ENERGY ANALYSIS FOR AGRICULTURAL PRODUCTION SYSTEMS

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ABSTRACT

Energy analyses of specific agricultural production systems can assist in predicting the future course of competition among rival systems, suggest ways to increase energy efficiency and help spot areas where successful research can have a high pay-off. A model for performing energy analyses is provided by the study of energy use in the U.S. grain maize system by Pimentel, **et al.** (1973). They list and discuss the unit energy values and required amounts for the following inputs: 1) tractor fuel, 2) fertilizer (N, P and K), 3) tractors and machinery, 4) irrigation, 5) herbicides, 6) insecticides, 7) labour, 8) seeds, 9) drying, 10) electricity, and 11) transportation. We have added 12) energy costs of animal maintenance, 13) energy costs of storage and other fixed installations, and 14) energy costs of land development.

Several examples of energy analyses are given in the paper including energy costs and energy and protein returns for grain maize, soybeans, grazing-pasture silage with and without irrigation, and two double cropping systems involving silage maize and winter lupins.

INTRODUCTION

Because fossil fuel supplies are being depleted and because oil prices have been rising rapidly, there is an increasing amount of interest in examining the energy use of all activities in society, including agriculture. Two types of agricultural energy budgets have been presented in the literature. National or overall energy budgets have been presented for Australia, Britain, United Stated, Israel and the Netherlands. These types of energy budgets are used in long range government and corporate planning and in public education. This paper concentrates on the other kind of energy budget, namely, on methods of energy analysis for specific agricultural production systems.

Energy analyses of specific agricultural production systems can assist in predicting the future course of competition among rival systems, suggest ways to increase energy efficiency, and help spot areas where successful research can have a high pay-off. A model for performing energy analyses is provided by the study of energy use in the U.S. grain maize system by Pementel, **et al.** (1973). Their method is applied to the study of energy costs and energy and protein returns for grain maize, soybeans, beef production on grazed pastures with and without irrigation, and beef production in a feedlot with silage maize and silage lupins.

ENERGY VALUES OF INPUTS AND OUTPUTS

To estimate the energy cost of an agricultural production process the following steps are taken: (1) list the items used in production, (2) estimate the amounts of each item used, (3) multiply the amount of each item by its unit energy value, and (4) total the amounts to get the energy cost.

The inputs and unit energy values which were used are as follows (with energies given in megajoules (MJ)):

1)	tractor fuel	40.1 MJ/1 (44 MJ/1 for diesel fuel)
2)	fertilizer	77.5 MJ/kg-N, 14 MJ/kg-P, 9.7 MJ/kg-K
3)	machinery wear	.92 MJ/(maximum PTO hp) per hour of use
4)	irrigation	3 MJ/m^{3} for sprinkler irrigation from shallow bores
5)	herbicide	101 MJ/kg
6)	insecticide	1.6 MJ/kg
7)	labour	1.6 MJ/hour
8)	seeds	2 x the energy required to produce the grain
9)	drying	.6 MJ/kg grain from 26 to 13.5% moisture
10)	electricity	3.6 MJ/kw-hour
11)	transportation	2.5 MJ/tonne-km
12)	animal costs	if these items are important to the system a separate assessment must be made
13)	storage and buildings	
14)	land development and fences	

For tractor fuel, fertilizer, irrigation, herbicide, insecticide, labour and electricity, the values given by Pimentel, **et al.** (1973) were judged to be reasonable and were merely converted to SI units. The figure for transportation was given by Hammond (1972).

Tractor wear was calculated from the energy of construction which was given by Steinhart and Steinhart (1974) as 2.65 x 10^{6} kcal per tractor horse power. If the assume a 12,000 hours lifetime then the rate of energy useage is .92 MJ/hour per maximum horsepower. If the tractor is used with one major implement, this figure is doubled. A value of 3.7 MJ/hour per horsepower should cover the total wear on all the pieces of equipment used in field work. The energy of repair could be roughly covered by the energy which could be salvaged from the tractor at the end of its useful life.

The first four items are usually the most important ones, although there are possible production systems for which any of the other inputs can be the major energy input.

In the absence of good records for a given production system the amounts of each input must be estimated. The greatest effort should be spent in estimating the major items, whereas nominal values can often be used for the remaining ones. The hours of tractor and implement use can be estimated from the guidelines given in the American Association of Agricultural Engineers Year Book ASAE (1971). If the rate of fuel consumption isn't known it can be estimated as .23 times maximum PTO horsepower (ASAE, 1971 p.298. In the absence of more specific knowledge, fertilizer requirements were estimated as 1.1 times the amount of nutrient removed with the crop.

ENERGY ANALYSES OF SOME SPECIFIC SYSTEMS

Grain Maize

As a comparison with Pimentel, **et al.** (1973) it is interesting to analyze a grain maize crop produced under average yields and conditions closer to those in New Zealand. The main differences are in the higher average yield in New Zealand, 8,000 kg/ha (125 bu/acre), and in the fact that all of the crop is dried as opposed to 30% of the U.S. crop. The energy yield of the crop is 8,000 kg x 16.6 MJ/kg = 132,800 MJ/ha. The energy cost is 22,000 MJ(Table 2) to give an energy return of 110,800 MJ/ha. The results obatined by Pimentel, **et al.** (1973) are an energy yield of 5,084 kg x 16.6 MJ/kg = 84,395 MJ/ha. Their energy costs are 30,000 MJ/ha which leaves an energy return of 54,395 MJ/ha. The smaller return obtained by Pimentel, **et al.** is due to much smaller average yields (81 bu/acre) and to unrealistically high estimates of the amounts of tractor fuel and electricity used in maize growing.

Soybeans

Because an increasing amount of meat extender made from soybeans is being used to replace meat it is interesting to calculate the energy costs of soy protein production and to compare them with the energy costs of several systems of producing beef. The average yield of soybeans was taken to be 2,000 kg/ha (29.7 bu/acre) of soybeans which are 38% protein, 20% fat and 30% carbohydrate. The protein yield is 760 kg. The energy costs are 7,500 MJ/ha (Table 2). The energy yield of the soybeans is 44,000 MJ/ha, which leaves an energy return of 36,5000 MJ/ha.

Beef Systems

The comparison will be made with the energy costs for beef production in irrigated and unirrigated pastures and in two slightly different forage cropping systems. In all of the systems the dry matter is assumed to be converted to beef as follows:

1) Jagusch (1973) has given an estimate of 3.061 kg pasture dry matter required to produce a liveweight gain of 300 kg when the animal goes from 150 kg to 450 kg at slaughter.
2) Blaxter (1969) has shown that 58% of the feed in the entire beef production system is used for replacing and maintaining the breeding herd are made. This leaves 42% of the feed for production of beef protein.
3) Carcass weight is assumed to be 55% of live weight.
4) The carcass is 66% lean meat, 16% bone, and 16% fat.
5) Lean beef is 20% protein.
6) Some allowance must be made for the relatively higher nutritional value of beef protein. We assume the net protein utilization (NPU) in the human diet is 0.6 for soybeans and 0.7 for beef. On the NPU basis the daily protein requirement for a 70 kg man is 43.6 grams.

Grazing — Pasture Silage

Consider the production of beef from a pasture system with 17% of the dry matter preserved as silage. The pasture is assumed to be on fertile soil and to produce 12,500 kg dry matter/year. The yield of meat is then 1.71 animals/ha (42% of 4.08) or 769 kg of live weight = 423 kg carcass = 279 kg of lean meat and 45 kg fat. The yield of protein is 56 kg. The energy costs (from Table 2) are 2,700 MJ/ha.

Irrigated Pasture

Assume that if the same pasture is irrigated with 200 mm of water and some additional fertilizer is applied, the yield of dry matter is increased to 18,000 kg/ha. As in the previous example, 17% of the dry matter is preserved as silage. The yield is 2.47 animals/ha (42% of 5.88) or 1,111 kg live weight. The yield is 611 kg carcass or 403 kg lean meat plus 98 kg fat. The protein yield is then 81 kg/ha or (81 x .7) = 56.6 kg/ha dietary protein. The energy costs (Table 2) are 9,700 MJ/ha.

Silage Maize — Winter Lupins

As a contrast to the pasture systems we analyze a forage cropping system with maize grown in the summer and lupins grown in the winter season. Both crops are ensiled. For simplicity, we will use the same assumptions on the conversion of dry matter into beef. The system is assumed to produce 18,000 ky dry matter/ha as maize silage and 7,800 kg dry matter/ha as ensiled lupins. The maize yield is reasonable for standard practice on fertile soils, whereas the lupin yields were obtained on research plots. The system was chosen to give an approximate balance of protein over the year. The yield is 3.54 animals /ha (42% of 8.43) or 1,593 kg live weight which yields 876 kg carcass. This is equal to 578 kg lean meat and 140 kg fat. The protein is 116 kg/ha or 81 kg/ha of dietary protein.

The energy costs were estimated for two different versions of the system. In the high energy system all of the fertilizer required was assumed to come from commercial fertilizers and the animal manured were simply disposed of. In the lower energy system most of the nitrogen fertilizer in the animal manures was assumed to be recovered and any additional nitrogen required was assumed to be left in the soil by the legume. The energy costs for the systems were 29,000 MJ/ha for the high system and 18,000 MJ/ha for the lower energy system (see Table 2).

TABLE 1: Energy costs and dietary protein yields/ha for several systems.

	energy cost	dietary protein yield	energy per kg protein
soybeans	7,500 MJ	456 kg	16.4
beef from pasture	2,700 MJ	39 kg	69.2
beef from irrigated pasture	9,700 MJ	56.6 kg	171.7
beef from forage crops I	29,000 MJ	81 kg	358
beef from forage crops II	18,000 MJ	81 kg	222

Although any increase in energy efficiency **at a given level of production** is a welcome development, energy efficiency should not be used as the main criterion in selecting and operating agricultural production systems as is sometimes suggested. For example, minimizing energy input per unit of product would imply that intensive grazing systems should be abandoned with some of the land managed as range land and the rest of it used for growing trees. Attention should be focused, instead, on maximizing the energy return which is the difference between the amount of energy in the product (or the amount of energy for which the product can be traded) and the energy input to the system.

It is interesting to try to predict the future course of competition among production systems on the basis of energy analysis. Although present grazed pasture systems require less energy input per unit of protein produced than do the forage cropping systems, they do so at a lower level of production. Futhermore, some of the methods of increasing production on grazed pastures bring the energy requirement well into the range of the more efficient of the forage cropping systems. Therefore, if protein can be traded for relatively large amounts of fossil fuel, them production of animal feeds from forage crops will tend to be increased. Continued strong competition from soybeans to replace a portion of the beef market can be expected if fuel prices continue to rise.

Although this is more properly a topic for a national agricultural energy budget, it is interesting to note that the amount of fuel required for double-cropping 1 million hectares is about 10% of the present fuel imports.

To achieve greater energy efficiency in forage cropping systems the analysis given in the previous section shows that more research is needed in the areas of the nitrogen balance in the soil and on how much of the nitrogen in the animal manures can be conserved. Additional savings in tractor fuel and machinery wear could be made by the development of minimum tillage cropping systems.

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TABLE 2: Energy costs of agricultrual production systems (Megajoules per hectare)

input	grain maize		.soybeans		grazed pasture		irrigated pasture		silage maize winter lupins I		silage maize winter lupins II	
	amount	energy MJ	amount	energy MJ	amount	energy MJ	amount	energy MJ	amount	energy MJ	amount	energy MJ
1) tractor fuel	89 1	3569	84 1	3368	20 1	802	29 1	1162	210 1	8421	232 1	9308
2) fertiliser N	120 kg	9300	none	-	none	-	none	-	145 kg	11237	none	-
P	50 kg	700	40 kg	560	45 kg	630	65 kg	910	80 kg	1120	50 kg	700
K	40 kg	388	40 kg	388	34 kg	329	45 kg	436	80 kg	776	40 kg	388
3) machinery wear		1223		1155		274		398		2886		3189
4) irrigation	none	-	none	-	none	-	200 mm	6000	none	-	none	-
5) herbicide	1.12 kg	113	1.12 kg	113	.5kg	50	.5 kg	50	1.12 kg	113	1.12 kg.	.113
6) insecticide	1.12 kg	113	1.12 kg	113	1.12kg	113	1.12kg	113	1.12 kg	113	1.12 kg	113
7) labour	12 hrs	19	10 hrs	16	6 hrs	10	15 hrs	24	30 hrs	48	35 hrs	56
8) seeds	21 kg	210	56 kg	560	.2 kg	10	.2 kg	10	25+75 kg	1000	25+75 kg	1000
9) drying	8000 kg	4800	2000 kg	1200	none	-	none	-	none	-	none	-
10) electricity	10 kw-hr	36	5 kw-hr	18	2 kw-hr	8	2 kw-hr	8	14 kw-hr	50	19 kw-hr	70
11) transportation	200 t-km	500	100tpkm	250	20 t-km	50	30 t-km	75	50 t-km	125	50 t-km	125
12) animal costs	-	-	-	-		40		60		86		86
13) storage and buildings		350		88		100		150		2500		2500
14) land development	-	-	-	-		263		263		200		200
TOTAL		21321		7269		2679		9660		28675		17848