Ecosystems, Sustainability, and Grassland Management[1,2]

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ABSTRACT: The long-term sustainability of modern agriculture is examined in an ecological context. As an aid to defining agriculture, animal agriculture, and sustainable agriculture, a broad overview of the structural and functional aspects of ecosystems is presented. The long-term sustainability of two corn production systems and four beef cattle production systems is then examined relative to energy output/cultural energy input ratios. Results indicate that as corn yields increase, ecological efficiencies decrease dramatically. But analyses of the four beef cattle production systems show an even more startling effect in that cultural energy inputs (i.e. fossil fuels) far exceed energy outputs. This low level of efficiency was found to be largely the result of the interaction effects of the high levels of cultural energy required to maintain a productive cow herd and grow and finish calves in the rather harsh environment of the Northern Great Plains. Results pointedly reveal the high level of dependency of the U.S. beef cattle industry on fossil fuels. These findings in turn bring into question the ecological and economic risks associated with the current technology driving North American agriculture.

Key Words: Ecological Efficiency, Sustainable Agriculture, Beef Cattle, Ecosystem, Energy Flow

Introduction

Sustainable agriculture is a subject of great interest and lively debate in many segments of the world. The debates stem largely from differing viewpoints as to what is sustainable agriculture (USDA, 1980; Lowrance et al., 1986; Dover and Talbot, 1987; Keeney, 1989; Science Council of Canada, 1992; Crews et al., 1991; Lehman et al., 1993). The resulting effect is that no concise, universally acceptable definition of sustainable agriculture has yet emerged. This is in part because sustainable agriculture is viewed more often as a management philosophy rather than a method of operation (MacRae et al., 1993), and as such acceptance or rejection of any definition is linked to one's value system (Clark and Weise, 1993). But regardless of its precise definition, most agriculturalists agree that the concept of sustainable agriculture is of paramount importance to the sustainability of our biosphere and its ever increasing human population.

There is a wide array of response variables that can be used to examine the potential long-term sustainability of various agricultural practices with one of the most useful methods being energy output/input ratios. Such analyses are performed to quantify the energy return from products produced relative to the cultural energy invested to produce the product. Energy outputs are estimated by the direct conversion of product yields of mass (e.g., lb or kg) to energy yields (e.g., kcal or MJ). For example, a corn grain yield of 7,000 kg/ha is equivalent to a yield of about 24.5 million kcal/ha because 1 kg of corn grain contains about 3,500 kcal of energy (Pimentel and Burgess, 1980). However, in contrast to estimating outputs, assessing energy inputs is a much more difficult task because: 1) the array of kinds of inputs included in the production of a product is extremely diverse (e.g., human labor, transportation, fertilizer, machinery, fuels, etc.); and 2) detailed estimates of energy inputs associated with the manufacturing and operation of all the equipment and products used in an agricultural enterprise are highly variable and difficult to quantify. But regardless of these difficulties, energy output/cultural energy input estimates are of considerable value because they provide an estimate of our level of dependence on exogenous energy sources to meet established production goals. Moreover, such estimates provide insight into agriculture's dependence on inexpensive fossil fuels to meet established economic goals. This information is important if it is assumed that adequate supplies of alternative energy sources may not be readily available when the world's finite sources of fossil fuels are exhausted.

The broad objective of this paper is to examine the potential role that rangeland management may play in developing fully sustainable agriculture systems. Because this objective necessitates that we define sustainable agriculture in a clear, unambiguous manner, First I will present, as an aid to developing this definition, a fundamental overview of the structural and functional attributes of ecological systems. Next, I will examine agriculture from an ecological perspective with emphasis on sustainability. I will then present two case studies to elucidate potential pitfalls of current North American agriculture as it relates to sustainability. I will then conclude the paper by briefly exploring the potential role that rangeland agriculture may play in the development of sustainable agriculture systems.

The Ecosystem Concept

The ecosystem concept is fundamental to understanding what agriculture generally, and animal agriculture specifically, is all about. An **ecosystem** is simply an assemblage of organisms and their associated chemical and physical environment (Briske and Heitschmidt, 1991). A fishbowl is an ecosystem, as is a vegetable garden, a field of corn, a pasture, an entire ranch or farm, a city, a state, a country, or the entire world. In other words, an ecosystem can be essentially anything we desire providing we can define its boundaries.

The structural organization of all ecosystems can be described as consisting of four components; one non-living and three living. The **abiotic** (i.e., non-living) component defines the chemical and physical environment of the biotic (i.e., living) component. It includes such things as climate, atmosphere, and soils. It is the water in the fishbowl and the soil, air, and sunlight in the garden, cornfield, and pasture.

The three **biotic** components are producers, consumers, and decomposers. **Producers** are organisms that capture solar energy. They are the phytoplankton in the fishbowl, the vegetables in the garden, the corn in the cornfield, and the grasses, forbs, and shrubs growing in the pasture. **Consumers** are organisms that obtain their energy by consuming other organisms. Consumer organisms are animals except in very rare instances (e.g., the Venus fly trap). Consumers that consume plants are called herbivores, those consuming other animals are called carnivores, and those consuming both plants and animals are called omnivores. Cattle are herbivores, coyotes are primarily carnivores, and people are omnivores. **Decomposers** are the final or last consumers of organic matter. They are the microorganisms, primarily bacteria and fungi, that complete the decomposition process.

The integrity of an ecosystem is dependent on the efficient flow of energy through the system and the efficient cycling of the raw materials required to capture and process solar energy. **Food chains** are energy processing pathways that determine the pattern of energy flow through an ecosystem (Figure 1). There are two types of food chains; **detrital** and **grazing**. In both chains, the first **trophic level** consists of the primary producers or green plants. The difference between the chains come at the second trophic level in that if the primary consumers are decomposers, then the food chain is a detrital food chain (e.g., chain #1, Figure 1), otherwise that defined food chain is called a grazing food chain (e.g., chains #2, 3, and 4, Figure 1).

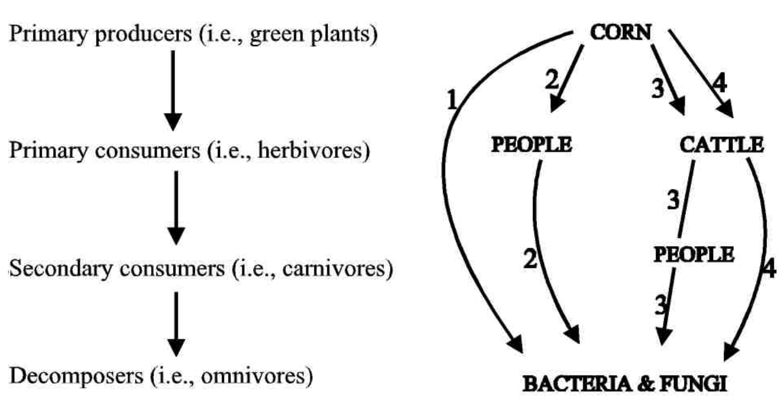

Figure 1. Schematic diagram of four potential food chains.

Regulation of energy flow through an ecosystem via various food chains is governed by the first two laws of thermodynamics. In their simplest form, these laws state that although energy can be transformed from one form to another, it can never be created nor destroyed nor

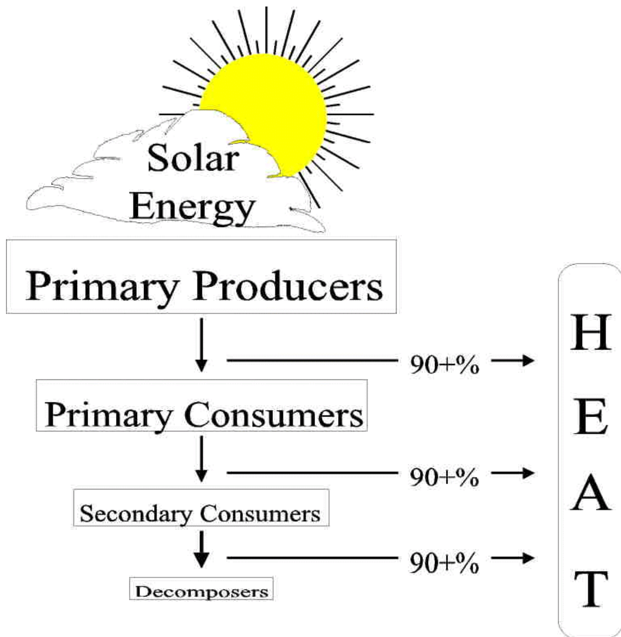

Figure 2. Simplified illustration of energy flow through a four trophic level food chain.

can any transformation be 100% efficient. The impact of these laws on energy flow through an ecosystem is that they dictate that the amount of energy that will flow through an ecosystem is set by the primary producers, and that a portion of this energy, usually greater than 90%, will be lost each time the energy is transferred from one trophic level to another. These concepts are depicted in Figure 2 wherein the largest energy store is the primary producers and the amounts of energy stored in each successive trophic level becomes smaller at every step.

The second indispensable function performed by ecosystems is the cycling of nutrients. Nutrients are the abiotic raw materials required by organisms to capture and process solar energy. Carbon, nitrogen, oxygen, and water are examples of nutrients that are continually cycled by ecosystems (Figure 3). The cycle revolves around the assimilation of nutrients by the primary producers followed by the sequential reduction of complex organic compounds by consumers to simpler, less complex forms.

The Ecosystem Concept and Agriculture

Agriculture is traditionally defined as the business of producing food and fiber. But a basic understanding of the structure and function of ecosystems reveals that **agriculture** can be defined also as the business of managing resources to capture solar energy and transfer it to people for their use. It can be reasoned then that success in agriculture is closely linked to the employment of management tactics that either: 1) enhance the efficiency that solar energy is captured; and(or) 2) the efficiency that captured solar energy is harvested; and(or) 3) the efficiency that harvested solar energy is assimilated.

Examples of management practices attempting to improve the efficiency that solar energy is captured, harvested, and assimilated are numerous. For example, irrigation, fertilization, and the planting of hybrid seeds are common tactics utilized to enhance efficiency of solar energy capture. Two examples of tactics used to improve the efficiency whereby captured solar energy is harvested are the use of insecticides and livestock grazing of post-harvest residue. In these instances, the insecticides are employed to shift the flow of captured solar energy from food chains that do not include people (e.g., rangeland forage ° grasshoppers ° decomposer) to those that do include people (e.g., rangeland forage ° livestock ° people ° decomposer). This shift is achieved by simply eliminating the competing consumer. Likewise, livestock grazing of post-harvest residue works in a similar fashion in that it shifts the flow of energy from a detrital food chain (e.g., corn stalks ° decomposers) to a grazing food chain that includes people (e.g., corn stalks ° livestock ° people ° decomposers).

Similarly, many different types of tactics are employed to improve the efficiency whereby harvested solar energy is assimilated. Two examples of tactics commonly used to directly enhance assimilation efficiency are the feeding of mineral supplements and doctoring sick animals. Often feeding just a small amount of a deficient nutrient or vaccinating to eliminate disease will dramatically improve an animal's performance. But the most common factor affecting assimilation efficiencies is quality of foodstuff. In fact, **food quality** can be defined relative to its effect on assimilation efficiencies in that high and low quality foods are those that result in high and low net energy gains to consuming organisms. For example, rangeland forages are deemed low quality human foodstuff but high quality ruminant livestock foodstuff. The reason for this disparity is that ruminant digestive systems are such that they can process range forages in a manner whereby they can derive most of their life giving nutrients from the forage. This is in contrast to human digestive systems which are incapable of effectively digesting these same forages. Thus, the assimilation efficiency of range forages is low for humans and high for ruminants.

Even the efficient production of fiber (e.g., cotton, timber, and wool) is dependent on the efficient capture of solar energy and its subsequent harvest. That is why cotton, for example, is often irrigated and fertilized (i.e., increase efficiency of solar energy capture). But in contrast to food production practices, post-harvest processing of fibers is designed primarily to interrupt food chains and prevent consumption of the fiber (e.g., termites consuming wood).

Sustainable Agriculture

A fundamental problem with the questions associated with sustainability stems in part from our inability to define what sustainability is or what it is not. An understanding of how ecosystems function provides an additional means of defining sustainable agriculture. As such,

sustainable agriculture may be broadly defined as ecologically sound agriculture and narrowly defined as eternal agriculture, that is, agriculture that can be practiced continually for eternity. It is those forms of agriculture that do not necessarily require exogenous energy subsidies to function.

But the issue of sustainable agriculture goes beyond the idea that it is eternal agriculture because without the use of fossil fuels, it is not possible for agriculturalists to feed and clothe the world's human population. Fossil fuel technology is a major reason that agriculturalists can produce an abundance of food and fiber. This is reflected in Table 1 which shows that as use of fertilizers, etc. (i.e., fossil fuels) are increased, corn yields increase also. But these data also reveal that the efficiency of production, as measured by energy output/cultural input ratios, decreases as yields increase. Moreover, analyses of four northern Great Plains cow-calf production systems shows energy output/cultural input ratios of <1 (Table 2).

Table 1. Energy output/cultural energy input ratios for corn production systems in Mexico (manpower only) and the United States (conventional)[a]

	Management system	
Item	Mexico	United States
	--------- kcal/ha ----------	
A. Cultural energy inputs	553,678	8,390,750
B. Grain yield	---------- kg/ha -----------	
1. Weight	1,944	7,000
	--------- kcal/ha ----------	
2. Energy	6,901,200	24,500,000
C. Energy output/input ratio	12.5	2.9

[a] Pimentel, 1984.

Table 2. Live weight, energy yield per animal, and energy output/cultural energy input ratios of moderate growth calves raised on Northern Great Plains rangeland until weaning.

	Days in finishing lot			
	0	84	168	252
Live weight (kg)	230	337	434	566
Energy Yield (Mcal)	280	496	802	1,120
Energy Output/Input Ratio[a]	0.23	0.28	0.33	0.36

[a] Based on moderate rate of stocking and 100% calf crop.

The data from these two studies reveal a fundamental problem with modern agricultural practices, that is our heavy dependence upon fossil fuels. This in turn brings into question the long-term sustainability of current agriculture practices. The challenge to agriculturalists stems around our abilities to develop and implement new technologies that will allow us to maintain and(or) increase yields of agriculture products while increasing ecological efficiencies.

Potential Role of Rangeland Managers

Based on the above concepts, **animal agriculture** can be defined as the business of managing animals so as to enhance the capture of solar energy and/or its transfer to people for their use. It follows then, that **rangeland agriculture** is a specific kind of animal agriculture in that it is the business of managing grazing animals. In other words, rangeland agriculture is grazing and grazing of indigenous grasslands is one of the most sustainable forms of agriculture known. This is because no other form of agriculture is less dependent on external finite resources, such as fossil fuels, and(or) external, potentially environmentally sensitive resources such as fertilizers, pesticides, etc., than grazing of native grasslands. In this sense, rangeland agriculture is the oldest, most unintrusive, mundane, environmentally friendly, fully sustainable form of agriculture known.

So if this is true, why do the data presented in Table 2 suggest otherwise. The underlying reason for these results is related largely to the interaction effects of low product output (i.e., small body mass) and the high cultural energy inputs required to maintain a productive cow and a growing or finishing calf in the rather harsh environment of the Northern Great Plains. For example, when minimal cultural energy was expended to grow and finish a weaned calf (Table 2, zero days in finishing lot), energy outputs were too low (280 Mcal) to offset the energy inputs required to maintain the cow-calf pair up to time of slaughter. And although improvements in the energy output/cultural input ratios were realized in the feedlot, they never approached a breakeven level of 1.0. Thus, the results of this study bring to question the long-term sustainability issue as it relates to currently accepted beef cattle production systems. The beef cattle industry's heavy reliance on fossil fuels to maintain a productive cow herd in regions where nutrient shortfalls are common and to market a consumer acceptable product carries with it some ecological and economic risks. These risks arise from the historical perspective that agriculture's continued success (i.e., sustainability) is tied to developing the technology needed to "control" nature as opposed to "living with" nature. Because the integrity of natural ecosystems is dependent on the efficient capture and processing of solar energy, ecosystem control strategies that alter natural flows of energy often require large inputs of exogenous energy. Risks accompany these control strategies because of future uncertainties about: 1) the availability of cheap sources of exogenous energy (e.g., fossil fuels); and 2) the potential disruption of critical life supporting ecological systems due to the continued generation of control strategy by-products (i.e., pollutants).

Central to the sustainability debate are the omnipotent technology and ecological constraint hypotheses. The omnipotent technology hypothesis embraces the fundamental concept that resource depletion (e.g., fossil fuels) automatically sets into motion a series of economic forces that alleviate the effects of depletion on society as a whole (Cleveland, 1987). On the other hand, the omnipotent ecological constraint hypothesis (Heitschmidt, 1991) is the underlying hypothesis supporting biophysical economic theory. Biophysical economics differ from standard economics in that they attempt to more fully factor the role of natural resources into the economic process (Pearce 1987). The focus is on merging ecology and economics so as to ensure that what is economically sound on the short-term is ecologically sound on the long-term. In this sense, it is important we recognize that economics is simply a measure of the intensity of society's beliefs rather than a measure of the merits of those beliefs (Sagoff, 1981). As such, some argue that "Economics can no longer afford to ignore, downplay or misrepresent the role of natural resources in the economic process. In the final analysis, natural resource quality sets broad but distinct limits on what is and what is not economically possible. Ignoring such limits leads to the euphoric delusion that the only limits to economic expansion exists in our own minds" (Cleveland, 1987).

These economic-ecological debates are central to the development of agricultural management strategies that are both ecologically and economically sustainable. Surely the results of our study provide some motivating interest to closely examine the general direction of agriculture research and specifically animal agriculture research. Our industry's heavy reliance on cheap fossil fuels is obvious and currently quite profitable. But is it the way of the future, and if not, what technology are we developing to meet this challenge? If we accept the premise that sustainable agriculture is eternal agriculture, i.e., agriculture that can be practiced forever, then what forms of animal agriculture might we consider sustainable?

The fundamental characteristic of sustainable animal agriculture systems must be that animals act as "energy brokers," that is they convert low quality human feedstuff (e.g., corn stalks, spoiled grains, waste products, etc.) into high quality human feedstuff for their consumption (e.g., meat, milk, eggs, etc.) (e.g., see Oltjen and Beckett, 1995). For example, livestock grazing of indigenous grasslands is fully sustainable in many regions of the world where level of cultural energy inputs required to maintain a productive herd of animals is low. Rangeland agriculture is grazing, and when properly managed, rangeland agriculture is fully sustainable having gone on long before the discovery of fossil fuels and will, without doubt, go on long after the depletion of fossil fuels.

Any discussion concerning the longterm sustainability of animal agriculture would be shallow and incomplete without some consideration given to the ecological relationship between human population food demands and livestock production systems. From an ecological perspective, humans are consumers that most often either solely occupy the second (herbivorous) or third (carnivorous) trophic level of food chains or concurrently occupy both the second and third trophic levels (omnivorous). Occupation of trophic levels greater than the second is in many instances a luxury afforded to only a privileged few, that being those living in an environment where human food demand is well below supply. However, when human food demand begins to exceed supply, the laws of thermodynamics dictate that humans occupy the second trophic level to the maximum extent possible, and as such, the role of animal agriculture is relegated to that of an "energy broker" (i.e., converting low quality foodstuff, such as rangeland forages, into high quality meat). Thus, the challenge to animal agriculturalists in a world of an ever increasing human population is to develop technology that will enhance animal conversion efficiencies of both high (e.g., cereal grains) and low (e.g., rangeland forages) quality foodstuff into high quality products that meet human expectations (e.g., tender, flavorable, etc.). Historically, North American animal agriculturalists have done a commendable job developing technology and associated seedstock that perform well in converting feed grains into consumer acceptable meat products. But because most selection criterion have focused largely on off-spring's performance in feedlot environments, it is not surprising that these same seedstocks do not generally do an acceptable job of converting grazable forages and other low quality roughages (e.g., straw) into highly desirable meat products. The fact of the matter is little effort has been expended in North America developing this ruminant animal production technology; and yet, it is this technology that will insure that North American animal agriculture will continue to play a critical and important role in sustaining the ever bulging human population inhabiting our biosphere.

I am hopeful that the contents of this article excite rangeland agriculturalists as to their potential role and responsibilities in developing and implementing sustainable agriculture technology. In addition, I am hopeful that the contents of this article provide rangeland agriculturalist with insight as to why the long-term health of modern day agriculture is highly dependent on the long-term health of this biosphere's human population and its associated ecological life support systems. Contrary to popular belief, the ecological ills of this biosphere are largely the result of human rather than agriculture production activities. Thus, the long-term health of rangeland agriculture is as dependent on focused, problem solving social science research activities as it is on traditional rangeland science research activities. Together we can overcome; apart we limit our options.

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