**Financial transition and costs of sustainable intensification versus ecological intensification practices**

**on a beef cattle and crop farm in Brazil’s Amazon**

Lorena Machado Pedrosa1, Aaron Kinyu Hoshide2,

Daniel Carneiro de Abreu3, Luana Molossi4, Eduardo Guimarães Couto5

1 Estudante de Pós-graduação em Agricultura Tropical pela Universidade Federal de Mato Grosso – Campus Cuiabá

2 Faculty Associate, School of Economics, University of Maine, Orono, ME USA

3 Professor do Instituto de Ciências Agrárias da Universidade Federal de Mato Grosso – Campus Sinop

4 Estudante de Pós-graduação em Zootecnia pela Universidade Federal de Mato Grosso – Campus Sinop

5 Professor do Programa de Pós-graduação em Agricultura Tropical pela Universidade Federal de Mato Grosso – Campus Cuiabá

**Supplementary Materials**

Table S1. Average productivity, economic, and environmental indicators of sustainable intensification practices and ecological intensification practice for beef farms in Brazil from literature for tropical and temperate beef species.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Climate - Cattle type** | **--------------------------------------------------------------- Agricultural Intensification Practice ---------------------** | | | | |
| **INDICATOR TYPE** | **----------------------------------------- Sustainable -----------------------------------------** | | | | **-- Ecological --** |
| **Agricultural**  **Sustainability Measure**1 | **Livestock**  **Supplementation** | **Pasture**  **Fertilization** | **Pasture**  **Re-seeding** | **Pasture**  **Irrigation** | **Crop Livestock**  **Integration** |
| **Tropical - *Bos indicus* / cross** |  |  |  |  |  |
| ECONOMICS |  |  |  |  |  |
| Average Daily Gain (ADG) |  |  |  |  |  |
| (kg/animal/day) |  |  |  |  |  |
| Extensive grazing | 0.223 | 0.473 | 0.220 | 0.390 | 0.495 |
| After practice | 0.327 | 0.636 | 0.260 | 0.640 | 0.640 |
| % increase over extensive | 77% | 48% | 29% | 36% | 52% |
| Literature articles | 4 | 3 | 2 | 2 | 2 |
| Total cost of practice |  |  |  |  |  |
| (US$ / ha) | $68.00 | $380.68 | $422.83 | $1,092 | $1,538.00 |
| Literature articles | 1 | 2 | 3 | 1 | 1 |
| Profitability (US$ / ha) |  |  |  |  |  |
| Net Farm Income (NFI) | - | $66.72 | $83.50 | -$83.00 | $518.00 |
| % increase over extensive | - | - | 40% | - | 1,417% |
| Literature articles | 0 | 1 | 2 | 1 | 2 |
| ENVIRONMENT |  |  |  |  |  |
| Carbon Footprint (CF) |  |  |  |  |  |
| (kg CO2e/kg bodyweight) |  |  |  |  |  |
| Extensive grazing | 28.3 | - | 25.7 | - | 18.5 |
| After practice | 25.1 | - | 17.2 | - | 12.6 |
| % decrease below extensive | -11% | - | -44% | - | -53% |
| Literature articles | 1 | 0 | 4 | 0 | 2 |
|  |  |  |  |  |  |
| **Temperate - *Bos taurus*** |  |  |  |  |  |
| ECONOMICS |  |  |  |  |  |
| Average Daily Gain (ADG) |  |  |  |  |  |
| (kg/animal/day) |  |  |  |  |  |
| Extensive grazing | 0.447 | - | 0.393 | - | - |
| After practice | 0.570 | - | 0.634 | - | - |
| % increase over extensive | 25% | - | 82% | - | - |
| Literature articles | 3 | 0 | 5 | 0 | 0 |
| Total cost of practice |  |  |  |  |  |
| (US$ / ha) | $328.50 | - | $944.00 | - | - |
| Literature articles | 1 | 0 | 1 | 0 | 0 |
| Profitability |  |  |  |  |  |
| Net Farm Income (US$ / ha) | $111.55 | - | $270.00 | - | $146.00 |
| % increase over extensive | 26% | - | 233% | - | 45% |
| Literature articles | 2 | 0 | 1 | 0 | 1 |
| ENVIRONMENT |  |  |  |  |  |
| Carbon Footprint (CF) |  |  |  |  |  |
| (kg CO2e/kg bodyweight) |  |  |  |  |  |
| Extensive grazing | 26.9 | -2 | 27.4 | - | 16.1 |
| After practice | 19.8 | -2 | 14.4 | - | 14.9 |
| % decrease below extensive | -21% | -30% | -50% | - | -8% |
| Literature articles | 3 | 1 | 5 | 0 | 1 |
|  |  |  |  |  |  |

1 Economic and environmental sustainability measure averages from literature (Supplementary Materials, Table S7).

2 Reduction in CF from 49 kg CO2e/kg carcass weight (CW) for extensive grazing to 34.5 kg CO2e/kg CW for pasture fertilization.

Table S2. Average annual temperature, solar radiation, and wind speed and seasonal precipitation measured at the cooperating farm in Mato Grosso, Brazil’s Amazon biome.

|  |  |  |  |
| --- | --- | --- | --- |
| **Weather Data** | **-------- 2015-16 --------** | **-------- 2016-17 --------** | **-------- 2017-18 --------** |
| Temperature |  |  |  |
| June-Aug. (°C) | 29.1 | 28.0 | 26.8 |
| Sept.-Nov. (°C) | 29.5 | 28.8 | 27.6 |
| Dec.-Feb. (°C) | 28.4 | 28.0 | 27.8 |
| Mar.-May (°C) | 28.9 | 27.7 | 26.4 |
| Annual (°C) | 28.9 | 28.1 | 27.1 |
| Precipitation |  |  |  |
| June-Aug. (mm) | 22.0 | 77.4 | 2.0 |
| Sept.-Nov. (mm) | 291.0 | 870.2 | 880.0 |
| Dec.-Feb. (mm) | 978.0 | 608.8 | 1,031.0 |
| Mar.-May (mm) | 321.0 | 277.0 | 474.0 |
| Annual (mm) | 1,612.0 | 1,833.4 | 2,387.0 |
| Average solar radiation  (MJ/m) | 17.4 | 17.3 | 16.5 |
| Average wind speed  (m/s) | 1.2 | 1.3 | 1.1 |
|  |  |  |  |

Table S3. Timing of fertilizer application, fertilizer types, and nutrients applied for sustainable agricultural intensification strategies for cooperating farm in Mato Grosso, Brazil’s Amazon biome.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Management characteristic** | **Supplementation** | **Fertilization** | **Re-seeding** | **Integration** | **Irrigated**  **Rotational Grazing** |
| Species |  | *Brachiaria brizantha* cv. Marandú | *Brachiaria brizantha* cv. Marandú | *Glycine max* & *Brachiaria brizantha* cv. Ruziziensis | *Brachiaria brizantha* cv. Marandú |
| Plant population (plants/ha) | - | 6,000 | 6,000 | 6,000 | 320,000 | 6,000 |
| Maturity group (MG II, III, IV, or V) | - | - | - | MG Group V (tropical) | - |
| Fertilizer application rates | - |  |  |  |  |
| Nitrogen (kg N / ha) | - | 1001 | 7.22 | 213 | 1001 |
| Phosphate (kg P2O5 / ha) | - | - | 362 | 1323 | - |
| Potash (kg K2O / ha) | - | - | 7.22 | 1083 | - |
| Lime (metric ton / ha) | - | - | 1.5 | 1.5 | - |
| Investment in watering system (US$) | - | - | - | - | $4,208 |
| Maximum annual irrigation (mm) | - | - | - | - | 10 |
| Watering (days / week) | - | - | - | - | 3 |
| Grazing period (months) | 12 | 12 | 12 | 6 | 12 |
| Concentrated feed (kg DM / head / day)4 |  |  |  |  |  |
| Corn grain | 1.25 | - | - | - | - |
| Soybeans | 0.45 | - | - | - | - |
| Cottonseed | 0.2 | - | - | - | - |
| Minerals4 | 0.05 | - | - | - | - |
| Operation(s)  (Starting Date) | - | Fertilizer application (December 20) | Lime application (September 10) | Lime application (August 10) | Fertilizer application (December 20) |
| - | - | Incorporation (September 10) | Incorporation  (August 10) | - |
| - | - | Fertilizer application (November 20) | Herbicide spray  (October 15) | - |
| - | - | Pasture seeding (November 20) | Soybean plant  (October 28) | - |
| - | - | Incorporation (November 20) | Pesticide spray 9 times  (November 12 to February 10) | - |
| - | - | - | Soybean harvest & pasture sowing  (February 15) | - |

1 Urea (45% N) was used as nitrogen source

2 Re-seeding pasture uses 120 kg/ha of fertilizer with NPK analysis of 6-30-6.

3 Soybean fertilizer at plant of 300 kg/ha with NPK analysis of 7-37-6, using additional side dress application of 150 kg/ha of KCl with analysis of 0-0-18 at about 50 days post plant.

4 Concentrated feed ration and minerals fed calculated as average values over 3 years.

Table S4. Crop-livestock production and economic indicators for the cooperating farm in Mato Grosso, Brazil’s Amazon biome.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Budget Line Item** | **Unit** | **2015-2016** | **2016-2017** | **2017-2018** |
| Total annual production | kg / ha / year | 46,695 | 57,747 | 54,120 |
| head / ha / year | 0.95 | 0.97 | 0.92 |
| Stocking rate | head / ha / year | 2.51 | 1.77 | 1.56 |
|  |  |  |  |  |
| Income from replacement/total income | % | 23 | 17 | 8 |
| Income from stockers/total income | % | 37 | 25 | 27 |
| Income from finishing/total income | % | 39 | 46 | 44 |
| Other income/total income1 | % | 1 | 12 | 21 |
|  |  |  |  |  |
| Total revenue (TR) | US$ / ha / year | $378 | $450 | $497 |
| US$ / head / year | $150 | $254 | $318 |
| Variable cost (VC) | US$ / ha / year | $395 | $400 | $388 |
| US$ / head / year | $157 | $226 | $248 |
| Fixed cost (FC) | US$ / ha / year | $78 | $77 | $80 |
|  | US$ / head / year | $31 | $44 | $51 |
| Total cost (TC) | US$ / ha / year | $472 | $477 | $468 |
| US$ / head / year | $188 | $270 | $299 |
| Total adjusted cost (TAC) | US$ / ha / year | $566 | $555 | $543 |
| US$ / head / year | $225 | $314 | $348 |
| Return over variable costs (ROVC) | US$ / ha / year | $17 | $50 | $109 |
| US$ / head / year | $7 | $28 | $70 |
| Net farm income (NFI) | US$ / ha / year | -$95 | -$27 | $30 |
| US$ / head / year | -$38 | -$15 | $19 |
| Net profit (NP) | US$ / ha / year | -$188 | -$105 | -$46 |
| US$ / head / year | -$75 | -$59 | -$29 |
|  |  |  |  |  |

1 Other incomes refers to incomes from crop sold and machinery sold that represents 1% of other incomes in the 3rd year.

Table S5. Crop-livestock production costs from cooperating farm in Mato Grosso, Brazil’s Amazon biome.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | **2015-16** | **2016-17** | **2017-18** | **2015-16** | **2016-17** | **2017-18** |
| **Budget Line Item** | ------------------------ US$ / ha------------------------ | | | ------------------------ US$ / head------------------------ | | |
| **1. Total revenue (TR)** |  |  |  |  |  |  |
| Animals sold | $229.56 | $115.15 | $79.80 | $91.38 | $65.10 | $51.10 |
| Slaughtered animals | $145.05 | $280.47 | $311.72 | $57.74 | $158.57 | $199.60 |
| Other incomes | $3.06 | $54.47 | $105.85 | $1.22 | $30.80 | $67.78 |
| **Total revenue** | **$377.67** | **$450.09** | **$497.37** | **$150.34** | **$254.47** | **$318.48** |
| **2. Production costs** |  |  |  |  |  |  |
| **2.1 Variable costs (VC)** |  |  |  |  |  |  |
| Labor | $143.29 | $128.32 | $137.62 | $57.04 | $72.54 | $88.12 |
| Grass reseeding | $4.73 | $2.97 | - | $1.88 | $1.68 | - |
| Pasture maintenance | $14.87 | $11.24 | $2.25 | $5.92 | $6.35 | $1.44 |
| Crop costs | $21.53 | $69.72 | $79.04 | $8.57 | $39.42 | $50.61 |
| Irrigation cost | $19.06 | $23.07 | $20.81 | $7.59 | $13.04 | $13.33 |
| Grain feed | $41.79 | $29.27 | $46.40 | $16.63 | $16.55 | $29.71 |
| Mineral cost | $14.44 | $13.04 | $8.96 | $5.75 | $7.37 | $5.74 |
| Medicines | $4.31 | $4.62 | $3.90 | $1.72 | $2.61 | $2.50 |
| Artificial insemination - AI | $3.06 | $0.97 | $1.89 | $1.22 | $0.55 | $1.21 |
| Corral materials | $3.51 | $1.72 | $2.17 | $1.40 | $0.97 | $1.39 |
| Energy and fuel | $13.37 | $13.07 | $11.83 | $5.32 | $7.39 | $7.57 |
| Technical assistance | $7.04 | $5.65 | $5.43 | $2.80 | $3.19 | $3.48 |
| Beef and beef transport taxes | $24.85 | $18.80 | $18.08 | $9.89 | $10.63 | $11.57 |
| Administrative cost | $16.93 | $12.49 | $9.36 | $6.74 | $7.06 | $6.00 |
| Machines & improvements maintenance | $33.37 | $23.19 | $14.90 | $13.29 | $13.11 | $9.54 |
| Rent cost | $19.77 | $28.23 | $16.86 | $7.87 | $15.96 | $10.80 |
| Feed - not grains | - | $6.43 | - | - | $3.64 | - |
| Transport cost | $8.71 | $7.40 | $8.41 | $3.47 | $4.19 | $5.39 |
| **Total variable cost** | **$394.63** | **$400.20** | **$387.91** | **$157.10** | **$226.25** | **$248.40** |
| **2.2 Fixed cost (FC)**1 |  |  |  |  |  |  |
| Improvement depreciation | $25.72 | $24.22 | $24.22 | $10.24 | $13.69 | $15.51 |
| Machines depreciation | $27.31 | $25.53 | $31.91 | $10.87 | $14.43 | $20.43 |
| Pasture depreciation | $24.80 | $27.26 | $23.53 | $9.87 | $15.41 | $15.07 |
| **Total fixed cost** | **$77.83** | **$77.01** | **$79.66** | **$30.98** | **$43.53** | **$51.01** |
|  |  |  |  |  |  |  |
| **TOTAL COST (TC)** | **$472.46** | **$477.21** | **$467.57** | **$188.08** | **$269.78** | **$299.41** |
| **2.3 Total capital remuneration cost** |  |  |  |  |  |  |
| Tied capital remuneration - Improvements | $27.00 | $25.43 | $25.43 | $10.75 | $14.38 | $16.28 |
| Tied capital remuneration - Machines | $16.39 | $19.15 | $19.15 | $6.52 | $10.82 | $12.26 |
| Tied capital remuneration - Animals | $34.98 | $16.66 | $16.66 | $13.92 | $9.42 | $10.67 |
| Tied capital remuneration - Pasture | $14.88 | $16.36 | $14.12 | $5.92 | $9.25 | $9.04 |
| **Total capital remuneration cost** | **$93.25** | **$77.60** | **$75.36** | **$37.11** | **$43.87** | **$48.25** |
|  |  |  |  |  |  |  |
| **Total adjusted cost (TAC)** | **$565.71** | **$554.81** | **$542.93** | **$225.19** | **$313.65** | **$347.66** |
|  |  |  |  |  |  |  |
| **Return over variable costs (ROVC)** | **-$16.96** | **$49.89** | **$109.46** | **-$6.76** | **$28.22** | **$70.08** |
| **Net farm income (NFI)** | **-$94.79** | **-$27.12** | **$29.80** | **-$37.74** | **-$15.31** | **$19.07** |
| **Net profit (NP)** | **-$188.04** | **-$104.72** | **-$45.56** | **-$74.85** | **-$59.18** | **-$29.18** |
|  |  |  |  |  |  |  |

1 Agricultural and farm land not included in fixed costs due to variable values per hectare.

Table S6. Livestock production and economic indicators for the cooperating farm in Mato Grosso, Brazil’s Amazon biome.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Indicators** | **Unit** | **2015-2016** | **2016-2017** | **2017-2018** |
| Total annual production | kg / ha / year | 46,695 | 57,747 | 54,120 |
| head / ha / year | 0.95 | 0.97 | 0.92 |
| Stocking rate | head / ha / year | 2.51 | 1.77 | 1.56 |
|  |  |  |  |  |
| Income from replacement/total income | % | 24 | 15 | 2 |
| Income from stockers/total income | % | 37 | 29 | 37 |
| Income from finishing/total income | % | 39 | 56 | 61 |
|  |  |  |  |  |
| Total Revenue (TR) | US$ / ha / year | $378 | $396 | $401 |
| US$ / head / year | $150 | $224 | $257 |
| Variable cost (VC) | US$ / ha / year | $335 | $310 | $497 |
| US$ / head / year | $140 | $175 | $181 |
| Fixed cost (FC) | US$ / ha / year | $70 | $70 | $71 |
|  | US$ / head / year | $28 | $40 | $45 |
| Total cost (TC) | US$ / ha / year | $404 | $380 | $354 |
| US$ / head / year | $168 | $215 | $227 |
| Total adjusted cost (TAC) | US$ / ha / year | $492 | $452 | $424 |
| US$ / head / year | $203 | $256 | $272 |
| Return over variable costs (ROVC) | US$ / ha / year | $43 | $86 | $118 |
| US$ / head / year | $10 | $49 | $75 |
| Net farm income (NFI) | US$ / ha / year | -$27 | $16 | $47 |
| US$ / head / year | -$17 | $9 | $30 |
| Net profit (NP) | US$ / ha / year | -$115 | -$57 | -$23 |
| US$ / head / year | -$52 | -$32 | -$15 |
|  |  |  |  |  |

Table S7. Livestock production costs for the cooperating farm in Mato Grosso, Brazil’s Amazon biome.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | **2015-16** | **2016-17** | **2017-18** | **2015-16** | **2016-17** | **2017-18** |
| **Budget Line Item** | ------------------------ US$ / ha------------------------ | | | ------------------------ US$ / head------------------------ | | |
| **1. Total revenue (TR)** |  |  |  |  |  |  |
| Animals sold | $229.56 | $115.15 | $79.80 | $91.38 | $65.10 | $51.10 |
| Slaughtered animals | $145.05 | $280.47 | $311.72 | $57.74 | $158.57 | $199.60 |
| Other incomes | $3.06 | $0.09 | $9.42 | $1.22 | $0.05 | $6.03 |
| **Total revenue** | **$377.67** | **$395.71** | **$400.94** | **$150.34** | **$223.72** | **$256.73** |
| **2. Production costs** |  |  |  |  |  |  |
| **2.1 Variable costs (VC)** |  |  |  |  |  |  |
| Labor | $121.79 | $107.77 | $112.02 | $48.48 | $60.93 | $71.73 |
| Grass reseeding | $4.73 | $2.97 | - | $1.88 | $1.68 | - |
| Pasture maintenance | $14.87 | $11.24 | $2.25 | $5.92 | $6.35 | $1.44 |
| Crop costs | - | - | - | - | - | - |
| Irrigation cost | $19.06 | $23.07 | $20.81 | $7.59 | $13.04 | $13.33 |
| Grain feed | - | $29.27 | $46.40 | $16.63 | $16.55 | $29.71 |
| Mineral cost | $41.79 | $13.04 | $8.96 | $5.75 | $7.37 | $5.74 |
| Medicines | $14.44 | $4.62 | $3.90 | $1.72 | $2.61 | $2.50 |
| Artificial insemination - AI | $4.31 | $0.97 | $1.89 | $1.22 | $0.55 | $1.21 |
| Corral materials | $3.06 | $1.72 | $2.17 | $1.40 | $0.97 | $1.39 |
| Energy and fuel | $3.51 | $13.07 | $11.83 | $5.32 | $7.39 | $7.57 |
| Technical assistance | $13.37 | $5.65 | $5.43 | $2.80 | $3.19 | $3.48 |
| Beef and beef transport taxes | $7.04 | $18.80 | $18.08 | $9.89 | $10.63 | $11.57 |
| Administrative cost | $24.85 | $12.49 | $9.36 | $6.74 | $7.06 | $6.00 |
| Machines & improvements maintenance | $33.37 | $23.19 | $14.90 | $13.29 | $13.11 | $9.54 |
| Rent cost | $19.77 | $28.23 | $16.86 | $7.87 | $15.96 | $10.80 |
| Feed - not grains | - | $6.43 | - | - | $3.64 | - |
| Transport cost | $8.71 | $7.40 | $8.41 | $3.47 | $4.19 | $5.39 |
| **Total variable cost** | **$334.67** | **$309.93** | **$283.27** | **$139.97** | **$175.22** | **$181.40** |
| **2.2 Fixed cost (FC)**1 |  |  |  |  |  |  |
| Improvement depreciation | $25.72 | $24.22 | $24.22 | $10.24 | $13.69 | $15.51 |
| Machines depreciation | $19.00 | $18.50 | $23.13 | $7.56 | $10.46 | $14.81 |
| Pasture depreciation | $24.80 | $27.26 | $23.53 | $9.87 | $15.41 | $15.07 |
| **Total fixed cost** | **$69.52** | **$69.98** | **$70.88** | **$27.67** | **$39.56** | **$45.39** |
|  |  |  |  |  |  |  |
| **TOTAL COST (TC)** | **$404.19** | **$379.91** | **$354.15** | **$167.64** | **$214.78** | **$226.79** |
| **2.3 Tied capital remuneration cost** |  |  |  |  |  |  |
| Tied capital remuneration - Improvements | $27.00 | $25.43 | $25.43 | $10.75 | $14.38 | $16.28 |
| Tied capital remuneration - Machines | $11.40 | $13.88 | $13.88 | $4.54 | $7.85 | $8.89 |
| Tied capital remuneration - Animals | $34.98 | $16.66 | $16.66 | $13.92 | $9.42 | $10.67 |
| Tied capital remuneration - Pasture | $14.88 | $16.36 | $14.12 | $5.92 | $9.25 | $9.04 |
| **Total capital remuneration cost** | **$88.26** | **$72.33** | **$70.09** | **$35.13** | **$40.90** | **$44.88** |
|  |  |  |  |  |  |  |
| **Total adjusted cost (TAC)** | **$492.45** | **$452.24** | **$424.24** | **$202.77** | **$255.68** | **$271.67** |
|  |  |  |  |  |  |  |
| **Return over variable costs (ROVC)** | **$43.00** | **$85.78** | **$117.67** | **$10.37** | **$48.50** | **$75.33** |
| **Net farm income (NFI)** | **-$26.52** | **$15.80** | **$46.79** | **-$17.30** | **$8.94** | **$29.94** |
| **Net profit (NP)** | **-$114.78** | **-$56.53** | **-$23.30** | **-$52.43** | **-$31.96** | **-$14.94** |
|  |  |  |  |  |  |  |

1 Agricultural and farm land not included in fixed costs due to variable values per hectare.

Table S8. Summary of literature indicators of sustainable agriculture intensification practices in Brazil.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Intensification Practice** | **Region & *Beef Species*** | **Production Indicators** | **Environmental Indicators** | **Economic Indicators** | **Reference** |
| Supplementation for cattle (grain where < 5% grain fed for every kg of cattle body weight or BW) | Southern Brazil Pampas  (Rio Grande do Sul state)  *Bos taurus*  (Angus breed) | Animal production with grain 1.325% supplementation was 7.9% greater than natural pasture with 0.48 kg/animal/day gain for native pasture with supplementation versus 0.44 kg/animal/day gain with only native pasture. | Greenhouse gas (GHG) emission sources were enteric animal emissions, feed production, and the production of resource inputs. ﻿GHG (kg CO2 equivalent) per hectare was higher for grain supplementation (2,591) than natural pasture (2,453). | Grain supplementation was 17% of total costs with a net return 2% worse than natural pasture ($99/ha versus $101/ha). Purchased feed for grain supplementation $22/ha. | Pereira et al., 2018 |
|  | Mid-west Brazil  (Mato Grosso do  Sul state)  *Bos indicus* /  *Bos taurus* cross  (Nelore cows with  Angus bulls) | Grain 0.32% supplementation (14% protein ration during finishing from 20 to 26 months) had 17.5% greater cattle live weight production per hectare with ADG of 0.08 kg/animal/day compared to extensive pasture with no grain supplementation where cattle slaughtered at 36 months with ADG of 0.05 kg/animal/day. | The grain supplementation system (25.1 kg CO2eq/kg live weight or LW) had 11.31% lower carbon footprint than the extensive pasture system (28.3 CO2eq/kg LW). | Difference in cost between (grain supplementation) and (extensive pasture only) cattle systems is $68/ha. | Florindo et al., 2017a & 2017b |
|  | Cerrado biome  *Bos indicus*  crossbreeds | Area to produce 1 kg of carcass on a degraded pasture drops from 320 m2 to 45 m2 when using feed supplement-ation with total mixed ration (TMR), while beef yield increases from 31 to 221 kg carcass weight/ha. | CF decreased from 28.6 kg CO2eq/kg live weight (58.3 kg CO2eq/kg carcass weight) for degraded pasture to 15.6 kg CO2eq/kg live weight (29.4 kg CO2eq/kg carcass weight) for feed supplement-ation using TMR. | n/a | Cardoso et al., 2016 |
|  | Southern Brazil  (Paraná state)  *Bos indicus*  (Nelore breed) | Supplementation at 0.5% during dry season and 1% during rainy season increased the average daily live-weight gain (ADG) of animals (0.31 and 0.6 kg/animal/day respectively). ADG higher for cross breed Nelore vs. Angus due to better feed conversion and for males versus females. | n/a | n/a | Guerra et al., 2016 |
|  | Southeast Brazil  *Bos indicus*  (Nelore breed) | ADG of 0.3 kg/animal/day significantly higher at 40% versus 25% protein supple-mentation fed at only 0.3% of BW during early dry-to-rainy season transition (8/23 to 9/2). | n/a | n/a | Fernandes et al., 2016 |
|  | Southern Brazil Pampas  (Rio Grande do Sul state)  *Bos taurus*  (Angus breed) | ADG of native pasture with protein supplementation (0.65 kg/animal/day) and with protein-energy supplement-ation (0.84 kg/animal/day) greater than just native pasture alone (0.51 kg/animal/day). | Carbon footprint (CF) is 22.2% to 45.4% lower for native pasture with protein supplementation (28.9 kg CO2equivalent/kg LW) and with protein-energy supplementation (20.3 kg CO2eq/kg LW) compared to just native pasture alone (37.2 kg CO2eq/kg LW). | Total system cost per area 8.8% to 10.7% lower for supplementation ($325 to $332/ha) compared to native pasture alone ($364/ha) due to shorter time to slaughter when using supplementation (16.8 to 21.7 months) versus just native pasture (27.6 months). | Ruviaro et al., 2016 |
|  | Southern  Brazil  Temperate beef species | Cattle also pastured on 2.4 t DM/ ha soybean crop residues (CR) and natural pasture (NP) had same ADG (0.39 kg/animal/day). Feedlot (FL) feeding corn, soy, and sorghum at 0.186 t DM/animal/year each increased ADG to 0.59 kg/animal/day. Beef yields for CR (43 kg/ha/year) lower and for FL (62 kg/ha/year) higher compared to just NP (48 kg/ha/ year) alone. | The carbon footprint for CR (26.8 kg CO2eq/kg LW) was similar to NP (27.3 kg CO2eq/kg LW), while FL was lower (23.3 kg CO2eq/kg LW). | Net farm income (NFI) increased from $81/ha for NP to $124/ha for CR (just NFI from cattle and not soybeans). Feedlot NFI was lower ($65/ha) than NP since concentrated feed costs were 41% of variable costs. | Pashaei Kamali et al., 2016 |
|  | Brazil  Both tropical and temperate beef species | Meta-analysis for tropical pasture supplementation (29% crude protein or CP) for ADG of 0.31 kg/animal/day, while temperate pasture supple-mentation (17% CP) had ADG of 0.25 kg/animal/day. | n/a | n/a | Tonello et al., 2011 |
| Pasture fertilization | Brazil  Both tropical and temperate beef species | EAGGLE model estimates increase in pasture dry matter yield from 3.9 to 19.6 t DM/ha/year by mowing, liming, re-seeding, and fertilizing with single phosphate, micro-nutrients, and 90 kg N/ha. | CENTURY model estimates increase in soil carbon from 26.1 to 84.3 t/ha going from extensive pasture with no interventions to mowing, liming, re-seeding, and fertilizing with single phosphate, micro-nutrients, and 90 kg N/ha. | Cost of mowing and liming ($42.50/ha), single phosphate application ($94.60/ha), re-seeding ($230.60/ha). Cost of nitrogen (N) fertilization at 45 kg N/ha ($249.40/ha) and at 90 kg N/ha ($399.30/ha). | De Oliveira Silva et al., 2018 |
|  | Southern Brazil  (Paraná state)  Crossbred tropical and temperate beef species | Alexander grass (*Brachiaria plantaginea*) pasture fertilized with 100 kg/ha of N with 0.5% of BW wheat bran supplementation produced significantly greater ADG (0.82 kg/animal/day) than did fertilization at 200 kg/ha (0.69 kg/animal/day) and only 100 kg/ha of N fertilization alone (0.73 kg/animal/day). | n/a | n/a | Venturini et al., 2017 |
|  | Southeast Brazil  Atlantic Forest biome (Minas Gerais state)  *Bos indicus*  (Nelore breed) | Beef productivity in fertilized pasture varied by year (2004-2007) and stocking rate, with values between 258 and 693.8 kg/ha/year at 2.4 to 3.8 AU(450 kg animal)/ha, increasing to between 588 and 1,061 kg/ha/year at 3.2 to 4.31 AU/ha. | n/a | For 165 ha farm, net farm income (NFI) averaged $66.72/ha from 2004-2007 (ranging from -$103.67/ha to $222.20/ha). Feeding cost (grain, meal, forage, and minerals) was 30.25% of total cost. Pasture fertilization cost estimated at $437/ha. | Santana et al., 2016 |
|  | Northern Amazon (Rondônia state)  *Bos indicus*  (Nelore breed) | Fertilization of rotationally grazed pasture increased numbers of calves, steers and heifers. Decreased slaughter age from 4 to 2 years. | Decreased CH4 emission, increased N2O and CO2. Fertilization increase from 50 to 400 kg N/ha/year lowers carbon footprint to 21 to 48 kg CO2eq/kg carcass weight compared to no fertilization (49 kg CO2eq/kg carcass weight). | n/a | Mazzetto et al., 2015 |
|  | Southern Brazil Pampas  (Rio Grande do Sul state)  *Bos taurus*  (Angus breed) | Higher pasture dry matter accumulation rate compared to no managed pasture. ADG for fertilized pasture (0.581 kg/animal/day) was not significantly higher than for natural pasture (0.473 kg/animal/day) likely due to pasture species diversity. | n/a | n/a | Ferreira et al., 2011 |
| Pasture improvements  (can include re-seeding) | West Brazil  Pantanal biome  (Mato Grosso do  Sul state) | Although beef growth and yield not measured, stocking density higher if using cultiv-ated pasture (0.513 AU/ha = 513 kg/ha) versus not (1.067 AU/ha = 1,067 kg/ha). | Traditional seasonal cattle grazing systems in the Pantanal where cattle are moved from flooded areas during the rainy season. Since landscape CH4 emissions are 10 to 23 times those of cattle, traditional wetlands grazing is GHG neutral. | n/a | Bergier et al., 2018 |
|  | Brazilian Amazon  (Acre state)  *Bos indicus*  (Nelore breed) | Improving pastures with tropical kudzu (*Pueraria phaseoloides*) and forage peanut (*Arachis pintoi* cv Belomonte) increased beef production by 1.3 to 1.5 times over baseline. | n/a | Average whole-farm profitability of $57 to $91/ha. Pasture improvement costs $426 to $544/ha during establishment year and $27/ha annually to maintain. Pasture improvement takes 3 to 4 years to payoff. | Zu Ermgassen et al., 2018 |
|  | (Amazonas, Mato  Grosso, Pará,  Rondônia states)  *Bos indicus*  (Nelore breed) | Lower slaughter age when using pasture management techniques such as pasture rehabilitation and rotational grazing (2.12 years) versus not (2.4 years). ADG higher (0.26 versus 0.22 kg/animal/ day) but not significant. | Farms using pasture management techniques such as pasture rehabilitation and rotational grazing produced 18.5 kg of CO2eq/kg of live weight or LW (36.4 kg of CO2eq/kg of carcass weight or CW) versus non-participating farms at 22.8 kg of CO2eq/kg LW (44.7 kg of CO2eq/kg CW), which represents 18.6% fewer emissions. | n/a | Bogaerts et al., 2017 |
|  | (Pará state)  *Bos indicus*  (Nelore breed) | For 13 cooperating farms, beef productivity projected to increase from ~75 kg CW/ha to ~150 kg CW/ha (year 6) to ~263 kg CW/ha (year 12). | When accounting for GHG emissions from enteric fermentation, manure, fertilizer, deforestation and carbon sequestration from restoration, projected net GHG emissions in year 12 estimated at 1.33 Mt CO2eq (0.033 kg CO2eq/ha) compared to base-line of 2.71 Mt CO2eq (0.068 kg CO2eq/ha). | Pasture restoration investment $261/ha to $697/ha upfront with $253/ha annual maintenance costs. | Garcia et al., 2017 |
|  | Mid-west Brazil Cerrado biome  (Mato Grosso do  Sul state)  *Bos indicus*  (Nelore breed) | Linear programming simula-tion of pasture restoration improved beef yield from 106 kg CW/ha/year for pasture restoration every 10-11 years to 216 & 222 kg CW/ha/year for fractional & uniform pasture restoration respectively without ABC credit. | For carbon footprint (CF) including sequestration for soil organic carbon but not including emissions from purchased calves, CF dropped from 9.26 kg CO2eq/kg of carcass weight (CW) to 3.59 kg CO2eq/kg CW due to optimized pasture restoration. | Net present values (beef revenue minus expenses dis-counted over time to present year) for traditional pasture restoration (-$9/ha/year) increased with uniform and fractional ($142-$146/ha/year) pasture restoration respect-ively without ABC credit. Invested $99-$510/ha/year for pasture restoration. | De Oliveira Silva et al., 2017 |
|  | *Bos indicus*  Crossbreeds | Area to produce 1 kg of carcass on a degraded pasture drops from 320 m2 to 50-71 m2 when improving pasture without TMR, while beef yield increases from 31 to 140-202 kg carcass weight/ha. | CF decreased from 28.6 kg CO2eq/kg live weight or LW (58.3 kg CO2equivalent/kg CW) for degraded pasture to 15.1 to 16.5 kg CO2eq/kg LW (29.6 to 32.4 kg CO2eq/kg CW) when improving pasture with legume (*Stylosanthes* spp. cv. Campo Grande) or Guinea grass (*Panicum maxiumum* cv Tanzânia) without using TMR. | n/a | Cardoso et al., 2016 |
|  | Southern  Brazil  Temperate beef species | Improved pasture (IP) system with ryegrass/clover, NPK fertilization (0-50-65 kg/ha/ year), and lime at 333 kg/ha/ year increased ADG to 0.53 kg/animal/day compared to 0.36 kg/animal/day for just natural pasture (NP). Beef yield for IP up to 270 kg/ha/ year from NP (48 kg/ha/year). | IP system had lower carbon footprint (18.7 kg CO2eq/kg LW) than extensive pasture (27.3 kg CO2eq/kg LW), whereas IP fossil energy use was higher (19.3 MJ/kg LW) compared to NP (0.7 MJ/kg LW). | Net farm income increased from $81/ha for NP to $270/ha for IP. | Pashaei Kamali et al., 2016 |
|  | Southern Brazil Pampas  (Rio Grande do Sul state)  *Bos taurus*  (Angus breed) | ADG on improved native pastures with ryegrass and sorghum ranged from 0.64 to 0.89 kg/animal/day compared to ADG on just native pasture alone (0.51 kg/animal/day). | CF is 30.7% to 50.3% lower for improved native pastures with ryegrass and sorghum (18.5 to 25.8 kg CO2equivalent/kg LW) compared to just native pasture alone (37.2 kg CO2eq/kg LW). | Total system cost per area 103% to 216% higher for improved native pastures with ryegrass and sorghum ($738 to $1,150/ha) compared to native pasture alone ($364/ha). | Ruviaro et al., 2016 |
|  | *Bos taurus*  (Angus breed) | Introduction of winter and summer grasses and legumes increased ADG to 0.5 to 1 kg/animal/day compared to extensive pasture baseline of 0.23 kg/animal/day. | CF of baseline of unimproved native pasture (22.5 kg CO2eq/kg LW) decreases by 79% to 92% to 1.8 to 4.7 kg CO2eq/kg LW for pastures improved by winter and summer grasses and legumes. | n/a | Dick et al., 2015a |
|  |  | n/a | Improved system (IS) for pasture with winter grasses, legumes, limes, and fertilization (50 & 60 kg of P2O5 and K2O/ha/year respectively) reduced CF compared to extensive system (ES) of natural pasture from 22.5 to 9.2 kg CO2eq/kg LW (45.1 to 18.3 kg CO2eq/kg CW). Land, fossil fuel, and fresh water use were lowered for IS compared to ES, in addition to freshwater eutrophication. | n/a | Dick et al., 2015b |
|  | Brazil pasturelands  Both tropical and temperate beef species | Current productivity of Brazilian pasture lands (94 million animals) is 32–34% of their estimated carrying capacity (274–293 million animals) with adequate intensification of pasture management. | If cattle productivity increased and no more land was de-forested, estimated emissions reductions of 14.3 Gt CO2 until 2040. Such lower emissions accomplished by reducing deforestation (12.5 Gt CO2) and lowering beef cattle enteric emissions (1.8 Gt CO2) by decreasing Brazil’s herd in addition to slaughtering animals earlier. | n/a | Strassburg et al., 2014 |
|  | Southern Brazil Pampas  (Rio Grande do Sul state)  *Bos taurus*  (Angus breed) | Improved pasture had higher ADG (0.492 kg/animal/day) versus natural pasture (0.473 kg/animal/day). | n/a | n/a | Ferreira et al., 2011 |
| Crop-livestock integration (CLI) | Brazilian Amazon  (Mato Grosso state)  *Bos indicus*  (Nelore breed) | Soybean monoculture (SOY) is the most productive system in terms of human digestible protein and energy production per hectare, followed by CLI, rotational grazing cattle on pasture (ROT), and extensive pasture (EP). | GHG emission were lowest for soybean monoculture (2.05 kgCO2eq/kg of human digestible protein or HDP) under every climate scenario (current, RCP 2.6, RCP 8.5). CLI (~20-30 kgCO2eq/kg HDP lower GHG emissions than extensive pasture (~90-100 kgCO2eq/kg HDP). | NFI was highest for CLI (~$625/ha) when operating at an optimal stocking rate, followed by soy (~$500/ha), and extensive pasture (~$150/  ha) for current climate. CLI & EP better at RCP 2.6, while SOY worse. All four systems worse at RCP 8.5. | Gil et al., 2018 |
|  | Southern Brazil  (Rio Grande do Sul state)  *Bos taurus*  (Angus breed) | Animal production of beef with non-integrated commodity soybeans was 7.9% greater than only beef on natural pasture | Total GHG (kg CO2eq) per hectare was lower for beef with non-integrated commodity soybeans (2,357) than for beef on natural pasture alone (2,453). | Adding commodity soybeans had 44% better net farm income than nature pasture ($146/ha versus $101/ha). | Pereira et al., 2018 |
|  | Tropical Brazil  *Bos indicus*  (Nelore breed) | Beef cattle in managed pasture (MP), crop-live-stock-forest (CLFIS), and degraded pasture (DP) systems were 900, 582 and 43 kg/ha/year respectively. ADG for MP, CLFIS, and DP were 0.62, 0.47, and 0.24 kg/ animal/day respectively. | CF decreases from 18.5 to 12.6 to 9.4 kg CO2eq/kg LW for DP, CLFIS, and MP respectively when not accounting for GHG sequestration by pasture in all three systems nor sequestration by crop (soy, corn, sorghum) and tree (eucalyptus) species for CLFIS. When accounting for such sequestration, CF decreases from 18.5 to 7.6 to -28.1 kg CO2eq/kg LW for DP, MP, and CLFIS respectively. | n/a | De Figueiredo et al., 2017 |
|  | Brazilian Cerrado biome (District Federal)  *Bos indicus*  (Nelore breed) | CLI increased meat prod-uction 4x compared to con-ventional, pasture production 17%, soybean yield 10%, and soil organic matter 15%. Fertilizer costs 45% lower. | Soil productivity capacity and chemical and physical parameters improved. | CLI decreased business risk by 50%. | Cordeiro et al., 2015 |
|  | Midwest Brazil  (Mato Grosso do Sul state)  *Bos indicus* / *Bos taurus* cross(Nelore withHereford / Charolais) | Better soil conditions in CLI so soybean & pasture yields less affected by drought & frost. CLI performed better than permanent pasture (PP), with non-dry season ADG for CLI (0.81 kg/animal/day) 8.7% more than PP (0.75 kg/ animal/day). CLI beef yield of 581 kg/ha 12.9% more than PP at 516 kg/ha. | CLI was very efficient, accumulating soil C and reducing emissions of greenhouse gases. Soil quality was improved in the CLI system with larger number of components and greater interaction between these components compared to simpler systems such as extensive PP and both the no-till system (NTS) and conventional system (CS) for row cropping. Soil ecology and biology more favorable for CLI, PP, and NTS compared to CS. | n/a | Salton et al., 2014 |
|  | Brazilian Cerrado biome (District Federal)  *Bos indicus*  (Nelore breed | Beef production greater for CLI (527 kg LW/ha) comp-ared to extensive pasture or EP (211 kg LW/ha). | n/a | NFI for CLI at $411/ha more than EP (-$17/ ha) but lower than soybeans ($443/ha). CLI system total cost of $1,538/ha greater than both EP ($1,104/ ha) and soybeans ($792/ha). | Martha Júnior et al., 2011 |
| Rotational grazing | Brazilian Amazon  (Acre state)  *Bos indicus*  (Nelore breed) | Rotational grazing increased beef production 1.2 to 2.3 times over baseline, while silvo-pastoral rotational grazing with leguminous trees and forage shrubs in-creased beef output 4-fold. | n/a | Average whole-farm profit-ability of $117 to $163/ha. Pasture improvement costs $397 to $946/ha during estab-lishment year and $58 to $486/ ha/year to maintain. Pasture improvement payoff 5-6 years. | Zu Ermgassen et al., 2018 |
|  | (Mato Grosso state)  *Bos indicus*  (Nelore breed) | Rotational grazing cattle on pasture (ROT) produces more human digestible  protein and energy product-ion per hectare than extensive pasture (EP). | Highest GHG emissions for extensive pasture (~90-100 kgCO2eq/kg HDP) followed by rotational grazing (~70 kgCO2eq/kg HDP). | NFI for rotational grazing (~$495/ha) greater than extensive pasture (~$150/ha) for current climate. EP better at RCP 2.6. ROT & EP systems worse at RCP 8.5. | Gil et al., 2018 |
|  | Tropical Brazil  Tropical beef species | n/a | Rotational grazing reduced carbon most by 17.7 Gt CO2eq, compared to mixture of methods (13.1 Gt CO2eq), animal confinement (8.3 Gt CO2eq), and shared raising with legumes (7.1 Gt CO2eq). | n/a | Palermo et al., 2014 |
|  | Southern Brazil Pampas  (Rio Grande do Sul state)  *Bos taurus*  (Angus breed) | Rotational grazing increased ADG to 1 kg/animal/day compared to extensive pasture baseline of 0.23 kg/animal/day. | CF of baseline of unimproved native pasture (22.5 kg CO2eq/kg LW) decreases by 100% to 0.11 kg CO2eq/kg LW for rotational grazing. | n/a | Dick et al., 2015a |
|  | Midwest Brazil  Pantanal biome  (Mato Grosso do Sul state)  *Bos indicus*  (Nelore breed) | Rotational grazing improved native pasture productivity (~3 t DM/ha) compared to continuous grazing (~1 t DM/ha) and increased cattle weights by 15% (+46 kg/ animal) after 17 months. | n/a | Higher cattle weight translates to additional revenue of +$68/animal. | Eaton et al., 2011 |
| Irrigation | Southeast Brazil  (São Paulo state)  *Bos indicus*  (Nelore breed) | ADG increased for irrigated pasture stocking 6.6 AU/ha (6,600 kg/ha) to 0.53 kg/ animal/day compared to degraded pasture (0.39 kg/ animal/day) stocking only 1.4 AU/ha (1,400 kg/ha). Meat quality not affected. | n/a | n/a | Oliveira et al., 2018 |
|  | Brazil Amazon biome  (Mato Grosso state)  *Bos indicus*  (Nelore breed) | Amazon regions currently dependent on green water sources (soil, plants) to evap-orate and fall as rain. In-creased use of blue water (rivers, lakes, groundwater) can increase beef and crop productivity but at expense of non-agricultural users. | A combination of expansion of cropland and pasture both using irrigation would considerably increase the amount of water required for agri-culture. Irrigation has the potential to maintain production and prevent further encroachment of agriculture into natural ecosystems. | n/a | Lathuillière et al., 2016 |
|  | Southern Brazil Pampas  (Rio Grande do Sul state)  *Bos indicus* /  *Bos taurus* crosses  (Nelore, Hereford, Angus) | Center pivot (CP) irrigation systems had beef output of 369-772 kg/ha. ADG for these three CP irrigated systems ranged from 0.67 to 0.83 kg/animal/day. | n/a | CP irrigated pasture NFI ranged from -$333/ha to $167/ha. Total annual costs for the 3 systems were $930/ha, $1,146/ha, and $1,201/ha. Capital investment during the initial set-up year was $7,737/ ha, $10,255/ha, and $12,479/ ha respectively. | Soares et al., 2015 |

Table S9. Soil parameters before and after crop-livestock integration from the cooperating farm in Mato Grosso, Brazil’s Amazon biome.

|  |  |  |
| --- | --- | --- |
|  | **------- Sample Averages -------** | |
| **Soil Parameter** | **2015-2016** | **2017-2018** |
| Sample size (n) | 1 | 1 |
| Soil type | Deep sandy loam | Deep sandy loam |
| Physical composition, % |  |  |
| Sandy | 81 | 81 |
| Silt | 3.2 | 3.2 |
| Clay | 15.8 | 15.8 |
| Organic matter content, g/dm3 | 16 | 12.8 |
| Organic matter content, % | 1.6 | 1.28 |
| pH | 4.6 | 5.4 |
| Base sum, mmolc/dm3 | 1.34 | 2.0 |
| CEC1, mmolc/dm3 | 4.15 | 4.0 |
| V2% | 32 | 50 |
| m3% | 6.9 | 0 |
|  |  |  |

1 CEC, cation exchange capacity

2 V%, base saturation

3 m%, aluminum saturation