On-farm Ecological Accounting: Methods, Resources and Challenges

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Abstract

The economy's tendency to discount the value of environmental resources and services jeopardizes the sustainability of society. This dysfunction is well illustrated by modern agriculture. Competition between farmers to deliver cheap food has proven to be environmentally disastrous.

Consequently, some people now propose the development of an *eco-economy*, which would price commodities to a greater extent according to their environmental cost. To explore the implications of such an eco-economy, an on farm ecological accounting exercise was initiated at Annapurna farm, Tamil Nadu.

This paper presents some of the conventions and challenges of the study, particularly with reference to energy accounting.

The sheer complexity of ecological accounting suggests that the *eco-economy* proposal, that prices of commodities should be informed by their site-specific ecological costs, is unworkable in an increasingly globalized economy. It is unlikely that a price tag can become a sufficient substitute for care and knowledge.

> *Market prices for agricultural inputs and products do not currently reflect the full costs of farming.*
>
> Pretty et al. 2001

> *Capitalism may collapse because it does not allow prices to tell the ecological truth.*
>
> Oystein Dahle,
> Retired V.P. of Esso, Norway

> *Food in the United States is much cheaper than it should be, and that's very destructive.*
>
> Dr. Robert Buggs, Entomologist
> University of California-Davis

> *This century will see the end of significant evolution of large plants and terrestrial vertebrates in the tropics.*
>
> Michael Soule 1980

> *Our only hope now is rapid systemic change – change based on market signals that tell the ecological truth. . . . Unless we can get the market to send signals that reflect reality, we will continue making faulty decisions as consumers, corporate planners and government policymakers. Ill-informed economic decisions and the economic distortions they create can lead to economic decline.*
>
> Lester Brown 2003

Introduction

In his popular book, *The Botany of Desire*, Michael Pollan observes:

> Partly by default, partly by design, all of nature is now in the process of being domesticated—of coming, or finding itself, under the (somewhat leaky) roof of civilization. Indeed, even the wild now depends on civilization for its survival. Nature's success stories from now on are probably going to look a lot more like the apple's than the panda's or the white leopard's. If those last two species have a future, it will be because of human desire; strangely enough, their survival now depends on what amounts to a form of artificial selection. This is the world in which we, along with Earth's other creatures, now must make our uncharted way. (2001 p. xxii)

Although he does not use the jargon of economics, economists will nevertheless recognize that Pollan is asserting that the economy has become a powerful arbiter of the survival or extinction of species. In other words, a specie's chance of survival correlates positively with the monetary value that we perceive in that species.[1] Considering that 95% of the Earth's terrestrial area is now appropriated for human use (Western and Pearl 1989), it is hardly surprising that human perceptions of utility have become such a determinate selection pressure upon all creatures. A price tag has become a prerequisite for survival.

This is bad news for India's "127,000 species of micro-organisms, plants and animals"(Damodaran 2001), as well as society's traditional ecological knowledge (TEK) which has evolved with such life forms. (Ramakrishnan 2001) The economy's inability to rationally value many of nature's critical functions and resources provides good reason to expect that it will also inadequately appreciate the value of biodiversity. The economy undervalues nature's functions and resources for a number of reasons. One reason is that the economy externalizes catastrophic costs as well as considerable benefits from its determination of prices. (Costanza et al. 1997, Pretty et al. 2000) Another reason is that the economy mistakenly assumes that, in the words of Herman Daly and Kenneth Townsend, "environmental sources and sinks are infinite relative to the scale of the economic subsystem." (Daly and Townsend 1996) If environmental sources and sinks are assumed to be infinite, their value will necessarily be deflated. A third reason is that prices, which serve as expressions or representations of value in the marketplace, are heavily influenced by consumers' subjective impressions of a commodity's scarcity (or abundance) or novelty, as well as their estimation of a product's utility. (Daly 1996) Such perceptions, demonstrated as willingness to pay, are generally entirely uninformed by any information about the environmental impact or biophysical costs of a product's production, processing, transportation and packaging. According to P.W. Gerbens-Leenes et al., "Environmental impacts of agriculture often remain unquantified and therefore do not influence

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[1] However, there are cases of an inverse correlation. For example, the extremely high value of some species, such as the Caspian sturgeon, is a factor that increases the probability of their extinction.

farmer or societal decision-making about production methods" (2003 p. 233). Prices are additionally distorted by government subsidies which often send misleading signals or indications to consumers and producers. (Myers 1998)

The findings of some recent studies indicate the scale of externalities, or the extent to which the environment is discounted by the economy. Pretty et al. (2000) conservatively estimated that agricultural production related externalities comprise 13% of average gross farm returns for the 1990s for farms in the UK, or around 208 British pounds per hectare per year for externalities arising from all 11.2 million hectares of arable land and permanent grassland. Susan Subak (1999) estimated that a tax of approximately 5% should be imposed on feedlot raised beef to reflect the costs of greenhouse gas emissions from beef production. Studies of the social externalities related to nuclear and coal based energy generation suggest that such costs would increase the prices of electricity in the USA by 50% and 100% respectively. (Zucchetto 1994, p. 440 cites Ottinger et al. 1990. See also Koomey and Krause 1997)

Such systemic economic misrepresentation is alarming not only for conservation biologists. Many people are disturbed by the economy's tendency to discount the value of environmental resources, amenities and services, and thereby generally underestimate the costs associated with production and consumption. This disjuncture between prices and costs has disastrous consequences for the entire ecosystem. Biodiversity's conservation is contingent upon a healthy, integral ecosystem. (Pimentel et al. 1996) Therefore, biodiversity's crisis cannot be resolved without also correcting the economy's tendency to discount the value of the rest of the ecosystem.

This crisis is well illustrated by agriculture. In agriculture, the economy's habit of underestimating the cost of food production means that consumers chronically shortchange farmers. Consequently, farmers, striving to remain competitive in the short term, are unable to afford the recurring investments that must be made to maintain soil health and productivity over the long run. Farmers are often economically rewarded if they overexploit, waste or degrade unpriced and underpriced inputs. (Blakie 1985) To make matters worse, the economy systematically culls ecologically responsible producers through the mechanisms called bankruptcy and foreclosure. Economic exigencies, aggravated by policy, have converted America's Midwest into an area that is now publicly regarded as an "ecological sacrifice zone."(Jackson 2002)

An economically successful farm is likely to be biologically simplified. Feedlots, confined feeding operations, and chemically dependent monocultures of cash crops do not leave many suitable niches for biological diversity. (Pimentel et al. 1996) Farms that practice rotational grazing, green manuring, crop rotations, and intercropping are likely to possess higher biodiversity (Jackson and Jackson 2002, Dobbs and Pretty 2001, Pimentel et al. 1996), but such practices are effectively prohibited by economic rationality.

The economy simply does not presently possess the capacity to recognize or appreciate the often subtle significance of biodiversity. The challenge, therefore, is to transform the economy from an engine of waste generation, environmental devastation and biological impoverishment into a mechanism which promotes and rewards rational, equitable and sustainable appropriation, allocation and use of natural resources.

One approach to reforming the economy is to create an ecologically informed economy, or eco-economy. (Brown 2001, Brown 2003, Daily and Ellison 2002) In such an economy, prices would be influenced to a greater degree by information about impacts of production processes upon the state of biophysical stocks and services, or "natural capital." In an eco-economy, products that require a larger amount of resources or which generate more environmental damage would have a higher price than alternative products which require fewer resources or which cause less environmental damage. Such a pricing regime would strengthen the economy's capacity for self-correction by counteracting distancing's tendency to disinform consumers. (Kneen 1989)

Key or central components of such reformation would be ecological audits and ecological accounting to produce information about biophysical inventories and costs. Such information would be used to inform prices, thereby giving consumers a better indication of the costs associated with products. Information generated by ecological accounts can also be used to monitor and verify producer compliance with non-market instruments, such as conservation reward and incentive programs for farmers. This is already being done in Switzerland and Holland, where farmers are required to maintain nutrient accounts. (Dobbs and Pretty 2001)

Context of the study

In the summer of 1999, I initiated a project to develop an agricultural ecological accounting framework at Annapurna, a 135 acre organic grain and dairy farm in the experimental international township called Auroville, near Pondicherry. This project was undertaken in part to inform the effort of Auroville's residents to decommodify the primary elements of their existence, such as food, land, shelter, health care and education. Although progress has been made in some of these areas, food remains particularly resistant to decommodification. This study aims to develop a means for identifying the biophysical costs of food production. Such information would then be used to value the food that is produced and consumed in Auroville, and to inform adjudication between alternative cropping patterns.

All but one of Auroville's farms are managed organically. To maintain their local natural capital, such farms employ methods which are generally regarded as prohibitively costly by conventional farmers. For example, some of Auroville's farms invest heavily in *in-situ* gene conservation, rainwater harvesting infrastructure, and green manures[2]. In such an unconventional context, where market forces are no longer the primary arbiter of resource allocation, and where ecological sustainability becomes a higher priority, a new system of accounting, one which more honestly and accurately acknowledges environmental costs and credits, must be developed. Such a new system is needed for assessing farmer efficiency, as well as for adequately compensating farmers. Such a framework must be informed by both the local environmental constraints and endowments or carrying capacity, as well as universal agroecological principles and theory.

Although this framework is being developed for the unconventional context of Auroville, the approach is of relevance to market mediated contexts as well. Such a system of informing prices on the basis of biophysical costs is essential if we are to correct the economy's present tendency to prohibit sustainable agriculture.

The findings of such agro-ecological audits may also help to address India's present need for "a rigorous information base on the typologies of (India's) agroecosystems."(Damodaran 2001) The generation of such a database is critical. According to Damodaran, "this serious information gap has precluded the formulation of national or sub-national policy on agroecosystems in India."(2001 p.1)

Methodology

I started the project by reviewing literature related to the assessment of agricultural sustainability, agricultural applications of environmental economics, and ecological accounting. I reviewed such literature in order to identify methods, parameters of interest, and conversion factors and biophysical benchmarks that would inform and shape my own project. The literature review led me to conclude that there is as yet no universally applicable format or framework for on-farm ecological accounting. However, there are interest and progress in this area. (see for example vanLoon et al. no date, See Gerbens-Leenes et al. 2003 for a recent example of analysis of sustainability of food production processes.)

Developing a framework for on-farm ecological accounting is difficult partly because of disagreement and uncertainty over the determinants of sustainability, partly because of the tremendous variability across different agricultural systems and ecosystem carrying capacities, partly because of the variety of ecological accounting methods, and partly because of the multidisciplinary character of the task. The literature that I reviewed commonly suggested that agriculture's sustainability is influenced by a production system's:

energy requirement
water requirement
impact upon soil health and quantity
impact upon biodiversity

[2] Green manures grown at Annapurna include velvet bean (*Macuna pruriens*), *Sesbania speciosa*, jack bean (*Canavalia)*, pilipisaaru *(Phaseolus trilobus)*, sunn hemp (*Crotalaria juncea).*

financial viability
nutrient balance

A system of ecological accounting would therefore have to monitor such parameters in order to develop a holistic impression of a system's biophysical costs and benefits. Naturally, it is critical to distinguish between a system's dependence upon renewable and non-renewable resources in the cases of nutrients, energy and water.

After identifying these indicators of agricultural sustainability, I selected some production processes to monitor and assess at Annapurna farm. I chose to monitor rice (*Oryza sativa)*, millets (Barnyard millet-*Echinochloa colona* and Kodo millet-*Paspalum scrobiculatum*) and milk (including cow fodder). I am presently in my third season of data collection from these production processes. From the processes, I am collecting a variety of data. (see Table 1)

I have used the data collected from these processes to inform the content and relationships of tables within the database. I used the information collected from my literature review to inform the database's capacity to categorize data, perform calculations, and convert or translate data across units. The database's reference tables and their contents are described in Table 2.

With the proper programming, the database will be able to use the production related data and the reference information stored in the program to generate reports that reveal the environmental cost of different crops. A list of such reports is in Table 3.

Table 1. data being recorded from production processes
date
name of activity
names of participants
duration (in minutes)
crop i.d.
tools used
equipment operated
plot i.d.
outputs (specify quantity)
inputs (specify quantity)

Table 2. reference tables for database

Tools and equipment table: contains tool and equipment names, i.d. numbers, fuel consumption rate, price, estimated lifetime in minutes, gross embodied energy, rate of depreciation of embodied energy, rate of financial depreciation, horsepower, carbon emission rate (in kg of C per minute).

Materials table: contains materials names, i.d. numbers, distance transported for purchased inputs, energy content, embodied cultural energy, nutrient content, crop association, source, indication of organic or not organic score, category (eg. grain, legume, oilcake), price.

Plot table: provides the plot i.d. number, and the area (in m^2).

Irrigation table: contains the irrigation source name, i.d. number, delivery rate (in ltr/min), and indication of renewable or non-renewable.

Employee table: contains employee name, i.d., gender, wage rate, (Rs/min).

Crop table: lists crop names, and i.d.

Activity table: contains all activity names, and i.d. number.

Table 3. reports generated by database program

Caloric gain: amount of energy harvested per unit of cultural energy invested or expended on the crop's production. This should distinguish between primary product (grain or milk) and secondary product (straw or compost). This should also distinguish between renewable and non-renewable energy invested in the crop.

Water productivity: kg. of crop harvested per 1,000 litres of water applied. This should distinguish between renewable and non-renewable water applied.

Nutrient balance: nutrients harvested vs. nutrients invested in the crop.

Financial balance: amount of money earned from a harvest vs. the amount of money spent on production.

Carbon emission efficiency: kg. of crop per kg. of carbon emitted in the production process.

I am presently in the process of clarifying the method for energy accounting. I had vastly underestimated the complexity of energy accounting, as well as the multiplicity of methods being used. Consequently, much of the remaining discussion in this paper will focus upon the challenge of accounting for the energy in agriculture.

Boundaries

For any such accounting exercise, it is necessary to clarify the boundaries of consideration. For this exercise I initially selected sample plots of rice and millet production in order to collect a sample of data which is representative of the full range of activities and materials of consideration. I chose to study the entire dairy, including the compost piles, and sample plots of irrigated (Napier) and rainfed fodder (*Cenchrus ciliaris).*

The accounting did not consider overhead or indirect costs, such as fence repair, road maintenance, farm administration, or storeroom construction. I did not set up accounts to analyze such indirect costs because I was primarily interested in the costs and immediate biophysical impacts of our discreet production processes. In addition, I did not include such indirect costs because indirect costs are highly site specific. Furthermore, accounting for such infrastructure would add considerable complexity to the accounting framework. However, conventions do exist for measuring the energy embodied in farm infrastructure (Doering 1980, Wells 2001).

I chose to monitor a crop's production process from the time of field preparation to the bagging of the dried and winnowed harvest. We also are not monitoring the post-harvest processing of the crops, except for instances where our crop, such as millet, must be processed before it becomes an input into our diary. The accounting does include the energy expended to transport purchased inputs to the farm from the place of purchase, although I did not attempt to include the energy that was expended to transport such goods from their original source to the retailer.

Instruments

The study required a number of special devices to facilitate the consistent collection of reliable data. Stopwatches were used to measure time. Time was measured and recorded in minutes. Water delivery was measured by water flow meters, manufactured by Anand Zenner. A hanging digital scale with ten gram sensitivity, manufactured by ATCO, was used to measure biomass and milk. This scale was especially useful for improving the accuracy of our milk production records because foam in the milk always distorted volumetric measurements. I also purchased a 1 kg digital scale with sensitivity of half a gram for measuring small biomass samples.

A locally fabricated soil sampling auger simplified soil sample collection.

Data records are presently being entered in Excel worksheets in a desktop personal computer. After the database has been developed, records will be transferred to the database program.

Conventions

I will focus my discussion largely on conventions for accounting for energy in agriculture because my study is presently considering the alternative approaches. A variety of methods and terminology are used, making energy accounting a more complex exercise than I had anticipated. For example, see Mitchell's discussion of three alternative ways that one might measure or regard the energy value of manure in a production system.(1979 p.69)

In ecological accounting, the productivity of energy use may be analyzed in a number of different ways. Generally, a crop's **caloric gain** is the ratio of the gross energy harvested to the cultural energy expended in the production of a crop. A farm's **energy ratio** is the ratio of the gross energy in the marketed outputs to the cultural energy embodied in the purchased or imported inputs. (Bender, personal communication) **Cultural energy** includes, "human and animal labor, fossil fuels burned by tractors and vehicles during cultivation and harvesting, and energy used in transportation and in processing. Cultural energy also includes all energy required to grow seed, construct buildings, and to produce machinery, chemicals and fertilizers." (Heichel 1974 p. 3)

For the human and animal labour component of cultural energy, Heichel uses the "expenditure of human and animal energy in agricultural operations."(1974 p. 6) Heichel explains that,

> Calculating the caloric gain, or the ratio of calories of yield to the investment of calories of cultural energy (kcal kcal^{-1}), for specific cropping systems reveals whether the investment has multiplied, remained static, or declined. Caloric gain will be considered as a measure of the efficiency of utilization of cultural energy. Thus, by contrasting caloric gain among cropping systems, the comparative efficiency of utilization of cultural energy is revealed. (1974 p. 5)

Another method to assess the productivity of energy is the measurement of **conversion efficiency**. This is used to assess the use of energy by a herd of farm animals for the production of a commodity. Since we keep cows primarily for the production of dung, we are interested in the efficiency with which the herd converts inputs into dung.

Some studies calculate "**energy efficiency**", which is a ratio of the outputs ("the energy equivalent of the yield") to the energy in energy of inputs, such as "machinery, manure, green manure, seeds, plant protection materials, irrigation network materials." (Kabourakis 1996 p. 51)

Makhjani analyzes "**the energy intensity of farming**", which he defines as "the amount of energy, including the indirect energy inputs in the form of fertilizers, that it takes to produce one ton of food." (1975:16)

My review of some of the literature indicates that there are generally three ways being used to account for human and animal energy in agriculture.

Many studies use estimates of the kilocalories exerted by people and animals to account for the energy that they contribute to a production process. This approach is taken by Pimentel and Pimentel

(1996), Heichel (1974), Revelle (1976), Lewis (1951), Mishra and Ramakrishnan (1981) and Rappaport (1971). Using this method, energy expenditure varies depending upon the difficulty of the tasks involved. Rates of exertion for human males range from 0.418 MJ/hr for sedentary work to 0.697MJ/hr for heavy labour. (Toky and Ramakrishnan 1982 cite Gopalan et al., 1978) Heichel (1974) used the rate of 0.73 MJ/hr for human labour. Pimentel and Pimentel(1996) used the rate of 1.67 MJ/hr to account for human energy input into production systems. Lewis (1951) estimated 2.15 MJ/hr for human labour.

A second approach is to account using the energetic content of the food consumed by animals and people in the production process, which Mitchell (1979) calls "the biotic cost of work." Mitchell defines the biotic cost of agriculture as, "the total combustible calories needed to support the animals (and humans) of a system."(1979 p.82) This approach is adopted by Sainz (n.d.). According to Mitchell, "the energetic cost of work . . . should be given as the total input of calories of food to the cattle and human populations."(1979 p. 46) Mitchell uses the rate of consumption calculated by Kalirajan (1976) of 11MJ/day for people in Tamil Nadu.

He explains that,

> This method of accounting is necessary for an ecosystem analysis that accounts for the flow of all the energy and is the equivalent of using the sum of all the energy for maintenance, manufacture and operation of a machine rather than only the work output of a machine. . . Of course the actual work output of draft animals can be given and this value is useful information when it is a question of asking how many machines would be needed to replace a herd of bullocks. (1979 p. 46)

A third approach is taken by Marty Bender, who is directing the Sunshine Farm project at the Land Institute in Salina, Kansas. Bender (2003) argues that the above-mentioned methods under-represent the energetic cost of humans and animals, particularly in the context of heavily mechanized and fossil fuel intensive agricultures. Furthermore, he points out that these methods reflect or report energetic costs which society can do little to manipulate. For these reasons, Bender proposes that the biotic cost of agriculture should be derived from the gross amount of cultural energy that a nation expends to maintain its rural workforce. Such a method was developed by Fluck (1981).

Consequently, in his study of the energy of soybean production at the Sunshine Farm, Bender (forthcoming) accounts for the energy cultural expended to maintain the lifestyle of rural Americans at the rate of 75 MJ per capita per hour. This represents the cultural energy needed to make the people's clothing, grow their food, manufacture their car, power their TV, etc . . . Bender applied this method to the rural Indian population and calculated that on average rural Indians require 1/30th the amount of energy for their lifestyle, or 2.5 MJ per capita per hour. (Bender personal communication)

This figure approximately corresponds with the amount of energy that people in north-eastern India consume in the forms of food and fuel (3.05 MJ/per capita/hr) as measured by Patnaik and Ramakrishnan (1989). Patnaik and Ramakrishnan's measurement was presumably based on the caloric content of the foods and fuels of such communities rather than the cultural energy expended to produce such food and fuels. Their figure is therefore likely to be greater than the cultural energy expended to produce such food and fuel. Bender's figure also roughly corresponds with Makhijani's (1975) estimate that the per capita energy use of residents in Mangaon, Bihar, in the mid-1970s was 1.75 MJ/hr.

This approach does however present the challenge of deriving embodied energy factors for those elements of a production process which participate in their own reproduction or maintenance. For example, the rate of embodied energy expenditure (MJ/hr) for the farm's oxen must be derived from production processes in which the oxen themselves participate. In other words, to calculate an embodied energy factor for the oxen, we must charge them for their own labour at a rate that we have not yet calculated.

To calculate the embodied energy factor for the oxen (in MJ/hr), one must aggregate the energy that was expended over a specified period of time in producing, harvesting, transporting and storing their feed and fodder, the energy embodied in the labour for their care, and, ideally, the energy to fabricate and construct their shelter, prorated over its lifetime. This aggregate figure is then divided by the number of hours that the oxen worked in the specified period. But the oxen are very much involved in producing and transporting their own food. Consequently, in such a case, one must calculate the oxens' embodied energy factor disregarding that portion of the work that was done by the oxen for their own maintenance. One excludes such work from the numerator and the associated time in the denominator of the embodied energy factor. The resulting ratio provides us with the oxen's embodied energy factor. At the moment, I am using Fluck's approach for energy accounting.

Embodied energy in machinery and equipment was calculated using the formulas provided by Doering III (1980).

I accounted for the energetic cost of motorized transport at the rate of 0.8 kcal/kg/km, which is an average of the rates used by Thor and Kirkendall (1982), Oltenacu and Allen (1980) and Kok et al., (2001). Sainz (nd) uses the figure of 1.82 MJ/kg/km (or 434.6 kcal/kg/km), which he has taken from a report from the OECD (1982). The method by which this high figure was derived is not explained.

References

Unfortunately, references that are needed for setting up an ecological accounting program are widely scattered and not always consistent. I've had to consult a great amount of material to collect the information that I needed. I've compiled such references into a handbook which I will share with anybody who is interested. Particularly useful information has been published by David Pimentel, most notably his *Handbook of Energy Utilization in Agriculture* (1980), and *Food, Energy, and Society* (1996), co-edited with Marcia Pimentel. Fortunately, a growing amount of reference material and reports are available on the world wide web. Some examples of such materials are listed in the references of this paper.

Limits

I am not measuring soil loss. I assume our soil loss to be within the tolerable range of between .004 and .05 tonnes per hectare per year (Abramovitz 1997) because our slope is approximately 1%, because we bund our fields, and because we leave a considerable amount of crop waste on the fields.[3]

Challenges

Some general challenges to on-farm ecological accounting deserve mention. The diversity and dynamism of production on organic farms considerably complicate ecological accounting. The diagram in figure 1. illustrates such complexity.

Green manures and fallows are often polycultures that grow, die back, reseed themselves, and re-grow between cropping seasons. It is a challenge to confidently account for the *in-situ* net contributions of such dynamics.

It is unclear how to economically value homegrown inputs, such as cowfood ingredients, fodder, compost, etc. . . If we assume that the market currently undervalues such goods, then we must devise a more accurate estimation of their value than the market price. For example, at what rate should we credit the dairy for the compost that it supplies for the rice plots?

Although scattered, self sown fodder materials may not have a production cost, they have protection and harvest costs. At what rate should we charge the dairy for self-sown or volunteer fodder materials?

The time limits of farmers pose a serious challenge to the feasibility of on-farm ecological accounting. The workload of recording and entering data is overwhelming and needs to be minimized. On-farm ecological accounting must compromise between the agroecologist's enthusiasm for data and the farmer's workload. Furthermore, a personal computer is essential for record keeping and analysis.

A formula must be developed to factor in overhead and indirect costs to create a complete estimation of production costs.

Another convention which must be established is for prorating investments of money, nutrients and energy for field preparation for perennial crops such as cowfodder. It is difficult to estimate the period over which to prorate the amounts expended on field preparation and planting. A field may be under preparation (successive plantings of green manures) for three years before the first crop is planted. If such initial expenditures are charged completely to the first harvest, the accounts become

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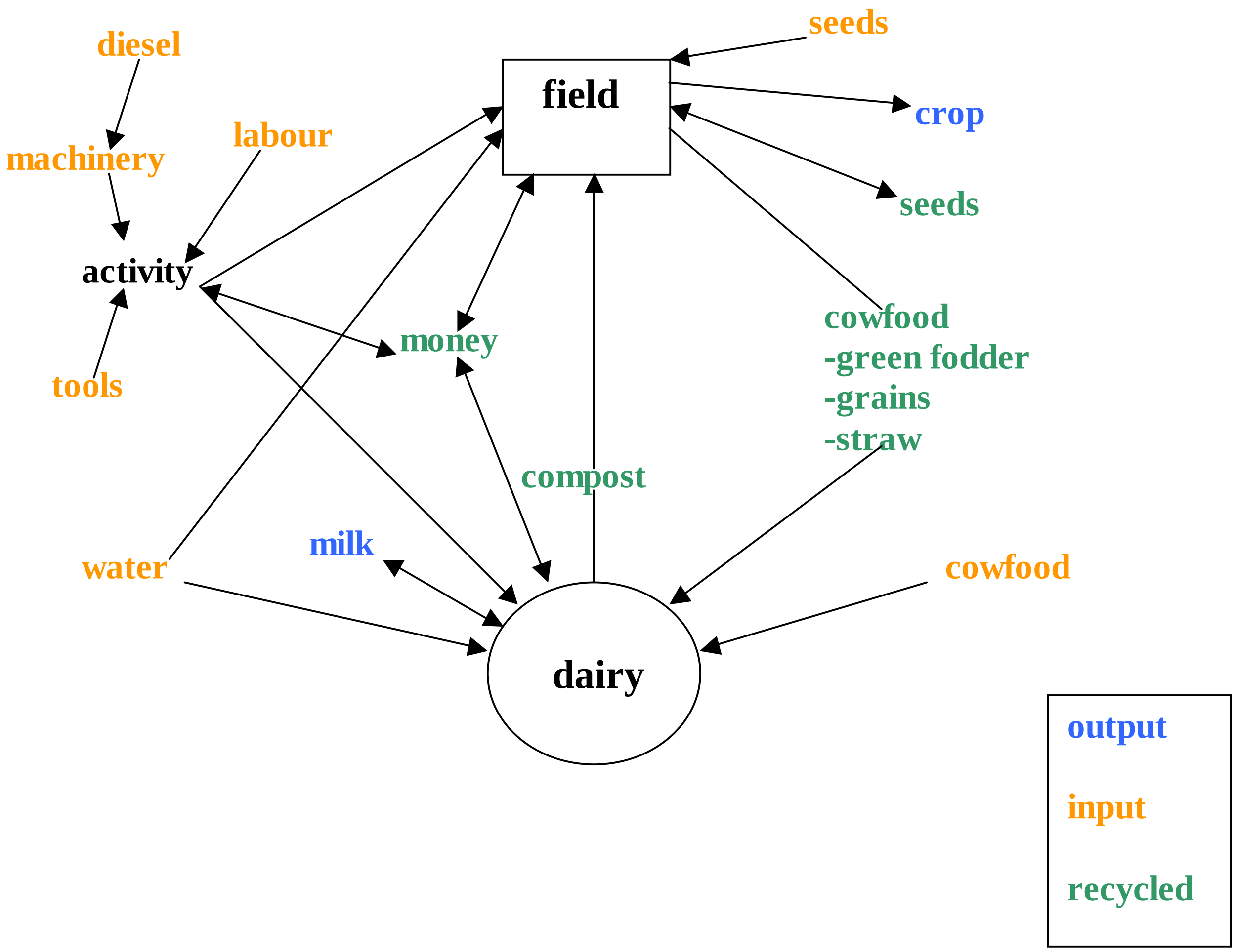
[3] Pimentel (1989) writes that soil loss @ 1 t ha^{-1} is tolerable.

distorted. It is difficult to estimate the number of years that the perennial crop will remain productive in a particular piece of land.

figure 1.



Scholars acknowledge the importance of calculating embodied energy factors that are based on local empirical data. (Sainz n.d.) Taking such measurements and performing such analysis are highly time consuming and complicated tasks.

Assumptions

It becomes necessary to make a number of assumptions in the course of the exercise. Some of these assumptions become questionable in the light of the dynamism on the farm. One such assumption is that moisture content of materials is relatively stable or consistent. I assume that fresh green matter has a moisture content of 65% based on several measurements of biomass on the farm.

This is slightly more than the 50% moisture content assumed in the literature. (Ayres and Ayres 1998) I assume that the moisture content of our farm yard manure remains around 40%, which is higher than the 25% moisture content of F.Y.M. assumed by Mitchell (1979). Field moisture of crop material at harvest is assumed to be 15%. (Makhijani and Poole 1975) Other assumptions are that the ratio of edible to inedible green fodder is 1:1, and that this ratio remains stable throughout the year. And we assume that nutrient contents of materials do not fluctuate throughout the year. These are probably imprecise assumptions, but we are unable to make daily measurements of materials and frequent adjustments of the database's formulas.

Makhijani (1975) assigns no energetic cost for the preparation of organic fertilizers in his crop energy budgets. We do not adopt this convention. We assume the cost of producing organic fertilizer to be the energy and wages expended cleaning the dairy stalls.

Like Doering (1979), I assume no energy recovery for scrapped or recycled tools and equipment because I cannot confidently estimate the amount of residual embodied energy recoverable from discarded or retired materials.

Preliminary findings and comparisons

Applying Fluck's method for energy accounting to Annapurna's dairy reveals that the dairy expends 137 Mcal per 100 kg of milk produced. Oltenacu and Allen (1980) report that the average energy expenditure on diary farms in the USA is 166 Mcal per 100 kg of milk. This suggests that in terms of energy the supposed efficiencies created by economies of scale of America's large dairies are off-set by that system's dependence upon long-distance transport and energy intensive inputs. Similarly, in the case of rice, Pimentel and Pimentel (1996) citing data from Rutger and Grant (1980) report that American rice farmers expend 7.35 MJ per kg of rice, (a caloric gain of 2.06:1)[4], whereas Annapurna expended[5] 6.23 MJ per kg of rice[6] (a caloric gain of 2.44:1) in 2002, and 4.82 MJ per kg of rice (a caloric gain of 3.15:1) in 2003.[7] Again, as in the case of milk, the supposed economies of scale of America's large farming operations clearly fail to deliver energetic efficiency.

Policy implications/considerations

There are a number of questions regarding the practicality of on-farm ecological accounting. By far, the largest question is how the findings of ecological accounting will be used to modify consumer and producer behavior. For some indication, we certainly watch the implementation of the crop diversification program in Punjab with interest.

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[4] I have adjusted the data from Rutger and Grant to conform with Bender's value for human energy in the rural American workforce.

[5] The figure is for energy expended for crop production only. The figure does not include energy expended on dehusking.

[6] The figures are for the caloric value of dehusked rice, not paddy. I assume that Rutger and Grant also account for rice, not paddy.

[7] Annapurna's figures differ from year to year depending upon the rainfall pattern and the inputs. In the 2002 rice crop, we used more sugar cane press mud which accounted for much of the energy difference between the two years.

Naturally, the approach taken by this study to energy accounting will produce findings which are very site specific. This approach should deliver precisely the intended insights which are needed to counteract the disinforming tendency of market forces. The disadvantage however is the intimidating complexity of calculating site-specific embodied energy factors.

Judging from the sheer complexity of on-farm ecological accounting, I suspect that a globalized economy will be ecologically unaccountable. While, in theory, informing or weighing prices to reflect site-specific ecological costs could be a solution to the economy's present tendency to largely disregard such costs, the idea is probably unworkable in the context of a globalized economy. It is very difficult to imagine how data about multiple bio-physical parameters can be translated and compressed into a price tag, particularly given the great disparity between competing producers' environmental endowments. It is unlikely that a price tag can become a sufficient substitute for care and knowledge.

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