AGENCY FOR INTERNATIONAL DEVELOPMENT
WASHINGTON, D. C. 20523

BIBLIOGRAPHIC INPUT SHEET

FOR AID USE ONLY
Batch 56

1. SUBJECT CLASSIFICATION

A. PRIMARY
Food production and nutrition — AE10-0000-0000

B. SECONDARY
Agricultural economics

2. TITLE AND SUBTITLE
Energy subsidy in protein formation,its use as a policy planning tool

3. AUTHOR(S)
Slesser,Malcolm

4. DOCUMENT DATE	5. NUMBER OF PAGES	6. ARC NUMBER
1972	90p.	ARC

7. REFERENCE ORGANIZATION NAME AND ADDRESS
Cornell

8. SUPPLEMENTARY NOTES *(Sponsoring Organization, Publishers, Availability)*

9. ABSTRACT

10. CONTROL NUMBER
PN-AAD-484

11. PRICE OF DOCUMENT

12. DESCRIPTORS
Energy needs
Factor analysis
Food supply
Planning
Proteins
Subsidy

13. PROJECT NUMBER

14. CONTRACT NUMBER
CSD-3158 211(d)

15. TYPE OF DOCUMENT

AID 590-1 (4-74)

PN-AAD-484

CSD 3158 211(d)
Cornell

ENERGY SUBSIDY IN PROTEIN FORMATION: ITS USE AS A POLICY PLANNING TOOL

by

Malcolm Slesser

September 22, 1972

F O R E W O R D

The work here reported had its origin in an effort to make a technology assessment of different forms of protein manufacture. In the sense that through energy calculations one may decide which of several alternatives make sense, this has been achieved. However early in the study it became clear that the methodology permitted one to look at even broader matters - the implications of a food generating policy within a given country. It is this outcome which may prove the more useful of the results of the study.

The work was done over a period of ten weeks in the summer of 1972 under a grant from the Program on Policies for Science and Technology in Developing Nations, funded by USAID grant csd 3158. At the outset a choice had to be made between an extremely careful and detailed look at one or two systems, or a less detailed, and thus less precise look at many systems. The latter course was chosen. As the report states, there is a region below an energy subsidy of 3 million k.cal/hectare of land where the data is more scattered than one would like, and considerably more effort should be expended in firming data in this region. Very likely additional measurements in the field will be necessary. The study and results must thus be regarded as those of pilot study, revealing a promising methodology for food generation policy making. In section four of the report many deductive calcula-

tions are done to expose the methodology. They are necessarily based on the correlations obtained in this study. Any conclusions shown, however, should be regarded as extremely tentative till such time as further and more precide data has been obtained, and the study amplified. I should greatly appreciate if those who follow in this path, or make use of the methodology outlined, kept me informed as they improve and up-date the work.

I should like to acknowledge with gratitude the help and advice of many Cornell faculty in the course of the work.

Malcolm Slesser

September 22, 1972

ENERGY SUBSIDY IN PROTEIN FORMATION: ITS USE AS A POLICY PLANNING TOOL

1. The Problem

There is a world protein shortage. As far back as 1964 the U.S. Department of Agriculture was forecasting that by 1970, 2373 million people would suffer from protein deficiency (1). The UN warned in 1968 (2) "the size, urgency and rapid emergency of this problem must be fully understood" and recommended the promotion of greater efficiency, use of new sources of protein, the greater use of fish protein concentrate, synthetic amino-acids and algae production. But it gave no guidelines as to which might be more appropriate to the needs of the developing countries, other than a general call to "apply science and technology".

As far back as 1965, Borgstrom (3) had pointed out the immensity of the task by showing that even at a consumption of 500 million tons a year of fertilizer by the year 2000 the protein so generated would be insufficient. Moreover, the energy requirement might amount to 25% of the world's gross consumption for this alone.

In 1971 the U.N. noted (4) referring to the "green revolution": "Despite the magnitude and rapidity of change, the progress is modest" and argued "in the long run new and unconventional sources of protein will be needed", again no estimate was given of what this might cost in terms of industrialization, of energy, or of human resources.

The FAO, in its 1969 INDICATIVE WORLD PLAN (5), projected needs to 1985, and while it's calculations showed an excellent 'benefit ratio' it expressed doubt about being able to capitalize at a sufficient rate. The plan does not discuss whether people in UDCs (under developed countries) will be able to afford the products of the new methods of producing more protein.

All in all, one is left with the impression that though the lifeboat has been launched and the drowning man has been contacted, the price of rescue is still being negotiated and meanwhile the shore-line has disappeared.

1.1. World Food Potential

Food production is a rate process. Like all rate processes it must have an inherent point of equilibrium. As in a chemical reaction, one may by various devices hasten the rate process, but one cannot alter the equilibrium condition. One may make the same distinction in considering the world's food production. There is the thermodynamic potential; that is, the possible yield from an equilibrium situation. To know this we need to know the conditions of the system - the land, the energy annually available, the water, and other available inputs and we need to know what increases production. The former is a matter largely beyond man's control, but which he ought to know, for it represents a point beyond which he cannot go. The latter is matter for application of technology; which technology and with what intensity. By determining the energy

subsidy to each process, one can normalize all forms of protein production and thus provide a logical means of choosing between alternatives.

A very early look at the problem reveals that Nature creates protein without any intervention or energy supplement by man, but in order to stimulate the annual rate of making protein, man must add an energy component over and above the solar input. To get some estimate of the size of these inputs one may take the figures of McPherson (6) who estimated that to meet global protein needs by 1980, we should embark upon a large-scale production of synthetic proteins and amino-acids and calculated that 9.9 million tons annually of synthetics plus 11.4 million tons of amino- acids would be needed. The energy to make such compounds would amount to no less than one-sixth of the global food energy content in 1972. Since it is in the underdeveloped lands that the food problem is generally its greatest, the question must be posed: Can the people in these lands afford the energy intensive food production methods that areso often proffered by the DCs (developed countries). For example, from the work reported later in this report, one may calculate that in India some 154,000 k. cals are needed per person.year in India, IF India is to be self-sufficient in her food supply. According to the work of Just (7) in 1967 the inverse ratio for agro-chemicals in the USA was 5700k.cal/$ that is, an Indian faced with using US inputs might have to expend $30 a head to feed himself, a figure clearly beyond a country with a per capita GNP of $90 or so.

1.2. Energy-Based Calculations

An examination of the energy subsidy to protein production is useful for two further reasons:

1. There is every sign that energy costs are going to rise. The rate and the extent depends on the Middle East oil situation and the technological success of the fusion reactor programme. Even optimistic views (8) foresee a doubling of energy prices by 1980. Already the energy consumption per unit of GNP has been rising in the USA since 1965.
2. Energy is the ultimate resource. Though there is much talk these days of resource shortages: land shortage, water shortages, minerals declining in quality, all this can in fact be substituted for, simulated, or won, provided there is sufficient energy, and the means of dissapating it when consumed - as waste heat. Oswald (9) for example, has calculated that all US protein needs could be made with an algae plant 25 square miles in area, though as can be shown later, the energy cost would be astronomical.

The energy available to us comes in two distinct ways:

a. Perpetual energy. This is photo-synthetic solar energy which is free; hydropower and geothermal power.

b. Non-renewable energy, like coal, oil or Uranium deposits.

By the year 2000 most easily accessible sources will have gone. Man will then be seeking the less accessible deposits, like Athabasca Tar Sands, or investing huge amounts in creating plants to create energy through fission,breeding, fusion or solar energy capture. If the costs of this energy are beyond the means of the countries dependent on energy for their food production, then nothing will have been gained.

It is vitally necessary that the developments in food production bear some relation to the countries abilities to furnish the inputs, all of which can be reduced to energy terms.

The primary purpose of this work is to assess the energy subsidy that goes to forming protein by all known methods, as a preliminary step to seeking a logical basis for food policy planning.

2. METHODOLOGY

2.1. Why Protein

Though many authorities believe that the key nutritional problem is protein, others maintain that except for expectant mothers and young children, if there be enough food calories, then there will be adequate protein. Since the stress in this work is on energy subsidy, and since the fixation of nitrogen is one of the most energy-intensive processes that have to be dealt with, all prime calculations will be done in terms of protein. However, the data is also processed to show the energy subsidy per unit of food calories, and both sets of data are presented and analysed.

2.2. Energy Subsidy

The term energy subsidy is capable of many interpretations. Its meaning in this work is best revealed by considering in detail a given protein process. Consider the process of growing corn (maize). This is a land and solar energy utilization process, and the calculation of subsidy is made by considering the inputs to a unit area of land, and comparing them with the product from that area.

Inputs:

1. Solar energy
2. Human energy
3. Mechanical energy - tractors, mechanical handling devices, etc.
4. Energy expended on bringing water to the land area
5. Energy expended in bringing in seeds, fertilizers, pesticides, etc., and in taking out products, waste, etc.: that is, transport energy
6. Energy content of fertilizers, pesticides, herbicides, etc.
7. Energy content of wastes, returned to soil
8. Energy content of the capital goods which depreciate as a result of their use in the process of production
9. Energy bought and consumed by workers associated with the growing process - e.g., transport of workers to and from home to farm, or their domestic energy consumption.

Not all these terms can and should be included:

1. Solar energy. This is a free good, perpetual and renewable. It is excluded. The energy subsidy is essentially a means of catalysing the process for capturing solar energy.
2. Human energy. The problem here is essentially philosophical. Since all forms of intensive agriculture have so far resulted in putting people off the land and out of work, it may be argued that human energy, like solar, is free, perpetual and in excess. In practical terms, where there is any degree of intensification the human energy component is so small as to make little contribution. For example, it is doubtful if the density of agricultural worker in the American mid-West is greater than 1 man per 40 ha. If his calorie intake is 3000 k. cals/day then his energy contribution is 27.4×10^3 k.cals/ha.yr. or at most 1% of mechanical and fertilizer inputs. The accuracy of this study does not justify considering such small effects. However, where the agriculture is simple, non-energy intensive as in much of Asia or Africa and where an entire family may help to work the soil, there may be densities as high as one person for every hectare of land. If peasant's calorie intake is 2000 k.cal/day then his bio-energetic contribution is some 150×10^3 k.cal/ha.yr. or the same order or greater than any

inputs he may purchase. For example, to purchase an input even equal to his own energy would cost him (7) at least $8. In 1967, the energy input to US land was $20/ha (7).

To make an adequate decision here seems to call for some more specific research. The decision taken, however, is to postulate 150 x 10^3 k.cal/ha.yr. as the minimum input to all agricultural processes, and to add this figure to all data taken from non-intensive or low-intensive agriculture. This is later defined as agriculture in which the energy subsidy amounts to less than 1150 x 10^3 k.cal/ha.yr.

3. Mechanical energy. This energy should certainly be included, but rarely is the data available to do so. Where data indicates fuel use, the figure is the heat of combustion of the fuel. Where it indicates tractor hours, this is computed at 2 US gallons per hour of gasoline.

4. Water. The energy to bring water to land can be in many cases a major element in the energy subsidy. If a gallon an hour of water is pumped from a well 100 feet deep, to a field of one hectare during a growing season of six months the energy use is some 40 million k. cals. Even with good yields this could amount to 5000 k.cal/lb product, a very significant figure indeed. Figures are given for Israel that are far higher (59). Irrigation in

Israel can be $20-$200/acre yr. Unfortunately, data on irrigation was rarely presented along side agronomic data, and this important energy element has to be omitted, and may explain why certain areas appear to be more effective growers than they are.

5. Fertilizers, soil conditioners, etc.

The addition of fertilizers, and the use of pesticides and herbicides is widespread and well-documented. Their energy content is often considerable, and is included in the assessment of energy subsidy.

6. Transport Energy This term, which should logically be included in any specific study, has been omitted for two reasons. In the first place the data is rarely available. Secondly, it varies greatly from place to place and whether it is by boat, train or truck. The Oak Ridge National Laboratory study (10) suggests that for bulk carriage, this energy cost is not great in relation to other inputs to intensive agriculture, but, once again is highly significant in relation to non-intensive agriculture. For example, moving by truck 500 miles adds 131 k.cal/lb to the energy cost - see Table 1.

7. Wastes. This term is not credited. However, in certain cases, for example where there is a high energy by-product, such as oil from fish meal processing, the energy content of the oil is credited to the process, or, as in free range animals their wastes are naturally neglected.

8. Capital goods. Without doubt no true assessment should omit this figure. It is, however, a major piece of research in itself to establish the energy content of capital goods. Work currently being completed by Hannon and Herenden at the University of Illinois (11) would enable such assessments to be made reasonably quickly if the components were known. They are not inconsiderable. For example, the energy required to make a small US automobile is calculated (Hirst 12) to be equivalent to 15,000 miles of gasoline consumption.

   In this work the energy content of capital goods is not included.

9. Energy subsidy of workers. In a marginal economy one may presume that agricultural workers utilize very little energy other than renewable energy in form of wood and dried animal droppings. No term is therefore included for them. In developed economies presumably the standard of living of a farm worker includes use of automobile, central

heating, and household gadgets. A modest figure for his domestic use would be 20 million k.cal/ year. If he effectively tended 40 ha, (see para 2.2.), then his per hectare use would be 500,000 k.cal/ha.yr. This is over three times the amount computed as the base line for bio-energetic economies. This sum is therefore added to all intensive agricultural figures, which is defined here as agriculture where the inputs exceed 2000 x 10^3 k.cal/ha.yr.

In this work the energy subsidy is the sums of terms [2+3+6+9]. Such a figure omits the important factors of water pumping cost and capital cost. Their effect may only be qualitatively guaged at this point in time.

2.3. Protein Quality

Proteins are needed for body building and cell renewal. Any given protein is composed of a mixture of amino-acids. Certain of these are key or limiting components in that if their fraction falls below a certain figure, they limit the body's ability to utilize the remaining protein molecules. Only eggs appear to have an almost ideal amino-acid distribution. At the other extreme is to be found peanuts of which only 48% of the protein is utilisable.

The quality of a protein is expressed by nutrionsits in terms of PER - Performance Ratio or NPU - net protein

utilization. Table 2 lists NPU values (data from WORLD FOOD PROBLEM vol 1)According to Call (13 verbal communication) it is not important to consider protein quality except where a person's diet consists of one type of protein. For example, in many parts of South America and Asia manioc (cassava) is almost the sole source of protein. Where people obtain a variety of protein, the lacks in one tend to be made up by surpluses in others.

It was felt that it would distort the picture study if the protein yields were in terms of NPU. The data is therefore presented in direct form, as k.cal used per unit of protein produced.

2.4 Source of Data

The time available for the pilot study was some ten weeks, too little to permit any experimentation or actual measurements of crop yields or inputs. All data were taken from the literature or from agricultural handbooks, such as those put out by the US Department of Agriculture.

2.4.1. Consultation

Cornell University. Cornell, with its large agriculture school, was possibly the best place in the USA where this study could have commenced. Consultation was had with the following individuals, all of whom led the author to various sources of data in their fields:

Agronomy:

Professor D. Bouldin and Professor M. Drosdoff. Dr. D. Coulter, a visiting professor from Rothamstead, England, was also of material assistance.

Nutrition:

Professor D. Call

Agricultural Economics:

Professor D.G. Sisler

Animal Science:

Professor J.T. Reid

Chemical Engineering:

Professor K. Bischoff and Professor V. Edwards

Entomology:

Professor D. Pimental

Elsewhere:

Professor H.T. Odum, Department of Environmental Engineering, University of Florida, Gainesville.

Professor David White and Mr. James Just, Department of Electrical Engineering, M.I.T., Cambridge, Mass.

Dr. H. Goeller and Dr. W. Fulkerson, Oak Ridge National Laboratory, Environmental Laboratoroes, Oak Ridge, Tennessee.

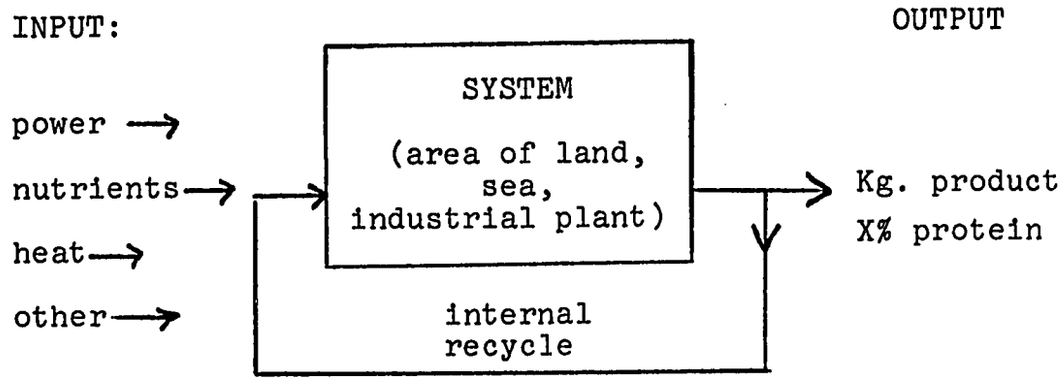
Dr. B. Hannon and Dr. J. Herendon, Center for Advanced Computation, University of Illinois, Champaign-Urbana, Illinois.

Dr. Erwin Hornstein, USAID, State Department, Washington, D.C.

Dr. Walter Pawley, FAO, Rome.

2.5 Treatment of Data

The data was treated according to a systems approach. No attention was paid to what happened within the system, only over the system. Thus, a typical approach would be:



If in any system there was waste, this was disregarded. The energy equivalent of all the inputs mentioned in para. 2.3 were totalled, and set against the production to yield the following data, which are embodied in the summary tables, Tables 6-11:

1. k.cal energy subsidy to form one pound of product - k.cal/lb.
2. k. cal energy subsidy to form one pound of protein of that product - k.cal/lb

3. Where appropriate: yield per hectare of land area kg/ha.yr
4. kg. protein produced per ha.yr
5. 10^3k.cals per ha.yr energy subsidy
6. k.cal/kg food value of product ha.
7. 10^3k.cal food value/ha.
8. energy ratio: the ratio of the metabolizable energy in the food product divided by the energy subsidy that went to create that food product

2.5.1 Land Area Equivalent(LAE)

In many cases the land area associated with a given production is not directly obvious. For example, if corn is grown in Illinois and then fed to cattle in feed lots in New York, a given weight of feed per year in New York is attributable to a specific growing area in Illinois. This area is called the land area equivalent (LAE) of the feed. Thus, when any component is introduced into a system, it will have as a rule an equivalent land area. By totalling all the inputs and LAE's, a figure may be obtained for the land area that went to support the system.

Usually in intensive systems the actual area of the system itself is trivial in relation to the land area equivalents of the input. For example, the LAE for the feed grain to feed-lot cattle is about 1.0 ha./per heifer.yr. A feed lot having an area of one hectare may support a hundred cattle, whose per unit land occupation is 0.01 ha, which is about 1% of the LAE .

A similar reasoning allows one to discount the land area of an industrial installation. If a Lysine factory is dependent on glucose as the starting product, the land area equivalent to grow the glucose is at least 100 times the factory area to process that glucose.

LAE is always expressed as ha. per produce. years. Thus, for example in study 13, the sum of energy inputs to an average NY State dairy cow is 5913 X 10^3 k.cal/cow and the LAE is 1.13 ha. This energy input and this area support a cow producing 13,323 lb. milk average over a year. From this one may compute the energy intensity per hectare = 5913 X 10^3/1.13 k.cal/ha.yr and the production intensity, (13,323/2.2)/1.13 = kg. milk produced per ha.yr.

2.5.2 Regression Analysis

To correlate the data regression co-efficients should be calculated. At the time of writing this report (September 1972) there has been neither time not facilities to do so. Correlations are 'best fits' by eye. When the data has been properly correlated, by regression analysis, any changes will be noted in a supplement to be added to this report. (See page 48).

2.6 Energy Equivalent of Inputs

Without exception all inputs are manufactured propucts. The energy equivalent of the inputs is the heart of the study, yet here too many compromises had to be made. For the reason outlined with respect to farm capital goods, the

energy content in the industrial capital equipment to form such diverse things as superphosphate fertilizer or 2-4-D pesticide was not accounted for. Thus the energy equivalents are necessarily on the low side.

All energy inputs were reduced to the heat of combustion of the hydrocarbon fuel needed to produce them. This in itself underestimates the energy equivalent, since energy is itself used to create and transport the hydrocarbon in its due form to the place of use. In the US, for every k.cal of hydrocarbon energy produced, 0.2 k.cal were used in the process (7).

Objection may be raised that reduction of all energy inputs to the equivalent hydrocarbon heat of combustion overlooks the fact that, for example, the TVA make fertilizer from hydro-power. But upon a global scale, hydro-power is small and dimishing fraction of energy source, representing today only 6% (14 Darmstadter, etc).

Where possible, comparisons were made with published results. A number of enquiries were sent to industrial forms. Only the Atlantic Richfield Company replied in a positive manner. All others either failed to reply or declined to disclose data.

It is important to note that the calculations of energy contents were made on the basis of an isolated industrial plant producing that particular product. A fully integrated agro-chemical complex would make better use of energy of exothermic processes.

Atlantic Richfield Co. quotes 6000 k.cal/lb N from an integrated agro-chemical factory.

Where a choice of methods was available, that method was chosen which represented up-to-date technology. For example, the energy content of amonia was based on the methane air process, not the old fashioned Haber process.

A summary of energy equivalents is given at the end of section 2 in Table 3. Individual calculations are shown in the appendices.

2.7 Accuracy

2.7.1 Energy Equivalent of Inputs:

Even for a chemical engineer, the estimation of the energy balance on a given industrial plant, if done accurately, could take several weeks. Some 20 such calculations required to be done. Since in reality the products are made in diverse factories around the world, a figure for one plant might differ significantly from another. Great accuracy seemed uncalled for at this stage of the study. The technique adopted was to examine the chemical process literature for flow sheet description, and then, using conventional chemical engineering techniques, estimate the energy balance of the system. In most cases an accuracy within about 10% is claimed. In the case of amino-acid synthesis, the confidence is less. None of the amino-acid manufacturers responded to requests for information, and the literature was scanty.

2.7.2 Agricultural Data

As every agricultural scientist knows, trials with plant or animal systems are difficult to reproduce. Much of the data showed fluctuations between trials of as much as 10%. The inputs may be said to have the same order of accuracy as the outputs.

2.8 Energy Inputs of Key Fertilizer Elements

Examination of section 2.8 (Table 3) shows that key elements like nitrogen, phosphorus and potassium are available in a number of compositions. Much agronomic data expresses inputs as so much nitrogen, potassium and phosphorus. It is helpful therefore to re-express the energy equivalent of inputs in terms of providing each of these elements, irrespective of the manner of addition.

2.8.1 Nitrogen

Table 3 lists five nitrogen sources: Nitric acid, ammonium nitrate, urea and ammonium sulphate. If these energy inputs are also expressed in terms of pounds nitrogen, the figures range from 9130 k.cal/lb to 10,870. In view of the 20% degree of accuracy aimed at, it is sufficient to assume that the energy equivalent of applying nitrogen to a system is 10,000 k.cal/lb nitrogen.

2.8.2 Phosphorus

Table 3 lists four sources of phosphorus: phosphoric acid, 12-40-0 poly-phosphate, 17-17-17 super-phosphate and 0-26-26 potassium metaphosphate. To compute the energy content of the phosphorus fraction, it is necessary to subtract that due to nitrogen and potassium.

Phosphoric acid	444 k.cal/lb	1187 k.cal/lb P
17-17-17 superphosphate	5462 k.cal/lb	721 k.cal/lb P
12-40-0 poly-phosphate	1744 k.cal/lb	1360 k.cal/lb P
0-26-26 metaphosphate	3090 k.cal/lb	10,000 k.cal/lb

Clearly the metaphosphate process is energy intensive which may account for the few plants in existence. The results are confused by the presence in all but the phosphoric acid of useful elements, particularly calcium and sulphur. The superphosphate 17-17-17 figure is very dependent on the subtraction of the nitrogen element in the process, thus leaving the two most valid measures of energy content that of phosphoric acid and metaphosphate. In this work the figure chosen for the energy content of phosphorus has been 1170 k.cal/lb P.

3. Results

3.1 Layout

Each of the 134 studies is reported individually, and are to be found in the appendix held by the Program on Policies for Science and Technology in Developing Nations.

A summary of the data is recorded in Tables 6-11.

3.2 Energy Subsidy to Form Protein

The energy subsidy per unit of protein formed varies enormously, and has no particular pattern. The data is given in column (2) in Tables 6 to 11, but a general impression may be gained from Figure 1. Naturally truly primitive systems use the least energy per unit of production, but in the middle range of energy subsidy, around 10^6 k.cal/ha not all unfertilized systems are more energy efficient than fertilized. For example fertilized peanute from Florida perform better than unfertilized wheat in England. However, it is at the higher energy subsidies that the surprises exist. Synthetic forms

of protein production like petro-protein, torula yeast, algae, are as energy consuming as beef, chicken, eggs made by intensive methods. Thus, synthetic means of producing protein provide us with no solution to the problem of producing protein. They simply represent alternatives, but as will be shown in section 3.3, use less land area.

A considerable surprise is the high energy cost of deep sea fishing, which can be as high as that for intensive beef raising, and suggest that the catching of fish to form fish meal as an intermediary step in animal feeding stuffs may be a very ineffective way of using the sea's natural product.

Sea fishing will be discussed more fully in Section 3.3.

3.3 Protein Yield, Area Basis

A more meaningful picture of the energy subsidy may be had by plotting the data on an area basis. This necessarily excludes all non-area based studies, such as sea fishing, but does not exclude fish farming, nor some of the synthetic processes. The data for non-fish and animal protein are plotted in Figure 6,* from which Figure 8 is derived. The data, though scattered, produces a remarkably linear function from an energy subsidy of 3×10^6 k.cal/ha.yr up to the highest study figure (algae) of 650×10^6 k.cal/ha.yr. Figure 8 bears three marks:

150×10^5 k.cal/ha, which is the bio-energetic input, (see Section 2.); 40×10^7 k.cal.ha, which is 1% of the solar input and 40×10^8 k.cal, which is 10% of the solar input. Odum notes that 2.2% is the highest efficiency of solar energy

* Figure is held by the Program on Policies for Science and Technology in Developing Nations.

capture to be found in plants (oil palm). In our study only synthetic process exceeded this figure.

The data is less satisfactory below an input of 3×10^6 k.cal/ha. Here data for animal, fish and vegetable protein produce a confused area in which animal protein seems often to give greater yields per unit of energy input than vegetable. Table 12 gives 15 case studies where the inputs were so low as to be at the bio-energetic level. The yields vary from 260 kg. protein/ha.yr (milk, England) to 4 kg. protein.ha.yr (rice, acid soil, India). An unweighted mean of these gives a bio-energetic mean yield of 114 kg. protein/ha. This value is indicated by the Square point in Figures 6 and 8. The line is extended to this point. It is hard to believe that this is truly the form of yield/energy plot. On thermodynamic grounds one would expect as the energy input increased that the benefit per unit increase would diminish, rather than the opposite. Indeed one would expect a plot analogous to that reported by FAO (ref. 53). This plot is reproduced as Figure 9. Before proceeding further, it is useful to analyse animal, fish and milk protein.

Figure 10 shows the data for animal protein and from fish farms. Clearly a great deal more data is needed to substantiate performance in the low-energy subsidy region. However, the best fit is drawn, and if now added to Figure 8, we find it intersects the vegetable protein plot at 59 kg. protein/ha. We would argue that the plot AC is more likely to represent the facts than plot BC.

An analogous plot has been discovered by Giles (ref 54) and is reproduced here as Figure 11. The meaning of the plot is obscure, since horse-power per hectare tells us very little without knowing the hours of operation of the mechanical implements. The shape, however, appears to reflect the same principle as out Figure 8 plot AC (the one is log-log, the other semi-log).

Plot AC yields: the relation: Kg.protein/ha.=

$$5.076 \times 10^{-3} \left(\frac{k.cal}{ha}\right)^{.742} \qquad \text{----(1)}$$

3.3.1 Animal and Fish Protein

Examination of Figure 10 shows that in some cases low energy inputs can produce remarkably high protein yields. Since it is generally accepted that animal protein is an inefficient way of using agricultural resources, this point bears further study. Our data is too skimpy at this time to draw many conclusions, but one does stand out. Figure 10 shows certain studies whose points are ringed. These are grass fed cows in New Zealand (29), Venezuela (18) and England (31). Their performance is clearly superior to that of feed lot cattle, even at high intensity, though the gap does narrow. Harlan (25) argues that this is because free-range cattle recycle large fraction of the nutrients to the soil.

A poor performance is recorded for US Lamb. This is feed-lot fattened lamb and though no precise figures have been unearthed yet, tentative figures for Scotland and New

Zealand suggest vastly better performances in those countries, where free range is the accepted method, summer and winter.

One firm impression gained is that the feed-lot method of animal protein production is energetically undesirable, and made economically possible only by the present low cost of energy. It is clearly undesirable from a pollution standpoint. Figure 10 yields (kg. animal protein/ha.)= 0.2735 (k.cal energy subsidy/ha)$^{.42}$---(2)

3.3.2 Milk

The data for milk are shown in Figure 12. Once again there is marked difference of performance between grass fed cows and penned cattle. The data in these studies was of a much better quality than obtained for the animal protein studies giving one high degree of confidence in interpretation. Professor Reid and others at Cornell have made a very thorough study of the yield and behavior of cows with "normal" feeds, and with liberal grain feeds. These are quoted in studies 129/131. For a given energy input grass fed cattle do twice as well. Once again the economic urge for using grain feeds must stem from the present low-cost of energy

Milk, especially from grass fed cows, turns out to be a surprisingly effective way of using the energy subsidy. On Figure 8 the grass fed milk line is included and is seen to cross the vegetable protein line at a very high point of intensity.

3.3.3 Sea Fish

The most surprising thing about the study on sea fish was the high energy cost of catching and bringing fish to port. The post-war years have seen the development of ships capable of very long voyages from home, with freezing and even fish meal processing facilities on board. From the literature one obtains the impression that the development of new fishing technologies simply benefits the users for a short time, till depletion of stocks make it harder for all to find the fish. FAO (55) record very little increase in global catch since 1964, though methods have greatly advanced and the energy expenditure has increased.

Study 22 gives some idea of the increase in energy consumption through the period 1924 to 1961 for the Cod Fishery off Faroes. In 1924 the energy cost was 559 k.cal/lb cod. By 1938 this had risen to 805. During the war fishing intensity necessarily diminished in the North Atlantic. This enforced conservation enabled the post-war boats to fish at 319 k.cal/lb cod. By 1961 this had risen to 1169 k.cal/lb, making cod comparable in energy cost to beef.

Today the energy costs vary from area to area. For example, inshore waters in the UK became protected in 1964 at the 12 mile limit, headland to headland, and conservation policies were implemented. The result is that inshore fishing in UK waters requires a low energy content. In the Hebridean area, where a very large area of sea is not open to

foreigners by virtue of the Hebridean islands, fish can be caught for an expenditure of just over 300 k.cal/lb. fish, compared to something like 10 or 12 times that figure for fishing in the Barents Sea or the Grand Banks, essentially a free for all. Fishing off Iceland is already becoming energy intensive, and the new Icelandic policy of having a 50 mile limit would appear totally justified.

Such now is the energy cost of fishing that it is hard to see how fish meal can be justified as an animal feed stuff if the cost of energy does significantly rise.

Though no data was elicited for Peru, Greenfield (56) notes that equipment of the Peruvian fleet is about the same as that of the US Gulf and Atlantic fleets, but that their intensity of use is far higher. Peruvian shrimp boats literally steam out from port, fish for a few hours, and return laden. Peru has a 200 mile fishing zone. We have arbitrarily ascribed to this fleet a very low energy subsidy - 75 k.cal/lb fish landed. Thus in Peru it may make sense to convert to fish meal or to fish protein concentrate. However, most of these commodities are sent to the USA for animal feed stuffs, where they are not needed, instead of being used in Latin America and Asia where they could be useful. Over-fishing or a rise in energy price may rapidly change the picture here.

3.3.4 Fish Farming

Farming fish in fresh water is an old established activity, having been known in China for 3000 years. Recently fish farming has come into prominence as the costs of sea

fishing have risen, and in response to the need in UDCs of more protein and in the DCs for more luxury foods like trout.

The data for fish farming are shown in Figure 10(+). On an area basis the yields are comparable to that of animal protein per energy unit.

Nutrients added vary from waste vegetable products and sewage(very productive) to special feeds, such as are used to breed catfish and trout. None of the studies examined gave data in a truly adequate form. There is considerable need for research here.

One interesting study was the effect of growing fish in the water channels of rice fields. It was found that feed had to be given to create useful yields, and that a reduced yield of rice resulted. The energy cost of the resulting fish was no better than average.

3.3.5 Rice

Rice seems a particularly good crop as Asians have known for centuries. Figure 13 shows how the yields respond to the energy inputs. What makes one dubious about the apparently good performance of rice is that it is highly dependent on irrigation, yet no figures for the energy costs of water are included. One suspects that in high yield situations these are often considerable. Here again further enquiry is called for.

3.3.6 Soya-beans

Soya-beans should be especially examined since they are so often quoted as a partial solution to the protein

problem. This does not appear to be the case. A better statement would be that soya-beans can assimilate energy outputs in the form of fertilizers and soil preparation to a much greater extent than any other plant. Thus, high yields per hectare can be achieved. But the energy input is correcpondingly higher. Moreover soya-beans are not immediately edible by humans. They need considerable preparation. Full fat soya-bean flour gives no better yield of protein per unit of energy than does rice, wheat or potatoes. Figure 17.

3.3.7 Diminishing Returns

Several studies were concerned with finding means of stimulating yields from poor soils. Two Indian studies (8,9) on laterite and saline soils showed that good yields could undoubtedly be had from very poor soils, but at a tremendous energy cost. For example a rice area which is annually innundated by sea could be made to produce as much as 1400 kg rice/ha, comparable to many typical yields in Asia today, but the energy cost was as much as 440 times as much.

One study sought the optimum yields for local species of millet in India and found that it varied widely with soil type. Laterite soils required twice the energy input per unit of product of other soils.

3.3.8 Is the World Calorie or Protein Limited?

A question posed at the outset was whether the world was protein or calorie limited (food calorie NOT energy subsidy calorie). On Figure 6 are plotted the data and the

best fit, and on Figure 8 the best fit alone. The resulting plot is much more widely scattered than the protein plot. The best fit gives:

$$\text{k.cal food energy/ha} = 3.5 \times 10^{-3} \text{ (k.cal energy subsidy/ha)}^{.693} \quad \ldots 3.$$

One may use these two relations to find the point at which a given intensity of energy subsidy will or will not yield sufficient food calories or protein, according to whatever standards it is desired to set. Setting a target of 3000 k.cal/day for food calories, and 30 kg/yr for protein, the world would have to become extremely crowded (some 20 persons per hectare of agricultural land), before the basic problem was calories. This assumption, of course, is fundamentally based on there being all the energy subsidy available that is needed. But whether that would be so is a separate question.

The equation 3 above would have to be very far wrong for one to come to any other conclusion than that the world was protein limited, not food calorie limited. But this assertion carries the rider that sufficient energy subsidy is always available.

3.3.9 Summary of Section Three

1. Synthetic proteins are not a meaningful solution to the protein problem at the present stage of the world's population density. Much less energy intensive methods are still open to use.
   The implantation of such energy intensive protein producing methods in UDCs does not serve them well.

2. Synthetic proteins and many industrial protein processes have their value in coping with short term emergencies or disasters, but would only have a logical place in a world whose population was about 30 billion.
3. Fish meal appears to be a poor use of a superb resource.
4. The index of 0,742 in equation 1 for protein yield per unit of energy subsidy shows a diminishing return for a given energy input as the intensity rises.
5. Feed lot methods of meat production appear to be unnecessarily energy intensive. If their existence reflects an economic advantage, then there is case of a new look at the economic system.
6. Soyabeans, contrary to popular view, it not a particularly efficient energy converter. Rather, its virtue would appear to be that it can assimilate a higher intensity of inputs than many other crops, but for a given input its performance is much the same as any other crop.
7. Crops may be grown productively on laterite soils, but the energy subsidies may be much higher.
8. The world is protein, not food calorie, limited.
9. Considerable further study is needed in the low and medium energy subsidy region.

3.4.1 Energy Ratio

From a policy aspect it is useful to know which processes are most responsive to energy subsidy. Column 8 Tables 6-11 gives the energy ratio. Table 13 lists some examples.

At the bottom of the scale are the synthetics, assimilating about five times as much energy as their food calorie content.

Sea fish and fish farm fish are also low, varying from 0.15 to about unity. Thus fish protein concentrate which depends on fish caught, lies even lower: 0.1 to 0.45. Beef varied widely from 4.7 for low intensity grazing to about 0.3 for feed-lot fattening methods.

Soyabean is seen to be far from spectacular, varying from 1.5 to at best 3.25.

Egg is comparable to beef

Milk gives a one for one return

Wheat gives a return varying from 2.7 to 6.5

Rice is exceptionally good, but, as already indicated, this may be a false figure due to failure to incorporate water costs. It varies from 7.2 (USA) to 36 in low intensity UDCs.

The humble potato varies from 2.5 in places like Alabama to 14 in England

The sweet potato likewise is an excellent way to capture solar energy.

3.4.2 Energetic Efficiency

A common way for agronomists and animal scientists to express efficiency of food conversion in animals is to divide the food energy in the product by the metabolszable energy in the feed. This, of course, is very useful in studying the animal and its response to food stuffs. However, it provides misleading figures in terms of true energy use because the energy ratio of the feed itself may vary widely. For example, our studies showed variations in energy ratio of soyabeans of from 1.6 to 3.2 and of corn from 2.9 to 5.5

Thus, T.C. Byerly (SCI 157, p.890) records the energetic efficiency of a cow as 44%. But in terms of actual energy use it is:
(energy in product)(metalizable energy/energy ratio). Thus while he shows variations from 44% (cow) to 17.5% (ewe) without knowledge of energy in the feeds, the true energy conversions cannot be computed.

We have taken his table 1 giving USA figures in 1969, and converted to true energy efficiency.

True energy efficiency for:

milk	210%
ewes	43%
hogs	22%
eggs	100%
broilers	31%
turkeys	29%
beef cattle	52%

4. POLICY

4.1 Lessons of the Study

One lesson of the study is to show that energy is energy, no matter where or how expended. If there is a capacity to purchase or obtain only a certain amount of energy, the best way must be sought. There are some ways in which it may be used more effectively than others. We reject completely a statement quoted in the World Food Problem (54) attributed to Johnson (57):

> "It is important to note that power and equipment do not consume food sources of energy as do work animals....It is appropriate, then, to consider mechanization as a means of substituting non-food energy for food energy in order to make additional food available for the growing urban population"

This distinction is quite unreal, and delusory, and if applied to UDCs may do harm. In those countries there is a limited income available to purchase energy. It should be purchased in the form where it can win the greatest benefit. For example the fuel for one hours operation of a tractor could put 8.5 lb. of nitrogen fertilizer into a hectare of soil and increase the yield of protein in a subsistence economy by 33% (Fig re 6).

Of course, solutions to individual problems require the individual attention of the agronomist and the nutritionist.

4.2 Energy Subsidy for Self-Sufficiency

Many developed countries in Europe are dependent on trade for their food. England, for example, imports 40% of her food. What level of energy expenditures would these countries have to spend in order to feed themselves? Many UDCs are dependent on imported food, given as gifts, as in FOOD FOR PEACE or in the form of long-term loans to purchase food. What energy would they have to expend in order to feed themselves? This question may be simply answered with the aid of Figure 6 (or 8) or equations 1 and 2.

However, first it is necessary to decide on the level of feeding. Figure 15 (ref 19) shows that the USA is consuming 33.6 kg protein/capita.yr, Argentina 35.7 while India consumes 18.6. Nutritionists declare 64 g/day or 23.6 kg/year as the desirable minimum for each person. The World Food Problem (21) points that much is lost by waste both in UDCs and DCs, though for different reasons. For the sake pf conputation, therefore, a target figure of 30 kg protein/cap.yr. has been selected.

In any given national territory, let H be the hectares of agricultural land per capita. Then, for self-sufficiency in protein the average protein yield must be

$$30/H \text{ kr protein/ha.yr}$$

Reference to Figure 6 or 8 or insertion in Equation 1 shows that in order to achieve 30/H the average energy intensity over the whole territory must be:

$$k.cal/ha. = \left[(30/H)/\ 5.076 \times 10^{3}\right]^{\frac{1}{742}} = f30/H \ldots\ldots 4$$

Now, k.cal/capita = (k.cal/ha)(ha/cap) = (Equation 4)(H)..5 Since economists normally quote energy consumption in terms of Tons of Coal Equivalent (TCE), Equation 5 will be divided by 5.72×10^{6} to convert k.cal to TCE. Thus, the energy needed per capita is a direct function of the population density expressed in agricultural area. Equation 5 is embodied in the line AB in Figure 16. In Table 15 are listed the computed energy needs for various countries to be self-sufficient in food. The final column expresses the energy as a fraction of 1967 total energy consumption in that country For DCs we have assumed 20 kg animal protein per cap.yr and 10 kg non-animal and for UDCs 30 kg of vegetable protein per year. Even though UDCs do consume some animal protein (Figure 15), their current consumption of protein is less than 5 kg/cap.yr, and this simplification is held to be justifiable. The cost of energy has been taken at the 1970 figure of $22/ton hydrocarbon. To establish the cost of providing the industrial plant to make the soil inputs, we have assumed all inputs are nitrogen. This results in a figure below the true figure. Nelson (53,p 107) estimates a nitrogen fertilizer factory at $500 per ton year of nitrogen. We have taken this figure and allowed a 5% for interest, but none for amortization or capital outlays, to arrive at the annual cost of the

energy to the agricultural sector (column 8) and the cost per capita (columa 9).

One sees that the direct energy costs are not high if the whole process is based inside the country of need. India is a useful example. If she were to feed herself this would only cost $3.05.capita, yet even this would amount to 32% of her energy consumption in 1967. Note that the assessed cost of being self-sufficient is 1747 million dollars/year. Revelle records (53, p 218) that in 1969 Indian agriculture products were $15,000M. Thus the necessary input is a reasonable fraction of the output.

By contrastthe USA is vastly more energy intensive than necessary, and could furnish all its needs without intensive agriculture if it chose to. Adherents of a Thoreau-esque way of life may like to know that option is still open in the USA.

Mayer and Hargrove at Iowa University Center for Agricultural and Economic Development have made a study (58) of the effect of restricting fertilizer application on US soil to 100, 50 and zero lb./acre using linear programming methods. They found zero fertilizer to be a perfectly practicable policy. Here are some of the consequences:

1. Some shift to legume crops to maintain nitrogen fertility
2. Ending of Government land retirement policy
3. Total use of all crop land in US
4. Feed grain exports drop slightly

5. Soyabean acreage cut from 39 million acres to 29 million, and some decline in soyabean exports
6. Livestock increases on individual farms
7. Rapid rise in farm gate prices - corn $2.30 a bushel by 1980 ($1.70, Sept. '72)
8. Small rise in soyabean price
9. 40% increase in cost of feed lot fattening methods by 1980
10. Consumer food prices up 11% on average
11. Farm incomes rise from $6041 (1970) to $10,261 (1980)

The study did not take into account any possible changes in energy costs to 1980. While pointing out that such a policy would diminish exports of food stuffs, it did not take into account the reduction in energy imports resulting from an end to fertilizer manufacture. In 1970 12 M tons of fertilizers were used in the USA, requiring an energy of 2 million tons oil or its equivalent. That alone is worth $44 million of imports saved at current prices. This is twice the value of present feed grain exports.

The World Food Problem Report II, p. 382 (21) records that an 11 M tons of extra fertilizer in the UDCs would increase its use by 80% (1969 levels). We know that from Figure 8 that the effect of inputs is most dramatic at the lower level. If the US was to export annually the now unused 12 M tons of fertilizer to the high density UDCs this would immediately assist the food problem in those countries

in a much more economical way than the export of food, and win itself some $240 M extra exports. These points all reinforce the situation that the US is over fertilized.

Singapore could theoretically feed itself, though on an extremely monotonous diet, provided it used no animal protein. For Singapore to enjoy a diet akin to a present day DC meal would not be possible whatever the energy input. This territory's quality of life is therefore totally dependent on its external sources of food. England and Netherlands are

England and Netherlands are two interesting examples of densely populated DCs. Though their energy needs to sustain their way of life are considerable, it is possible to do so.

Japan represents the extreme case of a large developed country. To enjoy a typical DC animla diet would be extremely energy intensive process. The records show (Figure 15) that she consumes very little animal protein, and that her purchases abroad are increasing.

4.3.1 The Potential

Many calculations have been made of the world's capacity to feed itself. Expressed in terms of the number of people who can be fed, estimates vary from 30 billion (60) to much higher (61). Figure 8 and Figure 10 enable this calculation to be made based on the following simplifying assumption.

4.3.1 Heat Dissapation Limitation

1. No animal protein available except from grazing land
2. The energy input per unit of production is three times/for that temperature or water limited land.

3. The maximum energy intensity is set at 1% of the solar input, averaged over the total world surface, oceans and land, polar and tropical. That is 208×10^{16} k.cal. On the basis of present evidence, such a figure looks like being as much as may be tolerated without upsetting the earth's climate (62). The earth's total surface is 52×10^{9} ha. According to the World Food Problem (21, p.429) the useable surface area amounts to:

   a. Arable land, neither moisture nor temperature limited 1.32×10^{9} ha.
   b. Grazing land, as above 1.267×10^{9} ha.
   c. Arable land, moisture or temperature limited 1.828×10^{9} ha.
   d. Grazing land, moisture or temperature limited 2.397×10^{9} ha.

Then, assuming the maximum possible yields from grazing land from Figure 10:

a. can yield 1.267×400 kg protein/ha=506.8×10^{9}kg. protein using 3.17×10^{16} k.cal.

b. can yield 2.39×400 kg. protein/ha= 956.8×10^{9} kg. protein using 11.95×10^{16} k.cal.

Total grazing energy	15.12×10^{16} k.cal
Deduct from maximum permissable of 208×10^{16}	192.88×10^{16} k.cal
Assume 15% for food, remainder for industrial, domestic.	29×10^{16} k.cal

This amount of energy to be used on 1.32 billion ha. good cropland; 1.828 billion ha. limited land.

Assuming limited land requires three times energy input per unit yield that good land requires. Equivalent land area is 6.8 billion ha.

Then average useful energy input is $29/6.8=4.2 \times 10^7$ k.cal/ha.

From Figure 8 this energy intensity will yield 2200 kg. prot/ha. Thus global cropland would be: $2200 \times 3.15 \times 10^9 = 6.93 \times 10^{12}$ kg.prot/yr.

Thus global protein production, animal and cropland = $(6.93 + .956 + 506) \times 10^{12} = 7.39 \times 10^{12}$.

Assuming a requirement of 30 kg protein/year.capita, this is equivalent to 245 billion people. This is an average global population density of 0.0025 ha/agricultural land/cap. At such a density the world is calorie limited. A more likely figure would thus be around 200 billion people.

4.3.2 Energy Limitation.

The earth's energy limitation is not yet known. One can only point out that the above population would require for food alone 7×10^{10} TCE/year, or 120 times as much energy as is used by the world today (1970) for all purposes. At this point the world would be using energy at a rate equivalent to using all the world's supposed reserved of fossil fuels in 1970 in 8 years. Thus there would be an almost total dependence on nuclear or fusion energy.

4.4 Population Growth

Since energy use to raise food is related directly to hectares of agricultural land per person, population growth has a marked effect on this parameter. It diminishes it in two ways:

By simple increase in people for a given area of land

By those extra people using land for housing and industry.

Thus population growth rapidly increases the per capita energy needs for food production. Simply as an example we have plotted the effect on a country such as Japan. This country had reached stable population till a recent government decision to stimulate population growth. The effect in terms of energy use by the country for an animal and no animal diet is shown in Table 14. 2% population growth has been assumed, but no further use of agricultural land for housing or industry.

No better illustration could be given of the effect of crowding on the quality of life if one ingredient is the pleasure of eating meat, fish,eggs and milk. In Japan, by the year 2000, only the very rich will be able to eat these commodities, unless they can be imported, Reid comes to a similar conclusion (14).

4.3 Technical Solutions

There are a number of technical solutions proposed to solve the world protein problem. One is amino-acid fortification. Another is creating manufactured foods such as Incaparina, or fish flours or fish protein concentrate. These solutions

may well have uses at moments of crisis - such as some major natural disaster hitting a region. Essentially they are manufactured products and their energy content puts them beyond the reach of any but the wealthy nations or the charitable givers. As a solution to long term problems they appear to be most misleading.

For example, one advocate of fortifying wheat with amino-acids (to improve the protein balance of the wheat) calculated that it would require 32.5 M lb. of Lysine to fortify at the 0.1% level the 1966 shipments of FOOD FOR PEACE from the USA. The energy content of that lysine would be 390 billion k.cal. If this energy subsidy could be applied annually in the form of nutrients or irrigation in any UDC it would yield 3.45 billion pounds a year of milk, probably more. That is 120 million lb milk protein. The wheat shipments amounted to 31 billion pounds, enough to feed 100 million people. It is for a nutritionist to decide whether it is better to let people enjoy 34 extra pints of milk a year or chemically treated wheat.

One suspects the driving force for some of these technical colutions lie with the major chemical and grain companies.

If this study shows anything, it is that the best policy for a UDC is to use its funds to put an energy subsidy into its own agriculture, which being at low intensity responds more fruitfully to a given energy input, than buying from a developed country higher on the energy scale, or by importing energy intensive technology.

5. CONCLUSION

5.1 Better Data

In examining the policy implications of energy subsidy of protein formation, we have rested heavily on Figure 8. While fair confidence may be placed on the data above input of 3×10^6 k.cal/ha., there is a less certain zone below this intensity. Yet it is just this zone in which many countries are now entering as their populations reach the density of 0.3 ha/capita. CONCLUSION 1 is the need for a great deal of careful measurement of all food creating processes in the low intensity region.

The method, once better substantiated, will permit intelligent forward planning, and measurement of ultimate potentials. Even with the existing figures one sees that if Japan indulges in further population growth, then animal protein will become almost non-existent in that country.

5.2 Technology Transfer to Underdeveloped Countries

There has been a tendency on the part of many UDCs to assume that agricultural and food technologies that have been developed in the DCs will automatically be desirable in the less developed countries. THe best techniques. are those that utilize energy at the minimum intensity necessary for that particular country. There is no sense, for example, in creating intensive beef raising methods in a spacious country like Venezuela simply because it has been shown necessary to do so in a crowded island like Puerto Rice.

The creation of protein by algae plants, or yeast preparations from sugar,fortification of wheats by Lysine all represent highly energy intensive activities, which though within the purse of a DC like the USA, are a gross waste of a UDC's presumably limited financial resources.

The world may indeed come to need such solutions to the protein problem, but only when global population growth has reached a level where the protein production has been required to reach the average level of 1000 kg/protein per hectare, or some 30 billion people on this earth. It is to be hoped such a concentration of people will not occur.

Figure 8 and the underlying methodology allow one to calculate the most logical and effective food path with a given resource. The answer will not be universal. It will depend on the characteristics of the region, the transport facilities, the alternative forms of energy available, whether there is unemployment or too many people, and their ability to pay for the products of more intensive systems. A failure to look at the problems in these terms may be to produce food at the expense of the people's dignity and social welfare, and to assist economically only those sectors of the community who are already rich enough to buy in the more intensive methods.

5.3 Policies for Development in UDCs

The foregoing should not be taken as an argument against industrial development or change. The purposes of the food and agricultural policy should be to maintain the

agricultural population in business, not to put it out of business. As the nation's economic plans develop there will be a growing need for workers, to be lured by the higher wages in the industrial sector. Then, as the agricultural sector loses population, policies requiring great intensity may be permitted. The task must be not to drive people off the land, but to give them the free choice as the country develops elsewhere.

5.4 Energy Availability

The question each nation should ask itself - has it available to itself a perpetual source of energy equal to its needs for food production. To grow in number, and develop a way of life that it cannot eventually sustain is to create the sort of problem we see in India today and may see in Europe.

The economic planners should ask the question: what amount of industry is needed to enable the nation to generate the wealth to secure the energy needs of the food supply industry. It is a fact that in many of the early post-war development plans in UDCs, industry was made the first objective of the new regime, where as the development must keep pace with the nation's ability to feed itself. To starve the food producing sector for energy in favor of industry is just as foolish as to over-intensify it. To intensify the food producing area above its needs is equally wasteful, creating as it does spare human beings with no useful occupation.

Energy availability is in many ways a more pressing problem for some DCs than it is to UDCs. Europe is heavily dependent on imports of energy. The USA has developed an agricultural system so energy-dependent that a Stanford Research Institute study of Post Attack Recovery in the USA after a nuclear war highlights the problem of getting fertilizer factories back into production. It is possible a new and simpler way of life might simply emerge.

5.5 Trade

The study indicates that it is more energy effective for a UDC to use energy to create fertilizer or pump water to use on native soils than to import food stuffs from other countries. Many European countries today are major importers of animal feeding stuffs. They are in effect leasing land area in other countries. In doing so they may be importing a more energy intensive source than they need to.

On the other hand it is questionable on an energy basis whether the importation of fertilizers by a UDC to grow more crops which are then exported to a DC is as intelligent use of an energy import, as to import the energy and utilize it in the best possible way on home territory.

It becomes more and more logical as the price of energy rises for energy owning countries to restrict energy export, and to increase product export.

5.6 Cost of Energy

My own interpretation of current events and developments suggest that energy will rise to from 4 to 5 times its present value in constant dollars by the end of the century. This places particular value at looking at food production on an energy basis. We see that though there may be but a trivial difference between the cost of food in Korea as opposed to Japan at the moment, a factor of 4 changes that into a huge difference. To India an energy cost of $12 per head may prove too high.

ADDENDUM

Page 16, Section 2.5.2

Regression analysis yields:

Eq.1 pg. 23 should read:

kg. protein/ha.yr = $0.568\ (10^3\ \text{k.cal/ha.yr})^{.82}$

standard error = 0.085

Eq.2 pg.24 should read:

kg. protein/ha.yr = $0.347\ (10^3\ \text{k.cal/ha.yr})^{.76}$

standard error = 0.186 " " "

R E F E R E N C E S

1. World Food Budget 1970, Economic Report #17, U.S. Department of Agricultire, Washington, D.C.

2. International Action to Avert the Impending Protein Crisis, United Nations, New York, 1968.

3. Borgstrom, G., Hungry Planet, p.67, MacMillan Co., New York, 1967.

4. Strategy Statement to Avert the Protein Crisis in Developing Nations, United Nations, New York, 1971.

5. Indicative World Plan, 1969, F.A.O., Rome.

6. McPherson, A.T., Chem. Eng. Prog., No. 10, p.101.

7. Just, J., Input-Output Table for the U.S. Economy in Terms of Energy - unpublished work.

8. Darmstadter, J., et al. Energy in the World Economy. Johns Hopkins, 1972.

9.

10. Hirst, E., Report ORNL-NSF-EP-15, p.5, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

11. Hannon, B., Center of Advanced Computation, University of Illinois, private communication.

12. Reardon, W.A., Input-Output Analysis of Energy Changes from 1947-58, Batelle NW Laboratories.

13. Call, D., Cornell University, Private communication.

14. Proceedings of Cornell Nutritional Conference, 1970, p.50-63.

15. Federal Power Commission, Washington, D.C.

16. Cornell Agricultural Economics Research Paper #310.

17. Bravard and Portal ORNL-MIT-132. Oak Ridge National Laboratory, Knoxville, Tennessee.

18. Shreve, R.N., Chemical Process Industries, 2nd Edition, McGraw-Hill, New York.

19. World Food Problem, Vol II: Report of the President's Science Advisory Committee, White House, 1967.

20. World Soil Research, #41, F.A.O., Rome.

21. World Food Problem, Vol I: Report of the President's Science Advisory Committee, White House, 1967.

22. Fisheries Statistics 1970, H.M.S.O., Edinburgh.

23. Fishery Policies and Economics, 1957-66. OECD, Paris.

24. Intensive Management of Tropical Forages in Puerto Rico, Bulletin 187, December 1964, University of Puerto Rico, Agricultural Research Statistics.

25. Harlan. Grassland Agriculture, Van Nostrand, New York, 1956.

26. Role of Nitrogen in Grassland Productivity, Commonwealth Agricultural Bureau, London. Bulletin #48, 1970.

27. Scott, W.O., and Aldrich, S.R., Modern Soyabean Production: 1970, Published by Farm Quality, Cincinatti, Ohio.

28. Welch, L.F., Illinois Research, Winter 1972, p.3, University of Illinois.

29. Jurian, F., and Henry, J.: De l'agriculture itinerante a l'agriculture intensifie; Institute Natural pour etude agronomique du Congo, 1967.

30. Proceedings 2nd Symposium on Tropical Root and Their Tuber Crops, Vol. I, Hawai, 1970, F.A.O., Rome.

31. J. Experimental Agriculture, 7, p.193, 1971.

32. Ivins, A. The Growth of the Potato. p.308, 1973, Butterworth, London.

33. Pulses of India, 1970, p.162. Indian Company for Agricultural Research.

34. Ensminger, M.E.: Poultry Science, 1970, Interstate Publishers, Illinois.

35. Burlew, B.: Algae Culture. 1953, Carnegie Institute publication.

36. Tannenbaum, S.R.: Single Cell Protein, 1968. M.I.T. Press, Cambridge, Mass.

37. Stanley, M.E: Industrial Fishery Products, 1963, Rheinhold, New York.

38. Hicklin, C.F.: Fish Culture, 1962, Faber, London.

39. Leaflet 584, U.S. Bureau of Commercial Fisheries, Washington, D.C.

40. Perry, H.: Chemical Engineer's Handbook, 1969, p. 1678, McGraw-Hill, New York.

41. Green, B.L.: Rice Journal, 62, #1, October 1959.

42. Holdberg, J.M.: J. Water Pollution Control Federation, February 1960.

43. Odum, H.T.: Power, Environment and Society, 1971, Wiley, New York.

44. Contract PH-86-67-204, Bureau of Solid Waste Management, Washington, D.C.

45. Kormandy, J.: Concepts of Ecology, 1969, Prentice-Hall, New Jersey.

46. Altschul, A.: Chemical and Engineering News, November 24, 1969.

47. McVicar, M.H.: Agricultural Anhydrous Ammonia, Memphis, Tennessee.

48. International Rice Year Conference, 1966: Mechanization and World Rice, F.A.O., Rome.

49. Mustakes, S.: World Protein Resources, Am. Chem. Soc., 1966, New York.

50. Agricultural Statistics, 1965. U.S. Department of Agriculture, Washington, D.C..

51. Fertilizer Use, Bulletin #408, 1965. U.S. Department of Agriculture, Washington, D.C.

52. DeGraff, C.: Cornell Agricultural Economics Paper #449, 1943.

53. Nelson, I.D. World Food Problem, Vol. III, p.97. Report of the President's Advisory Committee, White House, 1967.

54. Giles, G.W.: as in reference 53.

55. Fisheries in the Food Economy, Study #19, 1969, F.A.O., Rome.

56. Greenfield, F.: U.S. Bureau of Fisheries, St. Petersburg Florida. Private communication.

57. Johnson, A. and Lloyd, B.: J. Indian Soc. of Agricultural Engineering, 2, #2, December 1965.

58. CAED Report #38, State University for Agricultural and Economic Development, 1972.

59. World Food Problem, Vol II, p.429. A Report of the President's Advisory Committee, White House, 1967.

60. National Academy of Sciences, Resources and Man, 1970. W.H. Freeman and Co., San Francisco.

61. Clark, C.: Population Growth and Land Use, 1967, McMillan, London.

62. SCEP. Man's Impact on the Global Environment, 1970. MIT Press, Cambridge, Mass.

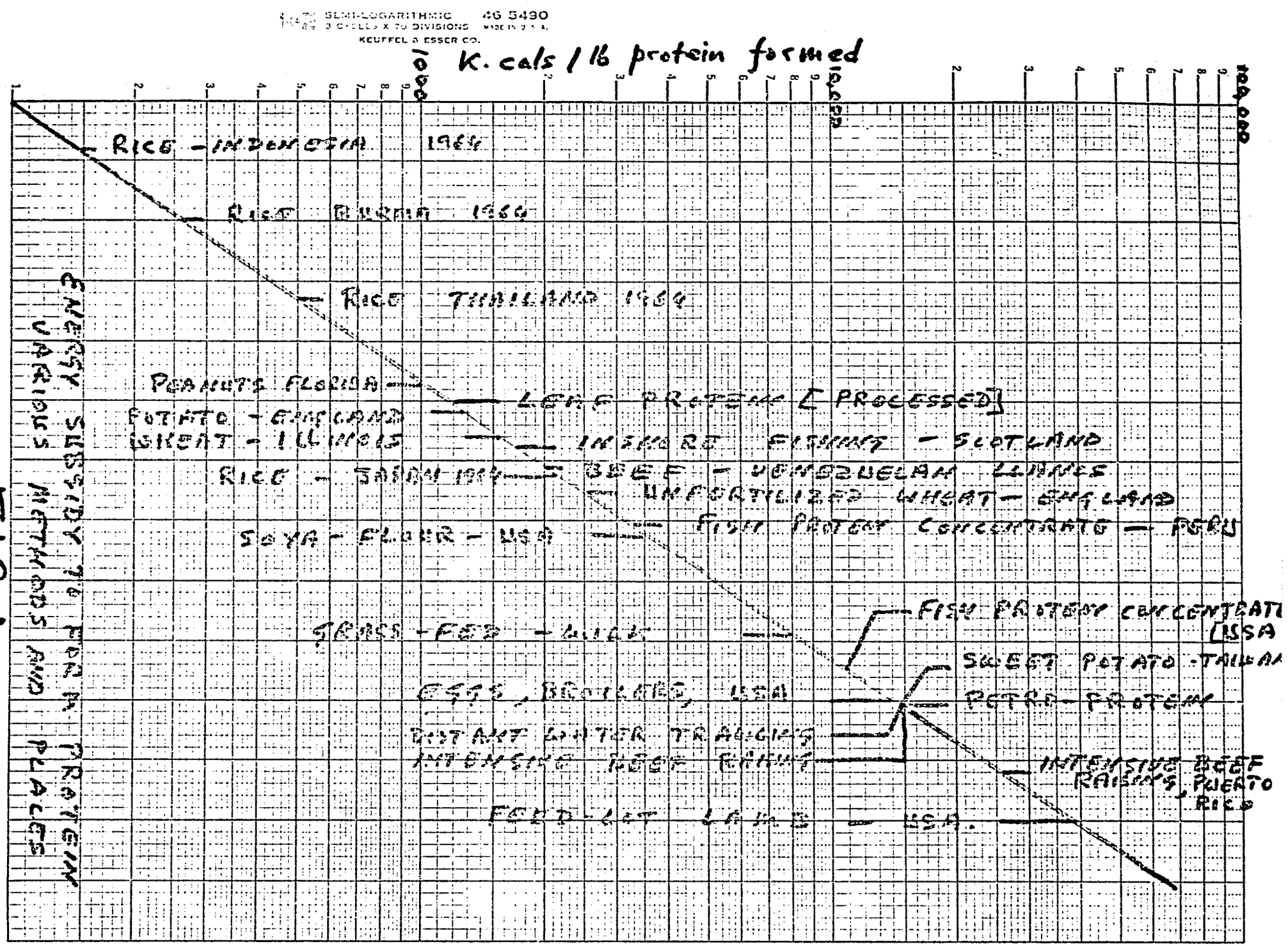


Fig. 1.

ENERGY VARIOUS SUBSIDY TO FOOD IN METHODS AND PRACTICES

TABLE 1

Source: Inter-Tech Corporation, Virginia

COMPARISON OF ENERGY TRANSPORTATION COSTS

	Capacity	Capacity in 10^9 k.cal/day	Cents/million k.cal.100 miles
Pipeline-Gas	1,000-5,000MMscfd.	250-1250	4 - 5
Pipeline-LNG	500-1,500MMscfd.	12	4 - .75
Pipeline-Oil	300,000-1,200,000 barrels/day	5000-20,000	.08 - .2
Pipeline-Coal	3-15 mill. tons annually	50-250	.3 - .9
Barge-Coal	900-1,400 tons/barge	--	.3 - .6
Tanker-Oil	100-300 thousand deadweight tons	--	.12
Rail-Coal	70-100 tons per car	--	1 - 1.5
Unit Train-Coal	3 mill. tons annually	50	.6
Highway-Coal	10-20 tons per truckload	--	2.2 - 4.5
Electric	600-1,000MW	25	1.7 - 3.5

TABLE 2

TYPICAL NPU AND PER VALUES

	NPU	PER
Potato	71	
Peanuts	48	
Pulses	46	
Fruit	70	
Fish	83	
Cassava	71	
Milk/Cheese	75	
Eggs	100	
Beef	82	
Chicken	80	
Wheat flour	52	1.3
Rice	57	1.5
Corn (maize)	55	1.5
Soyabean	46	
Sorghum	48	

2.8 SUMMARY OF ENERGY EQUIVALENTS OF INPUTS

TABLE 3

Item	Unit	K. Cal.	Alternate Form	Reference
Electricity	1 kwh	2,965		
	$1.0	183,000		
Methane	1 pound	6,119		
Hydrocarbon Fuel	$1.0	238,000		
Steam	1 pound	361		
Horse-power	horse-power .hour	2,221		
Tractor	1 hour	85,000		
Lime	1 pound	480		
Potassium sulphate	1 pound	2,500		
Potassium chloride	1 pound	794	1500k.cal/lb.K	
Ply-phosphate (12-40-0)		1,744		
Triple superphosphate (17-17-17)	1 pound	5,462		
Potassium metaphosphate (0-26-26)	1 pound	3,090		
Ammonium nitrate	1 pound	3,870	9950k.cal/lb.N	
Ammonia (liquid)	1 pound	7,490	9130k.cal/lb.N	
Ammonium sulphate	1 pound	2,670	10,870k.cal/lb.N	
Urea	1 pound	5,027	10,300k.cal/lb.N	
Nitrice acid	1 pound	2,209	10,135k.cal/lb.N	
Phosphoric acid	1 pound	444		
Carbon Dioxide	1 pound	70		
Sulphuric acid	1 pound	nil		
Calcium sulphate	1 pound	330		
Pesticides & herbicides	$1.0	5,000	11,000k.cal/pound	
Solvent extraction process	pound feed	230		
Expelling then solvent extraction per pound of feed		80		
Crop spraying from air	hectare	3,500		
Sugar (sucrose)	1 pound	184		
Transport (truck 500 miles)	1 pound	131		
Corn mechanization	hectare	1,666,000		
Rice mechanization	hectare	53,000		
Grain-binder	hectare	247,000		
Combine harvester	hectare	194,000		
Phosphorus in fertilizer	1 pound	1,170		
Nitrogen in fertilizer	1 pound	10,000		
Potassium in fertilizer	1 pound	1,500		
Fodder: Corn (small farm)	pound	435		
(large farm)		300		
Corn silage	pound	54		
Hay	pound	103		
Hay silage	pound	44		
Agro-chemical (just 7)	$	5,700		

K+E LOGARITHMIC 3 X 5 CYCLES 46 7520 MADE IN U.S.A. KEUFFEL & ESSER CO.

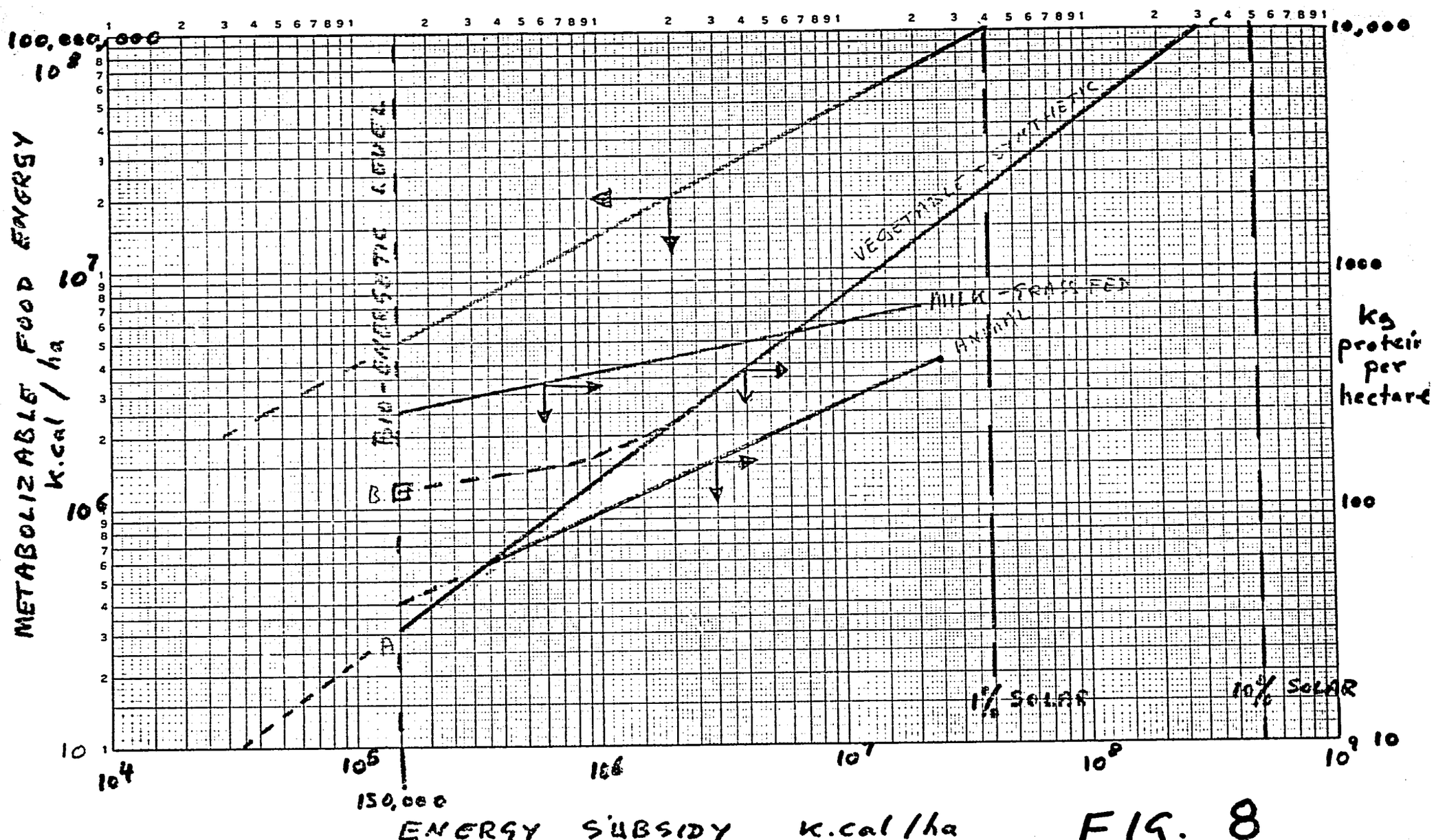


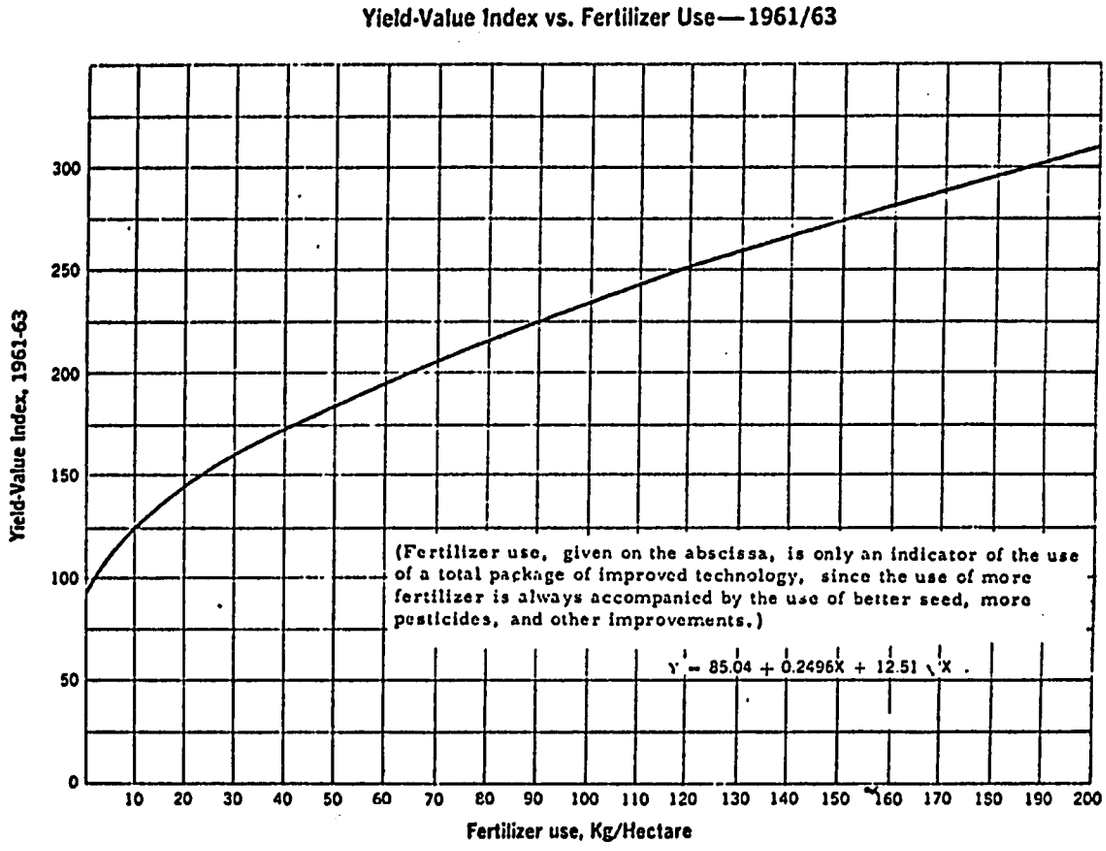
FIG. 8

TABLE 12

BIO-ENERGETIC YIELDS

STUDY	SPECIES	YIELD KG/HA	PROTEIN KG/HA	COUNTRY
1a	Rice - IR8	3687	295	India
2a	Rice-Padma	1311	105	India
3a	Wheat-S 308	2356	259	India
4a	Corn-Ganga Safed-2	693	66	India
6/1	Willet-deyland	562	56	India
8	Rice-saline soils	107	8.6	India
9	Rice-acid soil	47	4	India
14	Manioc	6000	210	Tropics
20	Dryland Wheat	180	20	India
30	Milk	7430	260	England
31	Beef	820	135	England
40	Cottonseed	2031		Congo
43	Oil Palm	29,800	?	Malaysia
45	Lima Bean	300	25	India (ref 33)
60	Tiliapas (fish farm)	140 lb/yr. no area term		Malacca
61	Milkfish		64/ha	Indonesia
63	Tiliapas	122	24	Malacca
66	Fish	119	23	Arkansas
77	Rice	1560	125	Burma

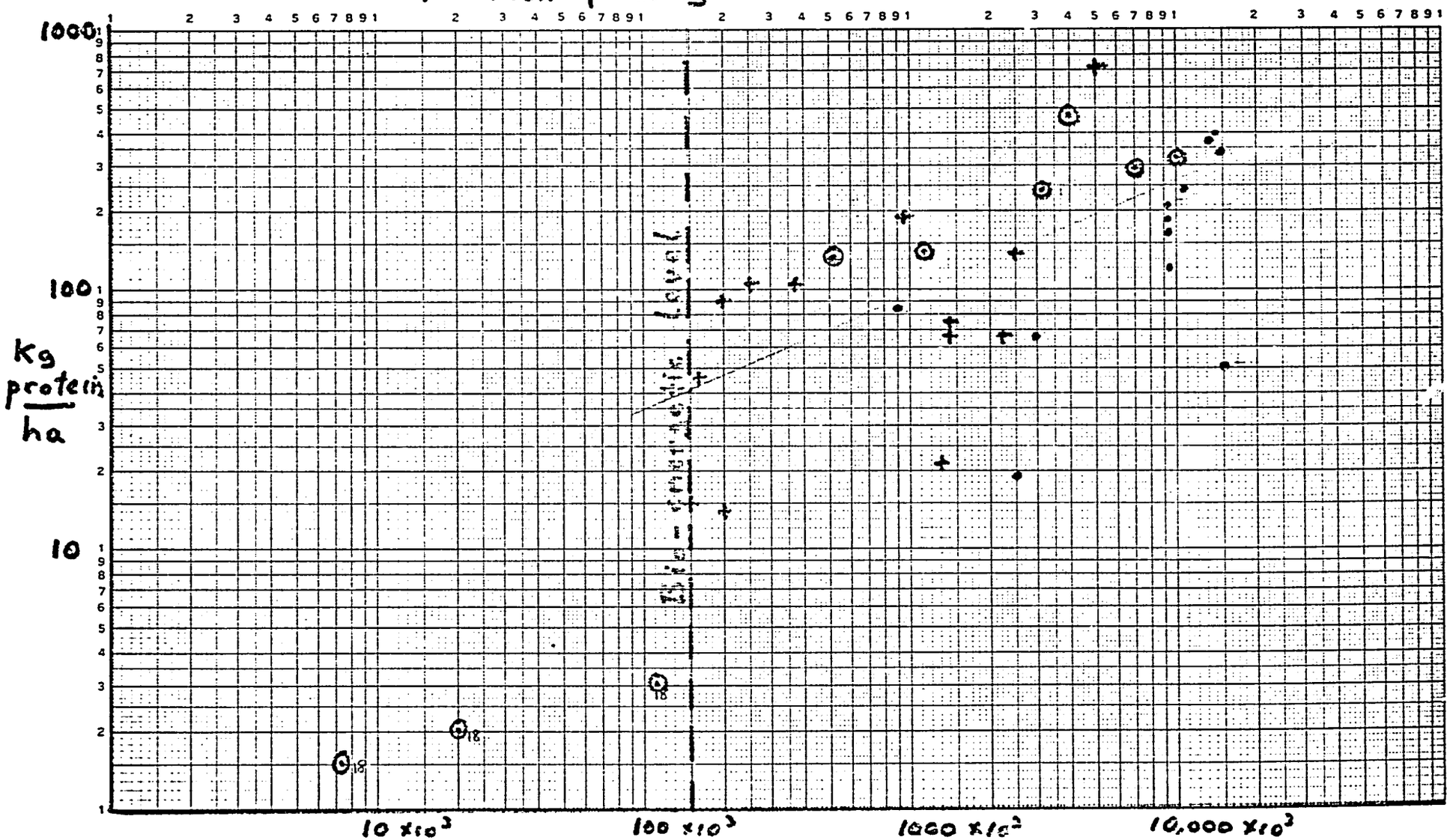
FIGURE 9


Yield-Value Index vs. Fertilizer Use—1961/63
Yield-Value Index, 1961-63
300
250
200
150
100
50
0
10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200
Fertilizer use, Kg/Hectare
(Fertilizer use, given on the abscissa, is only an indicator of the use of a total package of improved technology, since the use of more fertilizer is always accompanied by the use of better seed, more pesticides, and other improvements.)
Y = 85.04 + 0.2496X + 12.51 √X .

K&E LOGARITHMIC 3 X 5 CYCLES 46 7520 MADE IN U.S.A.
KEUFFEL & ESSER CO.

⊙ = Grass-fed beef
● = other non-milk protein
+ = Fish-farming

Note: Bio-energetic base line not applied to low intensity cattle ranching



FISH AND ANIMAL PROTEIN

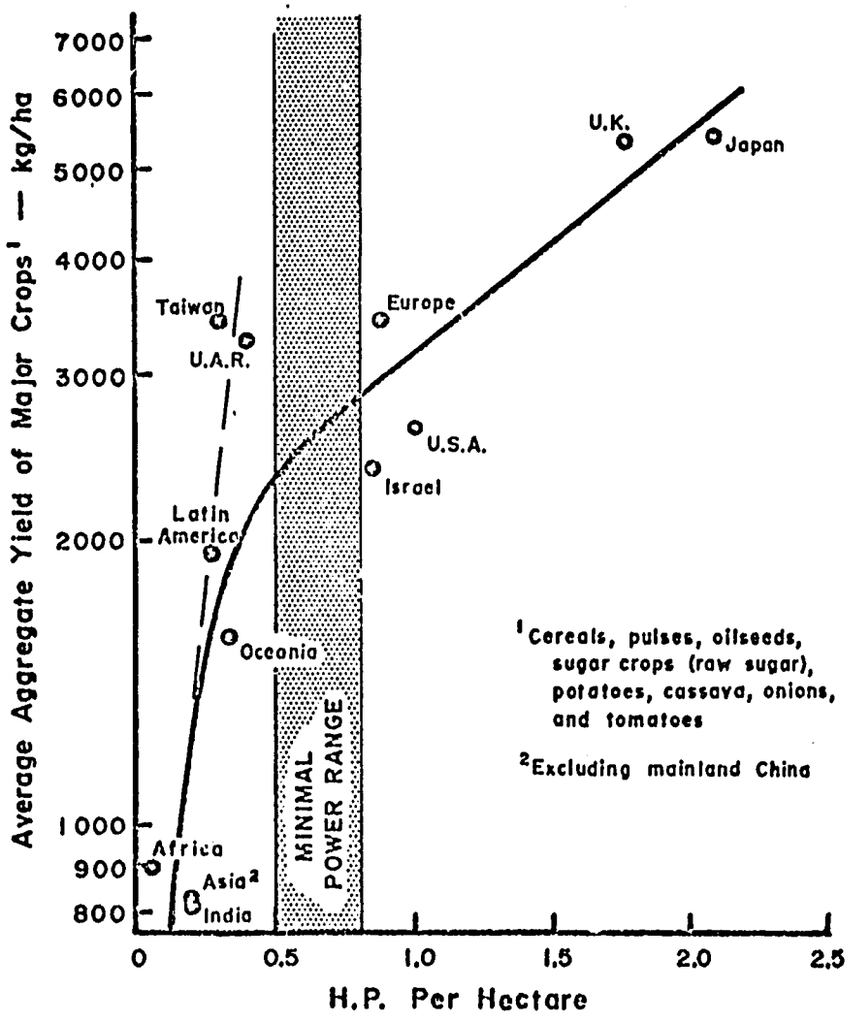
FIG 10

FIGURE 11

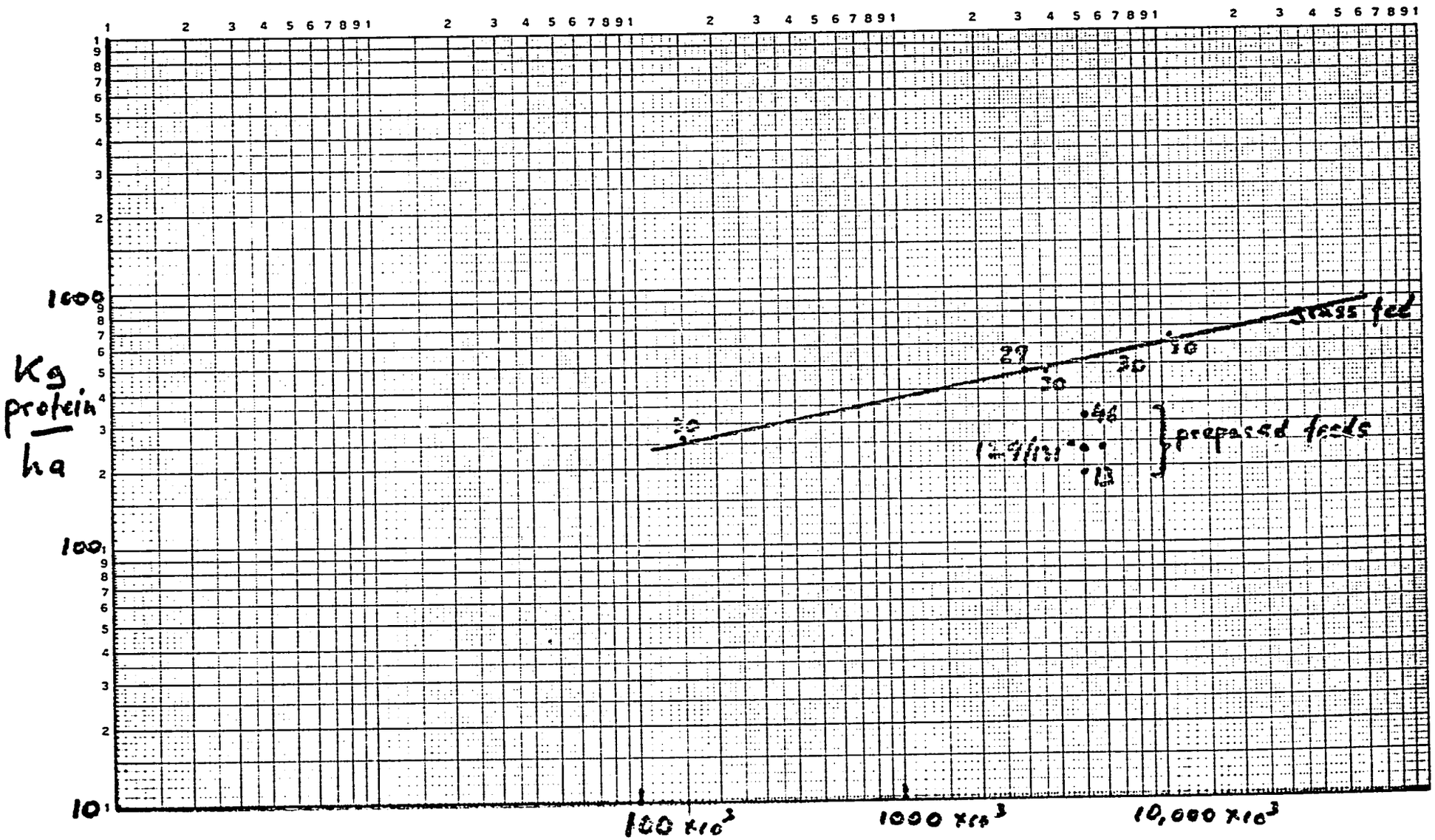
Figure 2

RELATIONSHIP BETWEEN YIELDS IN KG/HECTARE AND POWER IN HORSE POWER PER HECTARE

Major Food Crops



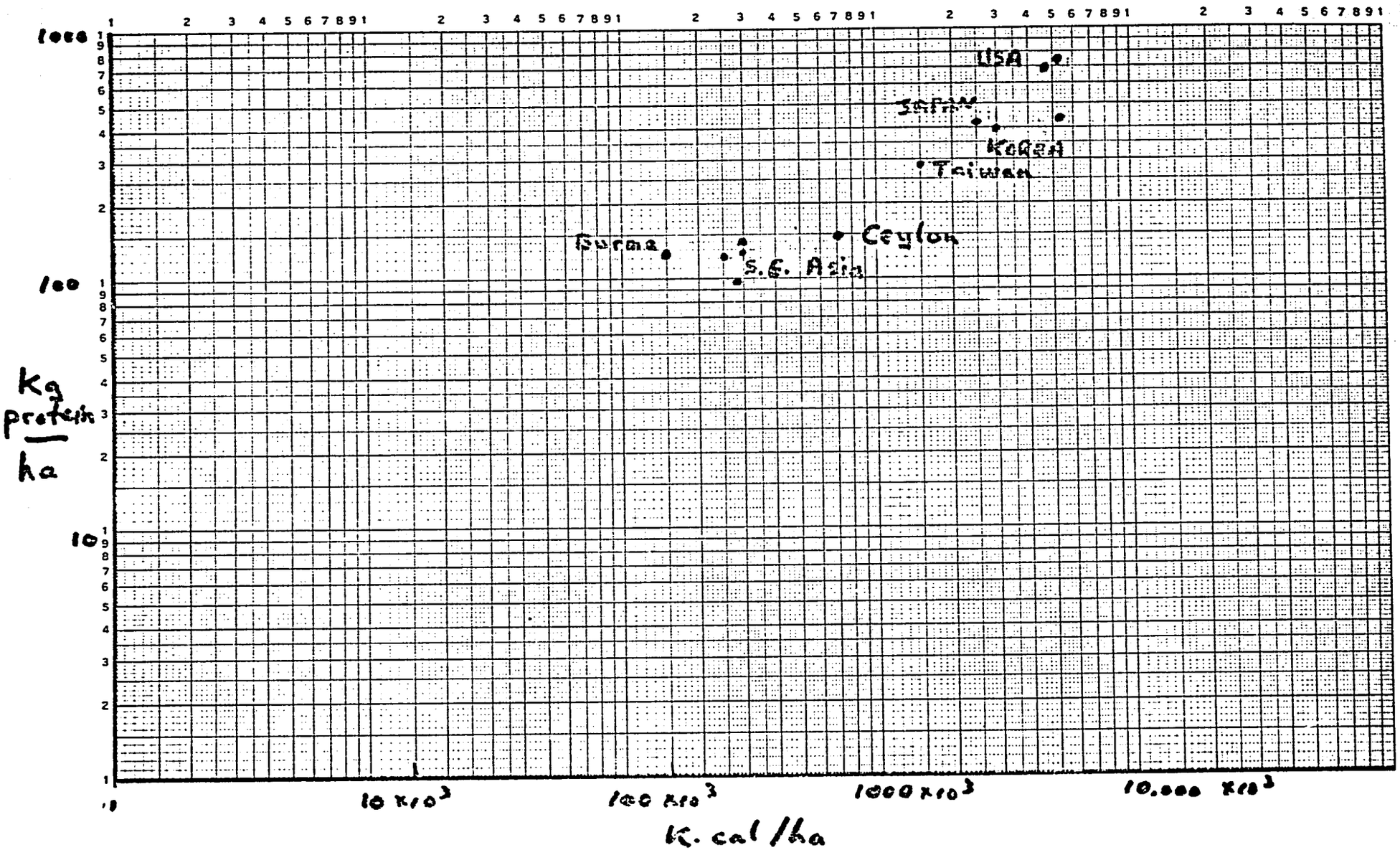
K&E LOGARITHMIC 46 7520
3 X 5 CYCLES MADE IN U.S.A.
KEUFFEL & ESSER CO.



MILK

FIG 12

K+E LOGARITHMIC 3 X 5 CYCLES 46 7520 MADE IN U.S.A.
KEUFFEL & ESSER CO.



RICE

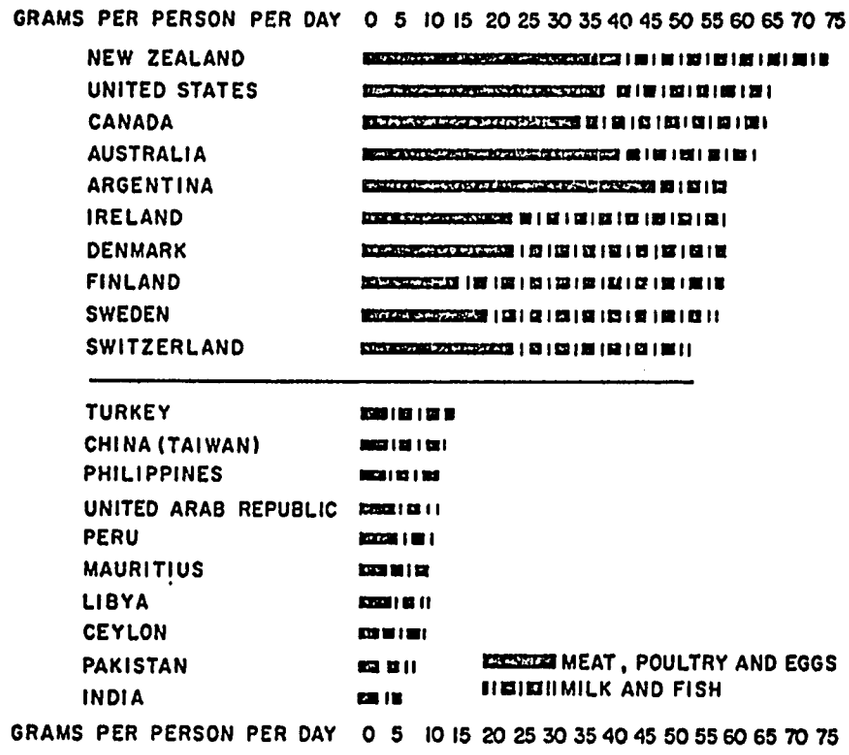
FIG 13

FIGURE 15

THE WORLD FOOD PROBLEM—VOL. II

Figure 5-1

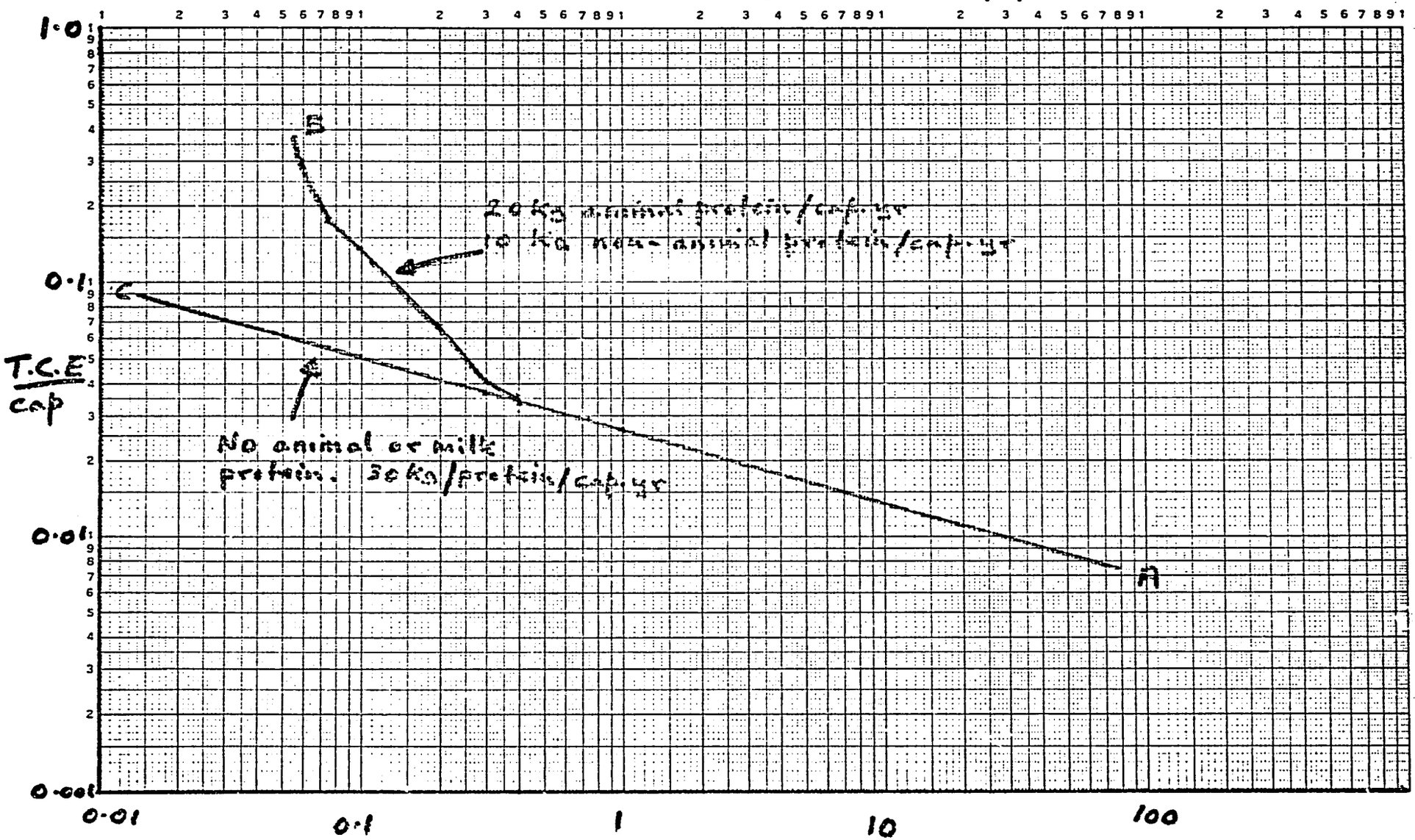
Available Total Edible Protein Supplies[1]



[1]Wilcke, Harold, General Outlook for Animal Protein in Food Supplies of Developing Areas; In: World Protein Resources, Adv. in Chem. Series 57, Amer. Chem. Soc., p. 17, Washington, D. C., 1966.

K+E LOGARITHMIC 3 X 5 CYCLES 46 7520 MADE IN U.S.A.
KEUFFEL & ESSER CO.

Minimum Energy [TCE/capita] required to feed population at various densities



Agricultural land ha/capita of total population

FIG 16

TABLE 13

ENERGY RATIOS

WHEAT	5.8 - 6.5 - 2.4 - 3.5
MILK	approximately 1
EGGS	0.4
BEEF	intensive 0.1
SWEET POTATO	18
SOYABEAN	1.6 - 3.
POTATO	14 (US 2 - 6.3)
OATS	7
CORN	2.9 - 5.42
RICE	US 7.5
BEEF	(grass fed) 0.35 - 5.4
FISH FROM SEA	0.08 - 4.0 (Peru)
FPC	0.45 (Peru)
PEANUTS	1.9 - 8.7
PETRO PROTEIN	0.16
ALGAE	1.2
RICE	UDC 10 - 36

TABLE 14

JAPAN - POPULATION GROWTH 2%

1970 Ha Agricultural land = 6.7×10^6 Ha

Date	Pop. $\times 10^6$	Ha Agric/cap.	Vegdiet TCE $\times 10^6$	Non-Vegdiet TCE $\times 10^6$
1972	102	0.065	5.9	25
1977	112.5	0.0596	6.75	28
1985	132	0.051	8.18	32
1990	146	0.046	9.34	60
2000	180	0.037	12.24	100

TABLE 15

ENERGY REQUIREMENT TO FEED A GIVEN POPULATION

(1) Country	(2) 1970 Pop. X10^6	(3)++ Ha. Agric. Land/cap.	(4) TCE/ cap.	(5) TCE total X10^6	(6)(-) Current Food Energy Cost 10^6 $	(7) Capital* investment to Supply Agric. Maintenance 10^6 $	(8) Total xx Agric. cost/yr. 10^6 $	(9) Agric. cost /cap.	(10) Fraction of '67 TCE to Food
India	572	.346	0.035	20.02	440	26,067	1747	3.05	32%
China	730	.30	0.037	27.01	59	5,169	2352	3.22	?
USA (Theory)	202	2.24	negligible	neg.	ne	nil	bio-energetic	neg.	-
USA (actual - 1967)		0.76		34.6(7)	134	5,000	3599	17.8	1.15
KOREA	30	0.078	0.054	1.62	35.6	2,109	141	4.7	13.0
U.A.R.	31	0.093	0.051	1.58	34.8	2,057	137	4.4	15.0
Singapore	2.0	0.006	0.15	0.30	6.6	391	26	13.0	?
England	50	0.269	0.049	2.45	53.9	3,190	213.4	4.27	0.9
Netherlands	12.7	0.18	0.074	0.94	20.6	1,224	81.7	6.44	2.0
Japan	100	0.067	veg.0.056	5.60	123.2	7,292	488	4.9	3.0
		animal&	veg.0.23	23.0	506	29,948	2,003	20.0	12.2

(-) Assume 1970 energy cost = $22/ton

++ UN Statistical Table 1968

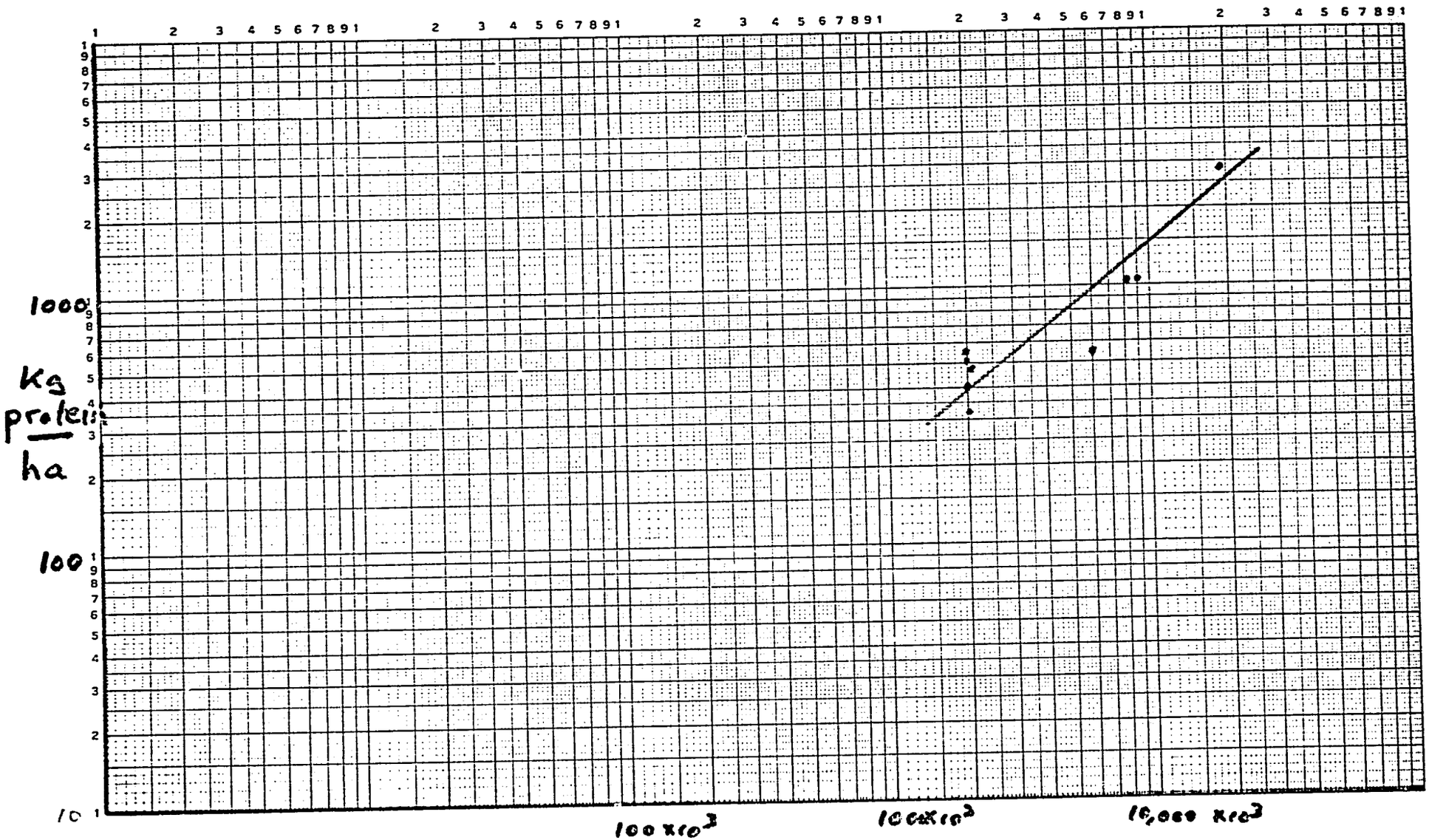
* $500 for each ton/yr N.: ton/yr N = column 6/production energy N = 220x10^{6}k.cal/ton or 3.84 TCE/ton

xx Assume interest @ 5% : ∴ [column ' X .05 + column 6]

Malcolm Slesser

Grant AID/csd 3158

K+E LOGARITHMIC 3 X 5 CYCLES 46 7520 MADE IN U.S.A.
KEUFFEL & ESSER CO.



Energy subsidy K. cal/ha

SOYA - BEANS

FIG 17

Study	Product	K.Cal/Lb.	K.Cal/Lb. Protein	Comments	
1	Rice - IR 8	225	2808		India
2	Rice - Padma	396	4944		India
3	Wheat S-308	309	2810		India
4	Maize Safed 2	479	5041		India
5	Wheat (local)	395	3950	alluvial soil (fertilized)	India
		334	3340	black soil (fertilized)	India
		263	2630	hilly (fertilized)	India
		676	6760	laterite (fertilized)	India
		390	3900	red (fertilized)	India
6	Millet HB1	0	0		India
		220	2200		India
		332	3320		India
		476	4760		India
7	Rice IR8	257	3210	laterite:kharit	India
		150	1870	rabi	India
8	Rice	0	0	saline soils	India
		3800	47,000	Ca SO_4 added	
		4000	49,000		
		5300	66,000		

Yield kg/ha	% Protein	Kg.Protein kg/ha.yr.	K.cal/ha.yr. x 10^3	Food energy k.cal/kg.	10^3 K.cal food energy/ha.	Energy Ratio
9066	8	752	4749	3600	32,630	6.9
5470	8	437	4944		19,700	4.0
7925	11	871	5390	3330	26,152	4.85
5021	9.5	476	5291		18,075	3.4
327	10	32.7	626		1,079	
386		38	626			
490	?	49	626	3300	1,617	2.5
190		19	626			
332		33	626		1,096	
562	9.9	56		3300?	1,854	12.4
1812		180	880		5,980	6.8
2405		239	1760		7,900	4.5
2619		260	2640		8,643	3.3
4300	8	258	2436	3600	15,500	6.3
			2436			
107	8	8.5	nil			
650		52	5445			
1250	8	100	10,890			
1400	8	112	16,335			

Study	Product	K.Cal/Lb.	K.Cal/Lb. Protein	Comments	
9	Rice	1490	18,620	arid soil 2000 lbs/acre lime	India
10	Wheat	255	2,318	unfertilized perpetual field - Rothamstead	England
11a	Leaf Protein	866	1,227	village pilot plant	Tropical
11b	Leaf Protein		4,175	solvent extracted "	
12	Heifer (500 lbs meat)	7910	47,000	NY dairy farm Feed lot farming	USA
13	Milk	444	12,700	NY dairy farm	USA
14	Cassava-based protein process	339	1,027	no cassava fertilization ∴ pointless	
	Cassava	0	0	Reference for 14	
15	Corn	291	3,23[illegible]	Iowa-typical	USA
16	Petro-protein	8779	13,934	BP process	Scotland France
17	Peanuts	1293	4,787	altika-intensive cropping	Guyana
18	Beef 1.	360	2,168	Univ. of Florida Management Schemes	Venezuela
	2.	706	4,280		
	3.	272	1,653		
	4.	630	3,810		
	5.	1170	7,100		

Yield kg/ha	% Protein	Kg.Protein kg/ha.yr.	K.cal/ha.yr. x 10^3	Food energy k.cal/kg.	10^5 K.cal food energy/ha.	Energy Ratio
1900	8	152	2748			
1110	11	122	255	3300	3663	14.4
Est.1000	leaf=?	Est 120	324			
Est.1000		120	324			
268/27.5 months	16.5	19	1965	4000	1070	0.54
5360	3.5	187	5232	650	3472	0.66
LAE 2.5 ha		553	1833			
15,000		150	150	1130	16,950	112
6285	9	565	4032	3480	21,871	5.42
		-	$70X10^3$	3000		0.16
2244	27	606	6382	5600	12,566	1.9
9.4	16	1.5	7.4	3230	30	4.0
13.0		2	20.2		42	2.1
190.3		30	114		613	5.4
812		130	526		2622	5.0
2926		468	3430		9450	2.8

Study	Product	K.Cal/Lb.	K.Cal/Lb. Protein	Comments	
19	All crops				
	Paddy Rice	233	2920	optimum fert.	Korean
	Barley	411	4569	"	"
	Wheat	356	3243	"	"
	Corn	285	3000	"	"
	Soyabean	416	1224	"	"
	Sweet Potato	40	2359	"	"
	Potato	82	4080	"	"
	Forage Crop	408	?	"	"
	Legume	421	?	"	"
20	Wheat	160	1456	Urea-aerial spraying dry lands rain fed area: No fertilizer	India
21	Rice	40	494	Urea-aerial spray "	
22	Petro-protein	11,600	18,680	Inst. Francaise Petroles	
23	Cod - 1924	559	2,943	Time Series 1924-1961	Faroes
	1938	805	4,240		
	1946	319	1,682		
	1956	695	3,659		
	1961	1169	6,150		
24	Trawling	4387	23,000	Medium/distant water. 1964 average (Ton-mile basis)	England
25	Seine Netting	1420	7,476	Near waters, based on av. HP + catch/day	Scotland
26	Trawling	2180	11,497	distant waters based on % cost to fuel	Germany

Yield kg/ha	% Protein	Kg. Protein kg/ha.yr.	K.cal/ha.yr. x 10^3	Food energy k.cal/kg.	10^3 K.cal food energy/ha.	Energy Ratio
5011	8	400	2576	3600	18,000	7.0
3320	9	299	3004	3480	11,550	3.8
3580	11	393	2810	3300	11,800	4.2
5540	9.5	526	5540	3480	19,280	6.9
1330	34	452	1055	4030	5,360	5.1
23,000	1.7	391	1926	1140	26,200	13.6
14,940	2.0	300	2688	760	11,324	4.2
8,620	?	?	7739			
4,400	?	?	4077			
280	.11	308	99			
1058	8	85	92			
	62.5					0.116
	19					0.65
	19					
	19					
	19					
	19					0.33
	19			800	363Kcal/lb.	0.08
	19					0.26
	19					0.17

Study	Product	K.Cal/Lb.	K.Cal/Lb. Protein	Comments	
27	Fishing Areas				
	North Sea				
	England: Trawling	655	3447		
	Scotland: Trawling	318	1670		
	England: Seine	487			
	Scotland: Seine	319	1673		
	Iceland				
	England	1435			
	Scotland	3150			
	Bear Island	1847			
	Grand Banks	3300	17,300		
	W. Greenland	1570			
28	Beef: various grasses				
	Napier	4122	25,000		Puerto Rico
	Guinea	3713	22,500	Hot, humid	Tropical
	Pongolu	4122	25,000		"
	Para	5712	35,000		
	Kudzu	829	5,025		
	Naper	3164	19,170	irrigated	
	Guinea	2737	16,590	semi-arid	
29	Beef	620	3750	low-intensity grazing	New Zealand
30	Milk	nil	nil		UK
		113	3220		UK
		191	5454		
		299	8532		

Yield kg/ha	% Protein	Kg.Protein kg/ha.yr.	K.cal/ha.yr. x 10^3	Food energy k.cal/kg.	10^3 K.cal food energy/ha.	Energy Ratio
						0.55
						1.14
	19					0.76
	"					1.14
	"					
	"					0.25
	"					0.12
	"					
	"					0.11
	"				363	0.23
1010	16.5	167	9168	3230	3262	0.36
1120	16.5	184	9168		3617	0.39
1010	16.5	167	9168		3262	
728	16.5	120	9168		2351	
504	16.5	83	920		1627	1.77
1456	16.5	240	10,155		5025	
392	16.5	65	2859		1266	
840	16.5	474 * or 139+	1148	3230	2710	2.4
7430	3.5	260	nil +153	650	4829	31
13,300		465	3283		8645	2.6
15,700		550	6566		10,200	1.6
17,850		625	9849		11,602	1.2

* butterfat
\+ beef protein

Study	Product	K.Cal/Lb.	K.Cal/Lb Protein	Comments	
31	Beef	nil	nil		UK
		1027	6224		
		1714	10,400		
		2284	13,800		
32	Soya	1250	3130	USA figures on nutrients found in Crop - since harvested assume input is 120% of output	
33	Corn	384	4050		
34	Rice	218	2728		
35	Wheat	423	3850		
36	Oats	252	1800		
37	Sorghum	461			
38	Alfalfa	319			
39	Soya	1110	2776	medium intensity	USA
40	Cottonseed	554	3262		Congo
41	Sweet Potato	280	15,058		Taiwan
42	Maize	544	6112		Tanzania
		688	7731		
43	Oilpalm	0	0		Malaysia
44	Potato	22	1265		England
45	Lima Bean	0	0		India
46	Milk		7432	Intensive food production in US- beef and lamb raised on unfertilized open range, then fattened.	
47	Fish (farmed)		15,300		
48	Eggs		16,000*		
49	Broiler		15,000*		
50	Turkey		20,400*	Probably higher energy since have to add many supplements: e.g.:	
51	Hog		19,000		
52	Beef		29,400	Vitamins Niacin Phosphate	
53	Lamb		46,000		

Yield kg/ha	% Protein	Kg.Protein kg/ha.yr.	K.cal/ha.yr. x 10^3	Food energy k.cal/kg.	10^3 K.cal food energy/ha.	Energy Ratio
820	16.5	135	nil + 153	3230	2640	17
1460	"	240	3283	"	4710	1.48
1750	"	289	6566	"	5650	0.8
1970	"	325	9849	"	6360	0.65
6720	34	2284	18,500	4030	27,000	1.45
10,080	9.5	958	8483	3480	35,070	4.1
8736	8	699	4202	3600	31,440	7.5
2688	11	296	2511	3300	8870	3.5
5376	14	753	3028	3900	20,970	7.0
8960	11	985	9237	3320	29,740	3.2
9856			7010			
3136	34	1066	7773	4030	12,630	1.62
2512	17	427	3065	3560	8940	2.9
40,000	1.7	680	2464	1140	45,600	18.5
1136	8.9	101	1360	3480	16,940	5.4
2060		183	3117			
29,800			nil			∞
47,700	1.7	812	2295	760	32,450	∞
300KG (seeds)	8.4	25.2	nil	1230	369	2.4
8650		303	4957	650	5622	1.13
2390		454	15,320	1460	3488	0.22
2930		378	13,300	1630	4776	0.4
		378	12,500			
		210	9440			
3990	9.1	363	15,680	5530	22,059	1.4
		216	14,000			
931		149	15,000	2470	2299	0.15

Study	Product	K.Cal/Lb	K.Cal/Lb Protein	Comments
54	Algae	285,000	416,000	Dutch field plant 1952
55	Algae	2,916,000	4,860,000	Japan:continuous unit
56	Yeast Culture	3,000	6,000	Molasses base
57	Yeast			Production Unit
58	FISH MEAL:			N_2 stick water re-cycled
	Continental Europe	8870	12,700	and oil credited
	W. of Scotland	1980	2,830	
	Iceland	1905	2,722	
	Peru	983	1,400	
59	FISH MEAL:			
	Continental Europe			Torry Research Station
	W. of Scotland	2760	3,942	
	Iceland			
	Peru			
60	Fish Farming: Tilapias	3154	16,600	various fertilizers Malacca
		5985	31,500	
		4123	21,760	
		2170	1,142	
		10,200	53,760	
		0	0	no fertilizer-no food
61	Fish Farm: Milkfish	0	0	volcania soil Indonesia
62		701	3692	feed maize Katanga
63	Fish Farming	0	0	as in 60 - various fertilizers
		57	300	
		189	994	
		83	441	

Yield kg/ha	% Protein	Kg.Protein kg/ha.yr.	K.cal/ha.yr. x 10^3	Food energy k.cal/kg.	10^5 K.cal food energy/ha.	Energy Ratio
	60					
	60					
2673	50	1336	35,200	2770	7217	0.2
50,000		22,500	647,000	same as yeast=2770	138,500	0.2
386	19	73	1216+153	700	270	0.2
361		69	2180			0.05
299		57	1235			
243		46	13.4		170	
114		22	1167			0.3
78		15	0			
64		12	0			
1020	19	194	785			0.45
122		23	0+153			
471	19	90	57			
533	19	101	222	700	373	1.7
534	19	102	99			

Study	Product	K.Cal/Lb.	K.Cal/Lb Protein	Comments
64	Fish Farm	218	1147	Using Napier grass feed
65	FPC	8,800	11,000	U.S. Bureau of Commercia Fisheries. Assume 1000 k.cal/lb. for catching
		2,649	3311	In Peru 75 k.cal/lb. fis
66	Fish farming in rice fields	1,083	5703	Fish fed Taiwan Soya Meal and subsidy from rice
67	Fish Farming in rice field			Total protein bases USA
68	Torula yeast	21,600	41,700	Sulphite waste liquors
69a	Yeast - torula	8,264	5,800	Ionics increase scale-up design
69b	Yeast - torula	6,133	11,800	General carbohydrate substrate.
70	Lysine		7,965	Synthetic
71	Lysine		12,980	Fermentation synthesis Japan
	<u>Rice</u>			
72				Average world yields 1964 — Japan
73				Taiwan
74				Ceylon
75				Indonesia
76				Philippines
77				Burma
78				Thailand
79				India

Yield kg/ha	% Protein	Kg.Protein kg/ha.yr.	K.cal/ha.yr. x 10^3	Food energy k.cal/kg.	10^3 K.cal food energy/ha.	Energy Ratio
68	17	14	63			1.45
						0.143 US 0.45 Peru
728	19	138	1942	700	690	0.35
		68.2	4582			0.335
118		62	5670			
4805	52	2460	87,400	2770	13,104	0.15
4805	52	2460	64,800	2770	13,104	0.2
	app.100					
	app.100					
	app.100	4426	126,000			
5240	8	419	1894	3600	18,864	10
3500	8	280	1250		12,600	10
1810	8	145	552		6,516	10
1740	8	140	124		6,264	20
1220	8	98	131		4,392	15
1560	8	125	7		5,616	36
1590	8	127	164		5,720	20.4
1540	8	125	102		5,540	22

Study	Product		K.Cal/Lb.	K.Cal/Lb. Protein	Comments
80	Mutton				Scotland hill sheep also makes wool.
81	Soya Flour				USA
82	Wheat:	Ohio	234		USDA - 1964
83		Illinois			
84		Kansas			
85		N. Dakota			
86		New York			
87		N. Carolina			
88		Oklahoma			
89		Montana			
90		Washington			
91		Idaho			
92	Corn:	New York	161		USDA - 1964
93		Ohio	191		
94		Indiana	167		
95		Michigan	176		
96		Minnesota	131		
97		Missouri	294		
98		S. Dakota	257		
99		N. Carolina	418		
100		S. Carolina	317		
101		Tennessee	305		
102		Texas	340		
103		Colorado	239		

Yield kg/ha	% Protein	Kg.Protein kg/ha.yr.	K.cal/ha.yr. x 10^3	Food energy k.cal/kg.	10^3 K.cal food energy/ha.	Energy Ratio
		26	870			
2422	44	1066	8524			
2002	11	220	1312	3300		
2486		273	1425		8203	6
1512		166	1345			
1624		178	825		5359	6.5
2419		266	1225			
1680		188	2000			
1546		170	1303			
1639		180	742		5409	2.4
2735		301	2252			
2486		273	1755			
3830	8.9	316	2380	3480	13,000	5.5
4368		360	2870			
4840		400	2800			
4166		385	2637			
3964		327	2160			
3420		283	3248			
2083		172	2192			
3772		312	4518			2.9
3158		261	3246			
3225		267	3200			
2212		183	2680			
4704		389	3512			

Study	Product	K.Cal/Lb.	K.Cal/Lb Protein	Comments
104	Soya Beans: Ohio	165		USDA - 1964
105	Illinois	143		
106	N. Dakota	257		
107	Nebraska	163		
108	Louisiana	200		
109	Maryland	196		
110	Potato: Florida	76		USDA - 1964
111	California	53		
112	Arizona	61		
113	Alabama	103		
114	Kansas	84		
115	Washington	62		
116	Colorado	36		
117	Peanuts: Georgia	220		USDA - 1964
118	Florida	100		
119	N. Mexico	1031		
120	N. Carolina	149		
121	Oklahoma	177		
122	S. Carolina	454		
123	Texas	383		
124	Hay	0		Agronomy Society -max yields
125		2140		Non-edible protein USA
126		2367		" " " "
127		4244		" " " "

Yield kg/ha	% Protein	Kg.Protein kg/ha.yr.	K.cal/ha.yr. x 10^3	Food energy k.cal/kg.	10^3 K.cal food energy/ha.	Energy Ratio
1512	34	514	1557	4030		
1680	34	571	1535			
940	34	320	1540			
1546	34	525	1562			
1376		468	1615		5545	3.43
1176		400	1515		4739	3.1
19,871	2.1	417	4630	760	15,101	3.3
42,019	"	882	6233		31,900	5.1
30,100	"	632	5130		22,876	4.5
13,933		293	4225		10,564	2.5
11,289		237	3110		8,588	
38,259		803	6290		29,000	4.6
24,465		514	2950		18,593	6.3
1915	26	497	1440	5640		
1747		454	1125		9853	8.75
2374		617	5960		13,390	2.24
2274		591	1250			
1680		437	2102			
1624		422	2146		9159	4.3
1148		298	1480			
7920	8	634	10			
19,000	11	2090	5350			
29,000	13	3786	5918			
2900	14.5	4200	10,480			