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Principles of integrated agricultural systems: Introduction to processes and definition

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Abstract

Agriculture has been very successful in addressing the food and fiber needs of today's world population. However, there are increasing concerns about the economic, environmental and social costs of this success. Integrated agricultural systems may provide a means to address these concerns while increasing sustainability. This paper reviews the potential for and challenges to integrated agricultural systems, evaluates different agricultural systems in a hierarchical systems framework, and provides definitions and examples for each of the systems. This paper also describes the concept of dynamic-integrated agricultural systems and calls for the development of principles to use in developing and researching integrated agricultural systems. The concepts in this paper have arisen from the first in a series of planned workshops to organize common principles, criteria and indicators across physiographic regions in integrated agricultural systems. Integrated agricultural systems have multiple enterprises that interact in space and time, resulting in a synergistic resource transfer among enterprises. Dynamic-integrated agricultural systems have multiple enterprises managed in a dynamic manner. The key difference between dynamic-integrated agricultural systems and integrated agricultural systems is in management philosophy. In an integrated agricultural system, management decisions, such as type and amount of commodities to produce, are predetermined. In a dynamic-integrated system, decisions are made at the most opportune time using the best available knowledge. We developed a hierarchical scheme for agricultural systems ranging from basic agricultural production systems, which are the simplest system with no resource flow between enterprises, to dynamic-integrated agricultural systems. As agricultural systems move up in the hierarchy, their complexity, amount of management needed, and sustainability also increases. A key aspect of sustainability is the ability to adapt to future challenges. We argue that sustainable systems need built-in flexibility to achieve this goal.

Key words: agricultural production systems, hierarchy, dynamic-integrated agricultural production systems

Introduction

Agriculture has successfully met the food and fiber needs of most of the world's population. World population has grown from 2.5 billion in 1950 to a projected 6.4 billion in 2005[1] and global average per capita food availability has risen from <2400 calories to >2700 calories[2]. This has been possible because cereal yields have increased by 150%, while land area in farms has remained relatively stable since 1950[3]. Today's agriculture uses only 0.2 ha of land per person[3]. However, agricultural producers are operating in an increasingly complex and rapidly changing environment. Besides the traditional focus on production, agricultural producers must also balance conflicting demands involving social, political, economic, technological and environmental issues.

Modern intensive agriculture alters the resource base and potentially reduces both its carrying capacity[4] and its sustainability[5,6]. In the Great Plains of the United States for example, many cropping systems are characterized by a lack of crop diversity[5] and declining soil organic carbon[7].

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At the same time, livestock production in the United States is based on efficiently converting feed grains into meat acceptable for human consumption, a system heavily dependent on fossil fuels[8].

Many small and mid-sized agricultural producers are concerned about economic sustainability of their farming operation. When farm income declines, government payments tend to increase to offset lower farm incomes[9]. Despite this buffering of farm income, farm numbers have continued to decline, especially among mid-size farms[10]. Seventy-two percent of the economic value of agricultural production now comes from large, very large and non-family farms[10]. Many small and medium sized farms rely on off-farm income. Average income from US farm-related activities ranged from 5 to 16% of the total farm income during 2001–2005, with the remainder coming from off-farm sources[11].

Integrated Agriculture

Full integration of agricultural systems at the producer or community scale may help in slowing or reversing some of the detrimental environmental and economic problems associated with specialized industrial agriculture. Modern agriculture requires intensive inputs. However, the use of forages and other diverse crops in the crop rotation can reduce intensive inputs[5,12,13], while in some cases increasing crop yield[12,14], enhancing nutrient cycling[5,13], reducing plant disease[15] and improving soil quality[7]. Integration of livestock and cropping systems has the potential benefits of enhancing nutrient cycling efficiency, adding value to grain crops, and providing a use for forages and crop residue[5]. Integrated crop/livestock producers traditionally have raised a greater diversity of crops, encouraging crop rotation[16] and have allowed livestock to convert low-quality crop residues or failed crops into higher value protein[17].

Integrated agricultural systems are not new. The number of commodities produced per farm has decreased from five in 1900 to approximately one in 2002[18]. Integrating forage, crop and livestock systems can spread economic and production risks over several different enterprises, thereby taking advantage of a variety of agricultural markets[5,7]. As an example, incorporating forages into a Canadian cropping system potentially reduced risk more than participation in government programs[12]. There are also potential environmental benefits to integrated systems. Research in Norway indicated that runoff of N and P was linked to the amount of ley in the system[19]. In New Zealand cropping systems, 2–4 years of grass-clover swards resulted in large net N input and increased soil aggregate stability, soil porosity, and earthworm activity. Soil properties rapidly declined during the subsequent 2–4 years of crop production[20].

Recently, some US producers have adopted more diversified management systems that include crops and livestock[7,21]. However, operators of integrated production systems face immense challenges, including labor availability and allocation, timing of operations, equipment considerations, and supply and market availability[22]. Even with economic risks spread over multiple enterprises, producers with integrated operations still require information on potential benefits and trade-offs to manage their enterprises successfully. Despite the advantages of integration, many farms in the Great Plains have increased crop diversity but have not fully integrated land use[7].

Challenges to Integrated Agricultural Systems

The complexity of today's agriculture forces producers to consider making decisions that meet multiple objectives (Fig. 1). A producer must set goals to define the endpoint towards which efforts will be directed. Agricultural producers must balance goals dealing with production, economic, social, political and environmental issues. Production goals involve producing the most appropriate crop or product under the resource and climatic regime in which they are operating. This is the most basic goal, since what is produced is usually considered directly proportional to the gross income received. However, economic goals and the interactions with other components of the system must also be considered. Pannell[23] showed the importance of accounting for farm-level interactions in evaluating lupin (*Lupinus angustifolius* L.) introduction to a Western Australian farm. By not incorporating the effects of lupins on nitrogen fixation, improved soil structure, reduced cereal disease levels, use as sheep feed and improved machinery efficiency, economic benefits from lupins would have been underestimated.

Producers must also consider the social ramifications of their decisions, not only for their own economic well-being but also on society as a whole. By 2007, it is projected that more people worldwide will live in urban environments than in rural areas[24]. This trend has already occurred in developed countries, resulting in fewer people with a direct connection to agriculture. However, the urban population still maintains its interest in how rural landscapes are managed[25]. Also, fewer farmers will impact the social communities in which they live and work because of their decreasing numbers.

Government farm policy can also influence management decisions. In the United States, farmers growing corn (*Zea mays* L.), soybean [*Glycine max* (L.) Merr.], wheat (*Triticum aestivum* L.), cotton (*Gossypium hirsutum* L.) and rice (*Oryza sativa* L.) received a majority of direct government payments[9], but payments only accounted for a fifth of total cash receipts in 2000[26]. Farm programs can influence land use and, to a lesser extent, the mix of crops planted[26]. Some farm programs, such as crop insurance and marketing loans, can increase production of certain commodities because of greater expected returns per unit of production[27]. Other farm programs, such as direct

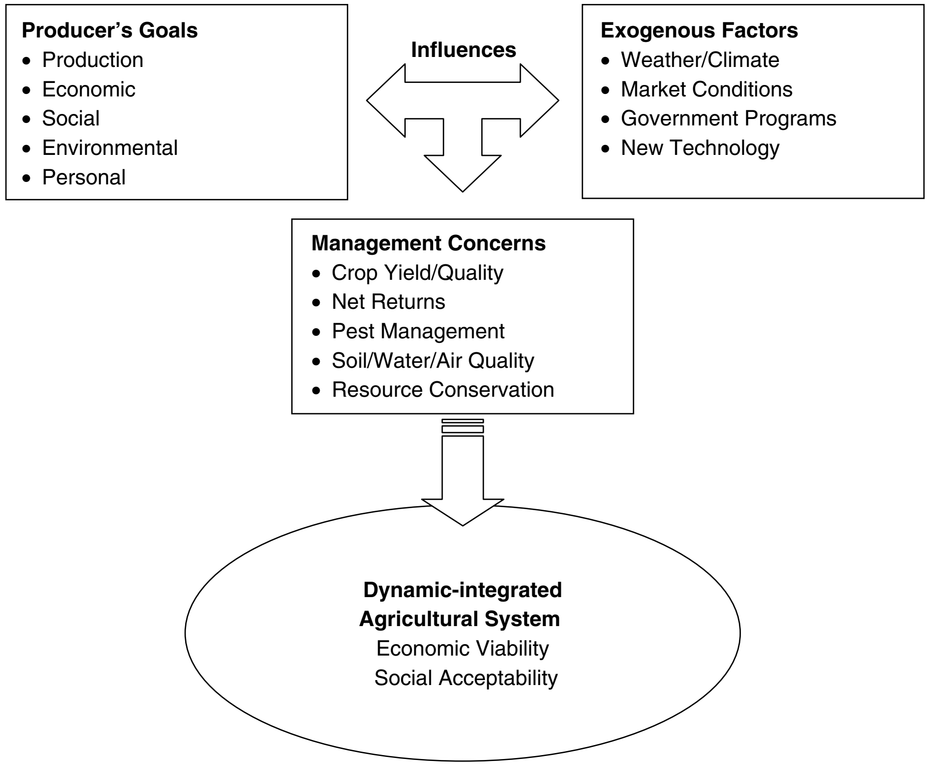

Figure 1. Producers in dynamic-integrated agricultural production systems must consider multiple criteria prior to making management decisions. These criteria and their relative importance influence producers' decisions. Adapted from Tanaka et al.[29].

payments and counter-cyclical payments, affect producer decision-making by increasing producer income and potentially their willingness to take risks[28]. However, by increasing income, these programs may also increase complacency among producers and reduce their incentive to try alternative approaches to agriculture. Producers need to consider the direct and indirect effects of government farm policy when they are making management decisions.

Finally, producers must consider the environment within which they operate. Uncontrollable issues further complicate the setting of goals by producers. Exogenous factors include weather/climate, market conditions, government programs and new technology (Fig. 1). These four external factors can do much to make or break an agricultural enterprise. By considering producer goals and the exogenous factors influencing agriculture, management systems can be developed to optimize such issues as product yield and quality, net enterprise return, pest (both insect and plant) management, soil, water and air quality, and resource conservation.

All of these issues, as well as rapidly changing technology, result in a complex and fluid environment in which agricultural producers must operate. Agricultural systems need to be developed that are sustainable and adaptable to change, but yet maintain their productivity. Therefore, we have developed a framework called 'dynamic-integrated agricultural systems' to achieve this goal.

Definitions

Tanaka et al.[29] described a concept called 'dynamic cropping systems' which provided an approach to cropping systems that producers could use to make sustainable crop production decisions. They described this concept as a long-term strategy of annual crop sequencing that would optimize crop and soil use options and the attainment of production, economic and resource conservation goals by using sound ecological principles. The dynamic aspect of this concept is a management philosophy that requires decisions to be made at the most opportune time with the best available information. A multi-directional information flow is an important component in decision-making. Key factors incorporated into decision-making in this system include diversity, adaptability, reduced input cost, multiple enterprise systems, awareness of appropriate information, and awareness of the environment. We extend this definition beyond cropping systems and incorporate aspects of it into a new concept called 'dynamic-integrated agricultural systems'.

To develop this framework, we must define some of the terms used to describe the different systems and approaches. We developed the philosophical concept for dynamic-integrated agricultural systems by evaluating and classifying other agricultural systems currently used in the northern Great Plains.

The concept of sustainability in agriculture has emerged as an important component of mainstream plant and animal production systems[30]. Sustainability has been considered the capacity to create, test and maintain adaptive capacity[31]. Lyson[32] noted that there are literally hundreds of definitions of sustainable agriculture but most definitions contain these key dimensions: (1) ecological, (2) economic and (3) social-community. Hence, we chose to define sustainable agriculture as:

> An approach to producing food and fiber which is profitable, uses on-farm resources efficiently to minimize adverse effects on the environment and people, preserves the natural productivity and quality of land and water, and sustains vibrant rural communities[33].

Agricultural production consists of one or more enterprises within the same economic unit. An enterprise can be a unit of economic organization or activity, a systematic purposeful activity[34] or a specific type of agricultural production[35]. Here, we define enterprise in a more systems-orientated manner as:

> A system component that produces an output and provides a resource for some other component within that system.

Agricultural producers combine one or more enterprises along with their management philosophy to form agricultural systems. These production systems can range in both structural and managerial complexity to form a hierarchy of production systems. In the next section, we define the more common production systems and their implications for complexity and sustainability.

Agricultural Systems

Figure 2 demonstrates the complexity of different agricultural systems, which are described below.

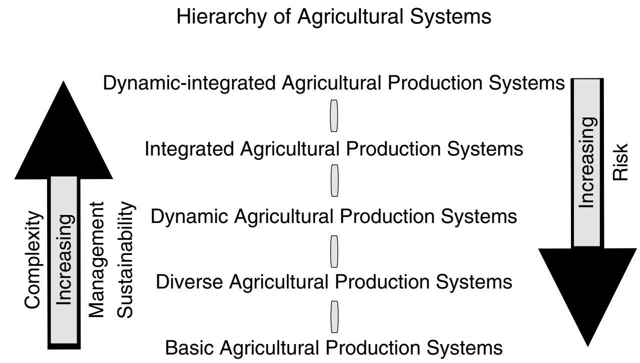

Figure 2. Hierarchial arrangement of agricultural production systems. As the systems progress from basic agricultural production systems to dynamic-integrated agricultural production systems, sustainability, system complexity and management input required increase, but risk decreases.

Basic agricultural production systems

These are the simplest, usually having no more than two enterprises. Enterprises in agricultural production systems have minimal interactions, i.e. resources do not flow from one enterprise to another.

Examples of an agricultural production system would be wheat–fallow, corn–soybean rotation, or confined animal production. In a wheat–fallow system, annual land use has been predetermined and a producer's management skills are focused on a single crop, i.e., wheat. Although water harvested in the fallow year is used by wheat, there is only one enterprise for the economic unit. In a corn–soybean rotation common in the US corn belt, both corn and soybean are planted and harvested within the same relative time period with similar equipment. The development of herbicide-tolerant varieties means weed management is comparable for both crops, and management is generally predetermined. The corn–cotton rotation in the US cotton belt is a similar example. Confined animal production systems may be the best example of basic agricultural production systems. Management decisions are not only predetermined but may be made off-farm, and the production is focused on delivering a single, consistent commodity to a food processor.

Diverse agricultural production systems

Diverse agricultural production systems contain three or more species of crops or livestock but strategic management of each enterprise is generally predetermined and follows a set of best management practices.

Examples of this type of system would be a fixed crop rotation or a crop–livestock farm in which interactions between the crop and livestock enterprises are limited, and the enterprises are managed in a predetermined manner. In both cases, management options such as land use or classes of livestock raised are predetermined, but structural and management complexity increases because the producer must consider management requirements of at least three crops or livestock.

There are examples of diverse agricultural production systems where producers may have other enterprises that are not specifically an additional crop or livestock species. One example would be a cotton farmer, who also owns, or is part-owner, of the cotton gin, warehouse and marketing association. The cotton produced on the farm would generate some revenue, and the ancillary enterprises (gin, warehouse and marketing association) would generate supplemental income. Another example is that of a catfish (*Ictalurus punctatus*) farmer, who owns or is part-owner of the catfish feed plant and catfish processing plant. These separate enterprises interact with the primary agricultural commodity—the catfish. While there is resource exchange in one direction (feed plant to catfish ponds to processing plant), the agricultural system is not integrated as there is no feedback from one enterprise back to the preceding one.

Dynamic agricultural production systems

These rely on an annual strategy to optimize the outcome of production, economic and resource conservation goals and allow producers to use production components (crops, crop sequences, livestock types, etc.) that result in optimal production with minimum input costs. These systems have diversity in time because producers must manage externalities that change.

These systems differ from diverse agricultural production systems in that management is not predetermined. Rather, things such as crop types or livestock production systems are adjusted yearly, based on weather conditions and potential returns. In these systems, the producer must understand the management of a series of crops or livestock types as well as understand their potential returns and any implications of previous management history. These factors lead to increased management complexity. However, in these systems, the different enterprises may not interact in space and/or time and these interactions are not specifically considered in planning.

Integrated agricultural production systems

Integrated agricultural production systems are agricultural systems with multiple enterprises that interact in space and/or time and the interactions result in a synergistic resource transfer among enterprises.

These systems differ from dynamic agricultural production systems because there is interaction between different enterprises and the synergistic resource transfer between enterprises. An example of an integrated agricultural production system may be an integrated crop–livestock production unit where manure from livestock is added to crop land and at least a portion of the grain grown on the farm or the stover (crop residue) is fed to livestock. Manure from livestock can replace some of the fertilizer inputs[36]. Feeding grain to livestock or allowing them to use crop residues can potentially add value to the grain or crop residue[17]. A cotton farmer who uses gin trash from a ginning operation as organic matter input for cotton production would have an integrated system because there is a synergistic resource transfer. Similarly, a catfish farmer who uses products from a catfish processing plant as fertilizer to produce soybeans, which were then used in catfish feed, would make the catfish/crop production system integrated. These operations may also reduce economic risk through diversified marketing opportunities and avoidance of price cycles. These operations involve increased management, because of the need for understanding not only crop and livestock management but also their potential interactions. However, these operations may not be dynamic, in the sense that their management may be fixed rather than determined on an annual basis by considering all of the producer goals.

Dynamic-integrated agricultural production systems

These are agricultural production systems with multiple enterprises managed in a dynamic manner that interact in space and/or time and these interactions result in a synergistic resource transfer among enterprises.

While dynamic-integrated agricultural production systems are similar in structural complexity to integrated agricultural systems, they require the highest degree of management. Producers must not only understand the management requirements of a variety of enterprises but they need to also use annual planning to determine the best combination of enterprises for their operations. They also have to consider the potential ramifications of interactions between enterprises to determine how to obtain maximum synergistic benefit.

If livestock were one of the enterprises in a dynamic-integrated agricultural production system, it would add additional challenges to producer adoption. Livestock enterprises have to consider animal genetics, reproduction considerations and consistent feed supplies. They may also be constrained by having a portion of their land that can only be used for livestock production (i.e. rangelands). However, there may be ways for producers to incorporate a dynamic philosophy into their livestock operations. For example, cow–calf producers could keep a portion of their calf crop and either graze or sell them the subsequent year, depending on prices and precipitation. Other options may be to alter the livestock class or species in response to producer goals, exogenous factors and management concerns (Fig. 1). For example, producers with mixed livestock systems, such as cattle and sheep, may consider altering the proportion of cattle to sheep in their herds in response to better prices for either sheep or cattle.

As the hierarchy progresses, agricultural production systems have more enterprises and require more management input (Fig. 2). For example, a diverse agricultural production system where multiple crops are grown has more enterprises and requires more management input than simple agricultural systems such as wheat–fallow. Adding the dynamic management philosophy onto a diverse cropping system may not increase the number of enterprises but will increase the management requirements because decisions are not predetermined but made after considering multiple factors. A dynamic-integrated agricultural system is therefore the most complex system because multiple enterprises are considered and the interactions between enterprises and management decisions are not predetermined. However, this system should be the most adaptable system to respond to future agricultural challenges.

Besides the increase in complexity, both in structure and management needed, from a basic agricultural production system to a dynamic-integrated agricultural production system, we feel there is a corresponding increase in sustainability (Fig. 2). Sustainable agriculture encompasses three dimensions; economical, environmental and social-community[32]. In dynamic systems, as defined by Tanaka et al.[29], all three of these dimensions are considered. In addition, as stated earlier, integrated agricultural systems can reduce the environmental impact of agriculture[5] and potentially lower risk for producers[5,7,12]. Also, as the hierarchy progresses, the inclusion of multiple enterprises should pose lower production and economic risks and an increase in adaptability. The maintenance of adaptive capacity[31] may be the greatest contributor to long-term sustainability.

We believe that risk decreases as the hierarchy progresses from a basic agricultural production system to a dynamic-integrated agricultural production system. Hardaker[37] defined risk as 'uncertainty of outcomes'. Agricultural producers are generally 'risk averse'[38]. The largest concern for many agricultural producers is income. Incorporating a variety of enterprises, using the best information available, and making decisions in a dynamic manner may give producers tools to reduce income uncertainty. Because sustainable agriculture implies a holistic, systems-oriented approach to agriculture that focuses on the interrelationships between environmental, social and economical factors[32], reducing the income uncertainty can enhance the sustainability of individual producers and may allow them to make decisions that will enhance social and environmental sustainability as well.

Factors Influencing Integrated Systems

Integrated agriculture has the potential to fully or partially address many of the problems that confront agriculture. Integrated agriculture can help increase agricultural diversity from the field to the farm scale, which may increase system stability[5]. Integrated agriculture may also be the best framework to use for developing sustainable agricultural systems. In Europe, an integrated approach to crop production called 'integrated farming systems' has been advocated as a sustainable approach to agriculture that can maintain farmer income and safeguard the environment[39]. Integrated agricultural systems are complex systems and developing and analyzing them can be difficult. The development of a set of principles underlying complex agricultural systems can assist in the difficult task of developing integrated agricultural systems.

Each of the described systems relies on principles to be successful. Principles have been described as 'the ultimate source or cause of something'[40]; 'advice, guidelines, prescriptions, condition–action statements, and rules'[41]; or 'guidelines or prescriptions for how to use intentions'[42]. These definitions range from highly definitive laws to loosely applied guidelines. We chose to define principles as:

> A set of concepts or ideas that help to explain how systems operate.

When looked at in this manner, even the simplest system relies on principles. For example, a wheat–fallow system is based on the principle that harvesting water and controlling weeds during the fallow year will enhance yields during the subsequent cropping year.

The first in a series of planned workshops to develop principles for integrated agricultural systems was held in Mandan, ND in November 2004. The objective of these workshops was to organize common principles, criteria, and indicators that exist across physiographic regions to provide insight into the management of integrated agricultural systems. At the first workshop, a series of factors influencing the development of agricultural systems was identified. These factors were diverse but mainly fell into four areas: (1) social/political, (2) economic, (3) environmental, and (4) technological. Following papers in this volume examine these drivers in detail. Understanding these factors is the first step in developing principles for integrated agricultural systems.

References

1 FAOSTAT data. 2005. Available at Web site http://faostat.fao.org/faostat/form?collection=Population (updated March 2005).

2 Ruttan, V.W. 1999. The transition to agricultural sustainability. Proceedings of the National Academy of Sciences of the United States of America 96:5960–5967.

3 Trewavas, A. 2002. Malthus foiled again and again. Nature 418:668–670.

4 Huang, J., Pray, C., and Rozelle, S. 2002. Enhancing the drops to feed the poor. Nature 418:678–684.

5 Brummer, E.C. 1998. Diversity, stability and sustainable American agriculture. Agronomy Journal 90:1–2.

6 Tilman, D., Cassman, K.G., Matson, P.A., Naylor, R., and Polasky, S. 2002. Agricultural sustainability and intensive production practices. Nature 418:671–677.

7 Krall, J.M. and Schuman, G.E. 1996. Integrated dryland crop and livestock production systems on the Great Plains: extent and outlook. Journal of Production Agriculture 9:187–191.

8 Heitschmidt, R.K., Short, R.E., and Grings, E.E. 1996. Ecosystems, sustainability, and animal agriculture. Journal of Animal Science 74:1395–1405.

9 Roberts, M.J., Osteen, C., and Soule, M. 2004. Risk, Government Programs, and the Environment. United States Department of Agriculture–Economic Research Service, Technical Bulletin No. 1908. United States Department of Agriculture, Washington, DC.

10 Hoppe, R.A. and Korb, P. 2005. Large and small farms: trends and characteristics. In: D.E. Banker and J.M. MacDonald (eds). Structural and Financial Characteristics of U.S. Farms: 2004 Family Farm Report. United States Department of Agriculture–Economic Research Service, Agricultural Information Bulletin No. 797. United States Department of Agriculture, Washington, DC, p. 5–21.

11 Covey, T., Green, R., Jones, C., Johnson, J., Morehart, M., Williams, R., McGath, C., Mishra, A., and Strickland, R. 2005. Agricultural Income and Finance Outlook. Electronic Outlook Report from the Economic Research Service. AIS-83. Available at Web site http://www.ers.usda.gov (accessed 7 November 2005).

12 Entz, M.H., Baron, V.S., Carr, P.M., Meyer, D.W., Smith, S.R. Jr, and McCaughey, W.P. 2002. Potential of forages to diversify cropping systems in the Northern Great Plains. Agronomy Journal 94:240–250.

13 Schiere, J.B., Ibrahim, M.N.M., and van Keulen, H. 2002. The role of livestock for sustainability in mixed farming: criteria and scenario studies under varying resource allocation. Agricultural Ecosystems and Environment 90:139–153.

14 Entz, M.H., Bullied, W.J., and Katepa-Mupondwa, F. 1995. Rotational benefits of forage crops in Canadian prairie cropping systems. Journal of Production Agriculture 8:521–529.

15 Krupinsky, J.M., Bailey, K.L., McMullen, M.P., Gossen, B.D., and Turkington, T.K. 2002. Managing plant disease risk in diversified cropping systems. Agronomy Journal 94:198–209.

16 Honeyman, M.S. 1996. Sustainability issues of U.S. swine production. Journal of Animal Science 74:1410–1417.

17 Oltjen, J.W. and Beckett, J.L. 1996. Role of ruminant livestock in sustainable agricultural systems. Journal of Animal Science 74:1406–1409.

18 Dimitri, C., Effland, A., and Conklin, N. 2005. The 20th Century Transformation of U.S. Agriculture and Farm Policy. Economic Research Service-United States Department of Agriculture, Economic Information Bulletin No. 3.

19 Eltun, R., Korsth, A., and Nordheim, O. 2002. A comparison of environmental, soil fertility, yield, and economical effects in six cropping systems based on an 8-year experiment in Norway. Agriculture, Ecosystems and Environment 90:155–168.

20 Haynes, R.J. and Francis, O.S. 1990. Effects of mixed cropping farming systems on changes in soil properties on the Canterbury Plains. New Zealand Journal of Ecology 14:73–81.

21 Coon, R.C., Leistritz, F.L., and Hertsgaard, T.A. 1986. Composition of North Dakota's Economic Base: A Regional Analysis. Department of Agricultural Economics, North Dakota State University, Fargo, ND.

22 Luna, J., Allen, V., Fontenot, J., Daniels, L., Vaughan, D., Hagood, S., Taylor, D., and Laub, C. 1994. Whole farm systems research: an integrated crop and livestock systems comparison study. American Journal of Alternative Agriculture 9:57–63.

23 Pannell, D.J. 1999. On the estimation of on-farm benefits of agricultural research. Agricultural Systems 61:123–134.

24 Kates, R.W. and Parris, T.M. 2003. Long-term trends and a sustainability transition. Proceedings of the National Academy of Sciences of the United States of America 100:8062–8067.

25 Kemp, D.R., Girdwood, J., Parton, K.A., and Charry, A.A. 2004. Farm management: rethinking directions. AFBM Journal 1:36–44.

26 Westcott, P.C. and Young, C.E. 2000. U.S. farm program benefits: links to planting decisions and agricultural markets. Economic Research Service–US Department of Agriculture, Agricultural Outlook October issue. p. 10–14.

27 Young, C.E. and Westcott, P.C. 2000. How decoupled is U.S. agricultural support for major crops. American Journal of Agricultural Economics 82:762–767.

28 Westcott, P.C., Young, C.E., and Price, J.M. 2002. The 2002 Farm Act: Provisions and Implications for Commodity Markets. Electronic Outlook Report from the Economic Research Service. Available at Web site http://www.ers.usda.gov (accessed 8 November 2005).

29 Tanaka, D.L., Krupinsky, J.M., Liebig, M.A., Merrill, S.D., Ries, R.E., Hendrickson, J.R., Johnson, H.A., and Hanson, J.D. 2002. Dynamic cropping systems: an adaptable approach to crop production in the Great Plains. Agronomy Journal 94:957–961.

30 Wagner, W.C. 1999. Sustainable agriculture: how to sustain a production system in a changing environment. International Journal for Parasitology 29:1–5.

31 Holling, C.S. 2001. Understanding the complexity of economic, ecological, and social systems. Ecosystems 4:390–405.

32 Lyson, T.A. 2002. Advanced agricultural biotechnologies and sustainable agriculture. Trends in Biotechnology 20:193–196.

33 UCSUSA. 2005. Available at Web site http://www.ucsusa.org/food_and_environment/antibiotics_and_food/terms-frequently-used-in-discussions-of-antibiotic-resistance.html (revised 10 August 2005; accessed 21 September 2005).

34 Merriam-Webster Online. 2005. Available at Web site http://www.m-w.com/dictionary/enterprise (accessed 9 November 2005).

35 Farm Credit Canada. 2005. Available at Web site http://www.fcc-fac.ca/en/aboutus/profile/glossary_e.asp (modified 5 July 2005; accessed 9 November 2005).

36 Powell, J.M., Pearson, R.A., and Hiernaux, P.H. 2004. Crop-livestock interactions in the West African drylands. Agronomy Journal 96:469–483.

37 Hardaker, J.S. 2000. Some Issues Dealing with Risk in Agriculture. No. 2000–3. Working Paper Series in Agricultural and Resource Economics. School of Economics, University of New England, Armidale, NSW 2351, Australia.

38 Archer, D.W., Pikul, J.L. Jr, and Riedell, W.E. 2003. Analyzing risk and risk management in cropping systems. In J.D. Hanson and J.M. Krupinsky (eds). Proceedings of the Dynamic Cropping Systems: Principles, Processes, and Challenges. Bismarck, ND. p. 155–164.

39 Morris, C. and Winter, M. 1999. Integrated farming systems: the third way for European agriculture? Land Use Policy 16:193–205.

40 The World Publishing Company. 1958. Webster's New World Dictionary, College Edition. The World Publishing Company, Cleveland, OH and New York, NY.

41 Armstrong, J.S. 2001. Introduction. In J.S. Armstrong (ed.). Principles of Forecasting: A Handbook for Researchers and Practitioners. Kluwer Academic Publishing, Norwell, MA. p. 3.

42 Morwitz, V.G. 2001. Methods for forecasting from intentions data. In J.S. Armstrong (ed.). Principles of Forecasting: A Handbook for Researchers and Practitioners. Kluwer Academic Publishing, Norwell, MA. p. 33–56.