein supplements in the animal diet, and the use of lime and fertilizer in the grazing area. Two programs additionally included extensive criteria beyond intensification strategies, spanning topics such as social welfare of workers, animal well-being, and environmental factors outside of the pasture area.

2.2 Study sites and farm selection

Our research sampled 40 beef cattle farms in five municipalities in different parts of the Brazilian Amazon using site visits and interviews with the owners and managers (figure 1). In Brazil, beef cattle are raised in all 27 states (Latawiec et al. 2014); however, production in the traditional states of the south and southwest has slowed in favor of increased production in the Cerrado and Amazon regions in the middle and northern parts of the country (McManus et al. 2016). Despite the smaller contribution of Amazonian beef to overall supply—37% of the total Brazilian herd— as compared with Cerrado-raised beef, we focus here on the Amazonian cattle industry because it has historically been associated with high rates of deforestation and is trending toward a larger share of total Brazilian beef production (Walker, Patel, and Kalif 2013). The expanding frontier edge of development and increasing infrastructure in the Amazon region make it particularly vulnerable to continued land use change.

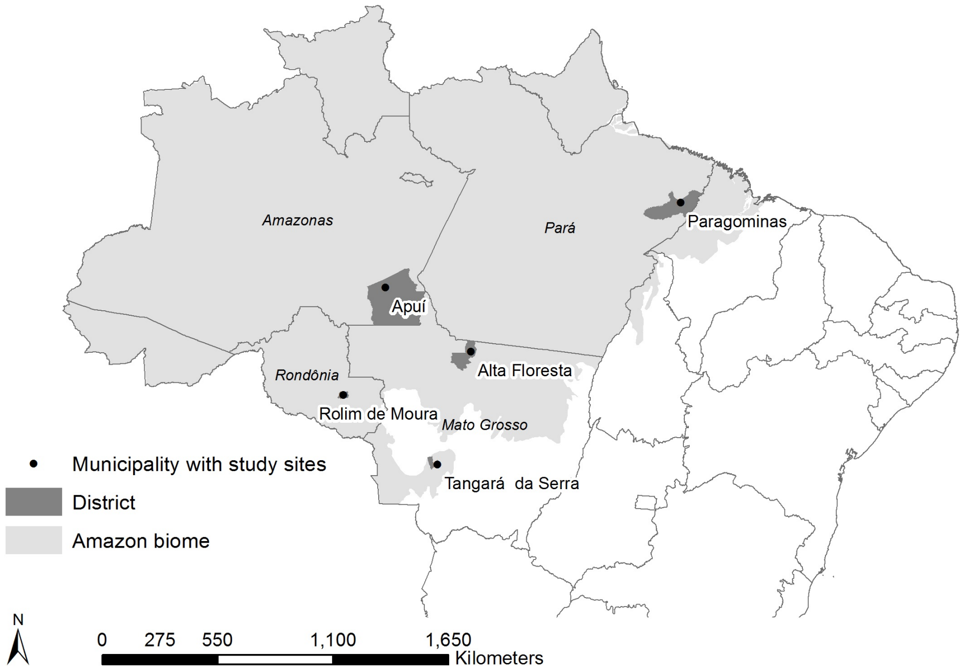

Figure 1. Municipalities where the surveyed farms were located within the Amazon biome.

Of the 40 sampled beef cattle farms, we interviewed 19 farmers who were participating in a sustainability program or certification and 21 farmers who were not participating in any such program. All farms in the sample primarily raised beef cattle using pasture-based systems and were located within the Amazon biome. We worked with program staff to connect with producers involved in the sustainability programs of interest; they were able to provide contact information and introductions to farmers. With program staff assistance, we then surveyed approximately the same number of non-program farmers in each study site area. We qualitatively assessed comparability of program and non-program farms at each study site based on size of operation, geographic proximity, and type of operation (i.e., primarily beef cattle raised on pasture, not confined feeding operations only) to ensure that program and non-program farms were as similar as possible in these respects. We were able to interview approximately the same number of participating and non-participating farms in each municipality. The exception was Tangará da Serra, Mato Grosso, where we could not find a non-participating farm comparable to the Sustainable Agriculture Network (SAN)-certified farm. Interviews were conducted with either farm owners or managers, all of whom were involved in day-to-day operations of the cattle portion of the farm.

Table 1. Summary of the five sustainability initiatives included in this study

Intervention	Administering Organization(s)	Location (municipality, state)	Dates of Implementation	Total Number of Participating Cattle Farms	Number Surveyed	Description of Intervention
Novo Campo Project	Instituto Centro de Vida	Alta Floresta, Mato Grosso	2012-present	15 (aim to increase to 300 in next few years)	7	• Technical support and some supplies paid at 50% • About 32 ha intensified per farm
Rondônia Intensification Program	Imaflora, Vida Verde, Marfrig Global Foods	Rolim de Moura, Rondônia	2013-present	4	3	• Technical support covered by program for pilot farmers to intensify about 32 ha
Silvipastoral Program	Instituto de Conservação e Desenvolvimento Sustentável do Amazonas (IDESAM)	Apuí, Amazonas	2014-present	8	4	• Technical support to intensify at least 4 ha and plant trees between intensified areas • Small loan scheme proposed • Focus on milk and beef production
Pecuária Verde Program	Sindicato Rural de Produtores Rurais de Paragominas	Paragominas, Pará	2011-2014	6	4	• Technical support to intensify as many hectares as preferred by farmers • Farm management and animal well-being components
SAN Standard for Sustainable Cattle Production Systems	Imaflora and SAN-Rainforest Alliance certified	Tangará da Serra, Mato Grosso	2011-present	1 (physically two properties under the same owner)	1	• Regular audit and certification (includes social, environmental, animal welfare considerations)

2.3 Survey development and administration

The owner or manager of each farm was surveyed from June to July 2015 regarding on-farm practices related to pasture management and beef production. Questions included owner demographics, herd characteristics, fertilizer and pesticide use, pasture characteristics and management, annual production, and anticipated future changes to farm management. Surveys were conducted in person and in Portuguese, aided by two native Portuguese speakers from the University of São Paulo. Producers who had no detailed data on hand during the survey were asked to provide the data in follow-up conversations. Therefore, in the months following survey administration, follow-up phone calls with producers were conducted to fill missing data gaps.

2.4 Emissions calculator selection

A few dozen GHG emission calculation tools are currently available to estimate emissions from agricultural operations or projects. Many are specific to a particular crop, country, region, or user group. Comparative assessments of agricultural GHG tools by Colomb et al. (2013) and Milne et al. (2012) defined key characteristics of available tools, which we used as a starting point in tool selection: geographic focus, scope of emission categories, ease of use, and speed of assessment. To these criteria we added several others: availability of an offline version for use at field sites, manipulability of pre-programmed defaults, and flexibility in reflecting differing cattle management practices.

We selected the Cool Farm Tool (Cool Farm Alliance 2015) as the best fit for our research needs, given its comparatively detailed livestock sub-module, ease of use, and snapshot-in-time format (i.e., the tool does not require incorporation of a temporal element or the entry of multiple alternative scenarios, as several tools do). A key strength of the Cool Farm Tool's livestock sub-module is that it allowed us to differentiate among farm practices with respect to livestock lifecycle, pasture management, and feed choice. This flexibility proved to be the most important criterion in our selection process, though given the complexity of modeling livestock operations in contrast with annual crops, it still remains less flexible than a custom-designed life-cycle assessment (Crosson et al. 2011). A customized life-cycle assessment, however, would be less comparable to other studies, and would not have the benefit of the more substantial development process that established tools have undergone.

2.5 Scope and assumptions of GHG calculations

Our calculations of GHG emissions focused on activities occurring on pastureland and directly relating to the raising of cattle. We followed common conventions for reporting emissions from cattle systems, including the following: reporting total emissions in kilogram CO_2e/kg of beef and including emissions from the production of external inputs such as fertilizer (ibid.). Specific emissions accounted for included CH_4 emitted from cattle (enteric fermentation) and manure deposited and left on pasture; direct and indirect N_2O emissions from manure deposited and left on pasture and nitrogen fertilizer applied to soil; and CO_2 associated with direct and indirect field N_2O emissions, fertilizer production, pesticide production, and livestock feed production.

The calculations did not include emissions from land use change, the raising of crops or other livestock on the farm, carbon sequestration from forests on the property, or variation in soil carbon stocks in pastureland. The impact of land use change (particularly deforestation) on total on-farm emissions can be significant; but in most of the municipalities we surveyed, little forest remained. All of the data collected reflect each interviewees' reporting of farm practices at the time of the survey (July 2015). Our independent variable of interest was whether farms participated in a sustainability program or not.

We included questions on the survey that directly addressed data variables required by the Cool Farm Tool, and transferred these data directly from the surveys into the calculator. When producers did not directly provide the data needed, we used default values (see the appendix). We determined default values based on extensive conversations with project partners in Brazil or average values received during survey administration. We also assumed a linear growth rate of cattle in the different stages of their life cycle. Where the Cool Farm Tool incorrectly assumed that a particular management practice was applied over the total farm area (e.g., the application of fertilizer), we adjusted the raw values to force the tool to produce a correct total application. Though we gathered detailed quantity and brand information on pesticide and herbicide use, these parameters are not reflected in the Cool Farm Tool. Therefore, pesticide and herbicide use is represented as a binary variable in our regression models. Other methods used to fit the data to the Cool Farm Tool involved restricting land area under consideration to pasture area (i.e., excluding forest areas) and adjusting the quality of pasture for those farms participating in a program with a pasture-improvement component.

2.6 Analysis

Survey data and Cool Farm Tool outputs for each of the 40 farms were analyzed using a series of methods. First, descriptive statistics were explored and scatter plots produced to examine any relationships between variables. Difference of means tests were used to analyze the statistical significance of the non-program farm versus program farm differences as well as potential extraneous factors that could have biased the results. Finally, linear regression was used to validate the findings of the difference of means test by including control variables such as location and farm size.

3. Results

3.1 Farm characteristics

Program farms had a mean (±SD) of 3,709.5 (±9,938.7) head of cattle on 1,352.4 (±2,805.3) ha of pasture, compared with 1,451.4 (±2,974.2) head of cattle on 756.7 (±1,541.0) ha of pasture on non-program farms (table 2). The mean number of heads of cattle and pasture area were positively skewed due to two outlier large farms. Program farms reported, on average, a 23% increase in the head of cattle on farm since joining their respective programs with no expansion of land area. Eight out of 19 program farms reported no increase since joining the program.

Owners of program farms were an average of 5.8 (±3.6) years older than owners of non-program farms. The number of years the farm had been owned was 3.6 (±3.1) years longer for program farms. Non-program farms reported having last cleared forest an average of 14 (± 9.4) years ago, and program farms 18.5 (± 7.8) years ago. None of the above stated differences between program and non-program farms were statistically significant; however, number of head of cattle, pasture area, and years farm owned were included in the subsequent multivariate regression analyses since the differences were not approximately zero.

The slaughter weight of animals was slightly higher for females on non-program farms—200.5 (± 14.5) kg compared with 198.92 (± 19.7) kg—but lower for males, 266.8 (± 29.1) kg compared with 275.4 (± 18.5) kg (table 2). The average slaughter age for females was 23.5 months on program farms, compared with 26.9 on non-program farms. The average slaughter age for males was 27.3 for program farms and 30.7 for non-program farms. The difference in slaughter age was statistically significant at a 95% confidence interval for males and at a 90% confidence interval for females.

Table 2. Comparison of non-program and program farms

	Non-program (SD)	Program (SD)	Difference (SE)	t-score (of difference)	Confidence Interval
Number of head of cattle	1,451.4 (2,974.2)	3,709.5 (9,938.7)	-2,258.1 (2,271.0)	0.994	(6855.48, 2339.285)
Pasture area (ha)	756.7 (1,541.0)	1,352.4 (2,805.3)	-595.7 (706.4)	-0.843	(-2025.779, 834.312)
Owner age (years)	51.3 (12.2)	57.1 (9.8)	-5.1 (3.6)	-1.606	(-9.910, 2.742)
Years owned farm	18.1 (10.4)	21.6 (9.3)	-3.6 (3.1)	-1.147	(-9.910, 2.742)
Last clearing of forest (years ago)	14.0 (9.4)	18.5 (7.8)	-4.5 (3.0)	-1.518	(-10.608, 1.541)
Slaughter age in months (female)	26.8 (5.5)	23.5 (3.2)	3.4 (1.9)	1.816*	(-.523, 7.384)
Slaughter age in months (male)	30.7 (5.9)	27.3 (2.6)	3.4 (1.6)	2.053**	(-.004, 6.774)
Slaughter weight in kg (female)	200.5 (14.5)	198.9 (19.7)	1.6 (7.8)	0.202	(-14.781, 17.939)
Slaughter weight in kg (male)	266.8 (29.1)	275.4 (18.5)	-8.6 (9.0)	-0.958	(-27.143, 9.883)

3.2 GHG emission results per kilogram of beef produced

On average, GHG emissions from beef production were lower on program farms at 36.4 (±14.6) kg of CO_2e/kg of beef produced than on non-program farms at 44.7 (±21.4) kg of CO_2e/kg of beef produced—a difference of 8.3 (±5.9) kg (table 3). This represents a reduction of 18.6% fewer emissions per kilogram of CO_2e/kg of beef produced, though this difference was not statistically significant.

Table 3. GHG emission outcomes for program and non-program farms

	Non-program (SD)	Program (SD)	Difference (SE)	t-stat (of difference)	Confidence Interval
GHG/kg (all farms)	44.7 (21.4)	36.4 (14.6)	8.3 (5.9)	1.418	(-3.549, 20.156)
GHG/kg (farms in locations 1 and 4)	53.1 (27.8)	34.1 (12.8)	19.0 (9.5)	2.005**	(-.990, 38.943)
Fertilizer emissions/kg	1.1 (3.4)	.8 (1.2)	.2 (.8)	.266	(-1.452, 1.891)
Nitrogen emissions/kg	1.8 (1.3)	1.3 (.8)	.5 (.4)	1.549	(-.167, 1.25)
Pesticides emissions/kg	.05 (.09)	.07 (.1)	-.03 (.03)	-.793	(-.093, .040)
Enteric fermentation/kg	33.0 (15.7)	26.7 (13.0)	6.2 (4.6)	1.358	(-3.051, 15.492)
Manure emissions/kg	8.0 (6.7)	6.7 (5.9)	1.3 (2.0)	.653	(-2.760, 5.386)

NOTES: Total GHG/kg beef is derived from emissions associated with fertilizer, nitrogen, pesticides, enteric fermentation, and manure per kilogram.

t-scores significant at 0.1 level are marked with *, .05 at **; Location 1: Alta Floresta, Location 4: Paragominas.

To verify whether emission outcomes were influenced by other explanatory factors, such as location, size of the farm, and years the farm was owned, a series of linear regressions were conducted. When controlling for the number of cattle, pasture area, and years of farm ownership, farms participating in programs contributed an average of 9.9 fewer kilograms of CO_2e/kg of beef when compared with non-program farms; however, this was not statistically significant at the 90% confidence level. To test whether results were impacted by locational differences, we ran a second regression controlling for location. The coefficient reduced to 7.4 fewer kilograms of CO_2e/kg of beef produced, which was not statistically significant ($p<0.10$). When taking into account farm characteristics, the coefficient on program participation results in a slight increase in the emission differences, whereas the coefficient on the regression controlling for locational differences results in a slight decrease in the emission differences.

Because these differences are minimal, and not statistically significant, the descriptive difference of 8.3 kg is believed to accurately represent the program difference, despite other explanatory factors. A regression that included both farm characteristics and location was not possible because of the small sample size, which restricted our controls to a maximum of four variables.

When restricting the data to two locations, Paragominas and Alta Floresta, where programs had been implemented for more than two years, the average difference was 19.0 kg of CO_2e/kg of beef produced, which was statistically significant ($p<0.05$) (table 3). This difference equates to 35.8% fewer kilograms of CO_2e/kg of beef from program farms. When holding constant the number of years that a farm had been owned and its location in a linear regression analysis, farms participating in a program in one of these locations had on average of 21.7 fewer kilograms of CO_2e/kg of beef produced compared with non-program farms in the same location (table 4). The coefficient was statistically significant ($p<0.05$). Non-program farms in Paragominas and Alta Floresta had a median kilogram of CO_2e/kg of beef produced higher than the median for all farms, whereas program farms in these two locations also had a slightly higher median than all farms (figure 2).

The location with the greatest average difference between program and non-program farms was Alta Floresta (figure 3). Farms that participated in Pecuária Verde, in the state of Pará, emitted 30.0 (± 16.8) kg of CO_2e/kg of beef on average, which was the lowest average among the eight groups of program and non-program farms across the four locations (figure 4). The single observation in Tangará da Serra, the SAN-certified sustainable farm, had a per-kilogram output substantially lower than the averages of other groups of farms at 19.7; however, there were other individual farms in the sample that had estimated emissions lower than this figure.

3.3 GHG emissions per hectare of pasture

On average, program farms had 2.25 (± 0.9) animals per hectare, compared with non-program farms with 1.92 (± 1.4) animals per hectare. Similarly, emissions per hectare on program farms was slightly higher at 4,552.2 (±2,106.6) kg of CO_2e/ha/yr, compared with non-program farms at 4,483.5 (±3,397.2) kg of CO_2e/ha/yr (table 5), yielding a difference of 67.8 kg of CO_2e/ha/yr. When controlling for number of cattle, pasture area, and years that a farm had been owned in the linear regression, program farms emitted on average 510.4 kg of CO_2e/ha/yr less than non-program farms (table 4), which was not a statistically significant difference ($p<0.10$). When controlling for location, the coefficient reduced to 419.6 kg less.

When restricting the data to Alta Floresta and Paragominas, where programs had been implemented for more than two years, program farms emitted 111.1 more kilograms of CO_2e/ha/yr on average compared with their counterparts, when controlling for number of head of cattle, years farm owned, and location (table 4), which was not statistically significant ($p<0.10$).

3.4 Total GHG emissions

The median total emissions per year for program farms was 2,081.6 tCO_2e, compared with non-program farms at 2,512.4 tCO_2e (table 5). Across all farms in the sample, 74% of total emissions were from enteric fermentation, 22% from manure, 2% from feed (production and transportation emissions), 2% from fertilizers, and less than 1% from pesticides (figure 4).

Table 4. Regression coefficients of program participation on kg of CO_2 per kg of beef produced and per hectare of pasture

	kg of GHG per kg of Beef Produced			kg of GHG per ha of Pasture Area		
	All Farms Adjusted for Control Variables	All Farms w/Controls and Location Effects	Alta Floresta and Paragominas Only	All Farms with Controls	All Farms w/Controls and Fixed Effects	Alta Floresta and Paragominas Only
Farm participating in program	-9.859 (5.696)	-7.386 (6.693)	-21.732** (9.653)	-510.369 (857.315)	-419.643 (690.150)	111.099 (682.293)
Number of cattle	-0.001			0.464**		-0.645
	(0.001)			(0.232)		(0.385)
Pasture area (ha)	0.002			-1.220		
	(0.003)			(0.781)		
Years farm owned	0.858*		0.901	72.057**		74.914**
	(0.297)		(0.621)	(35.011)		(35.199)
Location 1		23.522***	6.649		-3893.981***	863.896
		(5.343)	(10.001)		(560.307)	(739.348)
Location 2		13.609			-2735.864**	
		(6.873)			(1292.18)	
Location 3		18.368***			-7065.245***	
		(6.967)			(644.257)	
Location 4		11.788	-		-5318.664***	—
		(7.976)			(744.443)	
Location 5		—			—	
Intercept	29.254	26.586	29.769	3432.770	9445.543	3510.026
	(6.398)	(6.693)	(15.118)	(1139.965)	(690.150)	(1125.41)
R squared	0.26	0.13	0.39	0.18	0.41	0.30
N	40	40	19	40	40	19

NOTES: Standard errors are given in parenthesis; *** p<0.01, ** p<0.05, * p<0.1; Location fixed effects are labeled as follows: Location 1: Alta Floresta, Location 2: Rolim de Moura, Location 3: Apuí, Location 4: Paragominas, Location 5: Tangara da Serra; Location 5 is omitted from columns 2 and 5 for collinearity; Location 4 is omitted in columns 3 and 6 for collinearity.

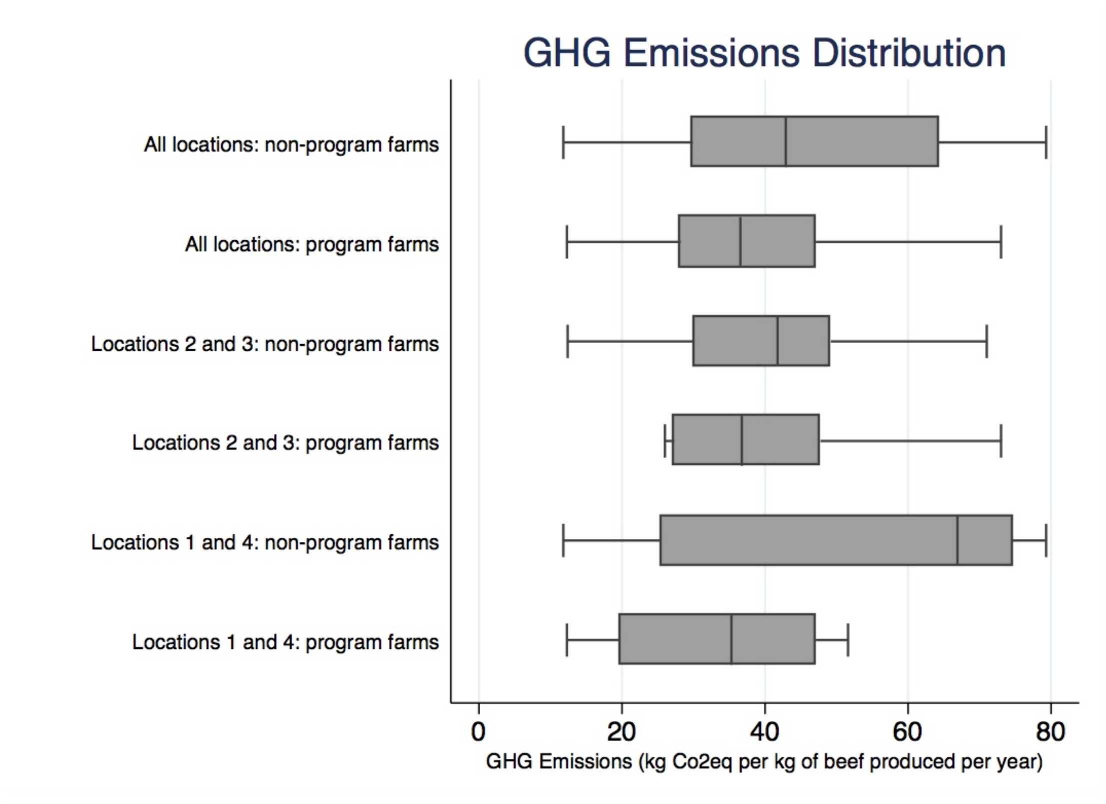

Figure 2. Box plots of kilogram of CO_2eq/kg of beef produced per year for all farms, farms in locations where the program has been implemented for less than two years (Locations 2 and 3), and farms in locations where the program has been implemented for more than two years (Locations 1 and 4) by program participation.

Notes: Location 1: Alta Floresta, Location 2: Rolim de Moura, Location 3: Apuí, Location 4: Paragominas.

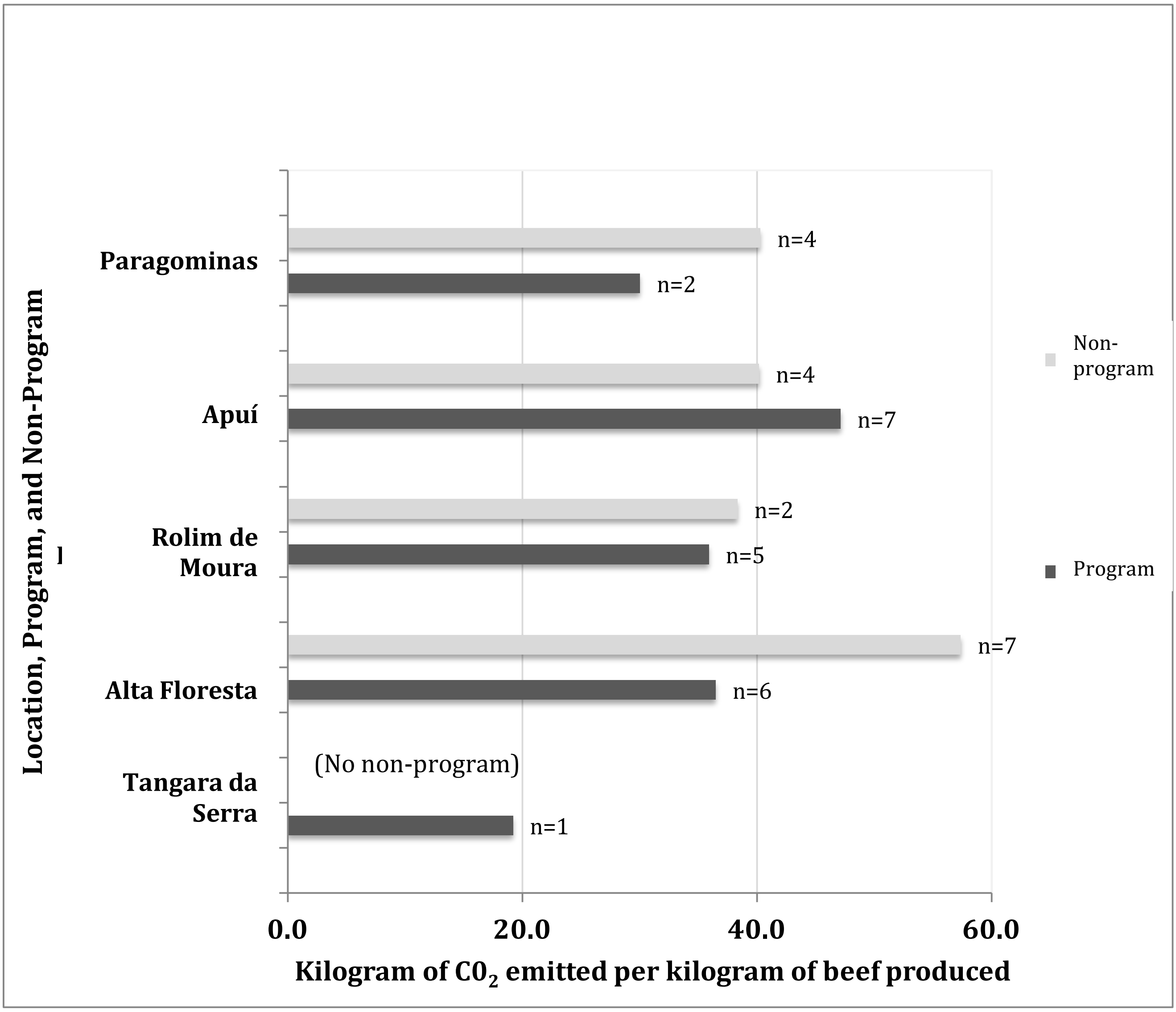

Figure 3. Kilogram of $C0_2$ emitted per kilogram of beef produced by location and program status.

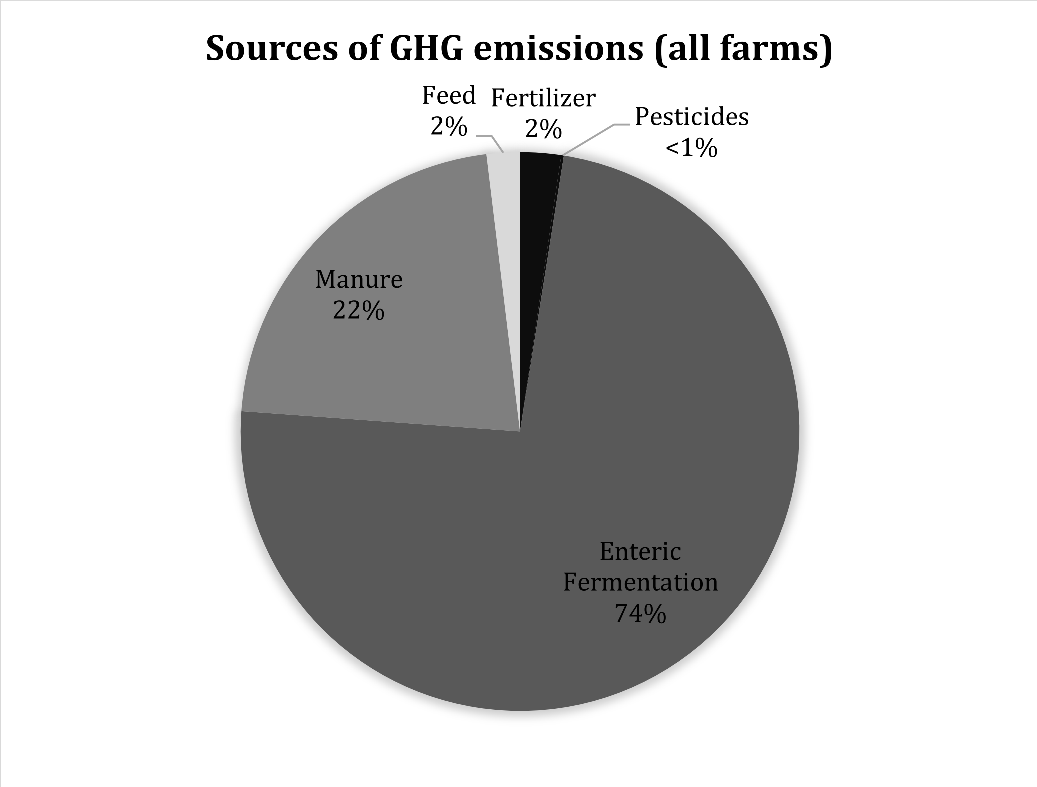

Figure 4. Sources of total GHG emissions for all farms in sample (n=38).

Table 5. GHG emissions summary by beef produced, area, and total annual farm emissions for all program and non-program farms aggregated together

	GHG emissions (kg of CO_2e/kg of beef produced/yr)	GHG emissions (kg of CO_2e/ha/yr)	Total GHG emissions (tCO_2e/yr)
Program farms (n=19)			
Mean	36.4	4,552.2	8,754.0
Median	35.3	4,928.4	2,081.6
Standard Deviation	14.6	2,106.6	25,670.5
Non-program farms (n=21)			
Mean	44.7	4,483.5	3,968.7
Median	42.9	3,873.9	2,512.4
Standard Deviation	21.4	3,397.2	9,167.6

NOTES: Total emissions for program farms is positively skewed due to two outliers.

4. Discussion

4.1 Implications of intensification and program participation

The results indicate that, on average, farms with some area of intensification experienced reduced emissions of CO_2e/kg of beef produced as compared with farms with no intensification, although not at statistically significant levels. Furthermore, farms that were participating in programs that had been established for more than two years showed even greater emission reductions per kilogram of beef than farms in more recently established programs; these differences were statistically significant. We hypothesize that the difference is due to some combination of level of technical assistance and program maturity (years in operation), but we cannot substantiate either claim with our current data set.

We analyzed farms participating in the Pecuária Verde and Novo Campo programs as a subset because of the programs' similarity in age and how they function and interact with ranchers, which includes more extensive and intensive interaction. It is uncertain whether program age or some other distinctive feature of these programs might explain the better performance of Pecuária Verde and Novo Campo in reducing GHG emissions.

Farms participating in programs had reduced slaughter age and increased stocking rates than did non-participating farms. Although there were, on average, more cattle per hectare on program than non-program farms, there was only a slight, not statistically significant increase in per-hectare emissions. Improvement in forage quality, as modeled by the Cool Farm Tool, accounts for some of the per-kilogram emission differences, presumably because the higher quality forage is believed to increase digestibility and therefore lower emissions. Increased productivity also accounts for a portion of the emission differences between the program and non-program farms. As program farms increase the size of their herds and produce more kilograms of beef per year on the same amount of land, per-kilogram emissions tend to decrease while emissions per hectare increase. We would therefore expect program farms to have slightly higher emissions per hectare due to intensification. Indeed, this is borne out for the locations where a program has been implemented for more than two years (table 4, column 6). This difference, however, is not statistically significant. When all sample farms are included, program farms actually have fewer emissions per hectare than their counterparts (table 4, columns 4 and 5). Again, the difference is not statistically significant. Possible explanations for the deviation in trend are the relatively small difference in number of cattle head per hectare between program and non-program farms and the relative youth of some of the programs (e.g., additional cattle may be phased into a farm's herd slowly over a period of years, and this process may not yet be apparent in the data).

This difference underscores the importance of choosing an appropriate metric for analysis when looking at program outcomes. Per-kilogram estimates are useful in understanding how a farmer producing at a certain level can expect intensification practices to increase the efficiency of production relative to emissions. On the other hand, per-hectare estimates are more useful for understanding how total emissions could vary according to land use change scenarios.

The farms in our sample's youngest program, IDESAM's project in Apuí, had been implementing intensification practices for less than one year. Results from intensification strategies may not appear immediately, given how recently many of the farmers adopted these practices. Many of the farms in Apuí applied fertilizers and divided their pastures just before the data were collected; thus they did not yet have updated production numbers to share. Therefore, their emission values are likely inflated, negatively impacting the GHG balance because fertilizer inputs are included but increased stocking rates have not yet been realized (figure 3).

4.2 Implications for program development and technical capacity

For farmers, adopting intensified management represents a departure from the traditional open-pasture management that has historically been used in the Brazilian Amazon. All intensification programs provided technical training to farmers on intensified rotational management. Yet very few technicians in Brazil are capable of training farmers to adopt these practices (Professor Moacyr Corsi, pers. comm. July 2015). The intensity and quality of the training that farmers receive are critical to the programs' achieving their performance goals. The advantages conferred by participating in more established programs (in existence at least two years) and with a longer period of assistance (at least two years) may help to explain why the production increased at farms in the longer established Pecuaria Verde and Novo Campo programs.

Herd size for program ranchers increased in the time since joining the program. Farmers increased their stocking rates on average by 23%, while reducing the slaughter age by 3.4 months. One goal for all of the programs was to help producers increase beef production, and these results indicate the positive progress toward that goal. Despite the evidence of increased stocking rates and decreased slaughter age, significant challenges to more widespread adoption remain due to lack of qualified technical assistance (ibid.).

4.3 Implications for GHG calculation tools

A secondary outcome of this paper is an improved understanding of how different off-the-shelf GHG emission calculation tools can be used to capture emissions from a range of livestock practices. We initially tested the EX-Ante Carbon balance Tool (EX-ACT) (FAO 2015) developed by the Food and Agriculture Organization of the United Nations, and World Resources Institute's emission calculator (World Resources Institute 2014. We decided, however, to use the Cool Farm Tool for several reasons: it was best able to calculate on-farm emissions using our data relative to the available tools; it was best able to incorporate the different feeds for the different life stages; and its snapshot-in-time mode and user friendliness. Despite these reasons, using the Cool Farm Tool entailed trade-offs, which indicates the need for improved tools that use local datasets, provide flexibility in capturing the different stages of animal lives, and can reflect different management practices.

One of the most pressing needs for future calculator development is a more robust method for incorporating potential carbon sequestration benefits from improved pasture management. Several studies show increased carbon sequestration in improved pastures rather than in degraded pastures (Braz et al. 2013; Maia et al. 2009; Cerri et al. 2007), which could reduce the overall emissions from ranching operations. Research has not been conclusive, however. Degradation of pastureland does not necessarily result in changes in carbon in the soil and biomass (Müller et al. 2004; Trumbore et al. 1995), and existing evidence indicates that factors such as clay content may play more of a role in soil carbon changes than management

(Hughes, Kauffman, and Cummings 2002). One of the biggest challenges in the existing literature is that studies examine different suites of management practices, so it is difficult to compare across studies. Longitudinal studies examining soil carbon stocks over time are rare and needed, given the wide variation in stocks based on factors such as soil type and land use history, which make even carefully selected chronosequences imprecise (Fearnside and Barbosa 1998). The Intergovernmental Panel on Climate Change (IPCC) has selected default values for carbon sequestration in grasslands that are incorporated into one tool, EX-ACT. Developers of other tools should consider incorporating IPCC defaults as well, though region- or soil type-specific default factors would be far better.

Nearly as pressing is a need for calculators that can reflect several pasture management regimes per farm. Because livestock often rotate between pastures under different management regimes at different life stages, calculators assuming a single regime are inadequate and force the use of loosely defined average conditions for the entire farm. For example, in our sample, all program farms contained both intensified and non-intensified areas. We observed a range of pasture quality conditions in different farm areas, yet these differences could not be reflected with precision in existing tools. Given these reasons, our estimates are likely negatively biased.

The current suite of available calculators does not reflect the emission benefits of reducing animal slaughter age, another key recommendation for inclusion in future calculators. GHG emissions increase as animals eat more (Shibata and Terada 2010). Animals will have lower emissions if they are slaughtered at younger ages and remain at heavier weights for less time. Demarchi et al. (2003) estimated that reducing average slaughter age for steers could reduce methane emissions by 10%. Animal lifespans were reduced significantly on program farms in our sample, but the Cool Farm Tool does not reflect the potential emission savings from this reduction. Reflecting carbon benefits of reducing cattle slaughter age would improve the ability of off-the-shelf GHG emission calculators to calculate ranching-related emissions.

4.4 Implications for deforestation

Although each program had different specific requirements for participation, a primary goal of each was to increase production on land that is already pasture in order to prevent future deforestation. Because our model's scope only included emissions directly related to ranching operations at a specified moment in time, we did not account for emissions associated with deforestation. However, the vast majority of farmers in our sample indicated no interest or need for future deforestation activity on their properties, giving the issue little weight at the level of individual farmers and existing cattle ranches in the studied areas. Several studies hypothesize potential carbon savings from avoided deforestation as a result of improved livestock practices in Brazil (Alves-Pinto, Newton, and Pinto 2013; Cohn et al. 2014). Realizing these savings requires addressing the structural causes of deforestation through options such as more attractive financing for ranchers interested in intensifying their operations, improved extension services, and greater monitoring and enforcement of environmental regulations to prevent a rebound effect; all would allow intensification programs to contribute to avoided future deforestation (de Gouvello 2010).

5. Conclusion

Our findings contribute to the literature on GHG emissions and cattle farming in Brazil. Our research uses information gathered through interviews with farmers participating in sustainable intensification ranching programs to model the impacts on per kilogram of beef emissions between program farms and non-program farms. It shows that program farms have lower per-kilogram emissions than do non-program farms, and that farm performance is greater among farms that are part of longer established programs. These differences were statistically significant for farmers who participated in the longer established programs. Further, this research outlines some of the important limitations of using off-the-shelf calculators for looking at emissions from ranching operations.

Recommendations for further research include returning to the farms in subsequent years to understand how per-kilogram of beef emissions change as farmers spend more time in programs and continue to implement the practices once program funding ends. In addition, this research highlights the need for off-the-shelf GHG emission calculators to better capture mitigation impacts of a variety of livestock-raising practices when measuring ranching rather than crop agriculture operations. Incorporating animal age structures and dividing the farm into different management areas would be essential for keeping track of changes in the cattle sector around the world. Furthermore, being able to reflect the effects of emission savings from improved pasture management would be an important step for accurately reflecting the environmental impacts of ranching operations.

The results of this research are an important stepping-stone to understanding how on-farm practices can make the biggest impact on GHG emissions from livestock. With increasing attention on climate change mitigation, it is imperative that the global increase in demand for beef does not drive unmanageable increases in emissions related directly to farming practices. Our hope is that further studies can build on the data collected from individual farms and illuminate the strengths, weaknesses, and importance of intensification programs in Brazil.

Appendix

Table 1A. Default values used in Cool Farm Tool calculations

Input Parameter	**Value**
Calf birth weight	33 kg
Cattle weight after one year	210 kg of live weight
Length of cow productive phase	96 months
Corn-to-soy ratio of supplemental feed	70:30
Percentage of animal weight consumed in pasture per day (no supplemental feed)	3.5% of live weight
Percentage of animal weight consumed in pasture per day (if supplemental feed)	2.5% of live weight
Percentage of cows giving birth each year	80%
Length of finishing phase (unless otherwise specified)	2.5 months
Mean annual temperature	WorldClim 2012 data
Soil characteristics	FAO Soil Map of the World

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