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Sustainability assessment of a farm in the Chianti area (Italy)

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Abstract

In the study of agricultural systems, where land fertility and environmental conditions are primary factors, it is essential to consider both the efficiency and the environmental sustainability of processes. Emergy analysis, introduced by H.T. Odum [Science 242 (1988) 1132], is an approach developed at the interface between thermodynamics systems ecology. It was here used to obtain sustainability indicators and to assess the efficiency of a complex agricultural system, a farm in the Chianti area.

The results for different crops were compared with Italian averages to obtain an idea of the long-term sustainability of this agricultural system. The cultivation of all the crops on the farm, except grapes, was more efficient and had less impact on the environment than the Italian standards. The Chianti grapes were compared not only with the Italian average but also with grapes of similar high quality, 'Brunello di Montalcino' and 'Nobile di Montepulciano', both grown in the same region. The production of grapes in the Chianti vineyard was more efficient and had an intermediate environmental impact, in the emergy sense, with respect to the other two systems.

The proportion of emergy inputs to the farm that are local or renewable is quite high. Thus the emergy analysis demonstrated that the Chianti farm has a relatively good long-term sustainability considering both the whole system, and its individual crops.

Keywords: Sustainability indicators; Environmental impact; Emergy analysis

1. Introduction

After many years of indiscriminate utilization of natural resources, human development needs to take into account the integrity of the environment in addition to the short-term economic development. Currently natural resources are consumed at a rate, which is higher than the rate at which they are replenished. In order to avoid a depletion of natural resources and a subsequent loss of well-being in the long term, consumption rates must be reduced. Human progress and public policy decisions should be based on the idea of sustainable development that considers not only the immediate economic prosperity, but also the preservation of the environment. In the study of agricultural systems, where land fertility and environmental conditions are primary factors, it is essential to consider both the efficiency and the environmental sustainability of processes.

A thermodynamic approach is used here to produce sustainability indicators and to assess efficiency of an agricultural complex system in Tuscany, Italy. Emergy analysis along with its related indices and ratios, constitutes a suitable tool for assessing the long-term sustainability and efficiency of various systems. Emergy analysis, is a science based evaluation system able to represent both the environmental values and the economic values with a common measure [2].

Emergy analysis is a technique of quantitative analysis which determines the values of nonmonied and monied resources, services and commodities in common units of the solar energy it took to make them (called Solar Emergy) [3]. The basis of emergy analysis is the conversion of all the process inputs into solar energy, by a conversion factor called *solar transformity*, namely the solar energy directly or indirectly necessary to obtain one unit of another type of energy. For a given process or flow, the total solar energy (direct or indirect) required to drive

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the process or flow is defined as the *solar emergy*. Thus the solar transformity is the emergy per unit of energy of product or flow. The solar emergy is expressed in solar emergy joules (sej), and the solar transformity in sej/J. This approach arose from the recognition that the ‘energy flows of the universe are organised in an energy transformation hierarchy’. By assigning value to objects on the basis of the cost in solar terms, ‘the position in the energy hierarchy is measured with transformities’ [2].

The farm to which emergy analysis was applied in this study is a typical agricultural system of Tuscany. It grows crops common in this area, including grapes for the prestigious Chianti wine. The farm, where a livestock system produces precious meat and meets a portion of its fertilizer needs, reducing the use of chemical fertilizers, is a good case study for demonstrating the potential of emergy analysis for assessing the sustainability and efficiency of complex systems. Here sustainability is intended in the thermodynamic, rather than social sense: resources should be used at a rate that allows their replacement. Since emergy incorporates all the (solar) energy needed, it is a suitable function for assessing sustainability. Efficiency is here intended as the ability to use less past and present work of the biosphere (emergy) to produce a unit of product.

To assess the efficiency and sustainability of the farm system, each crop and the whole system, were analysed and compared with the Italian means [4]. To test the sustainability of the vineyard subsystem, the Chianti vineyard was compared with two other Tuscan grape productions for two other famous wines, ‘Brunello di Montalcino’ and ‘Nobile di Montepulciano’. The comparison results are more significant, being between products all of very high quality and all located in the same region. The analysis of the farm as a whole and and of each crop was done to determine whether this traditional agricultural system is well integrated into the environment and sustainable in the long term.

2. Methodology

Emergy represents all the work given by the environment to sustain a certain system and produce a certain level of output. Transformity is a measure of both the quality of that output and of the production efficiency. When different processes or products are compared, that are the result of some kind of selection, e.g. natural or economic, the larger the transformity, the more solar energy is required for their maintenance, and the higher their position in the energy hierarchy of the universe [1,2]. For systems with the same output the lower the transformity, the higher the efficiency of the system.

The usual procedure adopted to perform an analysis is to draw a diagram where the system is described, with all its inputs, outputs and internal components (see Figs. 1 and 2). Then a table is made listing all the inputs and their amounts in terms of joules or grams (see Tables 2 and 3). The emergy contribution of each input is calculated multiplying the inputs by their (previously calculated) transformities. The total emergy is then obtained by adding all the contributions coming from independent inputs. Sunlight, wind and rain, which are co-products of the same phenomenon, the solar radiation heating the biosphere, cannot be considered as independent inputs. To avoid double-counting only the largest of these three contributions is considered. For an in depth discussion on the emergy ‘algebra’ and properties, please refer to [2,3].

Many types of systems have been analysed by emergy accounting. They have been on a regional [5–7] and national scale [4,8,9]; and have considered agricultural [10–12] industrial and energy production systems [2,13,14].

For all these studies emergy related indices have been introduced to better assess various aspects of the sustainability of the system under study (see [1–15]). We shortly describe the ones that are more important for a production system. The *emergy yield ratio* is the ratio of the emergy of a product to the emergy of the inputs that are received from the economy. Its value is always greater than one and indicates the competitivity of systems giving the same output. The higher the value of this index, the greater the return obtained per unit of emergy invested. The *environmental loading ratio* is the ratio of the total emergy of the non-renewable inputs, external and local, to the emergy of the environmental renewable inputs. For systems with the same technological level, the lower this ratio, the lower the stress to the environment. The *empower density* is the total emergy driving a process divided by the system’s area. If this ratio is particularly high it means that a large quantity of emergy inputs are used in a certain area and this can mean a quite high stress to the environment. Each of these indexes represents a different aspect of efficiency and sustainability. Thus results and conclusions of emergy analysis are obtained by the integration of the information given by all these parameters.

3. Case study: a farm in Chianti area

The farm ‘Le Fattorie Chigi Saracini’ covers about 800 ha in extent, is located in the Chianti area, near the town of Siena, and can be defined typical of Tuscany region in that has six different crops, all characteristic of this area (Table 1). Moreover, it presents a livestock sector that, besides a good quality meat production (that is out of the interest of the paper), is an important component of the farm agricultural management because it provides organic manure used as fertilizer.

Fig. 1 shows the energy system diagram of the farm

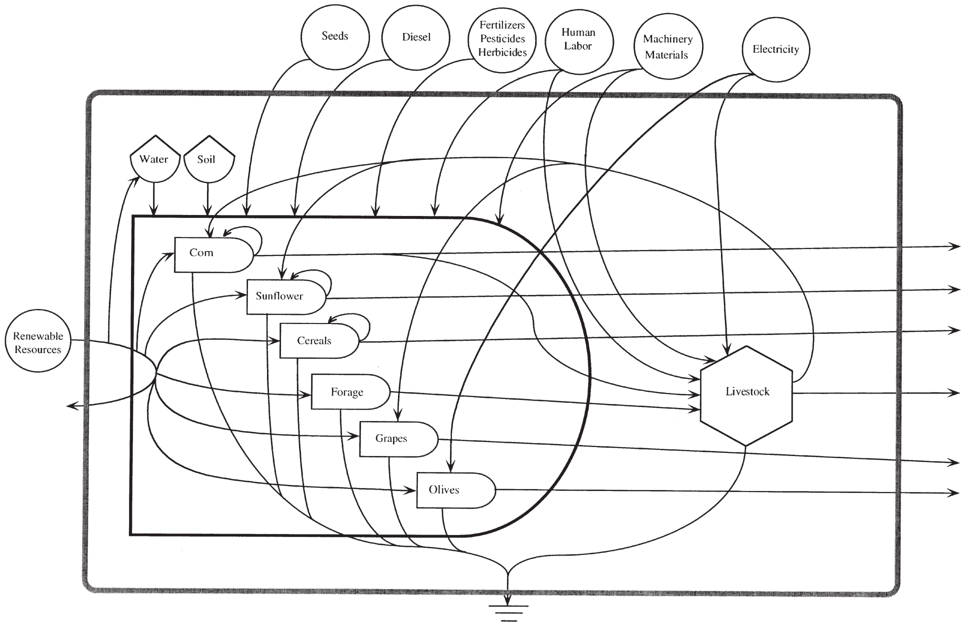
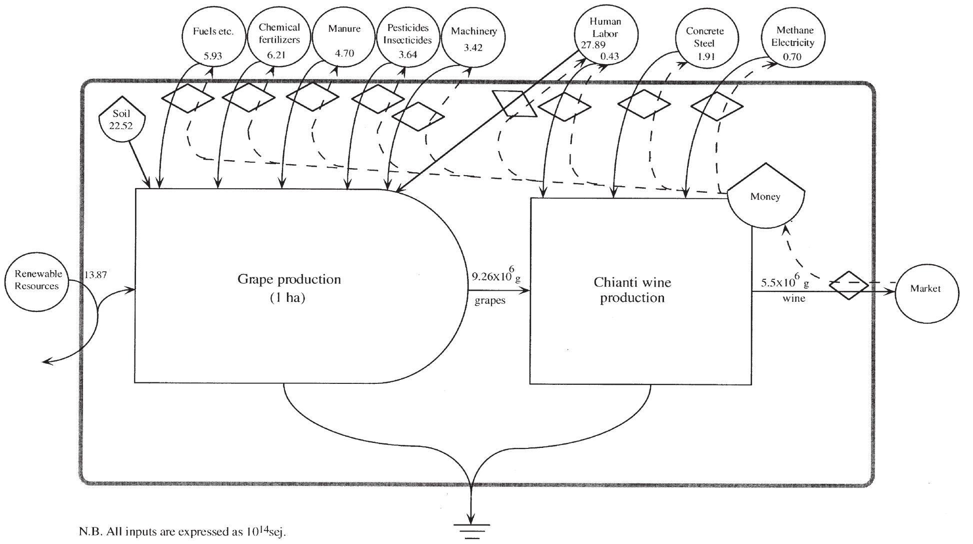


Fig. 1. Energy system diagram of a farm in the Chianti area. Items inside the system are represented, from left to right, according to increasing transformity.



N.B. All inputs are expressed as 10^{14}sej.

Fig. 2. Energy system diagram of grape production for Chianti wine.

Table 1
Crops of a farm in the Chianti area (central Italy)

Crop	Area (ha)	Quantity (kg/ha/yr of final product)
Grapes (Chianti)	54.0	9.26E+03
Olives	53.7	9.31E+02
Corn	30.0	1.47E+04
Sunflower	26.0	2.23E+03
Forage	150.0	3.33E+03
Cereals	140.0	3.57E+03

represented with the energy symbols introduced by Odum [16]. The crops in Fig. 1 are listed in order of transformity: the lowest on the left, the highest on the right. Manure used as fertilizer for corn, sunflowers, and grapes is represented as three feedbacks from the livestock component to these productions. Three other feedbacks are residues of corn, cereal, and sunflower crops, which can be regarded as fertilizers. Actually each crop has feedbacks, but only the principal ones are indicated. Feedbacks, i.e. recycling of an internal resource, are not inputs and therefore reduce the amount of emergy necessary to sustain the whole system and consequently reduce the environmental cost. Analogous energy diagrams were done for the grape production (Fig. 2) and for each crop (available for the readers on request to the authors).

After field collection of the data relative to all the system's inputs, outputs, and flows, in energy or mass unit, emergy analyses were carried out [17] for the total farm (Table 2) and for each individual crops, or subsystem, including the vineyard (Table 3). Each analysis incorporated all inputs, outputs, and energy flows in emergy terms. All the crops analyses were done over the extension area of each system (see Table 1), and then were standardised to one hectare in order to facilitate the comparison among different productions. The period of time considered for each analysis was one year. Transformity, emergy, and the related emergy indices were calculated for each cultivated crop of the farm and were compared with the Italian averages [4].

Because Chianti grapes are of exceptional quality, the vineyard is the focus of farm management. We therefore compared the results of the emergy analysis of the Chianti vineyard with those of other vineyards with grapes of similar high quality. In order to reduce the effects of climatic conditions and soil type on these results, two other famous vineyards in the same geographic region, namely 'Brunello di Montalcino' and 'Nobile di Montepulciano', were selected for comparisons.

4. Results and discussion

Table 2 shows the emergy analysis of the farm system as a whole. The notes necessary for the calculations of raw data are reported in Appendix A. At the bottom of the list of inputs, with the relative calculations of the

Table 2
Emergy analysis of a farm in the Chianti area

Input	Unit	Unit/yr	Emergy per unit (sej/unit)	Ref. for transf.	Solar emergy (E16 sej/ha/yr)	Type[a]
1 Sunlight	J	3.89E+16	1.00E+00	[2]	3.89	L R
2 Rain	g	5.53E+12	8.99E+04	[2]	49.67	L R
3 Wind	J	7.50E+13	1.50E+03	[2]	11.25	L R
4 Geothermal heat	J	2.68E+13	2.55E+04	[18]	68.31	L R
5 Loss of topsoil	J	5.76E+11	7.38E+04	[18]	4.25	L N
6 Water for livestock/irrigation	g	8.75E+10	8.99E+04	[2]	0.79	L R
7 Nitrogen fertilizers	g	5.54E+07	4.21E+09	[18]	23.31	N F
8 Phosphate fertilizers	g	2.20E+07	6.88E+09	[18]	15.12	N F
9 Potash fertilizers	g	1.25E+07	2.96E+09	[18]	3.69	N F
10 Insecticides	g	1.10E+06	1.48E+10	[18]	1.63	N F
11 Pesticides	g	1.63E+06	1.48E+10	[18]	2.41	N F
12 Diesel	J	2.45E+12	6.60E+04	[18]	16.17	N F
13 Agric. machinery	g	4.70E+06	6.70E+09	[18]	3.15	N F
14 Human labor	J	3.63E+10	7.38E+06	[4]	26.78	10%R;F
15 Corn seeds	g	5.80E+05	3.90E+08	[17]	0.02	N F
16 Sunflower seeds	g	1.50E+05	1.82E+09	[17]	0.03	N F
17 Forage seeds	g	2.50E+06	6.89E+08	[17]	0.17	N F
18 Industrial fodder	J	1.00E+12	6.60E+04	[4]	6.60	N F
19 Iron ore	g	2.85E+06	2.64E+09	[8]	0.75	N F
20 Concrete	g	4.49E+08	7.48E+08	[18]	33.55	N F
21 Wood	g	8.18E+06	4.04E+08	[18]	0.33	N F
22 Electricity	J	1.83E+10	2.00E+05	[18]	0.37	N F
(R) Sum of renewable inputs (sum of items 2, 4, 6, and 10% of 14)					121.45	
(LN) Sum of local non renewable inputs					4.25	
(F) Sum of imported non renewable inputs (sum of items 7–22, except 10% of 14)					131.40	
Total emergy used					257.10	
	Emergy yield ratio (total emergy used/F)	1.96				
	Environmental loading ratio ((LN+F)/R)	1.12				
	Empower density (total emergy used/area)	3.02E+11 sej/m^2				

[a] R: renewable resource; N: nonrenewable resource; F: resource purchased from outside; L: local resource.

Table 3
Emergy analysis of Chianti vineyard production

Input	Unit	Unit/yr	Emergy per unit (sej/unit)	Ref. for transf.	Solar emergy (E16 sej/ha/yr)	Type[a]
1 Sunlight	J	4.59E+13	1.00E+00	[2]	0.46	L R
2 Rain	g	6.50E+09	8.99E+04	[2]	5.84	L R
3 Wind	J	8.82E+10	1.50E+03	[2]	1.32	L R
4 Geothermal heat	J	3.15E+10	2.55E+04	[18]	8.03	L R
5 Loss of topsoil	J	3.05E+10	7.38E+04	[18]	22.52	L N
6 Nitrogen fertilizers	g	2.60E+04	4.21E+09	[18]	1.09	N F
7 Phosphate fertilizers	g	4.00E+04	6.88E+09	[18]	2.75	N F
8 Potash fertilizers	g	8.00E+04	2.96E+09	[18]	2.37	N F
9 Insecticides	g	3.52E+03	1.48E+10	[18]	0.52	N F
10 Pesticides	g	2.11E+04	1.48E+10	[18]	3.12	N F
11 Diesel and lubricants	J	8.99E+09	6.60E+04	[18]	5.93	N F
12 Human labour	J	3.78E+08	7.38E+06	[4]	27.89	10%R;F
13 Agric. machinery	g	5.11E+04	6.70E+09	[18]	3.42	N F
14 Iron ore	g	5.28E+04	2.64E+09	[8]	1.39	N F
15 Concrete	g	2.72E+05	7.48E+08	[18]	2.04	N F
16 Wood	g	3.78E+04	4.04E+08	[18]	0.15	N F
17 Organic manure	g	3.70E+06	1.27E+08	[17]	4.70	29%R;F
(R) Sum of renewable inputs (sum of items 2, 4, 10% of 12, 29% of 17)					18.03	
(LN) Sum of local non renewable inputs (item 5)					22.52	
(F) Sum of imported non renewable inputs (sum of items 6–17, except 10% of 12 and 29% of 17)					51.24	
Total emergy used					91.79	
Product						
18 grapes	g	9.26E+06	9.91E+08		91.79	
Emergy per mass—transformity			9.91E+08 sej/g		3.48E+05 sej/J	
Emergy yield ratio (total emergy used/F)			1.79			
Environmental loading ratio ((LN+F)/R)			4.09			
Empower density (total emergy used/area)			9.18E+11 sej/m^2			

[a] R: renewable resource; N: nonrenewable resource; F: resource purchased from outside; L: local resource.

emergy contributions, the total emergy is reported together with the parts of it which are renewable, local non renewable and imported non renewable. The renewable part is calculated as the sum of rain, geothermal heat and a fraction of the human labour contributions. In fact rain is the greatest of the three inputs (sunlight, rain and wind) that, as we previously said, represent effects of the same phenomenon, whereas geothermal heat is independent on the flux of solar radiation. The human labour is considered 10% renewable (though it cannot be regarded as local) after the emergy analysis of Italy [4].

The proportion of total emergy inputs to the Chianti farm that are local or renewable is quite high (Table 2). Almost half (48%) of the total inputs are local and almost all local inputs are renewable (97%). The emergy yield ratio for the farm (1.96) is higher than that for the Italian agricultural system (1.43) [4], indicating that the farm management is in large part dependent on available local resources. The environmental loading ratio and the empower density, both less than the means for the Italian agriculture system, suggest that the environmental stress is low. The farm as a whole is therefore, more sustainable than the national average.

Table 3 shows the emergy analysis of the part of the farm devoted to the grape production. Also for this table details of the calculations of raw data are given in Appendix A. Here it is important to note the organic manure input. This was not considered in the farm analy-

Table 4
Emergy and related indices for crops (other than grapes) produced on the Chianti farm and the Italian average

Crop	Solar transformity (sej/J)		Emergy yield ratio		Empower density		Environmental loading ratio	
	Chianti farm	Italy [4]	Chianti farm	Italy [4]	Chianti farm	Italy [4]	Chianti farm	Italy [4]
Olives	6.71E+05	5.30E+05	3.49	1.24	4.45E+11	7.66E+11	2.13	4.4
Corn	2.66E+04	8.52E+04	1.53	1.19	5.74E+11	9.40+11	2.47	5.63
Sunflower	7.14E+04	7.91E+05	1.64	1.04	4.70E+11	4.08E+12	1.89	27.78
Forage	2.27E+05	8.00E+04	2.57	1.76	2.30E+11	3.47E+11	0.64	1.45
Cereals	1.13E+05	1.59E+05	1.33	1.32	5.71E+11	6.21E+11	3.02	3.38

Table 5
Emergy related indices for Chianti, Brunello di Montalcino and Nobile di Montepulciano grape production compared with Italian average

Grape production	Solar transformity (sej/J)	Emergy yield ratio	Environmental loading ratio	Empower density (sej/m^2)
Chianti	3.48E+05	1.79	4.09	9.18E+11
Brunello di Montalcino	4.69E+05	1.63	4.60	9.81E+11
Nobile di Montepulciano	4.25E+05	1.57	3.23	7.47E+11
Italian average (see [4])	3.41E+05	1.20	5.33	8.98E+11

sis since it is an internal feedback. Nonetheless when only grape production is analysed this contribution has to be taken into account. As results of separate calculations we determined the transformity of this input and the fraction that can be considered renewable and local, on a farm scale [17].

The cultivation of the crops other than grapes, was more efficient and had less impact on the environment than the Italian averages (Table 4). For all five subsystems, the environmental loading ratio and the empower density values were lower than the national means and the emergy yield ratio was higher. The transformity of all the crops, except olives, was less than the Italian average indicating that cultivation of corn, sunflower, forage, and cereals were more efficient than the national mean. The slightly higher emergy requirement per unit product for olives, is justified by the high quality of the product.

The transformity of the Chianti vineyard was lower than that of the ‘Brunello’ and ‘Nobile’ production, indicating that Chianti has higher production efficiency (Table 5). The emergy yield ratio was also higher for Chianti than for the other two systems (Table 5), indicating good land management for this cultivation: less external investment is required for the exploitment of the local resources. The environmental loading ratio and the empower density of Chianti production were both higher than they are for ‘Nobile’ even though less than for ‘Brunello’ (Table 5). This makes the Chianti vineyard the best of the three in terms of production efficiency, and the ‘Nobile’ vineyard the best from an environmental viewpoint, but the worst in terms of production efficiency. For all three vineyards studied, the environmental loading ratio was lower than the mean Italian environmental loading ratio of 5.33 for grape production [4], indicating a globally low overall environmental impact.

In conclusion, the Chianti farm was found to have good long-term sustainability, considering the low environmental loading ratio of the whole system, the good results obtained for individual crops in comparison with the Italian means, and the good standards obtained for the grapes in comparison with the other two systems analysed.

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Appendix A

A.1. Notes to Table 2

1. **Sunlight**

Area	8.50E+06 m^2	
Insolation	1.37E+02 kcal/cm^2/yr	[19]

Albedo land	2.00E-01 (% given as decimal)	[20]
Energy (J/yr)=(area)(insolation)(1-albedo)		
	=8.50E+06(1.37E+02 Kcal/cm^2/anno)	
	=(1−0.20)(4186 J/kcal)	
	=3.89E+16 J/yr	
2. **Rain**		
Area	8.50E+06 m^2	
Rain (average)	6.50E-01 m/yr	[19]
Quantity=(area)(rain)(water density)		
	=(8.5E+06 m2)(0.65 m/yr)(1000 kg/m^3)	
	=5.53E+12g/yr	
3. **Wind**		
Area	8.50E+02 ha	
Energy on land	2.45E+04 kWh/yr/ha	[21]
Energy=(energy on land)(area)(3.6E6 J/kWh)		
	=7.50E+13 J/yr	
4. **Geothermal heat**		
Heat flow per area	3.15E+06J/m^2/yr	[22]
Area	8.50E+06 m^2	
Energy=(area)(heat flow per area)		
	=(3.00E+05 m2)(3.15E+6 J/m^2/yr)	
	=2.68E+13 J/yr	
5. **Loss of topsoil**		
Area	8.50E+06 m^2	
Erosion rate	2.00E+02 g/m^2/yr [23]	
% Organic in soil	1.50E-02 (given as decimal)	[23]
Energy content/g organic	5.40E+00k cal/g	
Net loss=(area)(erosion rate)		
	=(8.5E+06 m2)(3750 g/m^2/yr)	
	=1.70E+09 g/yr	
Energy of net loss (J/yr)=(net loss)(% organic in soil)(5.4 kcal/g)(4186 J/kcal)		
	=(1.13E+09 g/yr)(0.015)(5.4 kcal/g)(4186 J/kcal)	
	=5.76E+11 J/yr	
6. **Water for irrigation and livestock**		
Use	8.75E+04 m^3/yr	

Quantity=(use)(water density)	
	=(8.75E+04 m^3/yr)(1000 kg/m^3)
	=8.75E+10 g/yr
7. **Nitrogen fertilizers**	
N content	5.54E+07 g/yr
8. **Phosphate fertilizers**	
P_2O_5 content	2.20E+07 g/yr
9. **Potash fertilizers**	
K_2O content	1.25E+07 g/yr
10. **Insecticides**	
Quantity	1.10E+06 g/yr
11. **Pesticides**	
Quantity	1.63E+06 g/yr
12. **Diesel**	
Total use	5.13E+04 l/yr
Energy content per liter	4.78E+07 J/l
Energy (J/yr)=(total use)(energy content per l)	
	=(7531 l/yr)(4.78E7 J/l)
	=2.45E+12 J/yr
13. **Agricultural machinery**	
	=4.70E+06 g/yr
14. **Human labor**	
Energy input: total man-days	2.89E+03 working days/yr (8 h/day)
Daily metabol. energy	1.00E+03 kcal/day/person
Total energy input=(daily metabol.energy)(total man-days)(4186 J/kcal)	
	=2.89E+06 kcal/person/yr
	=1.21E+10 J/person/yr
15. **Corn seeds**	
Quantity	5.80E+05 g/yr
16. **Sunflower seeds**	
Quantity	1.50E+05 g/yr
17. **Forage seeds**	
Quantity	2.50E+06 g/yr
18. **Industrial fodder**	
Quantity	2.50E+08 g/yr
Energy for production	4.00E+03 J/g
Total energy required=(quantity)(energy for production)	
	=1.00E+12 J/yr

19. **Iron ore**

Quantity	2.85E+07 g
Lifetime	1.00E+01 yr
Quantity per year=(quantity)/(lifetime)	=2.85E+06 g/yr

20. **Concrete**

Sticks	7.35E+08 g
Silos	3.75E+09 g
Lifetime	1.00E+01 yr
Quantity per year=(sticks+silos)/(lifetime)	=4.49E+08 g/yr

21. **Wood**

Sticks	4.09E+07 g
Lifetime	5.00E+00 yr
Quantity per year=(sticks)/(lifetime)	=8.18E+06 g/yr

22. **Electricity**

Quantity	1.83E+10 J/yr

A.2. Notes to Table 3 (data are for the full extension of the crop)

1. **Sunlight**

Land area	5.40E+05 m^2	
Insolation	1.37E+02 Kcal/cm^2/yr	[19]
Albedo land	2.00E-01(% given as decimal)	[20]
Energy (J/yr)=(area)(insolation)(1-albedo)	=5.40E+05(1.37E+02 Kcal/cm^2/yr) =(1−0.20)(4186 J/kcal) =2.48E+15 J/yr	

2. **Rain**

Land area	5.40E+05 m^2	
Rain (average)	6.50E-01 m/yr	[19]
Quantity=(land area)(rain)(water density)	=(5.40E+05 m2)(0.475 m/yr)(1000 kg/m^3) =3.51E+11 g/yr	

3. **Wind**

Land area	5.40E+01 ha	
Energy on land	2.45E+04 kWh/yr/ha	[21]
Energy=(energy on land)(land area)(3.6E6 J/kWh)	=4.76E+12 J/yr	

4. **Geothermal heat**

Heat flow per area	3.15E+06 J/m^2/yr	[22]
Land area	5.40E+05 m^2	
Energy=(land area)(heat flow per area)	=(5.4E+5 m^2)(3.15E+6 J/m2/yr) =1.70E+12 J/yr	

5. **Loss of topsoil**

Land area	5.40E+05 m^2	
Erosion rate	9.00E+03 g/m^2/yr	[23]
% Organic in soil	1.50E-02 (given as decimal)	[23]
Energy content/g organic	5.40E+00 kcal/g	
Net loss=(land area)(erosion rate)	=(5.4E+5 m2)(9E+03 g/m^2/yr) =4.86E+09 g/yr	
Energy of net loss (J/yr) =(net loss)(% org. in soil)(5.4 kcal/g)(4186 J/kcal)	=(2.15E+09 g/yr)(0.015)(5.4 kcal/g)(4186 J/kcal) =1.65E+12J/yr	

6. **Nitrogen fertilizers**

N content	1.40E+06 g/yr

7. **Phosphate fertilizers**

P_2O_5 content	2.16E+06 g/yr

8. **Potash fertilizers**

K_2O content	4.32E+06 g/yr

9. **Insecticides**

Quantity	1.90E+05 g/yr

10. **Pesticides**

Quantity	1.14E+06 g/yr

11. **Diesel and lubrificants**

Total use	1.02E+04 l/yr
Energy content per liter	4.78E+07 J/l
Energy (J/yr)=(total use)(energy content per l)	=(10156 l/yr)(4.78E+7 J/l) =4.85E+11 J/yr

12. **Human labor**

Energy input: total man-days	1.63E+03 working days/yr (8 h/day)
Daily metabol. energy	1.00E+03 kcal/day/person
Total energy per yr=(daily metabol. energy)(total man-days)(4186 J/kcal)	=1.63E+06 kcal/person/yr

	=6.80E+09 J/person/yr
13. **Agricultural machinery**	
	2.76E+06 g/yr
14. **Iron ore**	
Total weight	2.85E+07 g
Lifetime	1.00E+01 yr
Total use per year=(total weight)/(lifetime)	
	=2.85E+06 g/yr
15. **Concrete**	
Total weight of sticks	7.35E+08 g
Lifetime	5.00E+01 yr
Total use per year=(total weight)/(lifetime)	
	=1.47E+07 g/yr
16. **Wood**	
Total weight of sticks	4.09E+07 g
Lifetime	2.00E+01 yr
Total use per year=(total weight)/(lifetime)	
	=2.04E+06 g/yr
17. **Manure**	
Quantity	2.00E+08 g/yr

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