MANAGEMENT OF AGRICULTURAL SYSTEMS

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Summary

Nutritional demands for food are expected to double before the world population stabilizes late in the new century. However, urbanization and rising incomes will increase economic food demands several times. The Green Revolution, based on improved crop varieties and supported with fertilizers and pesticides, replaced horizontal expansion in the 1960s and contributed to meeting the needs of the last doubling of world population. However, with the declining response to agricultural inputs and with ecological life support systems already strained, it is not clear how these demands will be met and sustained into the future.

Hope has been placed in emerging clean-energy technologies and biotechnology that promise to reduce pressure on the global carbon cycle, reduce dependence on pesticides, increase food safety, improve quality and increase yield. However, as with all significant new technologies, the effects on the global agrifood system and ecological life support systems are difficult to fully anticipate.

As important as technology are the expected impacts of trade liberalization and consequent changes in the structure and dynamics of the world agrifood system. Trade liberalization means that food will be produced where it can be obtained cheaply and sold on markets that offer the highest prices. To be globally competitive, the trend for aggregation of small farms, prevalent for the past 50 years in the western world, now extends to the vertical integration of the complete supply-chain from gene to consumer.

A significant part of the global food supply is now controlled by a few major multinational life science corporations or consortia. Although this provides enormous efficiencies, several issues of food security have been raised. These include unexpected collateral effects, loss of agricultural biodiversity and increased vulnerability to diseases, stock market crashes, and other catastrophes. There also is concern that food production is becoming increasingly irrelevant to rural development.

As markets for major commodities are claimed by corporate agriculture, small farms will, it is hoped, diversify to serve local, seasonal and niche markets. Programs of community-supported agriculture are bringing farmers and consumers together. Although agricultural land will continue to be devoted to food, fiber and bio-fuel production, farms will be increasingly appreciated as multifunction landscapes providing ecosystem services, nature conservation and recreation. The question is how this can be translated into incentives for conservation.

1.Introduction

The International Food Policy Research Institute's (IFPRI) 2020 Vision for Food, Agriculture, and the Environment hopes for a world "where every person has access to sufficient food to sustain a healthy and productive life, where malnutrition is absent, and where food originates from efficient, effective, and low-cost food systems that are compatible with sustainable use of natural resources.” Although few would argue with the goal, how it will be achieved is less clear.

Global human populations are expected to stabilize at about 10–12 billion late in this century. Much of this growth will occur in developing countries where 80% of the world’s population will live by 2025. About 50% of these people will live in urban areas. The challenge is to provide adequate safe food at affordable prices for the 84 million people added to the population each year.

The International Food Policy Research Institute’s IMPACT model (International Model for Policy Analysis of Agricultural Consumption) predicts the rapid growth of demand for agricultural products. Because human populations are expected to almost double before leveling off late in the new millennium, nutritional demands must at least double if the current 800 million undernourished people in the world are to be fed. However, rising incomes and urbanization are expected to increase market demand even further and to shift disproportionate demand to livestock products. By 2020, the global demand is expected to reach 2466 million tons (39% increase) for cereals, 864 million tons (37% increase) for roots and tubers and 313 million tons (58% increase) for meat.

All of this must be done in ways that ensure that the ecological life-support systems upon which agriculture depends—biodiversity, soil, water and even clean air—are sustained. Desertification, soil degradation by erosion and salinization, eutrophication of fresh and estuarine waters, contamination of ground water, loss of biodiversity, and even global warming are growing concerns.

The boundaries to efficient food production are that resources are used responsibly and respectfully. As food shortfalls are met, attention will continue to extend beyond the urgent issues of quantity and cost to quality, variety, safety, environmental effects and animal welfare. Consumers will increasingly demand wholesome, safe food produced in an environmentally responsible and welfare-sensitive way.

2. World Agrifood System

The global agrifood system comprises the entire food production, processing and distribution system including associated chemical and biotechnical industries. The entire supply and value-added chain is more relevant now than ever as corporate concentration embraces these functions in large vertically-integrated multinational “life science” companies or consortia.

2.1 Structure and Evolution

Agroecosystems are the core of the agrifood supply chain but are embedded within larger social and economic systems. The arrangement is hierarchical and can be viewed as, for example, plots or fields within farms and within farming communities within regional landscapes within political jurisdictions. Local, regional, national and international markets can be similarly visualized. The emerging issue is that sustainability is better addressed at the level of watersheds, agroecoregions or other natural units rather than those defined by property or political boundaries. The linkage of the biophysical with the social environment also needs to be explicit in a more inclusive holistic concept of agroecosystem.

Since ancient times, improved security, technology, transportation infrastructure, storage facilities, trade liberalization and strong distant markets have reduced the regional diversity of crops that once served the varied needs of local consumers. Although world trade has captured "regional advantage" and has been of enormous benefit to the world's people, this has come at the expense of crop and landscape diversity and the integrated agroecosystems that once sustained the world's rural people. The number of people supported by one farm worker has increased dramatically [for example, from 15 to 65 in the United States between 1950 and 1980] but it has taken its toll on ecological life support systems. *Ad luxus* use of pesticides, fertilizers and irrigation water that fuelled the Green Revolution has contributed to the reduction of biological diversity, eutrophication of rivers, lakes and estuaries, and perhaps global warming.

2.2 External Factors

Factors forcing the transformation of world agriculture are more obvious than the social and environmental implications. The business of food production is shaped by four main factors; namely, environment, technology, economics, and policy (Figure 1).

Environment: The biophysical environment including soils, seasonal climate, and competing organisms sets boundaries on crops, livestock and production systems. Day-length, humidity, heat-units and degree-days favor certain crops over others. Diseases such as trypanosomiasis, foot-and-mouth disease, brucellosis, tuberculosis, and bovine spongiomyelopathy may limit animal production or export market opportunities. Amelioration of these constraints is usually possible but often expensive, sometimes prohibitively so.

Technology: Technology can lift some constraints imposed by environment. Greenhouses and indoor rearing facilities for poultry or pigs are examples of heroic but nevertheless cost-effective technological solutions to provide controlled environments. The agricultural landbase also can be extended directly by clearing, drainage, irrigation, or indirectly by adopting new plant varieties and agronomic methods. The current knowledge-based agricultural revolution promises new transgenic crops and agrifood system integration through information and communication technology.

Economics: Subsistence agriculture is driven by family and community needs rather than profits on distant markets. In subsistence economies, risk aversion usually superceded maximization of production. Market forces and availability of capital encourage the industrialization of agriculture. This has been a dominant thrust of international development that has witnessed shifting emphasis on technology (methods, machinery, genetic resources), human capital (health, education) and social capital (infrastructure, institutions).

Policy: War, insecurity and trade barriers encourage diverse local production and marketing of food. Peace, trade liberalization and harmonization of food standards capitalize on regional advantage and create conditions for corporate concentration. Subsidies and other market distortions are considered to be a significant cause of environmental degradation.

Figure 1: Local, regional and global agrifood systems are shaped by environment, technology, economics and policy

3. Technological Adaptation

The development of agricultural production systems thus far has been largely a story of biotechnical innovation. The main strategies have been to expand the land base or increase productivity through genetic improvement or agronomic practices including water management, nutrient management, and pest management.

3.1 Land

Since the emergence of city-states several millennia ago, conquest was the main way civilizations secured resources. Although history is replete with war campaigns, the same goals were achieved through colonization of regions or entire continents such as America, Africa, and Australia.

The main technical means to increase the agricultural land base has been clearing and drainage. Colonization saw the cultivation of vast expanses of forests and wetlands. Marginal lands also could be brought into production by the development of adapted crops, irrigation, and improved agronomic practices.

Globally, this remained the main way to expand food production until about 1960 when most of the potentially arable land had been brought into production (Table 1). During the past 25 years, cultivated area increased only 4% whereas the world's population increased 40% with gains in world food production achieved mainly by improved productivity and storage. Nevertheless, half of the remaining 2.5 billion ha of tropical rainforests are expected to come under pressure for agricultural expansion.

Type of land	Area (billion ha)
Total ice-free land area in the world	13.4
Total land area with out water bodies	13.0
Land used	8.7
Potentially arable land	3.2
Moderately to highly productive	1.3
Low productive land	1.9
Current use of potentially arable land	3.2
Cropland	1.5
Permanent pasture, forest, and woodland	1.7

Source: International Food Policy Research, 1999

Table 1: Global supply and use of land

3.2 Genetic Resources

Few plant and animal species were domesticated 7–12 000 years ago and these now dominate global production (Table 2). Today, only 17 crops provide 90 per cent of the world's food and occupy 75 per cent of the global cultivated area. Cattle, sheep and goats, hogs, and poultry are the most abundant livestock.

Common crops	Cultivated area (hectares)	Common livestock	Livestock numbers
Wheat	213,790,032	Cattle	1,335,655,460
Rice	152,176,824	Sheep	1,070,625,480
Maize	139,878,084	Hogs	914,932,512
Soybean	71,886,955	Goats	708,885,630
Barley	57,546,009	Buffalo	158,535,341
Sorghum	45,865,955	Camels	19,024,575
Millet	37,033,130		
Field bean	26,871,166		
Groundnut	24,804,457		
Potato	17,586,058		
Cassava	16,601,523		
Oats	13,824,319		
Coconut	10,489,899		
Rye	10,015,735		
Sweet potato	9,001,961		
Peas	6,073,488		
Banana	3,807,307		

Source: FAO STAT, 1999

Table 2: World crops (million hectares) and livestock (million head) in 1999

A number of new plant and animal species have been adopted and can be considered modern domestications. New crops include canola, triticale, ginseng, a variety of herbs and spices, and kiwi and star fruits. New animal domesticates include bison, muskoxen, deer, eland, ostrich, capybaras, crocodiles and iguanas. These plants and animals serve niche markets using a wider range of land resources and offer to stabilize production, market prices and farm income.

Despite the promise of new domesticates, much more attention has focussed on genetic improvement of existing domestic species. All common crops and livestock have been genetically selected to improve product yields, consistency and quality. It is difficult to judge the relative contribution of genetic improvement and advanced agronomic/husbandry practices to increased yields, because these two factors interact.

Because performance depends very much on the environment in which they are grown, breed and variety development is better considered specialization than improvement. Improved crops that made the Green Revolution possible achieved this only with fertilization and adequate rainfall. Improved breeds of livestock often lose their competitive advantage in marginal environments.

Genetic change is induced by selection for favored production traits but the process is hastened by the following techniques:

- Wide crossing creates genetic variation by crossing dissimilar organisms. Among plants, this can be achieved by crossing different species but in animals this typically leads to severe out-breeding depression often expressed as male sterility, parturition difficulties and non-viable births. Mules and yak-cattle crosses are examples of useful hybrids but mammalian hybrids rarely collect the best traits of both parents. Attempts to cross bison and cattle failed to combine the hardiness and meat-producing quality of the parent stocks.
- Mutations that add to genetic variation can be achieved by irradiation or chemical mutagens. However, genetic changes are unpredictable and selection of desired traits is long and difficult.
- Polyploidy (multiple sets of chromosomes) is an option for crops and has produced several high-yielding varieties.
- Direct gene transfer allows genes from distantly related organisms (different families, orders or even kingdoms) to be inserted into an organism.

Direct gene transfer opens a whole new range of possibilities including:

- Improved resistance against insect, fungal, bacterial, and viral pests.
- Enhanced nutritional quality (vitamins, minerals, protein, etc). A gene encoding for beta- carotene/vitamin A in rice offers to ameliorate this vitamin deficiency among 180 million children. A gene that increases iron levels in rice threefold will ameliorate a mineral deficiency affecting more than 2 billion people.

- Herbicide tolerance. The market for herbicide-resistant crops already stands at almost $500 million.
- Altered plant architecture and flowering to facilitate harvest, reduce lodging, reduce seed loss
- Improved ripening and storage characteristics of fruits and vegetables.
- Elimination of allergens.
- Production of pharmaceuticals and edible vaccines.

Development of this technology and its exploitation as a business opportunity has been explosive. From its very recent introduction, the global market for about 80 biotechnology products already stands at about US$ 13 billion. Most of this is medically related. In the United States, over 500 000 dairy cows receive recombinant bovine somatotrophin (growth hormone) to increase milk production. In 1998, 28 million hectares of land were planted with 40 transgenic crops worth US$ 1.64 billion. Most of these crops were new varieties of cotton, corn, soybean, and rapeseed. Australia, Canada, France, Spain, and particularly the United States accounted for 85 percent of the area sown with transgenic crops. Argentina, China, Mexico, and South Africa comprised most of the remainder.

Despite this promise, concerns have mounted about the possible implications of these new transgenic materials for human health, environmental integrity, rural development and farmer vs. breeder rights. Many of the larger markets, such as Europe, are closed to genetically-modified foods until convincing proof of safety and a clear case for the need are presented. The issues of terminator genes and traitor technologies that stop the age-old practice of saving seed have caused as much concern among farmers as has food safety among consumers.

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Biographical Sketch

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