JARQ 34(3), 209–213 (2000) http://ss.jircas.affrc.go.jp

Evaluation of Alternative Farming Systems by Multicriteria Analysis

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Abstract
A methodology was presented for selecting a farming system from multiattribute discrete alternatives by multicriteria analysis. An ex ante evaluation of vegetable production systems was performed in addition to a review of previous case studies to demonstrate the usefulness of this methodology and difficulties in applying it. The various methods used in the studies were classified into 3 groups: the compensatory, the non-compensatory, and the distance-based approaches, and were reviewed from a practical viewpoint. Since problems with weighting occurred in many case studies, special attention was paid to weights, especially to their meaning and the way to assess them. On the basis of this discussion, a method using multiattribute value functions was utilized for the evaluation. Labor-saving vegetable production systems under development, in which a self-propelled harvester was introduced and thinning was eliminated, were compared with the conventional system at the farm level based on criteria of profitability and framework characteristics. Determination of which labor-saving production system appears more desirable and a framework to effectively investigate "what-if" questions were provided.

Discipline: Agricultural economics
Additional key words: multiattribute value functions, vegetable production systems

Introduction

Many alternative technologies have been proposed for improving farm management. For example, production systems using innovative farm machinery and management practices to mitigate environmental degradation have been studied; results related to profit and loss, working hours, ease of labor, soil erosion, chemical and nutrient contamination, etc., were analyzed or estimated using field experiments, survey methods and simulation techniques. These kinds of information are by themselves considered to be useful for farmers and extension services.

The attributes used for measuring the performance of the systems, however, are in general conflicting with each other. Costs increase when labor-saving machinery is introduced into farm management; margins may decrease when management aims at preserving the environment. Therefore, it is necessary to determine how to evaluate and select a farming system.

The purpose of this study was to develop an approach to select a multiattribute discrete alternative using multicriteria analysis. In Section 2 the methodology was described and difficulties were outlined through a review of previous studies. In Section 3 the methodology was applied to the evaluation of labor-saving production systems for vegetables.

Methodology and review of previous studies

In this study, farming systems were evaluated through solving the following decision problem: to select a solution from a discrete set of alternatives using a set of criteria. These problems (selection problems[11]) have been studied by discrete multicriteria analysis which attracts much attention because of its ability to deal with ill-structured problems as compared with multiobjective programming (continuous multicriteria analysis).

The methods were classified into 3 groups. First, in

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Received 1 December 1999, accepted 28 December 1999.

the compensatory approach, multiple attributes were aggregated into overall values by, for example, multiattribute value (utility) functions in which the concept of tradeoffs plays a crucial role. Second, in the non-compensatory or outranking approach, aggregation procedures based on concordance and discordance concepts were introduced; the concepts were derived from outranking relations, which indicate that an alternative is at least as good as another one. Third, in the distance-based approach such as compromise programming, the distance between an ideal point and the alternative was minimized.

In the following part, previous case studies will be reviewed and the difficulties in applying these methods will be outlined[6,7]. After surveying compensatory approaches such as methods using multiattribute value functions, other methods including outranking approaches will be considered.

A method based on an additive multiattribute model has been widely applied for ranking alternatives using an importance order of attributes without specifying numerical values of attribute weights[8,9,14]. Farming practices were evaluated from the viewpoint of profitability and environmental quality of soil and water. The method, however, was associated with the following problems. (1) The meaning of rank-ordered weights based on the relative importance of attributes was ambiguous. (2) The intervals of overall values were sometimes too wide to make decisions (to develop dominance relationships). (3) The fact that the structure of a value tree (a hierarchy of criteria) may affect the final results was not taken into account. Another method using ranking information on weights (pairwise ranking) has been applied for assessing alternative cropping systems from profitability and environmental quality perspectives[3]. The weighting procedure of the method, however, was also based on intuitive meaning, although weights based on importance judgments, not derived from attribute ranges, may distort rescaling of single-attribute value functions.

A common technique to alleviate the range problem is swing weighting. This technique has been applied to the evaluation of vegetable production systems from the viewpoint of profitability and farmwork[4]. Since the first step of the assessment is the development of a rank order, the ranked swing weights are also applicable to case studies instead of using intuitive ranked weights.

An outranking approach has been utilized for sorting cropping systems based on their impact on groundwater quality[1]. The revised "weighting with cards" method[2] has been used, although the concept of weights is quite different from the case of additive multiattribute value functions. The concept of weights which does not involve tradeoffs has also been used in the Analytic Hierarchy Process (AHP), though the aggregation procedure is based on compensation. Although this method has been applied to the evaluation of alternative farming systems[10,12], there are numerous limitations related to the notion of weights[5]; the method has been criticized even by advocates of outranking approaches[2]. The differences in the interpretation of weights suggest that using more than one type of methods may complicate the interpretation[6,13], although it seems to be a safe approach and some authors follow that procedure; for instance, the AHP and compromise programming are used for the same example[12].

An application: evaluation of labor-saving production systems

In this section an application of multiattribute value functions is presented. The decision problem this case study addressed is whether to introduce labor-saving production systems for daikon (*Raphanus sativus* L.) cultivation. The issue is the tradeoff relationship between profitability and working hours with reference to ease of labor. The decision maker was a representative farmer at Hiruzen Heights (440–520 m elevation) in the northern part of Okayama Prefecture, Japan. Since this is an *ex ante* evaluation, interval representation was introduced into models to cope with imprecision and uncertainty in data as well as in preferences[4].

1) Evaluation criteria

Farm profitability and farmwork characteristics were used as 2 main criteria that summarize the information contained in many indicators for the evaluation. Fig. 1 illustrates the calculation process. Since the profitability is based on the profit before accounting for unpaid family labor, there is no overlap or redundancy between the 2 attributes. Farm profitability was based on the net profit, which is affected by the percentage of germination, the percentage of the number of openings with germination to the total number of openings in plastic mulch, and the percentage of a yield of high quality to a gross yield. Farmwork characteristics were derived from working hours for each task such as seeding or harvesting.

2) Alternatives

Farming systems, alternatives in decision analytic terminology, can be defined as combinations of components and were developed using the strategy-generation table shown in Table 1. The following 3 production systems for daikon were generated:

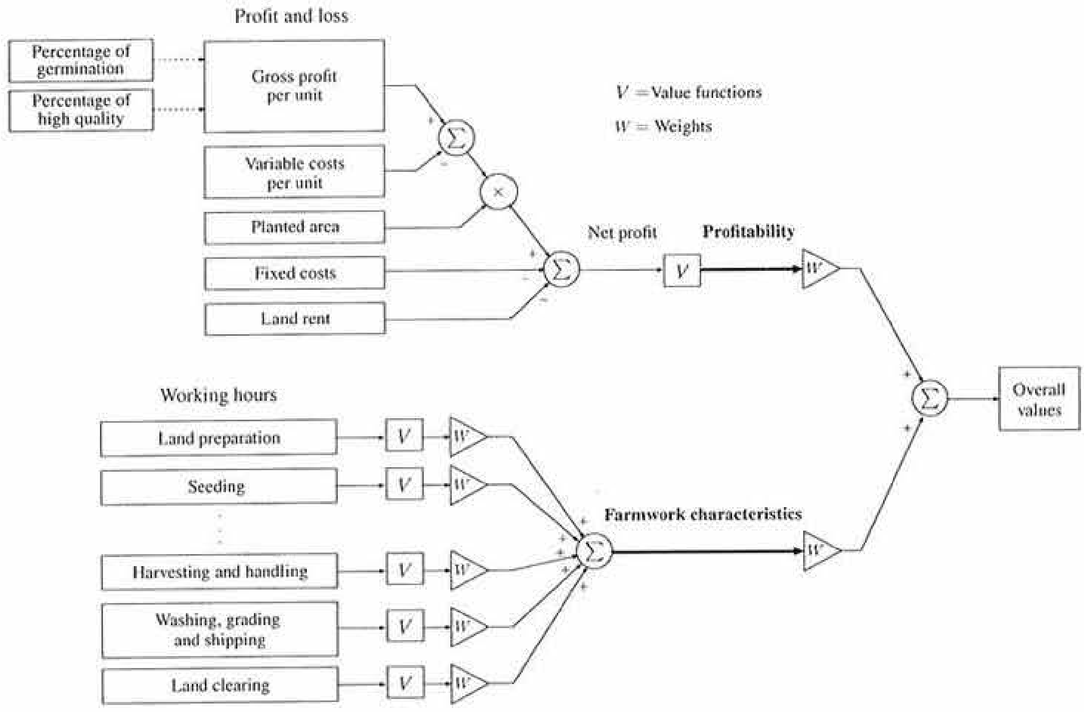

Fig. 1. Calculation process of overall values

(1) The conventional system, in which 2 (or 3 in the case of seeding, thinning, harvesting, and carrying) family workers (plus a few hired workers for thinning) cultivate a farm of 5 ha by sowing 2 seeds per opening in a plastic mulch and harvesting by hand.
(2) The first improved alternative (labor-saving alternative A, LS-A for short), in which 2 (or 3 in the case of seeding, harvesting, and carrying) family workers cultivate a farm of 5 ha by sowing 1 seed per opening to eliminate thinning work and harvesting with a self-propelled harvester to improve the ease of the work.
(3) The second improved alternative (LS-B), which is the same as LS-A except that seeding and harvesting labor is entrusted to an agricultural cooperative.

3) Results

Overall values of each alternative were obtained through the aggregation of weights for each attribute and single-attribute values. The swing weight for profitability was 0.769 and the weight for farmwork characteristics was 0.231. Sensitivity to the weights will be analyzed later. The values are shown in Table 2.

Using the overall values, the relationship among alternatives is represented graphically as (7) in Fig. 2. The representation shows that the conventional system was weakly preferred to LS-A, the conventional system and LS-B were indifferent, and LS-B was weakly preferred to LS-A. Since this is a preliminary analysis of new production systems, sensitivity analysis is expected to provide significant results. Thus, the following discus-

Table 1. Generation of alternatives

Altenative (strategy)	Seeds per opening /Thinning	Seeding labor	Purchasing a harvester	Harvesting method	Harvesting labor	Washing and shipping
Labor-saving A						
	1/Not practiced	Operator of AC	Yes	Harvester (all at once)	Operator of AC	Cooperative
Labor-saving B						
	2/Practiced	Family	No	Hand (selective)	Family	Individual
Conventional						

Table 2. Values of the alternatives

Attribute	V_i (LS-A)	V_i (LS-B)	V_i (Con.)
1. Profitability	[0.215, 0.215]	[0.212, 0.212]	[0.309, 0.309]
2. Farmwork characteristics	[0.698, 0.832]	[0.810, 0.886]	[0.457, 0.681]
2–1. Land preparation	[0.300, 0.593]	[0.300, 0.593]	[0.300, 0.593]
2–2. Seeding	[0.269, 0.671]	[1.000, 1.000]	[0.269, 0.671]
2–3. Thinning	[1.000, 1.000]	[1.000, 1.000]	[0.400, 0.733]
2–4. Weeding	[0.375, 0.375]	[0.375, 0.375]	[0.375, 0.375]
2–5. Chemicals application	[0.247, 0.592]	[0.247, 0.592]	[0.247, 0.592]
2–6a. Harvesting and handling (by hand)	[1.000, 1.000]	[1.000, 1.000]	[0.320, 0.500]
2–6b. Harvesting and handling (by machine)	[0.375, 0.479]	[0.583, 0.653]	[1.000, 1.000]
2–7. Washing, grading and shipping	[1.000, 1.000]	[1.000, 1.000]	[1.000, 1.000]
2–8. Land clearing	[0.737, 0.737]	[0.737, 0.737]	[0.474, 0.474]

sion will focus on the effects of changes in value judgments and in technical improvements.

The stability of the current results can be represented by weight intervals within which the preference relations do not change. For example, the current relation (7) does not change within $W_1 = [0.718, 0.784]$ and $W_2 = [0.216, 0.282]$. The stability of the results can be expressed as intervals of data that preserve the preference relations in the same way. The current relation (7) does not change within the interval of yield per unit that fluctuates from 0.68 to 1.12 times of the current level provided that the ratio of the high quality price to the low quality price does not change.

As Fig. 1 shows, the percentage of germination and the percentage of a yield of high quality to a gross yield affected the net profits and consequently overall values. These effects can be examined in a two-way sensitivity analysis. Fig. 3 illustrates the results. A point on the graph was defined by a pair of parameters; the first number is the percentage of openings with germination; the second number is the ratio of the percentage of high quality in the labor-saving systems (LS-A or LS-B) to the percentage of high quality in the conventional system. The regions surrounded by lines, which were numbered from (4) to (11), correspond to the preference relations shown in Fig. 2. The *status quo* was located at (0.9, 0.8). The figure shows that if improvements in the percentages were to be realized, LS-A and LS-B would be preferred to the conventional system, although neither of them would be strictly preferred to the conventional system due only to these technical improvements.

Concluding remarks

Research on the relationship between farm income and labor utilization is important for evaluating a farming

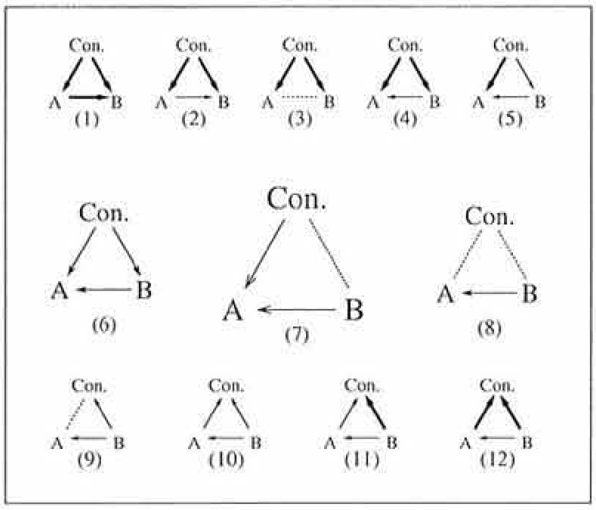

Fig. 2. Preference relations

Con.: the conventional system.
A: the labor-saving alternative A.
B: the labor-saving alternative B.
$a \Rightarrow b$: aPb. $a \rightarrow b$: aQb. $a \cdots\cdots b$: aIb.

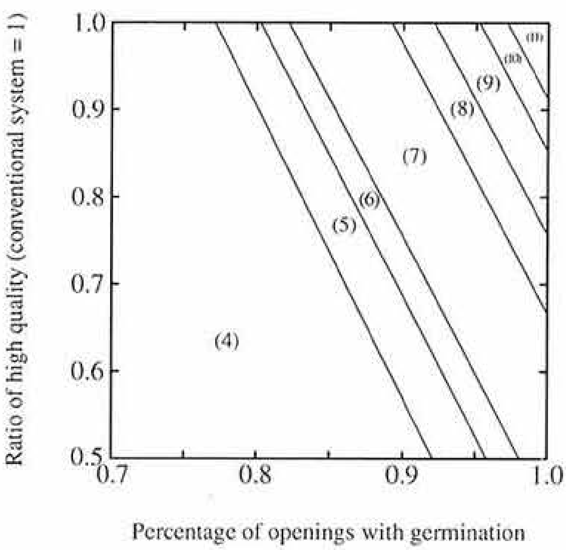

Fig. 3. Effects of technical improvements

system as illustrated already; it is a traditional theme and many case studies using multiobjective programming or goal programming have employed these criteria[7]. However, the growing concern about the severity of environmental problems such as pollution of groundwater, which may account for the recent increase of case studies using multicriteria analysis, will require that more complex problems be dealt with. Since criteria and alternatives do not exist beforehand and decision makers and perspectives are plural in that case, attention should be paid to problem structuring.

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