Handbook of Emergy Evaluation

A Compendium of Data for Emergy Computation
Issued in a Series of Folios

Folio #4 (2nd printing)
Emergy of Florida Agriculture

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Preface, Handbook of Emergy Evaluation

Emergy, spelled with an "m," is a universal measure of real wealth of the work of nature and society made on a common basis. Calculations of emergy production and storage provide a basis for making choices about environment and economy following the general public policy to maximize real wealth, production and use (maximum empower). To aid evaluations, this handbook provides data on emergy contents and the computations on which they were based. A series of Folios are to be issued. Folio #1 introduces concepts and evaluates the empower of the geobiosphere.

There may be Folios by many authors, who take the initiative to make new calculations or assemble results from the extensive but dispersed literature. Data on emergy content are in published papers, books, reports, theses, dissertations, and unpublished manuscripts. Tabulating unit emergy values and their basis is the main purpose of this handbook. Presentations document the sources of data and calculations. As received, Folios will go to reviewers, back to authors for revision and back for publication. Each will have an index to indicate the page where emergy is evaluated. Each Folio should be usable without reference to other Folios.

<u>Policy on Literature Review and Consistency</u>
This handbook is based on emergy evaluations assembled from various reports and published literature plus new tables prepared by Folio authors. Our policy is to present previous calculations with due credit and without change except those requested by original authors. This means that unit emergy values in some tables may be different from those in other tables. Some tables may be more complete than others. No attempt is made to make all the tables consistent. Explanatory footnotes are retained. The diversity of efforts and authors enriches the information available to users, who can make changes and recalculate as they deem desirable to be more complete, update, or otherwise revise for their purposes.

The increase in global emergy base of reference to 15.83 E24 sej/yr (Folios #1 and #2) changes all the unit emergy values which directly and indirectly are derived from the value of global annual empower. Two alternatives are suggested when using the values from this handbook with previously published unit emergy value: Either increase the older values or decrease the new values by a factor for the change in the base used. For example, to use unit emergy values based on the 1996 solar empower base (9.44 E24 sej/yr), multiply those values by 1.68. Or, multiply the emergy values of this handbook by 0.60 to keep values on the older base. This Folio #4 uses 15.83 E24 sej/yr.

— Howard T. Odum and Mark T. Brown

Introduction to Folio #4

Folio #4 presents emergy evaluations for 23 agricultural commodities raised in the state of Florida, U.S.A., and for two fertilizers produced and used extensively within Florida. All emergy values have been updated to reflect new global process transformities presented in Folio #1. Products with greater than 5000 ha in traditional commercial cultivation in Florida are included (Pierce, 1995). Alligator, although not in extensive production, is included as an example of Florida aquaculture. Part I has evaluation tables for alligators and agricultural commodities. Part 2 evaluates fertilizer. Part 3 summarizes indices.

This folio evaluates three key ratios relevant to agriculture: transformity (sej/J), an emergy specific ratio; emergy per mass (sej/g), a convenient ratio for products usually traded by weight; and empower density (sej/ha/yr), useful for landscape evaluations of emergy concentration. Empower density (areal empower density) identifies centers of energy hierarchy and compares spatial organization at a landscape scale similar to measures of development density used by city planners.

Procedures

The agricultural commodity evaluations presented in this folio primarily use data published by Fluck et al. (1992) which are a compendium and aggregation of agricultural statistics for commercial production in Florida from 1974 to 1992. The main categories of environ-mental input for each commodity are the same (Figure 1), with differences in input of goods and services.

To avoid counting the same environmental energy source twice, all work that can be attributed to dispersion of solar energy-–insolation, rain and evapotranspiration—were calculated and listed, but only evapotranspiration was used to determine total emergy flows. Evapotranspiration specific to each product was estimated from an agricultural field simulation (Smajstrla, 1990) based on the climatic region of the state with the most hectares in production for the commodity.

Total average daily caloric consumption for manual labor was that assumed necessary to support an average 8 hour work day. Because the person-hours allocated to each production system were averaged over the total hectares in production, his 2000 annual work hours were allocated to many hectares of production. Consequently, the total human energy consumption was multiplied by the fraction of annual work hours documented for each hectare of cultivation. The transformity of uneducated labor (Odum, 1996) was applied. Manual labor was separated from services provided by humans with a higher level of education, farm management or veterinarian services for example.

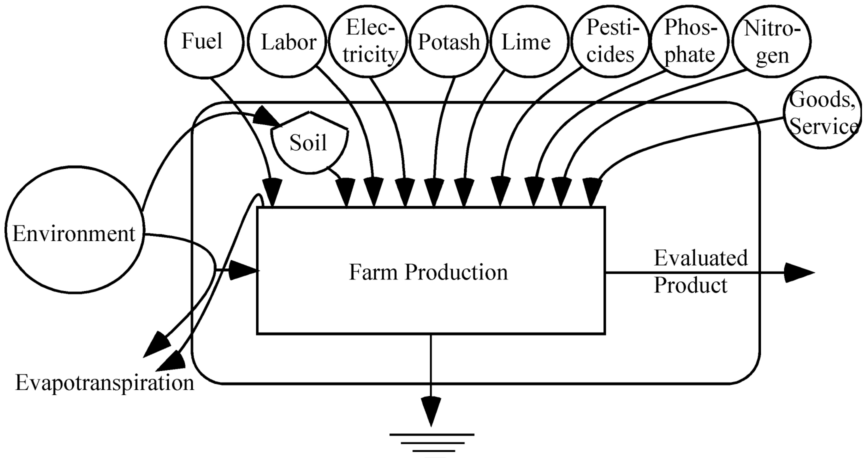

Figure 1. Energy diagram of inputs evaluated for products of Florida agriculture.

Erosion rates were estimated using some assumptions about most likely soil type and landscape characteristics for Florida locations having large acreage in agricultural production. A tour of one to three fields of every commodity and a brief interview with the managing grower were used to determine method for till/plant/harvest, and appropriate factors chosen for soil loss equations (Moore and Wilson, 1992; Griffin et al., 1988), with the exception of cotton. These values were averaged with values presented in Pimentel et al. (1995) for commodities not specifically covered in the Pimentel analysis. Cotton soil loss is taken directly from Pimentel (1995).

Evaluations end at harvest of each product. They do not include any processing that may be required for table-ready foods. Transportation to market is also not included. However, emergy ratios are calculated using dry weight of usable or edible product.

Several evaluations, including all notes, calculations and references, are presented in their entirety. Remaining evaluations present only the input tables and those assumptions that are different from the full samples provided. Transformities used in the evaluations are listed in the notes, with reference to source; the values used are 1.68 times higher than calculated with earth energy baseline used in 1996. See the Preface of this folio.

2. Emergy Evaluation Tables for Florida Agriculture

Tables 1-22 evaluate alligators and commodities in Florida agricluture.

Table 1

Annual Emergy Used to Produce Alligator Products, per Hectare

Note	Item	Inputs ha^{-1} yr^{-1}		Solar Emergy E13 sej/ha/yr
1	Sun	6.35 E13	J	6
2	Evapotranspiration	5.76 E10	J	89
3	Net topsoil loss	0.00	J	0
4	Fuel	6.96 E11	J	7713
5	Electricity	4.25 E10	J	680
6	Potash	0.00	g K	0
7	Feed, grain	2.75 E11	J	3707
8	Feed, livestock	8.81 E11	J	78280
9	Lime	0.00	g	0
10	Pesticides	0.00	g	0
11	Phosphate	0.00	g P	0
12	Nitrogen	0.00	g N	0
13	Labor	1.48 E9	J	658
14	Services	2.94 E4	$	10866
15	Total emergy	---------		101,993
16	Total yield, dry weight	2.69 E6	g	
17	Total yield, energy	7.15 E10	J	
18	Emergy per mass	3.79 E11	sej/g	
19	Transformity	1.43 E7	sej/J	
20	Empower density	1.02 E18	sej/ha/yr in the pens	
		5.10 E17	sej/ha/yr for pens and buffer	

FAECM = Florida Agricultural Energy Consumption Model
ASFIRS = Agricultural Field Scale Irrigation Requirements Simulation Model
DAP = Diammonium phosphate (super phosphate) fertilizer

1. Transformity 1 by definition. Solar insolation calculated using solar constant of 2 Langleys/sec and integration over changing surface area for a one year period at latitude 27.00 N, longitude 82.00 W: 6.9 E9 J/m^2/yr. Albedo 8% (NASAeosweb). Annual energy = (Avg. total annual insolation J/yr/m^2)(Area m^2)(1 - albedo).

2. Transformity for evapotranspiration 15,423 sej/J (Odum, 1996) corrected by factor of 1.68 (Odum et al., 2000). Grain evapotranspiration = 2.33 E10 J/acre/yr (ASFIRS estimate, Smajstrla, 1990). Annual energy = (evapotranspiration J/acre/yr)(area ha)(2.47 acres/ha).

3. Erosion rate estimated as less than 0.01 g/m^2/yr for aquaculture.

4. Fuel includes diesel, gasoline and lubricants and uses petroleum products transformity 6.60 E4 sej/J (Odum 1996) corrected by factor of 1.68 (Odum et al., 2000). Gallons of fuel/ha/yr from FAECM data (Fluck, 1992). Annual energy = (Gallons fuel)(1.32 E8 J/gal).

5. Transformity for electricity from average U.S. coal plant 1.60 E5 sej/J (Odum, 1996)

Footnotes for Table 1 (continued)

corrected by factor of 1.68 (Odum et al., 2000). kWh/ha/yr from FAECM data (Fluck, 1992). Annual energy = (kWh/ha/yr)(3.6 E6 J/kWh).

6. Transformity for potash (K_2O) 1.74 E9 sej/g K (Odum, 1996) corrected by factor of 1.68 (Odum et al., 2000). Grams of active ingredient from FAECM data (Fluck, 1992) converted to grams K, annual use = (g fertilizer active ingredient)(78 gmol K/94 gmol K_2O). Use listed as 0.00 g for alligator.

7. Transformity for grain feed 1.43E5 sej/J for corn from this folio. Grain is 47% of total feed, feeding rate of 25% of body weight first year and 18% for years 2-4, 5 days a week, body weights in Masser (1993). Average feed each year is 1202 lb per alligator, 180 alligators per hectare (derived from Masser 1993, Fluck 1992). Annual energy = (percent of feed)(pounds of feed)(454 g/lb)(17,000 J/g carbohydrate)(35% dry weight).

8. Transformity for livestock feed 9.15E5 sej/J for beef from this folio. Meat is 53% of total feed, feeding rate of 25% of body weight first year and 18% for years 2-4, 5 days a week, body weights in Masser (1993). Average feed each year is 1202 lb per alligator, 180 alligators per hectare (derived from Masser 1993, Fluck 1992). Annual energy = (percent of feed)(pounds of feed)(454 g/lb)(0.72 * 24,000 J/g protein + 0.28 * 39,000 J/g fat)(60% dry weight).

9. Transformity for limestone 1 E9 sej/g (Odum, 1996) corrected by factor of 1.68 (Odum et al., 2000). Annual use from FAECM data (Fluck, 1992). Use listed as 0.00 g for alligator.

10. Pesticides also include fungicides and herbicides. Transformity for pesticides 1.48 E10 sej/g (Brown and Arding, 1991). Use listed as 0.00 g for alligator.

11. Transformity for phosphorus 2.2 E10 sej/g P in DAP (Brandt-Williams, 1999) corrected by factor of 1.68 (Odum et al., 2000). Grams of active ingredient from FAECM data (Fluck, 1992) converted to grams P, annual use = (g fertilizer active ingredient)(31 gmol P/132 gmol DAP). Use listed as 0.00 g for alligator.

12. Transformity for nitrogen 2.41 E10 sej/g N in DAP (Brandt-Williams, 1999) corrected by factor of 1.68 (Odum et al., 2000). Grams of active ingredient from FAECM data (Fluck, 1992) converted to grams N, annual use = (g fertilizer active ingredient)(28 gmol N/132 gmol DAP). Use listed as 0.00 g for alligator.

13. Labor assumed to be primarily migrant with transformity for uneducated labor 4.5 E6 sej/J (Appendix A). Total daily consumption 2500 kcal/day applied to average 8-hour workday. Person-hrs/ha/yr from FAECM data (Fluck, 1992). Annual energy = (pers-hrs/ha/yr)(2500 kcal/day)(4186 J/kcal)/(8 pers-hrs/day).

14. Services for alligators include cost of land and management divided over estimated life of operation, veterinarian services, and medicine. Transformity is the emergy/$ ratio for year of study: 1984, 2.2 E12 sej/$ (Odum, 1996).

15. Total emergy is sum of all components except #1.

16. Yield from FAECM data (Fluck, 1992). 40% water (estimated from chicken, Paul and Southgate, 1978).

17. 83% protein at 24 KJ/g, 17% fat at 39 KJ/g, and 0.0% carbohydrates at 17 KJ/gram (estimated from chicken, Paul and Southgate, 1978).

18. Emergy per mass is the total emergy divided by the dry weight yield.

19. Transformity for commodity is the total emergy divided by the yield in joules.

20. Empower density is the total annual emergy inputs (line 13) divided by the area for pens. Buffer zone, estimated as equal to pens, was added for total farm density.

Table 2

Annual Emergy Use to Support Beef, with Two Steers per Hectare

Note	Item	Inputs $ha^{-1}\ yr^{-1}$		Solar Emergy E13 sej/ha/yr
1	Sun	6.53 E13	J	6
2	Evapotranspiration	1.15 E11	J	298
3	Net topsoil loss	6.33 E7	J	1
4	Fuel	1.20 E10	J	133
5	Electricity	0.00	J	0
6	Potash	6.89 E4	g K	13
7	Lime	5.52 E5	g	93
8	Pesticides	1.08 E4	g	27
9	Phosphate	7.63 E3	g P	28
10	Nitrogen	3.09 E4	g N	125
11	Labor	8.40 E7	J	37
12	Services	3.68 E2	$	136
13	Total emergy	---------		891
14	Total yield, dry weight	1.84 E5	g	
15	Total yield, energy	1.04 E10	J	
16	Emergy per mass	4.85 E10	sej/g	
17	Transformity	8.60 E5	sej/J	
18	Empower density	8.91 E15	sej/ha/yr	

Acronyms are identified in Table 1.

1. Transformity 1 by definition. Solar insolation calculated using solar constant of 2 Langleys/sec and integration over changing surface area for a one year period at latitude 27.00 N, longitude 82.00 W: 6.9 E9 J/m^2/yr. Albedo 8% (NASAeosweb). Annual energy = (Avg. total annual insolation J/yr/m^2)(Area m^2)(1 - albedo).

2. Transformity for evapotranspiration 15,423 sej/J (Odum, 1996) corrected by factor of 1.68 (Odum et al., 2000). Pasture evapotranspiration = 4.66 E10 J/acre/yr (ASFIRS estimate, Smajstrla, 1990). Annual energy = (evapotranspiration J/acre/yr)(area ha)(2.47 acres/ha).

3. Transformity for organic soil 7.38 E4 sej/J (Odum, 1996) corrected by factor of 1.68 (Odum et al., 2000). Erosion rate estimated at 7.0 g/m^2/yr (Pimentel et al., 1995) with 0.04% organics in soil. The energy content in organic soil is 5.4 kcal/g (Ulgiati et al., 1992). The net loss of topsoil is (farmed area)(erosion rate). The energy of soil used, or lost, = (net loss topsoil)(% organic)(5.4 kcal/g)(4186 J/kcal).

4. Fuel includes diesel, gasoline and lubricants and uses petroleum products transformity 6.60 E4 sej/J (Odum, 1996) corrected by factor of 1.68 (Odum et al., 2000). Gallons of fuel/ha/yr from FAECM data (Fluck, 1992). Annual energy = (Gallons fuel)(1.32 E8 J/gal).

Footnotes for Table 2 (continued)

5. Transformity for electricity from average U.S. coal plant 1.60 E5 sej/J (Odum, 1996) corrected by factor of 1.68 (Odum et al., 2000). kWh/ha/yr from FAECM data (Fluck, 1992). Annual energy = (kWh/ha/yr)(3.6 E6 J/kWh).

6. Transformity for potash (K_2O) 1.74 E9sej/g K (Odum, 1996) corrected by factor of 1.68 (Odum et al., 2000). Grams of active ingredient from FAECM data (Fluck, 1992) converted to grams K, annual use = (g fertilizer active ingredient)(78 gmol K/94 gmol K_2O). Use taken from pasture data.

7. Transformity for limestone 1 E9 sej/g (Odum, 1996) corrected by factor of 1.68 (Odum et al., 2000). Annual use from FAECM data (Fluck, 1992). Use taken from pasture data.

8. Pesticides also include fungicides and herbicides. Transformity for pesticides 1.48 E10 sej/g (Brown and Arding, 1991). Use taken from pasture data.

9. Transformity for phosphorus 2.2 E10 sej/g P in DAP (Brandt-Williams, 1999) corrected by factor of 1.68 (Odum et al., 2000). Grams of active ingredient from FAECM data (Fluck, 1992) converted to grams P, annual use = (g fertilizer active ingredient)(31 gmol P/132 gmol DAP). Use taken from pasture data.

10. Transformity for nitrogen 2.41 E10 sej/g N in DAP (Brandt-Williams, 1999) corrected by factor of 1.68 (Odum et al., 2000). Grams of active ingredient from FAECM data (Fluck, 1992) converted to grams N, annual use = (g fertilizer active ingredient)(28 gmol N/132 gmol DAP). Use taken from pasture data.

11. Labor assumed to be primarily migrant with transformity for uneducated labor 4.5 E6 sej/J (Appendix A). Total daily consumption of 2500 kcal/day applied to average 8-hour workday. Person-hours/ha/yr from FAECM data (Fluck, 1992). Annual energy = (pers-hrs/ha/yr)(3000 kcal/day)(4186 J/kcal)/(8 pers-hrs/day).

12. Services for beef include cost of land and management divided over estimated life of operation, veterinarian services, vaccination and medicine. Transformity is the emergy/$ ratio for year of study: 1981, 2.7 E12 sej/$ (Odum, 1996).

13. Total emergy is sum of all components except #1.

14. Yield from FAECM data (Fluck, 1992) given as dry weight.

15. 72% protein at 24 KJ/g, 28% fat at 39 KJ/g, and 0.0% carbohydrates at 17 KJ/gram (Paul and Southgate, 1978).

16. Emergy per mass is the total emergy divided by the dry weight yield.

17. Transformity for commodity is the total emergy divided by the yield in joules.

18. Empower density is the total annual flows into a unit area over a year, i.e. the total emergy line #13 because a single hectare was evaluated for a year in this study.

Table 3

Emergy Evaluation of Bell Pepper, per ha per year

Note	Item	Inputs ha^{-1} yr^{-1}		Solar Emergy E13 sej/ha/yr
1	Sun	6.35 E13	J	6
2	Evapotranspiration	5.43 E10	J	141
3	Net topsoil loss	7.69 E9	J	95
4	Fuel	5.57 E10	J	618
5	Electricity	7.49 E8	J	20
6	Potash	1.72 E5	g K	32
7	Lime	0.00	g	0
8	Pesticides	1.31 E5	g	330
9	Phosphate	5.27 E4	g P	195
10	Nitrogen	4.40 E4	g N	178
11	Labor	1.64 E9	J	728
12	Services	2.11 E3	$	578
13	Total emergy	---------		3,572
14	Total yield, dry weight	1.82 E6	g	
15	Total yield, energy	3.87 E10	J	
16	Emergy per mass	1.64 E10	sej/g	
17	Transformity	7.71 E5	sej/J	
18	Empower density	2.99 E16	sej/ha/yr	

Acronyms are identified in Table 1.

1. Transformity 1 by definition. Solar insolation calculated using solar constant of 2 Langleys/sec and integration over changing surface area for a one year period at latitude 27.00 N, longitude 82.00 W: 6.9 E9 J/m^2/yr. Albedo 8% (NASAeosweb). Annual energy = (Avg. total annual insolation J/yr/m^2)(Area m^2)(1 - albedo).

2. Transformity for evapotranspiration (Et) 15,423 sej/J (Odum, 1996) corrected by factor of 1.68 (Odum et al., 2000). Pepper evapotranspiration = 4.66 E10 J/acre/yr (ASFIRS estimate, Smajstrla, 1990). Annual energy = (evapotranspiration J/acre/yr)(area ha)(2.47 acres/ha).

3. Transformity for organic soil 7.38 E4 sej/J (Odum, 1996) corrected by factor of 1.68 (Odum et al., 2000). Erosion rate estimated at 850 g/m^2/yr (Pimentel et al., 1995; Moore and Wilson, 1992; Griffin et al., 1988) with 0.04% organics in soil. The energy content in organic soil is 5.4 kcal/g (Ulgiati et al., 1992). The net loss of topsoil is (farmed area)(erosion rate). The energy of soil used or lost = (net loss topsoil)(% organic)(5.4 kcal/g)(4186 J/kcal).

4. Fuel includes diesel, gasoline and lubricants and uses petroleum products transformity 6.60 E4 sej/J (Odum, 1996) corrected by factor of 1.68 (Odum et al., 2000). Gallons of fuel/ha/yr from FAECM data (Fluck, 1992). Annual energy = (Gallons fuel)(1.32 E8 J/gal).

Footnotes for Table 3 (continued)

5. Transformity for electricity from average U.S. coal plant =1.60 E5 sej/J (Odum, 1996) corrected by factor of 1.68 (Odum et al., 2000). kWh/ha/yr from FAECM data (Fluck, 1992). Annual energy = (kWh/ha/yr)(3.6 E6 J/kWh).

6. Transformity for potash (K_2O) 1.74 E9 sej/g K (Odum, 1996) corrected by factor of 1.68 (Odum et al., 2000). Grams of active ingredient from FAECM data (Fluck, 1992) converted to grams K, annual use = (g fertilizer active ingredient)(78 gmol K/94 gmol K_2O).

7. Transformity for limestone 1 E9 sej/g (Odum, 1996) corrected by factor of 1.68 (Odum et al., 2000). Annual use from FAECM data (Fluck, 1992) estimated as negligible for bell peppers.

8. Pesticides also include fungicides and herbicides. Transformity for pesticides 1.48 E10 sej/g (Brown and Arding, 1991).

9. Transformity for phosphorus 2.2 E10 sej/g P in DAP (Brandt-Williams, 1999) corrected by factor of 1.68 (Odum et al., 2000). Grams of active ingredient from FAECM data (Fluck, 1992) converted to grams P, annual use = (g fertilizer active ingredient)(31 gmol P/132 gmol DAP).

10. Transformity for nitrogen 2.41 E10 sej/g N in DAP (Brandt-Williams, 1999) corrected by factor of 1.68 (Odum et al., 2000). Grams of active ingredient from FAECM data (Fluck, 1992) converted to grams N, annual use = (g fertilizer active ingredient)(28 gmol N/132 gmol DAP).

11. Labor assumed to be primarily migrant with transformity for uneducated labor 4.5 E6 sej/J (Appendix A). Total daily consumption of 2500 kcal/day applied to average 8-hour workday and divided over total area possible to work in a given day. Person-hrs/ha/yr from FAECM data (Fluck, 1992). Annual energy = (pers-hrs/ha/yr)(2500 kcal/day)(4186 J/kcal)/(8 pers-hrs/day) = J/ha/yr

12. Services for bell peppers include cost of land and management divided over estimated life of operation, and annual expenditures on seedlings and equipment rental. Transformity is the emergy/$ ratio for year of study: 1981, 2.7 E12 sej/$ (Odum, 1996).

13. Total emergy is sum of all components except #1.

14. Yield from FAECM data (Fluck, 1992) given as fresh weight. 93.5% water (Paul and Southgate, 1978).

15. 26% protein at 24 KJ/g, 11% fat at 39KJ/g, and 63% carbohydrates at 17 KJ/gram (Paul and Southgate, 1978).

16. Emergy per mass is the total emergy divided by the dry weight yield.

17. Transformity for commodity is the total emergy divided by the yield in joules.

18. Empower density is the total annual flows into a unit area over a year, i.e. the total emergy line #13 because a single hectare was evaluated for a year in this study.

Table 4

Emergy Evaluation of Eggs, per 100 hens per year

Note	Item	Inputs 100 hens^{-1} yr^{-1}		Solar Emergy E13 sej/100 hens/yr
1	Sun	8.31 E13	J	8
2	Evapotranspiration	6.05 E10	J	157
3	Net topsoil loss	4.25 E9	J	527
4	Fuel	4.89 E10	J	542
5	Electricity	3.06 E9	J	82
6	Potash	1.57 E5	g K	29
7	Lime	5.25 E5	g	88
8	Pesticides	0.00	g	0
9	Phosphate	2.95 E4	g P	109
10	Nitrogen	7.99 E4	g N	323
11	Labor	1.56 E10	J	6927
12	Services	1.21 E3	$	331
13	Total emergy	--------		9,145
14	Total yield, eggs	2.29 E4	eggs	
15	Total yield, dry weight	8.55 E5	g	
16	Total yield, energy	2.08 E10	J	
17	Emergy per egg	3.99 E12	sej/egg	
18	Emergy per mass	1.07 E11	sej/g	
19	Transformity	4.40 E6	sej/J	
20	Empower density	3.99 E20	sej/ha/yr layer houses	
		2.26 E18	sej/ha/yr egg farm	

Acronyms are identified in Table 1.

Items with the same data sources, transformities and assumptions as tables 1-3 are not repeated here; items 1, 2 and 4 -11 include the 1.4 ha grain corn feed requirements (Austic and Nesheim, 1990).

2. Grain corn Et = 2.45 E10 J/acre/yr (ASFIRS estimate, Smajstrla, 1990).

3. Erosion rate estimated at 4700 g/m^2/yr (estimated from Pimentel et al., 1995; Moore and Wilson, 1992; Griffin et al., 1988) for corn production.

12. Services for eggs include cost of land, buildings and management divided over estimated life of operation, feed shipment and pullet replacement. Transformity is the emergy/ $ ratio for year of study: 1988, 1.75 E12 sej/$ (Odum, 1996).

14. Yield from FAECM data (Fluck, 1992) given as number of eggs per 100 hens.

15. 60.8 g/egg, (Cotterill et al., 1977), 74.8% water (Paul and Southgate, 1978).

16. 13.4 g edible, 97 cal per edible portion of egg (Cotterill et al., 1977).

20. Empower density was calculated from industry average of 34 ft^2/100 hens (estimated from Austic and Nesheim 1990, 3 racks of cages, 3 hens per cage) for the layer house value. Suggested manure treatment is 1 acre per 1000 hens (Douglas 1992), and this buffer zone was used to calculate empower density for an egg farm. Hens are not given run of the buffer zone; they remain in their cages for their entire lifespan.

Table 5

Emergy Evaluation of Oranges, per ha per year

Note	Item	Inputs ha^{-1} yr^{-1}		Solar Emergy E13 sej/ha/yr
1	Sun	6.35 E13	J	6
2	Evapotranspiration	6.51 E10	J	168
3	Net topsoil loss	6.33 E8	J	8
4	Fuel	1.99 E10	J	221
5	Electricity	4.68 E8	J	13
6	Potash	2.36 E5	g K	44
7	Lime	2.40 E5	g	40
8	Pesticides	1.79 E4	g	45
9	Phosphate	1.12 E4	g P	42
10	Nitrogen	3.01 E4	g N	122
11	Labor	2.71 E8	J	120
12	Services	3.01 E2	$	121
13	Total emergy	--------		944
14	Total yield, dry weight	4.91 E6	g	
15	Total yield, energy	8.65 E10	J	
16	Emergy per mass	1.92 E9	sej/g	
17	Transformity	1.09 E5	sej/J	
18	Empower density	9.44 E15	sej/ha/yr	

Acronyms are identified in Table 1.

Items with the same data sources, transformities and assumptions as tables 1-3 are not repeated here.

2. Citrus evapotranspiration = 2.63 E10 J/acre/yr (ASFIRS estimate, Smajstrla, 1990).

3

12. Services for oranges include cost of tree stock, land, buildings and management divided over estimated life of operation. Transformity is the emergy/$ ratio for year of study: 1983, 2.4 E12 sej/$ (Odum, 1996).

14. Yield from FAECM data (Fluck, 1992) given as dry mass.

15. 8.6% protein at 24 KJ/g, 0% fat at 39 KJ/g, and 91.4% carbohydrates at 17 KJ/gram (Paul and Southgate, 1978).

Table 6
Emergy Evaluation of Cabbage, per ha per year

Note	Item	Inputs ha^{-1} yr^{-1}		Solar Emergy E13 sej/ha/yr
1	Sun	6.35 E13	J	6
2	Evapotranspiration	6.30 E10	J	163
3	Net topsoil loss	7.69 E9	J	95
4	Fuel	1.74 E10	J	193
5	Electricity	1.36 E9	J	37
6	Potash	1.86 E5	g K	34
7	Lime	5.65 E5	g	95
8	Pesticides	6.60 E3	g	17
9	Phosphate	4.60 E4	g P	170
10	Nitrogen	4.75 E4	g N	192
11	Labor	2.05 E8	J	91
12	Services	4.43 E2	$	121
13	Total emergy	--------		1,209
14	Total yield, dry weight	2.31 E6	g	
15	Total yield, energy	4.47 E10	J	
16	Emergy per mass	5.23 E9	sej/g	
17	Transformity	2.71 E5	sej/J	
18	Empower density	1.21 E16	sej/ha/yr	

Acronyms are identified in Table 1.

Items with the same sources, transformities and assumptions as tables 1-3 are not repeated here.

2. Cabbage evapotranspiration = 2.55 E10 J/acre/yr (ASFIRS estimate, Smajstrla, 1990).

3. Erosion rate estimated at 850 g/m^2/yr (Pimentel et al., 1995; Moore and Wilson, 1992; Griffin et al., 1988)

12. Services for cabbage include cost of transplants, land, and maintenance divided over estimated life of operation. Transformity is the emergy/$ ratio for year of study: 1989, 1.63 E12 sej/$ (Odum, 1996).

14. Yield from FAECM data (Fluck, 1992) given as # crates. 50 lb/crate (William, 1984). 90.3% water (Paul and Southgate, 1978)

15. 33% protein at 24 KJ/g, 0% fat at 39 KJ/g, and 67% carbohydrates at 17 KJ/gram (Paul and Southgate, 1978).

Table 7
Emergy Evaluation of Corn (Sweet), per ha per year

Note	Item	Inputs ha^{-1} yr^{-1}		Solar Emergy E13 sej/ha/yr
1	Sun	6.35 E13	J	6
2	Evapotranspiration	6.05 E10	J	157
3	Net topsoil loss	2.44 E10	J	303
4	Fuel	1.25 E10	J	138
5	Electricity	0	J	0
6	Potash	1.39 E5	g K	26
7	Lime	0	g	0
8	Pesticides	1.11 E4	g	28
9	Phosphate	3.95 E4	g P	146
10	Nitrogen	5.71 E4	g N	231
11	Labor	2.54 E8	J	113
12	Services	7.76 E2	$	212
13	Total emergy	-------		1,315
14	Total yield, dry weight	5.29 E6	g	
15	Total yield, energy	1.04 E11	J	
16	Emergy per mass	2.49 E9	sej/g	
17	Transformity	1.26 E5	sej/J	
18	Empower density	1.31 E16	sej/ha/yr	

Acronyms are identified in Table 1.

Items with the same sources, transformities and assumptions as tables 1-3 are not repeated here.

2. Corn evapotranspiration = 2.45 E10 J/acre/yr (ASFIRS estimate, Smajstrla, 1990).

3. Erosion rate estimated at 2700 $g/m^2/yr$ (estimated from Pimentel et al., 1995; Moore and Wilson, 1992; Griffin et al., 1988) .

12. Services for corn include cost of land and management divided over estimated life of operation. Transformity is the emergy/$ ratio for year of study: 1990, 1.55 E12 sej/$ (Odum, 1996).

14. Yield from FAECM data (Fluck, 1992) given as lbs. 65.2% water (Paul and Southgate, 1978)

15. 13.6% protein at 24 KJ/g, 7.9% fat at 39 KJ/g, and 78.5% carbohydrates at 17 KJ/gram (Paul and Southgate, 1978).

Table 8

Emergy Evaluation of Cucumbers, per ha per year

Note	Item	Inputs ha^{-1} yr^{-1}		Solar Emergy E13 sej/ha/yr
1	Sun	6.35 E13	J	6
2	Evapotranspiration	6.02 E10	J	156
3	Net topsoil loss	7.69 E9	J	95
4	Fuel	2.19 E10	J	243
5	Electricity	0	J	0
6	Potash	1.49 E5	g K	27
7	Lime	5.65 E5	g	95
8	Pesticides	4.90 E4	g	123
9	Phosphate	4.20 E4	g P	155
10	Nitrogen	4.75 E4	g N	192
11	Labor	6.41 E8	J	285
12	Services	1.50 E3	$	411
13	Total emergy	--------		2,013
14	Total yield, dry weight	1.33 E7	g	
15	Total yield, energy	2.61 E11	J	
16	Emergy per mass	1.34 E9	sej/g	
17	Transformity	6.84 E4	sej/J	
18	Empower density	1.78 E16	sej/ha/yr	

Acronyms are identified in Table 1.

Items with the same sources, transformities and assumptions as tables 1-3 are not repeated here.

2. Cucumbers evapotranspiration = 2.44 E10 J/acre/yr (ASFIRS estimate, Smajstrla, 1990).

3. Erosion rate estimated at 850 $g/m^2/yr$ (estimated from Pimentel et al., 1995; Moore and Wilson, 1992; Griffin et al., 1988).

12. Services for cucumbers include cost of land and management divided over estimated life of operation. Transformity is the emergy/$ ratio for year of study: 1990, 1.55 E12 sej/$ (Odum, 1996).

14. Yield from FAECM data (Fluck, 1992) given as bushels. 55 lb/bu (William, 1984). 96.4% water (Paul and Southgate, 1978)

15. 24% protein at 24 KJ/g, 4% fat at 39 KJ/g, and 72% carbohydrates at 17 KJ/gram (Paul and Southgate, 1978).

Table 9

Emergy Evaluation of Green Beans, per ha per year

Note	Item	Inputs ha^{-1} yr^{-1}		Solar Emergy E13 sej/ha/yr
1	Sun	6.35 E13	J	6
2	Evapotranspiration	5.65 E10	J	146
3	Net topsoil loss	7.69 E9	J	95
4	Fuel	1.94 E10	J	215
5	Electricity	1.65 E9	J	44
6	Potash	6.98 E4	g K	13
7	Lime	5.65 E5	g	95
8	Pesticides	1.22 E4	g	31
9	Phosphate	1.98 E4	g P	73
10	Nitrogen	2.38 E4	g N	96
11	Labor	6.23 E7	J	28
12	Services	1.87 E3	$	512
13	Total emergy	-------		1,371
14	Total yield, dry weight	5.55 E5	g	
15	Total yield, energy	1.12 E10	J	
16	Emergy per mass	2.43 E10	sej/g	
17	Transformity	1.20 E6	sej/J	
18	Empower density	1.35 E16	sej/ha/yr	

Acronyms are identified in Table 1.

Items with the same sources, transformities and assumptions as tables 1-3 are not repeated here.

2. Green beans evapotranspiration = 2.29 E10 J/acre/yr (ASFIRS estimate, Smajstrla, 1990).

3. Erosion rate estimated at 850 $g/m^2/yr$ (estimated from Pimentel et al., 1995; Moore and Wilson, 1992; Griffin et al., 1988).

12. Services for green beans include cost of harvest equipment, land and management divided over estimated life of operation. Transformity is the emergy/$ ratio for year of study: 1990, 1.55 E12 sej/$ (Odum, 1996).

14. Yield from FAECM data (Fluck, 1992) given as bushels. 30 lbs/bu (William, 1984). 89% water (Paul and Southgate, 1978).

15. 36% protein at 24 KJ/g, 3% fat at 39 KJ/g, and 61% carbohydrates at 17 KJ/gram (Paul and Southgate, 1978).

Table 10

Emergy Evaluation of Lettuce (Romaine), per ha per year

Note	Item	Inputs ha^{-1} yr^{-1}		Solar Emergy E13 sej/ha/yr
1	Sun	6.35 E13	J	6
2	Evapotranspiration	5.27 E10	J	136
3	Net topsoil loss	7.69 E9	J	95
4	Fuel	2.63 E10	J	291
5	Electricity	0	J	0
6	Potash	1.86 E5	g K	34
7	Lime	0	g	0
8	Pesticides	4.43 E4	g	112
9	Phosphate	2.63 E4	g P	97
10	Nitrogen	4.75 E4	g N	192
11	Labor	3.87 E8	J	172
12	Services	1.65 E3	$	452
13	Total emergy	-------		1,721
14	Total yield, dry weight	8.08 E5	g	
15	Total yield, energy	1.87 E10	J	
16	Emergy per mass	1.96 E10	sej/g	
17	Transformity	8.45 E5	sej/J	
18	Empower density	1.58 E16	sej/ha/yr	

Acronyms are identified in Table 1.

Items with the same sources, transformities and assumptions as tables 1-3 are not repeated here.

2. Lettuce evapotranspiration = 2.13 E10 J/acre/yr (ASFIRS estimate, Smajstrla, 1990).

3. Erosion rate estimated at 850 $g/m^2/yr$ (estimated from Pimentel et al., 1995; Moore and Wilson, 1992; Griffin et al., 1988).

12. Services for lettuce includes repairs and custom work. Transformity is the emergy/ $ ratio for year of study: 1990, 1.55 E12 sej/$ (Odum, 1996).

14. Yield from FAECM data (Fluck, 1992) given as crates. 30 lb/crate (Williams, 1984). 96% water (Paul and Southgate, 1978).

15. 38% protein at 24 KJ/g, 16% fat at 39 KJ/g, and 46% carbohydrates at 17 KJ/gram (Paul and Southgate, 1978).

Table 11

Emergy Evaluation of Peanuts, per ha per year

Note	Item	Inputs ha^{-1} yr^{-1}		Solar Emergy E13 sej/ha/yr
1	Sun	6.35 E13	J	6
2	Evapotranspiration	5.27 E10	J	136
3	Net Topsoil Loss	7.69 E9	J	95
4	Fuel	1.01 E10	J	112
5	Electricity	2.05 E9	J	55
6	Potash	8.38 E4	g K	15
7	Lime	9.04 E5	g	152
8	Pesticides	1.52 E4	g	38
9	Phosphate	1.19 E4	g P	44
10	Nitrogen	3.56 E3	g N	14
11	Labor	3.00 E7	J	13
12	Services	6.67 E2	$	202
13	Total emergy	-------		878
14	Total Yield, dry weight	2.95 E5	g	
15	Total Yield, energy	9.5 E9	J	
16	Emergy per mass	2.97 E10	sej/g	
17	Transformity	9.21 E5	sej/J	
18	Empower Density	8.78 E15	sej/ha/yr	

Acronyms are identified in Table 1.

Items with the same sources, transformities and assumptions as tables 1-3 are not repeated here.

2. Peanuts evapotranspiration = 2.13 E10 J/acre/yr (ASFIRS estimate, Smajstrla, 1990).

3. Erosion rate estimated at 850 $g/m^2/yr$ (estimated from Pimentel et al., 1995; Moore and Wilson, 1992; Griffin et al., 1988).

12. Services for peanuts include spraying, drying, repairs and other fixed costs. Transformity is the emergy/$ ratio for year of study: 1987, 1.8 E12 sej/$ (Odum, 1996).

14. Yield from FAECM data (Fluck, 1992) given as lb. 3.1% water (Paul and Southgate, 1978).

15. 30% protein at 24 KJ/g, 60% fat at 39 KJ/g, and 10% carbohydrates at 17 KJ/gram (Paul and Southgate, 1978).

Table 12

Emergy Evaluation of Potatoes, per ha per year

Note	Item	Inputs ha^{-1} yr^{-1}		Solar Emergy E13 sej/ha/yr
1	Sun	6.35 E13	J	6
2	Evapotranspiration	5.77 E10	J	149
3	Net topsoil loss	7.69 E9	J	95
4	Fuel	1.75 E10	J	194
5	Electricity	1.36 E9	J	37
6	Potash	1.63 E5	g K	30
7	Lime	5.65 E5	g	95
8	Pesticides	3.45 E4	g	87
9	Phosphate	3.95 E4	g P	146
10	Nitrogen	4.75 E4	g N	192
11	Labor	1.37 E8	J	61
12	Services	1.59 E3	$	435
13	Total emergy	-------		1,571
14	Total yield, dry weight	5.43 E6	g	
15	Total yield, energy	8.55 E10	J	
16	Emergy per mass	2.80 E9	sej/g	
17	Transformity	1.78 E5	sej/J	
18	Empower density	1.52 E16	sej/ha/yr	

Acronyms are identified in Table 1.

Items with the same sources, transformities and assumptions as tables 1-3 are not repeated here.

2. Potato evapotranspiration = 2.34 E10 J/acre/yr (ASFIRS estimate, Smajstrla, 1990).

3. Erosion rate estimated at 850 $g/m^2/yr$ (estimated from Pimentel et al., 1995; Moore and wilson, 1992; Griffin, 1988).

12. Services for potatoes include repairs and interest divided over period of operation. Transformity is the emergy/$ ratio for year of study: 1990, 1.55 E12 sej/$ (Odum, 1996).

14. Yield from FAECM data (Fluck, 1992). 75.8% water (Paul and Southgate, 1978).

15. 9% protein at 24 KJ/g, 1% fat at 39 KJ/g, and 90% carbohydrates at 17 KJ/gram (Paul and Southgate, 1978).

Table 13

Emergy Evaluation of Tomatoes, per ha per year

Note	Item	Inputs ha^{-1} yr^{-1}		Solar Emergy E13 sej/ha/yr
1	Sun	6.35 E13	J	6
2	Evapotranspiration	6.02 E10	J	156
3	Net topsoil loss	6.33 E7	J	1
4	Fuel	7.37 E10	J	817
5	Electricity	0	J	0
6	Potash	1.39 E5	g K	26
7	Lime	3.29 E6	g	553
8	Pesticides	1.59 E5	g	401
9	Phosphate	4.60 E4	g P	170
10	Nitrogen	4.75 E4	g N	192
11	Labor	8.56 E8	J	381
12	Services	4.38 E3	$	1199
13	Total emergy	-------		4,202
14	Total yield, dry weight	2.43 E6	g	
15	Total yield, energy	4.54 E10	J	
16	Emergy per mass	1.60 E10	sej/g	
17	Transformity	8.57 E5	sej/J	
18	Empower density	3.90 E16	sej/ha/yr	

Acronyms are identified in Table 1.

Items with the same sources, transformities and assumptions as tables 1-3 are not repeated here.

2. Tomato evapotranspiration = 2.44 E10 J/acre/yr (ASFIRS estimate, Smajstrla, 1990).

3. Erosion rate estimated at 7 $g/m^2/yr$ (Pimentel et al., 1995) for protected soils.

12. Services for tomatoes include cost of stakes, plastic, land, buildings and management divided over estimated life of use. Transformity is the emergy/$ ratio for year of study: 1990, 1.55 E12 sej/$ (Odum, 1996).

14. Yield from FAECM data (Fluck, 1992). 93.4% water (Paul and Southgate, 1978)

15. 24% protein at 24 KJ/g, 0% fat at 39 KJ/g, and 76% carbohydrates at 17 KJ/gram (Paul and Southgate, 1978).

Table 14
Emergy Evaluation of Watermelon, per ha per year

Note	Item	Inputs ha^{-1} yr^{-1}		Solar Emergy E13 sej/ha/yr
1	Sun	6.35 E13	J	6
2	Evapotranspiration	5.43 E10	J	140
3	Net topsoil loss	7.69 E9	J	95
4	Fuel	2.07 E10	J	230
5	Electricity	0	J	0
6	Potash	7.44 E4	g K	14
7	Lime	0	g	0
8	Pesticides	3.79 E4	g	96
9	Phosphate	2.63 E4	g P	97
10	Nitrogen	2.86 E4	g N	116
11	Labor	4.00 E8	J	178
12	Services	1.05 E3	$	288
13	Total emergy	—		1,253
14	Total yield, dry weight	1.88 E7	g	
15	Total yield, energy	3.29 E11	J	
16	Emergy per mass	6.67 E8	sej/g	
17	Transformity	3.81 E4	sej/J	
18	Empower density	1.25 E16	sej/ha/yr	

Acronyms are identified in Table 1.

Items with the same sources, transformities and assumptions as tables 1-3 are not repeated here;

2. Watermelon evapotranspiration = 2.2 E10 J/acre/yr (ASFIRS estimate, Smajstrla, 1990).

3. Erosion rate estimated at 850 $g/m^2/yr$ (estimated from Pimentel et al., 1995; Moore and Wilson, 1992; Griffin et al., 1988).

12. Services for watermelon include cost land and management divided over estimated life of operation. Transformity is the emergy/$ ratio for year of study: 1981, 2.7E12 sej/$ (Odum, 1996).

14. Yield from FAECM data (Fluck, 1992) given as fresh. 47% water (Paul and Southgate, 1978)

15. 7% protein at 24 KJ/g, 0% fat at 39 KJ/g, and 93% carbohydrates at 17 KJ/gram (Paul and Southgate, 1978).

Table 15

Emergy Evaluation of Corn (Grain), per ha per year

Note	Item	Inputs ha^{-1} yr^{-1}		Solar Emergy E13 sej/ha/yr
1	Sun	6.35 E13	J	6
2	Evapotranspiration	6.05 E10	J	157
3	Net topsoil loss	4.25 E10	J	527
4	Fuel	8.12 E9	J	90
5	Electricity	7.85 E8	J	21
6	Potash	1.12 E5	g K	21
7	Lime	3.73 E5	g	63
8	Pesticides	1.69 E3	g	4
9	Phosphate	2.11 E4	g P	78
10	Nitrogen	5.71 E4	g N	231
11	Labor	1.32 E7	J	6
12	Services	4.39 E2	$	133
13	Total emergy	-------		1,335
14	Total yield, dry weight	9.17 E5	g	
15	Total yield, energy	1.81 E10	J	
16	Emergy per mass	1.45 E10	sej/g	
17	Transformity	7.37 E5	sej/J	
18	Empower density	1.33 E16	sej/ha/yr	

Acronyms are identified in Table 1.

Items with the same sources, transformities and assumptions as tables 1-3 are not repeated here

2 Corn evapotranspiration = 2.45 E10 J/acre/yr (ASFIRS estimate, Smajstrla, 1990).

3 Erosion rate estimated at 4700 g/m^2/yr (Pimentel et al., 1995) tilled.

12 Services for corn include cost of land and management divided over estimated life of operation. Transformity is the emergy/$ ratio for year of study: 1987, 1.8E12 sej/$ (Odum, 1996).

14 Yield from FAECM data (Fluck, 1992) given as bushels. 56 lb/bu (William, 1984). 65% water (Paul and Southgate, 1978)

15 13.6% protein at 24 KJ/g, 7.9% fat at 39 KJ/g, and 78.5% carbohydrates at 17 KJ/gram (Paul and Southgate, 1978).

Table 16
Annual Emergy Used to Produce Milk, per Cow per year

Note	Item	Inputs cow^{-1} yr^{-1}	Solar Emergy E13 sej/cow/yr
1	Sun	1.48 E14 J	15
2	Evapotranspiration	1.51 E11 J	391
3	Net topsoil loss	7.69 E9 J	95
4	Fuel	1.75 E10 J	194
5	Electricity	5.02 E9 J	135
6	Potash	1.49 E5 g K	28
7	Lime	9.28 E5 g	156
8	Pesticides	2.33 E3 g	6
9	Phosphate	3.35 E4 g P	124
10	Nitrogen	5.07 E4 g N	205
11	Labor	1.28 E8 J	57
12	Services	2.19 E3 $	1177
13	Total emergy	-------	2,568
14	Total yield, dry weight	7.63 E5 g	
15	Total yield, energy	1.98 E10 J	
16	Emergy per mass	3.37 E10 sej/g	
17	Transformity	1.29 E6 sej/J	
18	Empower density	1.90 E18 sej/ha/yr feed lot 5.19 E16 sej/ha/yr average S. FL. farm	

Acronyms are identified in Table 1.

Items with the same sources, transformities and assumptions as tables 1-3 are not repeated here; items 1-3 and 7-11 include both area of domicile and feed requirements, estimated at 0.25 ha hay, 0.76 ha corn and 1.48 ha soybeans (estimated from personal communication, Lourd, 1996)

12. Services for milk include cost of veterinarians, medicines, transport of feed, dairy aged bulls, maintenance and capital costs divided over estimated life of operation. Transformity is the emergy/$ ratio for year of study: 1980, 3.2 E12 sej/$ (Odum, 1996).

14. Yield from FAECM data (Fluck, 1992). 87.6% water (Paul and Southgate, 1978)

15. 28% protein at 24 KJ/g, 32% fat at 39 KJ/g, and 40% carbohydrates at 17 KJ/gram (Paul and Southgate, 1978).

18. Average of 10 - 50 cows per acre in feed lot, 4-9 months a year (pers. comm., Lourds, 1996). Empower density = (30 cows/acre)(emergy per cow)(2.47 acres/ha). Total dairy farm acreage in Okeechobee watershed was 15,500 acres with 12,655 cows (Gale et al. 1993).

Table 17

Emergy Evaluation of Oats, per ha per year

Note	Item	Inputs ha^{-1} yr^{-1}		Solar Emergy E13 sej/ha/yr
1	Sun	6.35 E13	J	6
2	Evapotranspiration	6.05 E10	J	156
3	Net topsoil loss	7.69 E9	J	95
4	Fuel	2.59 E9	J	29
5	Electricity	0	J	0
6	Potash	9.29 E4	g K	17
7	Lime	0	g	0
8	Pesticides	0	g	0
9	Phosphate	1.32 E4	g P	49
10	Nitrogen	5.11 E4	g N	207
11	Labor	4.79 E6	J	2
12	Services	1.30 E2	$	44
13	Total emergy	-------		599
14	Total yield, dry weight	1.36 E6	g	
15	Total yield, energy	2.72 E10	J	
16	Emergy per mass	4.40 E9	sej/g	
17	Transformity	2.20 E5	sej/J	
18	Empower density	5.99 E15	sej/ha/yr	

Acronyms are identified in Table 1.

Items with the same sources, transformities and assumptions as tables 1-3 are not repeated here.

2. Oats evapotranspiration = 2.45 E10 J/acre/yr (ASFIRS estimate, Smajstrla, 1990).

3. Erosion rate estimated at 850 $g/m^2/yr$ (estimated from Pimentel et al., 1995; Moore and Wilson, 1992; Griffin et al., 1988).

12. Services for oats include repairs and fixed costs. Transformity is the emergy/$ ratio for year of study: 1985, 2.0 E12 sej/$ (Odum, 1996).

14. Yield from FAECM data (Fluck, 1992) given as 41.7 bushels per acre. 32 lb/bushel (USFDA 1980), 8.9% water (Paul and Southgate 1978),

15. 13.2% protein at 24 KJ/g, 9.2% fat at 39 KJ/g, and 77.6% carbohydrates at 17 KJ/gram (Paul and Southgate, 1978).

Table 18

Emergy Evaluation of Soybeans, per ha per year

Note	Item	Inputs ha^{-1} yr^{-1}		Solar Emergy E13 sej/ha/yr
1	Sun	6.35 E13	J	6
2	Evapotranspiration	6.15 E10	J	159
3	Net topsoil loss	1.81 E7	J	<1
4	Fuel	7.01 E6	J	68
5	Electricity	2.97 E8	J	8
6	Potash	3.73 E4	g K	7
7	Lime	3.72 E5	g	62
8	Pesticides	7.07 E2	g	2
9	Phosphate	1.05 E4	g P	39
10	Nitrogen	2.38 E3	g N	10
11	Labor	7.34 E6	J	3
12	Services	1.48 E2	$	41
13	Total emergy	-------		401
14	Total yield, dry weight	4.04 E5	g	
15	Total yield, energy	9.86 E9	J	
16	Emergy per mass	9.87 E9	sej/g	
17	Transformity	4.04 E5	sej/J	
18	Empower density	3.99 E15	sej/ha/yr	

Acronyms are identified in Table 1.

Items with the same sources, transformities and assumptions as tables 1-3 are not repeated here.

2. Soybeans evapotranspiration = 2.49 E10 J/acre/yr (ASFIRS estimate, Smajstrla, 1990).

3. Erosion rate estimated at 2 g/m^2/yr no till (estimated from Pimentel et al., 1995; Moore and Wilson, 1992; Griffin et al., 1988).

12. Services for soybeans include repairs and fixed costs. Transformity is the emergy/$ ratio for year of study: 1989, 1.63 E12 sej/$ (Odum, 1996).

14. Yield from FAECM data (Fluck, 1992) given as bushels. 60 lb/bushel (William 1984). 70% water (Stetens Livsmedelsverk 1988)

15. 40% protein at 24 KJ/g, 21% fat at 39 KJ/g, and 39% carbohydrates at 17 KJ/gram (Stetens Livsmedelsverk 1988).

Table 19

Emergy Evaluation of Sugarcane, per ha per year

Note	Item	Inputs ha^{-1} yr^{-1}		Solar Emergy E13 sej/ha/yr
1	Sun	6.35 E13	J	6
2	Evapotranspiration	6.83 E10	J	177
3	Net topsoil loss	7.69 E9	J	95
4	Fuel	5.46 E9	J	63
5	Electricity	0	J	0
6	Potash	1.49 E5	g K	27
7	Lime	0	g	0
8	Pesticides	1.96 E3	g	5
9	Phosphate	1.05 E4	g P	39
10	Nitrogen	0	g N	0
11	Labor	1.37 E7	J	6
12	Services	1.35 E3	$	454
13	Total emergy	-------		870
14	Total yield, dry weight	2.27 E7	g	
15	Total yield, energy	4.12 E11	J	
16	Emergy per mass	3.81 E8	sej/g	
17	Transformity	2.10 E4	sej/J	
18	Empower density	8.66 E15	sej/ha/yr	

Acronyms are identified in Table 1.

Items with the same sources, transformities and assumptions as tables 1-3 are not repeated here.

2. Sugarcane evapotranspiration = 2.76 E10 J/acre/yr (ASFIRS estimate, Smajstrla, 1990).

3. Erosion rate estimated at 850 $g/m^2/yr$ (estimated from Pimentel et al., 1995; Moore and Wilson, 1992; Griffin et al., 1988) .

12. Services for sugarcane include customs charges, repairs and fixed costs. Transformity is the emergy/$ ratio for year of study: 1985, 2.0 E12 sej/$ (Odum, 1996).

14. Yield from FAECM data (Fluck, 1992). 75% water (Ulgiati, 1992).

15. 16% protein at 24 KJ/g, 0% fat at 39 KJ/g, and 84% carbohydrates at 17 KJ/gram (estimated from Paul and Southgate, 1978).

Table 20

Emergy Evaluation of Cotton, per ha per year

Note	Item	Inputs ha^{-1} yr^{-1}		Solar Emergy E13 sej/ha/yr
1	Sun	6.35 E13	J	5
2	Evapotranspiration	5.80 E10	J	150
3	Net topsoil loss	8.23 E10	J	1020
4	Fuel	9.70 E9	J	108
5	Electricity	3.15 E8	J	8
6	Potash	7.44 E4	g K	14
7	Lime	5.65 E5	g	95
8	Pesticides	4.97 E3	g	13
9	Phosphate	1.58 E4	g P	58
10	Nitrogen	1.90 E4	g N	772
11	Labor	8.90 E7	J	40
12	Services	4.07 E2	$	123
13	Total emergy	-------		1,737
14	Total yield, dry weight	7.38 E5	g	
15	Total yield, energy	1.25 E10	J	
16	Emergy per mass	2.31 E10	sej/g	
17	Transformity	1.36 E6	sej/J	
18	Empower density	1.71 E16	sej/ha/yr	

Acronyms are identified in Table 1.

Items with the same sources, transformities and assumptions as tables 1-3 are not repeated here.

2. Cotton evapotranspiration = 2.35 E10 J/acre/yr (ASFIRS estimate, Smajstrla, 1990).

3. Erosion rate estimated at 9100 $g/m^2/yr$ (Pimentel et al., 1995).

12. Services for cotton include ginning, interest and fixed costs. Transformity is the emergy/$ ratio for year of study: 1987, 1.8 E12 sej/$ (Odum, 1996).

14. Yield from FAECM data (Fluck, 1992) given as bales. 480 lb/bale (Pierce, 1995)

15. 100% carbohydrates at 17 KJ/gram (Paul and Southgate, 1978).

Table 21

Emergy Evaluation of Bahia Pasture, per ha per year

Note	Item	Inputs ha^{-1} yr^{-1}		Solar Emergy E13 sej/ha/yr
1	Sun	6.35 E13	J	6
2	Evapotranspiration	5.43 E10	J	141
3	Net topsoil loss	6.33 E7	J	1
4	Fuel	2.46 E9	J	27
5	Electricity	2.22 E8	J	6
6	Potash	3.63 E4	g K	7
7	Lime	3.73 E5	g	63
8	Pesticides	0	g	0
9	Phosphate	7.38 E3	g P	27
10	Nitrogen	1.55 E4	g N	63
11	Labor	4.85 E6	J	2
12	Services	2.24 E1	$	6
13	Total emergy	-------		342
14	Total yield, dry weight	3.63 E6	g	
15	Total yield, energy	6.88 E10	J	
16	Emergy per mass	9.41 E8	sej/g	
17	Transformity	4.98 E4	sej/J	
18	Empower density	3.42 E15	sej/ha/yr	

Acronyms are identified in Table 1.

Items with the same sources, transformities and assumptions as tables 1-3 are not repeated here.

2. Pasture grass evapotranspiration = 2.63 E10 J/acre/yr (ASFIRS estimate, Smajstrla, 1990).

3. Erosion rate estimated at 7 $g/m^2/yr$ (Pimentel et al., 1995).

12. Services for pasture include interest and fixed cost. Transformity is the emergy/ $ ratio for year of study: 1985, 2.0 E12 sej/$ (Odum, 1996).

14. Yield from FAECM data (Fluck, 1992) given as dry mass.

15. 18% protein at 24 KJ/g, 3% fat at 39 KJ/g, and 79% carbohydrates a 17 KJ/gram (estimated from Paul and Southgate, 1978).

Table 22

Emergy Evaluation of Pecans, per ha per year

Note	Item	Inputs ha^{-1} yr^{-1}		Solar Emergy E13 sej/ha/yr
1	Sun	6.35 E13	J	6
2	Evapotranspiration	6.50 E10	J	168
3	Net topsoil loss	6.33 E8	J	8
4	Fuel	1.32 E10	J	146
5	Electricity	2.96 E8	J	8
6	Potash	7.54 E4	g K	14
7	Lime	3.73 E5	g	63
8	Pesticides	7.20 E3	g	18
9	Phosphate	2.11 E4	g P	78
10	Nitrogen	4.88 E4	g N	118
11	Labor	4.53 E7	J	20
12	Services	2.11 E3	$	344
13	Total emergy	-------		986
14	Total yield, dry weight	8.00 E5	g	
15	Total yield, energy	2.30 E10	J	
16	Emergy per mass	1.23 E10	sej/g	
17	Transformity	4.28 E5	sej/J	
18	Empower density	9.84 E15	sej/ha/yr	

Acronyms are identified in Table 1.

Items with the same sources, transformities and assumptions as tables 1-3 are not repeated here.

2. Pecan evapotranspiration = 2.63 E10 J/acre/yr (ASFIRS estimate, Smajstrla, 1990).

3. Erosion rate estimated at 70 $g/m^2/yr$ (estimated from Pimentel et al., 1995; Moore and Wilson, 1992; Griffin et al., 1988) for orchards.

12. Services for pecans include cost of tree stock, land, buildings and management divided over estimated life of operation. Transformity is the emergy/$ ratio for year of study: 1989, 1.63 E12 sej/$ (Odum, 1996).

14. Yield (Sibbet et al.1998) given as dry in shell weight per acre; dry edible portion 42% of nut weight (Hall 2000).

15. Calorie content 6.87 Kcal/g (Hall 2000),

3. Emergy Evaluation of Fertilizers

Most Florida agricultural industries now use “superphosphate” fertilizer, or diammonium phosphate (DAP) for increased productivity. This fertilizer, produced by ammonification and concentration of phosphorous acid (P_2O_5), is a more bioavailable form of phosphorus than phosphate rock, as well as a source of nitrogen fertilization.

The emergy per mass ratios are much higher than previously reported for phosphate fertilizer (Odum, 1996) because this evaluation takes the initial phosphate rock process through two more concentrating steps. The values for emergy per gram phosphorus and nitrogen resulting from the DAP evaluation were used in the emergy evaluations of all Florida agriculture presented in this folio.

The emergy evaluation for the base component, P_2O_5 (Table 23), and the final fertilizer, DAP (Table 24), were evaluated using industrial process information and annual reports from IMC-Agrico, a production firm in Florida. Similar processes have been in use internationally for 50 years (Shreve, 1945; industry communication from a Florida fertilizer plant operator wishing to remain anonymous, 1996).

4. Summary Tables of Emergy Ratios

Listings of the emergy ratios calculated from the preceding tables are summarized in Tables 25-26 for quick reference.

Emergy Ratios

Values calculated for transformity (emergy/energy) and emergy per mass ratios (Table 25) exhibit high variability between products within the state of Florida. Products with the lowest transformities — sugarcane, watermelons and oranges — have been in production in the state for over a century and are particularly well suited for the specific soil types prevalent in the areas of the state in production. Mass production of eggs, with the highest transformity, is a relative newcomer to the state. It is a high intensity process housing 24 layers per square meter with cages stacked 6 to 8 high, and requires cooling and extensive veterinarian services (Austic and Nesheim, 1990).

Empower Density (Empower Concentration per Area)

Areal empower densities of egg and poultry production (Table 26), are comparable to a power plant and higher than most developed cities. Empower densities of most agricultural commodities in Florida are similar to those of rural nations or small American towns. For comparative data see Odum (1996), Lambert (1999), Brandt-Williams (1999).

Table 23
Emergy Evaluation of Phosphorous Acid, 35% P_2O_5

Note	Item	Inputs		Solar Emergy E12 sej
1	Water	1.40 E8	J	11
2	Phosphate rock	7.49 E5	g P	4,907
3	Electricity	1.89 E8	J	51
4	Labor	1.05 E6	J	43
5	H_2SO_4 (94%)	8.85 E5	g	136
	Total emergy	-------		5,149
6	Total yield	9.08 E5	g	
	Total phosphorus in yield	3.96 E5	g P	
7	Emergy per gram, P_2O_5	5.67 E9	sej/g	
	Emergy per gram, phosphorus	1.30 E10	sej/g P	

1. Water - 7.5 E3 gal (Shreve, 1945)
(7.5 E3 gal)(3785.43 cm^3/gal(1g/cm^3)(4.94 E3 J/g) = 1.40 E8 J
Transformity for stored water 4.1 E4 sej/J (Odum, 1996) corrected by factor of 1.68 (Odum et al., 2000).

2. Phosphate rock, 70 BPL - 2350 lb (Shreve, 1945)
(0.7)(2350 lb)(454 g/lb) = 7.49 E5
Transformity for mined phosphate rock = 3.9 E9 sej/g (Odum, 1996) corrected by factor of 1.68 (Odum et al., 2000).

3. Electricity - 5.25 E1 (Shreve, 1945)
(5.25 E1 kWh)(3.6 E6 J/kWh) = 1.89 E8 J

4. Labor - 8 E-1 pers-hrs (Shreve, 1945)
(8 E-1 pers-hrs)(2500 kcal/day)(4186 J/kcal)/(8 pers-hrs/day) = 1.05 E6 J
Transformity - high school graduate (Odum, 1996)

5. Sulfuric acid - 1950 lb (Shreve, 1945)
(1950 lb)(454 g/lb) = 8.85 E5 g
Transformity for 20% sulfuric acid 9.13 E7 sej/g (Odum et al., 2000) with a linear concentration factor assumed for 94% acid, corrected by factor of 1.68 (Odum et al., 2000).

6. Yield - 908 kg 35% P_2O_5
Ratio P to P_2O_5: 62 gmol P/142 gmol P_2O_5

7. Total emergy divided by yield mass

Table 24
Emergy Evaluation of Diammonium (Superphosphate) Fertilizer

Note	Item	Inputs	Solar Emergy E16 sej
1	Fuel	2.74 E14 J	1,315
2	Electricity	1.08 E15 J	17,280
3	Labor	2.43 E12 J	5,978
4	NH_3	2.78 E11 g N	127,880
5	P_2O_5 (35%)	1.14 E12 g	646,380
6	Capital, 1984	3.69 E5 $	81
	1981	2.51 E6 $	678
	1979	2.84 E5 $	99
	1975	1.56 E6 $	936
	Total emergy	-------	800,627
7	Total yield	2.41 E12 g DAP	
	5.53 E11 g P		
	5.05 E11 g N		
8	Emergy per mass	3.32 E9 sej/g DAP	
	1.45 E10 sej/g P		
	1.59 E10 sej/g N		

DAP = Diammonium Phosphate

1. Fuel - 2.6 E6 therms natural gas (IMC-AGRICO, 1995)
(2.6 E6 therms)(1.05 E8 J/therm) = 2.74 E14 J

2. Electricity - 3.01 E8 kWh (IMC-AGRICO, 1995)
(3.01 E8 kWh)(3.6 E6 J/kWh) = 1.08 E15 J

3. Labor - 1.86 E6 pers-hrs (IMC-AGRICO, 1995)
(1.86 E6 pers-hrs)(2500 kcal/day)(4186 J/kcal)/(8 pers-hrs/day) = 2.43 E12 J
Transformity - high school graduate (Odum, 1996)

4. Ammonia - 3.37 E11 g (IMC-AGRICO, 1995; Shreve, 1945)
(3.37 E11 g)(14g N/17g NH_3) = 2.78 E11 g N

5. P_2O_5 - 35% - 1.14 E12 g (IMC-AGRICO, 1995; Shreve, 1945)

6. Capital = (plant capital costs)/(life expectancy)/(% of capacity dedicated to DAP)

7. Yield - 2.4 E9 kg $(NH_4)_2(HPO_4)$
Ratio P: 31 gmol P/ 132 gmol DAP; Ratio N: 28 gmol N/ 132 gmol DAP

8. Total emergy divided by yield mass

Table 25

Transformities and Emergy per Mass Ratios

Commodity	Transformity E4 sej/J	Emergy per mass E8 sej/g	Emergy Table[3] #
Table ready foods [1]			
Bell pepper	77	164	3
Cabbage	27	52	6
Corn, sweet	13	25	7
Cucumbers	7	13	8
Eggs	440	1070	4
Green beans	120	243	9
Lettuce	85	196	10
Oranges	11	19	5
Peanuts	92	297	11
Pecans	43	123	22
Potato	18	28	12
Tomatoes	86	160	13
Watermelon	4	7	14
Unprocessed foods [2]			
Alligator	1430	3790	1
Beef	86	485	2
Corn, grain	74	145	15
Milk	129	337	16
Oats	22	44	17
Soybeans	40	99	18
Sugarcane	2	4	19
Non-food Items			
Cotton	136	231	20
Sod/hay (Bahia grass)	5	9	21

1 Products not requiring processing prior to sale

2 Dry weight of edible product; no processing energy is included

3 Emergy evaluation table in Section 1

Table 26

Empower Densities[1]

Commodity	E15 sej/ha/yr	Commodity	E15 sej/ha/yr
Table ready foods		*Unprocessed foods*	
Bell pepper	30	Alligator	1,029[2]
Cabbage	12		510[3]
Corn, sweet	13	Beef, range fed	9
Cucumbers	18	Corn,grain	13
Eggs	398,652[2]	Milk	1,937[2]
	2,260[3]		52[3]
Green beans	14	Oats	6
Lettuce	16	Soybeans	4
Oranges	9	Sugarcane	9
Peanuts	9		
Pecans	10		
Potato	15	*Non-food Items*	
Tomatoes	39	Cotton	17
Watermelon	13	Sod/hay	3

1 Emergy yield per hectare from Tables 1-22

2 For hen houses or feed lot without buffer zone

3 For entire egg farm or dairy and alligator operation with estimated buffer zones.

Table 27

Emergy per Mass Ratios for Florida Fertilizers[1]

Fertilizer	Emergy per Mass sej/g total	Emergy per Mass P sej/g P	Emergy per Mass N sej/g N
DAP	3.32 E9	1.45 E10	1.59 E10
P_2O_5	5.67 E9	1.30 E10	-------

DAP = Diammonium Phosphate

1 Complete emergy evaluations presented in Tables 23 and 24, Section 2.

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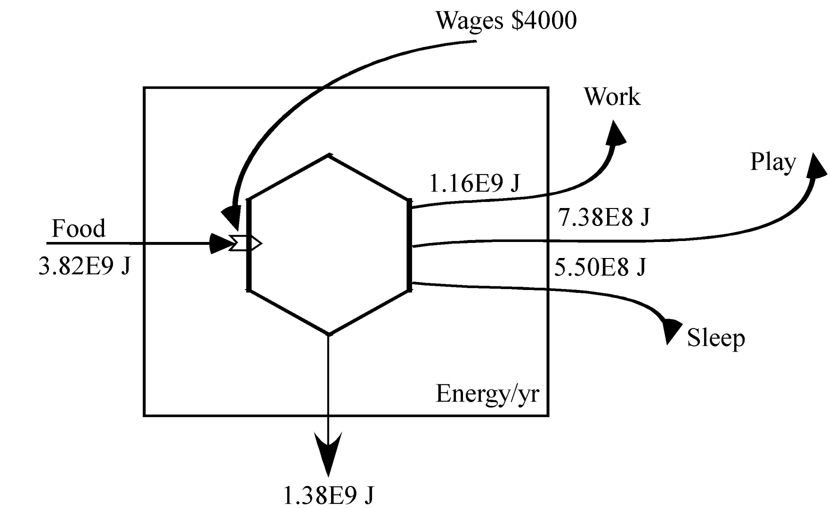
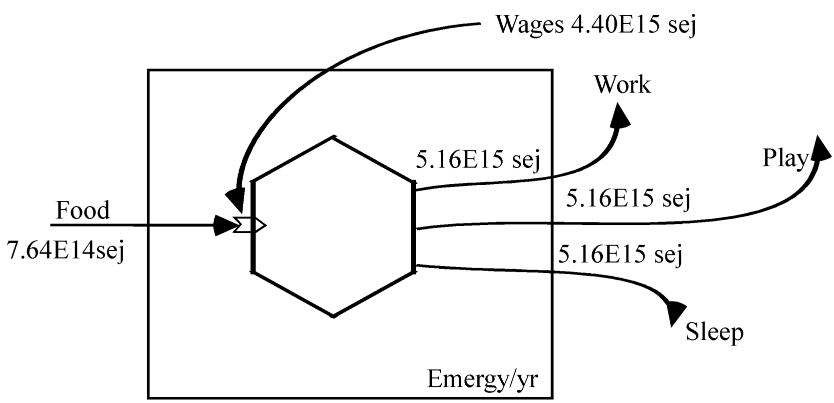
Appendix A

These diagrams illustrate the determination of the transformity for annual energy flows to migrant labor.





$$\text{Work Transformity} = \frac{5.16\text{E}15 \text{ sej}}{1.16\text{E}9 \text{ J}} = 4.45\text{E}6 \text{ sej/J}$$

The following assumptions were made in this evaluation:
1) The majority of Florida farm labor is a mix of legal and illegal immigrants receiving about 60% of average legal wages of $6500/yr (derived from Buchanan 2000, FLS 2000 and NWAS 2000).
2) Work, play and sleep are coproduct energies, not splits, all being necessary for the health of an individual human, and being, on average, equal 8-hour segments.

3) Basal metabolism was calculated for a male, 30 years of age, 150 pounds (Harris and Benedict 1919).
4) Values for work were calculated using 7 hours of heavy labor and 1 hour of low level activity, play was 1 hour of moderately intense sport and 7 hours of low intensity activity, while sleep requires 45 calories per hour (Harris and Benedict 1919).
5) The amount of American life experience gained each year is roughly equivalent to the wages earned.
6) 90% of a migrant farmer's diet will be carbohydrates. This was used to determine the appropriate transformity for food inputs.
7) The emergy to dollar ratio was approximately $1.1 E12 sej/$ for year 2002.

References are included in the literature list on pgs. 35-36.

Index of Emergy Evaluation in Folio #4

Notes