Setting Up the Books For On-farm Ecological Accounting

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The western world is now suffering from the limited moral outlook of the three previous generations . . . The two evils are: one, the ignoration of the true relation of each organism to its environment; and the other, the habit of ignoring the intrinsic worth of the environment which must be allowed its weight in any consideration of final ends.

Alfred North Whitehead
Science and the modern world, 1925

If we are concerned about land abuse, we have begun a profound work of economic criticism. Study of the history of land use (and any local history will do) informs us that we have had for a long time an economy that thrives by undermining its own foundations. Industrialism, which is the name of our economy, and which is now virtually the only economy of the world, has been from its beginnings in a state of riot. It is based squarely upon the principle of violence toward everything on which it depends.

Wendell Berry
The Natural Farmer, Fall 1998

We routinely produce economists who lack the most rudimentary understanding of ecology or thermodynamics. This explains why our national accounting systems add the price of the sale of a bushel of wheat to the gross national product while forgetting to subtract the three bushels of topsoil lost to grow it. As a result of incomplete education, we have fooled ourselves into thinking that we are much richer than we are.

David Orr
The Ecologist August 1999

All that lies just below the surface has in it a large element of capital, the produce of man's past labour. Those free gifts of nature which Ricardo classed as the 'inherent' and 'indestructible' properties of the soil have been largely modified; partly impoverished and partly enriched by the work of many generations.

Alfred Marshall
Principles of economics 1947

We have so mastered science and engineering that we can keep the cost going down even as we use the stuff up.

Amory Lovins
Rocky Mountain Institute Newsletter
Winter 1992

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Abstract

Conventional frameworks for the assessment of agricultural production practices, such as financial accounting and input-output analysis, fail to fully recognize and represent many of the connections and flows within agroecosystems. A more holistic, ecological understanding of agricultural practices is required for the purpose of determining which practices are ecologically economical, and to reveal shadow efficiencies which may be hidden by conventional analytical approaches.

In the initial stage of an ecological accounting exercise on farms in Tamil Nadu, a body of literature (handbooks, articles and research reports) was collected and reviewed for the purpose of identifying concepts, methods and baseline data that can shape and inform a new, holistic analytical approach: on-farm ecological accounting. This paper presents some of the insights gained during the review of the collected resources, as well as the list of resources, grouped by subject area.

Acknowledgements

I'm grateful to be with you today to share the results of work that I have been doing for the past seven months to prepare myself for an on-farm ecological accounting exercise that will begin next year in Tamil Nadu. First, I must take this opportunity to thank the people who have helped me, particularly those who kindly responded to my requests for material for this study. My deep appreciation goes to Marty Bender, David Pimentel, Norman Myers, Susan Subak, Colin Laird, Amarjit Singh and Frank Golley. I am especially grateful to Rudolf de Groot and Martin Bender for granting permission to reproduce portions of their work in this presentation. I also want to thank Dr. Chopra and Dr. Bisaliah, Ms. Preeti Sethi and all the others who have worked to arrange this important gathering. Funding for this research comes from the Foundation for World Education.

Introduction

I first encountered the concept of on-farm ecological accounting in 1989, while I was an intern at the Land Institute, a small, independent agricultural research institute in Salina, Kansas, in the USA. In fact, I have taken the title of my presentation from a question that I once heard being asked by the Land Institute's co-founder and president, Wes Jackson. Wes asked, "What would it mean to set up the books for on-farm ecological accounting?" I was quite challenged by Wes's question, and during the decade since I left the Land Institute I have often wondered what it would mean to set up the books for on-farm ecological accounting.

This challenge became more enticing and imperative for me recently after I settled at Annapurna farm, a 135 acre organic farm that is a part of the experimental, international township called Auroville, near Pondicherry. At Annapurna we produce primarily fieldcrops: oilseeds, grains and pulses, but also milk, and fodder for the cattle.

Over time, we, the managers of the farm, have come to understand that the farm's financial accounts provide only a partial picture or assessment of our performance as farm managers. We believe that our accounts, in fact, tell us little, if anything, about the ecological sustainability of our approach to food production.

This disjuncture, between our monetary balance and our ecological balance is not surprising if, as Paul Ekins insists, "practically every marketed activity or product that uses environmental resources is underpriced"(Ekins 1996 p.145). By this, Ekins means that a product's price in the marketplace is an imperfect or incomplete, and therefore misleading representation of that product's cost of production. Others have also recognized this inadequacy of market prices (Barbier 1994, Maler et al. 1994, Costanza et al. 1997, Odum 1994).

After working on farms and studying the political economy of agriculture, I have come to the conclusion that in many instances conventional economists mistakenly regard exploitation as efficiency. I have observed that the competitive atmosphere of a free market generates economic selection pressures which advantage the most ruthless exploiter.

Because our conventional accounting approach is not a reliable indicator of the ecological viability of our practices, we are looking for a way to analyze our production practices in terms of their ecological sustainability. An ecological accounting would be of particular interest to us, and particularly appropriate, because Annapurna is not a business in any conventional sense. The labour of the 4 managers is decommodified, in the sense that we are volunteers, compensated entirely in kind. The land is also decommodified, by which I mean that it is not the private property of an individual. It has a specified purpose, which is to be a farm, and the land is not expected to generate monetary profit. Our responsibility as managers at Annapurna is not to make money. Rather, we are expected to produce food in ways that are ecologically economical. I suspect that our time horizon is longer, and the breadth of our considerations is greater than those of farmers who produce food for profit.

Our peculiar situation has a number of material consequences. For example, to conserve biodiversity we maintain an *in situ* seed bank with approximately 30 traditional varieties of rice. We use indigenous cattle in our dairy, even though exotic breeds might be more profitable. To reduce our use of groundwater, we catch and store monsoon rain in a 7,800 m^3 pond which we have created. To provide space for other creatures, a large portion of the farm is planted to mixed forest. Along with farming organically, these are some of the things that would probably be regarded as uncompetitive, or as having a prohibitive opportunity cost by conventional economists.

In order to gain a clearer understanding of the impact of our production and conservation practices on the physical, chemical, biological and energetic flows, relationships and storages at Annapurna, and to assess such impacts against indicators of sustainability, I have started to wrestle with the question, "what would it mean to set up the books for on-farm ecological accounting?" My presentation today is the outcome of the first stage of this empirical, ecological accounting exercise. I have started the exercise by reviewing over 100 articles, book chapters, research reports and handbooks to identify existing concepts, methods and baseline data that can inform and shape an approach to ecological accounting. I want to share with you what I have learned while reviewing this collection of material.

I should point out that Annapurna's managers are the intended primary beneficiaries of this ecological accounting exercise. By this, I mean that the study is primarily intended to inform the managers' day to day decision making process, as well as their long range development strategy and priorities for the farm.

I should also add that in this paper I will not discuss the very contentious and complex issue of valuation of unpriced environmental resources and services. I will not discuss valuation because my empirical exercise at Annapurna will attempt valuation only after an ecological accounting methodology has been developed and applied, which is likely to take years. Another reason that I will not discuss valuation is that it is an enormous issue which itself requires considerable additional attention, especially the challenge of incorporating shadow values and costs into policy, and into transactions and exchanges in a marketplace.

However, in the attached references I have included resources and studies that address the valuation of unpriced environmental goods and services.

Ecological Accounting; Why and How?

The need for agricultural ecological accounting has become apparent as people have recognized shortcomings or limitations of existing analytical approaches, which tend to focus on single or isolated aspects of agriculture, particularly the inability of conventional analysis to effectively diagnose or address agriculture's worsening unsustainability. Reductionistic and mechanistic analytical approaches have indeed generated solutions to agricultural problems. But far too many of these solutions have over time demonstrated serious dysfunctions, often because the designers of such solutions regard the agro-ecosystem as nothing more than a factory.

According to Giampietro et al.:

> In general, the assessment of technologies of agricultural production is based on the calculation of ratios, such as kilograms of crop or livestock produced per hectare of land tilled per hour of labour . . . This approach becomes problematic when a holistic assessment of costs and benefits related to the management of ecosystems for agricultural production is desired (1992a p.451).

Examples of the conventional approach are Ruthenberg (1980) and Heichel (1974).

Hannon et al. similarly have observed:

> Accounting of material and energy flows has long been an important tool in ecosystem ecology. But each material is usually handled separately and independently. The connections *between* materials, energy, plants, animals, etc. have not been incorporated into the accounting framework, and 'service' or information flows (such as flower pollination by bees) are usually ignored (1991 p. 195).

The failure of conventional accounting frameworks to acknowledge externalities, defined as "uncertain social costs transferred to other social groups, or to future generations" (Martinez-Alier 1991 p.118), also called "shadow prices" (de Groot 1994), or "shadow costs" (Subak 1999), is another reason that we must develop a more adequate approach for assessing the performance of agricultural systems. Barbier explains that:

> The market mechanisms determining the 'prices' for natural resources and products derived from natural resource systems do not automatically take into account wider environmental costs, such as disruptions to ecological functions, assimilative capacity, amenity values, and other environmental impacts or foregone option and existence values . . . Nor do market mechanisms account for any user cost—the cost of foregoing future direct or indirect use benefits from resource depletion or degradation today (1994 p. 311).

Yet another criticism of conventional methods of assessing agriculture's performance is their normative expectation that agricultural systems will behave and perform with mechanistic predictability (Soule and Piper 1992, Rees and Wackernagel 1994 pp.364-365).

Ecological accounting should become an analytical tool or method which provides farmers and scientists with an impression of how multiple ecological processes on a farm are interacting and performing. Ecological accounting will undoubtedly reveal new insights into agriculture. To do this, it will require the adoption of a new way of seeing, as well as an emphasis on concepts not previously considered. It will also require an extension of the time horizon of analysis (Soule and Piper 1992, Giampietro et al. 1992a).

According to Judith Soule and Jon Piper(1992), researchers must adopt an “ecological perspective”. Soule and Piper assert that:

> The ecological perspective differs . . . from the economic perspective . . . with respect to both the complexity of factors involved in the system and the long time frame of consideration . . . An ecological time frame, in contrast to the short time frame of economics, permits the tracking of slow, insidious losses and beneficial effects that take more than a fiscal year to show up. An holistic, long term perspective is simply more appropriate to biological systems and essential for gaining an understanding of sustainability in agriculture(1992 p.80).

Soule and Piper elaborate how their proposed ecological perspective will shape agricultural scientists’ questions:

> Ecologists ask how ecosystems function, how they are sustained by sunlight, how species interact and coexist, and how energy and materials circulate within and between adjacent ecosystems. A move toward a sustainable agriculture implies that similar questions ought to be asked about agroecosystems. Researchers should be attempting to understand the functioning of agroecosystems rather than simply trying to manipulate their functioning. They should be asking how to make agroecosystems function more on sunlight and less on fossil fuels. They should investigate whether some crops might grow better together rather than alone in certain cases. And they should be trying to obtain efficient circulation of energy and materials within agroecosystems and to minimize or take advantage of exports to adjacent ecosystems (1992 p.80).

Additionally, they point out that, “adopting an ecological approach to agriculture means a shift toward dealing with unique circumstances and a simultaneous shift away from general formula solutions applied over a broad range of conditions”(1992 p.80).

Carl Folke et al. also address what it will mean to break away from the conventional analytical perspective:

> Successful attempts to integrate ecological and economic research requires [sic.] that ecological systems be viewed as sets of processes rather than a collection of resources, and that we focus on ecosystem behavior and discontinuities (system thresholds that mark the limits of system resilience) . . . A challenge for ecological economics is to incorporate the dynamic components of ecological systems into economic analysis (1994 p.13).

Others insist that researchers should be more attentive to natural system efficiencies (Van Tassel 1998), which we might call shadow efficiencies, and the value of ecosystem health (Corry 1998). It is clear that ecological accounting will require us to see and think about agriculture in different terms than we have in the past.

Critical concepts for ecological accounting

Two critical concepts for ecological accounting are natural capital and carrying capacity. Herman Daly defines natural capital as, “the stock that yields the flow of natural resources”(1994 p.30). He emphasizes that “natural capital is divided into two kinds . . . renewable and non-renewable”(1994 p.30). And, he adds, “natural capital was not and cannot be made by man”(1994 p.30). Rees and Wackernagel add that:

> Natural capital is not just an inventory of resources; it includes all those components of the ecosphere, and the structural relationships among them, whose organizational integrity is essential for the continuous self-production of the system itself(1997 p.4).

Clear recognition of the role and value of natural capital is imperative for ecological accounting so that the liquidation or destruction of natural capital, a process of impoverishment, is not mistakenly regarded as income or wealth creation, as routinely occurs in conventional accounting(Orr 1999, Serafy and Lutz 1989 p.3).

The second critical concept, carrying capacity, is, according to Paul Erlich, “central to the discipline of ecological economics”(1994 p.42). Erlich defines carrying capacity as, “the maximum population size of a given species that an area can support without reducing its ability to support the same species in the future”(1994 p.42).

The concept of carrying capacity is emphasized because ecological economists are aware of the existence of biophysical limits, an awareness not shared by neoclassical economists (Costanza et al. 1997b p.69). One dramatic illustration of biophysical limits is the fatigue of the green revolution. The diminishing returns that we are witnessing in green revolution agriculture demonstrate the limits of chemically dependent agriculture (Repetto 1994). One major research challenge for on-farm ecological accounting will be to discover and document the limits of well managed organic farms.

Frameworks for on-farm ecological accounting

To acquire insight into how I might actually apply ecological accounting at Annapurna, to shape and inform my own empirical study, I collected and read over 100 articles, chapters, handbooks and reports, surveying some of the thinking and applications that have been done to date. Since agricultural ecological accounting is still more of a concept or aspiration than a refined discipline, I looked for guidance from approaches such as environmental economics, input-output analysis and agricultural sciences, in addition to the nascent literature identifying itself with ecological economics. From this survey, I identified two studies which I would classify as agricultural ecological accounting. I also identified two methodologies that could inform an on-farm ecological accounting exercise.

Bruce Hannon defines an ecological accounting system as:

> A framework in which the quantified connections between organisms (individual species, collections of species) and their abiotic environment can be placed and balanced, without ambiguity, omission or double counting exchanges, at any scale which the investigator chooses. ‘Connections’ means any kind of exchange of product or service (e.g., nectar from a plant, pollination time from an insect) between ecological processes (e.g., insect and plant) (1991 p.235).

Selecting on the basis of Hannon’s definition, I identified two works that I would classify as agricultural ecological accounting; Martin Bender’s report, “A general accounting framework for ecological systems: a relational database methodology for human systems”(forthcoming), and the article, “Assessment of different agricultural production practices”, by Giampietro et al.(1992a).

Two other works, Rudolf de Groot’s (1994) environmental function analysis, and Vandana Shiva’s (1995) biodiversity based productivity framework, also offer constructive approaches.

Martin Bender is directing a 10-year study of the energetics of an organic farm belonging to the Land Institute. The study, which is completing its seventh year, is designed in part to discover what portion of the farm’s energy requirements can be satisfied from renewable sources on the farm itself. Bender has used the wealth of data that he has collected to develop a sophisticated relational database program which he proposes for various, agricultural as well as non-agricultural, applications. In his article, Bender presents the application of his database framework to soybean production. From the production process, he has collected data to inform 29 fields in the database (see table 1 for fields in Bender’s database). Table 2 shows the results of the analysis performed by the database.

Bender’s proposed general accounting framework has been used in this example to analyze the energetics of soybean production. He suggests that the database could be used as a tool to analyze other aspects of a lifestyle or a production process, such as nutrient flow, changes in soil health or the release of greenhouse gas. Energy efficiency is only one indicator of sustainability. It would be a considerable challenge to build a relational database that tracks or monitors and analyzes the multiple indicators of agricultural sustainability, but ultimately this is precisely what is needed for agricultural ecological accounting. And Bender’s work demonstrates that relational database software can be a valuable tool.

Table 1.
Database fields (Bender forthcoming, used here with permission)

Fields	Data	Description
Event Number	A,M	Unique number to identify record.
Date	M	For an event, or last date in period of regular event
Object Year	A,M	Year in Date field, or year of output for enterprises which may be later than year in Date field.
Downstream Agent	L,M	Recipient of supplies in a flow event (entries in both Upstream and Downstream Agent fields), or sole agent in a non-flow event. An exchange of two associated flows, such as a trade of goods, is entered as two records with the two agents switched in the second record.
Downstream Sector	A,M	Various classifications for industry, government or households, depending on the desired accounting categories, if any at all. If entry in Downstream Agent field is from the list, then the entry here would be entered automatically from a corresponding program file.
Upstream Agent	L,M	Donor of supplies in a flow event.
Upstream Sector	A,M	Same list as for Downstream Sector field.
Activity	L	Industrial processes, agricultural tasks, government services, household activities, etc. Examples of agricultural activities include field operation, animal care, repair, construction, transportation, and a few other general tasks. Special activities would be in list for Subobject field or could be manually entered in that field.
Equipment	L,S	Specific vehicles, tractors, industrial machines, draft animals, farm implements, appliances, tools, etc.
Horse Labor	M	Number of hours.
Human Labor	M	Number of hours.
Fuel	L	Specific fuels, including electricity.
Fuel Amount	M	According to Fuel Units field.
Fuel Units	A	Units that the amount is given in. Dictated by selection in Fuel Field.
Object	L,S	Object(s) and/or enterprise(s) for which activity was done. For example, a list for a farm would contain specific crops, livestock, tractors, vehicles, implements, equipment, buildings, bins, etc. Since objects and enterprises are focal points for the remaining fields below, a supplementary data table may also include keyed supplementary tables from Plots and/or Item Description fields.
Subobject	L,M	Specific part of enterprise in Object field for which activity was done. Subobject may be physical (e.g., fence for the cattle) or a special activity (e.g., veterinary care of cattle).
Plots	L,S	To indicate the plots of land associated with the activity and object, such as tillage of crops on a farm.
Acreage	A	Acreage of plots indicated in Plots field for enterprise chosen in Object field, summed from values for plots in program file.
Item Description	M,S	For internal reference, freestyle description of item in the event. A supplementary data table would also include entries in the remaining fields below.
Item Monetary Amount	M	Debit for downstream agent and credit for upstream agent. Usually entered in records of transport activities.
Item Amortization Period	M	Estimated useful lifetime of item in years.
Item Disposition	P	Appearance (import or internally produced output) or disappearance (export or consumed input) of a supply with respect to system boundary. Hence, four entries: import, output, export, and input. Entry of output notes that the item is a product or outgoing supply, not an input. Entries of disappearance indicate records in which the downstream agent or associated enterprise is charged the value for the ecological property of the supply (see Supply and Supply Origin fields).

Supply	L,S	The embodied energy (inputs and some outputs) or gross energy content (some outputs) of an entry in Item Description field is dictated by the entry in this field. The entry in Item Description field is matched by selection of an entry for this field from a large list of processed supplies and semi-processed basic materials. If entry in Item Description field is not in this list, then it must be disaggregated into simplified composition of supplies and/or materials that are in this list. For each property in the accounting, such as embodied energy or carbon dioxide emission, there would be a separate program file containing known factors for various supplies and materials that would be applied to quantities in the Supply Amount field. A supplementary data table would also include entries in the remaining fields below.
Supply Category	L	Entry from a list of accounting categories for the supplies in the list for Supply field. For example, the categories for a farm might include crop, seed, feed, animal and other supply, the last one including unlisted supplies as well as some listed ones.
Supply Origin	P	Origin of supply determines the value of ecological property for supply. Entries made when there are entries of disappearance in the Item Disposition field. Three possible entries for origin are: import, internal (system), and internal (agent). There could also be other entries of origin if they have unique values for the ecological property of the supply.
Supply Amount	M	Quantity according to Supply Units field.
Supply Units	A	Units that the amount is given in. Dictated by selection in Supply field.
Supply Property Value	M	Entered factor of atypical value for ecological property of listed supply that overrides standard factor stored in corresponding program file.
Supply Property Type	M	Property for which atypical value is entered in Supply Property Value field.

a) L, selection from a standardized field list; M, Manual entry; P, pushbutton entry; A, automatically entered by software, sometimes from a program file; S, supplementary data table keyed to the main data table in order to store multiple entries for field(s) in an event. Each field list is constructed by user according to database application.

Table 2.

Soybean energy budget generated from database program (Bender forthcoming, used here with permission).

Input	Quantity (unit/ha)	Energy (MJ/ha)	Ratio (output/total input) Without labor	with labor
Human labor	--hours/ha—			
Field operation				
Tractor and combine	6.1	460		
Draft horses	8.0	600		
Hand-hoeing weeds	8.5	640		
Preparation for field operation				
Tractor, combine & implements	0.5	40		
Draft horse harnesses	1.5	110		
Transportation	0.8	60		
Prorated human labor				
Repair of tractors, combines and trucks	1.6	120		
Horse care	5.1	380		
Production of on-farm horse feed [a]	6.4	480		
Amortized, constructed facilities [a,b]	1.6	120		
Total labor	40.1	3,010		
Supplies	--kg/ha—			
Liquid fuels	71	3,210		
Feed for draft horses and foal	246	830		
Seed and inoculant	52	1,070		
Freight transport to dealers [c]	(201)	220		
Subtotal	369	5,330		
Prorated machinery and facilities	--kg/ha—			
Tractor repair	3	200		
Materials for horse care	5	140		
Amortized capital				
Pick-up truck and grain truck	8	410		
Tractor and back-up tractor	7	360		
Combine	30	1,520		
Implements	7	390		
Equipment/tools	1	70		
Constructed facilities [a,b]	77	810		
Freight transport to dealers [c]	(138)	150		
Subtotal	138	4,050		
Total input	507	9,380 w/o labor; 12,390 with labor		
Output	--kg/ha—	MJ/ha		
Oilseed yield	2,560	43,010	4.6 MJ/MJ	3.5MJ/MJ
Protein yield	1,020	---	0.11kg/MJ	0.082kg/MJ
Oil yield	460	17,100	1.8MJ/MJ	1.4MJ/MJ

a) Due to underemployment of horses, inputs for horses were decreased by a factor of 0.28 to reflect the prorating that would result from full employment of 5 horses, the number that would be needed if the 50 acres of crops were farmed only with horses.
b) Barn, horse, feed storage (hay shed and grain bins), horse stalls, fencing, water supply, harness storage.
c) Delivery of purchased materials from factories to dealers, not including horse feed produced on farm.

Mario Giampietro, Giovanni Cerretelli and David Pimentel(1992a) acknowledge the complexity of agricultural systems, and, accordingly, assess four different approaches to beef production using a number of different scales. Giampietro et al. use six different parameters; "(i) requirement of land, (ii) requirement of labor, (iii) level of technological capitalization, (iv) ecological impact, (v) ratio of densities of energy throughput: *the system of production and the ecosystem exploited*, (and)(vi) sustainability of the production"(1992a p.454), in their assessment of different agricultural practices.

A great deal of their assessment is done by converting parameters into energy equivalents. The final parameter, "sustainability of the production", which is curiously considered apart from "ecological impact", is determined by considering the system's dependency on non-renewable fossil fuel, and by averaging the following indicators;

-soil erosion and rate of water runoff;
-change in parameters describing the soil (structure, organic matter content, soil biota, etc.);
-loss of biological diversity, on a regional basis;
-decrease in standing plant biomass;
-increase in chemical and organic pollution in the ecosystem(1992a p.456).

Unfortunately, the measurement and interpretation of these sustainability indicators is not thoroughly elaborated, particularly the matter of adjudicating between agricultural systems which score or perform inconsistently across indicators.

Their framework is notable for its recurring reference to the limits of natural ecosystems as indicators of sustainable production levels. The use of nature for instructive benchmarks is further elaborated and developed in their paper, "Energy analysis of agricultural ecosystem management: human return and sustainability" (Giampietro et al., 1992b).

Giampietro et al. propose the concept of "biophysical capital";

> to describe the ecosystem's ability to use solar energy for self-organization: that is, the generation of biophysical processes that maintain the biosphere's structure and function . . . The biophysical capital of an ecosystem can be assessed by the quantity of solar energy that is used in the work of self-organization ($W\ m^{-2}$). This parameter is determined by the quantity of standing biomass ($Kg\ m^{-2}$) and by the energy dissipated to maintain 1 kg of biomass structure ($W\ kg^{-1}$)(1992a p.452).

They calculate the "biophysical capital affected" (BCA) by multiplying the area altered by the biophysical capital of the wild ecosystem (1992a p.455).

Giampietro et al. maintain that:

> Sustainability . . . implies that human exploitation of natural processes leaves in the ecosystem a flow of energy

> sufficient to maintain the stability of its biophysical capital, that is, its original structures/functions. . . Coming to sustainability in agriculture, if the agro-ecosystem is not in a steady state and resources are harvested from the biological compartment at a rate higher than that at which they are produced, then agricultural production implies a slow destruction of its structure/function (1992a p.452).

Another aspect of agricultural assessment which Giampietro et al. repeatedly emphasize the importance of is the production system's social or cultural context. They insist that: "any assessment of agricultural production should address the type of interaction between human society and its environment"(1992a p. 451). Although they emphasize this point, they do not elaborate it greatly or apply it systematically. This is unfortunate because analysis of social context can reveal those relations of production which will be possible, which will be unlikely, and which will perhaps be entirely prohibited, each of which comes with its own environmental possibilities and limits (e.g., Strange 1988). For example, as I mentioned earlier, in a very competitive economic environment, the pressures to discount the present and future value of land and labour make it unlikely that one will find many farmers who adequately replenish their soil's fertility naturally. In such an economic context it is hardly surprising that most farmers simply cannot afford to farm sustainably.

Giampietro et al. present an approach to assessment which can provide a basis, or elements for a comprehensive framework for agricultural ecological accounting.

In my review of the literature, one proposed framework stood out for its emphasis on biodiversity. Vandana Shiva's biodiversity based productivity framework provides a biodiversity-centric framework for the assessment of agricultural systems. Shiva's framework is structured to inventory the biological resources on a farm and to identify and quantify the monetary values of the services that such resources perform.

The framework proposed by Shiva is simple, intended for use at the grassroots, and intended, she says, to "be adapted to reflect the complexity of the socio-economic context of farming"(1995 p.20). This framework is indeed unique because of its focus on an issue that others have not rigorously addressed, an omission that is surprising considering both the importance of biodiversity, and the alarming rate of biodiversity's erosion (Erlich and Erlich 1992). Yet, at the same time, the omission of biodiversity from agricultural accounting assessments is understandable, given the difficulty of finding a way to properly and meaningfully credit those farmers who practice *in situ* conservation of endangered varieties of crops and animals.

For example, Giampietro et al. maintain that biodiversity is to be preserved in an area that is to be kept wild (1992a p.453), but they do not specify whether this wild space is on the farm or off the farm, nor do they suggest who should bear such expense.

Shiva's framework is also notably unique in its simplicity. Shiva's approach and the approach by Giampietro et al. demonstrate the two extremes of the complexity spectrum that one might find in agricultural ecological accounting.

A methodology proposed by Rudolf de Groot for recognizing and calculating the value of ecosystem functions can be useful for shaping on-farm ecological accounting studies. De Groot’s “function evaluation” uses “a checklist of 37 functions that can be attributed to natural ecosystems”(1994 p.153). De Groot defines environmental functions as, “the capacity of natural processes and components to provide goods and services that satisfy human needs (directly and/or indirectly)”(1994 p.152). He categorizes the functions according to “regulation functions, carrier functions, production functions, and information functions”(p.152). Table 3 contains de Groot’s list of environmental functions.

I reproduce de Groot’s list of environmental functions here because the list can help to identify dynamics that should not be omitted from a farm’s ecological balance sheet. The list helps one to begin to see things differently, from an ecological perspective.

De Groot applies his list of functions in a matrix against various approaches to valuation, as a procedure for calculating the complete value of environmental functions.

Parameters for on-farm ecological accounting

The studies and articles that I reviewed identified a number of different parameters that should ideally be included in an on-farm ecological accounting exercise. These include; soil, water, energy, nutrients, pollutants, productivity and biodiversity.

Soil should be monitored in a number of respects. According to Soule and Piper, “if sustainability is the goal, the soil, as the prime determinant of an agroecosystem’s carrying capacity, . . . becomes the major focus of research and stewardship”(1992 p.82). Giampietro et al. maintain that one indicator of sustainability is, “change in parameters describing the soil (structure, organic matter content, soil biota, etc.)” (1992a p.456), as well as “soil erosion”(1992a p.456). Water holding capacity is also an important characteristic.

In a comparative study of soil quality on conventional and biodynamic farms in New Zealand, John Reganold, Alan Palmer, James Lockhart and A. Neil Macgregor measured the soil’s bulk density, penetration resistance (at 0-20 cm., and 20-40 cm.), carbon content, respiration, mineralizable nitrogen, topsoil thickness, cation exchange capacity, total nitrogen, total phosphorous, pH, and extractable phosphorous, sulfur, calcium, magnesium, and potassium (Reganold et al. 1993). According to Reganold et al., “soil respiration and the ratio of mineralizable nitrogen to organic carbon give an indication of the microbial activity in the soil . . . Earthworms were counted to give another indication of biological activity” (1993 p. 347).

Table 3.
Rudolf de Groot's environmental functions (1994 p.154)
(included here with permission)

Regulation Functions
1. Protection against harmful cosmic influences
2. Regulation of the local and global energy balance
3. Regulation of the chemical composition of the atmosphere
4. Regulation of the chemical composition of the oceans
5. Regulation of the local and global climate
6. Regulation of runoff and flood-prevention (watershed protection)
7. Watercatchment and groundwater recharge
8. Prevention of soil erosion and sediment control
9. Formation of topsoil and maintenance of soil-fertility
10. Fixation of solar energy and biomass production
11. Storage and recycling of organic matter
12. Storage and recycling of nutrients
13. Storage and recycling of human waste
14. Regulation of biological control mechanisms
15. Maintenance of migration and nursery habitats
16. Maintenance of biological (and genetic) diversity

Carrier Functions-providing space and a suitable substrate for:
1. Human habitation and (indigenous) settlements
2. Cultivation (crop growing, animal husbandry, aquaculture)
3. Energy conversion
4. Recreation and tourism
5. Nature protection

Production Functions
1. Oxygen
2. Water (for drinking, irrigation, industry, etc.)
3. Food and nutritious drinks
4. Genetic resources
5. Medicinal resources
6. Raw materials for clothing and household fabrics
7. Raw materials for building, construction and industrial use
8. Biochemicals (other than fuel and medicines)
9. Fuel and energy
10. Fodder and fertilizer

Information Functions
1. Aesthetic information
2. Spiritual and religious information
3. Historic information
4. Cultural and artistic inspiration
5. Scientific and education information

In the studies that I collected, energy also receives much attention. The overall caloric gain ratio of a production process is indicative of general energetic efficiency (Heichel 1974), although it is important to distinguish between dependency upon renewable and non-renewable energy inputs (Giampietro et al. 1992a).

Monitoring a farm's impact on groundwater availability and quality is a crucial component of ecological accounting, possibly more critical than energy from an ecological perspective.

Susan Subak(1999) has analyzed the release of greenhouse gases in beef production. Greenhouse gas production is certainly an issue that deserves greater attention.

It is also important to monitor the nutrient flow on a farm, identifying storage sites and leakage points. One would want to track nitrogen, in its many forms; nitrate, nitrite, ammonia and ammonium, phosphorous and potassium, in addition to other nutrients, depending on local circumstances that would make particular nutrients critical. Special attention should be given to seasonal fluctuations of availability that might correlate with local weather patterns and biological activity.

Biodiversity can be inventoried, as Vandana Shiva has proposed, and such an inventory, if updated, can be used to recognize change over time. Such inventories can be useful at the village, bioregional or national level for informing the design and implementation of conservation measures.

I believe that there is the possibility of broadening Bender's database to include such parameters as soil characteristics, water, nutrients and biodiversity. Bender has demonstrated the tremendous capacity of such software for tracking and analyzing complex data.

Conclusion

The field of ecological accounting is young, and therefore has tremendous scope for development and application. This review of the literature suggests that there is much need for additional research and work in the areas of developing and applying accounting frameworks that incorporate multiple indicators of agriculture's ecological sustainability.

The academic resources and raw material for such a task are abundant. Many resources are listed in the reference section of this paper. The tools for such complex analysis are better than any that we've had before, as Martin Bender demonstrates with his application of Oracle software. Perhaps Mapmaker or Mapmaker Pro software could be applied for such a purpose. And, finally, the crisis of agriculture makes the need for such holistic analysis greater than ever before.

This paper is the initial product of an investigation which I am beginning now, and which is likely to go on for several years. Since I have been trained in Rural Sociology, I am academically poorly prepared for an exercise of such complexity. Consequently, I invite and welcome your comments, suggestions and criticisms. Moreover, I hope that out of this meeting a group will be formed to collaboratively develop and apply agricultural ecological accounting in the Indian context.

I thank you for your kind attention.