NEW AND RENEWABLE SOURCES OF ENERGY FOR AGRICULTURE AND RURAL DEVELOPMENT

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Introduction

The share of total commercial energy used in agriculture in the developing countries is 4.0%. 68% of it is used in fertilizers. In the developed countries the respective figures are 3.4% and 40%, while the average, world figures are 3.5% and 45% (ESCAP, 1982). The figures show that although developed countries use much more commercial energy in agriculture than developing countries, the rate of increase is less than that in the non-agricultural sectors. The portion used in fertilizers in developed countries also declines which means that more energy is used in the other activities of agriculture. Apparently the need for conserving commercial energy is more pressing in the non-agricultural sectors, and in the agricultural sector conserving is more urgent for the non-fertilizer inputs.

Although the consumption in agriculture is relatively small, there is still one critical point of the rising costs of fossil fuels and of related agricultural inputs. On the other hand, to achieve the desirable rates of growth in crop and livestock production, large increases in the use of commercial energy and energy intensive inputs would be required in developing countries. It has been reported that for several important food crops the ratio of yield increase to labor input ranges from 2.9:1 (sweet potato, cassava) to 5:1 (groundnut). For transplanted rice it is 3.5:1 and for maize 3.9:1. For fibre crops (cotton, jute, kenaf) the ratio is 1.5:1 to 4.4:1. For oil crops it is 2.7:1, while for sugar cane it is 3:1 (ILACO B.V., 1981).

These two contradictory factors call for two options. The first is to ensure greater efficiency in the use of large fossil energy consuming inputs such as fertilizers, pesticides, mechanical equipment and, water lifting devices. The second one is to make more effective use of locally available and renewable as well as non-depletable resources. These are the recycling of organic matter such as agricultural and domestic wastes, biological nitrogen fixation, biologically induced improvement of the availability of native nutrients of soils

(mycorrhiza), small-scale hydropower, draught animals, biogas, solar, wind, tidal and geothermal.

Agriculture can make itself useful by producing commercial renewable energy (energy cropping, photosynthetic conversion). This includes the production of fuelwood, gasohol from cellulosic or starch rich material (wood waste, cassava, sugarcane, maize, etc.), biogas and electrical power from bagasse of the sugar industry (Gopalakrishnan and Nahan, 1977). The generation and utilization of these new and renewable sources of energy would have a number of aspects which require the establishment of operational linkages between the urban and industrial communities on one hand and the rural community as a whole on the other.

**Concept of Energy Budgeting in Agriculture**

Energy budgeting is meant to use energy effectively and efficiently. It is more than just obtaining the highest Eo/Ei, where Eo stands for the total energy output and Ei is the total energy input. It is aimed more so at the most productive distribution of Ei to the different activities within the agricultural enterprise. Thus agriculture should be treated as a functional system consisting of an organization of interacting, interdepending and intercorrelating components. The relationship of nutrient applied to crop yield, for instance, is controlled by soil, plant genetic and bio-environmental conditions. These conditions determine the effective uptake of nutrients by the crop and this in turn is the direct yield determining factor.

The core problem will then be the finding of the appropriate distribution of the input of energy among the different activities of soil cultivation, irrigation or drainage, plant breeding, crop protection and the application of fertilizers. It becomes clear that energy budgeting is site and time dependent. It is the identification of the relative importance of each intrinsic activity in crop production by area and season. In this context it is urgent to subdivide a country into land systems. A land system should be reasonably homogeneous to serve as a managerial unit.

A land system is composed of a gross land pattern, formed by the recurrence of similar sites of site sequences within a finite area, where the sites are defined on partial interdependence and intercorrelation of several attributes. Where a steady state of dynamic equilibrium is approached, there is almost complete interdependence and intercorrelation of attributes and all components of the land are mutually adjusted (Ruxton, 1968).
Energy budgeting also considers alternate sources of energy. Alternatives are selected on the basis of whether the energy is commercial (price, market supply) or subeconomic, subjected to depletion or non-depletable, renewable or non-renewable, it can be generated by agriculture itself or it has to be brought in from outside the agricultural sector, the amount of competition with non-agricultural users, and the technical practicability of the economic feasibility with existing agricultural systems or with currently employed production techniques. The understanding of all these is needed for the short term planning process.

An agricultural system generally emerged from a long history of adaptation to the physical and biological environments. It also reflects the established tradition of the people. In long term planning one more crucial point has to be taken into account, and that is how flexible the present system of technique is to accommodate the technical, economical and social requirements of the new source of energy. In short term planning alternatives are limited by the existing conditions and situation, so that energy budgeting is also limited. In long term planning, however, more room for selection will be available and energy budgeting may approach maximization of output. The ultimate objective of conserving energy in agriculture calls for the formulation of an exhaustive energy budgeting. To this end the development of systems analysis using energy simulation models is imperative (Dvoskin and Heady, 1977). A regional cooperative effort should be strongly encouraged.

**Energy Use Pattern in Agriculture**

Figure 1 shows in a general way the common input-output flow in agricultural production (solid lines). The dotted lines depict flows that can be made operational by the utilization of internal transformations of energy. If this is feasible to be done, the energy inputs from outside sources may be reduced. This will ultimately lead to a partial self-reliance of agriculture in its energy need. By concentrating the use of the internally generated energy on the most crucial step in agricultural production, agriculture will be more viable in times of commercial energy crisis. Electrical and thermal energy are the most useful products of the internal transformations, so that the emphasis of energy source substitution should be on Input III and IV (trashing, hulling, milling, drying, cooling, room air circulation, etc.). In addition, electricity so produced is a profitable alternate for water lifting for irrigation.
Fig. 1. Input-output and internal transformations of energy in agricultural production and their possible utilization

- Rice bran
- Bagasse of sugar industry: electrical energy
- Molasses of sugar industry: commercial output
- Ditto: fertilizer
- Manure, draught animal
- Soil amendment
- Mechanical energy
- Mechanical or thermal energy

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Fig. 2. Input-output flow and internal transformations of energy in crop production (……….long term input; --------subsidies)
With a more controllable supply of energy to processing and storage, the share of total produce loss in both operations may be reduced (smaller Y2-Y4). This means an improvement in the use efficiency of energy. It may also be envisaged that for every group of ordinary farms there will be one complementary energy farm. The gasohol that is produced by the energy farm should relieve input I, II and V from whatever commercial energy source they are dependent on. The energy farm may easily supplement Input III and IV also.

Figure 2 is similar to Figure 1, except that it is focused on crop production. Thus Figure 2 is an elaboration of the upper part of Figure 1. Crop production consists of two major operations which may be called physical and biological. The physical operations are land preparation, seedbed preparation wherever this is proper for the crop under consideration, soil cultivation of tillage, fertilization or manuring, hydromelioration (irrigation and/or drainage), and soil and water conservation. On newly acquired lands, land reclamation is included. The biological operations are raising seedlings in nurseries for transplantation, seedling transplantation or planting of cuttings or direct sowing of seeds (whichever the proper practice is), crop protection (including weeding) and harvesting.

In crop production, crop waste is the principal raw material for the internal transformation of energy. The latent biochemical energy in crop waste may enter Input III as mulch or incorporated organic matter with the purpose of reducing the need for mechanical soil cultivation. It is also useful in Input VI as the soil will be more protected against the dispersive action of the kinetic energy contained in rain drops or runoff. Evaporation is reduced and more water can be stored in the soil, so that indirectly it affects positively Input V. The recycled mineral nutrients in crop waste by microbial decomposition add to the maintenance of soil fertility. This is also true due to the formation of humic compounds which improve the buffering and nutrient storage capacity of the soil, thus it may partly substitute Input IV. For this latter purpose it is much better to compost the waste first before applying it to the soil, or to feed cattle, sheeps or goats and collect the dung for manure. In the long run the benefit of recycled waste through Input III may effect a decrease in Input II, so that land preparation for the next season crop will be less energy consuming. If need be the internal energy, transformations in crop production can be facilitated by waste subsidies from the processing of agricultural produces or in the form of decomposable domestic (rural and urban) or industrial refuse.
The traditional compost making and the use of dung should be inspired. The link between farm and non-farm operations to transmit subeconomic energy sources from the latter to the former should be enhanced. The big question to town and city people should not be how to dispose of refuse hygienically, but how to utilize refuse hygienically and profitably. The answer rests with the microbial population of the farm lands.

Sources of Energy Used in Agriculture

The energy sources used in the various agricultural operations depend on a number of factors. Tradition is one of them. Another factor is whether the farm is operated commercially or run as a subsistent farm. The effectiveness of extension programs and credit services may motivate farmers for increasing use of energy from better sources. The obtainability of the different sources of energy locally influences decisions about what source of energy to use, etc. In the Indonesian case of food crop production, it may suffice to consider the two systems of non-bimas, permanent cultivation, and Bimas, including Inmas, Insus and other improved systems of cultivation. The crops considered are wet land rice, dry land rice, maize, cassava, groundnut and soybean.

Between the harvest product and the consumable product there are still other operations which consume photosynthetic (man) as well as fossil energy (especially hullers, mills, on-site generated electricity for lighting or air circulation in storage barns, and transport vehicles). For the present purpose only the sources of energy involved in land preparation, fertilization, hydromelioration (specifically irrigation) and plant protection will be considered. Table 1 contain the power or material input used in each farm operation and its corresponding source of energy.

Table 2 indicates the primary sources of energy that are or can be used to generate useful power, and the inter-conversion of power. Fossil energy for the generation of electricity, for instance, may be substituted by solar, wind, kinetic, juvenile or nuclear energy. For the generation of mechanical power, it can be replaced by all, except solar. But solar energy can produced mechanical power indirectly by way of the inter-conversion of thermal to mechanical, or that of electricity to mechanical. Of course, the longer the path of transformation, the lower will be the efficiency and the higher the cost of production. However, the cost of production or acquirement has to be weighed against the magnitude of the problem attached to the use of the energy source to be substituted. On the other hand, the decision about the use of an alternate source has to be made on the basis of
knowledge about the technical, economical and social prerequisites of the new technology. Unless the required studies have been done thoroughly, the expected result will be not only dubious, but more so it will contain a potential risk which is too much for the farmer to bear.

Table 1. Power on material input used in each farm operation and its corresponding source of energy

<table>
<thead>
<tr>
<th>Farm operations</th>
<th>Non-Bimas</th>
<th>Bimas</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Power or material input</td>
<td>Energy</td>
</tr>
<tr>
<td>Land preparation</td>
<td>man (labor) animal</td>
<td>photosynthetic</td>
</tr>
<tr>
<td>Seedbed preparation*</td>
<td>man</td>
<td>photosynthetic</td>
</tr>
<tr>
<td>Planting</td>
<td>man</td>
<td>photosynthetic</td>
</tr>
<tr>
<td>Soil cultivation</td>
<td>man</td>
<td>photosynthetic</td>
</tr>
<tr>
<td>Fertilization</td>
<td>man manure, organic waste</td>
<td>photosynthetic</td>
</tr>
<tr>
<td>Hydromelioration</td>
<td>Man** Water&quot; &quot;</td>
<td>photosynthetic gravitation</td>
</tr>
<tr>
<td>Soil and Water conservation</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Plant protection</td>
<td>man (weeding)</td>
<td>photosynthetic</td>
</tr>
<tr>
<td>Harvest</td>
<td>man</td>
<td>photosynthetic</td>
</tr>
<tr>
<td>Transportation from field</td>
<td>man animal</td>
<td>photosynthetic</td>
</tr>
<tr>
<td>Drying</td>
<td>man sun heat</td>
<td>photosynthetic</td>
</tr>
</tbody>
</table>

* Wet land rice
** Watering from shallow field wells
*** Cement and lime

It is the very nature of a subsistent family farm that it may survive with even a low productivity level, provided that it is secured against a too frequent a crop or harvest failure. Farmerwise the success of the intensification programs in Indonesia lays primarily on the greater security of harvest, and not so much on increasing the marketable surplus of the farm produces.
Table 2. Kind of power that can be generated by available source of energy and the inter-conversion of power

<table>
<thead>
<tr>
<th>Energy source</th>
<th>Power</th>
<th>Electric</th>
<th>Mechanical**</th>
<th>Thermal</th>
<th>Photosynthetic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wind</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kinetic*</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fossil</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Juvenile</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nuclear</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Energy source power

- Electric
- Mechanical**
- Thermal
- Photosynthetic

* Falling or running water, tidal movement (gravitation)
** motive or stationary

Distribution of Energy Used Among the Different Farm Operations

1. Land Preparation (applicable also to soil cultivation or tillage)

Power involved: man (human labor), draught animal, and/or tractor

<table>
<thead>
<tr>
<th></th>
<th>area/hr (m²)</th>
<th>Cal / hr</th>
<th>Cal / ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>man</td>
<td>33</td>
<td>300</td>
<td>90909</td>
</tr>
<tr>
<td>draught animal</td>
<td>138</td>
<td>1500*</td>
<td>108696</td>
</tr>
<tr>
<td>tractor</td>
<td>468</td>
<td>18653**</td>
<td>398568</td>
</tr>
</tbody>
</table>

* An agricultural worker develops a power of 0.1 hp and the power developed by a work animal is 0.5 hp, which is 5 x that of man
** On the average a tractor consumed 2 litres of diesel oil per hour, and 1 litre of diesel is equivalent to 9326.3 Cal. (Rao and Singh, 1977; Goodhart and Shils, 1974; Williamson and Payne, 1978; Triharso, 1980; Rusdi, personal communication; Ward et al., 1977)

2. Fertilization

The total energy used in fertilizers can be broken down into the amount used in the mining and transportation of raw material, the manufacturing process, transport and
distribution of the finished product and the field application. In Indonesia the field application is done by hand, so that its share should be negligible. According to the 1978/79 figures the percentage import dependence of Indonesia of nitrogen, phosphate and potassium fertilizers were 3.0, 99.5 and 100, respectively (ESCAP, 1980). This means that the transport and distribution of N fertilizers are almost all within the country. If the US figures could be applied to Indonesian condition, the energy requirement is quite small. By truck, rail, barge and pipeline they are respectively 0.60, 0.17, 0.14 and 0.11 Ca/kg (Davis and Blouin, 1977). To these should still be added the energy required for storage and transfer of materials throughout the transport and distribution system. As nitrogen and potash is produced where the raw material is abstracted or mined, no raw material transport energy is required. By far the most energy-consuming phase in the fertilizer system is the manufacturing process. It amounts to 88% of the total energy used (Davis and Blouin, 1977).

Total energy requirements for the production of:

<table>
<thead>
<tr>
<th>Product</th>
<th>Energy Requirement (Cal/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urea, prilled</td>
<td>12348</td>
</tr>
<tr>
<td>Urea, solution</td>
<td>11340</td>
</tr>
<tr>
<td>TSP</td>
<td>2016</td>
</tr>
<tr>
<td>Normal Superphosphate</td>
<td>504</td>
</tr>
<tr>
<td>KCl</td>
<td>1008</td>
</tr>
</tbody>
</table>

(Davis and Blouin, 1977; Ward et al., 1977)

Practically all energy used comes from fossil sources (natural gas, fuel oil) and some of it is derived from electricity.

3. Pesticides (including herbicides)

On the average the amount of energy used per kg of active ingredient in:

<table>
<thead>
<tr>
<th>Stage</th>
<th>Energy Requirement (Cal)</th>
</tr>
</thead>
<tbody>
<tr>
<td>production</td>
<td>24255</td>
</tr>
<tr>
<td>formulation</td>
<td>20948</td>
</tr>
<tr>
<td>packaging</td>
<td>5513</td>
</tr>
<tr>
<td>transport and distribution</td>
<td>1103</td>
</tr>
<tr>
<td>field application</td>
<td>20948 (with machine)</td>
</tr>
<tr>
<td>total</td>
<td>72767</td>
</tr>
</tbody>
</table>
When field application is done by hand, the energy needed is only 1.7% of what is needed in machine application in terms of fossil energy. Of course, the energy in the form of human labor required for the substitution should be calculated (Vaughan et al., 1977; Pimentel et al., 1973; Buffington and Zar, 1977).

4. Irrigation

In the US on-farm pumping for irrigation consumes 21% of the total energy used for farm production (Sloggett, 1977). The power consumption in electricity is 1.2 kwh for small pumps or 1.6 kwh for bigger pumps per acre-foot of supply and per foot of lift. The generation of 1 kwh of electric power needs 2646 Cal of primary fossil energy. So for the said performance the pump consumes 3175 - 4234 Cal. Conversion to IS units, the production of one ha-mm of irrigation water by one meter of lift requires the input of 79 - 106 Cal of primary fossil energy. The energy value of 1 kwh electricity is only 860 Cal (Rawlins, 1977; Ward et al., 1977). This means that the transformation efficiency from fossil energy to electric power is as low as 32.5%. Water pumping with gasoline or diesel motors by transforming the energy first into electric power is quite wasteful.

Alternate Sources of Energy

The energy use situation in Indonesia’s agriculture within the intensification program may be presented as follows. Only farm operations which are related to the abstraction of fossil energy are listed. The figures are equivalent kilocalories per ha per growing season of wet land rice.

Land preparation, fully mechanized…………………………….. 398.568 Cal
Fertilizers, energy for production
Only : Urea, prilled, 90 kg N …………………. 1.111.320 Cal
TSP, 75 kg P₂O₅ ………………………………………… 151.200 Cal
Total …………………………………….. 1.262.520 Cal
Pesticides, 2 kg of 50 WP or LC, manual application. 26.266 Cal
Irrigation, full pump irrigation, once every week over 8 weeks irrigation period, assuming a 5 cm depth of flooding, a lift of 100 m from an aquifer and daily loss of 7 mm due to evapotranspiration and percolation ………………………………………………………. 3.700.000 Cal
Total on-farm consumption ………………… 5.387.354 Cal
Equivalent to litres of gasoline ………………… 658
The energy expense for fertilizers increases if transport, storage, transfer and distribution are included. Roughly these may amount to 10% of the energy equivalent of the material, that is 126252 Cal. Harvest is not included as it is still done manually. Threshing is by trampling or by small peedle-threshers.

The average yield of ‘gabah’ per ha per crop is 2.86 tons. The caloric value is 3570 Cal/ kg. The calorie output is 10.210.200 Cal, and the input efficiency is 1.90 (ratio Cal return to Cal input). If the handling of fertilizer is added, the input efficiency drops to 1.85. This is already rather small, so that particularly for the large energy consuming operations alternate less or non-depletable sources of energy should be found. High priority should be given to conserve energy used in fertilizers and irrigation.

Fertilizer need can be cut by inciting biological N fixation, mycorhiza induced improvement of the availability of native nutrients of soils and the recycling of decomposable waste (agricultural, including dung, household, industrial). For instance, the legume Sesbania aculeata may fixed 96kg N/ha/crop, saving up to 1.185.408 Cal (Mears, 1981). Organic manures may replace some of the phosphate fertilizers. Ash of fuelwood is an excellent substitute for potash fertilizers.

If full pump irrigation is the only solution to water shortage, the use of electricity transmitted from hydroelectric plants will save 67.5% of energy, that is 2.497.500 Cal, because the low efficiency of converting fossil fuel to electricity can be avoided. One of the recommendations of the Symposium on Solar Science and Technology held in Bangkok (1980) has stated, that solar photovoltaic systems (SPS) offer an attractive alternative for meeting the basic needs of electricity in rural areas. SPS can be a profitable source of energy for pump irrigation. In fact several pumps in the 25 kW and higher ranges have been fabricated and evaluated, yielding 25.000 litres/day from a depth of 5 meters. The possibility of utilizing wind energy should be duly studied.

The full utilization of rainfall is a major way out. Toward this end soil moisture conservation is crucial. The development of simulation models of soil moisture dynamics should be stressed. The ultimate goal will be redefining the role of irrigation in agriculture as being supplemental to the natural supply of rain. In this context the construction of field retention basins for rain water is instrumental. Although pumping may still be needed, the energy will be less as the lift is small. Tidal energy has been proven quite useful for the hydromelioration of reclaimed tidal lands.
Another saving of energy comes from limiting the use of machineries for land preparation or soil cultivation. By using working livestock two things can be effected. The actual energy input is reduced by 289.872 Cal/ha/crop which is the difference between the energy consumption of tractor and draught animal. In addition, there will be no input of fossil energy. Instead, the energy is entirely photosynthetic or living, thus renewable. Agronomic measures, such as crop rotation, proper selection of planting time and growing resistant cultivars, and an ecological approach to crop management, can save considerable fossil energy used in pesticides.

Environmental Impact of Alternate Energy Sources

The usefulness of a new energy source may be offset by its hazardous impact on the environment of by causing strong inconveniences to the community. Gopalakrishnan and Nahan (1977) have listed several impact criteria. Some of the most important points are given here:

- Area committed for conversion
- Area committed for transmission
- Use of air space
- Air pollution
- Water pollution
- Solid waste
- Heavy metals of toxic substances
- Thermal discharge
- Visual intrusion
- Noise generation
- Public health
- To these may be added:
  - Compatibility with common practices
  - Economic and social consequences of permanent nature

Each criterion needs a comprehensive study in order to come to a relevant and well weighted scoring system.

Reference


