# SUPPLEMENTAL MATERIALS

### Assumed stage flows on the partitioning of agricultural crops and livestock production into functional elements

Common bean

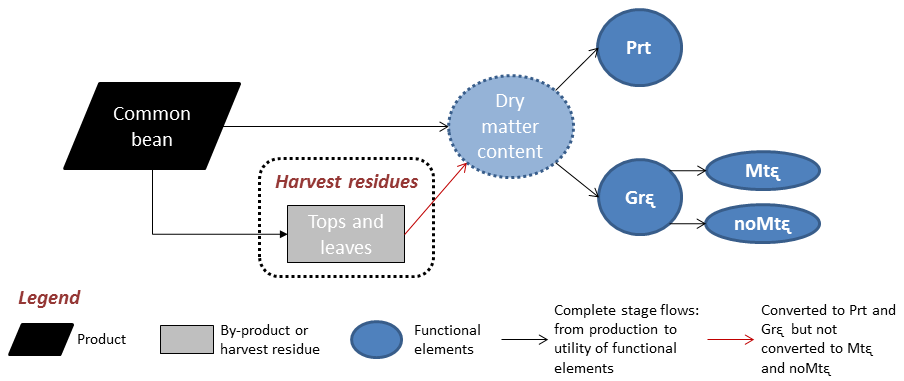


Figure S1 – Common bean partitioning into products, by-products and harvest residues and their conversions to functional elements.

*Cotton seed (whole)*

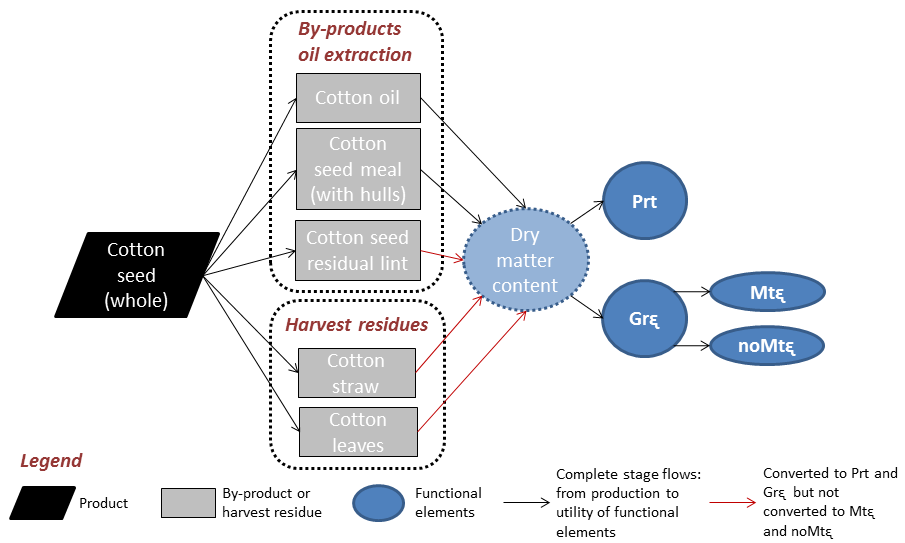


Figure S2 – Cottonseed partitioning into products, by-products and harvest residues and their conversions to functional elements.

*Rice grain (with hulls)*

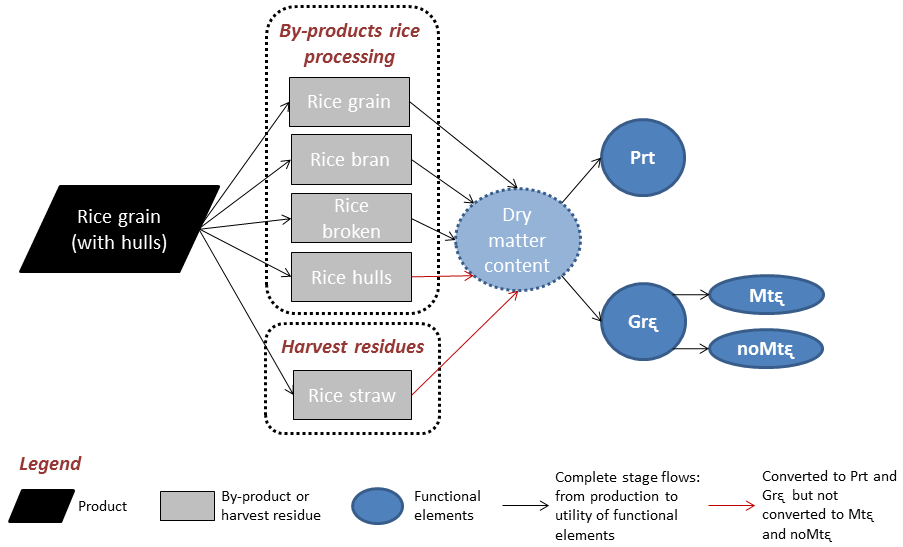


Figure S3 – Rice grain partitioning into products, by-products and harvest residues and their conversions to functional elements.

*Maize grain*

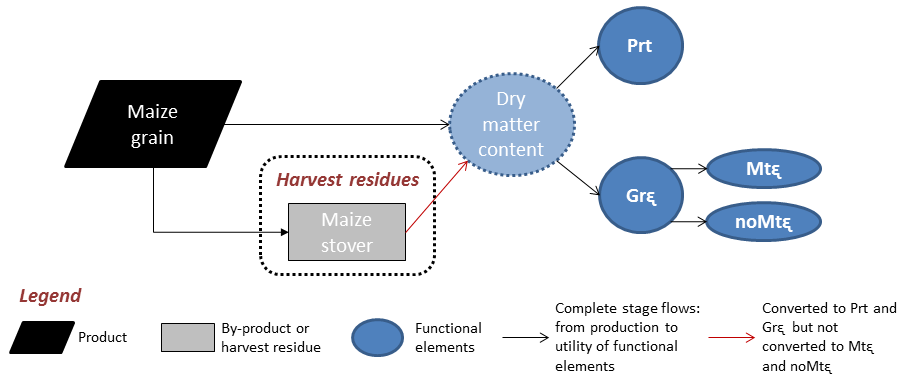


Figure S4 – Maize grain partitioning into products, by-products and harvest residues and their conversions to functional elements.

*Soybean seed*

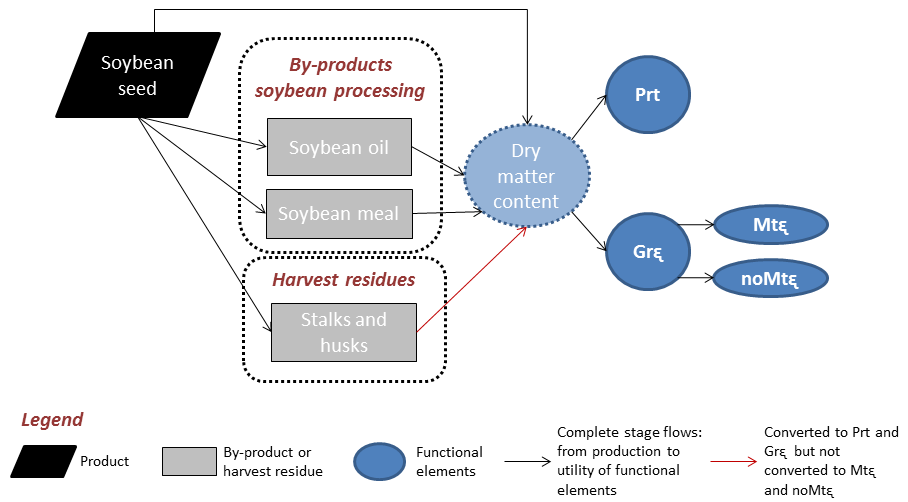


Figure S5 – Soybean seed partitioning into products, by-products and harvest residues and their conversions to functional elements.

*Wheat grain*

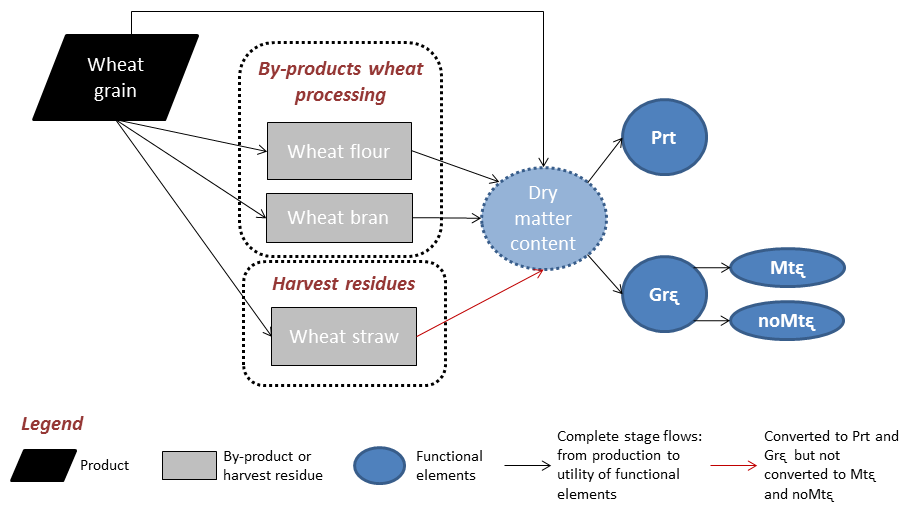


Figure S6 – Wheat grain partitioning into products, by-products and harvest residues and their conversions to functional elements.

*Cocoa beans*

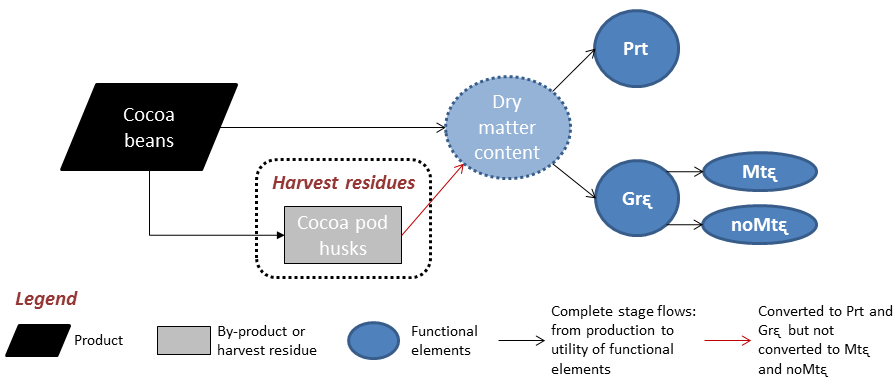


Figure S7 – Cocoa beans partitioning into products, by-products and harvest residues and their conversions to functional elements.

*Coffee beans*

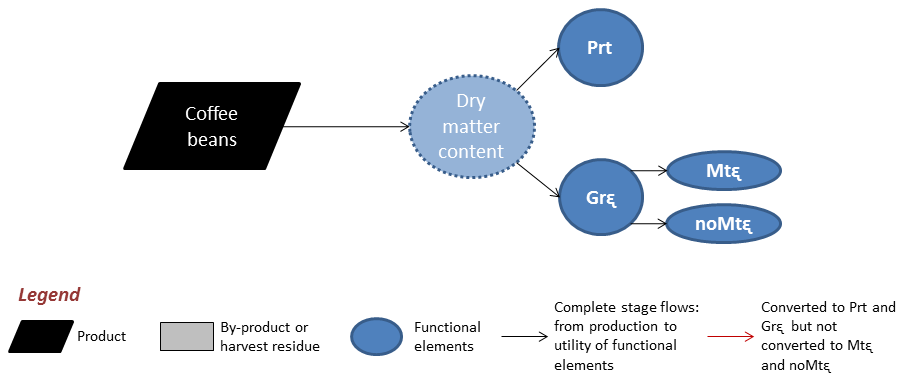


Figure S8 – Coffee beans partitioning into products, by-products and harvest residues and their conversions to functional elements.

*Banana bunches*

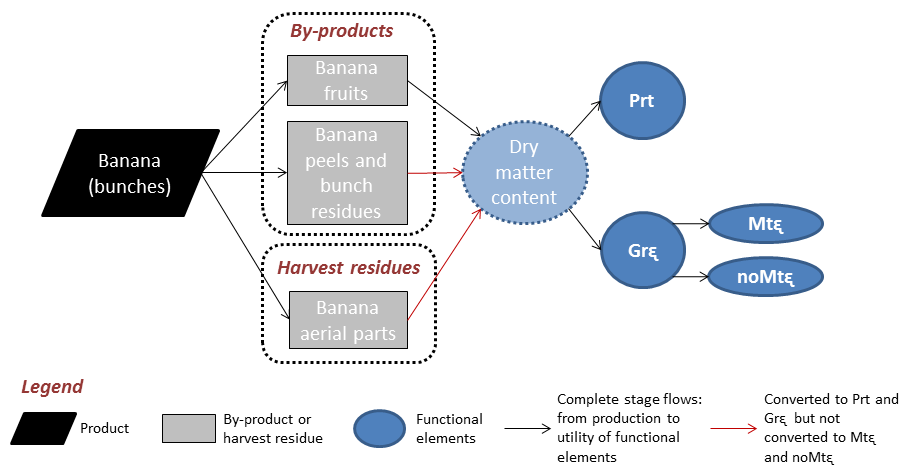


Figure S9 – Banana bunches partitioning into products, by-products and harvest residues and their conversions to functional elements.

*Orange fruits*

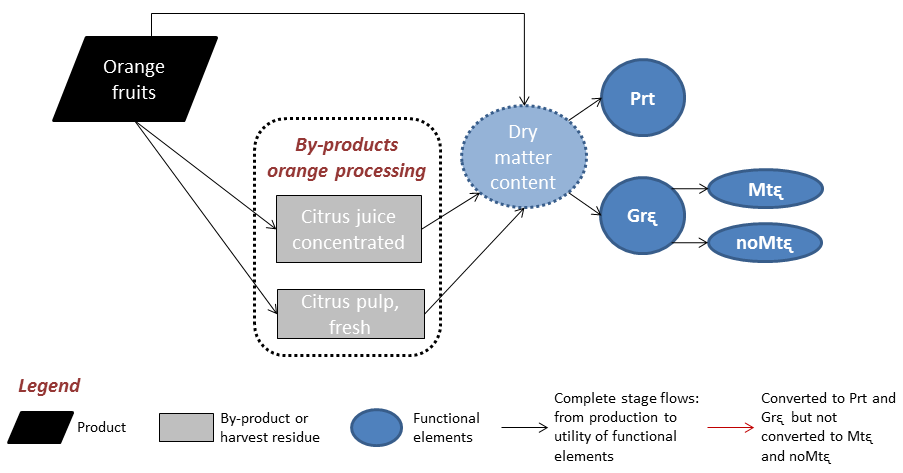


Figure S10 – Orange fruits partitioning into products, by-products and harvest residues and their conversions to functional elements.

*Cassava tuber*

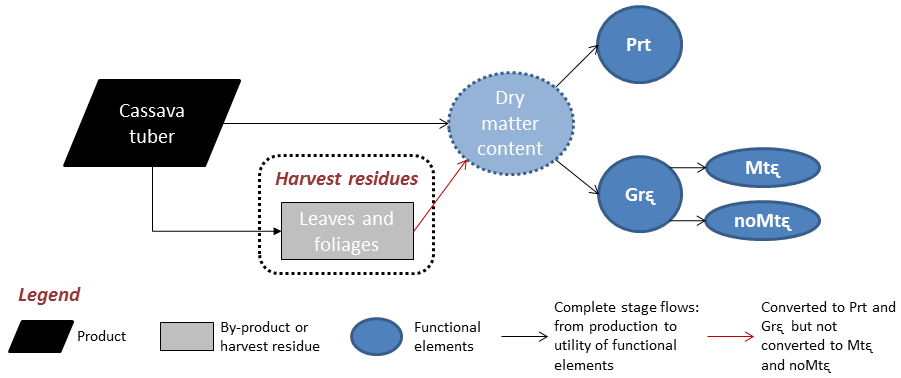


Figure S11 – Cassava tuber partitioning into products, by-products and harvest residues and their conversions to functional elements.

*Sugarcane (sugar production)*

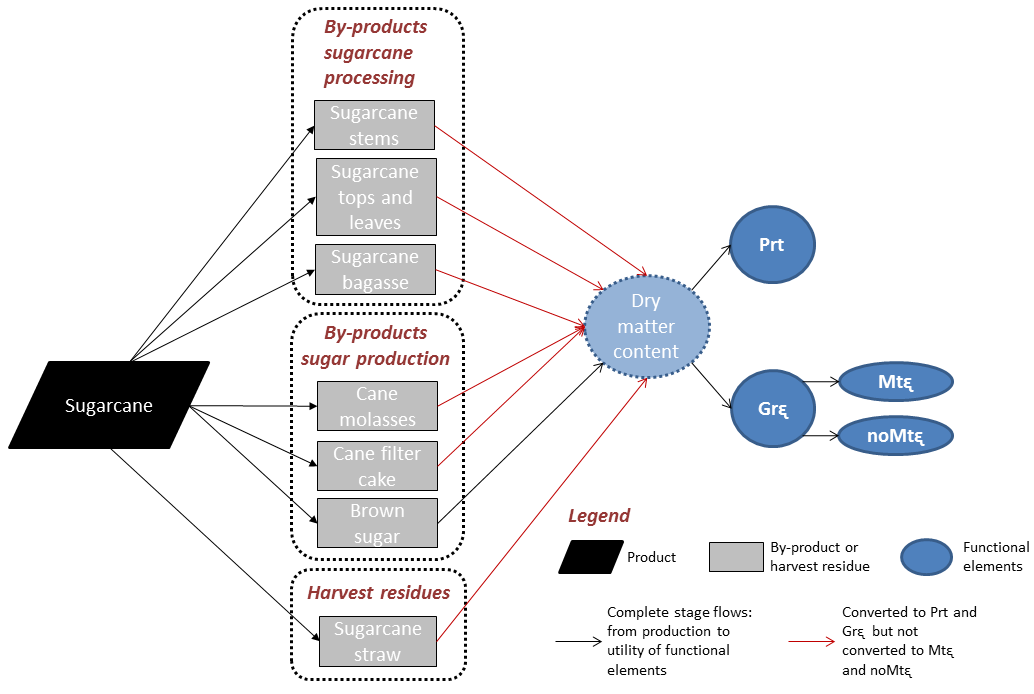


Figure S12 – Sugarcane partitioning into products, by-products and harvest residues and their conversions to functional elements. Sugar production stage flows.

*Sugarcane (ethanol production)*

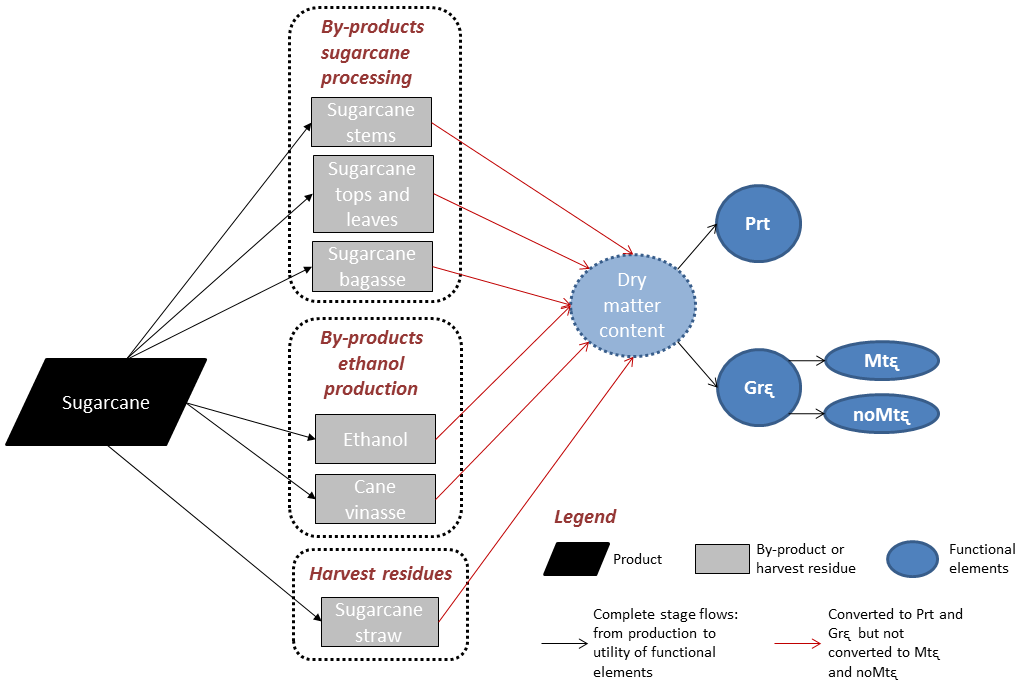


Figure S13 – Sugarcane partitioning into products, by-products and harvest residues and their conversions to functional elements. Ethanol production stage flows.

*Animal carcass*

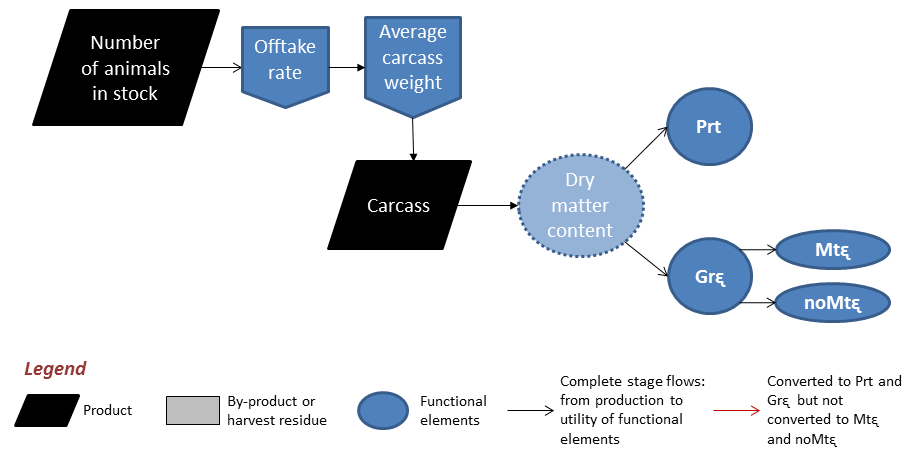


Figure S14 – Animal carcass conversion to functional elements. Offtake rate is defined as the proportion of animals sold or consumed in a year in comparison to animals in stock.

*Other animal foodstuff*

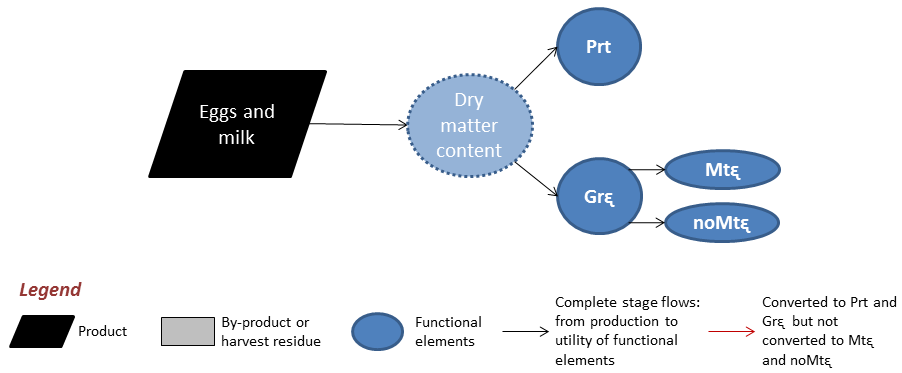


Figure S15 – Eggs and milk conversion to functional elements.

*Feed to meat conversion*

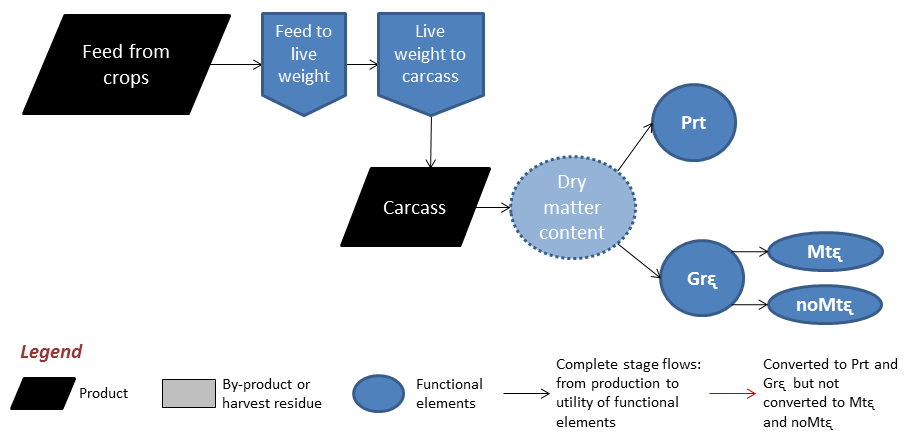


Figure S16 – Feed to carcass conversion coefficients.

### Text S1. Assumed values on the partitioning of agricultural crops and livestock production into functional elements

As illustrated above, all modeled stage flows start from the agricultural products themselves and continue first with their transformation to dry matter (DM) content and then with their transformation to functional elements, i.e., protein (Prt), gross energy (Grᶓ) and metabolizable energy (Mtᶓ) contents. The calculation of Mtᶓ depends on the agricultural product allocation (food, feed, energy, field residue, fertilizer, industrial processing, and waste), in that only products allocated to either food or feed will have their Mtᶓ content calculated based on the Mtᶓ factors for humans, pigs or chickens.

Before functional elements can be obtained, the model implements the partitioning of the dry matter content of each agricultural product to specific sub-components or by-products based on a percentage of the DM content (% DM basis in Table S1). Further, each sub-component or by-product is converted to DM based on their representative shares in total product DM (% DM as-is in Table S1). For example, in Table S1, the product “soybean seed” has two sub-components, each one accounting for a specific share of the entire soybean production (20% allocated as soybean seeds and 80% allocated for industrial soybean processing). In this example, if one ton of soybean is produced, the model will allocate 200 kg as soybean seeds and 800 kg to be designated for oil extraction. Soybean seed is considered to be directly consumed by humans and its contents of DM, Prt, Grᶓ, and Mtᶓ are then calculated. The soybean processing sub-component is further decomposed in soybean oil (15%, or 120 kg in the given example) and soybean meal (85%, or 680 kg in the given example), and the amount of each sub-component is then converted to DM and latter to functional elements.

For the agricultural products allocated for any industrial process (i.e., rice, sugarcane, orange, soybean, and wheat), the total estimation of functional elements *production* and *utility* are not equivalent in quantity due to the losses and additions (other inputs) inherent to industrial processing steps. In average, the observed difference between *production* and *utility* was 4% and 13% respectively for protein and gross energy, with the biggest difference being observed for sugarcane gross energy (54%). Without considering sugarcane, the average difference between gross energy *production* and *utility* was only 3%. For the sake of clarity, we decided to present the results of *functional elements* *production* as being the sum of *functional elements* *utility*, making the total values of *production* and *utility* to be exactly the same.

Finally, the model accounts for the production of field residues based on the concept of harvest index, which is defined as the weight of a harvested product as a percentage of the total plant weight of a crop. Following the “soybean seed” example, this product has a harvest index of 0.5, what means that for each kilogram (kg) of soybean produced there is another kg produced of harvest residues (soybean stalks and husks in this case). Estimated field residues are then transformed to DM and Grᶓ.

Following we present the assumed values used on the partitioning and the allocation of agricultural crops and livestock stage flows (Tables S1, S2, S3).

Table S1 - Assumed values on partition and allocation of agricultural crops stage flows.

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Agriculture crops production** | **Harvest Index** | | **Partition (% DM basis)** | | **DM Factor (% as-is)** | **Prt (% DM)** | **Grᶓ (GJ/tonne DM)** | | **Human Mtᶓ (GJ/tonne DM)** | | **Pig Mtᶓ (GJ/tonne DM)** | | **Chicken Mtᶓ (GJ/tonne DM)** | | **Allocation** |
| **Common bean** | 0.40 b | | - | | 89.1c | 24.8 c | 18.6c | | 13.1 d | | - | | - | | Food |
| Harvest residues |  | |  | |  |  |  | |  | |  | |  | |  |
| Tops and leaves | 0.60 b | | - | | 88.0 c | 7.1 c | 17.9 c | | - | | - | | - | | Field residue |
| **Cotton seed (whole)** | 0.60 e | | - | | 92.3 c | 21.8 c | 23.8 c | | - | | - | | - | | Industrial processing |
| Cotton oil |  | | 20.0 c | | 100.0 a | 0.0 a | 39.3 a | | 37.0 a | | - | | - | | Food |
| Cotton seed meal |  | | 70.0 c | | 92.9 c | 37.4 c | 21.5 c | | - | | 12.3 c | | 9.4 c | | Feed |
| Cotton seed residual linter |  | | 10.0 c | | 94.7 s | 0.0 s | 39.6 s | | - | | - | | - | | Energy |
| Harvest residues | 0.40 e | |  | |  |  |  | |  | |  | |  | |  |
| Cotton straw |  | | 70.0 c | | 75.7 c | 6.4 c | 18.8 c | | - | | - | | - | | Field residue |
| Cotton leaves |  | | 30.0 c | | 27.3 c | 12.2 c | 19.0 c | | - | | - | | - | | Field residue |
| **Rice grain (with hulls)** | 0.45 a | | - | | 90.1 c | 9.8 c | 18.4 c | | - | | - | | - | | Industrial processing |
| Rice grain (polished) |  | | 50.0 c | | 89.2 c | 10.4 c | 18.0 c | | 16.7 a | | - | | - | | Food |
| Rice bran |  | | 10.0 c | | 90.1 c | 14.8 c | 21.2 c | | - | | 15.6 c | | 12.7 c | | Feed |
| Rice broken |  | | 20.0 c | | 89.2 c | 10.4 c | 18.0 c | | - | | 13.2 c | | 10.7 c | | Feed |
| Rice hulls |  | | 20.0 c | | 91.9 c | 3.7 c | 16.3 c | | - | | - | | - | | Energy |
| Harvest residues |  | |  | |  |  |  | |  | |  | |  | | - |
| Rice straw | 0.55 a | | - | | 92.8 c | 4.2 c | 15.5 c | | - | | - | | - | | Field residue |
| **Maize grain** | 0.50 f | | - | | 88.0 a | 10.0 a | 18.8 a | | - | | - | | - | | - |
| Maize grains (human share) |  | | 40.0 g† | | 88.0 a | 10.0 a | 18.8 a | | 16.0 a | | - | | - | | Food |
| Maize grains (animal share) |  | | 60.0 g† | | 88.0 a | 10.0 a | 18.8 a | | - | | 16.4 a | | 15.7 a | | Feed |
| Harvest residues |  | |  | |  |  |  | |  | |  | |  | |  |
| Maize stover | 0.50 f | | - | | 85.0 a | 5.5 a | 16.5 a | | - | | - | | - | | Field residue |
| **Soybean seed** | 0.50 h | | 20.0 i† | | 91.0 a | 40.0 a | 23.4 a | | 19.0 a | | - | | - | | Food |
| Soybean processing |  | | 80.0 i† | |  |  |  | |  | |  | |  | |  |
| Soybean oil |  | | 15.0 c | | 100.0 a | 0.0 a | 39.3 a | | 37.0 a | | - | | - | | Food |
| Soybean meal |  | | 85.0 c | | 87.9 c | 51.8 c | 19.7 c | | - | | 16.8 c | | 10.9 c | | Feed |
| Harvest residues |  | |  | |  |  |  | |  | |  | |  | |  |
| Soybean stalks and husks | 0.50 h | | - | | 90.0 a | 5.0 a | 16.5 a | | - | | - | | - | | Field residue |
| **Wheat grain** | 0.40 j | | - | | 88.0 a | 13.0 a | 18.4 a | | - | | - | | - | | Industrial processing |
| Wheat flour |  | | 80.0 k† | | 86.0 a | 11.5 a | 18.3 a | | 16.0 a | | - | | - | | Food |
| Wheat bran |  | | 20.0 k† | | 87.0 c | 17.3 c | 18.9 c | | - | | 10.8 c | | 7.8 c | | Feed |
| Harvest residues |  | |  | |  |  |  | |  | |  | |  | |  |
| Wheat straw | 0.60 j | | - | | 91.0 c | 4.2 c | 18.5 c | | - | | - | | - | | Field residue |
| **Agriculture crops production** | | **Harvest Index** | | **Partition (% DM basis)** | **DM Factor (% as-is)** | **Prt (% DM)** | **Grᶓ (GJ/tonne DM)** | **Human Mtᶓ (GJ/tonne DM)** | | **Pig Mtᶓ (GJ/tonne DM)** | | **Chicken Mtᶓ (GJ/tonne DM)** | | **Allocation** | |
| **Cocoa beans** | | - | | - | 97.0 b | 20.0 b | 17.8 b | 9.6 b | | - | | - | | Food | |
| Harvest residues | |  | |  |  |  |  |  | |  | |  | |  | |
| Cocoa pod husks | | - | | 300.0 c | 91.0 c | 7.7 c | 17.4 c | - | | - | | - | | Field residue | |
| **Coffee beans** | | - | |  | 94.5 d | 14.6 d | 19.9 a | 16.6 d | |  | |  | | Food | |
| **Banana bunches** | | 0.125 l | |  |  |  |  |  | |  | |  | | - | |
| Banana fruits | | - | | 70.0 m | 22.0 c | 5.3 c | 17.2 c | 15.2 b | | - | | - | | Food | |
| Banana peels and bunch residues | | - | | 30.0 m | 15.4 c | 7.1 c | 18.4 c | - | | - | | - | | Waste | |
| Harvest residues | |  | |  |  |  |  |  | |  | |  | | - | |
| Banana aerial parts | | 0.875 l | | - | 16.0 c | 16.6 c | 17.7 c | - | | - | | - | | Field residue | |
| **Orange fruits** | | - | | 30.0 n r† | 13.5 c | 7.4 c | 17.6 c | 9.0 a | | - | | - | | Food | |
| Orange processing | | - | | 70.0 n r† |  |  |  |  | |  | |  | | Industrial processing | |
| Citrus pulp (fresh) | | - | | 50.0r | 23.0 c | 6.0 c | 18.1 c | - | | 13.0 c | | 5.8 c | | Feed | |
| Citrus juice (concentraded) | | - | | 4.8r | 42.3 o | 6.0 o | 15.8 o | 9.0 a | | - | | - | | Food | |
| **Cassava tuber** | | 0.55 a | | - | 37.6 c | 2.6 c | 17.1 c | 12.8 a | | - | | - | | Food | |
| Harvest residues | |  | |  |  |  |  |  | |  | |  | |  | |
| Cassava leaves and foliage | | 0.45 a | | - | 22.5 c | 24.9 c | 19.9 c | - | | - | | - | | Field residue | |
| **Sugarcane** | | 0.60 a | |  |  |  |  |  | |  | |  | |  | |
| Sugarcane tops and leaves | |  | | 8.0 a | 28.0 c | 5.0 c | 17.0 c | - | | - | | - | | Energy | |
| Sugarcane stems | |  | | 92.0 a | 27.0 c | 1.5 c | 17.0 c | - | | - | | - | | Industrial processing | |
| Harvest residues | |  | |  |  |  |  |  | |  | |  | |  | |
| Sugarcane straw | | 0.40 a | | - | 42.4 c | 5.2 c | 17.0 c | - | | - | | - | | Field residue | |
| Sugarcane stems processing | |  | |  |  |  |  |  | |  | |  | |  | |
| Sugarcane bagasse | |  | | 28.0 p | 46.0 c | 1.8 c | 18.4 c | - | | - | | - | | Energy | |
| By-Products (sugar production) | |  | | 43.0 q† |  |  |  |  | |  | |  | |  | |
| Brown sugar | |  | | 11.8 p | 97.5 d | 0.0 d | 17.5 a | 16.2 d | | - | | - | | Food | |
| Sugarcane molasses | |  | | 5.0 p | 73.0 c | 5.5 c | 14.7 c | - | | - | | - | | Industrial processing | |
| Sugarcane filter cake | |  | | 3.0 p | 25.0 c | 5.5 c | 24.6 c | - | | - | | - | | Fertilizer | |
| By-Products (ethanol production) | |  | | 57.0 q† |  |  |  |  | |  | |  | |  | |
| Ethanol | |  | | 6.3 p | - | - | - | - | | - | | - | | Energy | |
| Sugarcane vinasse | |  | | 109.7 p | 6.1 c | 12.2 c | 12.8 c | - | | - | | - | | Fertilizer | |

Sources: a WIRSENIUS et al., 2010; b Adapted from similar crops in WIRSENIUS et al., 2010; c FEEDIPEDIA, 2015; d FRIDA FOODDATA, 2017; e ABRAPA, 2016; f DURÃES et al., 2002; g ABIMILHO, 2016; h BRAGA and COSTA, 1983; i ABIOVE, 2016; j COELHO et al., 1998; k ABITRIGO, 2016; l FERIOTTI, 2010; m EMBRAPA, 2009; n BOTEON, 2008; o SELFNUTRITIONDATA, 2014; p EMBRAPA, 2016; q UNICA, 2016; r NEVES et al., 2010; s BEZERRA et al., 2017; † Numbers represent the historical average of the agricultural crops production allocation in domestic market, which were calculated based on the cited references. The exported production share received the same allocation of the domestic consumed production share.

Table S2 - Assumed values on partition and allocation of livestock stage flows.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Livestock production** | **Average carcass weight (ton)** | **Offtake rateg** | **Carcass production (ton)** | **DM Factor (% as-is)** | **Protein (% DM)** | **Grᶓ (GJ/tonne DM)** | **Human Mtᶓ (GJ/tonne DM)** | **Allocation** |
| **Animal conversion rates - carcass** |  |  |  |  |  |  |  |  |
| Bulls/Cattle carcass | - | - | 0.0352 a | 40.7 b | 46.2 b | 26.1 b | 17.6 b | Food |
| Goats and sheep carcass | 0.02 c | 25.0%c | 0.0039 c | 42.9 d | 42.5 d | 26.5 d | 17.9 d | Food |
| Horses, donkeys and mules carcass | 0.20 e | 5.0% f | 0.0101 e | 50.0 d | 41.7 d | 26.5 d | 17.9 d | Food |
| Pigs | - | - | 0.0427 a | 45.4 b | 38.6 b | 29.5 b | 23.6 b | Food |
| Poultries | - | - | 0.0051 a | 40.5 b | 43.5 b | 26.0 b | 16.6 b | Food |
| **Animal conversion rates - milk & egg** |  |  |  |  |  |  |  |  |
| Cattle milk | - | - | - | 12.2 b | 26.5 b | 31.5 b | 21.9 b | Food |
| Goats and sheep milk | - | - | - | 12.2 b | 26.5 b | 31.5 b | 21.9 b | Food |
| Chicken eggs | - | - | - | 32.3 b | 35.0 b | 29.1 b | 17.2 b | Food |

Sources: a Calculated based on ABATE (IBGE, 2006) and Agricultural Census (IBGE, 2006); b WIRSENIUS et al., 2010; c JUNIOR and NOGUEIRA, 2004; d Adapted from WIRSENIUS et al., 2010; e FURTADO et al., 2010; f Estimated value; g Offtake rate is defined as the proportion of animals sold or consumed in a year in comparison to animals in stock.

Table S3 - Assumed values on feed to meat conversion.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Animal conversion rates (feed to meat)** | **Feed to live weight conversion** | **Feed share** | **Live weight to carcass conversion** | **DM Factor (% as-is)** | **Protein (% DM)** | **Grᶓ (GJ/tonne DM)** | **Human Mtᶓ (GJ/tonne DM)** | **Allocation** |
| Pig | 0.25 a | 0.5 b | 0.7 c | 45.4 d | 38.6 d | 29.5 d | 23.6 d | Food |
| Chicken | 0.50 a | 0.5 b | 0.6 c | 40.5 d | 43.5 d | 26.0 d | 16.6 d | Food |

Sources: a GODFRAY et al., 2010; b Assumed value; c SMIL, 2013; d WIRSENIUS et al., 2010.

**SUPPLEMENTARY TABLES**

This section presents aggregated results of Production Functionality for Brazilian states and regions (Table S4 to Table S14).

Table S4 – Functional elements production from crops.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **States** | **PrtCr (kton)** | | | | **GrᶓCr (Peta joule)** | | | |
| **1975** | **1985** | **1995** | **2006** | **1975** | **1985** | **1995** | **2006** |
| Rondônia | 32 | 77 | 65 | 115 | 6 | 15 | 12 | 16 |
| Acre | 16 | 16 | 22 | 39 | 3 | 3 | 4 | 8 |
| Amazonas | 59 | 77 | 85 | 34 | 10 | 12 | 13 | 6 |
| Roraima | 3 | 7 | 12 | 18 | 0 | 1 | 2 | 3 |
| Pará | 150 | 220 | 158 | 302 | 28 | 41 | 29 | 55 |
| Amapá | 6 | 3 | 2 | 1 | 1 | 1 | 0 | 0 |
| Tocantins | 0 | 96 | 60 | 266 | 0 | 19 | 12 | 30 |
| Maranhão | 207 | 218 | 227 | 676 | 44 | 47 | 42 | 101 |
| Piauí | 70 | 85 | 92 | 382 | 14 | 17 | 18 | 49 |
| Ceará | 185 | 195 | 195 | 505 | 34 | 36 | 36 | 91 |
| Rio Grande do Norte | 44 | 90 | 92 | 90 | 9 | 22 | 25 | 19 |
| Paraíba | 111 | 203 | 237 | 171 | 24 | 49 | 64 | 38 |
| Pernambuco | 413 | 644 | 444 | 563 | 109 | 175 | 116 | 142 |
| Alagoas | 270 | 523 | 444 | 762 | 78 | 159 | 134 | 227 |
| Sergipe | 41 | 65 | 43 | 73 | 9 | 16 | 10 | 16 |
| Bahia | 416 | 649 | 705 | 1,855 | 70 | 107 | 96 | 227 |
| Minas Gerais | 598 | 1,271 | 1,389 | 2,329 | 124 | 235 | 251 | 406 |
| Espírito Santo | 101 | 226 | 183 | 174 | 18 | 42 | 32 | 38 |
| Rio de Janeiro | 205 | 246 | 138 | 91 | 53 | 63 | 39 | 25 |
| São Paulo | 1,649 | 3,751 | 4,010 | 5,652 | 365 | 973 | 1,113 | 1,630 |
| Paraná | 2,351 | 3,467 | 4,299 | 5,879 | 312 | 506 | 612 | 817 |
| Santa Catarina | 490 | 729 | 710 | 1,209 | 88 | 120 | 125 | 211 |
| Rio Grande do Sul | 2,730 | 3,513 | 2,987 | 5,051 | 349 | 450 | 423 | 670 |
| Mato Grosso do Sul | 185 | 969 | 1,114 | 2,217 | 31 | 110 | 148 | 283 |
| Mato Grosso | 75 | 861 | 2,330 | 5,990 | 16 | 96 | 268 | 629 |
| Goiás | 396 | 963 | 1,486 | 3,152 | 81 | 148 | 219 | 400 |
| Distrito Federal | 2 | 32 | 40 | 77 | 0 | 3 | 6 | 9 |
| **Brazil** | **10,805** | **19,197** | **21,571** | **37,674** | **1,879** | **3,467** | **3,850** | **6,149** |
| **Regions** |  |  |  |  |  |  |  |  |
| North | 265 | 496 | 404 | 776 | 49 | 92 | 73 | 118 |
| Northeast | 1,757 | 2,672 | 2,480 | 5,077 | 392 | 628 | 540 | 912 |
| Southeast | 2,554 | 5,494 | 5,721 | 8,245 | 560 | 1,314 | 1,435 | 2,099 |
| South | 5,571 | 7,709 | 7,996 | 12,140 | 749 | 1,076 | 1,160 | 1,698 |
| Central-west | 658 | 2,825 | 4,970 | 11,436 | 128 | 357 | 642 | 1,322 |

Table S5 – Occupied area by agricultural crops and pastures.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **States** | **Crops land use (kha)** | | | | **Pastures land use (kha)** | | | |
| **1975** | **1985** | **1995** | **2006** | **1975** | **1985** | **1995** | **2006** |
| Rondônia | 193 | 531 | 497 | 504 | 225 | 1,101 | 2,922 | 4,845 |
| Acre | 41 | 69 | 106 | 164 | 124 | 326 | 614 | 1,051 |
| Amazonas | 205 | 287 | 332 | 866 | 192 | 476 | 529 | 820 |
| Roraima | 27 | 28 | 186 | 116 | 1,353 | 1,247 | 1,543 | 724 |
| Pará | 704 | 1,079 | 1,257 | 1,885 | 3,037 | 6,596 | 7,456 | 11,069 |
| Amapá | 25 | 33 | 58 | 61 | 350 | 479 | 245 | 267 |
| Tocantins | - | 655 | 643 | 632 | - | 10,651 | 11,078 | 8,113 |
| Maranhão | 1,056 | 1,305 | 1,815 | 2,453 | 3,809 | 5,447 | 5,311 | 5,752 |
| Piauí | 687 | 1,075 | 1,245 | 1,351 | 3,700 | 3,550 | 2,398 | 2,690 |
| Ceará | 2,140 | 2,376 | 2,086 | 1,922 | 3,602 | 3,493 | 2,632 | 2,614 |
| Rio Grande do Norte | 826 | 1,029 | 805 | 675 | 1,668 | 1,535 | 1,246 | 1,200 |
| Paraíba | 1,141 | 1,229 | 884 | 663 | 1,969 | 1,982 | 1,852 | 1,680 |
| Pernambuco | 1,561 | 1,850 | 1,473 | 1,696 | 2,718 | 2,057 | 2,131 | 1,975 |
| Alagoas | 719 | 998 | 921 | 904 | 770 | 806 | 862 | 872 |
| Sergipe | 239 | 314 | 310 | 317 | 1,169 | 1,275 | 1,154 | 945 |
| Bahia | 2,664 | 4,160 | 4,817 | 5,201 | 11,219 | 15,004 | 14,490 | 12,863 |
| Minas Gerais | 3,981 | 5,340 | 4,915 | 5,325 | 31,931 | 28,924 | 25,349 | 18,212 |
| Espírito Santo | 654 | 1,072 | 874 | 751 | 2,131 | 1,880 | 1,821 | 1,342 |
| Rio de Janeiro | 618 | 625 | 375 | 349 | 1,859 | 1,757 | 1,545 | 1,290 |
| São Paulo | 5,180 | 6,525 | 5,487 | 6,975 | 11,356 | 9,926 | 9,062 | 6,972 |
| Paraná | 5,628 | 6,063 | 5,488 | 6,512 | 4,983 | 6,000 | 6,677 | 4,733 |
| Santa Catarina | 1,434 | 1,869 | 1,722 | 1,723 | 2,404 | 2,469 | 2,339 | 1,707 |
| Rio Grande do Sul | 5,929 | 6,592 | 6,242 | 6,955 | 13,773 | 12,963 | 11,680 | 9,243 |
| Mato Grosso do Sul | 1,275 | 1,903 | 1,502 | 2,239 | 20,793 | 21,803 | 21,811 | 21,055 |
| Mato Grosso | 501 | 2,129 | 3,446 | 6,417 | 11,243 | 16,404 | 21,452 | 22,053 |
| Goiás | 2,561 | 2,928 | 2,419 | 3,785 | 29,164 | 20,895 | 19,405 | 15,836 |
| Distrito Federal | 13 | 85 | 66 | 97 | 109 | 142 | 96 | 80 |
| **Brazil** | **40,002** | **52,148** | **49,971** | **60,540** | **165,652** | **179,188** | **177,700** | **160,001** |
| **Regions** | | | | | | | | |
| North | 1,195 | 2,681 | 3,079 | 4,228 | 5,281 | 20,876 | 24,387 | 26,889 |
| Northeast | 11,033 | 14,336 | 14,356 | 15,182 | 30,624 | 35,148 | 32,076 | 30,591 |
| Southeast | 10,432 | 13,562 | 11,651 | 13,402 | 47,277 | 42,487 | 37,777 | 27,815 |
| South | 12,991 | 14,523 | 13,452 | 15,189 | 21,160 | 21,432 | 20,697 | 15,683 |
| Central-west | 4,350 | 7,046 | 7,434 | 12,539 | 61,310 | 59,244 | 62,764 | 59,024 |

Table S6 - Crops potentially maximum utility for food.

**(Peta joule)**

**(Peta joule)**

**(kton)**

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **States** |  |  |  |  |  |  |  |  |  |  |  |  |
| **1975** | **1985** | **1995** | **2006** | **1975** | **1985** | **1995** | **2006** | **1975** | **1985** | **1995** | **2006** |
| Rondônia | 15 | 48 | 42 | 88 | 3 | 7 | 6 | 9 | 2 | 6 | 5 | 8 |
| Acre | 5 | 6 | 7 | 17 | 1 | 1 | 2 | 4 | 1 | 1 | 1 | 3 |
| Amazonas | 10 | 12 | 12 | 8 | 6 | 6 | 6 | 3 | 4 | 4 | 5 | 2 |
| Roraima | 1 | 3 | 4 | 11 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 |
| Pará | 41 | 72 | 52 | 114 | 15 | 20 | 15 | 31 | 12 | 16 | 12 | 24 |
| Amapá | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Tocantins | - | 52 | 33 | 219 | - | 8 | 5 | 16 | - | 7 | 5 | 14 |
| Maranhão | 98 | 97 | 122 | 455 | 21 | 20 | 18 | 50 | 18 | 17 | 16 | 44 |
| Piauí | 34 | 42 | 47 | 290 | 6 | 8 | 8 | 24 | 5 | 6 | 7 | 22 |
| Ceará | 62 | 60 | 74 | 256 | 13 | 13 | 13 | 40 | 10 | 11 | 11 | 33 |
| Rio Grande do Norte | 13 | 14 | 14 | 31 | 3 | 5 | 5 | 6 | 2 | 4 | 4 | 5 |
| Paraíba | 30 | 33 | 27 | 45 | 7 | 10 | 11 | 9 | 6 | 9 | 10 | 8 |
| Pernambuco | 50 | 59 | 52 | 89 | 22 | 31 | 21 | 28 | 19 | 27 | 18 | 24 |
| Alagoas | 21 | 17 | 23 | 53 | 12 | 23 | 20 | 36 | 11 | 21 | 18 | 32 |
| Sergipe | 10 | 13 | 13 | 29 | 3 | 5 | 3 | 7 | 3 | 4 | 3 | 5 |
| Bahia | 146 | 258 | 458 | 1,219 | 29 | 41 | 43 | 106 | 21 | 31 | 36 | 92 |
| Minas Gerais | 320 | 749 | 875 | 1,483 | 55 | 105 | 116 | 178 | 47 | 90 | 99 | 154 |
| Espírito Santo | 41 | 103 | 108 | 67 | 8 | 18 | 17 | 13 | 6 | 15 | 14 | 11 |
| Rio de Janeiro | 17 | 23 | 8 | 7 | 9 | 11 | 6 | 4 | 8 | 10 | 6 | 4 |
| São Paulo | 627 | 861 | 704 | 697 | 109 | 207 | 209 | 273 | 95 | 183 | 185 | 244 |
| Paraná | 1,833 | 2,412 | 3,121 | 4,413 | 171 | 234 | 285 | 389 | 150 | 206 | 252 | 344 |
| Santa Catarina | 300 | 465 | 459 | 768 | 45 | 59 | 62 | 104 | 38 | 50 | 53 | 90 |
| Rio Grande do Sul | 2,187 | 2,816 | 2,327 | 4,062 | 180 | 231 | 213 | 346 | 161 | 207 | 191 | 311 |
| Mato Grosso do Sul | 127 | 767 | 826 | 1,685 | 15 | 53 | 69 | 130 | 13 | 48 | 61 | 117 |
| Mato Grosso | 42 | 697 | 1,854 | 4,801 | 7 | 48 | 128 | 328 | 6 | 44 | 117 | 299 |
| Goiás | 233 | 662 | 1,049 | 2,390 | 37 | 66 | 102 | 181 | 32 | 59 | 90 | 163 |
| Distrito Federal | 1 | 27 | 31 | 61 | 0 | 2 | 3 | 5 | 0 | 2 | 3 | 4 |
| **Brazil** | **6,265** | **10,367** | **12,342** | **23,357** | **777** | **1,234** | **1,387** | **2,320** | **672** | **1,079** | **1,220** | **2,059** |
| **Regions** | | | | | | | | | | | | |
| North | 74 | 192 | 151 | 457 | 25 | 43 | 35 | 64 | 20 | 35 | 29 | 53 |
| Northeast | 463 | 593 | 829 | 2,468 | 116 | 156 | 143 | 306 | 95 | 131 | 122 | 265 |
| Southeast | 1,006 | 1,735 | 1,695 | 2,253 | 181 | 341 | 348 | 468 | 156 | 298 | 304 | 413 |
| South | 4,320 | 5,694 | 5,906 | 9,243 | 396 | 524 | 559 | 839 | 349 | 464 | 495 | 745 |
| Central-west | 402 | 2,153 | 3,760 | 8,936 | 59 | 169 | 301 | 643 | 52 | 152 | 271 | 583 |

**Table S7** – Pasture production and utility for food**.**

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **States** |  |  | **(kton)** |  |  |  |  | **(Peta joule)** | **(Peta joule)** |  |  |  |
| **1975** | **1985** | **1995** | **2006** | **1975** | **1985** | **1995** | **2006** | **1975** | **1985** | **1995** | **2006** |
| Rondônia | 0.4 | 5.2 | 26.5 | 57.0 | 0.0 | 0.3 | 1.5 | 3.2 | 0.0 | 0.2 | 1.0 | 2.2 |
| Acre | 0.8 | 2.3 | 5.7 | 11.6 | 0.0 | 0.1 | 0.3 | 0.7 | 0.0 | 0.1 | 0.2 | 0.4 |
| Amazonas | 1.4 | 2.9 | 5.2 | 8.1 | 0.1 | 0.2 | 0.3 | 0.5 | 0.1 | 0.1 | 0.2 | 0.3 |
| Roraima | 1.7 | 2.1 | 2.7 | 3.6 | 0.1 | 0.1 | 0.2 | 0.2 | 0.1 | 0.1 | 0.1 | 0.1 |
| Pará | 10.3 | 25.0 | 43.0 | 95.7 | 0.6 | 1.4 | 2.4 | 5.4 | 0.4 | 1.0 | 1.6 | 3.7 |
| Amapá | 0.5 | 0.6 | 1.2 | 1.7 | 0.0 | 0.0 | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.1 |
| Tocantins | - | 24.4 | 35.1 | 44.0 | - | 1.4 | 2.0 | 2.5 | - | 0.9 | 1.3 | 1.7 |
| Maranhão | 13.4 | 23.8 | 27.5 | 39.8 | 0.8 | 1.4 | 1.6 | 2.3 | 0.5 | 0.9 | 1.1 | 1.5 |
| Piauí | 11.3 | 13.4 | 14.1 | 13.5 | 0.7 | 0.8 | 0.8 | 0.8 | 0.4 | 0.5 | 0.5 | 0.5 |
| Ceará | 15.1 | 19.2 | 18.4 | 16.5 | 0.9 | 1.1 | 1.1 | 0.9 | 0.6 | 0.7 | 0.7 | 0.6 |
| Rio Grande do Norte | 5.4 | 6.6 | 6.9 | 6.6 | 0.3 | 0.4 | 0.4 | 0.4 | 0.2 | 0.3 | 0.3 | 0.3 |
| Paraíba | 8.6 | 9.9 | 9.7 | 9.8 | 0.5 | 0.6 | 0.6 | 0.6 | 0.3 | 0.4 | 0.4 | 0.4 |
| Pernambuco | 11.6 | 14.2 | 14.4 | 14.3 | 0.7 | 0.8 | 0.8 | 0.8 | 0.4 | 0.5 | 0.6 | 0.6 |
| Alagoas | 4.5 | 5.3 | 6.6 | 6.3 | 0.3 | 0.3 | 0.4 | 0.4 | 0.2 | 0.2 | 0.3 | 0.2 |
| Sergipe | 5.5 | 6.0 | 6.5 | 6.2 | 0.3 | 0.3 | 0.4 | 0.4 | 0.2 | 0.2 | 0.2 | 0.2 |
| Bahia | 59.2 | 67.3 | 63.1 | 73.0 | 3.4 | 3.8 | 3.6 | 4.2 | 2.3 | 2.6 | 2.4 | 2.8 |
| Minas Gerais | 135.0 | 135.3 | 135.4 | 136.8 | 7.6 | 7.7 | 7.7 | 7.7 | 5.2 | 5.2 | 5.2 | 5.2 |
| Espírito Santo | 14.2 | 11.9 | 12.1 | 12.0 | 0.8 | 0.7 | 0.7 | 0.7 | 0.5 | 0.5 | 0.5 | 0.5 |
| Rio de Janeiro | 11.2 | 12.1 | 12.2 | 13.0 | 0.6 | 0.7 | 0.7 | 0.7 | 0.4 | 0.5 | 0.5 | 0.5 |
| São Paulo | 77.4 | 82.7 | 83.1 | 70.9 | 4.4 | 4.7 | 4.7 | 4.0 | 3.0 | 3.2 | 3.2 | 2.7 |
| Paraná | 45.2 | 58.9 | 67.6 | 61.6 | 2.6 | 3.3 | 3.8 | 3.5 | 1.7 | 2.3 | 2.6 | 2.4 |
| Santa Catarina | 15.3 | 18.8 | 21.1 | 21.1 | 0.9 | 1.1 | 1.2 | 1.2 | 0.6 | 0.7 | 0.8 | 0.8 |
| Rio Grande do Sul | 93.6 | 97.0 | 92.8 | 78.8 | 5.3 | 5.5 | 5.3 | 4.5 | 3.6 | 3.7 | 3.6 | 3.0 |
| Mato Grosso do Sul | 59.6 | 100.5 | 132.0 | 137.7 | 3.4 | 5.7 | 7.5 | 7.8 | 2.3 | 3.8 | 5.0 | 5.2 |
| Mato Grosso | 20.9 | 43.9 | 96.4 | 137.9 | 1.2 | 2.5 | 5.5 | 7.8 | 0.8 | 1.7 | 3.7 | 5.3 |
| Goiás | 85.7 | 97.2 | 110.5 | 121.8 | 4.8 | 5.5 | 6.3 | 6.9 | 3.3 | 3.7 | 4.2 | 4.6 |
| Distrito Federal | 0.3 | 0.5 | 0.6 | 0.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| **Brazil** | **708** | **887** | **1,050** | **1,200** | **40** | **50** | **60** | **68** | **27** | **34** | **40** | **46** |
| **Regions** | | | | | | | | | | | | |
| North | 15 | 63 | 119 | 222 | 1 | 4 | 7 | 13 | 1 | 2 | 5 | 8 |
| Northeast | 134 | 166 | 167 | 186 | 8 | 9 | 10 | 11 | 5 | 6 | 6 | 7 |
| Southeast | 238 | 242 | 243 | 233 | 13 | 14 | 14 | 13 | 9 | 9 | 9 | 9 |
| South | 154 | 175 | 181 | 162 | 9 | 10 | 10 | 9 | 6 | 7 | 7 | 6 |
| Central-west | 166 | 242 | 340 | 398 | 9 | 14 | 19 | 22 | 6 | 9 | 13 | 15 |

**Table S8** – Crops production and utility efficiency**.**

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **States** | **(ton.ha-1)** |  |  |  | **(TJ.ha-1)** |  |  |  | **(TJ.ha-1)** |  |  |  |
| **1975** | **1985** | **1995** | **2006** | **1975** | **1985** | **1995** | **2006** | **1975** | **1985** | **1995** | **2006** |
| Rondônia | 0.08 | 0.09 | 0.08 | 0.17 | 14 | 14 | 12 | 18 | 12 | 12 | 10 | 16 |
| Acre | 0.12 | 0.08 | 0.06 | 0.11 | 34 | 18 | 16 | 23 | 27 | 14 | 13 | 19 |
| Amazonas | 0.05 | 0.04 | 0.04 | 0.01 | 28 | 20 | 19 | 3 | 21 | 15 | 14 | 3 |
| Roraima | 0.03 | 0.11 | 0.02 | 0.09 | 8 | 21 | 5 | 13 | 6 | 18 | 4 | 11 |
| Pará | 0.06 | 0.07 | 0.04 | 0.06 | 21 | 19 | 12 | 16 | 16 | 15 | 9 | 13 |
| Amapá | 0.03 | 0.02 | 0.01 | 0.01 | 17 | 8 | 3 | 2 | 13 | 6 | 2 | 2 |
| Tocantins | - | 0.08 | 0.05 | 0.35 | - | 12 | 8 | 25 | - | 11 | 7 | 23 |
| Maranhão | 0.09 | 0.07 | 0.07 | 0.19 | 20 | 16 | 10 | 20 | 17 | 13 | 9 | 18 |
| Piauí | 0.05 | 0.04 | 0.04 | 0.21 | 9 | 7 | 6 | 18 | 8 | 6 | 5 | 16 |
| Ceará | 0.03 | 0.03 | 0.04 | 0.13 | 6 | 5 | 6 | 21 | 5 | 4 | 5 | 17 |
| Rio Grande do Norte | 0.02 | 0.01 | 0.02 | 0.05 | 4 | 5 | 6 | 9 | 3 | 4 | 5 | 7 |
| Paraíba | 0.03 | 0.03 | 0.03 | 0.07 | 6 | 9 | 13 | 14 | 5 | 7 | 11 | 12 |
| Pernambuco | 0.03 | 0.03 | 0.04 | 0.05 | 14 | 17 | 14 | 17 | 12 | 15 | 12 | 14 |
| Alagoas | 0.03 | 0.02 | 0.03 | 0.06 | 17 | 23 | 22 | 40 | 15 | 21 | 20 | 35 |
| Sergipe | 0.04 | 0.04 | 0.04 | 0.09 | 13 | 15 | 10 | 21 | 11 | 12 | 8 | 17 |
| Bahia | 0.05 | 0.06 | 0.09 | 0.23 | 11 | 10 | 9 | 20 | 8 | 7 | 7 | 18 |
| Minas Gerais | 0.08 | 0.14 | 0.18 | 0.28 | 14 | 20 | 24 | 33 | 12 | 17 | 20 | 29 |
| Espírito Santo | 0.06 | 0.10 | 0.12 | 0.09 | 12 | 17 | 20 | 18 | 10 | 14 | 16 | 15 |
| Rio de Janeiro | 0.03 | 0.04 | 0.02 | 0.02 | 15 | 18 | 16 | 12 | 13 | 16 | 15 | 11 |
| São Paulo | 0.12 | 0.13 | 0.13 | 0.10 | 21 | 32 | 38 | 39 | 18 | 28 | 34 | 35 |
| Paraná | 0.33 | 0.40 | 0.57 | 0.68 | 30 | 39 | 52 | 60 | 27 | 34 | 46 | 53 |
| Santa Catarina | 0.21 | 0.25 | 0.27 | 0.45 | 31 | 32 | 36 | 61 | 26 | 27 | 31 | 52 |
| Rio Grande do Sul | 0.37 | 0.43 | 0.37 | 0.58 | 30 | 35 | 34 | 50 | 27 | 31 | 31 | 45 |
| Mato Grosso do Sul | 0.10 | 0.40 | 0.55 | 0.75 | 11 | 28 | 46 | 58 | 10 | 25 | 41 | 52 |
| Mato Grosso | 0.08 | 0.33 | 0.54 | 0.75 | 14 | 23 | 37 | 51 | 12 | 21 | 34 | 47 |
| Goiás | 0.09 | 0.23 | 0.43 | 0.63 | 14 | 23 | 42 | 48 | 13 | 20 | 37 | 43 |
| Distrito Federal | 0.04 | 0.32 | 0.47 | 0.62 | 8 | 20 | 46 | 52 | 7 | 18 | 40 | 45 |
| **Brazil** | **0.08** | **0.13** | **0.16** | **0.25** | **16** | **19** | **21** | **28** | **13** | **16** | **18** | **25** |
| **Regions** | | | | | | | | | | | | |
| North | 0.05 | 0.07 | 0.04 | 0.11 | 17 | 16 | 11 | 14 | 14 | 13 | 9 | 12 |
| Northeast | 0.04 | 0.04 | 0.04 | 0.12 | 11 | 12 | 11 | 20 | 9 | 10 | 9 | 17 |
| Southeast | 0.07 | 0.10 | 0.11 | 0.12 | 15 | 22 | 24 | 26 | 13 | 19 | 21 | 22 |
| South | 0.30 | 0.36 | 0.40 | 0.57 | 31 | 35 | 41 | 57 | 27 | 31 | 36 | 50 |
| Central-west | 0.08 | 0.32 | 0.50 | 0.69 | 12 | 23 | 43 | 52 | 10 | 21 | 38 | 47 |

**Table S9** - Pasture production and utility efficiency

**(ton.ha-1)**

**(T.ha-1)**

**(TJ.ha-1)**

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **States** |  |  |  |  |  |  |  |  |  |  |  |  |
| **1975** | **1985** | **1995** | **2006** | **1975** | **1985** | **1995** | **2006** | **1975** | **1985** | **1995** | **2006** |
| Rondônia | 0.002 | 0.005 | 0.009 | 0.012 | 0.098 | 0.268 | 0.512 | 0.666 | 0.066 | 0.181 | 0.346 | 0.449 |
| Acre | 0.007 | 0.007 | 0.009 | 0.011 | 0.374 | 0.394 | 0.526 | 0.627 | 0.252 | 0.265 | 0.354 | 0.423 |
| Amazonas | 0.007 | 0.006 | 0.010 | 0.010 | 0.405 | 0.349 | 0.553 | 0.560 | 0.273 | 0.235 | 0.373 | 0.378 |
| Roraima | 0.001 | 0.002 | 0.002 | 0.005 | 0.071 | 0.096 | 0.101 | 0.283 | 0.048 | 0.065 | 0.068 | 0.191 |
| Pará | 0.003 | 0.004 | 0.006 | 0.009 | 0.191 | 0.215 | 0.327 | 0.489 | 0.129 | 0.145 | 0.220 | 0.330 |
| Amapá | 0.001 | 0.001 | 0.005 | 0.006 | 0.081 | 0.075 | 0.282 | 0.356 | 0.055 | 0.050 | 0.190 | 0.240 |
| Tocantins | - | 0.002 | 0.003 | 0.005 | - | 0.129 | 0.180 | 0.307 | - | 0.087 | 0.121 | 0.207 |
| Maranhão | 0.004 | 0.004 | 0.005 | 0.007 | 0.201 | 0.249 | 0.294 | 0.392 | 0.136 | 0.168 | 0.198 | 0.264 |
| Piauí | 0.003 | 0.004 | 0.006 | 0.005 | 0.176 | 0.218 | 0.340 | 0.290 | 0.119 | 0.147 | 0.229 | 0.196 |
| Ceará | 0.004 | 0.005 | 0.007 | 0.006 | 0.241 | 0.315 | 0.400 | 0.362 | 0.163 | 0.213 | 0.270 | 0.244 |
| Rio Grande do Norte | 0.003 | 0.004 | 0.006 | 0.006 | 0.185 | 0.247 | 0.318 | 0.316 | 0.125 | 0.166 | 0.214 | 0.213 |
| Paraíba | 0.004 | 0.005 | 0.005 | 0.006 | 0.249 | 0.284 | 0.299 | 0.334 | 0.168 | 0.192 | 0.201 | 0.226 |
| Pernambuco | 0.004 | 0.007 | 0.007 | 0.007 | 0.244 | 0.395 | 0.387 | 0.414 | 0.165 | 0.266 | 0.261 | 0.279 |
| Alagoas | 0.006 | 0.007 | 0.008 | 0.007 | 0.333 | 0.370 | 0.437 | 0.413 | 0.224 | 0.250 | 0.295 | 0.278 |
| Sergipe | 0.005 | 0.005 | 0.006 | 0.007 | 0.267 | 0.267 | 0.319 | 0.374 | 0.180 | 0.180 | 0.215 | 0.252 |
| Bahia | 0.005 | 0.004 | 0.004 | 0.006 | 0.301 | 0.256 | 0.248 | 0.323 | 0.203 | 0.173 | 0.168 | 0.218 |
| Minas Gerais | 0.004 | 0.005 | 0.005 | 0.008 | 0.239 | 0.265 | 0.303 | 0.425 | 0.161 | 0.179 | 0.204 | 0.287 |
| Espírito Santo | 0.007 | 0.006 | 0.007 | 0.009 | 0.377 | 0.359 | 0.375 | 0.507 | 0.254 | 0.242 | 0.253 | 0.342 |
| Rio de Janeiro | 0.006 | 0.007 | 0.008 | 0.010 | 0.340 | 0.390 | 0.449 | 0.569 | 0.230 | 0.263 | 0.302 | 0.384 |
| São Paulo | 0.007 | 0.008 | 0.009 | 0.010 | 0.386 | 0.472 | 0.519 | 0.576 | 0.260 | 0.318 | 0.350 | 0.388 |
| Paraná | 0.009 | 0.010 | 0.010 | 0.013 | 0.514 | 0.556 | 0.574 | 0.737 | 0.347 | 0.375 | 0.387 | 0.497 |
| Santa Catarina | 0.006 | 0.008 | 0.009 | 0.012 | 0.361 | 0.431 | 0.510 | 0.699 | 0.244 | 0.290 | 0.344 | 0.472 |
| Rio Grande do Sul | 0.007 | 0.007 | 0.008 | 0.009 | 0.388 | 0.426 | 0.451 | 0.484 | 0.262 | 0.287 | 0.304 | 0.326 |
| Mato Grosso do Sul | 0.003 | 0.005 | 0.006 | 0.007 | 0.162 | 0.261 | 0.342 | 0.370 | 0.109 | 0.176 | 0.231 | 0.249 |
| Mato Grosso | 0.002 | 0.003 | 0.004 | 0.006 | 0.105 | 0.151 | 0.254 | 0.354 | 0.071 | 0.102 | 0.171 | 0.238 |
| Goiás | 0.003 | 0.005 | 0.006 | 0.008 | 0.166 | 0.263 | 0.322 | 0.435 | 0.112 | 0.177 | 0.217 | 0.293 |
| Distrito Federal | 0.003 | 0.004 | 0.006 | 0.007 | 0.144 | 0.208 | 0.345 | 0.408 | 0.097 | 0.140 | 0.232 | 0.275 |
| **Brazil** | **0.004** | **0.005** | **0.007** | **0.008** | **0.244** | **0.293** | **0.369** | **0.447** | **0.165** | **0.197** | **0.249** | **0.301** |
| **Regions** | | | | | | | | | | | | |
| North | 0.003 | 0.004 | 0.006 | 0.008 | 0.174 | 0.218 | 0.354 | 0.470 | 0.118 | 0.147 | 0.239 | 0.317 |
| Northeast | 0.004 | 0.005 | 0.006 | 0.006 | 0.244 | 0.289 | 0.338 | 0.358 | 0.165 | 0.195 | 0.228 | 0.241 |
| Southeast | 0.006 | 0.007 | 0.007 | 0.009 | 0.336 | 0.372 | 0.412 | 0.519 | 0.226 | 0.251 | 0.277 | 0.350 |
| South | 0.007 | 0.008 | 0.009 | 0.011 | 0.421 | 0.471 | 0.512 | 0.640 | 0.284 | 0.317 | 0.345 | 0.432 |
| Central-west | 0.003 | 0.004 | 0.006 | 0.007 | 0.144 | 0.221 | 0.316 | 0.392 | 0.097 | 0.149 | 0.213 | 0.264 |

**Table S10** – Protein utility from crops for food, feed and field residues**.**

**(kton)**

**(kton)**

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **States** |  | **(kton)** |  |  |  |  |  |  |  |  |  |  |
| **1975** | **1985** | **1995** | **2006** | **1975** | **1985** | **1995** | **2006** | **1975** | **1985** | **1995** | **2006** |
| Rondônia | 10 | 34 | 32 | 38 | 6 | 14 | 11 | 50 | 16 | 30 | 23 | 28 |
| Acre | 4 | 4 | 5 | 11 | 1 | 2 | 2 | 6 | 11 | 10 | 15 | 22 |
| Amazonas | 10 | 11 | 12 | 6 | 1 | 1 | 1 | 1 | 49 | 65 | 73 | 27 |
| Roraima | 1 | 2 | 3 | 5 | 0 | 1 | 2 | 6 | 2 | 4 | 7 | 7 |
| Pará | 31 | 54 | 38 | 73 | 11 | 19 | 14 | 42 | 109 | 147 | 106 | 187 |
| Amapá | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 3 | 2 | 1 |
| Tocantins | - | 26 | 17 | 52 | - | 26 | 16 | 167 | - | 45 | 26 | 47 |
| Maranhão | 61 | 59 | 53 | 149 | 37 | 39 | 70 | 329 | 109 | 119 | 104 | 198 |
| Piauí | 23 | 27 | 28 | 89 | 12 | 18 | 21 | 201 | 35 | 39 | 44 | 92 |
| Ceará | 43 | 41 | 51 | 166 | 28 | 50 | 25 | 91 | 114 | 105 | 120 | 248 |
| Rio Grande do Norte | 10 | 11 | 11 | 24 | 8 | 9 | 5 | 8 | 26 | 70 | 77 | 58 |
| Paraíba | 23 | 24 | 19 | 33 | 14 | 18 | 9 | 13 | 74 | 161 | 208 | 125 |
| Pernambuco | 39 | 43 | 40 | 63 | 14 | 19 | 12 | 26 | 360 | 582 | 392 | 474 |
| Alagoas | 17 | 13 | 20 | 44 | 5 | 10 | 5 | 10 | 247 | 500 | 420 | 709 |
| Sergipe | 7 | 9 | 10 | 18 | 3 | 7 | 5 | 14 | 31 | 49 | 28 | 42 |
| Bahia | 130 | 215 | 201 | 402 | 22 | 79 | 269 | 981 | 264 | 355 | 235 | 472 |
| Minas Gerais | 185 | 403 | 440 | 589 | 149 | 385 | 449 | 902 | 264 | 483 | 501 | 838 |
| Espírito Santo | 32 | 92 | 104 | 65 | 9 | 11 | 5 | 3 | 60 | 123 | 75 | 107 |
| Rio de Janeiro | 12 | 16 | 6 | 5 | 7 | 8 | 3 | 1 | 186 | 222 | 130 | 84 |
| São Paulo | 301 | 416 | 294 | 277 | 435 | 623 | 498 | 476 | 913 | 2,712 | 3,218 | 4,898 |
| Paraná | 658 | 828 | 863 | 1,185 | 1,242 | 1,791 | 2,324 | 3,234 | 452 | 849 | 1,112 | 1,461 |
| Santa Catarina | 122 | 190 | 193 | 296 | 179 | 275 | 266 | 472 | 189 | 264 | 251 | 441 |
| Rio Grande do Sul | 611 | 779 | 695 | 1,128 | 1,577 | 2,037 | 1,632 | 2,934 | 542 | 696 | 659 | 988 |
| Mato Grosso do Sul | 49 | 178 | 193 | 371 | 86 | 611 | 651 | 1,330 | 50 | 180 | 269 | 516 |
| Mato Grosso | 25 | 166 | 398 | 1,005 | 17 | 534 | 1,467 | 4,066 | 32 | 162 | 465 | 919 |
| Goiás | 115 | 199 | 279 | 532 | 130 | 487 | 806 | 1,883 | 152 | 277 | 401 | 736 |
| Distrito Federal | 0 | 6 | 10 | 19 | 0 | 21 | 21 | 43 | 2 | 5 | 9 | 15 |
| **Brazil** | **2,519** | **3,847** | **4,012** | **6,645** | **3,991** | **7,096** | **8,588** | **17,289** | **4,295** | **8,255** | **8,971** | **13,740** |
| **Regions** |  |  |  |  |  |  |  |  |  |  |  |  |
| North | 55 | 131 | 105 | 185 | 19 | 63 | 47 | 273 | 191 | 303 | 252 | 318 |
| Northeast | 354 | 443 | 432 | 987 | 142 | 249 | 419 | 1,673 | 1,261 | 1,980 | 1,629 | 2,418 |
| Southeast | 530 | 927 | 843 | 936 | 600 | 1,027 | 954 | 1,383 | 1,423 | 3,540 | 3,924 | 5,927 |
| South | 1,390 | 1,797 | 1,752 | 2,610 | 2,998 | 4,104 | 4,222 | 6,640 | 1,183 | 1,808 | 2,022 | 2,891 |
| Central-west | 190 | 549 | 880 | 1,928 | 232 | 1,653 | 2,947 | 7,322 | 236 | 624 | 1,144 | 2,186 |

**Table S11** – Gross energy utility from crops for food, feed and field residues**.**

**(Peta joule)**

**(Peta joule)**

**(Peta joule)**

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **States** |  |  |  |  |  |  |  |  |  |  |  |  |
| **1975** | **1985** | **1995** | **2006** | **1975** | **1985** | **1995** | **2006** | **1975** | **1985** | **1995** | **2006** |
| Rondônia | 1.7 | 5.1 | 4.4 | 5.6 | 1.0 | 2.3 | 1.8 | 3.5 | 3.7 | 7.7 | 5.5 | 7.3 |
| Acre | 1.2 | 0.9 | 1.3 | 2.6 | 0.3 | 0.3 | 0.4 | 1.1 | 1.5 | 1.6 | 2.1 | 3.8 |
| Amazonas | 5.7 | 5.5 | 6.1 | 2.8 | 0.1 | 0.2 | 0.2 | 0.2 | 4.4 | 6.4 | 7.1 | 2.9 |
| Roraima | 0.1 | 0.4 | 0.6 | 0.9 | 0.1 | 0.2 | 0.3 | 0.6 | 0.3 | 0.7 | 1.3 | 1.9 |
| Pará | 12.9 | 17.1 | 12.5 | 25.8 | 1.8 | 3.2 | 2.5 | 5.1 | 13.5 | 20.5 | 14.3 | 24.1 |
| Amapá | 0.4 | 0.3 | 0.2 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.5 | 0.3 | 0.2 | 0.1 |
| Tocantins | 0.0 | 4.7 | 3.1 | 7.5 | 0.0 | 3.1 | 2.2 | 8.1 | 0.0 | 11.2 | 7.2 | 14.4 |
| Maranhão | 14.7 | 14.3 | 11.9 | 28.9 | 6.1 | 6.2 | 6.3 | 22.2 | 23.6 | 26.5 | 23.5 | 50.3 |
| Piauí | 4.3 | 5.1 | 5.2 | 13.0 | 2.0 | 2.8 | 2.6 | 11.5 | 7.6 | 9.3 | 10.4 | 25.0 |
| Ceará | 9.2 | 9.1 | 8.8 | 23.6 | 4.1 | 5.3 | 4.4 | 16.8 | 20.7 | 21.2 | 22.4 | 50.9 |
| Rio Grande do Norte | 2.4 | 4.7 | 4.4 | 4.3 | 0.8 | 0.8 | 0.7 | 1.5 | 5.5 | 16.5 | 19.6 | 13.4 |
| Paraíba | 5.8 | 8.7 | 10.0 | 7.2 | 1.8 | 2.3 | 1.5 | 2.3 | 16.3 | 38.1 | 53.0 | 28.7 |
| Pernambuco | 19.7 | 28.3 | 18.5 | 23.3 | 2.2 | 3.1 | 2.2 | 4.9 | 87.5 | 143.7 | 95.6 | 113.6 |
| Alagoas | 11.8 | 22.3 | 19.4 | 34.3 | 0.7 | 1.0 | 0.8 | 1.9 | 65.7 | 136.2 | 113.7 | 190.9 |
| Sergipe | 2.7 | 4.1 | 2.7 | 4.5 | 0.5 | 1.1 | 1.2 | 2.8 | 6.2 | 10.5 | 5.9 | 8.8 |
| Bahia | 26.0 | 35.9 | 28.6 | 60.7 | 3.4 | 7.5 | 15.7 | 54.8 | 40.6 | 63.1 | 51.6 | 111.8 |
| Minas Gerais | 32.8 | 69.9 | 74.2 | 102.7 | 23.6 | 37.4 | 42.9 | 75.8 | 67.8 | 128.2 | 133.6 | 227.6 |
| Espírito Santo | 5.9 | 16.2 | 16.4 | 12.9 | 1.7 | 2.0 | 0.9 | 0.5 | 10.3 | 24.0 | 15.1 | 24.5 |
| Rio de Janeiro | 8.2 | 9.9 | 5.7 | 3.9 | 1.4 | 1.6 | 0.5 | 0.3 | 43.0 | 52.0 | 33.2 | 21.1 |
| São Paulo | 77.4 | 168.8 | 171.7 | 238.4 | 40.9 | 58.3 | 55.1 | 49.4 | 246.9 | 746.0 | 885.9 | 1,342.1 |
| Paraná | 95.2 | 135.0 | 144.7 | 190.6 | 79.2 | 110.9 | 144.5 | 198.5 | 137.6 | 260.1 | 322.6 | 428.2 |
| Santa Catarina | 24.1 | 31.9 | 31.1 | 50.5 | 20.9 | 27.3 | 30.5 | 54.1 | 42.7 | 61.2 | 63.1 | 106.5 |
| Rio Grande do Sul | 93.7 | 118.4 | 108.7 | 169.3 | 87.0 | 112.7 | 104.3 | 176.4 | 168.7 | 218.9 | 210.5 | 324.2 |
| Mato Grosso do Sul | 8.3 | 26.9 | 33.2 | 62.2 | 6.7 | 27.1 | 36.4 | 68.5 | 15.9 | 55.8 | 78.6 | 152.3 |
| Mato Grosso | 4.3 | 23.9 | 60.4 | 149.4 | 2.8 | 24.6 | 67.9 | 193.8 | 9.2 | 47.1 | 140.1 | 285.9 |
| Goiás | 19.6 | 33.4 | 47.9 | 86.1 | 18.1 | 34.0 | 55.8 | 96.0 | 43.0 | 80.9 | 115.6 | 218.0 |
| Distrito Federal | 0.1 | 0.8 | 1.4 | 2.5 | 0.0 | 0.9 | 1.7 | 2.6 | 0.2 | 1.4 | 2.6 | 4.3 |
| **Brazil** | **488** | **801** | **833** | **1,314** | **307** | **476** | **583** | **1,053** | **1,083** | **2,189** | **2,434** | **3,783** |
| **Regions** |  |  |  |  |  |  |  |  |  |  |  |  |
| North | 22 | 34 | 28 | 45 | 3 | 9 | 7 | 19 | 24 | 48 | 38 | 55 |
| Northeast | 97 | 132 | 110 | 200 | 22 | 30 | 35 | 119 | 274 | 465 | 396 | 593 |
| Southeast | 124 | 265 | 268 | 358 | 68 | 99 | 99 | 126 | 368 | 950 | 1,068 | 1,615 |
| South | 213 | 285 | 285 | 410 | 187 | 251 | 279 | 429 | 349 | 540 | 596 | 859 |
| Central-west | 32 | 85 | 143 | 300 | 28 | 87 | 162 | 361 | 68 | 185 | 337 | 660 |

Table S12 – Metabolizable and non-metabolizable energy utility from crops for food and feed.

**(Peta joule)**

**(Peta joule)**

**no (Peta joule)**

**(Peta joule)**

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **States** |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| **1975** | **1985** | **1995** | **2006** | **1975** | **1985** | **1995** | **2006** | **1975** | **1985** | **1995** | **2006** | **1975** | **1985** | **1995** | **2006** |
| Rondônia | 1.5 | 4.3 | 3.6 | 4.7 | 0.7 | 1.8 | 1.5 | 2.7 | 0.2 | 0.8 | 0.8 | 0.9 | 0.3 | 0.6 | 0.4 | 0.8 |
| Acre | 0.9 | 0.7 | 1.1 | 2.1 | 0.2 | 0.3 | 0.3 | 0.9 | 0.3 | 0.2 | 0.3 | 0.5 | 0.1 | 0.1 | 0.1 | 0.2 |
| Amazonas | 4.3 | 4.2 | 4.7 | 2.1 | 0.1 | 0.2 | 0.1 | 0.2 | 1.4 | 1.3 | 1.5 | 0.7 | 0.0 | 0.0 | 0.0 | 0.0 |
| Roraima | 0.1 | 0.3 | 0.5 | 0.8 | 0.0 | 0.2 | 0.2 | 0.5 | 0.0 | 0.1 | 0.1 | 0.1 | 0.0 | 0.1 | 0.1 | 0.2 |
| Pará | 10.1 | 13.3 | 9.7 | 19.8 | 1.4 | 2.4 | 1.9 | 3.9 | 2.9 | 3.8 | 2.8 | 6.0 | 0.4 | 0.8 | 0.6 | 1.1 |
| Amapá | 0.3 | 0.2 | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Tocantins | 0.0 | 4.2 | 2.8 | 6.7 | 0.0 | 2.2 | 1.6 | 5.8 | 0.0 | 0.5 | 0.3 | 0.9 | 0.0 | 0.9 | 0.6 | 2.3 |
| Maranhão | 12.4 | 12.1 | 10.2 | 24.8 | 4.3 | 4.5 | 4.6 | 16.1 | 2.3 | 2.2 | 1.8 | 4.1 | 1.8 | 1.7 | 1.7 | 6.1 |
| Piauí | 3.5 | 4.2 | 4.3 | 11.1 | 1.6 | 2.2 | 2.0 | 8.5 | 0.8 | 0.9 | 0.9 | 1.9 | 0.4 | 0.6 | 0.6 | 3.0 |
| Ceará | 7.4 | 7.5 | 7.2 | 19.0 | 3.2 | 3.9 | 3.6 | 14.1 | 1.7 | 1.5 | 1.6 | 4.6 | 0.9 | 1.5 | 0.8 | 2.6 |
| Rio Grande do Norte | 1.9 | 4.0 | 3.8 | 3.5 | 0.6 | 0.6 | 0.5 | 1.2 | 0.5 | 0.8 | 0.6 | 0.8 | 0.2 | 0.3 | 0.1 | 0.2 |
| Paraíba | 4.7 | 7.5 | 8.8 | 6.1 | 1.4 | 1.7 | 1.2 | 1.9 | 1.1 | 1.2 | 1.1 | 1.1 | 0.4 | 0.5 | 0.3 | 0.4 |
| Pernambuco | 16.9 | 24.8 | 16.2 | 20.2 | 1.8 | 2.5 | 1.8 | 4.2 | 2.8 | 3.4 | 2.3 | 3.0 | 0.4 | 0.6 | 0.3 | 0.7 |
| Alagoas | 10.5 | 20.3 | 17.4 | 30.5 | 0.6 | 0.7 | 0.6 | 1.6 | 1.3 | 2.0 | 1.9 | 3.8 | 0.2 | 0.3 | 0.2 | 0.4 |
| Sergipe | 2.2 | 3.3 | 2.0 | 3.5 | 0.4 | 0.8 | 0.8 | 2.2 | 0.5 | 0.8 | 0.6 | 1.0 | 0.1 | 0.3 | 0.4 | 0.7 |
| Bahia | 18.8 | 26.3 | 22.2 | 50.3 | 2.7 | 5.5 | 11.7 | 39.1 | 7.2 | 9.6 | 6.4 | 10.4 | 0.7 | 2.0 | 4.0 | 15.6 |
| Minas Gerais | 27.7 | 59.5 | 62.9 | 87.7 | 19.1 | 29.2 | 34.4 | 60.7 | 5.1 | 10.4 | 11.3 | 15.0 | 4.4 | 8.1 | 8.5 | 15.0 |
| Espírito Santo | 4.8 | 13.5 | 13.7 | 10.8 | 1.4 | 1.6 | 0.7 | 0.5 | 1.1 | 2.8 | 2.7 | 2.0 | 0.3 | 0.4 | 0.2 | 0.1 |
| Rio de Janeiro | 7.3 | 8.8 | 5.1 | 3.5 | 1.0 | 1.2 | 0.4 | 0.2 | 1.0 | 1.1 | 0.5 | 0.4 | 0.4 | 0.5 | 0.1 | 0.1 |
| São Paulo | 67.3 | 148.5 | 151.8 | 213.6 | 30.0 | 40.7 | 39.5 | 35.3 | 10.1 | 20.2 | 19.9 | 24.8 | 10.9 | 17.6 | 15.5 | 14.1 |
| Paraná | 81.2 | 116.2 | 124.4 | 164.1 | 59.7 | 80.1 | 110.0 | 152.6 | 14.1 | 18.9 | 20.3 | 26.5 | 19.6 | 30.8 | 34.4 | 46.0 |
| Santa Catarina | 19.9 | 26.4 | 26.1 | 42.9 | 17.1 | 22.0 | 24.7 | 43.9 | 4.2 | 5.5 | 5.0 | 7.6 | 3.8 | 5.3 | 5.8 | 10.2 |
| Rio Grande do Sul | 81.3 | 103.6 | 95.8 | 149.3 | 63.2 | 81.5 | 76.4 | 129.8 | 12.4 | 14.8 | 12.9 | 20.0 | 23.8 | 31.2 | 27.9 | 46.5 |
| Mato Grosso do Sul | 7.4 | 23.7 | 29.0 | 54.5 | 4.7 | 19.0 | 27.3 | 51.2 | 0.9 | 3.3 | 4.2 | 7.7 | 2.0 | 8.1 | 9.1 | 17.3 |
| Mato Grosso | 3.8 | 21.1 | 53.4 | 131.5 | 2.0 | 17.5 | 49.3 | 139.3 | 0.5 | 2.8 | 7.0 | 17.9 | 0.8 | 7.1 | 18.6 | 54.5 |
| Goiás | 17.2 | 29.3 | 41.7 | 75.5 | 14.0 | 25.7 | 43.2 | 71.5 | 2.4 | 4.2 | 6.3 | 10.6 | 4.1 | 8.3 | 12.6 | 24.4 |
| Distrito Federal | 0.1 | 0.7 | 1.2 | 2.1 | 0.0 | 0.7 | 1.3 | 2.0 | 0.0 | 0.1 | 0.2 | 0.4 | 0.0 | 0.3 | 0.3 | 0.6 |
| **Brazil** | **414** | **688** | **720** | **1,141** | **231** | **349** | **440** | **790** | **75** | **113** | **114** | **173** | **76** | **128** | **143** | **263** |
| **Regions** |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| North | 17 | 27 | 22 | 36 | 2 | 7 | 6 | 14 | 5 | 7 | 6 | 9 | 1 | 2 | 2 | 5 |
| Northeast | 78 | 110 | 92 | 169 | 17 | 22 | 27 | 89 | 18 | 22 | 17 | 31 | 5 | 8 | 8 | 30 |
| Southeast | 107 | 230 | 233 | 316 | 52 | 73 | 75 | 97 | 17 | 35 | 35 | 42 | 16 | 27 | 24 | 29 |
| South | 182 | 246 | 246 | 356 | 140 | 184 | 211 | 326 | 31 | 39 | 38 | 54 | 47 | 67 | 68 | 103 |
| Central-west | 29 | 75 | 125 | 264 | 21 | 63 | 121 | 264 | 4 | 10 | 18 | 37 | 7 | 24 | 41 | 97 |

Table S13 – Protein production from crops considering its allocation to food or feed and its content in harvest residues.

|  |  |  |  |
| --- | --- | --- | --- |
| Year | Food Prt share | Feed Prt share | Residues Prt content |
| 1975 | 23% | 37% | 40% |
| 1985 | 20% | 37% | 43% |
| 1995 | 19% | 40% | 42% |
| 2006 | 18% | 46% | 36% |

Table S14 – Gross energy production from crops considering its allocation to food or feed and its content in harvest residues.

|  |  |  |  |
| --- | --- | --- | --- |
| Year | Food Grᶓ share | Feed Grᶓ share | Residues Grᶓ content |
| 1975 | 26% | 16% | 58% |
| 1985 | 23% | 14% | 63% |
| 1995 | 22% | 15% | 63% |
| 2006 | 21% | 17% | 62% |

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