PRODUCTIVITY, EFFICIENCY AND RESILIENCE OF CROP AND LIVESTOCK PRODUCTION

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Summary

Hundreds of millions of people depend on food aid whereas about one in five in the developing world remains undernourished. Food riots escalated in 2008 as food prices outstripped the ability of many the world's people to pay. How can the world's farmers and ranchers produce enough food swiftly enough to keep up with population growth? Here, we provide an overview of productivity, efficiency and resilience of crops and livestock production in both industrialized and developing worlds in the context of sustainability. The challenges and opportunities in major patterns of food production are considered at enterprise, national and international levels. Sub-themes like crop versus animal production, the promise of genetically modified foods, sound agricultural

policies and potential effects of climate change on sustainable agriculture are addressed. Finally, recommendations on general strategies for sustainable crop and livestock production are provided. This chapter serves as an overview and introduction to companion chapters in this theme.

1. Introduction

Despite their diversity, crop and livestock systems can be assessed by performance indicators disconnected from the rapid fluctuations and underlying cycles that influence economic measures such as production costs and profitability.

Production considers the output of agricultural effort, whether food, fiber or fuel from crops or livestock. Production describes the performance of an agricultural system at any point in time whereas sustained yield describes its long-term capacity to generate the same harvest. Where a land base is expected to provide a variety of products and services, sustained yield may not be equivalent to sustainability.

Productivity has been and remains the primary measure of animal and crop production. In general terms, it is the ratio of product to a critical input notably land [e.g., kilograms/hectare]. But because there are usually multiple inputs, the expression takes many forms. Production of individual animals often is assessed as milk yields, weaning rates, carcase yields or, at the population level, herd offtakes. The implied denominator is time – usually a season or year, so by definition these are **rate efficiencies.** To deal with compounding processes such as growth, instantaneous rates (e.g. kg kg^{-1} d^{-1}) or some allometric scalar (often $X^{0.75}$ for metabolic processes) is used. These are called **turnover efficiencies (**output/asset) to distinguish them from **transfer efficiencies** (output/input).

The traditional transfer efficiency is annual yield per unit land area to accommodate what historically has been the limiting input. Total production per farm unit, regional jurisdiction or even national and international entity can be calculated by multiplying average productivity by the total land area devoted to any particular use. Refinement in these totals is achieved by appropriate stratification according to land quality or production practice.

This measure has served well during much of agricultural history when land was a major input and land clearing and cultivation were the means to serve growing markets. Expansion of the arable land base through clearing and irrigation supported much of the growth in the 19th and early 20th centuries. Fertilizers and selective breeding improved yields on this larger land base and sustained growth into current times.

Selective breeding and genetic manipulation seek to further these successes. Productivity measured in this way, of course, loses meaning when applied to "landless" systems of crop (greenhouse and hydroponics) and livestock (intensive rearing facilities) production. However, accounting for the land base that provides nutrients to support these "landless" systems is a way to skirt this problem.

Some well-known expressions of transfer efficiency are feed conversion ratios, water-use efficiency, and energetic efficiency. Energy output/input ratios have been argued as appropriate for evaluating modern agricultural systems as fuel supplies dwindle and costs increase. In a broader ecological sense, energy flow has been used to describe and compare ecosystem function.

Resilience describes how well production systems withstand and/or rebound from perturbation. Because resilience considers disturbances (which may be irregular and unpredictable), resilience is necessarily focused on long-term temporal scales. As such, resilient agricultural systems might be considered the most meaningful aspect of sustainability. However, because resilience does not have short or medium term economic returns, and many governments subsidize their farmers, resilience remains more of a notion than an operational principle. Resilience is one of several measures of sustainability. Related concepts include resistance, connectedness, vulnerability and adaptability. Analysis of risk is a rapidly growing field in a risk-averse society.

Such measures if carefully selected and critically applied provide summary criteria to evaluate and improve the performance of crop and livestock production systems. However, they still fail to capture certain critical system characteristics and must be considered at multiple scales and accommodate larger issues of human interaction and social justice. Inappropriate application of simple indices may lead to false hope for new technologies and disregard of negative externalities. **Sustainability**, a more comprehensive framework, attempts to address these and other critical parameters (Figure 1).

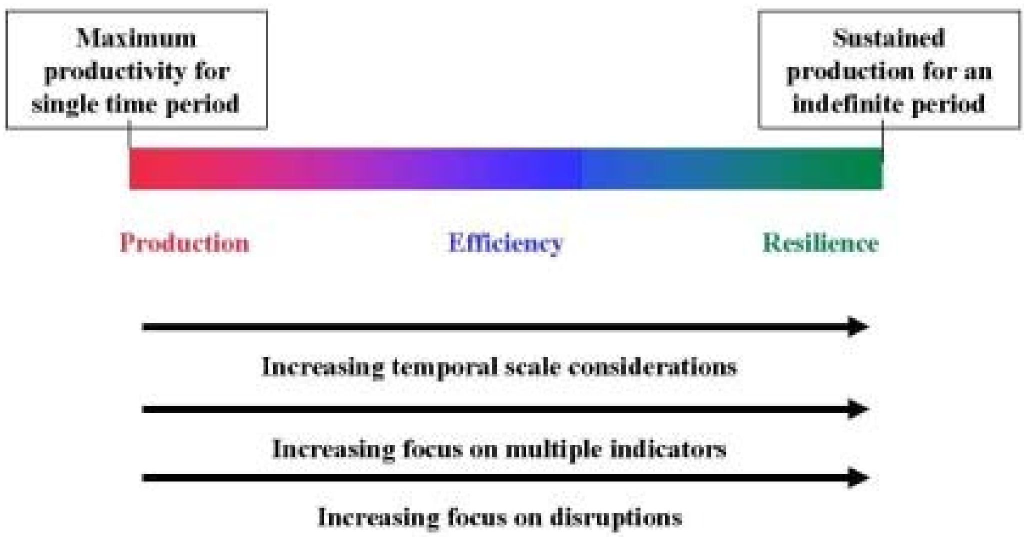

Figure 1: A continuum of productivity. "Production" on the left of the continuum is a consideration of outputs. Because inputs are often limiting, few agricultural producers likely focus only on production. The extreme example would be producing crops or livestock for a single time period. The focus of "efficiency" is both outputs and inputs, as well as expected levels of disturbance. Conventional economic analysis is useful for measuring efficiency. "Resilience" considers production while acknowledging gradual degradation of the system (e.g. through nutrient depletion, soil erosion, impoverishment of biodiversity) and unexpected shocks (e.g. pest outbreaks). As such, resilience

considers multiple factors of production, including soil conditions and pest environmental services, such as pest predators. Resilience can be viewed as the most meaningful characteristic of sustainability.

2. Science of Sustainability

Sustainability science is an emerging field of systems research that crosses disciplinary domains and stresses the important interactions of natural, economic and social capital. Operationally, it recognizes the importance of linking science, policy and practice.

Sustainability science is necessarily transdisciplinary because it deals with processes and trends at large spatial and temporal scales; it studies global systems in entirety whereas disciplinary studies compartmentalize system processes. The importance of contextual knowledge is widely recognized but considered formidably difficult to operationalize. It may require different tools, different ways of thinking, and different organizational and incentive structures.

Conventional sciences generally look at how things are, how things **were**, and how things **changed** to get to where they are. They generally are not future-oriented.

In contrast, sustainability science is future-oriented, which brings a dynamic that greatly complicates matters (Figure 2). Instead of dwelling on an improved understanding about current or past states, sustainability science dares to forecast what the future will be like. Projecting current rates of change is often used to anticipate the future but this is based on the dangerous assumption that current rates will continue. The focus of sustainability science is on understanding dynamic interactions that influence how these rates might change and how the future might unfold.

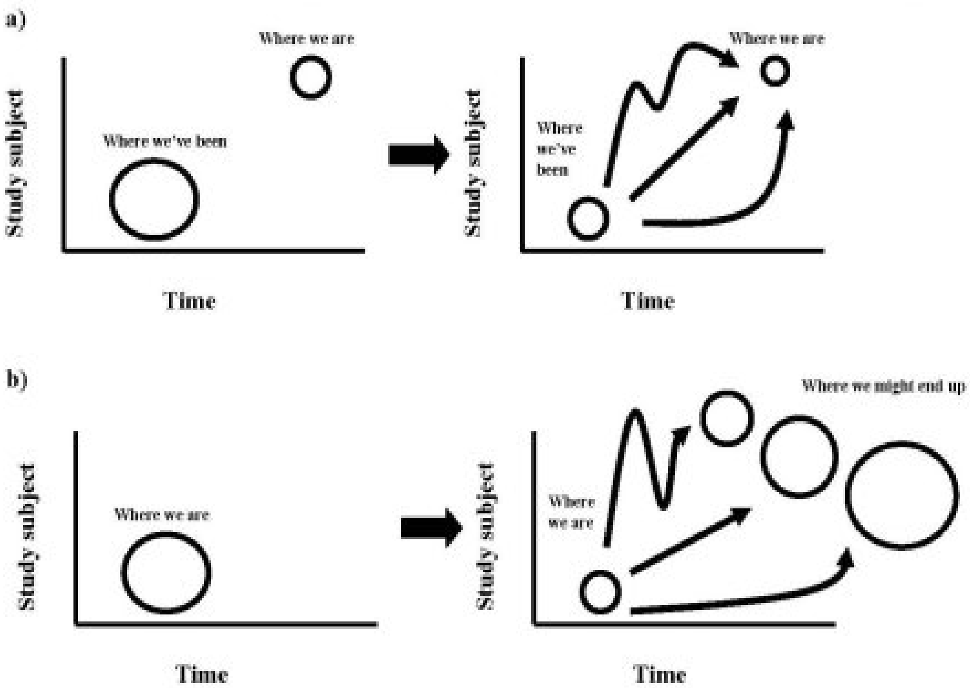

Figure 2. a) Scope of conventional sciences. There is a rough idea of where a subject/process was, and there is a finer understanding of where the subject/process is now. The main goal is to understand how phenomena developed. There are differing opinions on where things once were (multiple circles) and are now. Similarly, the farther in the past the subject is studied, the more vague the idea of its state (larger circle). b) Scope of sustainability science. Understanding of the current state of a subject is important, but because there is only one endpoint in a trajectory, determining the shape and direction of the trajectory is difficult. The longer the forecasting horizon, the more uncertain the predictions (larger circles).

2.1. Sustainability Goals

The goals of sustainability are commonly depicted as the nexus of economy, environment, and society (Figure 3a). Viewed this way, three key disciplines are to achieving sustainable goals. Economists are concerned mainly with growth, efficiency and maximum use of resources. Ecologists are concerned with the integrity of natural systems and issues related to living within the carrying capacity of the environment. Sociologists focus on human needs and on such concepts as equity, empowerment, social cohesion and cultural identity.

Although helpful in defining a target for sustainable development, this three-ringed representation of sustainability correctly identifies the parts but not the nature of their interaction. It runs the risk of conveying the notion that economy, society and environment, although intersecting, are largely independent. A consequence is that governments can focus on the three domains individually and inequitably; indeed, this kind of thinking already dominates, as governments (even those who embrace the term sustainable development) give primacy to the economy with limited consideration awarded broader issues of society or environment. The triple-bottom-line accounting promoted by industry gives little reassurance.

Another visualization shows the economy nestled within society in turn nestled within the broader environment (Figure 3b). The economy is a social construct in that society embraces human actions and interactions, and economic processes are human-mediated. Social actions take place within the environment. The greater environment supplies human demands, and humans themselves are organisms that are part of the environment. So economic activity always impacts societies and the environment, and social impacts always impact the environment. Yet not all environmental impacts are felt by societies, nor are all societal impacts economic ones. This implies that the economy depends on social stability and well-being and both the economy and society depend on environmental products and stability.

Economic growth is almost universally considered a worthwhile goal. The conservation of ecosystems and culture are also accepted as important. These three large-scale systems are not independent so one cannot focus on one goal while ignoring the other two. The ever-expanding web of globalization and industrialization, partly caused by the expanding human population, further links these three systems. In 1987, the term **sustainable development** was brought into common use by the World Commission on Environment and Development. The commission’s report, *Our Common Future*, defined the term as a form of development that “meets the needs of the present without compromising the ability of future generations to meet their own needs." Both developed and developing countries have embraced the concept of sustainable development, but often in different ways. The shared goal, however, is to maintain and improve the long-term welfare of both humans and ecosystems.

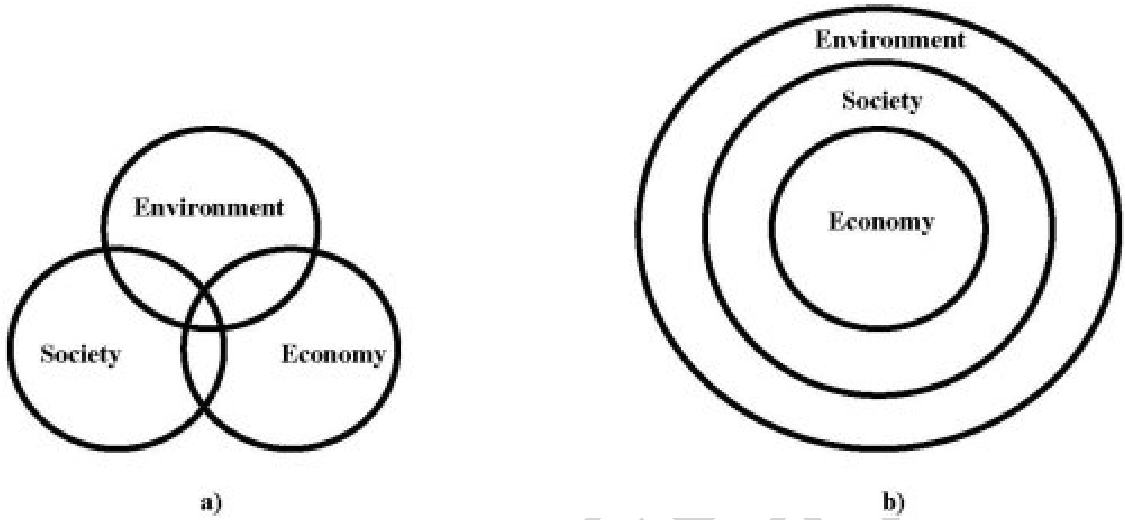

Figure 3: a) A conceptual view of sustainable development. This is a poor representation of the world but gives a clear target. b) an alternative integrated and representative view of the world than a).

2.2. Definitions of Sustainability

With regards to agriculture, the definition of sustainability can be refined "as practices that meet current and future societal needs for food and fiber, ecosystem services, and healthy lives while appropriately accounting for all costs and benefits." Several points are raised. First, sustainability is human-centered — the concept of sustainability was developed by humans for humans. To further develop this point, sustainability requires that resources must meet human needs. This is not the same as saying that resource harvest must stay constant. Production of needed resources must be considered in the context of their need. Second, sustainability considers the economic, social, and environmental spheres. A single measure of success (e.g. GDP) does not capture sustainability. Stresses on these systems should not exceed their capacity to handle them – the resilience of systems, particularly at larger scales should not be compromised. Third, sustainability considers the system around resources and not resources themselves — "sustained harvest" levels are hardly ever sustainable. Conditions around the sustained harvests are not constant, and a system that does not account for shifting conditions, needs and values is inherently unsustainable. Sustainability is more of a process than a state and hence is usually a moving target.

As global interdependencies increase and research/experience accumulate, understanding of ecological, social, and economic systems, priorities of sustainability will change. Sustainable strategies recognize that landuses operate on a dynamic landscape, with multiple interests in space and limited resources.

If additional land is used for crop and livestock production, land available for other uses is diminished. Similarly, changes made to the intensity of agricultural production change resource requirements, and limit resources available to other landuses.

With the growth of human populations and the world economy, land use will continue to be contentious issues. Three broad, competing interests will be those of immediate needs (e.g. food, fiber and biofuel), those of comfort demands (e.g. leisure residences), and those of nature conservation (e.g. protected parks). There will likely be contention within these interests as well. Should land used for food production be used for crops or livestock or both? Should water be used for irrigation, or industrial and urban use? Should comfort demands be fulfilled by creating cottage communities or spreading urban areas? Should nature conservation areas limit human access or facilitate it? These are large-scale, difficult questions that depend on skillfully linking science, policy and practice. All of this requires inter-jurisdictional cooperation at unprecedented scales.

3. Central Problem

Agriculture seeks to produce food, but sustainable agriculture adds the condition that production should provide for the present and the future. Currently, the world produces enough food to meet the growth of effective demand for food. Food demand increases with human population (projected to reach 9 to 11 billion within the next century) and wealth with its associated expectations.

The problem is that effective demand is always less than potential demand because of poverty and inequitable distribution. Poverty is projected to be a continued characteristic of future economies; there are over 800 million people (the so-called bottom billion) who are undernourished worldwide and this number is unlikely to decrease. These people, who theoretically should have the greatest demand, add little to effective global demand for food. Because agricultural products are, to a great extent, market commodities — those who cannot afford food will not impact the market. However, as sustainability is concerned with feeding everyone, potential demand must be considered. Theoretically, potential demand can equal effective demand if everyone in the world has a relatively high caloric intake (~2 700 calories a day).

Food demand beyond meeting basic needs can be considered luxury demand, where the basic goal of feeding everyone is met. Since sustainability is a “moving target,” then different goals may gain prominence and food demand beyond basic needs may become a priority. However, agricultural production does operate in a global market so excess food cannot be taken from the mouths of citizens of the developed countries and turned over to those in developing countries. Closing the gap between potential and effective demand must operate in a world where food production is distributed inequitably.

3.1. Human Population Dimensions

Food demand is tightly coupled with population growth. The fertility rate of developed regions such as North America and Europe are below replacement levels, and a similar trend has occurred to some degree in Latin America. Global food supply is projected to stay abreast of projected population growth, but on regional scales, malnutrition will remain a major concern. As some developing countries shift agriculture from subsistence-based to market based, their citizens will rely increasingly on food imports. This may lead to conditions where regional food production will not keep pace with the needs if you need purchasing power of local people.

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Biographical Sketches

Gerald Singh holds a degree from the University of Alberta specializing in Conservation Biology. He is a graduate student at the Institute for Resources, the Environment, and Sustainability at the University of British Columbia, where he studies ecosystem services.

His interests include community ecology, ecosystem ecology, environmental goods and services, global agriculture, dynamic modeling, and environmental economics. During 2006-2007, he worked for Agriculture and Agri-Food Canada researching agroforestry practices. He was part of a team to amend the ALCES landuse cumulative effects model, with Brad Stelfox to monitor impacts of agroforestry on multiple environmental values. He also contributed to research into the benefits of pollinator diversity to oilseed crop production.

Dr Robert Hudson (PhD, University of British Columbia 1973) is Professor of Sustainability Science and Associate Dean (International) with the Faculty of Agricultural, Life and Environmental Sciences at the University of Alberta. He is Editor-in-Chief of the Open Journal of Conservation Biology, Associate Editor of the Journal of Wildlife Management and member of the Editorial Board of several international journals.

His research is on bioenergetics, nutrition, behavior and management of bison, elk, deer, caribou and other hoofed mammals. He also studies community-based management and dynamics of wildlife and rangeland systems and has been involved in the development of codes of humane practice for bison and deer.

Dr Hudson has supported graduate student projects in the Canadian Arctic, Cameroon, Kenya and Malaysia and has collaborated on research in China and Korea. Working with others, he has several hundred publications including books on bioenergetics, wildlife production and sustainable use.

Dr Noble Donkor (PhD, University of Alberta 2001) is a Professor of Biology at the Canadian University College. Noble did his doctorial thesis under the supervision of Dr Robert Hudson. He earned a BSc. (Hons.) in Natural Resources Management (with specialization in wildlife and range management) from the University of Science and Technology in Ghana and a MSc. in Wildlife Ecology from University of Guelph, Ontario. Dr Donkor's research interests are dynamics of wildlife and rangeland systems, and particularly focus on ungulate (deer, elk, and bison) and beaver nutrition, behavior and management. His teaching of Conservation Biology and Human Ecology has heightened his interests in application of ecological principles to the solution of human population and environmental problems, and sustainable use.