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EUROPEAN AGRICULTURE IN AN INTEGRATING ECONOMY

ENERGY-SAVING TYPES OF AGRICULTURE

A CRITIQUE OF THE MECHANICAL AND CHEMICAL ORIENTATION OF FARMING

by

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READING ENGLAND

Of all man's deliberate activities, agriculture is by far the largest user of solar energy, unless forestry is counted separately, although this can only be partly judged from the energy produced by crops (see Table 1). In addition, the human race is, of course, entirely dependent on solar radiation to warm the environment sufficiently for life to be possible at all. This is worth bearing in mind when considering estimates of the relatively low efficiency of energy conversion in photosynthesis by agricultural crops (Table 2).

Even so, the energy actually used in crop production is much greater than that which appears in the crop itself, partly because of the energy used in the production processes, including very large amounts used in the transpiration of water (Table 3) and partly because the crop is usually only a part of the plant grown.

However, although Agriculture would seem to be based on solar radiation, it is now widely recognised (Black, 1971; Leach, 1975; Spedding and Walsingham, 1975) that the agricultural systems of the developed world are also heavily dependent on the use of support energy ("fossil" fuels) (see Table 4). This dependence has come about by the use of machines, fuel to run them and inputs, such as fertilisers and pesticides, that cost a great deal of energy to make. It has been estimated (de Wit, 1975) that about one third of this support energy has been used to provide inputs that increase production per unit of land and about two thirds has been used to displace known labour. Certainly, increased use of support energy has been accompanied by a reduction in the use of labour, an increase in the use of tractors, a decrease in the use of horses and a reduction in the biological content of agriculture (Spedding, 1976). Thus, modern intensive farming exercises greater control over crop and animal production by substituting non-biological for biological processes. Artificial insemination, incubation of eggs, feed collection and processing, and manure disposal are all examples of this.

In consequence, the efficiency of resource use, in terms of land, labour and time, has increased but the efficiency of support energy use has decreased and is low for all intensive farming systems (Table 5). Animal production is less efficient than crop production, where these can sensibly be compared, because all animal production is based on crop production, somewhere along the line.

Of course, it has to be recognised that animal products command higher prices per unit of energy or protein (Holmes, 1975) and are generally more highly valued, that animal production is sometimes possible on land that cannot be cropped economically, and that, if cows milk is wanted, nothing will prove more efficient than a cow of one sort or another. Furthermore, there is no reason to suppose that energetic efficiency, in processes such as protein production, should be at any particular level. (Efficiency is used here simply to denote a ratio of output per unit of input (see Spedding, 1976)).

However, the <u>cost</u> of energy cannot be disregarded and it is this that makes high energy-dependence an important feature of modern farming. It is frequently pointed out that Agriculture uses only a small proportion of the national total (Table 6) but this, of course, makes no difference whatever to the cost of purchasing it, which is what concerns the farmer. It is probable that there are no large users, except by aggregation, and that if economy <u>is</u> required, it may have to come from many small economies: however, the price mechanism is the most likely way of achieving such economies , so the argument always reaches the same point, unless Agriculture is to be protected in some way from the higher prices of support energy that are certain to come. (Incidentally, this is independent of whether oil and coal run out or not, since if additional reserves are found, these will be more costly to exploit.)

The main reason, then, for considering energy-saving types of agriculture is the high cost of energy that is likely to obtain in the future. Whether or not shortage of supply make it necessary to use less support energy, it will certainly be worth considering ways in which the use of such a costly resource can be reduced or made more efficient.

I THE PATTERN OF SUPPORT ENERGY USE IN AGRICULTURE

If we wish to reduce the usage of support energy, we need to know where it is used, what it does, how important it is and whether substitutes exist.

Table 7 shows the pattern of support energy use in crop and animal production systems and Table 8 indicates the relative use of support energy "upstream" of the farm, on it, and "downstream". The latter proportions vary according to the product considered (and also within a farm product) but it is clear that the food production industry may use a great deal of energy in processing, packaging and distribution, beyond the farm gate. It is therefore possible that the least-damaging reductions in support energy use in the agricultural industry as a whole (including processing and distribution) might be in the "downstream" category.

It is more difficult to make sensible distinctions between "upstream" and "on farm" support energy and it does not follow that economies can best be made in those areas where most support energy is used. On the other hand, however energy costly inputs are, if the quantity used is very small, little energy can be saved by eliminating them: indeed, in the case of herbicides alternative methods of weed control may use even more energy.

Certain areas stand out as inviting further investigation. Fertiliser is one and, in quantitative terms, nitrogenous fertiliser is usually the most important.

A. FERTILISERS

Without an adequate supply of nutrients there will be little or no production: the problem is concerned with ways of ensuring an adequate supply. Recycling of nutrients can help but, unless sewage is included, minerals taken off in the products must be replaced. Water has its own hydrologic cycle but may nonetheless have to be supplied in arid areas and this costs energy also. Nitrogen illustrates both the possibility of alternatives and the complexity of the problem (Tatchell, 1976).

Many crops require a great deal of nitrogenous fertiliser and grass responds in a virtually linear fashion up to an input of about 300 kg N/ha. Since crop production rises so dramatically with input of nitrogenous fertiliser, the efficiency of output per unit of most resources (land, labour, capital, solar radiation) increases as well.

Since the greater fertiliser use greatly increases the input of support energy, here is a good example of the use of additional support energy to make better use of solar radiation. Very often this is nevertheless accompanied by a decrease in the efficiency with which the support energy is used but, in some cases, because of big effects on output, increased use of support energy is associated with an approximately constant efficiency of support energy use (see Fig. 1).

Alternatively, legumes can be used and, since they fix atmospheric nitrogen symbiotically, no nitrogenous fertiliser may be needed, at least on established swards. The effect of this on the efficiency of support energy use, at approximately the same level of output, can be seen in Table 9. The latter also illustrates how such gains can be lost if an energy-costly operation such as high temperature drying is superimposed.

It is interesting that legumes make such a small contribution to the world's food supply, but it is likely that they and free-living nitrogen-fixing organisms, such as the blue-green algae in rice production, for example, will play a bigger role in the future.

The main reasons for a more prominent role are (a) that the level of production now required also requires high levels of nitrogen supply, (b) that fertiliser nitrogen costs a lot of energy and its monetary cost will therefore rise, and (c) that the atmosphere is largely (c.80%) nitrogen and this supply is therefore ubiquitous and constantly renewed. Furthermore, an increasing number of plants have been found to have intimate associations, mainly around the root, with free-living organisms that supply nitrogen.

The fact that legumes cannot always yield as much, especially carbohydrate, per hectare is partly a reflection of the fact that less effort has been directed to legume breeding so far. Even so, yields of protein are high and the legumes include a number of important oil-producing species.

One major development towards agricultural systems that use less support energy, therefore, would be a shift towards legumes and a reduction in the use of nitrogenous fertiliser.

B. LABOUR

One of the major categories of support energy use in agriculture is in machinery. The latter may be used to eliminate drudgery, to achieve operations impracticable for unaided men, to speed up operations and thus to exploit "timeliness" of cultivation, sowing and harvesting, and to influence "scale" of operation. The effects, however, are always to reduce the need for labour and increase the need for skill, capital and support energy.

The usual way of calculating efficiency of labour use always results in pressure to reduce the amount of labour per unit area of land, since the area of land is commonly fixed. If, however, output increased with increased labour input, there would be an incentive to employ more people per unit area. However, where machines can replace men, high output per man is not associated with high labour input. Commonly, of course, machines tend to be large and expensive and need a large area to justify them. There is no reason at all why machines should not be devised that are appropriate to a wide range of conditions, including land area, and indeed this is what intermediate or appropriate technology is about.

It is also worth questioning the usual assumptions about the relationship between output per man and the number of men employed per unit area, especially for very small areas. It is quite possible that the greater flexibility of men over machines could allow crop mixtures and sequences, of sowing, cultivation and harvesting, that would make small areas with a high labour input extremely productive both per unit area and per man (Spedding, 1978).

In any case, the importance of a ratio such as output per man depends greatly on the relative cost of labour and whether one of the purposes of an agricultural activity is to provide employment.

Certainly, increased efficiency of labour use is normally accompanied by decreased efficiency of support energy use.

Another way in which agriculture could economise on support energy, therefore, would be to use more labour and less machinery. This need not imply any retrogressive moves towards peasant farming and it is consistent with trends towards both small-scale and part-time farming.

All such developments would need to try and preserve, at least, current levels of output per unit area and this may require certain minimum levels of energy input in addition to direct solar radiation. These kinds of development are therefore likely to be based on better use of solar radiation as the energy source for all purposes, since solar radiation is the one big source that can be regarded as guaranteed (and at a known level of daily incident radiation).

II BETTER USE OF SOLAR RADIATION

Since agriculture requires a source of energy, the main ways of saving support energy must be (a) to eliminate wasteful or unnecessary use of support energy itself, or (b) to use more of the incident solar radiation.

A. THE ELIMINATION OF WASTE

There is substantial scope in this area, well illustrated by the wasteful use of oil in glasshouses, where little attention has been paid to insulation and expulsion of warm air has been a major feature of the ventilation system. There are thus a range of rather obvious economies that could be made: in addition, there are more ingenious ways of operating systems that might result in energy saving. Amongst these are the juxtaposition of different production processes, such as fish production in the warm water from power stations, combinations of glasshouses (that need heat and CO_2) with animal houses (that generate both), or duck production combined with multi-species fish production.

B. SOLAR RADIATION

Solar radiation is primarily used in crop production and there are doubtless many ways in which this can be improved, although it has been estimated that the potential for photosynthetic efficiency may not be greater than about 8% (i.e. energy fixed as a % of total incident radiation) and that this is not so far above the best performance of existing species (Roberts, 1976). Nevertheless, there are possibilities of intercepting a higher proportion of the annual receipt of solar radiation by better plant cover (leaf area and leaf duration). Some of the ways in which this might be achieved include crop mixtures and sequences, some of which might be more suited to labour-intensive, small-scale farming.

There are also ways in which more use could be made of the solar energy that is actually fixed in photosynthesis. In many crops, quite a high proportion of the tissues grown do not finish up in the product at all. Some of these (such as roots of cereal crops) remain in the soil and contribute to soil fertility, while, of the above-ground residues (see Table 10), some are wasted, some recycled and some are used as raw materials for other enterprises.

The question here is whether the waste or by-products can be used to save energy. There are two main possibilities. The first is that any further use of such materials may increase the total output and thus the output per unit of energy employed. Fish production based on vegetable waste could do this for total protein output per unit of support energy. On the other hand, the outcome is not necessarily in this direction, as with some uses of cereal straw, where more extra energy may have to be employed than is gained in the whole enterprise.

The second possibility is that these materials could be used as a source of fuel. Clearly they could, since there are satisfactory processes for converting wet and dry biomass to a variety of solid, liquid and gaseous fuels. The problem is to do so with both energetic and economic efficiency, though the latter varies with the price of fuel.

III FUEL CROPPING

There are now some established systems for growing crops specifically as a source of fuel (Saddler et al., 1975; Calvin, 1976; Oswald, 1976; Howlett and Gamache, 1977), quite apart from forestry. Some are based on sugar cane and some on coppicing: many other crops are being considered in research programmes.

In general, fuel crops may make sense for countries that have more land than they need for their own food production and are short of support energy. Eire, New Zealand and Brazil are examples of this. In countries where this is not so, fuel crops are more likely to be confined to waste land or to marginal or difficult land (e.g. heather in Scotland or bracken in Wales). The exploitation of natural vegetation has obvious advantages but there are still harvesting costs and, maybe, difficulties to be overcome. Clearly fuel cropping could lead to quite novel agricultural systems but it is not yet clear whether the contribution to energy supplies would be of national or mainly local significance. The form in which fuel would be required, would depend greatly on the use envisaged and on questions of distribution and storage.

Another major possibility is that crop production would become increasingly multipurpose, producing food for people, feed for animals and feedstock for fuels, simultaneously.

As already mentioned, most existing crop plants already have edible and non-edible fractions (although the argument should not be confined to food crops only) but it is possible that different crops, crop mixtures and crop sequences may be used where multi-purpose production is the aim.

This raises interesting questions about harvesting methods and when and how the partitioning should be done.

An illustration of the possibilities can be derived from current research on Green Crop Fractionation (G.C.F.). Devised primarily to extract protein from leaves of either unwanted species, by-products or leafy crops not directly usable by Man or simple-stomached animals (Pirie, 1975), the process is efficient at producing protein per unit of land but requires a high energy input, especially if the product is dried. At the same time, it dewaters the fibrous fraction, which can be used to feed ruminants and on which similar performance can be obtained to that from the original herbage, since the main effect is the removal of nitrogenous fractions surplus to the requirements of most ruminants.

However, the fibrous residue could also be used as a fuel, to provide the power needed within the harvesting and processing system. This would lead to quite different energetic efficiencies in the production of protein (see Table 11) and could form the basis of a number of agricultural systems.

This raises the possibility of farms that are energetically self-sufficient, partly by reduction in energy need, partly by contributions from other sources (such as windmills) and partly by some fuel production from biomass produced on the farm, either as waste, by-product, main crop or by fractionation of crops.

IV CONCLUSION

There are many ways in which the energetic efficiency of farming systems could be improved and there is no need to visualise this as "going back" or "a return to earlier practices". The problem is how to go forward but in a different direction, that takes account of the effect of high oil prices on the relevance of measures of productivity.

Many of these changes do not necessarily imply changes in what Agriculture produces, simply in the ways in which production is carried out.

However, there is no doubt that the biggest reductions in support energy use in Agriculture, and the biggest increases in all aspects of energetic efficiency, would result from a shift in the balance of crop and animal production (away from the latter).

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Fig 1. Effect of Fertiliser Input on Efficiency of Support Energy Use in Crop Production

Fig 1. Effet de l'input d'engrais sur l'efficacité de l'utilisation d'énergie complémentaire dans la production végétale

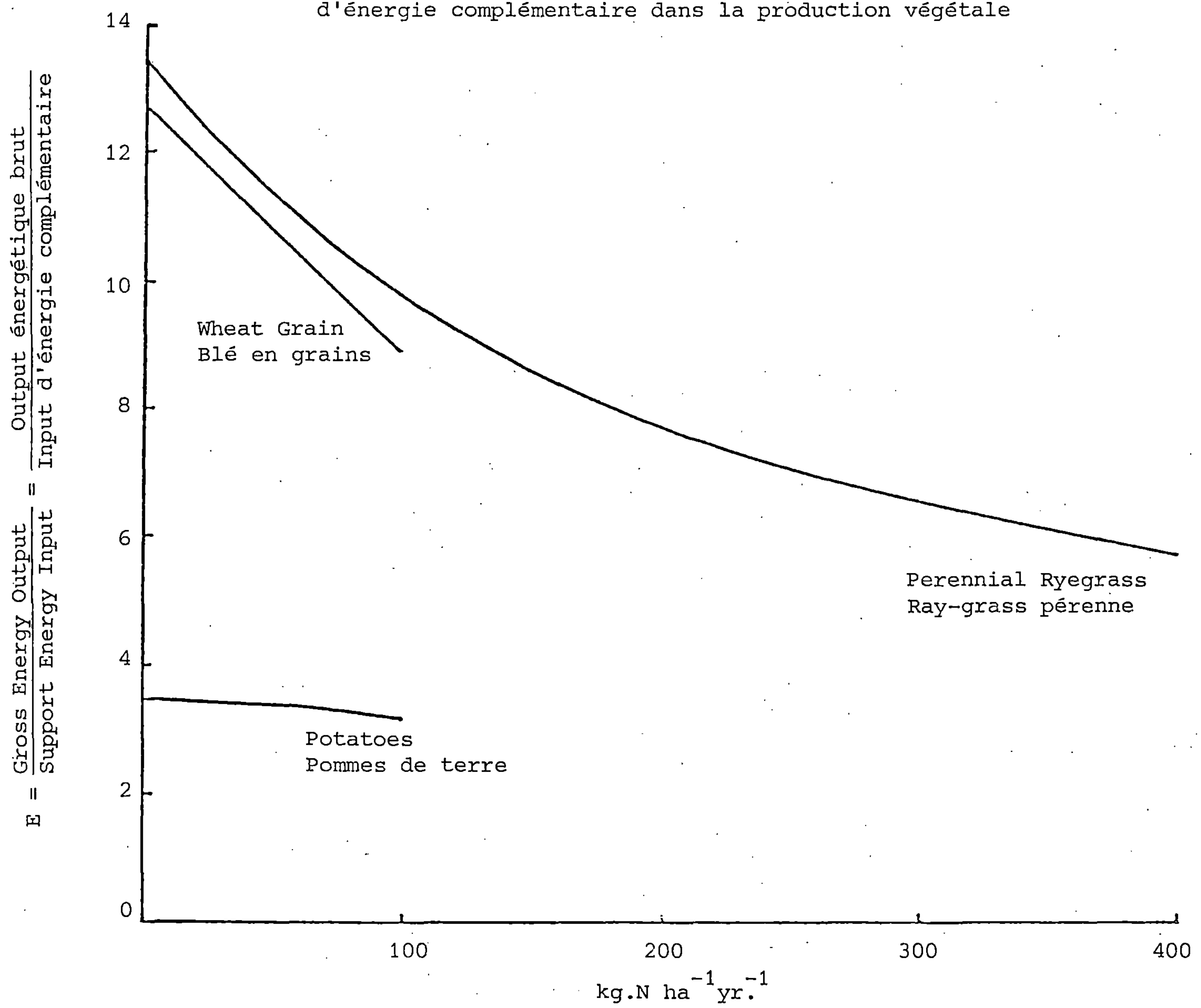

Table 1. Energy fixed by Agriculture and by Three natural Community Types (after Leith, 1972)

Tableau 1. Energie fixée par l'agriculture et par trois systèmes de végétation (d'après Leith, 1972)

	Area Superficie ($10^6 km^2$)	Energy produced Energie produite (10^{18} J)
Agriculture :		
Cultivated land Terres arables	14	11
Grassland Herbages	24	251
Forest / Forêts	50	1158
Woodland / Végétation ligneuse	7	82
Ocean / Océans	361	1090

Table 2. Annual Energy Fixation of some temperate Crops (Cooper, 1975)

Tableau 2. Fixation annuelle d'énergie de quelques productions végétales tempérées (Cooper, 1975)

Crop Culture	Country Pays	% Fixation $(\frac{\text{Energy in crop}}{\text{Total insolation}} \times 100)$ Fixation en % $(\frac{\text{Energie de la récolte}}{\text{Rayonnement total}} \times 100)$
Perennial ryegrass Ray gras pérenne	U.K.	1,29
Sugar beet Betterave à sucre	U.K.	0,73
Potato Pomme de terre	U.K.	0,69
Wheat Blé	U.K.	0,47
Maize Maïs	NL	0,47

Table 3. The use of solar Energy in Transpiration and Photosynthesis

Tableau 3. Energie solaire utilisée pour la transpiration et la photosynthèse

Crop Culture	Location Situation	Gross daily Insolation Ensoleillement quotidien brut ($KJ.cm^{-2}$)	% used in Photosynthesis % utilisé pour la photosynthèse	% used in Transpiration % utilisé pour la transpiration
Wheat Blé (1)	A.C.T. Australia	2,9	1,2	34
Pinus radiata (1)	"	2,5	2,5	54
Sunflower Tournesol (2)	Montpellier, France	2,8	1,8-2,8	48
Bulrush Millet Millet (3)	N.T. Australia	> 2,5	< 1,9	58

(1) Denmead (1969)

(2) Calculated from Eckhardt et al. (1971)
Calculé d'après Eckhardt et al. (1971)

(3) Calculated from Begg et al. (1964)
Calculé d'après Begg et al. (1964)

Table 5. Energetic Efficiencies of agricultural Products at the Farm Gate (Spedding and Walsingham, 1975)

Tableau 5. Efficacité énergétique de produits agricoles au seuil de l'exploitation (Spedding and Walsingham, 1975)

Product Produit	$\frac{\text{Gross energy in product}}{\text{Support energy input}}$ $\frac{\text{Energie brute dans le produit}}{\text{Energie complémentaire absorbée}}$
Maize / Maîs	2,8
Barley / Orge	1,8
Sugar beet / Betterave à sucre	1,8
Potato / Pomme de terre	1,1
Milk + cull cows Lait + vaches de réforme	0,62
Battery hen eggs + cull carcases Oeufs de poules élevées en batterie + carcasses de réforme	0,16
Beef (18 months grass fed) Boeuf (de 18 mois, nourri à l'herbe)	0,11

Table 4. Energetic Efficiencies of Seven national agricultural Systems and their major Energy Inputs

Tableau 4. Efficacité énergétique de sept agricultures nationales, et leurs principaux inputs énergétiques

Country Pays	Food energy produced / Support energy input Energie alimentaire produite / Energie complémentaire absorbée	Proportion of total Energy Inputs contributed by : Part des inputs dans le total des inputs énergétiques			
		Direct fuel and electricity (%) Fuel et électricité directement consommés (%)	Fertiliser (%) Engrais (%)	Machinery (%) Machines (%)	Irrigation (%)
Canada[1]	5,8	60	17	7	-
Australia[2]	2,8	57	19	19	?
Hong Kong[3]	1,2	0,5	53	0,02	14
U.S.A.[2]	0,7	50	25	17	6
Holland[2]	0,6	70	20	<10	?
U.K.[2]	0,5	36	27	11	-
Israel[2]	0,5	16	12	2	63

1 : Downing (1975) 2 : Gifford (1976) 3 : Adjusted from Newcombe (1976)
Ajusté d'après Newcombe (1976)

Table 6. Agriculture's Share of gross national Energy Consumption in Seven different Countries

Tableau 6. Part de l'agriculture dans la consommation nationale brute d'énergie dans sept pays différents

	National Energy Consumption[1] Consommation énergétique nationale[1]	Agricultural Energy Consumption Consommation énergétique agricole	
	(MGJ)	(MGJ)	(%)
Israel	162,0	19,5[2]	12,0
Holland	1536,5	140[2]	9,1
Australia	1778,5	97[2]	5,5
Canada	4921,5	198[3]	4,0
U.S.A.	60953,4	2391[2]	3,9
U.K.	8052,5	299[2]	3,7
Hong Kong	123,4	0,42[4]	0,34

1 : UNSO (1972). All figures for 1968 (except Hong Kong : 1971)
UNSO (1972). Toutes données pour 1968 (sauf Hong Kong : 1971)
2 : Gifford (1976)
3 : Downing (1975)
4 : Newcombe (1976)

Table 7. Patterns of Support Energy Use in agricultural Systems (Spedding, 1975)

Tableau 7. Utilisations d'énergie complémentaire dans des productions agricoles (Spedding, 1975)

Inputs	% contributed to total support energy cost of system % de l'apport total en énergie complémentaire à la production			
	Potato Pomme de terre	Barley Orge	Beef Boeuf	Milk Lait
Fertiliser / Engrais	54	46	61	65
Machinery manufacture Fabrication des machines	10	27	8	<1
Field operations Opérations de culture	17	20	12	20
Herbicides	4	1	<1	-
Seed / Semences	15	-	2	-
Grain drying / Séchage	-	6	15	-
Electricity / Electricité	-	-	2	15

Table 8. Energy Use in U.K. Food Provision (White, 1975)

Tableau 8. Utilisation d'énergie dans l'approvisionnement alimentaire au Royaume-Uni (White, 1975)

Part of System / Partie du système		Energy used / Energie utilisée (MGJ)	(%)
"Upstream" / "En amont"		241	22
On farm / Sur l'exploitation		122	11
"Downstream" / "En aval"			
Processing / Transformation	476	734	67
Distribution	139		
Cooking / Cuisson	99		
Refridgeration / Réfrigération	20		
Total		1097	100

Table 9. Efficiency of Support Energy Use in Grass and Legume Production, and the Effect of Drying (Walsingham, 1978)

Tableau 9. Efficacité de l'utilisation d'énergie complémentaire pour la production de graminées et de légumineuses, et effet du séchage (Walsingham, 1978)

Crop Culture	Yield Récolte ($t.ha^{-1}.an^{-1}$)	Gross Energy in Crop / Support Energy Input Energie brute dans la récolte / Energie complémentaire absorbée	
		Fresh / Frais	Dried / Sec
Perennial ryegrass Ray-grass pérenne	6	5,5	0,98
Lucerne / Luzerne	8	38,0	1,15

Table 10. Crop Residues as a Proportion of above-ground dry Matter Production

Tableau 10. Résidus des récoltes en proportion de la production aérienne de matière sèche

Crop Culture	Above-ground Production Production aérienne ($t.ha^{-1}.an^{-1}$)	Residue Résidus ($t.ha^{-1}.an^{-1}$)	(%)
Sprouts[1] Choux de Bruxelles[1]	10,4	7,97	76,2
Wheat / Blé[2]	9,3	4,73	50,9
Peas / Petits pois[1]	6,2	3,10	50,0
Beans / Haricots[1]	13,6	6,02	44,2
Barley / Orge[2]	7,4	3,27	44,2
Cabbage / Choux[3]	5,4	1,85	34,3
Cauliflower / Choux-fleur[3]	4,2	1,30	30,9
Tomato / Tomates[3]	22,7	4,70	20,7

1 : Calculated from Knott (1978) / Calculé d'après Knott (1978)
2 : Calculated from Smith et al. (1975); 3 : Calculated from Shiels (1978)

Table 11. The energetic Efficiency of Protein Production in Two Systems using G.C.F., compared with a conventional One (McDougall, 1978)

Tableau 11. Efficacité énergétique de la production de protéines dans deux systèmes utilisant le F.R.F., en comparaison avec un système conventionnel (McDougall, 1978)

System Inputs Inputs du système	Use of Fibrous Fraction Utilisation de la fraction fibreuse	System Products Produits du système	$\frac{\text{Protein Output}}{\text{Energy Input}}$ (g.MJ^{-1}) $\frac{\text{Output protéinique}}{\text{Input énergétique}}$
Pasture and silage Pâturage et ensilage	(No fractionation) (Pas de fractionnement)	Beef Boeuf	2,28
Fractionated ryegrass Ray-grass fractionné	Beef feed Aliments du bétail	Beef + L.P.C.(1) Boeuf + C.L.P.(1)	2,28
" "	Fuel Combustible	L.P.C.(1) C.L.P.(1)	4,77

(1) - Liquid Protein Concentrate
Concentré liquide de protéines