Energy Use in Agriculture: an Empirical Note on Technical Development and Ecological Loading

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Key words: Agriculture - Energy - Agricultural development.

Summary

Technical development in agriculture is largely dependent upon the interaction of labour productivity with demographic pressure on available arable land.

The paper is aimed at sketching out the relation of relative energy utilization levels in agriculture with labour productivity, land availability and environmental loading.

It is accordingly discussed the position of selected countries around the world. Four groups of countries are roughly identifiable; major problems seem to arise where a high energy use per unit of food is coupled with a low labour productivity and with a relatively high level of environmental loading.

Résumé

Le développement technique dans l'agriculture dépend largement de l'association particulière de deux facteurs à savoir: (i) la productivité du travail; relative au niveau du développement économique de la société; et (ii) la pression démographique relative à la disponibilité de terrains arables. Cet essai examine la relation qui existe entre la déficience énergétique, la pression démographique, la productivité du travail et l'impact de l'agriculture sur l'environnement. Dans cette perspective on a examiné la performance technologique dans un groupe de pays représentatifs de possibles combinaisons de productivité du travail et pression démographique. Quatre groupes de pays peuvent être définis dans cette analyse. Les plus grands problèmes se vérifient quand la limitation du terrain arable s'associe à un haut niveau de développement économique. Cette combinaison exige une importante demande d'énergie pour la production alimentaire, un impact considérable sur l'environnement, et un niveau de productivité du travail nettement inférieur au niveau nécessaire à assurer un revenu adéquat pour le paysan.

Background

Linking economics with the environment obviously implies relevant methodological problems, mainly arising from the systemic features of the latter which requires, at least, the involvement of subjects which have been for a long time quite far away from each other. Steady-state economics (1) and complex system analysis (3) have been proposed as frameworks to address issues of environmental impact of human activities taking into account their economics. A special reference to agriculture is quite common, since this industry deals more directly than the others with the ecosystem.

Today's picture of technical development in agriculture is largely dependent upon the interaction of labour productivity levels with demographic pressure on available arable land (3). Two well known regularities, drawn respectively from development and agricultural economics, state, first, that the more a country is developed, the more average labour productivity in agriculture, as in other activities, tend to be high; on the other hand, population density tend to shape the intensity of agricultural production, since the more the population, the more pressure is exerted on available arable land of food production. This has been highlighted by the theory of induced innovations suggested first by Hicks in the 1930s and restated by Hayami and Rutton in the 1970s. Technical development in land-scarce areas will, thus, be based mostly on the adoption of land-saving techniques, that is, on the intensification in the use of inputs which allow to increase output per unit of land.

Through massive employment of agricultural technology, developed countries, including the most important producers and exporters, manage to keep in agriculture a share of the labour force smaller than 10%, independently form how much arable land is available. In poor developing countries, a low average labour productivity still tend to imply, on average, a more massive labour employment in agriculture. Technology requires energy to be operated; in order to produce food with increasingly smaller amounts of labour, an increasing use of energy per unit of food

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Received on 15.03.96 and accepted for publication on 19.04.96.

Table 1 : Converting factors for inputs

Item	Value	Source
Average weight of machinery (tons)	15 for USA. Canada, Australia; 8 for Argentina and the European Community (EU); 6 for Asia and Africa	(10, p. 75)
Fuel consumption (tons per year)	5 for USA, Canada, Australia; 3.5 for Argentina and the EU: 3 for Asia and Africa	(10, p. 75)
Energy equivalent of machinery weight (kcal/kg)	34.230 divided by 10 (ten years life-span)	(10, p. 75)
Energy equivalent of fuel (kcal/kg)	10,181	(10, p. 75)
Irrigation (kcal/ha/year)	2 million for Argentina, USA, EU, Asia; 2.3 million for Africa, and Australia	(10, p. 88)
Pesticides (kcal/kg)	70,000 in developing countries: 100,000 in developed countries	(6. p. 194-196)
Fertilizers (kcal/kg)	Nitrogen (N) 18,650 Phosphate (P_2O_5) 4,157 Potash (K_2O) 3,273	(6, p. 184)

produced is usually required. This is mainly fossil energy, obtained by stocks depletion, employed in the production and operation of machinery, irrigation systems, fertilizers, pesticides and other agricultural inputs: the increase is energy requirement due to demand for meat, which regularly grows with income, it is not accounted here for simplicity.

The increase is the amount of energy employed per unit of food produced can be, obviously, efficient from an economic point of view, given that energy prices reflect their social costs of production and use, i.e. given that energy prices reflect long-term implications like the effects on the environment or the fast depletion of stocks. This is a difficult issue, at least because, first, social costs should be predictable, quantifiable and discountable over time, while responses from the environment are often non-linear; second, there are serious doubts about the feasibility of a timing substitution of actual energy sources; third, it is very difficult to assess the real importance of environmental goods before problems arise. Thus, technical development of agriculture in poor countries may pose a malthusian problem of fossil energy availability and, more generally, of carrying capacity. It must be said, however, that the whole issue of future carrying capacity looks very far from clear. E.g. Paris and Paris (9, section 2) point to the high uncertainty surrounding information on the topic.

Looking at technical development in agriculture from the point of view of relative amount of energy employed per unit of agricultural output, allows to include the environment in the analysis, since relative energy utilization is a measure of energy commercial throughput, which can be considered a measure of environmental loading. The term has been suggested by Odum (8). This note is aimed at sketching out the relation of relative energy utilization levels in agriculture with labour productivity, land availability and environmental loading, and at briefly discussing the position of selected countries around the world, according to their energy use in agriculture. Relative energy utilization in agriculture, being considered an indirect measure of technical development, would be basically determined by a combination of technology and natural resources, i. e. a) labour productivity in agriculture, and b) the amount arable land available per capita, and it would give a rough ranking of countrie's environmental loading.

Material and methods

Relative energy utilisation can be measured by an energy output/input ratio, i.e. by the comparison of the amount of energy employed in agricultural production, such as that consumed through fertilizers, pesticides and machinery, with the amount of energy produced through food. The intensity of application of energy inputs per farmer has been calculated in kcal per hectare, as an indicator of environmental loading. The average amount of arable land per farmer has been calculated as a measure of demographic pressure, while the amount of output per farmer has been considered as a measure of labour productivity in agriculture.

All reported calculations are necessarily dependent upon very large simplifications and aggregations, and they do not account for any of the significant differences existing within each country in terms of land use, distribution, institutional arrangements and cropping techniques. Animal production is not taken into account; although its inclusion would, probably, support the point made. GNP per capita is used as an overall indicator of well being despite its known relevant limitations for this purpose. All data are retrieved from FAO yearbooks for the year 1990; converting factors from metric tonnes to kcal have been calculated by comparing FAO data reported in both terms, which are consumption data from food balance sheets. Converting factors for inputs are drawn from different sources, which are reported in Table 1.

Results

Four groups of countries are roughly identifiable. Countries where labour productivity is high but land availability is relatively low, such as those listed in

Table 2 : Country groups

countries	GNP per capita (US $)	Arable land per capita (ha)	Energy inputs per hectare (million Kcal/ha)	Agricultural output/farmer (Kcal)	Inputs/ farmer (million Kcal)
group 1					
Japan	23810	0.02	46.70	14.80	46.00
Netherlands	15920	0.10*	36.50	58.00	141.80
Italy	15120		14.00	44.86	72.20
Germany (F.R.)	20440		18.50	84.97	117.40
France	17820		9.90	135.08	127.20
United Kingdom	14610		10.08	138.67	121.70
group 2					
Argentina	2160	0.38	1.30	93.79	27.05
Australia	14360	1.35	1.40	194.92	164.50
Canada	19030	0.85	2.80	334.85	276.60
United States	20910	0.37	4.40	386.12	284.40
group 3					
China (P.R.)	350	0.04	5.70	2.65	1.17
India	340	0.10	1.40	2.98	1.09
Bangladesh	180	0.04	2.10	2.98	0.84
Zimbabwe	650	0.13	1.24	4.16	1.33
Egypt	640	0.02	11.00	6.33	4.36
Mexico	2010	0.14	2.20	11.29	5.50
Costa Rica	1780	0.05	8.40	11.75	9.60
group 4					
Burundi	220	0.24	0.20	1.95	0.09
Ghana	390	0.18	0.30	4.90	0.13
Uganda	250	0.38	0.05	1.64	0.03

* European Union average value.
Source: our calculations of FAO data.

group 1 (see figures 1, 2 and table 2). Here, the energy output/input ratio is the lowest an GNP per capita is high, so that a high average standard of living is coupled with a high energy use per unit of agricultural output and with a high level of environmental loading, as measured by the high amount of energy inputs per hectare.

		Labour productivity	
		low	high
Land availability	low	output/input avg. 2.0 group 3	output/input <1,0 group 1
	high	output/input >20 group 4	output/input avg. 1.0 group 2

Figure 1 : Effects of labour productivity and land availability on the output/input ratio in agriculture

Countries of group 2, with both high labour productivity and land availability, show a medium-high level of the output/input ratio, averaging 1.0, and a medium-low level of environmental loading with a high GNP per capita. Here a high labour productivity, with a lot of land and technology, allows to be well off and to produce food with a more reasonable impact on the environment.

		Labour productivity	
		low	high
Land availability	low	total energy input avg. 4.5 group 3	total energy input 10 - 50 group 1
	high	total energy input <0.5 group 4	total energy input avg. 2.5 group 2

Figure 2 Effects of labour productivity and land availability on total energy input in agriculture as million kcal/ha (environmental loading)

Where land is relatively abundant but labour productivity is low such as in African countries of group 4 -

people is poor on average, but, at least, food production does not imply a significant environmental loading, since land is not a significant factor in increasing the demand of technical inputs; energy output/input ratio are, on average, higher than 20. Such a situation, however, is probably unstable, since rapid population growth and the widespread aspiration toward high living standards are pushing traditional farming systems to substitute environmental-friendly techniques with more intensive (western-fashioned) ones. On the other hand, in this group of countries, there is still room to orientate technical development of agriculture on a path that balances legitimate aspirations of better economic conditions of farmers with the concern for sustainability of agricultural production and of the ecosystem.

Finally, where both labour productivity and land availability per farmer are low - as it is in countries of group 3 - the energy output/input ratio result medium, with an average of 2.0, and total energy inputs is medium-high; this indicates that, a relatively high consumption of energy per unit of food produced is coupled with a relatively low average standard of living and with a relatively high level of environmental loading.

Thus, it seems that it is possible to be well off with a low level of environmental loading if a lot of arable land is available. In order to be well off with few arable land it is necessary to load relatively more from the environment. At the same time, being poor, it is possible to load few resources from the environment only if a lot of arable land is available, while, with a high demographic pressure, also a poor society needs a considerable relative energy use to feed itself.

Countries listed in group 3, with high demographic pressure and relatively low labour productivity in agriculture, are those which may require significant increases of energy for food production in the future, so they are the most likely to experience even more significant environmental damages from agriculture. Here the actual amount of energy per food produced is already high, due to demographic pressure. Should overall labour productivity grow in the future, even more technology use would be required to increase labour productivity in agriculture, and to make more labour force available for other sectors, like industrial manufacturing and services. As it has been frequently reported recently, this will also result in increased import requirements, likely to significantly affect world food markets.

Literature

1. Daly H. E. 1992 "Steady State Economics: Concepts, Questions, Policies", Ecological Economics n. **6**.
2. FAO 1990, Production Yearbook, Food Balance Sheets, Fertlisers Yearbook.
3. Giampetro M., Bukkens S., Pimentel D. 1995 "Effects of demographic pressure on agricultural performance", mimeo, Rome.
4. Giampietro M., Cerretelli G., Pimentel D. 1992 "Assessment of different agricultural production practices, Ambio **21** (7).
5. Giampietro M., Cerretelli G., Pimentel D. 1992a "Energy analysis of agricultural ecosystem management: human return and sustainability", Agriculture, Ecosystems & Environment, **38.**
6. Hesel Z. 1992 "Energy and alternatives for fertilisers and pesticide use", in Fluck R. C. (ed.) Energy in farm production (Vol. 6 of Energy in World Agriculture ed. by Stout B. A.), Elsevier, Amsterdam.
7. Kaufmann R. K. & Cleveland C. J. 1992 "Measuring natural capital and sustainable development: lessons from ecology, thermodynamics and economics"
8. Odum H. T. 1993 System Ecology, John Wiley, New Haven.
9. Paris P. & Paris Q. 1995 "Agriculture in the Twenty-First Century: Agronomic and Economic Perspectives", plenary session paper presented at the XXV Annual Meeting of the European Society for New Methods in Agricultural Research, September 15-19, Castelnuovo Fogliani, Piacenza, Italy.
10. Stout B. A. 1991 Handbook of Energy for World Agriculture, New York, Elsevier.

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