Evaluating Farming Practices: Use of Health and Ecological Risk Concepts

Kiyotada Hayashi

Paper prepared for presentation at the 13th International Farm Management Congress, Wageningen, The Netherlands, July 7-12, 2002

EVALUATING FARMING PRACTICES:
USE OF HEALTH AND ECOLOGICAL RISK CONCEPTS

Kiyotada Hayashi

Natl. Agr. Res. Ctr. (Tohoku), Natl. Agr. Res. Org.

Shimo-Kuriyagawa, Morioka, Iwate 020-0198, Japan

Tel: +81-19-643-3491

Fax: +81-19-641-7794

Email: hayashi@affrc.go.jp

ABSTRACT

Methodologies for evaluating farming practices are reviewed to provide systematic perspectives on agri-environmental issues in which diversified research topics have been discussed. As a representative method for selecting farm management systems, multicriteria analysis is surveyed and difficulties in weighting procedure are outlined. To resolve the difficulties, applicability of risk concepts for health and ecological issues is examined. After clarifying relationships between farming practices and their environmental impacts by a mapping technique, problems with valuations of human health and the environment are investigated. Since a common measure is difficult to obtain, problems with weighting are revisited and a dilemma in applying economic evaluation methods and decision analytic approaches is discussed.

INTRODUCTION

Sustainability has become one of the important concepts in understanding the current state of various fields of scientific research and business practices. It has attracted professional attention in research on food production systems, which are fundamental in maintaining and enriching life of future generations.

In understanding sustainability of agriculture, considering the relationship between agriculture and the environment will be crucial. In the first place, we have to recognize the fact that environmental degradation has been caused by conversion of natural ecosystems. Actually, agricultural conversion of natural ecosystems to croplands and managed pastures has affected about 26 percent of the land area and agriculture has displaced one-third of temperate and tropical forests and one-quarter of natural grasslands; agricultural conversion is still an important pressure on natural ecosystems in many developing nations. In addition, forest ecosystems and grassland ecosystems are converted and fragmented into agricultural and urban uses (United Nations Development Programme, United Nations Environment Programe, World Bank and World Resource Institute, 2000).

Moreover, although there is a discussion as to the environmental benefit that maintaining a particular farming system will support a rich variety of flora and fauna as well as scenic landscape, we have to pay attention to the fact that farming practices may have negative impacts on the environment. A serious example is water pollution such as the nitrate issue caused by chemical fertilizers and manure. This is a common problem that can be observed worldwide, although agriculture is not the only source of the contamination (Fried, 1991; Heathwaite, Burt and Trudgill, 1993; Addiscott, 1996; Kumazawa, 1999; Lægreid, Bøckman and Kaarstad, 1999).

Thus, in order to assess the total impact of agriculture on the environment and to evaluate farming practices as a whole, it is necessary to introduce integrated methodologies. Developing agri-environmental indicators is a method for identifying and quantifying the extent of the impacts of agriculture on the environment (OECD, 2001). Environmental life cycle assessment (LCA) is another method for integrating various impacts on the environment and it has been applied to agricultural products (Sleeswijk et al., 1996; Audsley, 1997).

However, since tremendous research topics as well as various research methodologies are discussed in these fields, it is necessary to provide systematic perspectives. Methodologies for coping with multiple evaluation criteria will provide such views.

Actually, multicriteria analysis has been studied in the evaluation phase of environmental life cycle assessment (Heijungs, 1992a; Heijungs, 1992b). Moreover, multiattribute value functions, for example, have been used for selecting agricultural practices (Hayashi, 2000a). This kind of approach is especially important in considering recommended agricultural practices known as good agricultural practices, best agricultural practices, and best management practices because investigation of those agricultural systems inevitably involves environmental consideration.

Therefore, this paper rethinks appropriateness of the methodologies to treat multiple criteria applied to agri-environmental problems and discusses how the suitability for evaluating farming practices is improved by risk concepts for health and ecological issues. In Section 2 criteria used for evaluating farming practices are compared with each other and difficulties in applying multicriteria analysis are outlined through a review of previous studies. In Section 3 after discussing a method for restructuring problems to reconsider the criteria used for evaluating farming practices, applicability of health and ecological risks is discussed to make integrated methodologies more appropriate.

NECESSITY OF INTEGRATING PLURAL PERSPECTIVES

In evaluating farming practices with reference to their impacts on the environment, it is necessary to pay attention to various aspects of the impacts caused by farming practices. In this case, a methodology to systematically cope with multiple perspectives, multicriteria analysis, will be promising. Thus, this section outlines the methodology and reviews criteria used for evaluating farming practices. In addition, difficulties in finding a balance between criteria, the most crucial part of this methodology, are discussed.

Coping with Multiple Criteria

Multicriteria analysis is a methodology to select an alternative with respect to multiple criteria. This method has been used for selecting farm management systems with integrating different and sometimes conflicting objectives. (In the following description, attributes refer to descriptors of objective reality such as profit and costs; objectives represent directions of improvement or preference such as maximizing profitability; and criteria are a general term that expresses attributes, objectives, and goals.) Although many variations of the methodology have been applied to agricultural and natural resource management (Hayashi, 1999; Hayashi, 2000b), there are two basic types. One is the compensatory approach, which aggregates multiple attributes into overall values by, for example, multiattribute value (utility) functions in which the concept of tradeoffs plays a crucial role. The other is the non-compensatory or outranking approach, which introduces aggregation procedures based on concordance and discordance concepts that are derived from outranking relations, which express that an alternative is at least as good as another one. The distance-based approach such as compromise programming, in which the distance between the ideal point and the alternatives is minimized, can also be applicable to the decisions.

Table 1 summarizes the evaluation examples of farming practices by multicriteria analysis. One of the main features in these applications is that attention is paid to the tradeoffs between economic objectives and environmental objectives except for Arondel and Girardin (2000). That is, most of the problems can be expressed hierarchically as depicted in Figure 1. Agricultural practices are evaluated from the viewpoint of profitability and environmental quality of soil and water.

Although this hierarchical representation of criteria will be useful by itself especially for understanding evaluation problems, it is necessary to elicit attribute weights, parameters to determine tradeoff rates between criteria. Weights elicited from decision makers are combined with the values of attribute levels in order to derive overall values for alternatives, which are used for comparing the performance of each alternative.

Table 1: Criteria used for evaluating farming practices

Authors	Economic	Environmental		
		Fertilizer	Pesticide	Other
Yakowitz, Lane and Szidarovszky (1993)	Net income	N (percolation) N (surface) P (surface)	Atrazine (surface) Atrazine (percolation) Serin (surface) Carbofuran (surface)	Sediment yield
Foltz et al. (1995)	Net returns	N (surface) [a] N (percola-tion) [a]	Atrazine (surface) [b] Alachlor (surface) [b]	Soil loss [c]
Heilman, Yakowitz and Lane (1997)	Net returns	N (runoff) NO_3-N (perco-lation)	Atrazine (runoff) Atrazine (sediment) All other pesticides in surface or ground-water	Soil detachment Sediment yield
Lawrence et al. (1997)	Above ground net primary production			Range condition Channel erosion Annual runoff Annual maximum peak runoff rate Quail and javalina [NRCS [d] wild habitat index]
Tiwari, Loof and Paudyal (1999)	Farmers' NPV Government NPV Societal NPV			land suitability
Arondel and Girardin (2000)		N management (amount, balance, date, splitting up, improving tech-niques)	Pesticide manage-ment (amount, half-life,mobility, toxicity, location, date)	water manage-ment (hydric balance, amount)

[a] Estimated by Erosion Productivity Impact Calculator (EPIC).
[b] Estimated by Groundwater Loading Effect of Agricultural Management Systems (GLEAMS).
[c] Calculated by Universal Soil Loss Equation (USLE).
[d] USDA-Natural Resources Conservation Service.

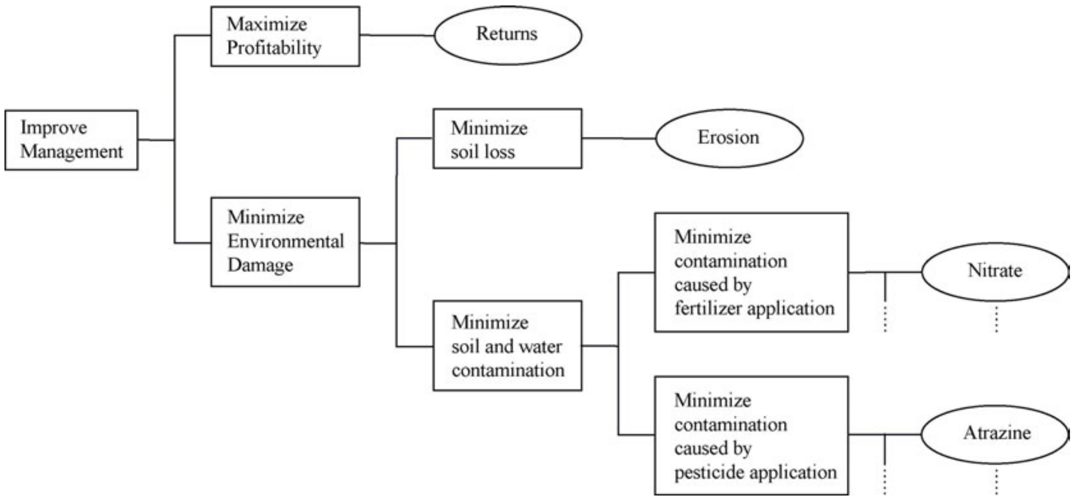

Figure 1: A value tree for farming practices.

Finding a Balance between Criteria

As a concept used for adjusting a balance between criteria, importance weights are used in many studies. There are, however, difficulties in weighting. The most serious difficulty is that the meaning of weights based on the relative importance of attributes is ambiguous. Moreover, the weights based on importance judgments may distort rescaling of single-attribute value functions. It is a well-known result that weight elicitation methods without relying on attribute ranges might lead to biased weights (von Nitzsch and Weber, 1993; Fischer, 1995). Because of the difficulty, weighting steps are referred to as “optional element” in ISO 14042 (2000), although weighting is recognized as a crucial part of LCA (Goedkoop, Effting and Collignon, 2000).

Thus, researchers on decision analysis recommend several weighting techniques that are theoretically and experimentally desirable. One is a method based on difference value measurement, in which weights are based on relative strengths of preference of the best over the worst attribute level across attributes (Dyer and Sarin, 1979). The other is swing weighting, in which the best and the worst attribute levels are referenced and direct numerical estimation is used for weighting (von Winterfeldt and Edwards, 1986). These weighting methods can be expected to provide us proper weights for attributes.

Unfortunately, there is another difficulty, even if we have the theoretically sound procedures for measuring appropriate weights. For example, attribute weights for raw data such as nitrate levels in groundwater are in general difficult to understand for decision makers and even for experts as compared with the case of the tradeoffs between a salary and a vacation in a job decision. Moreover, if raw data are used as attributes, the number of criteria will increase. This means the problems in the real world tend to have a considerable number of attributes. Consequently, we have to measure huge numbers of weights that may be beyond human cognitive ability. Indeed, the difficulty in weighting when a problem has 10 attributes or more is pointed out in LCA (Goedkoop, Effting and Collignon, 2000).

Therefore, it is necessary to introduce a methodology for transforming the data into the other values so that the meaning is easy to grasp. This is especially true for societal decision making because without introducing understandable measures into evaluation processes, differences in perceptions are not settled. In the next section, a mapping method is used to conceptually reduce the number of attributes. Then, the current state of understanding on health and ecological risks is outlined to recognize the possibility of aggregating attributes by the concept of risks.

USE OF RISK CONCEPTS

Problem Structuring by a Mapping Method

As a method to clarify how the attributes used for evaluating farming practices are transposed into two basic risk concepts – health risks and ecological risks, a mapping method (a concept map) is used because it can graphically represent the complex relations among actions, phenomena, and concepts.

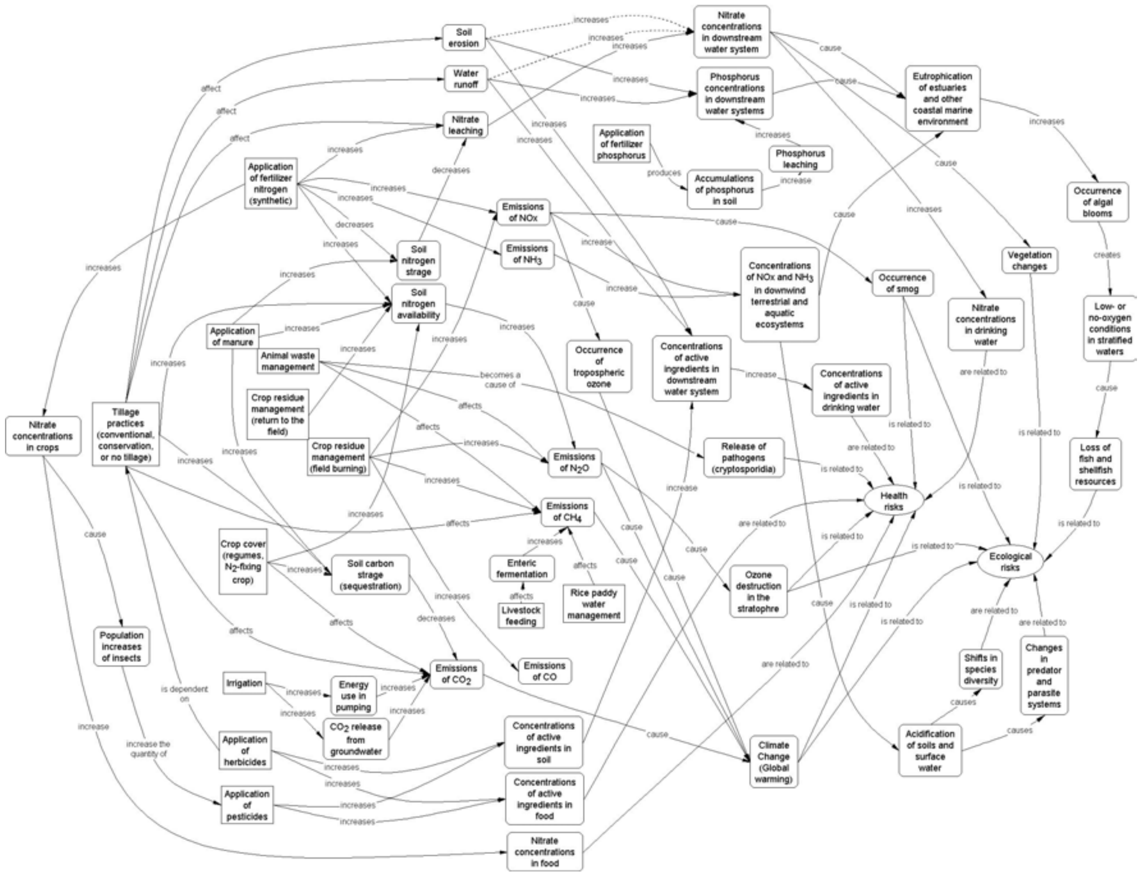

Figure 2: A concept map on the impacts of farming practices.

Figure 2 shows an example of a concept map. This figure illustrates that the practices such as fertilizer application cause many effects on the environment. This diagram expresses one of the possible recognition constructed on the basis of previous studies (Matson et al., 1997; Vitousek et al., 1997; Lægreid, Bøckman and Kaarstad, 1999; Tilman, 1999). In the actual evaluation, the influence on production costs and the availability of limited resources will be assessed in addition to the environmental effects depicted by the figure.

The main features of this figure are summarized as follows. (1) The attributes employed in the evaluation of agricultural practices explained in the previous section are recognized as intermediate attributes. Consequently, those attributes may be inappropriate in evaluating agricultural practices, although calculating the risks is in general not easy because of the difficulty in obtaining sufficient data. (2) Many attributes illustrated in this figure result in the two important concepts: human health risks and ecological risks. Protection of human health and protection of the environment (ecosystems) can be considered as dual goals of laws and regulations that use risk assessment to inform decision making (Presidential/Congressional Commission on Risk Assessment and Risk Management, 1997b).

Having clarified the pervasiveness of the two risk concepts, our next task will be to examine what kinds of measures are used for each risk. In the following section, the current situation of these fields is outlined, rather than concentrating detailed measurement and calculation processes.

Health Risks

A standard economic tool used for evaluating health care programs is cost-benefit analysis. In cost-benefit analysis all benefits are measured in terms of money and thus the results obtained from the analysis can be used to make decisions as to whether to fund a program because net benefits are defined as benefits minus costs.

There are, however, difficulties and controversies in assigning a monetary value to human life (a value of a statistical life) or to a change in the quality of life. The concerns that economic analysis places too much emphasis on assigning monetary values to aspects of health and the environment that are difficult to quantify in monetary terms are expressed (Presidential/Congressional Commission on Risk Assessment and Risk Management, 1997a). Thus, the other effective measures are used in cost-effectiveness analysis and cost-utility analysis, which are practiced, for example, in resource allocation decisions in health and medicine. Table 2 illustrates the examples of output measures.

Table 2: Output measures used for evaluating health risks

Analysis	Output measure
Cost-benefit analysis	Willingness-to-pay (WTP) measures of change in health risks
Cost-effectiveness analysis	Years of life gained,
	Improvement in functional status, etc.
Cost-utility analysis	Quality-adjusted life-years (QALYs)
	Healthy-year equivalents (HYEs)

In cost-effectiveness analysis, natural units such as years of life gained are used, whereas in cost-utility analysis utility-change indices such as QALYs and HYEs are introduced, although not all of the researchers accept the term cost-utility analysis (Gold et al., 1996). QALYs are calculated as the sum of the years of life in each health state times the quality of life (weights) in each health state in order to combine expected increments in the quantity of life from an intervention with the effects on the quality of life. In HYEs, after measuring the utility for each possible health path of changing health states, this utility is converted into the number of healthy years.

In addition to these measures, disability-adjusted life years (DALYs) are introduced into the life cycle impact assessment (Hofstetter, 1998; Goedkoop and Spriensma, 2000). DALYs are defined as the sum of the years of life lost (YLL) due to premature mortality and the years lived with disability (YLD). This concept is used in international organizations such as the World Health Organization and the World Bank.

Although the diversity in these output measures shows the difficulties and controversies in calculating health risks, concepts derived from life-years will, to say the least, play an important role in evaluating farming practices. In fact, without such concepts, the knowledge on toxicology, epidemiology and exposure assessment cannot be applied to the evaluations.

Ecological Risks

As compared with measurement of benefits from health programs, which is based on the concept of a statistical life (including a risk concept) and on survey techniques using willingness-to-pay, valuation of the environment has considerable difficulties. One reason is that the monetary evaluation method has to be applied without physical concepts. Indeed, contingent valuation surveys are recognized as notoriously unreliable, especially when applied to issues with which the public is unfamiliar; ecosystems are, in general, poorly known and are likely to remain elusive (Daily et al., 2000).

Moreover, the fact that areas where issues concerning biodiversity raise are in many cases located next to residential area makes valuation tasks more complicated. That is, the problem is the evaluation of biodiversity as secondary nature. Consequently, it is necessary to think about appropriate interaction between humans and nature.

Recent developments in evaluation methodologies are related to the above points. The diversity of species is considered as a representative measure for the quality of ecosystems in the LCA context (Goedkoop and Spriensma, 2000) and in the risk-benefit context (Oka, Matsuda and Kadono, 1999), although the definition of species has a slight ambiguity. In the former Eco-indicator 99 impact assessment methodology, the Potentially Affected Fraction (PAF) of species, which can be interpreted as the fraction of species that is exposed to a concentration equal to or higher than the No

Observed Effect Concentration (NOEC), is used for toxicity. In addition, the Potentially Disappeared Fraction (PDF), which can be interpreted as the fraction of species that has a high probability of no occurrence in a region due to unfavorable conditions, is utilized for acidification, eutrophication, and land-use. In the latter analysis, the index of expected loss of biodiversity (ELB), which is defined as the weighted sum of the increments in the probabilities of extinction of species that would be caused by human activities such as land-use conversion or pollution, is developed.

We have to understand that evaluation methodologies for ecological risks are still under development and that there are difficulties in evaluating ecological risks as in the case of health risks. However, we will find the similarity in the two risk concepts; measures for both risk concepts can be constructed on the basis of life years. The evaluation of the diversity of species can be considered as the evaluation of ecological life years of the environment.

Evaluation as a Whole

As shown in the earlier discussion, health and ecological risks will be key concepts in translating the various consequences into common measures. At the current level of risk assessment methodology and scientific knowledge, however, it may be difficult to integrate all the environmental indicators into a physical scale using the risk concepts. Thus, multiattribute evaluation techniques will play an important role in calculating overall values and in selecting preferable farming practices.

The situation is reflected in the recent trend in LCA. Since impact categories in traditional LCA (e.g., acidification, ozone layer depletion, ecotoxicity, and resource extraction) are difficult to grasp the seriousness and the number of the categories (10 or more different categories) is too large to be weighted (Goedkoop, Effting and Collignon, 2000), the recent life cycle impact assessment methodology has introduced the damage assessment procedure and a weighting triangle (Hofstetter, 1998; Goedkoop and Spriensma, 2000), which can be recognized as a method to systematically perform sensitivity analyses using a triangular graph. By contrast, the Eco-indicator 95 uses the so-called Distance-to-Target approach, in which the seriousness of an effect is related to the difference between the current and target values (Goedkoop, 1995).

This indicates that the necessity to formally consider the multiattribute models in understanding the weights; that is, maximizing a multiattribute value (utility) function will be one of the most general decision criteria and weight elicitation should be based on a sound measurement theory.

CONCLUDING REMARKS

The above discussion shows that in order to evaluate the health and environmental issues, it is necessary to rely on subjective value judgments. In this case, scientific approaches to value tradeoffs such as multiattribute value theory will be useful. In addition, since technical data that are necessary for assessing health and ecological risks are limited or nonexistent, expert judgment becomes crucial in assessing and modeling dependence among many variables. Thus, methods to formulate uncertainties using network representation will become important.

Although these studies are expected to improve evaluation methodologies, we have to consider the following dilemma. On the one hand, cost-benefit analysis can be recognized as a method that is theoretically sound and that is difficult to apply in many cases because placing monetary values on the outcomes of health and ecological issues is difficult and even immoral for some people. But on the other hand, multicriteria analysis might be an expedient although this sometimes means the importance of problem structuring steps.

Further consideration should be given to these kinds of issues including the differences in the attitude toward solving the problems between decision analysis and economics.

REFERENCES

Addiscott, T. M.: 1996, Fertilizers and nitrate leaching, *Issues in Environmental Sciences*, 5, 1–26.

Arondel, C. and Girardin, P.: 2000, Sorting cropping systems on the basis of their impact on groundwater quality, *European Journal of Operational Research*, 127(3), 467–482.

Audsley, E. (ed.): 1997, *Harmonisation of Environmental Life Cycle Assessment for Agriculture*, Silsoe, U.K.: Silsoe Research Institute.

Daily, G. C., Söderqvist, T., Aniyar, S., Arrow, K., Dasgupta, P., Ehrlich, P. R., Folke, C., Jansson, A., Jansson, B.-O., Kautsky, N., Levin, S., Lubchenco, J., Märler, K.-G., Simpson, D., Starrett, D., Tilman, D. and Walker, B.: 2000, The value of nature and the nature of value, *Science*, 289, 395–396.

Dyer, J. S. and Sarin, R. K.: 1979, Measurable multiattribute value functions, *Operations Research*, 27(4), 810–822.

Fischer, G. W.: 1995, Range sensitivity of attribute weights in multiattribute value models, *Organizational Behavior and Human Decision Processes*, 62(3), 252–266.

Foltz, J. C., Lee, J. G., Martin, M. A. and Preckel, P. V.: 1995, Multiattribute assessment of alternative cropping systems, *American Journal of Agricultural Economics*, 77(2), 408–420.

Fried, J. J.: 1991, Nitrates and their control in the EEC aquatic environment, *in* Bogárdi, I. and Kuzelka, R. D. (eds), *Nitrate Contamination*, Berlin: Springer-Verlag, pp. 3–11.

Goedkoop, M.: 1995, *The Eco-Indicator 95: Final Report*, Amersfoort, The Netherlands: PRé Consultants.

Goedkoop, M., Effting, S. and Collignon, M.: 2000, *The Eco-Indicator 99: A Damage Oriented Method for Life Cycle Impact Assessment, Manual for Designers*, 2nd edn, Amersfoort, The Netherlands: PRé Consultants.

Goedkoop, M. and Spriensma, R.: 2000, *The Eco-Indicator 99: A Damage Oriented Method for Life Cycle Impact Assessment, Methodology Report*, 2nd edn, Amersfoort, The Netherlands: PRé Consultants.

Gold, M. R., Siegel, J. E., Russell, L. B. and Weinstein, C. M.: 1996, *Cost-Effectiveness in Health and Medicine*, New York: Oxford University Press.

Hayashi, K.: 1999, Multicriteria analysis for natural resource management: Coping with diversity of methods, *in* Musy, A., Pereira, L. S. and Fritsch, M. (eds), *Emerging Technologies for Sustainable Land Use and Water Management*, Lausanne, Switzerland: Presses Polytechniques et Universitaires Romandes, pp. 10 (CD-ROM).

Hayashi, K.: 2000a, Evaluation of alternative farming systems by multicriteria analysis, *Japan Agricultural Research Quarterly (JARQ)*, 34(3), 209–213.

Hayashi, K.: 2000b, Multicriteria analysis for agricultural resource management: A critical survey and future perspectives, *European Journal of Operational Research*, 122(2), 486–500.

Heathwaite, A. L., Burt, T. P. and Trudgill, S. T.: 1993, Overview – the nitrate issue, *in* Burt, T. P., Heathwaite, A. L. and Trudgill, S. T. (eds), *Nitrate: Processes, Patterns and Management*, New York: John Wiley & Sons, pp. 3–21.

Heijungs, R. (ed.): 1992a, *Environmental Life Cycle Assessment of Products: Backgrounds*, Leiden, The Netherlands: Center of Environmental Science.

Heijungs, R. (ed.): 1992b, *Environmental Life Cycle Assessment of Products: Guide*, Leiden, The Netherlands: Center of Environmental Science.

Heilman, P., Yakowitz, D. S. and Lane, L. J.: 1997, Targeting farms to improve water quality, *Applied Mathematics and Computation*, 83(2-3), 173–194.

Hofstetter, P.: 1998, *Perspectives in Life Cycle Impact Assessment*, Dordrecht, The Netherlands: Kluwer Academic Publishers.

ISO 14042: 2000, *Environmental Management – Life Cycle Assessment – Life Cycle Impact Assessment*, Geneva, Switzerland: International Standard Organization.

Kumazawa, K.: 1999, Present state of nitrate pollution in groundwater, *Japanese Jour-*

Journal of Soil Science and Plant Nutrition, 70(2), 207–213. (in Japanese)

Lawrence, P. A., Stone, J. J., Heilman, P. and Lane, L. J.: 1997, Using measured data and expert opinion in a multiple objective decision support system for semiarid rangelands, *Transactions in the ASAE*, 40(6), 1589–1597.

Lægreid, M., Bøckman, O. C. and Kaarstad, O.: 1999, *Agriculture, Fertilizers and the Environment*, Wallingford, U.K.: CABI Publishing.

Matson, P. A., Parton, W. J., Power, A. G. and Swift, M. J.: 1997, Agricultural intensification and ecosystem properties, *Science*, 277, 504–509.

OECD: 2001, *Environmental indicators for agriculture, Volume 3, Methods and Results*, Paris, France.

Oka, T., Matsuda, H. and Kadono, Y.: 1999, Ecological risk-benefit analysis of a wetland development based on risk assessment using `expected loss of biodiversity', Paper presented at Society for Risk Analysis, 1999 Annual Meeting, December 6, 1999, Atlanta.

Presidential/Congressional Commission on Risk Assessment and Risk Management: 1997a, Framework for environmental health risk management, Washington, D.C.

Presidential/Congressional Commission on Risk Assessment and Risk Management: 1997b, Risk assessment and risk management in regulatory decision-making, Washington, D.C.

Sleeswijk, A. W., Kleijn, R., van Zeijts, H., Reus, J. A. W. A., van Onna, M. J. G. M., Leneman, H. and Sengers, H. H. W. J. M.: 1996, *Application of LCA to agricultural products*, Centre of Environmental Science, Leiden, The Netherlands: Leiden University.

Tilman, D.: 1999, Global environmental impacts of agricultural expansion: The need for sustainable and efficient practices, *Proceedings of the National Academy of Sciences*, 96, 5995–6000.

Tiwari, D. N., Loof, R. and Paudyal, G. N.: 1999, Environmental-economic decision-making in lowland irrigated agriculture using multi-criteria analysis techniques, *Agricultural Systems*, 60(1), 99–112.

United Nations Development Programme, United Nations Environment Programe, World Bank and World Resource Institute: 2000, *World Resources 2000–2001: People and Ecosystems: The Fraying Web of Life*, Oxford, U.K.: Elsevier Science.

Vitousek, P. M., Aber, J. D., Howarth, R. W., Likens, G. E., Matson, P. A., Schindler, D. W., Schlesinger, W. H. and Tilman, D. G.: 1997, Human alteration of the global nitrogen cycle: Sources and consequences, *Ecological Applications*, 7(3), 737–750.

von Nitzsch, R. and Weber, M.: 1993, The effect of attribute ranges on weights in multiattribute utility measurements, *Management Science*, 39(8), 937–943.

von Winterfeldt, D. and Edwards, W.: 1986, *Decision Analysis and Behavioral Research*, Cambridge, U.K.: Cambridge University Press.

Yakowitz, D. S., Lane, L. J. and Szidarovszky, F.: 1993, Multi-attribute decision making: Dominance with respect to an importance order of the attributes, *Applied Mathematics and Computation*, 54, 167–181.

BIOGRAPHICAL SKETCH

KIYOTADA HAYASHI has been a senior researcher at the National Agricultural Research Organization, which is an independent administrative institute of the Ministry of Agriculture, Forestry and Fisheries of Japan. His research interests include evaluation of farm management practices, analysis of agri-environmental problems, and development of agricultural planning models. Dr. Hayashi is the author of *Agricultural Decision Analysis under Multiple Criteria and Multiple Participants* (Yokendo 2000, in Japanese), which took a prize offered by the Farm Management Society of Japan. He has been a Guest Research Scholar at International Institute for Applied Systems Analysis in 2001/02. He is a member of scientific program committees and editorial review panels of several international conferences.