Alan Borst

DEFINING THE RELATIONS BETWEEN ENERGY AND AGRICULTURE

FINAL REPORT

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Development Sciences Inc.
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Sagamore, MA 02561

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Chief, AFR/TR/SDP
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EXECUTIVE SUMMARY

The most general form of the problem which this report addresses is the disruption of an historic pattern between the national consumption of energy and the growth of national product. In West Africa especially, national productivity is not keeping pace with increasing energy consumption. There are, many reasons for this change which are not the subject of this report, but it is essential that USAID development assistance projects take full advantage of the role that energy can play in increasing agricultural productivity.

Energy is one of the several critical factors in attaining increased agricultural productivity. It is especially critical that energy do its job in the agricultural sector in Africa. Establishing a means to determine the direction of an energy program for African agriculture is the long-term objective of this report.

It is a worthwhile objective. Energy in agriculture pays off well in a broad range of activities. Economic analysis often indicates rapid rates of return with the addition of water pumping, fertilizer, and other energy intensive inputs. For years, rural development strategies included roads and fuel distribution to bring products to market or to preserve them for later use. This was done in recognition of the fact that agricultural systems benefit from modernizing and from their ties to the modernizing sectors.

Now, development strategies for modernizing recognize the essential problem of the balance of payments as a constraint on using imported energy to increase yield. In many cases the energy would be paid for in foreign exchange and the food produced would be paid for in local currency. Vast non-export agricultural systems in Africa are, therefore, potentially left out of consideration for increased application of energy.

Thus, the energy component of agriculture needs to be treated with an understanding that leads to an increased application of energy, but with concern for sources, types, and conversion devices best suited to the economic, social, and natural circumstances of the country involved.

The problem of increasing the use of energy in agriculture is a sophisticated one because the relationship is complex. Adding energy does not necessarily add productivity. Choosing the point of intervention for energy supply programs not only requires agricultural experience, but also increased sophistication on the part of energy program designers and managers.

This report is a small and early step toward better understanding of the relationship between energy and agriculture; toward identifying the most significant targets for intervention through energy accounting; and, therefore, toward defining the process of energy program participation in agriculture.

For the purposes of defining the most appropriate direction for this early step, an accounting tool has been built. The tool was fashioned from basic energy analysis in the agricultural literature and methods previously employed by the contractor for DOE. A number of measures were used to reduce the cost and effort associated with the methodology of energy accounting and to bring it in line with the use to which it ultimately will be applied. The method is based on accounting for energy use. It does not provide a causal input-output model. The closest analogue to the agricultural accounting system is the industrial energy audit. While economic analysis provides evaluative criteria, the agricultural accounting provides the means by which targets are identified for such evaluation. With time, the tool will become more sophisticated and the data base will build to set expectations of desired efficiency levels.

The analytical tools that are needed to assist with program design and evaluation comprise the bulk of this report and are described and applied in the main sections. Basically, the analysis consists of accounting for the significant uses of energy throughout the agricultural system, from production through final delivery. While the data base is embryonic and the work yet incomplete, there are some early findings that should be taken into consideration in future program design.

The findings are:

- That the context for introducing energy is essential to determining its contribution to productivity. Such factors as size of holdings, background characteristics of land owners, climatological features, and others set the stage for what can be expected from adding energy. This "noisy" causal situation means that statements about the contribution of energy to productivity have to be bounded within selected categories of farms. Ten such categories are hypothesized, ranging from subsistence to commercial farms. These categories can be tested and redefined empirically when additional data are collected. At present, the role of such categorization is to limit the generalizations which would lead to too simple program design. There is no simple relationship between energy and productivity within a category of farm, nor can it be assumed that the modernization process includes moving progressively through the categories.

- That within a given category of farm, the largest energy inputs and, therefore, the most important targets for programs are identifiable by the methodology used in the report. For example, in the transitional set of categories, one case examined just prior to mechanization shows irrigation to be a prime user of energy, as much as tenfold over hybrid seeds, fertilizer, or human and animal labour. Of course, at the level of the individual farm or USAID project, these relationships are highly site-specific. The analytical format of the approach in this report is designed to be specific at the level of the farm. Nonetheless, it permits and encourages the expansion of data collection in a manner that would eventually discover patterns and, hence, more general program design and evaluation features.

- That the discovery of these patterns requires a systematic process of data collection and analysis, which can be done as routine project design and evaluation is conducted in the normal course of USAID business. The steps to be taken at the level of a single project are identifiable and are defined herein. Also, the analytical modules can be made available for the expansion from the level of the farm to the national arena and to the consideration of long-term R&D to assist different categories of farms to use energy.

- That the energy accounting used to trace energy flows is needed to augment economic analysis if the most appropriate form of energy is to be defined by the agricultural and energy specialists working together. Just as the 'energy audit' is used to define conservation opportunities in industry and the final decision is usually based on economic analysis, so the energy analysis herein is useful to help the energy analyst measure the potential for applying energy. In developed country agriculture, the issue is usually to conserve energy and use less while increasing output. In developing country agriculture, the issue is to use more energy to increase output, but the tools to define the targets are the same. Therefore, the next steps would include the application of the method in this report to additional circumstances with the goal in mind to develop an agricultural and energy strategy to take advantage of the opportunity for increased yield.

The following recommendations are, therefore, made:

1. A 'joint venture' team of agricultural and energy experts be formed and sent to the field to apply the approach to a realistic case.

2. A search through the 'technological inventory' at USAID's disposal be conducted to bring the most applicable technology to bear on the case examined. The range of choice may include pumping or plowing, solar or animal power sources, or any of the many choices that the past R&D work has identified. This information should be modified in such a manner as to be available to the 'joint venture' team. Gaps in knowledge should also be identified as targets for future R&D.

3. Since the results of analysis will frequently call on the need for an agricultural strategy that uses more energy, then the analysis should move from the level of the farm to the national implications. The energy supply requirements of the hoped-for opportunities will require special efforts to make them available to different categories of farms. In some cases, the opportunity will call for improved strains of draft animals with animal husbandry infrastructure, while in others, the issue will involve fossil fuels with distribution infrastructure. Energy accounting can be done to help the agriculturist, economist, and the energy professional to determine the most suitable course.

INTRODUCTION

This report provides an analytical foundation for the creation of USAID energy and agriculture programs. As stated above, the prime objective of this work is to facilitate the increase of agricultural productivity through the application of energy. The several chapters of the report each contribute a piece to the whole view needed to address the issues.

The first chapter shows how the flow of energy can be usefully traced through an agricultural system. A minimum of analysis is proposed to accomplish the needs of program design. The second chapter defines the data sets needed and the third provides an analytical format for examining the data.

The next two chapters apply the format for analysis to parts of the agricultural system in Zimbabwe. This application provides some concreteness to the conceptual framework. While the results are only the product of a brief visit and are limited to the production of maize, they illustrate the kinds of information that energy accounting can provide.

The report then concludes with a few key themes and turns to the programmatic implications of the work for future consideration.

Finally, a series of exhibits elaborates on how irrigation choices would be analyzed; on how energy analysis could be extended to additional uses; and how applications can be made easier in the future.

Chapter One

PROJECT APPROACH

Energy used for agriculture includes many sources and many forms. It may be human labor involved in land clearing, planting, or harvesting. It may be energy supplied with animal power or tractors. The fuels for tractors can range from gasoline or diesel to palm oil or other more exotic sources. Similarly, energy is required as input to the manufacture of tools and fertilizers and for the pumping and distribution of water.

A total energy balance showing all uses with all inputs and all energy transfers is a large task for even a simple agricultural activity. Consequently, it is important to select only those energy uses which are significant and relate to specific objectives. Such objectives might include:

- delineating the largest uses of petroleum energy within a project in order to examine substitution alternatives;
- identifying opportunities for substituting improved hand tools as a procedure for increasing productivity;
- assessing the relationship of agricultural energy use to national issues such as allocation and/or pricing policies which affect the agricultural sector and the import/export balance.

The basic energy assessment format presented in this report in a later section is designed to anticipate multiple objectives of this kind. They include determining where in the agricultural production and consumption processes it would pay for a USAID energy program to intervene; when a special effort is required to assure supplies of energy to a vital sector; and how the most appropriate policy mechanism, be it price or some other system of prioritization, might be applied to achieve desired goals.

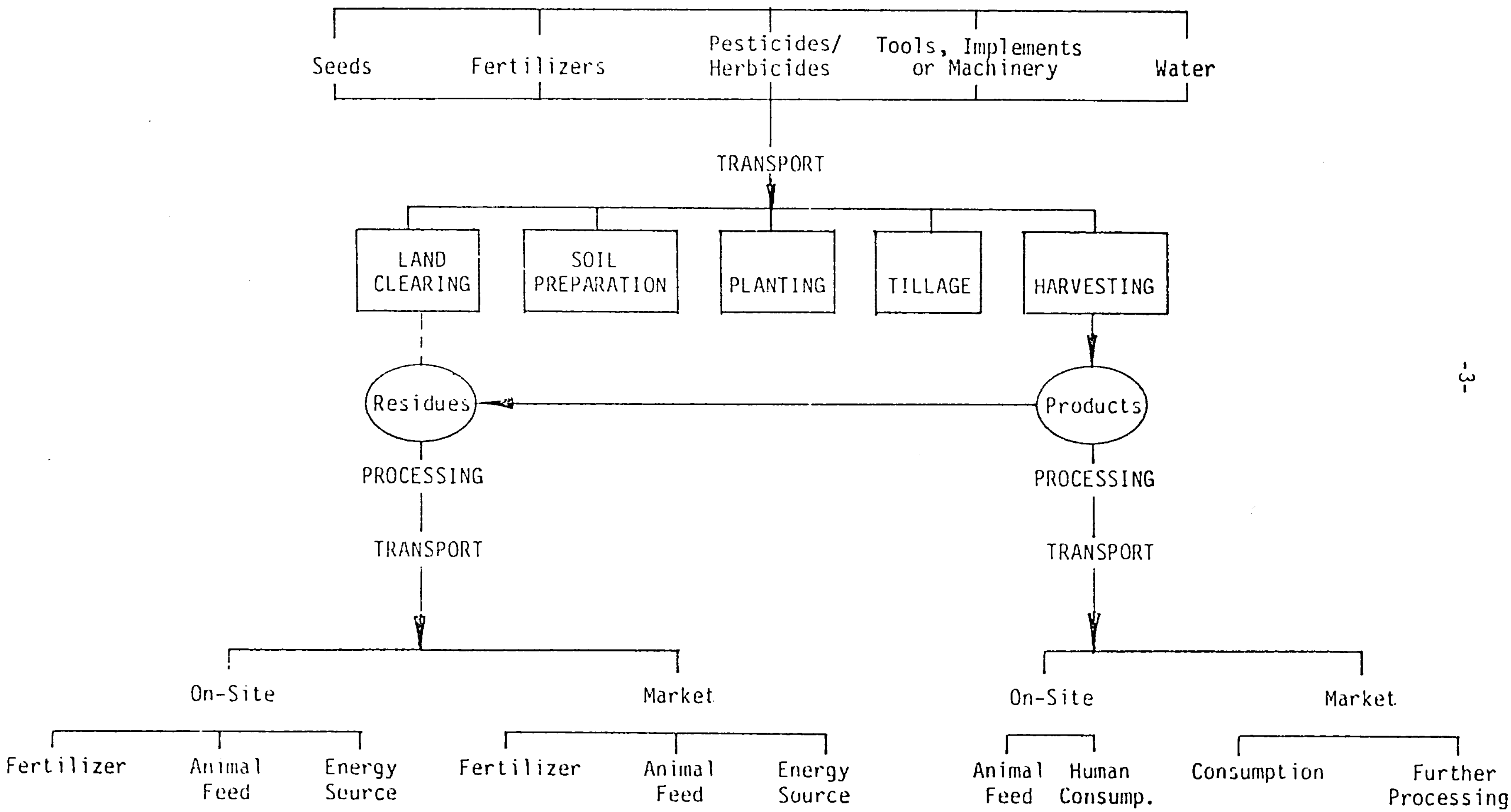
The format is designed to account for the energy associated with an agricultural project, and is, therefore, both project and site specific. Where, in an agricultural project, is energy utilized, which forms and types of energy are critical to the project, and what quantities are involved? Use of the format can improve the design and implementation of agricultural projects by providing the information needed to select among the most effective and economic energy alternatives for key agricultural inputs.

The understanding of the energy flows within a proposed or existing project permits an extension of the project into the surrounding relevant economy. Agricultural inputs which require transport can be identified and the energy needed for transport considered. Similarly, products and residues which move from the agricultural site to markets or further uses can be identified and that transport energy quantified. If there are potential processing steps which also require energy, they too can be identified and quantified. The final tabulation then shows the major uses of energy associated with the project from both the site specific aspects as well as from the wider economic boundaries.

In examining the relationship between agriculture and energy, both direct and indirect forms of energy need to be considered. Figure 1, "The Energy/Agriculture Interface," illustrates both direct and indirect forms with a flow diagram. All of the inputs at the top including seeds, fertilizers, pesticides, implements, and water require indirect energy in the form of raw materials, manufacturing, maintenance, etc. Then they must be transported to the farm site with fossil fuel energy. Next, the farm site will undergo land clearing, soil preparation, planting, tillage, and harvesting operations which require energy from human labor, animal power, or machinery. Finally, there are products and residues which can undergo processing and transport activities which require energy to permit final consumption or utilization. They can be consumed or used on-site, sent to a domestic market, or even exported.

Figure 1

THE ENERGY/AGRICULTURE INTERFACE

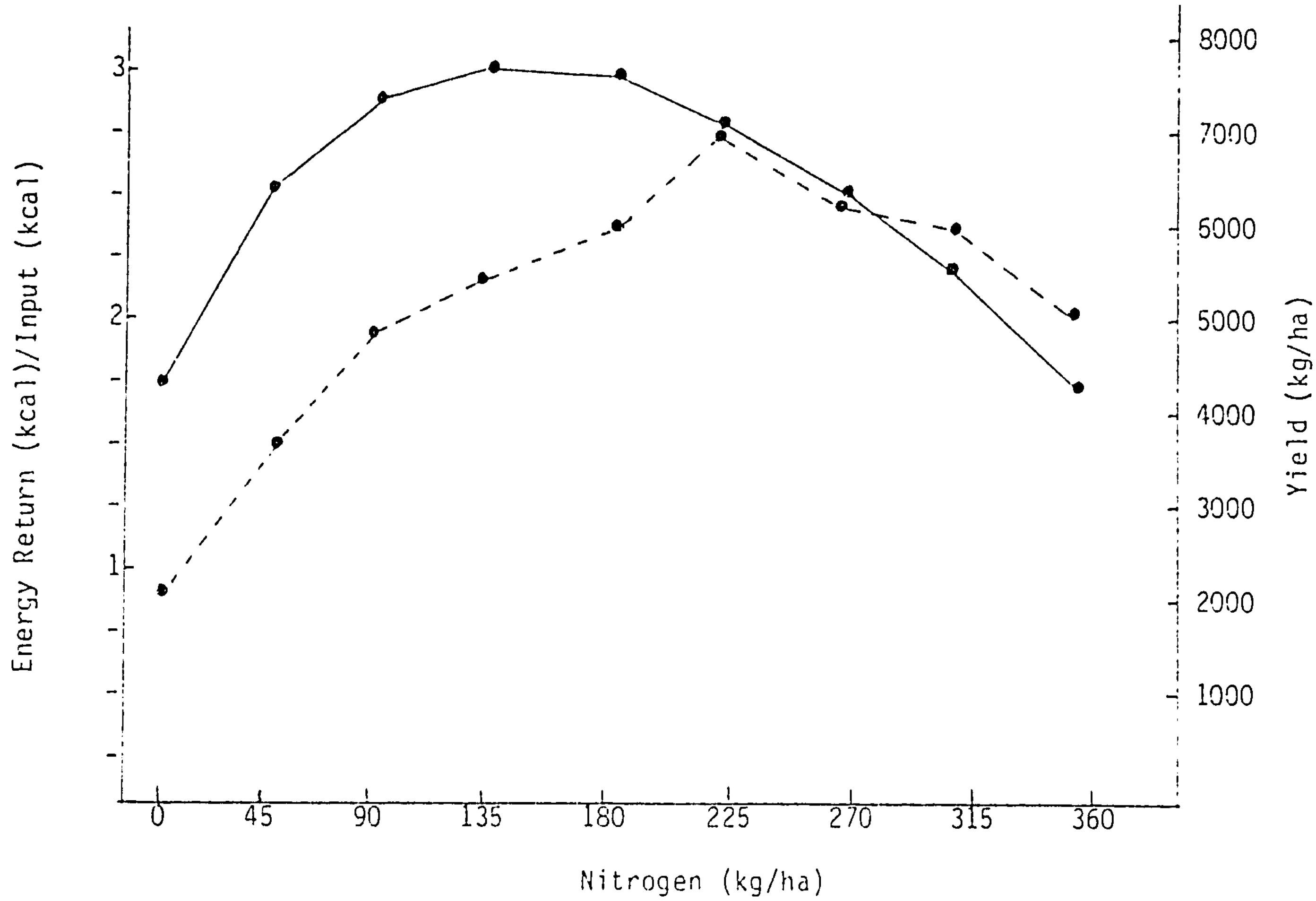


This report including the format stresses the selection of those energy data most useful for specific functions. For example, it is important to know the largest uses of energy within a given agricultural project in order to set priorities for action. Second, it is advantageous to know where there are energy alternatives available in a specific country in order to evaluate economic consequences of change. Third, it is helpful to be aware of the relationship between the energy form and the import balance for the country to assist in decreasing the loss of foreign exchange where possible and still ensure reliability of supply. Fourth, an understanding of how manpower can substitute for animal or mechanical power is important in permitting an increase in manpower where that is desired or similarly a decrease in manpower where that outcome is preferred. Fifth, a knowledge of the relationship between energy use and productivity will permit the use of energy in the most beneficial manner. All of these functions dependent upon the use of energy in agriculture are important to understand from a developing country point of view.

The basic evaluative format considers the complexity of the relationship between the use of energy and its effect upon agricultural productivity. It is a simplifying, but erroneous, assumption to accept that any increase in the use of energy will result in a related increase in productivity. In most cases, there is not a simple relationship. Figure 2, for example, "Corn Production Increase with Fertilizer Use," shows that the corn yield will increase only up to a certain point with increasing quantities of nitrogen fertilizer. After that maximum point has been reached, corn yield will begin to decrease. Similarly, one cannot assume that by increasing the use of energy through added machinery or animals to apply the fertilizer, that the corn yield will continue to rise. It is only the specific nitrogen fertilizer quantity which

Figure 2

CORN PRODUCTION INCREASE WITH FERTILIZER USE*



● - - - ● Corn Yield with varying amounts of Nitrogen (Phosphorous = 37 kg/ha)

● ——— ● Energy Return (kcal) per input (kcal)

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* Taken from Handbook of Energy Utilization in Agriculture, Edited by David Pimentel. CRC Press, Inc., 1980. p. 5.

increases plant growth up to the maximum point as shown in Figure 2 that is important. Neither the indirect energy of manufacturing or the added energy associated with the use of animals or machinery increases productivity. Both these energy values should be included in any evaluation of impact, however, for they represent quantities of energy which must either be produced by the country or imported. Thus, they form an important part of the overall energy balance.

Generally, in developed countries an increase in fossil energy use has played a part in an increase in production. A look at corn yields in the US or the UK will show values over 7 - 8 x 10^3 kg/ha, whereas a developing country will often produce less than 1 x 10^3 kg/ha. That fossil energy in developed countries has been used not only to optimize the use of fertilizers, but also to save human labor. In developing countries, however, the desirability of saving human labor in an agricultural situation is dependent upon many other considerations.

The difference in agricultural yields among countries is due to many factors. Soil fertility, rainfall, temperature range, as well as agricultural practices are all important. Frost free areas may permit the cultivation of certain plants on a double cropping basis. Variations in rainfall and temperature range strongly affect crop yield. The use of hybrid seeds usually ensures a higher production rate. The timing of planting, cultivating, fertilizing, harvesting, etc., are all extremely sensitive to the soil and weather conditions. Consequently, it is the combination of specific site conditions which then establishes the need for energy related inputs of water, fertilizer, pesticides, etc., as well as the level of energy associated with their distribution and use and finally the resulting agricultural yield.

In order to prepare a summary of these important parameters, a categorization of African farms has been produced. Figure 3, "African Farms," illustrates a simple set of 10 categories based upon farm size, typical ownership, basic energy form, fertilizer use, and maize yield. This set of parameters will be used to establish the energy inputs for typical African farms within traditional, transitional and modern modes.

Traditional farming in Africa includes both shifting (non-continuous) and continuous cultivation and fits into categories 1 through 3. Transitional farming includes different ownership patterns with more use of draught animals and an introduction of tractors. This is illustrated in categories 4 through 7. Modern or commercial agriculture is based upon larger farms with a higher level of mechanization including fertilizer, pesticide/herbicide use and resulting higher maize yields. Following Figure 3, categories 8 through 10 show relevant African examples of modern agriculture.

The flow diagram in Figure 1 and the classification of African farms in Figure 3 derived from the flow diagram, in combination, form the basis of the energy assessment format. This format is presented in Chapter Three. The next chapter on data collection illustrates the types of information needed for the format.

Figure 3

AFRICAN FARMS

Cat. No.	Cultivated Land (ha)	Ownership*	Energy Form	Fertilizer	Pest./Herb.	Yield of Grain/ha (kg x 10^3) 15-12% moisture	Other Parameters
1	0-1	Family	Human	None	No	0.3 - 0.5	RF-L-AD(NC)
2	1-2	Family	Human and Animal	Manure & Veg. Res.	No	0.5 - 0.7	RF-L-AD
3	2-5	Community	Human and Animal	Manure & Veg. Res.	No	0.6 - 0.9	RF-L/H-AD
4	6-10	Community	Human and Animal	Manure & Veg. Res.	Yes	0.6 - 1.2	RF-H-AD
5	5-10	Cooperative	Human and Animal	Manure & Veg. Res. Some Chemical	No	0.9 - 1.5	RF-H-AD
6	10-25	Cooperative	Human/Animal/ Mechanical	Manure & Veg. Res.	No	1 - 3.5	RF-H-AD
7	over 25	Cooperative	Human/Animal/ Mechanical	Some Chemical	Yes	2.5 - 5	RF/I-H-KD/AD-S
8	5-10	Private	Human and Animal	Manure & Veg. Res.	No	2.5 - 4	RF-H-AD
9	10-25	Private	Human/Animal/ Mechanical	Chemical	Yes	5 - 10	RF/I-H-KD/AD-S
10	over 25	Private/ State	Human/Animal/ Mechanical	Chemical	Yes	5 - 10	RF/I-H-KD-S

RF = rainfed L = local seeds AD = air dry S = silage for cattle
I = irrigation H = hybrid seeds KD = kiln dry (NC) = non continuous farming system

* Ownership descriptions are only to be used as examples.

Chapter Two

DATA COLLECTION

This chapter covers the need for collecting data and focusses attention on those data sets of the most utility to the USAID project designer or evaluator. The major parameters for identification of both direct applications of energy including fuels and indirect applications of energy embodied in a product such as fertilizer are noted.

Data on energy use in agriculture have been collected in the developed world for more than ten years. Considerable information is available on both the direct and indirect energy associated with the production of farm inputs; as well as on the direct energy use of fuels and electricity, and the additional energy required for transport and processing operations. Fewer data are available for developing countries, but during the last few years certain areas in the Far East and Central America have been evaluated.

African agricultural energy data are more difficult to obtain, and a short field trip to Zimbabwe was completed both to collect specific data and to serve as a case study. Zimbabwe was selected because it has all categories of farms; traditional, transitional, and modern, as shown in Figure 3. Specific data from Zimbabwe are included in the case example.

This chapter discusses the types of data needed to understand the agricultural use of energy and its relation to agricultural productivity. The information collected to date includes specific values on numbers of man-hours and animal-hours needed to accomplish specific operations as well as liters of fuel or kilograms of fertilizer required for these operations. In addition, indirect energy values for agricultural inputs have been assembled. As data are collected, they are converted to common units of kilocalories and are also presented as petroleum equivalents.

All data have been associated with the general agricultural classification of traditional, transitional, and modern, and also, where possible, with the specific ten African farm categories. Following Figure 1, "The Energy/Agriculture Interface", there are agricultural inputs to be provided to the farm site and there are specific activities to be carried out at the farm site. Both utilize energy. All of the inputs--seeds, fertilizers, pesticides, tools and implements, and water--require direct energy in their application or use. They also require indirect energy for their production or manufacture. Either of these, the direct as well as the indirect, can be large. Fertilizers, for example, have a high indirect energy based upon their feedstocks and production; and water, depending upon its source, may have a larger direct energy in its actual distribution and use.

Generally, it is best to evaluate the direct energy separately from the indirect. In this way, all direct energy used as fuel and electricity can be considered. This combination permits summing fuel and/or electrical use for an agricultural project over a specific time period. Thus, it facilitates an example an estimate of import requirements needing foreign exchange, or an evaluation of alternative fuels, if this is appropriate. The development of the format illustrates alternative energy comparisons. Renewable energy forms such as alcohol can be evaluated, or the use of biomass compared with fossil fuels. The development of the format illustrates alternative energy comparisons. Next, the two activities of transport and processing must be considered. Transport includes moving all the agricultural inputs to the site and then removing the products and residues from the site as appropriate. Depending upon the crop, agricultural processing may be only drying, or it may include storage and/or further packaging steps.

These five inputs, with their indirect energies, their direct energy for utilization, and the transport and processing activities, make up the eight major energy consuming parameters. Following the flow diagram of Figure 1, "The Energy/Agriculture Interface", each of the inputs and activities can be briefly described.

The energy for seed propagation when the crop is maize can be either the energy required to produce that part of the crop that is saved for seed (local seeds) or the amount of energy to produce different seed (hybrids). If hybrids are used, both the energy and economic costs are higher. For example, in Zimbabwe, maize sells at approximately Z $138 per tonne, whereas hybrid seeds average Z $802 per tonne. Approximately 25 kg of seed are needed for a hectare. Obviously, a site-specific study for each type of seed is necessary for an accurate propagation energy value. Typical developing country energy values for maize seed can be used as estimates. Values will be expressed in kcal/kg of seed.

The energy for fertilizer production is based upon the specific type of fertilizer and its required energy for extraction, manufacture, transport, etc. Again, there are general US values for nitrogen, phosphate, and potash which can be applied to African use since they are specific for the particular fertilizer and fertilizer production practices are duplicated in most cases. Values will be expressed in kcal/kg of fertilizer content.

The energy situation for pesticides and herbicides is similar to that of the fertilizers in that they also require hydrocarbon feedstocks and heat and electricity in their various manufacturing processes. Again, there are US data which are relevant for the major pesticides used in Africa and they will be expressed in kcal/kg of chemical content.

Tools, implements, and machinery are composed of wood and metal which also require energy for manufacturing. When the specific item is imported, US or other developed country values can be used. When the item is locally produced, rough estimates of energy based upon the specific materials in the implement will be required. All values will be in kcal/kg of specific material.

The energy required to provide water for an agricultural project can be the largest single energy requirement when considered over the life of the project. In order to provide information on this energy use and also to demonstrate the use of the format, a separate section has been prepared. Exhibit A, "Energy for Irrigation," illustrates the energy associated with water supply and development, water motive power, and water distribution in order to tabulate total energy requirements of an irrigation system.

The energy associated with the on-site farm operations will be in the form of human labor, animal labor, and machine use. Both human and animal labor will be measured in hours required to accomplish the specific operation and then converted to kcal per hectare. Machine use will be in either liters of fuel or kilowatt-hours and similarly converted to kcal per hectare.

The transport of specific inputs to the farm will be described by weight, distance, and mode of transport from a relevant central distribution location. Similarly, outputs will be separated into products and residues and their potential final locations identified in order to establish weight, distance and mode of transport. Values will be tabulated and totalled to show estimates of energy use attributable to transport of inputs and outputs over a given time frame.

There are processing options which can utilize energy and, thus, should also be included in the format. Depending upon the market requirements of the crop and other variables such as temperature, further energy using steps such as storage and fumigation, drying and packaging could be needed. Such operations as corn drying and/or packaging will be briefly described and their energy use on a weight basis estimated.

These eight parameters including the five major inputs and the direct energy associated with farm operations, transport, and processing will be tabulated and totalled in such a way as to provide an understanding of the use of energy in a given agricultural project.

It is important to understand the usefulness of indirect energy. This energy required to produce a product such as a fertilizer or to produce, install, and maintain an irrigation system can often be hidden. In reality, it shows up as the high cost of purchase or import of the fertilizer or irrigation system and is not apparent as an energy cost. When it is recognized that the high cost of nitrogen fertilizer is caused by its large indirect energy of production, alternatives can be examined. There may be an opportunity to produce fertilizer locally, depending upon the availability of indigenous resources such as natural gas or coal, or there may be an agricultural alternative such as crop rotation.

Similarly, there may be opportunities for substituting materials or processes associated with the irrigation system which are less energy-intensive. Understanding the concept of indirect energy permits an examination of alternatives which, over a project's lifetime, may provide substantial opportunities for energy and economic savings.

Thus, the combination of direct and indirect energy utilized in providing the five inputs, the direct fuel and electricity used at the site, and the transport and processing energy for any specific agricultural project permits the accomplishment of a preliminary energy evaluation for the project. Once this preliminary evaluation has been made, depending upon the nature of the project and the purposes to be served by the evaluation, there are several optional activities which can provide various sets of conclusions.

Tabulating the data in several versions facilitates decisions on issues such as the following: the largest uses of energy within a project by type or source, alternative sources and forms of energy which may be substitutable, opportunities for manpower/animal power/machine power substitutions, relationships between energy use and agricultural productivity, and relationships on a national basis between energy use and foreign exchange balances. As the format evolves from its present preliminary concept to one designed for a larger data base and more functions, computerization will assist in more extensive agricultural energy evaluations to serve a greater number of users.

Chapter Three

INTRODUCTION TO FORMAT

This chapter provides the analytical framework in which data are to be collected and projects designed and evaluated. The format provides the basic set of information needs to choose targets for intervention in projects. Developing such information requires six or seven steps which are outlined in the text.

It is AID policy to assist low-income countries in improving country policies to remove constraints to food and agricultural production, marketing, and consumption. In addition, it is policy to "develop human resources and institutional capacities, especially to generate, adapt, and apply improved science and technology for food and agricultural development, and to conduct research on developing country food and agriculture problems", as a principal means to achieve food and agriculture development.*

There are special concerns in seven cross-cutting areas. These include:

1. Management systems for sustained productive use of fragile environments;
2. Management systems for sustained high productivity in more favorable natural resource areas with particular emphasis on irrigated areas;
3. Minimum-purchased-input systems;
4. Crop and animal protection (pre- and post-harvest) by most cost-effective and environmentally acceptable means;
5. Livestock in mixed farming systems;
6. Food and agriculture policy; and
7. Institutional capability to generate suitable technologies and to get them applied.

The use of energy is an issue in each of these areas, for its most appropriate and timely application can increase production, marketing, and

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* Taken from AID description of technical services relating to planning, design, and evaluation of agricultural programs and projects.

consumption. The basic format developed in this chapter can serve as an approach to understanding both the type of energy used in a project and the function served by the use of energy. In this way, the format will assist in evaluating energy's role in a project as well as evaluating and selecting the most appropriate alternative forms and sources of energy which may be available in any given agricultural situation.

Any specific project which has an associated use of energy in either the direct form, such as human/animal/machine labor, or an indirect form, such as a fertilizer or irrigation system, can be reviewed to determine such energy functions as the largest energy uses, opportunities for substitution of man/animal/machine power, opportunities for substitution of energy sources and forms, the relationship between energy use and productivity, and the relationship between energy use and specific national priorities. This basic format is designed to identify the uses of energy in a specific project and, thus, facilitate the making of energy-related decisions.

Use of Format

The format developed here consists of a series of six steps designed for use in examining maize production. As a preliminary approach to defining the major energy using inputs and operations in an agricultural project, it must be recognized as a guideline. It is anticipated that a manual will be developed based upon these steps with the addition of data for new crop species, locations, and agricultural practices.

The format was developed for agricultural project officers with the responsibility of designing and evaluating agricultural projects. In those circumstances in which the format indicates that national energy plans could be implicated due to high use of electricity or fuel, a national energy planner could easily participate.

It should be noted that the format is not intended to be an energy impact analysis methodology required for all projects. It is intended to identify uses of energy which are important to the design and evaluation of selected agricultural projects, whether they are selected for particular issues or for long term comprehension of energy factors.

The basic format is presented as a series of steps. Before they can be utilized, however, the type of project and its objectives must be understood. Does the project stress increasing productivity? Is sustained yield agriculture its goal? Is irrigation included or is it a low input system? These questions and others, as appropriate, should be answered before the energy evaluation is started in order to understand the purpose(s) for using energy in the project.

Each agricultural situation is unique with its own specific set of climatic and soil conditions and its own set of institutional policies and constraints. These factors are usually known and understood by agricultural experts. The energy evaluation format only identifies energy by forms and sources that are utilized in a project. The format serves only to identify uses of energy and show potential alternatives among sources and forms for the needs of energy experts. By recognizing the sources and types of energy which are included in the project over its lifetime, it is possible to draw conclusions about quantities of fuel, manpower estimates, quantities of residues, timing of requirements, etc. that will assist in either designing a better project or in redesigning an ineffective project.

Once the agricultural project is well-defined and the purpose or purposes for the energy evaluation stated, the process of accounting can be initiated. The following six steps make up the basic evaluation format.

Step 1

ESTABLISH PROJECT BOUNDARIES

This basic format is designed as an approach to energy evaluation of many types of agricultural projects. It is assumed that projects containing energy use will include examples from the following areas: Agricultural Economics and Sector Planning, Crop Production and Protection, Soil and Water Management, Agribusiness, and Appropriate Technology Evaluations. Most project assessments will involve all of the steps, and depending upon content, may be iterative. Other, less complex, projects may be evaluated with only a few steps.

The energy using agricultural aspects of the overall project must be defined first. Then their boundaries can be established. The location should be set and soil and climatic conditions identified. Items such as the following should be included: type and texture of soil, yearly rainfall pattern, frost-free periods, temperature, altitude, etc.

Next, the agricultural situation should be described. This includes the crops and size and type of farm as described in Figure 2, and the types of inputs and operations used as identified in Figure 1. Specific data on quantities per hectare for inputs and either man-hours or animal-hours for operations will be required. All tools, implements, and machines must be identified. All fuel and electricity use should be identified and associated with the particular operation and quantified by number of hectares. It is useful to prepare tables for data collection, following the use of inputs and operations. This first step should establish an outline of the project.

Step 2

DEFINE ENERGY USING INPUTS AND OPERATIONS

This second step should produce a table or set of tables describing the energy-consuming inputs, operations, and outputs. Following the flow diagram of Figure 1, "The Energy/Agriculture Interface", all inputs, operations, and outputs should be listed. A project specific flow diagram will assist in identifying all relevant energy-consuming elements such as the following:

Farm Inputs: Seeds, Fertilizers, Pesticides and Herbicides, Tools/Implements/Machinery, and Water

Each input: Direct energy for transport.

Seeds: Indirect energy associated with production, processing, and distribution.

Fertilizers: Indirect energy associated with raw material and manufacture.

Pesticides and Herbicides: Indirect energy associated with raw material and manufacture.

Tools/Implements/Machinery: Indirect energy associated with raw material and manufacture.

Water: After developing requirements for crop type and location; includes indirect energy associated with components related to water supply/development, water motive power, distribution system; and direct energy associated with above activities.

Farm Operations: Clearing, Land Preparation, Plowing, Planting, Cultivation and Fertilization, Harvesting.

Each operation: Direct energy associated with human labor, draft animals, and machine labor.

Farm Outputs: Products and Residues.

Each output: Indirect energy associated with products and residues and direct energy needed for transport, storage, and processing prior to consumption.

Once identified, tables should be prepared listing inputs and outputs by kg/hectare. These can be converted to kcal/hectare by the use of conversions such as in Table 1, "Energy Values for Agricultural Inputs". Where data known to be relevant are unavailable, refer to similar use of inputs and operations in other projects. Always give preference to developing country data when possible. Refer to the data presentation in Zimbabwe Case Study as an example of the process.

Next, list all operations and identify the hours of human labor, animal power, and machine power associated with their use and then convert to kcal/hectare. A discussion of human labor appears in Exhibit C, "Human Energy Used in Agriculture", and relevant conversion values are presented there. A typical value is 515 kcal/hour or 4120 kcal/day.* Animal power,** similarly, is first measured in hours and then converted to kcal/hectare. Conversion units vary depending upon type of animal, weight, nature of operation, etc. A typical value for oxen is 2500 kcal/hour.* Standard values for the energy content of common machine fuels are readily available; 10,109 kcal/liter of gasoline is a typical value.* Fuels prepared from biomass must be evaluated specifically in order to determine their heat content for use in this type of assessment.

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* Pimentel, D. and M., Food, Energy, and Society, p. 63.

** For additional information on animal power conversions, see GOE, M.R., "Current Status of Research on Animal Traction" in World Animal Review.

Table 1

ENERGY VALUES FOR AGRICULTURAL INPUTS

Farm Machinery

Tires: 20,500 kcal/kg
Steel: 15,000 kcal/kg
Tractor: 11,814 kcal/kg (Embodied energy)
Combine: 12,013 kcal/kg (Embodied energy)

Nitrogen Fertilizers

Anhydrous Ammonia: 11,700 kcal/kg N
Urea: 13,500 kcal/kg N
Ammonium Nitrate: 13,900 kcal/kg N

Phosphate and Potash Fertilizers

Phosphate Rock: 400 kcal/kg of P205
Normal Super P (0-20-0): 600 kcal/kg of P205
Triple Super P (0-46-0): 2,200 kcal/kg of P205
Muriate of Potash (0-0-60): 1,100 kcal/kg of K20

Liming Materials

Mining crushed and broken limestone: 15.45 kcal/kg
Manufacturing lime products: 1893 kcal/kg

Seed Production, Processing and Distribution

Seed corn, hybrid: 3,480 kcal/kg (Mexican value)
24,306 kcal/kg (U.S. value)

Production, etc. for Pesticides

Average Herbicide (powder): 62,770 kcal/kg
Average Insecticide (powder): 74,300 kcal/kg

Source: Handbook of Energy Utilization in Agriculture, D. Pimentel, 1980

Step 3

RESET BOUNDARIES, IF NECESSARY, BY ADDING TRANSPORT AND PROCESSING OPTIONS

Develop flow diagram following Figure 1, "The Energy/Agriculture Interface" or use previously developed flow diagram to identify all inputs. Then establish transport requirements for all inputs. Identify a transport network based on a central city for distribution. Calculate the energy use associated with the weight, distance, and mode of transport for each input. A rough estimate of transport energy based upon a mix of rail and truck in the U.S. is 0.4 kcal/kg per km.*

Establish a market site with processing and/or storage requirements, if relevant, for each product. Estimate the processing energy based upon the weight of product and energy required for specific operations including those associated with storage. An example of a processing energy for grain drying can be based upon maize. Depending upon the moisture content at harvesting and the quantity of water removed, an estimate for the energy needed can be made. A rough value of 198 kcal/kg of maize can be used.* Estimate energy use for transport of product(s) based upon weight, distance, and mode of transport.

Establish the fate of all residues. Similarly, calculate transport and processing energy use associated with each, based upon weight, distance, mode of transport and type of processing activity.

Estimate total transport and processing energy use required for inputs and outputs.

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* Pimentel, D. and M., Food, Energy and Society, p. 69.

Step 4

SELECT MAJOR ENERGY USING INPUTS AND OPERATIONS

By defining major energy using inputs and operations for a specific project, it is possible to estimate significant effects over a long term basis. Such an opportunity would be particularly relevant for a project calling for irrigation with diesel fuel when in the long term the country was planning an alternative energy policy. A policy, for example, of rural electrification or renewable energy use, could prove competitive. Similarly, a long-term dependency on imported diesel fuel for irrigation could prove incompatible with the developing country's import balance.

Set up tables showing comparison of indirect energy associated with inputs. Review major inputs and evaluate alternatives, if practical. For example, there is a high energy requirement for nitrogen fertilizers. Alternatives to be evaluated include use of manure and/or specific agricultural practices.

Evaluate manpower, animal power, and machine power to total each by either kcal per hectare or fuel/electricity units per hectare. Select major energy using categories for further evaluation. Determine opportunities for substitution by energy source or form.

Step 5

DEVELOP MEASURES OF COMPARISON

Depending upon the nature of the project, developing a procedure for comparison with other similar agricultural projects may be useful. The easiest comparison is usually on a yield basis after soil and climatic conditions have been established. Such comparisons must be carefully evaluated, for soil fertility always varies and greatly affects productivity. As a start, use estimates from Figure 3, "Farm Categories," as examples of relevant data. If a yield comparison is desired, either of the following: kcal out/kcal in, or kcal out per hour of human labor, or simply kg per hectare/year will suffice. This step also offers the opportunity of comparing energy use for a specific operation with similar operations at other sites to determine if energy consumption is reasonable, or if alternatives should be sought. This step offers the opportunity of comparing either the yield or a specific energy consuming operation with others. Due to the large number of causal factors, these comparisons will provide empirical data that are ultimately important to establishing correlations among inputs and outputs.

Step 6

PREPARE PROJECT CONCLUSIONS TO SHOW IMPACTS AND ALTERNATIVES

Develop tabulations of energy use to show totals, especially of manpower, animal power, and machine power. Evaluate use of imported fuels, if a national priority.

Expand assessment of project/program to a period of one year in order to understand additional requirements for manpower, animal power, and machine power over more than growing period. Determine additional requirements necessary to ensure availability of manpower, animal power, and machine power over growing period. Examine institutional constraints to availability. Determine opportunities for additional uses of required manpower, animal power, and machine power during off season.

Expand assessment of project/program to estimated life time in order to show long term effects of inputs and operations. Include totals by input as well as by manpower, animal power, and machine power. Show totals for all imported fuels and major electrical needs.

On either a short-term or long-term basis, as appropriate, evaluate alternatives such as raw material change, farming method change, fuel substitutions, etc.

Develop set of conclusions and recommendations based upon totals for energy use, anticipated or existing productivity, and available alternatives.

* * * * *

The project conclusions will vary depending both upon the nature of the project and the objectives which dictated the completion of the energy assessment with the format. There will be opportunities to compare alternatives within a project for manpower/animal/mechanical power and for fuel type. As the data base grows, there will be increasing opportunity to compare this project with another from a similar location to examine alternative energy uses and corresponding crop yields.

By extending the assessment timing to a reasonable project life, there will be added potential of estimating energy use by source and type over a longer period of time. This will permit an understanding of the project's long term energy supply requirements which will be of interest to a national agricultural or energy planner.

In addition, there is the opportunity of expanding the format to include a seventh step which multiplies the energy requirements by type and source for this specific project, by the number of hectares estimated to contain similar agricultural sites to produce a national estimate of energy use for this specific example. In this way, energy use for typical agricultural situations can be upgraded to the national level over time and, thus, verify agricultural sector energy analyses.

The use of the format at the national level opens wider opportunities for both planning and program activities. Increased development of the format will provide a method for estimating agricultural sector energy use given certain energy policies. Alternative pricing policies will then relate given energy use practices with specific results in terms of productivity and associated agricultural input requirements. A directed effort towards increasing the data base in the format will permit, first, more understanding of the use of energy in agriculture; and, second, more opportunities for increasing energy use with a corresponding increase in productivity.

Chapter Four

REVIEW OF ENERGY USE FOR AGRICULTURE IN ZIMBABWE

As part of the development of the analytical procedures, a field visit to Zimbabwe was made and the results described. While the results are only tentative, they are intended to be illustrative of the findings that could be developed should a full effort be made.

The agricultural sector in Zimbabwe includes both communal areas (16,840,000 ha; Categories 1-5 from Figure 3) which account for 43 percent of the total land area of the country, and the commercial or modern area (16,355,000 ha; Categories 6-10 from Figure 3) occupying 42 percent of the total land area. The remainder consists of the parks and wildlife lands (4,370,000 ha) at 12 percent and forest lands (907,000 ha) at 3 percent.

The communal areas provide a subsistence living for 80 percent of the total country's population; contributing, however, only 20 percent of the total agricultural market production. The remaining 80 percent is produced by the commercial sector. Data concerning the level of energy input and the range of agricultural yields of communal areas were obtained from information provided by the Research Centre of the Zimbabwe Ministry of Agriculture. They conducted a diagnostic survey (1981/82) of the South of Chibi District which analyzed the differences that exist between farms with draft animals and farms relying only on human labor.

One-fourth of the communal areas relies only on human labor and three-fourths relies on the combination of labor and draft animals. These percentages were obtained during the brief trip and should be considered as estimates at this time. Also, the farms classified as having draft animals represent a smaller percentage of the actual number of farms where draft animals are used, because there is a considerable exchange of animals for traction between cattle owners and non-cattle owners. Energy inputs for the communal areas' agriculture range from hand tools, such as hoes and spades, to certain amounts of chemical fertilizers, hybrid seeds of maize, pesticides, herbicides, draft animal implements, and occasional mechanical power provided in particular locations by state farms.

A general lower level of energy inputs exists in those areas which rely only on human labor with a resulting decrease of crop productivity. The farms with draft animals have better crop yields because of deeper, more uniform plowing and a supply of fertilizer through manure. The communal areas without mechanization are characterized by extremely low productivity, estimated to average 670 kg/ha for maize.

Farms in Zimbabwe fall into three groups following Figure 3, "African Farms".

Farms with Human Labor (Categories 1 - 3)

In Zimbabwe, as elsewhere in Africa, population pressure has contributed to stabilizing agriculture into continuous farming systems. Typical "shifting cultivation" is practically non-existent and "short fallow" is only sporadically practiced close to the Zambian border where population density is lower. In all other cases, cultivation is done repetitively on the same plots of land. Therefore, the depletion of soil nutrients due to the crop cultivation must be restored with fertilization in order to guarantee satisfactory yields. At this stage of agriculture, maize intercropping can be practiced with pumpkins and/or beans.

Fertilization is provided by manure supplied by cattle owners or ashes of burned firewood, food wastes, manure or crop residues. Manufactured fertilizer, which can be purchased through a particular credit facility available in restricted areas of Zimbabwe or with part of the salaries earned by working occasionally in the commercial sector, is also used. Where fertilization is not used, crop yields are sometimes so low that they do not meet subsistence levels. From direct field observation in Zimbabwe it was estimated that maize crop yields are extremely variable, reaching maximum levels not higher than 900 kg/ha/year. The range for those farms with only human labor is from 450 to 600 kg/ha/year.

The energy balance at this particular level of production seems to be relatively simple since the percentage of indirect energy used in the production process is only that which is required for the manufacture of tools and fertilizers, if used, and the propagation of seeds. Direct human energy, however, involved in crop production (seeding, hoeing, weeding) and processing (harvesting, transporting, shelling, grounding) or in collateral crop production activities building (fences, huts and grain storage sheds, making tools and supplies) is relatively difficult to evaluate. It depends upon variables such as age, sex, physical constitution of the operators, efficiency of the work performed, quantity of energy ingested in terms of food, and quantity of energy utilized during work activities.

It is difficult to increase productivity at this level with chemical fertilizers since African subsistence farmers do not have available cash to purchase farm inputs. Since human work capacities cannot be considerably increased, better crop yields are obtainable only through a more rational use of human energy and the improving of traditional ways of farming. Therefore, at this stage, an improvement of husbandry practices requiring no particular increase in commercial energy consumption represents a feasible approach to increasing crop production. Growing crop varieties suited to the climate, preparing land in time, planting at correct times with correct spacing and early thinning, and harvesting at correct times are all non-cash-related operations which can increase crop yields. Improved scheduling may be more effective at this level of farming than adding energy. Training is required to give the farmers the skills to implement such operations.

Farms with Draft Animals and Human Labor (Categories 4 - 5)

At this stage, agricultural yields are higher than in farming systems relying only on human labor. The yield of maize can reach, in extraordinary cases, levels of 2000 - 2500 kg/ha without use of mechanical equipment.

Better performance due to tractive animal power is primarily the result of deeper and generally more thorough land preparation and on the availability of manure for maintaining soil fertility. Commercialization of part of the product can also allow the farmer to purchase chemical fertilizers, pesticides and herbicides.

Table 2, "Maize Production With Labor and Ox Power,"* shows the hours spent by human labor and oxen to cultivate maize from hybrid seeds in an agricultural region characterized by 450-800 mm of rain per year. In addition, data from this table are utilized in a case example of the format in Chapter 5, "Energy Alternatives for Agriculture in Zimbabwe".

A factor which places severe limitations on the development of draft animal use in agriculture is the increasing population pressure on the environment with a consequently higher number of animals required to till the land. In addition, the 1981/82 drought which affected the agricultural sector of

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* SOURCE: Data taken in part from G.D. Mudimu (Farm Management Specialist, Agricultural, Technical and Extension Service) in Communal Areas Production Crop Budgets, 1983-84, Zimbabwe, 1983.

Personal comment of Mr. J.F. Douse (Grain Specialist, Department of Research and Specialistic Services, Ministry of Agriculture of Zimbabwe) December, 1983, Harare, Zimbabwe.

Table 2

MAIZE PRODUCTION WITH LABOR[1] AND OX POWER[2]

OPERATION	ENERGY SOURCE	hr/ha	MACHINERY, TOOLS IMPLEMENTS	PHYSICAL INPUTS FOR 1500 Kg/ha OF CROP YIELD[3]
(1) MANURING	1 - M	3.35	Two-wheeled cart	500 kg. manure
by hand using ox cart	1 - O	3.00		
(2) LIMING by hand	1 - M	28.00		150 kg. Dolomitic Lime
(3) PLOWING	1 - M	8.70	Reversible Plow	
by 4-ox team	4 - O	8.70		
(4) PLANTING	1 - M	2.48	Single furrow moldboard plow	
a - row marking	2 - O	2.48		
b - fertilizing by hand	1 - M	9.50		
c - planting by hand	1 - M	34.80		25 kg triple hybrid seed
(5) CULTIVATING	1 - M	9.85	One cultivator	
a - by ox	2 - O	9.85		
b - by badza	1 - M	70.00	One hoe	
(6) TOP-DRESSING by hand	1 - M	3.75		100 kg[4] ammonium nitrate
(7) HARVESTING	1 - M	27.75		
a - Reaping off the plant				
b - Transport to homestead	1 - M	15.00		
c - Prepare shelling floor	1 - M	2.00		
d - Shelling/Threshing	1 - M	41.60		
e - Winnowing and grading	1 - M	5.90		
f - Bagging/weighing/storage	1 - M	12.70	1 scale and 16 bags	
(8) OTHER	1 - M	5.50		
	1 - O	5.50		

TOTAL: Human Labor hr/ha - 280.88
Oxen hr/ha - 67.95

ABBREVIATIONS USED: M = Man O = Ox

1/ = Labor is provided by the rural family

2/ = Draft power is assumed to be a family-owned resource

3/ = Yield expected in agroecological regions with rainfall from 450 to 800mm/year

4/ = 34.5 percent nitrogen content

Zimbabwe, particularly in the southwestern regions, was responsible for a decrease in herd size. This resulted from lack of feed and caused a reduction of draft power in agriculture. This was then compounded by the worsening climatic condition in 1982/83, leading to a decline in crop yields of disastrous proportions.

The tractive power of draft animals is, among other factors, dependent on the availability of fodder. The development of forage, which comes from pasture lands, crop residues, and cultivations grown especially to produce animal feed can be improved in order to obtain better animal performances and a decrease in competition with natural vegetation. Technical improvement of draft animal implements is also an important element in rationalizing the energy used in field work operations.

Commercial Sector (Categories 6 - 10)

Farms with both human labor and draft animals represent a stage of transitional agriculture. When draft animal performances are improved and the need to obtain higher productivity exists, a shift must be made from transitional to modern techniques of farming. When this kind of alternative arises, the size, type, and power of the tractor are important choices in determining the success of the mechanization process in a rural society which has no prior experience with modern technology.

Agriculture of the commercial sector in Zimbabwe is characterized by the use of mechanical power which relies, however, on tractors with an average age of 10 years. New tractors, and spare parts for the old ones, are now needed to improve mechanical performances.

The rate of crop yield depends, in part, on the quantity of direct and indirect energy used for crop production and also on elements such as natural fertility of the soil, rainfall and temperature. Frost-free areas are suitable for cultivation all year round. The mean maize production of this sector varies from 4000 to 6000 kg/ha for rainfed cultivation, to 6000 to 8000 kg/ha with irrigation.

The energy concerns of commercial farms are mainly related to obtaining the best results with minimum expenditure of renewable and non-renewable sources of energy. Crop production, storage, processing and transportation are areas in which energy could be saved or used more rationally. Because the use of tractors permits soil preparation in very short periods of time, certain varieties of maize can be produced on a double cropping basis in these locations.

New types of tractors, pumps for water lifting, and also new techniques of cultivation are required to obtain a more efficient energy use and possibly lower the dependence on imported oil-derived fuels. The introduction of new machinery and new technology to optimize the energy efficiency seems particularly dependent on the availability of an infrastructure able to support these innovations in the future. This includes mechanics, welders, skilled machinery operators, and necessary spare parts.

General Observations

From the results of the direct field observation in Zimbabwe, crop productivity in communal areas was found to depend, among other factors, on the use of tractive power by draft animals. The technical skills of the farmers and climatic, edaphic, and ecological conditions are all involved with crop productivity in determining the quantity of crop output.

A survey conducted by the Department of Research and Specialistic Service and the Department of Land Management, University of Zimbabwe (1982) on 96 farms, 46 with draft animals and 50 without, found that maize productivity was, in this particular case, almost two times higher in the first group than in the second one. The following data show the results of the survey:

Table 3

MAIZE PRODUCTION ON SOME ZIMBABWE FARMS WITH AND WITHOUT DRAFT ANIMALS

	Farms With Draft Animals	Farms Without Draft Animals
Average area cultivated (ha)	3.23	2.40
Average maize production (kg/yr)	2313	846
Average cash income (Z$)	240	105

Taking into account the limits of inference from the correlation of aggregated variables, the improvement of draft animals' performances could represent a means of increasing the total power input in agriculture, which could ultimately result in better crop productivity.

Improvements can be achieved by providing livestock with adequate food. Also, a better management of crop residues which can be used as a fodder, and a more rational utilization of the grazing lands represent short term solutions to the need of communal areas for additional tractive power. Draft animals' performances can then be improved by developing better animal-drawn equipment such as implements, harnesses, and carts.

However, even though increased use of animal power generally provides good results, farmers must still dedicate land to providing fodder for their feeding. When a certain rural area is overpopulated, and the availability of land represents a limiting factor, a different source of draft power should be considered. Mechanization is an alternative capable of lowering the pressure on the environment and giving the farmers more tractive power than that of draft animals.

The lack of cash from surpluses or from off-season work characterizing farms with [illegible] human labor, suggests that an increased crop productivity could be obtained through the practice of a better husbandry or utilizing, where it is possible, draft animals and manure of cattle owners.

For the commercial sector, the relationship that exists between agricultural productivity and energy use depends mostly on the consumption of oil derived fuels. Available data also show that the ratio of energy output to input for maize production in Zimbabwe is almost comparable to the American and European farming system. There is no doubt that the use of more energy efficient tractors, and the development of new plowing practices, such as reduced or no tillage, could have positive effects on energy consumption while still maintaining high crop yields.

However, no single solution seems applicable for the commercial sector as a whole. Different strategies must be evaluated for different agricultural circumstances.

At this stage, it should be emphasized that even though the commercial sector is capable of improving crop yield through optimizing the use of energy, the picture which emerges from the agricultural context of Zimbabwe is that low productivity and low energy inputs are both common characteristics applicable primarily to the communal areas. Communal farmers do not or cannot obtain sufficient energy related inputs of pesticides, fertilizers, and improved plowing systems, to produce yields adequate to satisfy their own food requirements. Furthermore, very little is done to maintain soil fertility. Thus, the degradation of the land threatens crop yields of future years.

Chapter Five

ENERGY ALTERNATIVES FOR AGRICULTURE IN ZIMBABWE

To further illustrate the approach, the issue of draft animals and tractor power is examined quantitatively. The Chapter provides a preview of how an analyst would approach a typical problem for quantification. Clearly, as in an energy audit in industry, more factors than the quantification herein would have to be taken into account before a final recommendation. The two week field visit did not permit sufficient time to reliably second-guess the local experts or to deal with the complexities of animal traction in Africa. It did permit an illustration of what information the previous format will provide.

As described in the previous chapter, Zimbabwe proved to be an excellent case study illustrating farm types in all categories from one to ten. In addition, the availability of agricultural data showing energy use in Zimbabwe has permitted a preliminary evaluation of alternative approaches for supplying energy. Two approaches are discussed in this section; one based upon the development of draft animal power and the second based upon the introduction of mechanical tractive power. In addition, data from the transitional level of agriculture (Categories 4-5) were utilized to illustrate the evaluative format presented earlier.

This chapter thus begins with a description of the use of animal power as an approach to adding energy, continues with a description of the use of tractors as an alternative to draft animals, and ends with a case example of the format. The case example is based upon data collected on the field trip and, thus, typifies the common agricultural practices of Zimbabwe. By selecting a communal area with limited animal use, however, it is a good example for much of Africa.

Development of Draft Animal Power

The problem of providing agriculture with additional energy in order to obtain better crop yields has usually been examined on the basis of two general approaches. The first is oriented towards the improvement of traditional methods of farming, increasing the performances of human labor and draft animals. Very often this approach has been considered as an intermediate stage of rural development leading to a gradual introduction of modern or more mechanized techniques of farming. The second is based instead on the introduction of modern agricultural technologies, mainly through the promotion of mechanical tractive power. The existence of certain infrastructures in developing countries permits such innovation.

The level of poverty associated with subsistence agriculture in developing countries suggests, however, that the dualism created by these alternatives is resolved more appropriately in favor of upgrading the traditional techniques of farming. An example of this is the case found in Zimbabwe where the Ministry of Agriculture attributed a higher level of crop productivity to a better management of draft animals. The small size of the farms, the lack of cash, and the absence of the skills necessary to operate and maintain a tractor are among the major reasons why traditional sources of energy are more likely to be suited to subsistence levels of agriculture than mechanized power.

According to FAO (1983), although the use of tractors in the world has increased since 1969, draft animal energy inputs in agriculture in 1980 were nine times higher than the energy provided by tractors. An increase in tractive animal power for cultivation can effectively enhance agricultural productivity if its promotion is thoroughly introduced into the rural context in which it will operate. The availability of land, the absence of diseases, and the existence of an infrastructure--nutritionists, veterinarians, a laboratory for analysis, and veterinary pharmaceuticals to support development--are important elements in determining the success of their use.

In any case, the use of draft animals does not correspond to any specific formula which can be "a priori" suitable for a developing country. High population pressure, presence of diseases, and general low availability of land are the constraints to animal draft development. When these factors occur, alternative sources of energy must be found.

Consideration of Animal Traction for African Agriculture

Animal traction, either as a new energy source or as an improved energy source, represents an important element in increasing crop yields for several reasons. First, farmers have an immediate availability of energy both in the form of animal tractive power and also from the source of organic fertilizer provided by manure. Second, immediate availability means also that agricultural operations such as manure distribution, plowing and harrowing can be performed whenever it is convenient for crop cultivation with no dependence on fuels, lubricants, or spare parts which would be necessary when using a tractor. Third, since a constraint for increased agricultural productivity on small farms in Africa results from lack of available labor during planting and harvesting, animal power can assist in accomplishing these tasks. Fourth, theoretically, there is no need for cash to purchase draft animals because they can be bred within a rural community and also they can be fed with crop residues or the natural vegetation of the area.

The support of draft animals will, however, raise the problem of determining the quantity of fodder necessary for feeding. If one considers that an ox requires in one year 11 times its weight of fodder (15-18 percent moisture content), then 4,950 kg/year of fodder will be necessary for an animal weighing 450 kg. This suggests that a corn yield of 2000 kg/ha/year with a correspondent production of stems and leaves of approximately 2700 kg/ha/year cannot provide enough residue to feed an ox of medium weight. In reality, the optimal situation in which all crop residues are entirely utilized for animal feeding is practically non-existent; therefore, additional pastureland will be necessary to support a single draft animal.

In Zimbabwe, it was estimated that at the end of the dry season, 6-7 ha of grazing land were required to provide maintenance levels of feeding, when maize residues were often used either as a substitute for firewood, as material for construction, or even left unutilized in the field. Another important element characterizing draft animals is that feeding must also be provided when the animal does not perform any particular working activity. There is, therefore, a consumption of energy associated with feeding even during idle periods.

For this reason, a draft animal should be carefully managed in the sense of programming its work performance with a rational continuous schedule of agricultural operations during the entire year. In addition to typical crop production operations such as plowing and harrowing for which draft animals are generally used, other energy consuming activities can be adapted to be performed by animals. Water pumping, intra- and inter-farm transportation, and grain grinding are all activities which draft animals can accomplish when strictly related field operations are not required.

Often, however, the animals are undernourished at the beginning of the cropping season due to lack of pastureland fodder. Under these conditions, the utilization of the animals for heavy tractive work is particularly inefficient because of their reduced strength and poor physical condition, and physical injuries can occur. If it were possible to sustain maintenance and work levels of nourishment during the dry season, the animals could perform much more effectively. A careful evaluation of feed resources and animal needs in comparison with the work to be performed should be made before prescribing a schedule of energy requiring activities for the animals.

Draft Animal Feeding

The quality and quantity of nutrients required by a draft animal are determined by breed, sex, age and tractive working activities. Rational animal management must also take into account the suitability of a certain environment to produce sufficient supplies of fodder in relation to the amount of land available. This evaluation will not only be related to nutritional needs, but also to other criteria which determine the limit that the use of draft animals can reach in a certain rural environment.

The complexity of this particular interaction between animals and environment emerged frequently during the trip to Zimbabwe, suggesting that the pivotal factors in determining the land necessary to feed an animal included traditional, cultural, and sociological elements. Animals to be used for traction must have feed rations which provide energy for maintenance, growth, and the work to be performed.

Factors correlated with energy needs for work will depend upon the work frequency, power produced during working activities, physical condition of animals, ambient temperature and air humidity. Table 4, "Estimated Total Digestible Nutrient Needs For Oxen of Various Sizes," gives values of estimated energy requirements for oxen of different weights working different periods of time. An observation which has emerged from studying oxen energy requirements is that even though oxen work in this case for up to eight hours,

Table 4

ESTIMATED TOTAL DIGESTIBLE NUTRIENT (TDN) NEEDS FOR OXEN OF VARIOUS SIZES WORKING AT DIFFERENT RATES FOR 4-, 6- and 8-h PERIODS

Weight (kg)	Tractive Effort (kgf)[1]	Tractive Effort (% Body Weight)	Speed (km/h)	Power[2] kcal/hr	TDN needs (kg/hr)[3]		
					4h	6h	8h
250	25	10	4.0	241	3.3	3.8	4.3
250	30	12	3.5	249	3.5	4.0	4.6
250	35	14	3.2	267	3.6	4.3	4.9
300	30	10	4.0	284	3.7	4.3	4.9
300	36	12	3.5	301	3.9	4.6	5.2
300	42	14	3.2	318	4.1	4.8	5.5
350	35	10	4.0	335	4.2	4.8	5.4
350	42	12	3.5	344	4.4	5.1	5.8
350	49	14	3.2	370	4.5	5.4	6.2
400	40	10	4.0	378	4.7	5.4	6.2
400	48	12	3.5	396	4.9	5.8	6.6
400	56	14	3.2	421	5.2	6.1	7.0
450	45	10	4.0	430	5.2	5.9	6.7
450	54	12	3.5	447	5.4	6.3	7.2
450	63	14	3.2	482	5.6	6.7	7.7
500	50	10	4.0	473	5.4	6.3	7.1
500	60	12	3.5	499	5.7	6.7	7.6
500	70	14	3.2	533	5.9	7.0	8.1
550	55	10	4.0	516	5.7	6.6	7.5
550	66	12	3.5	550	6.0	7.0	8.0
550	77	14	3.2	584	6.3	7.4	8.5
600	60	10	4.0	568	6.1	7.0	7.9
600	72	12	3.5	593	6.4	7.5	8.5
600	84	14	3.2	636	6.7	7.9	9.1

1 - Kgf: Kilograms force (one kgf = 9.806 Newtons)

2 - These values represent the amount of effective work output per hour.

3 - These values include daily maintenance needs (one kg of TDN = 4409 kcal of digestible energy and 3615 kcal of metabolizable energy.

Source: Adapted from Goe, M.R., "Current Status of Research on Animal Traction," World Animal Review, No. 45, p. 12, September/December, 1983.

trials conducted in West Africa showed that heavy work cannot be performed for more than five hours for several days.* Also, to avoid health injuries, this limit of five hours can be overcome only if the animals are fed with an adequate diet of forage or concentrate to guarantee a daily recovery of body weight lost during hard work.

Nutritional requirements in Africa for an ox weighing 450 kg include 2.6-2.9 kg of total digestible nutrients (TDN). However, an important element to consider in determining the maintenance diet of draft animals fed on pastureland is their energy expenditure when forced to walk in search of water and grazing areas. This activity is particularly intensive during the dry season. M.R. Goe states that the energy expended for such exertion can reach as much as 170 percent of the requirements for stall-fed animals.**

The growth energy requirements are also particularly important for immature animals occasionally used for draft purposes. Only an adequate diet can provide a guarantee for their normal physical development.

Draft Animal Equipment

In order to optimize the tractive effort of draft animals, particular attention should also be paid to the improvement of the drawn equipment. During the last two years, the Institute of Agricultural Engineering of Harare, Zimbabwe has developed, for example, a series of studies addressing the most common shortcoming of traditional implements in order to make them

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* Matthews, M.D.P and Pullen, D.W.M., "Cultivation Trials with Ox-Drawn Equipment in the Gambia", 1973-75, The Agricultural Engineer, Vol. 32, No. 3, pp. 77-80, 1977.

** Goe, M.R., "Current Status of Research on Animal Traction", World Animal Review, No. 45, pp. 2-17, September/December 1983.

more efficient. Implements such as plows, harrows, and cultivators were tested and improved, correcting the following points:

- weight, usually making implements lighter in order to ease operation;
- angle of attachment to the animal(s) and angle of plowing;
- height of handles to facilitate human work; and
- depth of operation, making it adjustable by hand.

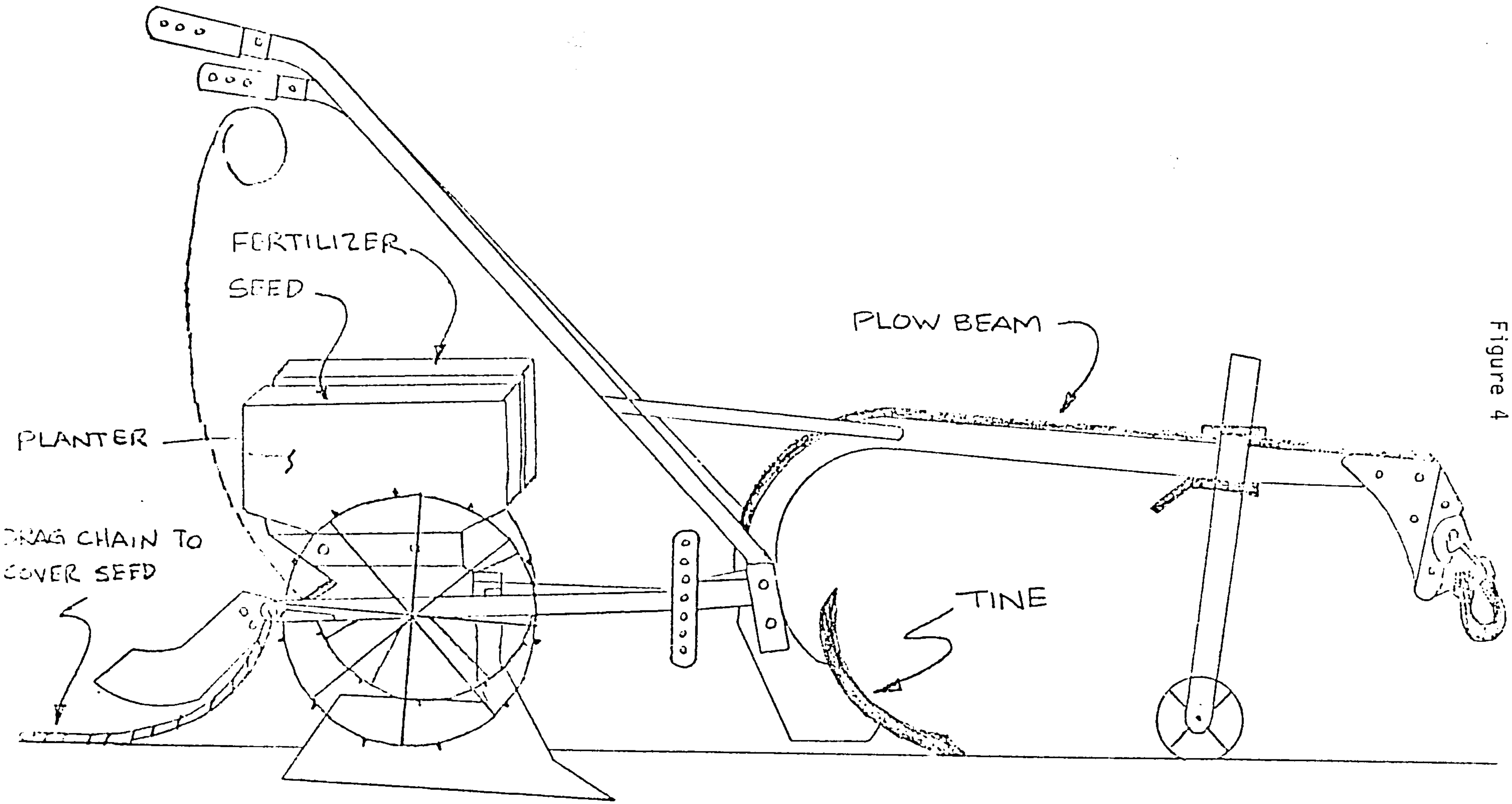
A modified implement, the "Haydock Planter and Fertilizer" used for minimum tillage, is shown in Figure 4. With the minimum tillage system, the land is plowed at 20-25 cm at least once every three years. When this implement is used, it allows the combination into one operation of the following four procedures:

1. Row marking with a tine;
2. Fertilizer application by hand;
3. Planting, either by hand or tool; and
4. Covering the seeds, in the case of hand planting, with spike tooth harrow.

Depending upon the draft power available (one or two oxen), the "Haydock Planter and Fertilizer" accomplishes this operation in only a slightly longer time period than that needed for one procedure. For maize 3 to 3.30 hr/ha were needed.

The Institute also developed several forms of improved neck yokes in order to utilize draft animal power more efficiently. For this purpose, farmers are provided with designs of yokes, a method of assembling, and lists of materials to use for the construction of these yokes directly on the farm.

In order to optimize the use of draft animals, it seems that particular attention should be paid to the following points:



HAYDOCK PLANTER/FERTILIZER MACHINE BEHIND TINE

Figure 4

- select the agricultural zone and rural population in which socially, culturally, ecologically and economically they can perform the best results;

- undertake a more accurate study to improve the quality of equipment to be draft by the animals in order to obtain an optimal relationship between energy input and work results;

- identify alternative work to be performed such as water lifting in which more efficient pumps designed especially for animals should be constructed;

- avoid unproductive periods of inactivity when fodder is available;

- improve animal feeding, considering the extra energy used for maintenance of animals on pasturelands and the energy required for work;

- genetically improve draft animals in order to emphasize certain characteristics such as muscle development, limiting of height, stamina for work, and adaptation to local climatic conditions; and

- organize a better management of pasturelands with rotation of the grazing areas.

Tractors as an Alternative to Draft Animals

The use of draft animals for agricultural development in Africa is, unfortunately, not always possible when population pressure on the environment is high. Even though animal tractive power can be improved based upon a better use of crop residues and grazing areas, open land must still be available to meet their feeding requirements.

In addition to this, it was found that in Zimbabwe, farms relying on draft animals were not able to surpass a production rate of 2500 kg of maize per hectare, while, where tractors were used, maize yields could range from 3000 to 8000 kg per hectare. Thus, the low yields produced with draft animals were not sufficient for the portion of agriculture directed toward commercial production. In other circumstances, draft animals could not be used because of the existence of disease (i.e., tsetse fly area close to Zambezi River).

In Zimbabwe, the use of tractors as an alternative to animal power seemed to depend on:

- The unavailability of land to provide adequate animal feeding;
- The need to obtain high crop yields; and
- The presence of diseases which constrained draft animal development.

The Tractor Choice

The use of the appropriate type of tractor emerges as an alternative to the human and animal energy supplied in traditional methods of farming or, as is now occuring in Zimbabwe, as a complementary source of energy to be put side-by-side with the traditional ones. At the level of a single farm, the first step in mechanization is the determination of the appropriate size of tractor to be used in relation to the quantity of work to be performed. Considering that a large tractor is more economically expedient on a larger number of hectares, it has often been assumed that small tractors would be more appropriate for small farms.

Following this logic, agricultural manufacturers during recent years have dedicated increasing resources to small tractors, generally less than 20-25 hp. The advantage of these mechanical units is related to their economical accessibility in terms of their lower cost to the individual user. The promotion of these small and low power tractors, therefore, will enhance mechanization in areas where tractors are not currently in wide use.

Also, from the point of view of energy consumption, small scale mechanization may encourage a savings on imported fuel such as gasoline, permitting the option to use renewable fuels such as vegetable oil, methyl alcohol and methane gas, whenever their prices are competitive with those of oil derived products. In terms of practical results, however, small tractors show some shortcomings, dependent first on the fact that they were used on single farms, and second on their reduced technical performances.

In the first instance, a trend to provide small farmers holdings with tractors lower than 20-25 hp has been developing to the extreme of recommending power tillers; questioning the suitability of small tractor policy as an effective means of rural development. African farms are very often small, fragmented, and subjected to old patterns of ownership. This restricts the opportunity for unification of the land into larger holdings. Thus, it appears that excessively small tractors can maintain a static position of rural land ownership patterns without encouraging any form of cooperation or association among smallholders.

From the technical point of view, the impact represented by small tractors in an agriculture which has had no previous experience with modern technology is almost comparable to the introduction of other mechanical power units no matter what their size and power may be. For example, tractors of 10 hp employed in the communal areas of Mzarabani in Zimbabwe were operated for only 2-3 years, after which they were left unused for lack of spare parts. Also, reduced tractive power showed a decreased flexibility in performing deep tillage, land reclaiming, fast field operations, and versatility in using drawn implements. It should be noted that the results obtained with small tractors in other parts of Zimbabwe and in other African countries vary widely.

It is not possible to generalize on their performances without knowing more specific horsepower ranges and characteristics of the agricultural context where they are supposed to operate. Differences exist in the quantity of work produced, weight of the units, fuel consumption, maneuverability and resistance to climatic conditions in different types of small tractors. It can be concluded, however, that small tractors often suffer from both the problem of poor maintenance habits and limited agricultural applicability.

Those who support the use of conventional, more powerful tractors, argue that inadequate power is generally assumed to be a primary constraint to agricultural production. If in a certain country, therefore, it is necessary to produce more food, and capital is available to devote to agricultural development, the use of higher powered tractors (more than 25 hp) can actually generate an increase of crop yield per unit of surface area. Furthermore, large tractors, intrinsically directed towards large hectarage farms, can enhance the organization of cooperatives among smallholders. The responsibility of maintaining tractor efficiency will then be shared among more farmers. Consequently, it can be seen that the issue of small tractor vs. large tractor is site specific, and cannot be solved without additional data on the location and agricultural requirements.

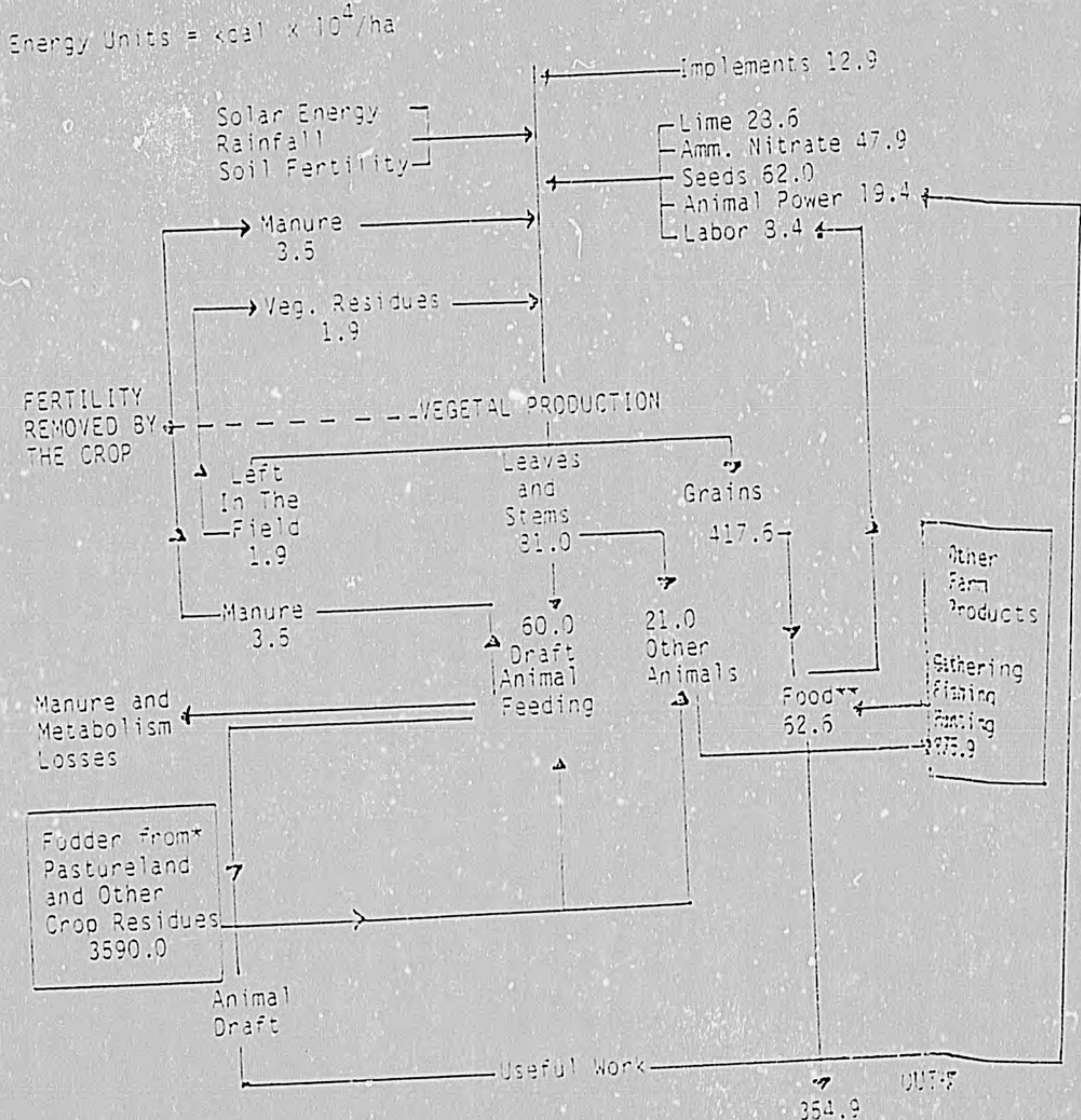
Case Example of Format: Energy Use in Maize Production (Category 4-5)

In order to demonstrate an application of the format, a hypothetical farm was established in a communal area of Zimbabwe. Based upon the data presented in Table 2, "Maize Production with Labor and Ox Power" of Chapter Four, "Review of Energy Use for Agriculture in Zimbabwe," and relevant assumptions as described, an overall energy balance was first developed.

In this energy balance shown in Figure 5, "Energy Flow for Cultivation of One Hectare of Maize," the most significant energy values associated with the agricultural process are represented. The energy inputs necessary to achieve crop production as well as the energy outputs obtained with the vegetal

Figure 5

ENERGY FLOW FOR CULTIVATION OF ONE HECTARE OF MAIZE



* Assuming that one ox requires an average of 25,000 kcal/day, [illegible]^6 kcal are required for four oxen in one year.

** 180 kg of grains are utilized for householders consumption. [illegible] food consumption for the eight members of the household [illegible] per person.

production have been computed with the intent to show how energy circulates in a traditional farming system. In this particular case, therefore, the energy balance can be considered as the analysis of the energy flow that occurs in maize production on a surface of one hectare in one year.

The energy associated with grains is primarily analyzed in terms of food value since most of the maize production in the communal areas is carried out for this purpose. Figure 5 also shows that the amount of fodder for the four oxen is partially provided by crop residues. An additional 3590 kcal$\times 10^4$ are provided by fodder from grazing areas.

To illustrate the allocation of the energy flow in more detailed terms, one can tabulate all major inputs and operations by weight and time and then convert them to kcal/ha. Similarly, all outputs were estimated and converted to kcal/ha in order to develop an output/input ratio as a measure of productivity. These values are shown in Table 5, "Energy Inputs and Outputs per Hectare Per Year for Maize Production with Labor and Ox Power".

Information on the site and the farm follows.

General Information

Data concerning the amount of time required for the cultivation of maize with labor and ox power in Table 1 were obtained in reference to an average communal land farm, without any specific reference to geographical location. To facilitate the computation of the values of kcal output and kcal input involved in the agricultural process, however, a hypothetical farm has been proposed for the Uzumba communal area 150 km Northeast of Harare. This farm was visited during the direct field observation in Zimbabwe.

In this particular area, maize is cultivated by 80-90 percent of the farmers, even though only 10-15 percent of them are able to obtain sufficient

Table 5

ENERGY INPUTS AND OUTPUTS PER HECTARE PER YEAR
FOR MAIZE PRODUCTION WITH LABOR AND OX POWER

Item	kcal	Quantity/ha	Total kcal/ha/yr
	INPUTS		
Labor	300/hr	280.88 hr	84,264
Oxen	2860/hr*	67.95 hr	194,337
Manure	70/kg	500.00 kg	35,000
Ammonium Nitrate	13,900/kg (for N content)	100.00 kg (34.5% N)	479,550
Dolomitic Lime	1,908/kg	150.00 kg	286,200
Triple Hybrid Seed	24,806/kg**	25.00 kg	620,150
Implements:			
Steel	15,000/kg	347.00 kg	115,667***
Tires	20,500/kg	10.00 kg	13,667****
	TOTAL		1,828,835
	OUTPUTS		
Grains	3,480/kg	1,200.00 kg	4,176,000
Leaves & Stems (as fodder)	500/kg	1,620.00 kg	810,000
Roots & Other Residues (as fertilizer)	50/kg	390.00 kg	19,500
	TOTAL		5,005,500

Output/Input Ratios:

a. With only grains as an output and not including manure energy....2.32

b. With only grains as an output and including all inputs...........2.28

c. Values of output and input as in this table......................2.73

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* The value: 2860 kcal represents the total animal energy requirement per hour for the working activity. Such a value was obtained assuming an effective work output of 430 kcal/hr at an efficiency level of 15%.

** Based upon procedures followed by Seed Coop Company of Zimbabwe.

*** Assume lifetime of 15 years and 3 hectares of cultivated land.

**** Assume lifetime of 5 years.

yields for commercial production. Maize in this farm is grown as a rainfed crop, and irrigation, if practiced, is done only for vegetables cultivated for home consumption, carrying the water in small containers from rivers or other sources of surface water.

Productivity in this farm, as in the majority of the farms of this communal area, fluctuates greatly according to the amount of annual rainfall.

Geo-Climatic Information

The farm is located in Natural Region III*, characterized by:

- total amount of rainfall ranging from 650-800 mm;
- average number of rainy pentads from 14-16;
- rainfall distribution concentrated between October and April;
- the region is affected by severe mid-season dry periods and, therefore, is considered marginal for the cultivation of maize, tobacco and cotton;
- temperatures are generally high, but the communal area of Uzumba is not a frost free area; therefore, maize could not be cultivated on double cropping basis;
- the elevation above sea level is 900 m.

The soil is mainly red clay loam of a heavy texture. It is characterized by a higher water holding capacity than the sandy soils typical of other areas in the same natural region. The pH is fairly low (4-4.5); therefore, liming is required to guarantee better crop yields.

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* The natural Regions of Zimbabwe were determined through an Agro-Ecological survey conducted in 1961 and recently updated by Agritex (Department of Agricultural, Technical and Extension Service). In this survey, Agritex established a very close relationship between crop productivity and amount of rainfall during the rainy season. Precipitation was measured as rainy pentads. (A pentad is a period of five days. A rainy pentad is defined as one of the three five day periods which together receive more than 10 mm of rainfall and two of which receive at least 8 mm of rainfall).

Farm Information

Other elements characterizing the farm are:

- Total farm size	ha 3.50
maize	ha 1.50
groundnuts	ha 1.00
vegetables grown for household consumption (cabbage, spinach, onions, tomatoes, etc.)	ha 0.50
homesite and unproductive	ha 0.50
- Estimated land available for grazing in communal area	ha 2.30
- Land for grazing further South, used during dry season	not defined

Livestock

- oxen	4
- poultry	12-15
- goats	3

Agricultural Implements

1	Two wheeled cart	kg 150
1	Reversible plow	kg 70
1	Single furrow mouldboard plow	kg 60
1	Cultivator	kg 65
1	Hoe	kg 2
1	Scale	kg 50

Number of Householders* — 8 persons

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* Due to the communal tenure, all the land generally belongs to the community. Therefore, we use the term householder to indicate the people usually resident in that area.

This example demonstrates the use of the format for a theoretical location based upon actual farming practices for maize in a region of Zimbabwe. At this time, the transport network has not been developed to allow calculation of the additional energy associated with the movement of inputs and outputs. Similarly, no processing requirements have been established to show the potential use of additional energy for those changes. The example [illegible] as an illustration of a typical set of agricultural practices which can be associated with Category 4-5 of transitional farming.

Summary

For this particular farming system, the major energy consuming inputs and operations have been identified; opportunities for alternative practices such as mechanization could be evaluated, if desired; the relationship between project energy use and productivity has been illustrated; and there could now be a transitional baseline case for further analysis.

This transitional case can form the basis of estimating energy use associated with this type of agriculture on a national level for sectoral planning purposes. It can also form the basis of estimating economic costs associated with alternative energy strategies on either a project specific or sectoral level to mesh with national policies on importation of fuels for agricultural use or the import balance. Consequently, the use of a format such as the one illustrated in this section can prove to be an important first step in understanding the use of energy in agriculture and its relationship with agricultural productivity.

Chapter Six

CONCLUSIONS

One of the objectives of this report was to identify the largest uses of energy in agriculture as a means of understanding the relationship between energy and agriculture. The result varies according to the classification of African farms outlined in the text.* For example, in traditional farming (Categories 1-3)*, human labor is the chief source of energy. Under those circumstances, energy management consists of introducing efficient tools or better scheduling of agricultural activities according to natural events, or, when possible, animal power. The animal provides a double benefit of traction and manure with significant results in increasing yield.

In the next class of farm, transitional (Categories 4-6), where human and animal power may both be in use, either seeds or fertilizer are the greatest energy inputs. If irrigation is practiced, that may dominate energy consumption. A highly technical and scientifically well-supported production and distribution system of hybrid seeds for maize, as an example, can require over 20,000 kcal/kg or more than 600,000 kcal for a hectare over a year. Fertilization with ammonium nitrate can include 14,000 kcal/kg or almost 500,000 kcal for a hectare. Adding irrigation to supply 500 mm of water from a shallow well powered with an animal will require 1.5×10^6 kcal/hectare and a deeper well based on a diesel-powered pump can range to 10×10^6 kcal/hectare.

Comparing these values with a combination of just human and animal labor gives an estimate of less than 800 hours per hectare for both, requiring less

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* See Figure 3, "African Farms", for details of classification system.

than 100,000 kcal. Thus, irrigation clearly dominates among energy uses as seen in the following table:

Table 6

TYPICAL ENERGY VALUES FOR A HECTARE OF MAIZE IN 10^6 KCAL

Human and Animal Labor	0.1
Hybrid Seeds for Maize	0.6
Fertilizer for Maize	0.5
Irrigation (500 mm of water)	1-10

In this case, energy management consists of achieving the most efficient relationship between input and output. It also calls for choosing the most favorable energy source from among the substitutable alternatives, given the national criteria for energy and agricultural policy.

The class of farming called modern (Categories 7-10) combines human, animal, and mechanical forms of energy with an enormous increase in productivity, as diesel or gasoline engines are employed. These engines are the largest users of energy on a modern farm, some of which may be associated with irrigation.

An understanding of the energy related inputs leads to program strategies which aim to supply the necessary energy for the devices found on this type of farm. As is indicated in the Zimbabwe example,* the changing of energy form can have dramatic results on agricultural yield. Making energy available from among the options with the least negative impact at the national level should be a matter of concern to the energy planner as well as to the agricultural project designer.

The addition of energy does not relate proportionally to productivity. Productivity increases only when energy is used appropriately and in the context of the agricultural system. It is possible to misuse energy. Thus,

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* See Chapters 4 and 5 for details of Zimbabwe case study.

while the relationship between energy and agriculture projects is generally one of creating programs which make more energy available to farmers, this has to be done selectively and with attention to the category of farm to be served. An energy program that is sensitive to the needs of agriculture should plan to provide the variety of energy forms, amounts, and sources that are dictated by the assimilative capacity and methods of farming associated with the targeted group.

The assessment format developed herein should assist in stimulating designers to consider the most appropriate forms of energy and energy systems. It should also make designers aware of the various alternatives and the information and data base building needed to make decisions at the point where agriculture and energy meet. The report and its methodology selected and adapted from the literature as well as a Zimbabwe case study identifies:

- the largest uses of energy in traditional, transitional, and modern African farms;
- the complex relationship between energy and agricultural productivity in these different farm categories; and
- the alternatives for substitution by energy form or source within the various types of African farms.

The type of information in this report can be of use to agricultural and energy program designers to evaluate proposed and existing projects. When a data base is built and manipulated to ease the work of evaluating alternatives agricultural/energy specialists will be able to accurately identify needs which should be given priority. Programmatically, this means that the energy information for different agricultural situations should be presented in a useful format and that the agricultural designer should call on his or her energy colleague to make provisions for energy in the form and location where it is needed. The job at hand is to increase energy availability for the agricultural sector, in the form and amounts needed. The work in this report begins to show how to identify the most significant targets for program design and, with collected experience, to identify the research needed to improve on existing knowledge.

The report only lays a foundation for accomplishing its ultimate objective of increasing the supply of energy for agricultural use. Breaking the barriers of the inherent limits of human or animal power or imported fuel mechanization will require building on this foundation. Since the range of solutions may involve better hand tools or major capital expenditures at the other extreme, any energy program to assist agricultural productivity will need a broad range of skills and support.

This means that there is an essential role for each of the levels of USAID responsibility. The central offices of S&T in Washington have both a technical and planning function. The technical function would include codifying existing knowledge about technologies applicable to agriculture. The range of considerations may be as broad as assembling knowledge about diesel pump sets and the substitutes for them as well as an evaluation and assessment of the replicability of genetic research on draft animals.

In the area of planning, the activities would include assembling information and supporting case studies to determine the methods for supplying energy in its appropriate forms and locations in the agricultural sector.

This primarily informational role would also extend to long-term research and demonstration, especially demonstration. While many technologies are regionally specific and not global, the central offices can identify the broadest range of opportunity and pass the evaluation of applicability on to the regional and mission levels.

In some way, the regional office functions are similar to the central office, only tailored to focus on those concerns and solutions of applicability in the region. Ideally, the region filters opportunities for relevance, but still has a broader set of alternatives available than would be found at the mission level.

The closer one gets to the mission level, the better the market for technology and services can be defined. Therefore, communications will be essentially circular with either the central offices informing the users of available solutions to problems identified by the missions and regions; or, as is often the case, both problem and solution are found in the field and the role of the central office is to recognize opportunities for replicability.

It is not the purpose of this study to design and assign functions for an energy and agricultural program. Only a foundation has to be laid that illustrates the complexity of the relationship between two USAID areas of activity. Scientific sophistication, along with experience in the craft, need to be combined in attacking the limits on agricultural productivity. A 'joint venture' between agricultural and energy professionals would be helpful to bring energy to the farm. Doing so taps knowledge and resources that are national and even global. The site-specific characteristics of the farm could benefit from the focussing of such resources on the typical circumstances of the African farmer. That is the essential meaning of the "global village."

Exhibit A

EVALUATING ENERGY USAGE FOR IRRIGATION IN AFRICA

This in-depth illustration of energy analysis for irrigation shows the development of a procedure for evaluating both indirect and direct energy usage. It includes detailed data on the major energy components of irrigation. Through the use of this procedure and the data presented, energy usage for different irrigation designs is determined. This exhibit summarizes the important aspects of energy analysis within a procedure that is useful for energy and agricultural project planning.

EVALUATING ENERGY USAGE FOR IRRIGATION IN AFRICA

Introduction

An evaluation of energy usage for irrigation must begin with a definition of irrigation in an African context.

Irrigation can be defined as the artificial control and delivery of water to a crop. By conventional understanding, this involves pumps, motors, and other irrigation hardware. In reality, irrigation practices can occur at many levels of farming.

A study of energy usage in irrigation throughout Africa must cover irrigation practices from the subsistence level all the way up through commercial level farming practices. At the subsistence level, irrigation practices consist mainly of water management or conservation techniques through mulching, green manuring (using the bound water in organic matter), and rainfall diversion to farmed croplands. The energy inputs are almost entirely human labor with draft animal energy input being possible where environmental conditions and land availability permit. On the other end of the scale are modern farming systems which may consist of a reservoir or groundwater pump, extensive piping, motors, sprinklers, and other energy intensive irrigation equipment. A comprehensive examination of energy usage in irrigation will permit comparisons to be made among human, animal and mechanized technologies when evaluating projects, programs, or long term planning effects.

Principle Stages of Energy Input

Energy for irrigation in Africa can be best understood through a three stage analysis of irrigation projects.

The first element is Water Resource Development. Energy is required to develop any water resource. The resource, especially in Africa, may be in the form of simple water conservation, large scale surface water development as in dams and reservoirs, or ground water development involving drilling and equipping wells.

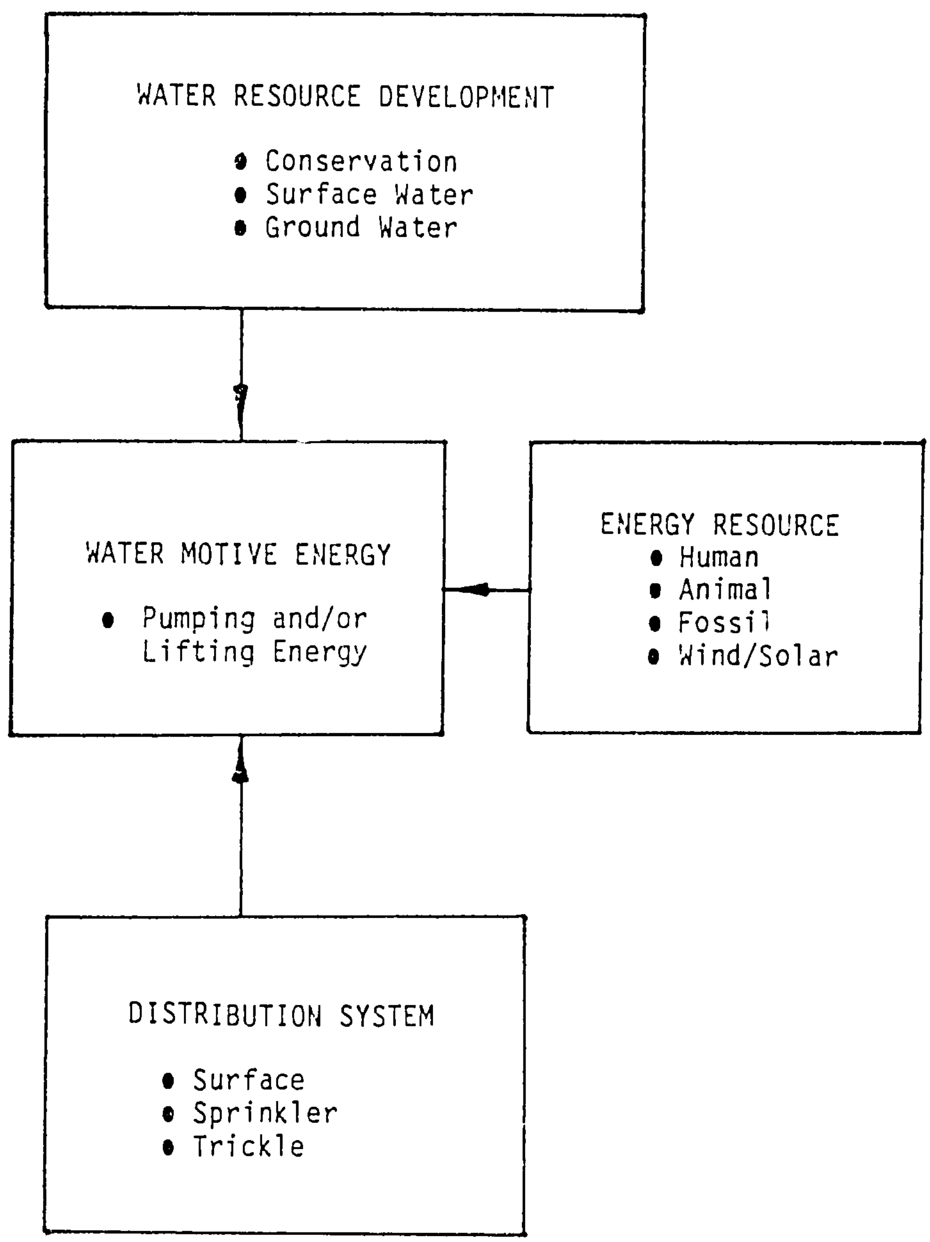
The second major element of analysis involves a determination of the energy required to move water from the source to the field. This is the energy for pumping and/or lifting water. The term used for this stage is Water Motive Energy. Within this stage one must consider both a pumping technology and the energy required by that technology to move the water. For example, the amount of diesel fuel and equivalent animal energy to provide irrigation may need to be determined. This is possible by treating the Energy Resource as a separate component for analysis at the Water Motive Energy stage.

The third element of any irrigation system is the Distribution System. This involves an analysis of the energy required to deliver water from the pump or field source to the plant. The water delivery efficiency and the pressures which may be characteristic of a given distribution system are two important factors that directly influence the amount of energy that is required to irrigate.

Figure A-1 graphically shows these three basic elements of energy analysis. As described above, at the Water Motive Energy stage there is an analysis of the Energy Resource itself which concentrates on determining the amount of energy required and expended by a specific energy resource.

FIGURE A-1

MAJOR ENERGY INPUTS TO IRRIGATION



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This breakdown of the major energy inputs for irrigation provides a conceptual analysis of energy usage in irrigation. As such, it shows the energy impacts of irrigation decisions on a project planning level. As one begins to perform actual comparisons between irrigation technologies or energy sources, a more detailed analysis is required. This exhibit provides some basic data in sufficient detail to understand the potential value of in-depth energy analysis, and the importance of examining certain interrelationships.

This basic flow chart, Figure A-1, is referred to throughout the report. At relevant times, details are provided on the methods used to develop energy input values. Also, examples of energy calculations are performed to show the procedure for analyzing different irrigation projects.

Indirect and Direct Energy

At each stage of analysis, both direct and indirect energy must be considered. It is not always one or the other which is significant. In surface water distribution systems where no pumping is required, the indirect energy costs for manufacture of materials and construction represent a high percentage of the total energy for irrigation. On the other hand, direct energy for pumping in medium and deep ground water wells makes indirect energy costs, for the well equipment and installation, insignificant.

Indirect energy, for this analysis, refers to that fixed energy input for materials, construction, and installation of an irrigation system. It includes pumping equipment, piping, concrete and earthwork energy. In addition, labor energy for construction from humans and animals, is part of the indirect energy for irrigation.

Direct energy is that energy which is provided on an as-needed basis and can be directly related to the amount of water delivered. It is the energy required by a pump, engine, or motor. It is also that energy input from human and animal energy resources when they are used to pump or carry water.

Maintenance and other related energy inputs may be considered either indirect or direct energy. These are assumed to be insignificant for the purposes of this study.

WATER RESOURCE DEVELOPMENT

Water Resource Development represents the first stage of total energy analysis for irrigation.

There are three principle methods of water resource development in Africa; Conservation, Surface Water Development, and Groundwater Development.

- Conservation, while not usually considered irrigation, is a form of water resource development which is most applicable to underdeveloped farming areas.
- Surface Water Development refers to large scale dams and reservoirs, lakes, diversionary projects, and the surface transport systems (channels, piping, etc.) used to provide water to the farming area.
- Groundwater Development consists of boreholes, tube wells, shallow and deep wells and all the equipment that is considered to be part of the well.

Conservation is the water that is captured through relatively low scale dispersed development efforts. Several examples of water or moisture conservation practices are contained in Table A-1. Each method may require considerable indirect energy inputs in the form of human, animal, or mechanized power.

Table A-1

MOISTURE CONSERVATION TECHNIQUES

Method	Description and Purpose
Run-Off Interception	Used on sloped land to retain rainfall and reduce erosion. Involves intercepting run-off by making ridges, terraces, furrows, and basins which run across the slope. (Energy input for construction and maintenance.)
Run-Off Farming	The practice of concentrating surface run-off for cultivation in desert and semi-desert regions. Run-off from catchment basins is directed onto farmed fields. Recent work has shown that areas with total annual rainfall of less than 100 mm can be cultivated.*
Contour Seepage Furrows	Small ditches following the contour levels across drainage areas to retain run-off and permit increased water seepage and natural storage as for grazing. (Example: dambos of Zambia; energy input is for furrow construction, maintenance, and operation.)
Mulching	Placing material on the soil to suppress evaporation and conserve water within plant's root zones. (Energy input primarily at low level from human and animal power. NOTE: There is the potential for an additional energy input of fertilizer when appropriate mulches, such as dung, are applied.)
Other Methods	Soil Moisture Traps made of thin plastic sheets with small perforations buried 5 cm deep in the soil. Moisture which passes through the sheet is trapped and evaporation reduced so as to extend the growing period. (Energy input for construction and materials.)

* Proportions between catchment area and cultivated area must be correct.

Source: Stern, Peter, Small Scale Irrigation, Intermediate Technology Publication Ltd. London, pp 31-53, 1979.

In all water conservation practices except mulching, energy is required for the construction of channels and furrows. It is important to quantify the construction energy for furrows at a rural level because it represents the primary energy input to low scale water resource development.

Furrow construction by axe and hoe represents relatively difficult human labor. For animal draft power, it may be compared to deep plowing. Mulching, on the other hand, is easier work which can be performed by human labor or in combination with animals.

In order to quantify the indirect energy, one must determine values for human and animal energy expenditure. Determining the human and animal energy inputs for this work can be complex. Energy is required to perform the work and also to maintain the worker or animal. If the activity under study requires a full day's labor, applying a daily energy expenditure rate is more accurate than an isolated task figure. The daily energy expenditure rate includes energy for productive work, eating, rest, and other activities. It does not include energy for days not worked on the project being evaluated, such as off-season maintenance.

Human energy expended for digging furrows is estimated to be 3500-4000 kcal/day.* For mulching activities and for surface irrigation maintenance work, approximately 3000-3500 kcal/day are necessary. For animal labor, again on a daily energy expenditure rate, 20,000-35,000 kcal/day are required to support a large farm animal such as an ox. The actual value varies according to the strenuousness of the principal activity. Rough estimates such as these for human energy consumption are useful for comparisons with other technologies. In addition, they serve to point out the direct relationship between work output and human energy expenditure.

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* See Exhibit C, "Human Energy Used in Agriculture," for more detail.

To determine the energy input necessary to perform specific low technology irrigation practices, daily energy expenditures must be multiplied by the amount of time required to perform a job. Unfortunately, very little data are available for the time required to construct such a furrow, by human or animal labor. Since it is a very similar activity to plowing, published draft animal energy input will be used to obtain a measure of the energy applied to the soil.

Setting the amount of work equal to that required to plow a field provides the following data on constructing irrigation furrows for maize.*

Animal Power	4 oxen-2 days	=	320,000 kcal/ha
	2 man-days	=	6,000 kcal/ha
	TOTAL		326,000 kcal/ha
Human Power	35 man-days	=	140,000 kcal/ha

In terms of energy expended per meter of furrow, the above figures would convert to 32.6 kcal/meter for animal power and 14 kcal/meter for human labor.

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* Data from Zimbabwe show that four oxen working for 3.7 hours per hectare are required to plow a field. At a power output level of 500 watts per animal, and when a certain amount of inefficiency is applied for animals working in combination (70%)[1] 12.2 kwh of equivalent animal work is applied to the soil. For human labor, which can produce 70 watts[2] of power over an extended period, 174 man-hours would be required. If work is performed at an average of five hours/man-day, the total man-days required would be about 35 days. At an energy expenditure rate of 4000 kcal/day,[3] 140,000 kcal/ha human energy would be required. This compares to an animal plowing energy expenditure of 326,000 kcal/day[4] which includes the energy for one farmworker to drive the draft animal (3000 kcal for 2 days).

1. Goe, M.R., "Current Status of Research on Animal Traction," World Animal Review, No. 45, pp. 2-17, September/December 1983.

2. At an energy expenditure rate of 350 kcal/hr.

3. Pimentel, D. and Pimentel, M., Energy, Food and Society, Edward Arnold Ltd. (Publishers), London, 1979.

4. 4-400kg oxen at 40,000 kcal/day/animal for 2 days (4.5 hrs. productive work day). Refer to Table 3.

These figures can be used to estimate the indirect energy required to perform any of the moisture conservation activities by either animal or human labor.

The next method of water resource development, surface water development, is discussed below.

Surface Water Development

Surface water development generally pertains to large scale development projects and the energy required to bring them into existence. Most large scale dam projects are built to serve multiple purposes. Irrigation may often be of lower priority than provision of electric power or drinking water. Any attempt, therefore, to determine the indirect energy costs associated with dam and reservoir development for irrigation must proportion the material and construction energy components to the portion of water designated for irrigation.

One such effort was performed recently by Smerdon and Hiler.* They evaluated several international water control and irrigation dam projects for total project costs, irrigation components, and numbers of hectares irrigated. The resulting values in dollars per hectare were converted into energy units per hectare by determining a relationship between project dollar costs and energy expenditure. This was accomplished by assuming that highway construction resembled dam construction for raw material and construction energy costs. The effort resulted in an annualized energy investment cost of 178,000 kcal/ha/yr for surface water development. This includes the materials and construction costs necessary to capture water and deliver it to the field at the point where it would be taken into an irrigation field distribution system.

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* Ref. Smerdon, E.T.; and Hiler, E.A., Energy in Irrigation in Developing Countries: An Analysis of Energy Factors to be included in a National Food Policy, USAID PN. 930-0091, December 1980.

The same procedure for determining the material and construction energy costs can be used with specific in-country data as they become available. The following formula represents one method of establishing indirect energy costs for surface water development.

Indirect Energy for Surface Water Development = $/ha irrigated x energy/dollar expended

Groundwater Development

Groundwater development is the third major division of water resource development. Because of the lack of appropriate data, a similar indirect approach must be used to estimate groundwater development costs. From studies in Pakistan and Bangladesh on tubewell energy development costs*, an average annual capital operating cost of $23.27 per hectare per year was obtained. This estimate was made by averaging annualized construction and material costs for over 125,000 tubewells in 1970 dollars.

Estimates for manufacturing energy required for pumps, motors, engines, piping and other pumping equipment can be obtained by examining each sector's energy input per dollar output. Smerdon and Hiler developed an estimate of 70,000 Btu/dollar (1963) and multiplied it by the annualized cost in dollars/hectare irrigated. The capital energy cost for groundwater can be estimated by multiplying the dollar per hectare irrigated by the energy expenditure per dollar invested. From their efforts, a value of 410,500 kcal/ha/yr was calculated as the indirect energy development costs for groundwater development.

Indirect Energy for Groundwater Development = $/hectare irrigated x energy dollar expended

410,500 kcal/ha/yr = $23.27/ha x 70,000 BTU/dollar

Compared with surface water development, groundwater development is more than twice as costly from an energy perspective.

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* Smerdon and Hiler

Alternate Method for Determining Indirect Energy Costs

Methodologies for determining indirect energy costs differ because of the assumptions that are required. Determination of indirect costs based on economics project and manufacturing costs are difficult because of the time value of money. As indirect energy may be significant to an analysis, effort should be expended to calculate accurate values. An alternate method for estimating indirect energy is to determine energy input as a function of the weight of material.

The following table provides indirect fixed energy values for common materials on a megajoule (MJ) per unit kilogram basis. One megajoule is equal to 238.3 kcal of energy.

Table A-2

INDIRECT ENERGY/KG

Product	Annual Fixed Energy (MJ/kg-year)
Steel	2.4
Aluminum	9.8
Brass	14.0
PVC	3.0
Polyethylene	16.0
Asbestos Cement	.4
Concrete (ditches)	.2
Excavation & Fill	.25 x 10
Ditching & Trenching	.375 MJ/m-year
	.75 MJ/m-year (20 year life)
	1.5 MJ/m-year (10 year life)
Pumps (electric)	6.8
Pumps (diesel)	4.5

Source: Pimentel, David, Handbook of Energy Utilization in Agriculture.

Based on these data, indirect energy cost per pound or meter, as in the case of earthwork, can be estimated. Then a project under review can be evaluated for indirect energy cost per hectare irrigated by dividing total indirect energy by the number of hectares irrigated to develop an estimate of energy/hectare for comparison with other values.

For the purposes of this report, energy development costs for surface and groundwater resource development will be based on Smerdon and Hiler's work, summarized in Table A-3. It is possible to utilize these estimates because, in general, indirect energy costs represent a small portion of the total annual cost for operating and maintaining conventional irrigation systems.

Table A-3

INDIRECT ENERGY FOR WATER RESOURCE DEVELOPMENT

Surface Water Development	178,000 kcal/ha/year
Groundwater Development	410,000 kcal/ha/year

WATER MOTIVE ENERGY

The second element of irrigation energy analysis deals with determining the highest direct energy cost for any irrigation system: pumping energy. Pumping and/or lifting energy is that energy required to move water from the source to the field and to provide it with sufficient energy for distribution. It is a combination of four main factors:

1. The depth or location of the resource,
2. The amount of water to be transported,
3. The pressure at which it must be delivered, and
4. The efficiency with which the entire effort is performed.

Each of these factors is proportional to the total direct energy that is required to provide irrigation. As such, they can be mathematically combined to yield the amount of pumping/lifting energy required for a specific quantity of water for irrigation. The amount and form of the energy resource which may supply the pumping/lifting energy can also be determined. Treated in a separate manner, energy resources can be compared for substitutability. For now, it is important to understand the factors which go into determining pumping/lifting energy.

The depth or location of the resource refers to the elevation difference between source and end use point. Water depths are dependent on the hydrology of the site. Since they are very site-specific, baseline data would be required before any analysis could be performed to determine the actual pumping/lifting energy required for irrigating. Because of the energy intensity of the activity, groundwater pumping for irrigation, from depths greater than 30 meters, is generally not practiced in Africa. In addition, it is important to note that because of the great amounts of energy that are required to raise water, surface water resources are much preferred over groundwater sources.

In a similar way to groundwater depth, the amount of irrigation water that is required by the plant is dependent on parameters outside the scope of this analysis. Irrigation water requirements are established by examining the plant needs, expected natural rainfall, the soil characteristics, and other specific agricultural factors. For purposes of this analysis, irrigation water requirements will refer to the amount of water required at the plant's roots.

The next most important factor in determining pumping/lifting energy is the pressure which must be provided to distribute the water. This is a function of the design of the distribution system. Distribution system designs and pressure requirements are discussed and provided at the third stage of analysis. Irrigation system pressure and application efficiency are the two most important distribution system factors needed to assess the pumping energy requirement of an irrigation system.

The last and most crucial component of determining pumping energy is the efficiency with which the pump converts mechanical energy to hydraulic energy. Depending on the sophistication of the pump, efficiencies may vary from 40-70%.

As mentioned, these factors can be combined into one formula for determining pumping energy.

$$PE = K \frac{ADH}{Ei\ Ep} \qquad \text{(Equation 1)}$$

where,

- PE = pumping energy (required by the pump)
- K = conversion factor depending on the units used
- A = area irrigated
- D = net depth of irrigation (A X D = total volume of water to be pumped)
- H = pumping head or the sum of elevation difference, operating pressure, friction, and other minor losses
- Ei = irrigation efficiency or application efficiency of the distribution system
- Ep = pumping efficiency (specifically of the pump)

In order to show how an analysis of direct pumping energy can be performed, specific data on common pump types and operating efficiencies are necessary. In addition, it is essential to consider the various types of distribution systems to provide factors for irrigation efficiency (Ei) and the pressure requirement portion of the total head variable (H) for the pumping energy equation.

Pumping Efficiency

The operating efficiency of an irrigation pump is a function of the design and field loading of a pump. Commercially available pumps are designed for specific ranges of pumping volumes and pressures. Under actual field conditions these ranges may not be followed. Values can be approximated for operating efficiency based on pump design and application. Tested or manufacturer claimed efficiencies can easily be used in the analysis. Table A-4 contains a listing of irrigation pumps found in developing countries. Ranges for pump efficiencies have been presented.

Table A-4

PUMP/MOTOR EFFICIENCIES

Energy Source	Pump or Equipment	Efficiency/Notes
Man	Hoe and Shovel	* (To divert surface water)
	Beam and Bucket	*
	The Indian "Dall"	*
	Archemedean Screw	60%
	Chain Pump	*
	Bucket Pump	40-50%
	Reciprocating Pump	40-50%
	New #6 Hand Pump	60% (Bangladesh)
	Semi-Rotary Pump	50-60%
Animal	Persian Wheel	50-60%
	Indian "Mot"	50-60%
	Water Wheel	50-60%
Motor/Diesel Solar/Wind (depending on system design)	Centrifugal	55% Low Head 20m
	Axial	50-60% Low Head
	Positive Displacement Jack Pump	50% High Head 20m
	Progressing Cavity	60-70%

* Field or manufacturer estimates not available.

DISTRIBUTION SYSTEM

The distribution system represents the third element of energy analysis for irrigation. It refers to the field water conveyance system which takes water from the pump, in the case of a pressurized or groundwater irrigation system, or from the surface water resource directly, and applies it to the crop. The efficiency with which it delivers the water to the crop and the pressures that may be required impact significantly on the amount of direct pumping energy required.

The following table, A-5, "Distribution System Efficiency," provides nominal distribution efficiencies for common field irrigation systems.

Table A-5

DISTRIBUTION SYSTEM EFFICIENCY

Distribution System	Efficiency
Surface, Unimproved, traditional leveling (covers small field furrow and earthen distribution channels)	50%
Surface, Improved and leveled (human energy input 5000 kcal/ha/yr)	70%
Surface with IRRS* (developed farm)	85%
Sprinkler	60-90%
Center Pivot	75%
Hand Move Sprinkler	75%
Drip or Trickle	85-90%

* Irrigation Run-off Recovery System

Operating pressure represents an energy component of pumping equal in significance to that required due to the depth of a resource. In fact, distribution system pressure can be converted into an equivalent amount of water depth by the following simple relation.

$$\text{Head} = \frac{\text{Pressure}}{\text{Density of Water}} \qquad \text{(Equation 2)}$$

For head in feet and pressure in pounds per square inch:

$$\text{Head (ft)} = 2.31^{*} \times \text{Pressure (psi)}$$

* Conversion factor (144 in^2/ft^2) divided by density of water (62.4 lbs/ft^3)

Therefore, 50 psi is equal to 116 feet of groundwater lift energy. Calculations demonstrate that the pressure requirement for piped distribution systems is energy costly. There are other factors such as operability, reliability, and control aspects which may serve to balance the negative energy aspects of highly pressurized distribution systems.

Table A-6 provides approximate values of the pressure required by certain common field irrigation systems.

Table A-6

IRRIGATION SYSTEM PRESSURES

System	Psi	Equivalent Head (Ft. of Water)
Surface, Unimproved	0	0
Surface, w/gated pipe	8-10	20
Sprinkler - Low Pressure	15-30	30-70
Medium Pressure	30-75	70-170
Drip or Trickle	30-60	70-140

In addition to the design aspects which impact the direct energy needed for pumping, there are indirect energy requirements for distribution systems that should be included in total energy input figures. Indirect energy is from material, construction, and installation energy costs. These refer mainly to piping, sprinklers, nozzles, and earthen furrows. The indirect costs for field distribution relate to the field irrigation system itself and, except for field earthen irrigation furrows, they should not be confused with the indirect energy required for surface water development on the large scale.

Table A-7 summarizes the energy required to manufacture and install certain common irrigation distribution systems.

Table A-7

ANNUAL FIXED ENERGY INPUTS IN KCAL X 10^3/HA/YR REQUIRED FOR THE INSTALLATION OF DIFFERENT TYPES OF IRRIGATION EQUIPMENT

Irrigation System	Manufacture of Pump	Manufacture of Pipe and Other Equipment	Earthworking Leveling and Ditching	Total
Surface	16.7	15.5	78.8	111.3
Surface with IRRS	16.7	195.1	79.3	291.1
Hand Moved Sprinkler	20.3	168.8	3.3	192.4
Trickle	17.7	975.5	13.4	1006.6

1 Systems are designed to meet a peak water use rate of 8.4 mm/day.
2 IRRS is irrigation runoff return system.
3 The trickle system is designed for a permanent orchard crop.
Source: Smerdon and Hiler

These indirect energy costs are considered in a total energy calculation at the conclusion of this report.

Pumping Energy Calculation

For the purposes of determining the direct energy for pumping, distribution system pressures and irrigation efficiencies can be obtained from Tables A-5 and A-6. These factors can be combined with pump efficiency values and pumping energy estimated.

As an example, fixing the amount of water to be supplied at 500 mm/ha/yr, with a groundwater depth of 2 meters; a traditional surface irrigation system requiring no pressure (50% irrigation efficiency), and a pump efficiency of 60%, the following calculation can be performed using Equation 1.

Depth of Irrigation (D)	=	.5 m
Area Irrigation (A)	=	10,000 m2
Head (water depth)	=	2 m
Irrigation Efficiency (Ei)	=	.5
Pumping Efficiency (Ep)	=	.6

$$\text{Conversion Factor (K)} = \frac{1000 \text{ kg/m3}}{426.9 \text{ kg.m/kcal}}$$

$$\text{Pumping Energy} = \left[\frac{1000 \text{ kg/m3}}{426.9 \text{ kg.m/kcal}}\right] \times \left[\frac{10{,}000 \text{ m2}(.5\text{m})(2\text{m})}{(.5)\quad(.6)}\right] = 78{,}082 \text{ kcal}$$

As one can see, any factor in the equation can affect the required amount of pumping energy. The choice of pump or irrigation distribution system can have a marked effect on the pumping energy requirement. Equipment design is often dictated by the water resource location or the energy source itself. This simple calculation provides an illustration of the kind of analysis that can be made to determine pumping energy requirements as a function of system component design and water and energy resource.

This energy calculation is needed to provide an indication of the amount of energy demanded from different power inputs. The power input can be human, animal, fossil fuel (e.g., diesel or gasoline), electric, wind, solar, or even biomass. The irrigation requirements and location of the water resource are major determinants to what energy source is applied. A brief analysis of the different energy sources available in Africa will aid in assessing the substitutability of one resource for another.

Energy Sources

Each power source has its own efficiency for conversion of energy from one energy form to another. The use of a conversion efficiency in the same manner as the pumping and irrigation efficiencies provides for comparative analysis among different resources.

Table A-8 from Smerdon and Hiler provides a rough guideline of operating energy conversion efficiencies for a variety of energy sources.

Using these values and the previous example of pumping energy, the amount of diesel fuel energy that would be required can be determined. Dividing 78,082 kcal/ha by the efficiency of a typical diesel engine (15%), results in 520,550 kcal/ha of fuel. This converts to approximately 58 liters of diesel fuel. A comparison to animal draft power shows more than 1,320,000 kcal/ha of food energy being necessary with the animal having to work an average of five hours/day for 44 days to provide the water motive energy.* The reason for the high kcal/ha value for animal energy is that the total daily energy requirement for the animal is dedicated to the activity. Working over an eight hour day, a conversion efficiency, as provided in Table A-8, of 10 percent would occur which translates to 780,000 kcal of food energy. The purpose of this example is to show the different kinds of parameters that can and must be considered when comparing one energy source with another.

Though it appears that selecting a technology and energy source for irrigation can be an exacting task, it can be simplified by grouping energy sources by their ability to supply a given pumping energy requirement. For example, these requirements can be written as a function of groundwater depth, irrigation system, or irrigation water requirement.

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* One animal producing 400 watts continually over 5 hours, expending 30,000 kcal/day.

Table A-8

ENERGY CONVERSION EFFICIENCIES FOR VARIOUS TECHNOLOGIES

Motive Power	Conversion Efficiency	Notes
Human (food/mechanical energy)	20%	By task, not including maintenance energy
	14%	By day*
Animal (food/mechanical energy)	10%	By day**
Motors (electrical/electrical)		
Brushless DC	67-72%	Optimum Efficiency for units rated under.7 kw
Standard DC	75-82%	
AC Motor	30-35%	Generally for units rated under .7 kw
Engines (thermal/mechanical)		
Diesel	25%	Manufacturer claimed
Diesel	10-15%	Field estimates***
Gasoline	20-30%	Manufacturer claimed
Kerosene	3-5%	
Other Fuel, Biomass	5%	
Solar (sunlight/electricity)	8-10%	Electric to pump by small DC conversion
Wind (wind/mechanical)	9%	Pump & Wind Turbine Combined

* (70 kcal/hr output x 8 hours)/(4000 kcal/day input) = 14%

** (375 kcal/hr output x 8 hours)/(30,000 kcal/day) = 10%

*** Halcrow, W. and Partners, Small Scale Solar Powered Pumping Systems: The Technology, Its Economics and Advancement, The World Bank, London, June 1983. Section 8.1.2.

NOTE: Efficiencies for motors, diesel engines, solar, and wind technologies are from Halcrow, W. and Partners. Human and animal values are calculated as noted.

Comparing Energy Sources

A consideration of different energy sources for irrigation may be desired because of the high cost of one particular resource, a national energy or agricultural policy, or the need to increase employment. Comparing energy resources may pose a problem because of the different units that are used to express particular energy resources.

Animal and human energy requirements, for example, are most useful when expressed in terms of kilocalories of food energy. Diesel energy, on the other hand, may be expressed as fuel thermal energy or more conventionally in liters or barrels of oil. Electrical energy usage is generally considered in kilowatt-hours. These energy sources have in common the fact that they are used as direct energy for irrigation. Other energy sources, specifically renewable, have little or no direct energy component, being made up of primarily indirect capital expenses. The comparison of indirect with direct, and one form of energy with another can be made in several ways on a project-by-project basis.

First, comparisons may be made among direct energy resources such as food or biomass and fossil fuels through standard energy conversions. This may be desired to determine the practical substitutability of one energy resource for another. In addition, human and animal energy can be given an economic value as a function of equivalent amounts of a commercial fuel.

Comparisons between indirect and direct energy resources require that indirect capital energy be annualized. Solar and wind energy systems are good examples. Because the energy which these systems utilize is relatively "free", it is basically only the annualized life cycle energy cost which must be compared to other competing sources.

Solar electric energy, for converting sunlight to electricity for pumping, is almost entirely indirect capital costs. These can be converted to annualized life cycle values for comparisons with conventional fuels. In a similar manner, the capital energy invested in wind power equipment can be dealt with on a life cycle basis. Comparisons on a life cycle basis can be performed in economic terms. At the present stage of application of these two technologies, economical comparisons with other fuels are most often applied. To make accurate and reliable estimates, however, information on system life and maintenance requirements must be obtained. Information such as this is not readily available from independent sources.

Figure A-2 makes an attempt at such comparisons. In economic evaluations of energy, the time value of energy resources must also be considered. Also, energy subsidies of different fuels or other resources may be very difficult to isolate so that fair energy comparisons can be performed. Still, the graph does show evidence that energy resources may be substitutable at small energy requirement levels.

There are other factors to be considered when evaluating solar or wind technologies. For solar electric, the physical size of an array may result in lost farming area. Wind energy resources must be considered for their reliability and availability. These factors are technology and location specific and subsequently cannot be dealt with in adequate detail in this exhibit.

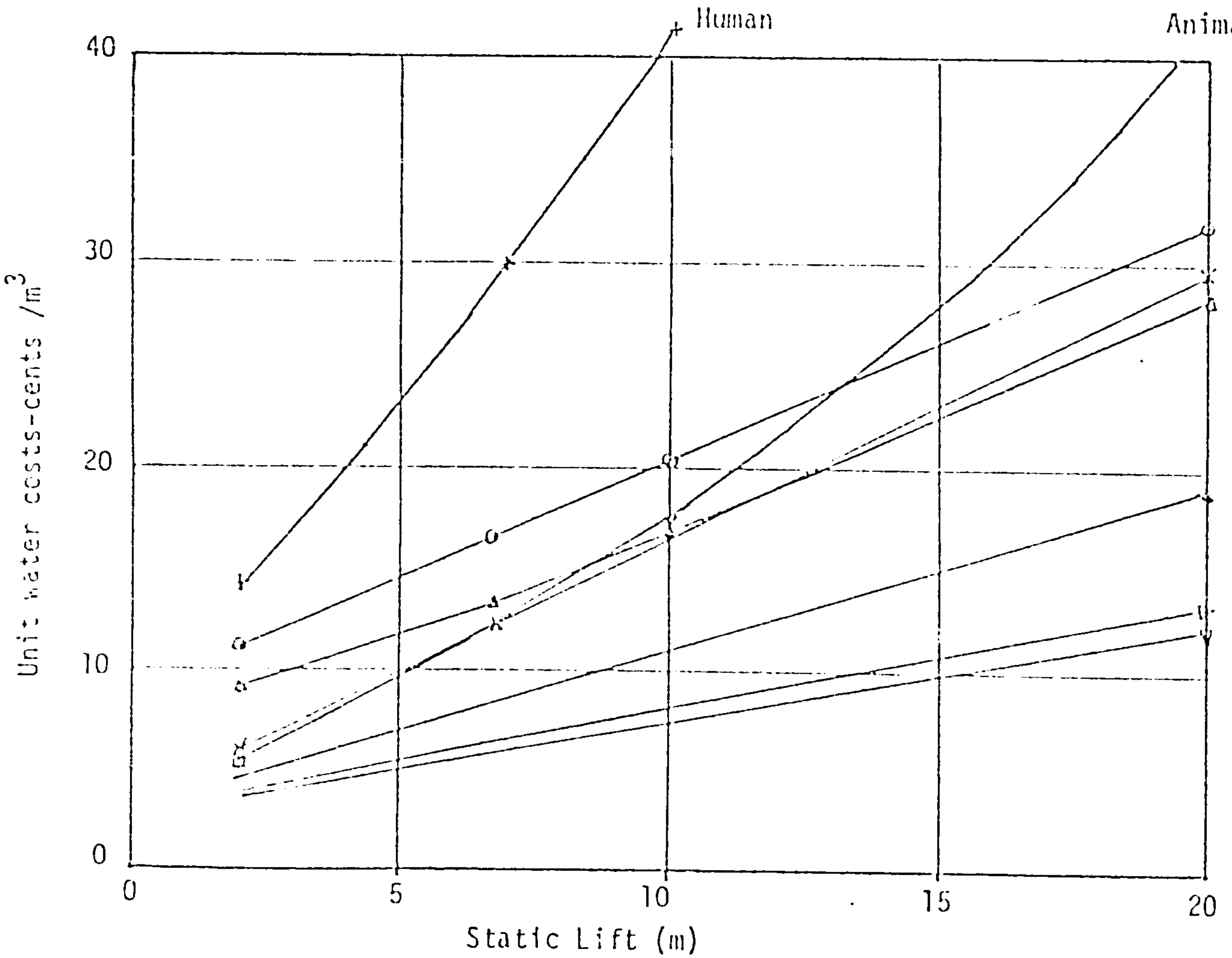
Total Direct and Indirect Energy - Three Examples

The three stages of analysis provide a format for estimating the total indirect and direct energy inputs for irrigation. These are made up of Resource Development Energy, primarily indirect energy; Water Motive Energy or calculations to determine pumping energy; and Distribution Energy, both direct

Figure A-2

EFFECT OF REDUCED PV SOLAR PUMPING SYSTEM CAPITAL COSTS IN COMPARISON WITH ALTERNATIVES AS A FUNCTION OF STATIC LIFT

(Baseline Irrigation Scenario--No Storage)



Note:

1. Solar channel present more expensive than solar piped present and not shown.
2. Solar piped target and potential more expensive than channel and not shown.

*This figure is the product of an in-depth evaluation of solar pumping for irrigation performed by Sir William Halcrow and Partners entitled Small Scale Solar Powered Pumping Systems: The Technology, Its Economics and Advancement, Main Report with ITDG, The World Bank, London, June 1983. The study compared both a best and worst case diesel pumping unit (high and low efficiency, respectively) to solar, wind, animal, and human pumping technologies. Solar pumping was considered at a present cost tar ted cost, and potential cost level for two distribution systems.

and indirect. Lastly, a separate, but technically related, analysis of the applied Energy Resource will permit a total energy analysis, specific for the energy resource, to be performed for a variety of irrigation systems. The following example of irrigation energy analysis for three levels of farming development demonstrates the format and the relative impacts of indirect and direct energy on irrigation.

Example One: Subsistence

Irrigation practices are limited to labor intensive moisture conservation practices (water management) or in certain areas, small scale rainfall diversion work through the construction of furrows. A total energy input analysis must concentrate on the labor energy inputs from human, animal, or mechanized power. Data have been provided on human and animal energy expenditure to show a method of estimating this energy input. The amount of water that is actually collected and the amount of energy that is expended are related to the size of the effort and the environment of the site. Unfortunately, very little data are available on this matter. For an in-depth energy analysis of subsistence level irrigation practices, data must be acquired on the work performed, the amount of water captured, and finally, the increase in productivity associated with the irrigation practice.

For example, a farmer may construct furrows to divert water from a catchment land area. If he expends an amount of energy equal to that of plowing a field, he will invest an estimated 140,000 kcal/ha/yr. If that diversion effort supplies an additional 200 mm of rain to his two hectare field, he will markably increase his yield. The increase in yield can be estimated, but the amount of delivered water must be determined on a specific project basis. Generally, applying human and animal energy to perform conservation work provides increased moisture to a plant with relatively small energy expenditures. In the best case, furrow irrigation systems on small plots can be fed from surface water resources developed on a larger scale.

Direct energy inputs at this level are for maintenance and operation by human and animal labor. They are assumed to be small compared to the indirect energy for construction.

Example Two: Transitional

A transitional level example of total energy analysis involves both direct and indirect energies. A farm which irrigates using some method of pumping requires energy to acquire the pump, construct the well and distribution system, and operate the pump. The previous example of an irrigation system involving 500 mm of water/ha/yr, a groundwater depth of 2 meters, a traditional earthen furrow distribution system, and a pump efficiency of 60 percent resulted in a direct pumping energy of 78,082 kcal. This direct energy combines with indirect energy for the construction of the furrows (by animal power) and the energy to drill and equip the well to given a total energy input figure, at the pump, as shown in Table A-9.

Table A-9

TRANSITIONAL FARM IRRIGATION ENERGY

Indirect Energy (kcal/ha/yr)		Direct Energy (kcal/ha/yr)	Total
Irrigation System Construction Energy	Energy to Drill and Equip Well	Pumping Energy	
326,000	100,000*	78,082 (at pump)	504,082

* Estimated from data in Table A-11

The direct energy can be supplied by at least two reasonable means; animal and diesel fuel. As calculated earlier in the discussion on Energy

Resource analysis, the pumping energy from diesel fuel would approximate 520,000 kcal. The food energy necessary for using animal power would be approximately 1,320,000 kcal. The totals of direct and indirect energy are shown in Table A-10.

Table A-10

TOTAL ENERGY FOR TRANSITIONAL FARM IRRIGATION

Energy Source	Indirect	Direct	Total
Diesel	426,000	520,000	946,000 kcal
Animal	426,000	1,320,000	1,746,000 kcal

* Estimated from data in Table A-11

This comparison of energy sources can be performed for other resources. The pump calculations may need to be modified to reflect specific operating efficiencies of equipment, relative to the energy source. This brief example points out the calculations and relationships among energy input factors for a relatively low energy irrigation project. More comprehensive analysis can be best illustrated by examining a commercial scale irrigation system.

Example Three: Commercial or Developed Scale

Data are provided in Table A-11 on a developed irrigation system. Total energy input as a function of the type of distribution system is presented. In this analysis, as in the previous example, it is necessary to fix certain parameters. Here, a net irrigation of 1000 mm/ha/yr is chosen. Two different water resources are considered, one from surface water and the other from groundwater at a depth of 50 meters. Also, pumping energy is calculated using a pump efficiency of 70 percent, and a pump power unit (diesel engine) efficiency of 26.4 percent. Combining pump and driver efficiency in one term (.7 x .264 = .185), results in a direct energy figure in terms of the energy

Table A-11

ESTIMATES OF ENERGY REQUIRED PER YEAR TO PROVIDE NET IRRIGATION OF 1000 mm/ha 1/*

(in thousand kcal) 2/

Type of farm irrigation system	Irrigation efficiency (%)	Energy for installation of farm system	Surface water supply			Groundwater supply (50 m lift)		
			Energy to provide supply	Pumping energy	Total energy	Energy to provide supply 3/	Pumping energy	Total energy
Surface irrigation	50	111	178	760 4/	1,049	308	13,432	13,850
Surface irrigation with IRRS 5/	85	291	178	746 4/	1,215	308	8,200	8,799
Hand-moved sprinkler	75	193	178	8,955	9,326	308	17,403	17,904
Trickle 6/	90	1,006	178	4,928	6,112	308	11,985	13,299

* The data base was compared to irrigation systems in the USA.
1/ Systems are designed to meet a peak water use rate of 8.4 mm/day.
2/ Can be converted to tpe with the equation 1 kcal = 10^{-7} tpe.
3/ To drill and equip well.
4/ To overcome friction head loss and to provide a small elevation of water to ditch level. In systems where canal water is supplied at sufficient elevation to permit gravity flow, pumping energy is zero except for energy required to recover the water runoff.
5/ Irrigation runoff recovery system.
6/ Designed for orchard crops.

Source: Adapted from J. Batty and J. Keller, "Energy Requirements for Irrigation," in Handbook of Energy Utilization in Agriculture, ed. by D. Pimental (Boca Raton, Florida: CRC Press, 1980), pp. 35-44. Reported in E. Smerdon and E. Hiler, "Energy in Irrigation in Developing Countries: An Analysis of Energy Factors to be Included in a National Food Policy," a study prepared for the United States Agency for International Development (Washington, D.C., December 1980), p. 19.

source applied. Though this method loses the distinction of specific pumping energy, it is useful when comparing different designs for their affect on the amount of energy resource that is required.

A graphical representation of the total energy requirements for different irrigation systems is summarized in Figure A-3. It is useful for making general comparisons among common irrigation systems using the fixed factors for pumping efficiency and the same energy source.

Summary

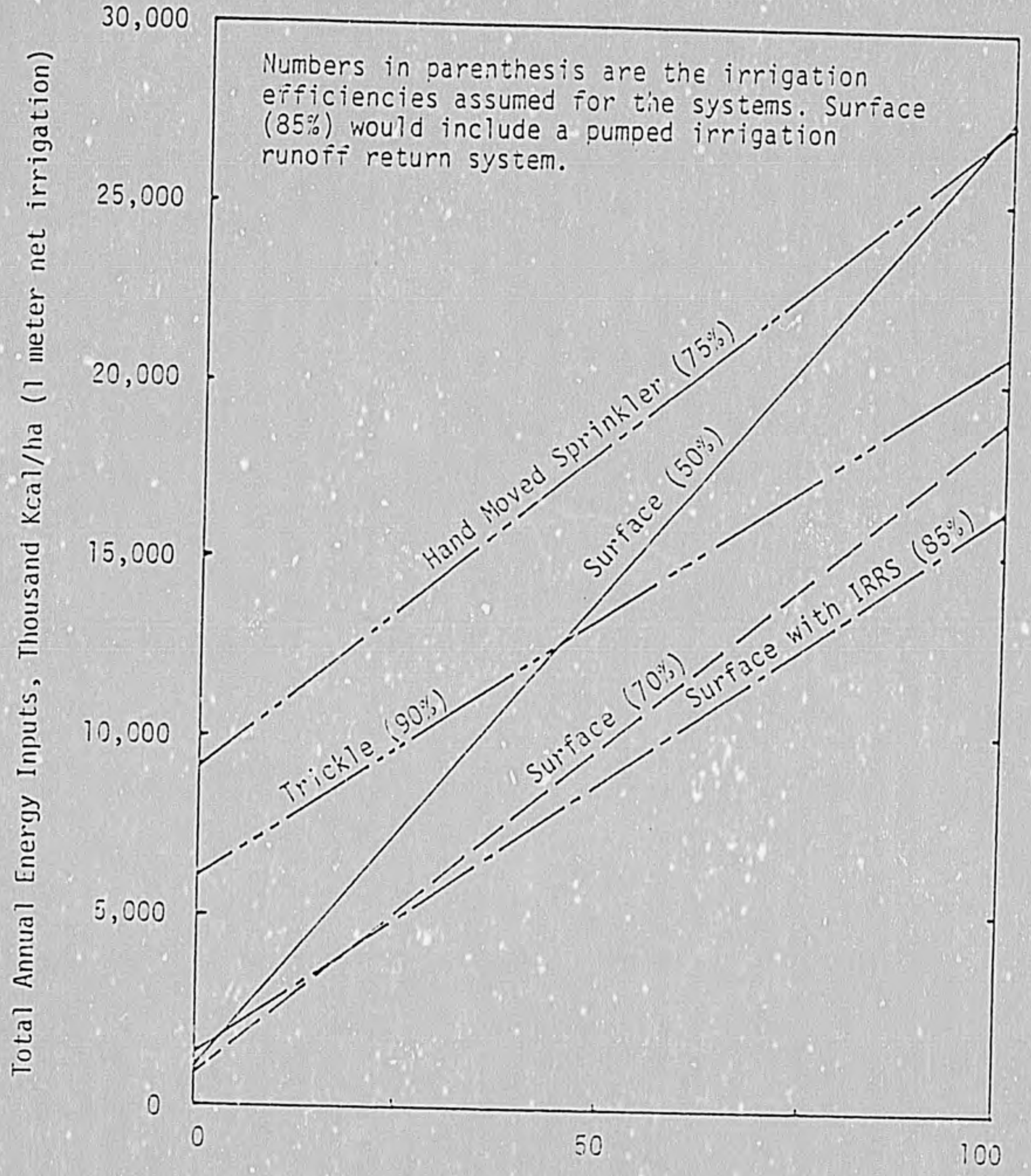
These examples begin to show the process of evaluating energy usage for irrigation. Indirect and direct energy costs must be quantified for the total energy required to develop the water resource. From past studies of the relative amounts of energy needed for developing surface and groundwater resources, it is apparent that groundwater requires much more indirect development energy than does surface water.

The next stage of analysis concerns the amount of energy that is required to move the water. Pumping/lifting energy, as it has been referred to, is a function of several specific factors; the depth of the resource, the amount of water needed for irrigation, the pressure at which it must be delivered and finally, the system through which it is delivered.

There are a number of different distribution systems. The two most important factors related to distribution of energy input are the required operating pressure and the efficiency at which water is applied.

Using estimates for the above factors, one can approximate the amount of pumping energy required for a given irrigation requirement. This pumping energy can be supplied by a certain number of appropriate energy resources. Comparing these resources through a separate analysis provides the energy or

Figure A-3



Total annual energy requirements for different irrigation systems related to pumping lifts.

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agricultural project planner with information about the substitutability of energy resources. Summing these factors yields values on the total energy inputs for any specific irrigation project or program.

The basic conclusions of this illustrative analysis are that indirect and direct energy costs for irrigation systems can be applied in a method that is useful for irrigation energy analysis. In addition, the primary energy components for irrigation can be used to show the impact of various irrigation design decisions on total energy usage. This has been briefly shown in the examples.

In general, the amount of energy that is required for irrigation is first dependent on the scale of development of the farm irrigation system and secondly on the location of the water resource. Table A-12 provides a comparison of the energy required for irrigation among different projects for the three major levels of agricultural development.

Table A-12

COMPARISON OF TRADITIONAL, TRANSITIONAL AND COMMERCIAL IRRIGATION PROJECTS*

Irrigation Project	Activity	Amount of Irrigation/ ha/yr	Energy Source	Energy Use/ha (kcal)
Traditional - Water management by run-off diversion	Construction of run-off and irrigation furrows	200 mm	Human	140,000
Transitional - Shallow ground-water pumping to earthen furrow distribution (2 meters depth)	Construction of well and distribution systems, well and pump equipment, pumping energy.	500 mm	Animal Diesel	1,746,000 946,000

* Estimated from Table A-11

Table A-12
COMPARISON OF TRADITIONAL, TRANSITIONAL AND COMMERCIAL IRRIGATION PROJECTS
(Continued)

Irrigation Project	Activity	Amount of Irrigation/ ha/yr	Energy Source	Energy Use/ha (kcal)
Developed or Commercial - Deep ground-water pumping to piped sprinkler distribution system(medium pressure) (50 meters depth)	Construction of well and distribution systems, well and pump equipment, distribution equipment, pumping energy	500 mm	Diesel	9,000,000

In any table or graph, certain key factors must be fixed. This limits the usefulness of the example. In as complicated a subject as irrigation energy analysis, it is important to consider the application of microcomputers to the analysis effort. As presented, each major stage of energy analysis can be treated as a separate component for detailed consideration. Planning design decisions can be made at a component level and then combined through appropriate rules or relationships. The present power of small microcomputers will permit quick and informative "what if" planning work to be performed. Large or small scale irrigation systems can be analyzed, using a format such as is offered in this report. Such an effort would yield an understanding of the impact of irrigation project designs on the energy required from a number of alternative resources.

This report has attempted to identify and present, in a useful format, the major energy components of irrigation. The use of the format may be best handled by first defining the level of energy analysis required and second facilitating the effort with the application of microcomputers to the planning analysis.

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Exhibit B

PROPOSED MODULES FOR ADDITIONAL USES

Just as a design goal of some architects is that form should follow function, so it is a researcher's goal that methodology should follow user's decision functions. Therefore, the approach to be taken in defining the relations between agriculture and energy should follow the course of answering questions which arise as a potential user carries out a given objective. Figure B-1 anticipates functions and audiences for the work presented here. The discussion of varied objectives is provided in the following five modules.

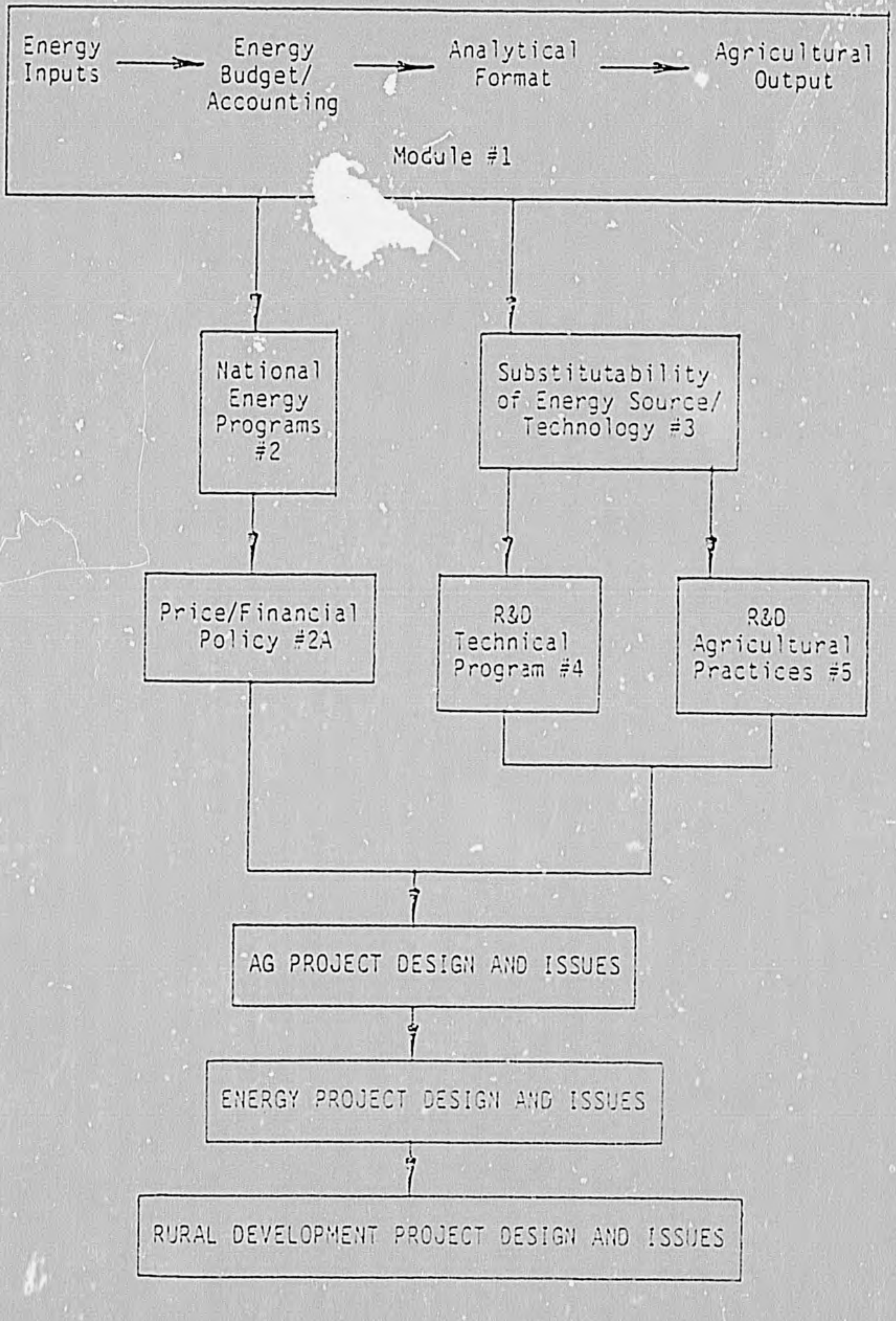
Basic Energy Accounting: Module #1

One group, professional energy analysts, seek the most comprehensive data and analysis possible with the objective of constructing archives of use for the broadest group of users. Their work results in a form of energy budgeting which serves a host of functions. The collection and completion of a data base is almost an end in itself for the ends are so diverse that a broad and comprehensive data set is constructed with little or no specialization of function.

This approach is rather common because, in a relatively new field, the management objectives are often ill defined. Thus, both direct energy consumed, such as diesel fuel, and indirect energy, such as that associated with the production of a fertilizer, are completely included in the accounting. Furthermore, the boundaries surrounding the system under investigation may be quite broad, including the fuel consumed in the ship that was used to import the fertilizer.

Figure B-1

PROPOSED DEVELOPMENT OF MODULES, FOR FURTHER DELINEATING THE RELATIONS BETWEEN AGRICULTURE AND ENERGY



The approach taken in this report defines boundaries and the use of indirect energy much more narrowly in order to provide a more rapid and less expensive means of collecting data, without misleading the targeted group of users. Standard values are used to reduce the analysis that localized and custom surveys entail. These trade offs are specified in the text.

For its completion, Module #1 should now include at least a cash crop and another country to ensure that the format is comprehensive.

National Energy Programs: Module #2

The next step in the development of analytical procedures is to link the project level analysis of this document with the national consequences of a project. Most projects are undertaken with the notion of expanded replicability such that consequences of that project would be important regionally or nationally. Under these conditions where national impact is to be expected, the consequences for the availability of the correct form of fuel, its infrastructure for distribution, and its balance of payment's impact should be known. Energy supplies have a long lead time in many cases and national planners should have advance notice of shifts in location and types of demand.

During discussions undertaken to assess user needs, the national level concerns became paramount because the success of agricultural projects often requires national attention from the Ministries of Planning, Finance and Environment, as well as from the Ministry of Agriculture. Thus, when the project level designers claim national importance for their project, the energy implications are of special interest. Often the ecological concerns dealing with long term productivity of the soil are of interest as well.

Furthermore, since foreign exchange is usually a major concern, its allocation to the production of food for domestic use requires justification.

Modifications and interpretations of the results of the analysis provided here would result in an understanding of the value of allocation of foreign exchange to the agricultural sector.

In this case, the results of the work would have to be made compatible with national planning analysis such as the relative merit of dollars or energy spent in a sector. If agriculture is to compete with the more modern industrial sector for hard currency, it has to make its case on the same or similar terms. Each national priority is different in this matter. In designing the analytical format, attention was paid to how it fits into different national decision structures.

Here, the relations between economic analysis and energy analysis become more important. If national decision-makers are not shadow pricing foreign exchange or have only done financial analysis, agriculture is likely to be given less attention than it should have. One step in the development of methodology would be to test interpretations of results given by economic and energy analysts.

Whatever the development needs of the next phase of energy analysis may be, experimentation at the national level is important. As indicated, one such area for treatment would be a follow up piece of work dedicated to Module #2A for energy and agricultural pricing and financial policies. In this regard, testing the analysis on a cash crop would provide new insights about the different decision processes within the more modern sectors. These modern sectors could also be contrasted with less commercial agriculture.

Substitution of Energy Source: Module #3

This module is likely to be the one most frequently used by analysts. People trained in agriculture will not ordinarily have a background in energy systems and energy professionals will not ordinarily have a background in agriculture. The activity of choosing replacement or substitute fuels, therefore, is one of fostering communication among different disciplines.

The format accomplishes this by identifying alternative modes and sources of providing energy as well as matching them to a variety of agricultural circumstances. The data base that would be used for this module would have the additional benefit of encouraging energy analysts to report their findings from research and pilot efforts in comparable terms, meaningful to agricultural project designers.

The interaction between energy analysts and agriculturists may result in benefits similar to those between forestry and agriculture where, for example, agro-forestry solutions to competition for arable land may provide common ground on which tradeoffs can be made. Nitrogen fixing trees can have a symbiotic relationship that improves the yield of crops as a substitute for the use of commercial energy in agriculture as well as for fuelwood. Another example is the tradeoff for the use of agricultural residues for combustion energy, when they might have a more productive use as fodder or for water management. Fuelwood projects might free agricultural residuals for better uses then combustion.

Substitutability also applies to such replacement fuels as palm oil for diesel. The format also may show that a human to animal to mechanical device progression is possible, but it is not simply a move to modernization that follows a set path. Even though the progression might, for good reason, be interrupted and fixed at a particular phase, there is room for improvement within the limits of the form of energy used. Oxen may provide the greatest possible source of energy that a farmer will ever see. Or human labor may be the limit of expectations that are reasonable. In either case, the format helps define alternative means to improve yield.

Research and Development Technical Program: Module #4

As data for project design are acquired and the value of energy assessments for agricultural productivity is more widely appreciated, certain targets for research and development will emerge. For example, we already know that irrigation is often the largest consumer of energy. Furthermore, we know that there are many options from which to choose when planning an energy source. An R&D program to determine the best means for different categories of farms could have strong impact in Africa. Such a program would have to be more sophisticated than existing technology demonstrations designed to prove the economic or social feasibility of pumping water. Rather than the energy engineer taking specifications from the agronomist, agricultural and energy systems would be designed together to increase the number of options under consideration. Using the format in the report as a design tool, with a data base to support a number of "if/then" design considerations, alternative designs could be tested until the most suitable combination were discovered.

Such an R&D process could be repeated for a number of different relations between agricultural and energy project design. Fertilization would probably be the next target; then, following the progression through the most significant choices for the use of energy, a long term R&D program could be devised.

Research and Development for Agricultural Practices: Module #5

As the examination of energy needs has proceeded, it has become clear that agricultural practices themselves are influential in the increased yield that can be expected from added energy. Scheduling of different activities before or after rainfall results in more productivity than other times. Slower and longer irrigation pumping than current practices which arise from familiarity with diesel power would enable more use of sunlight over the day. This may make substitution possible. In addition, there are ways to avoid deep plowing during certain years and, thereby, permit the use of different energy forms and agricultural equipment. Furthermore, in the categories of farms which are in the non-cash economy, energy analysis may be the best means to compare efficiency of different practices.

In sum, when working together, energy and agricultural specialists can create alternative modes for increasing yield which would not appear without close communication. Economic analysis would lead to the best of the known options; energy analysis should stimulate and create new options.

The results which can be expected from the forms of energy analysis proposed throughout this report are a strong working relationship between agricultural and energy project designers as well as an improvement in rural development plans which can include the integrated needs of agricultural development with that of the delivery of energy supplies and services.

Unfortunately, these results cannot all be promised immediately. This report was written to illustrate how energy analysis could be of use. Data have to be gathered, and means to investigate and analyze different categories of farms have to be created. In the work below, the use of microcomputers is discussed as a means of rendering energy analysis practical and economical.

Use of Microcomputers

There are four significant reasons for introducing the microcomputer as an aid in the process of understanding and applying the approach taken in this report. The first is to clarify the logic of the approach to project evaluation and design. If the six steps are taken according to a computer assisted logical path, a comprehensive and thorough checklist of concerns can be addressed. The computer program will guide the very experienced or newly hired professional to respond to the critical questions in an orderly fashion. Not only will this assure comparability of results so that later analysis of multiple projects will be reliable, but it will provide a minimum set of information for reviewing projects regardless of the immediate and limited objectives or experience of the professional using the format.

An evaluation would not be done well without experience in either agricultural or energy areas. As a practical matter, it would be difficult to replicate the logic of an expert in computer software. Expertise is needed to give credibility to the results of a broadly applicable diagnostic model. The computer can only ensure a minimum level of attention to important issues while making comparative and cumulative analysis possible. Future expertise and learning of value to future agriculture program design will occur when results from a number of varied conditions can be scientifically compared and analyzed for patterns.

The second reason to introduce microcomputers is to assure a comparable data base among projects as data are added to a repository. Computerization assists in maintaining quality control. Equally important is that the repository can eventually be used as a data source for estimating quantities under similar circumstances. A good data base management program will make retrieving and adding data economical, rapid, and easy. An existing software package can be modified or a custom program can be written. Either way, the computer reduces the problems of international and intraregional comparative analysis and use of shared data.

The third benefit of introducing microcomputers is the ability to prompt the user to consider alternatives, such as energy sources which are unfamiliar. The analytical format used in this report could be tied to a data base containing the performance characteristics and likely costs of alternative sources of energy. An examination of the data base would suggest or eliminate the desirability of pursuing matters further.

These three benefits--clear and comparable logic, easy data retrieval, and the prompting of alternatives--all argue for the application of computers. Finally, the most compelling argument is that microcomputers probably provide the least expensive way of getting the three benefits by facilitating the operational aspects of project design and evaluation. Since the variety of relations between energy and agriculture is so complex, a set of handbooks or rules of thumb would be unlikely to capture the desired circumstances relevant to the users' problem. It would require an enormous index in a paper manual to maintain up-to-date and broadly useful information about the classifications of farms and configurations of energy alternatives. A data base management system can make the effort practical, efficient, and within the reach of most agricultural officers. Costs for equipment and software are continually declining as well.

Assuming these benefits will justify at least a pilot effort, then the format and its six steps should be further specified and put into a computer look-up form. Next, data base conventions should be set and a data management system designed to handle future data collection. Finally, a data analysis package should be selected to provide ease of calculations and to begin the search for established relations between energy and agricultural performance. All of this should be done with the assumption of the availability of only a minimum of microcomputer skills among staff members.

Exhibit C

HUMAN ENERGY USED IN AGRICULTURE

Human energy requirements for agriculture must be considered as the total daily energy required to support the worker. This includes the energy required to perform a specific task and also that required to maintain the person throughout the entire day. Field data show that human energy expenditure can vary from 2000 kcal per day to over 4000 kcal per day depending on the activity. Table C-1 lists a collection of values for human energy expenditure by task. Several daily energy expenditure values are also included to show the variation.

Table C-1

ENERGY EXPENDED BY TASK*

Activity	Energy Input	Hours
Heavy Hoeing	400 kcal/hr.	5 hours/day
Axe and Hoe Farming	350 kcal/hr	8 hours/day
Hand Spraying	300 kcal/hr.	8 hours/day
Pumping	260 kcal/hr**	8 hours/day
Rest	45 kcal/hr.	10 hours/day
Eating, Other Activities	145 kcal/hr.	6 hours/day
Farming Legumes	2,100 kcal/day	(Worldwide)
Subsistance Farming	2,400 kcal/day	(New Guinea)
Subsistance Farming	2,118 kcal/day	Beans and Corn (Central America)

* Adapted from Pimentel, David and Marcia, Food, Energy & Society, pp. 45, 29, 49, 30, 65, and

Sir William Halcrow and Partners, "Small-Scale Solar Powered Pumping System: The Technology, Its Economics and Advancement."

Approximate figures from the above table can be used to estimate human energy inputs to farming.

More accurate estimates can be obtained by breaking down a day's activities into the number of hours spent at each activity and the energy expended in a given task. The total sum will be the daily energy input for a human, performing that specific type of farmwork as illustrated in Table C-2.

Table C-2

CORN PRODUCTION USING MANPOWER ONLY (w/axe and hoe)*

Activity	Consumption Rate	Hours	Total
Work	350 kcal/hr.	8	2,800
Eating, etc.	145 kcal/hr.	6	870
Rest	45 kcal/hr.	10	450
			4,120 kcal/day

This second method for estimating human energy inputs to farming shows the direct relation which the activity has on the total daily energy requirement.

These two methods can be used to estimate human energy required for different levels of farm work.

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* Adapted from Pimentel, David and Marcia, Food, Energy and Society,

Exhibit D

FACTORS OF CONVERSION

1 toe = one tonne oil equivalent

1 kcal = 10^{-7} toe

1 kJ = 24×10^{-9} toe

1 kWh = 0.86×10^{-4} toe

1 tce (tonne coal equivalent) = 0.7 toe (approx.)

1 BTU (British Thermal Unit) - 25.2×10^{-9} toe

Exhibit E

ZIMBABWE TRIP REPORT
(21 November 1983 - 13 December 1983)

24 November — Arrival in Harare.

25 November — Interview with Mr. D. Meltzer (USAID Mission in Harare).

- General information on maize cultivation procedure in Zimbabwe.
- List of people to contact in different sector of maize production.

Interview with Mr. J. F. Douse (Grain Specialist, Department of Research and Specialistic Service, Ministry of Agriculture).

- Characteristics of maize production in communal areas, commercial farms, and state farms. Energy used at different levels of productivity.

28 November — Interview with Mr. Enos M. Shumba (Agronomy Institute, Department of Research and Specialistic Service, Ministry of Agriculture).

- Discussion on draft animals and cropping systems in communal areas -- methods of improving draft animals' performances.

29 November — Contacted Mr. Neighbour (Department of Agricultural, Technical and Extension Services [Agritex Maps Office])

- Information on natural regions and farming areas of Zimbabwe.

Interview with A. H. (Bob) MacGregor (Agritex Senior Form Management Specialist).

- Data on step-by-step maize production with draft animals and with 100% tractor draft power.

30 November — Contacted Mr. Peter Ivy (Deputy Director, Technical Branch of Agritex)

- More information on maize production procedure in Zimbabwe.

Interview with Mr. Allan Rowe (Research Agronomist, University of Zimbabwe, Crop Science Department).

- Discussion on growth stages of maize, soil preparation techniques, fertilization, irrigation weed and pest control for Maize Information and the GMB (Grain Market Board).

December 1 Field trip with Mr. Allan Rowe

- Visited: 1) Communal areas of Chinamora and Msana.
  2) The Rattray Amold Research Station (production of hybrids of maize)
  3) 1400 ha commercial farm (200 ha arable) located in the Arcuturus area.

December 2 Field trip with Mr. Allan Rowe and John C. Brown (Agricultural Development Manager of Chibuku Holdings Limited)

- Visit to Mzarabani state farm; interview with farm manager, information on maize double cropping systems and methods of tractor management in state farms.

December 4 Field trip in communal areas of Seki

December 5 Interview with Mr. Richard Winkfield (Grain Production and Extension Executive, Commercial Grain Producers Association).

- Information on Zimbabwe maize processing systems.

Interview with Mr. Allan Norton (Farm Machinery Training Centre, Agritex).

- Information on alternative energy sources related to tillage practices (tractors).

December 6 Further interviews with Enos M. Schumba and Richard Winkfield.

Contacted Mr. Jerry Austen (Dore & Pitt, specialists in sprinkler irrigation).

- Discussion on irrigation systems in Zimbabwe (hand-move, center pivot) -- sources of water for irrigation (boreholes-surface water).

Contacted Mr. Y. Mantel (Tinto Industry).

- Information on Teco pumps for irrigation and characteristics of tractors imported in Zimbabwe.

December 7 Interview with Mr. C. D. Kacoro (Research Engineer, Institute of Agricultural Engineering).

- Information on draft animals equipment.

Contacted Mr. Frank White (Representative of Windmill Agricultural Products Supplier).

- Information on chemical fertilizers, pesticides and herbicides used for maize cultivation in Zimbabwe.

December 8	Interview with Mr. Bert Vinall (Director of Elcombe Haulage (Pvt) Ltd. (transportation company).
	- Information on grain transportation by truck in Zimbabwe.
	Interview with Mr. A. F. Clarck Farr (Director of Railroad Department, Ministry of Transport).
	- Information on grain transportation by train.
December 9	Interview with Mr. A. J. Prestt (Agritex, Irrigation Division)
	- More information on maize irrigation systems in Zimbabwe.
December 11	Departure from Harare.

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