Staff Paper 339 May, 1994

Analytic Hierarchy Process and the Farmer's Decision Problem: Choosing Between Alternative Farming Systems

by

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When using analytical tools to make decisions, farmers and farm managers complement formal analysis with personal experience, judgement, and intuition as part of the decision making process. The availability and sophistication of decision aids at their disposal is continually expanding. Some decision aids are more complex than others, but almost all are based on the rigorous analysis of factual information and quantitative data (Downey and Erickson).

In this article we illustrate the application of a new method, the Analytic Hierarchy Process (AHP), to a problem in farmer decision making. Unlike traditional decision tools, AHP is based on the principle that decision maker knowledge and experience are as valuable to the decision making process as quantitative data and information from other sources. In this theory of measurement, quantitative and intangible criteria in the decision making process are blended. Recently, AHP was applied to problems in economic modelling (Harker & Vargas).

AHP was initially developed by Saaty in the 1960s and 1970s in response to corporate and military contingency planning, the allocation of scarce resources, and also in response to a need for political participation in negotiated agreements (Golden et. al.; Vargas). AHP is helpful for understanding a complex decision making process involving intricate systems by reducing each decision to a relatively simple sequence of pairwise comparisons between properly defined components of the system (Saaty, 1990).

Since it was introduced, AHP has enjoyed an increasing appeal in a number of different applications, and several books have been published (Alexander; Anderson et al.; Kearns; Saaty and Vargas.), in addition to special issues of academic journals with hundreds of articles. The availability of a microcomputer software package, Expert Choice®, which models complex decision problems, has broadened its applications to such diverse areas as economics (Hughes; Peniwati; Saaty 1987; Bahmani et al. 1986), accounting and finance (Arrington et al.; Bahmani et al. 1987; Neim and Teed), resource allocation (Liberatore; Saaty and Mariano), sociology (Saaty 1986; Saaty and Wong), politics and conflict analysis (Alexander; Arbel et al.), architecture [Saaty and Beltran), engineering (Beaumariage; Ikedi), health care (Dolan; Dougherty and Saaty), and transportation (Saaty 1977).

Some of the problems to which AHP has been applied, especially in the areas of marketing (Schwartz; Wind), resource allocation (Saaty and Mariano), risk analysis (Jensen), and health care (Dolan), are similar to those faced by farmers. However, we found no previous literature that has specifically applied AHP to a decision problem in agricultural economics. Hence, the primary objective of this article is to demonstrate how AHP can be used by agricultural economists to better understand how farmers make choices among alternative decision paths.

AHP and Sustainable Farming Systems

The problem used to illustrate AHP is the farmer's choice decision between a conventional and two alternative, "sustainable" farming systems. A sustainable farming system is defined as a management strategy that helps the farmer as a producer in the selection of hybrids and varieties, cultural practices, soil fertility programs, and pest management approaches that reduce the costs of purchased inputs, minimize the impact of farming on the immediate and off-farm environment, and provide a sustained level of production and profit from farming (Granatsein). Sustainable farming systems inherently involve multiple goals or objectives. Conflicts may arise not only between different goals pursued by a single farmer but also between a farmer's goals and society's goals. For instance, in the short run, it may be in the best interest of the farmer to use pesticides and other chemicals to maximize profits by reducing labor costs. However, the cost to society of using commercial chemical fertilizers may be much higher than the application costs borne by the producer.

The two alternatives, biological and organic farming, are broadly consistent with the goals and objectives of sustainable agriculture. Public concern for the environment and the need for a more nearly sustainable development process has also increased farmers' awareness and concern over environmental degradation, health, and long term productivity. What was once a simple choice based on profit, or perhaps net worth maximization, now contains additional and sometimes conflicting objectives. AHP is especially well suited to decision making problems involving multiple goals or criteria.

In the farmer's quest for greater utility or satisfaction, greater efficiency of resource use, and a balance with the environment, the decision problem remains fundamentally a choice of the optimal among three alternative farming systems. As the top goal, this choice is based on four main objectives (sub-goals), which are profit maximization or economic performance, improvement of human health, environmental protection through improved quality of land, water and air, and sustainability or the stewardship of land and other natural resources or through soil erosion reduction to insure long-term soil productivity.

Using the analytic hierarchy process, this study estimates the weights and ranks assigned by profit-maximizing farmers to the aforementioned objectives (sub-goals). These weights and ranks are used to determine the rankings and weights for a choice between three alternative farming systems, and that choice remains the single most important outcome of the study. Each objective may conflict with others; nonetheless, sustainable agriculture treats them jointly. For example, to be economically sustainable, farming must be profitable but not at the expense of health and safety concerns or the protection of the environment. Even though these sub-goals may compete with one another in the short run, they may complement each other in the long run. Furthermore, if the environment is not protected, the resource base of agriculture will deteriorate, along with long-run yields and profits. An increasing number of farmers are thus opting for a long-run strategy of attempting to maximize net worth rather than short-run profits in a few production seasons (Debertin; Schaller).

Analogies in the Literature

An analogy to the farmer's decision problem in choosing a farming system was found in a health care study using AHP in Rochester, New York. The doctors were faced with a choice between several antibiotic regimens representative of the current treatment recommendations (Dolan). Like farmers who must choose between farming systems in an uncertain environment, doctors also must choose among several antibiotic treatments, also under conditions of uncertainty. The lack of a urine test (which is available to the doctor only 48 hours later) makes the antibiotic's effectiveness uncertain, just as the unpredictability of the weather renders a crop yield from the farming system chosen by the farmer random until the end of the growing season. The structure of the decision problem in this analysis is similar to ours in that each of the four major criteria or objectives was divided into sub-criteria or sub-objectives.

Another example which parallels the farmer's decision problem was found in a study by Beaumariage. AHP was used to compare and evaluate two simulated environments widely used by engineers. Here, the decision maker (in this case an engineer), chose between a traditional simulation environment and a modern environment (Object Oriented Modeling). Our case is analogous in that the farmer's choice is between a new sustainable farming system and the conventional farming system.

A study by Ikedi comprises another example. Here, World Bank development experts rank-ordered development objectives. The ranks and weights of these objectives were later inserted into a goal programming model for long-term labor-planning purposes. In our problem, farmers use AHP to rank objectives to choose a farming system. The weights generated by the farmer using AHP which represent a product of our analysis, could also be inserted into a goal programming model to help farmers improve the allocation of inputs.

Structuring the Farmer's Decision Problem.

Once it is established whether the decision problem concerns allocating resources, planning a future course of action or choosing the best alternative (farming system in our case), the first of four steps in applying AHP is to structure the decision problem. A farmer with a single criterion or objective, (i.e., profit), would only need to choose the alternative that generates the highest value for that objective.

Increasing concerns about food safety, externalities from farming such as groundwater contamination, and other environmental concerns have made a once simple choice more complex.

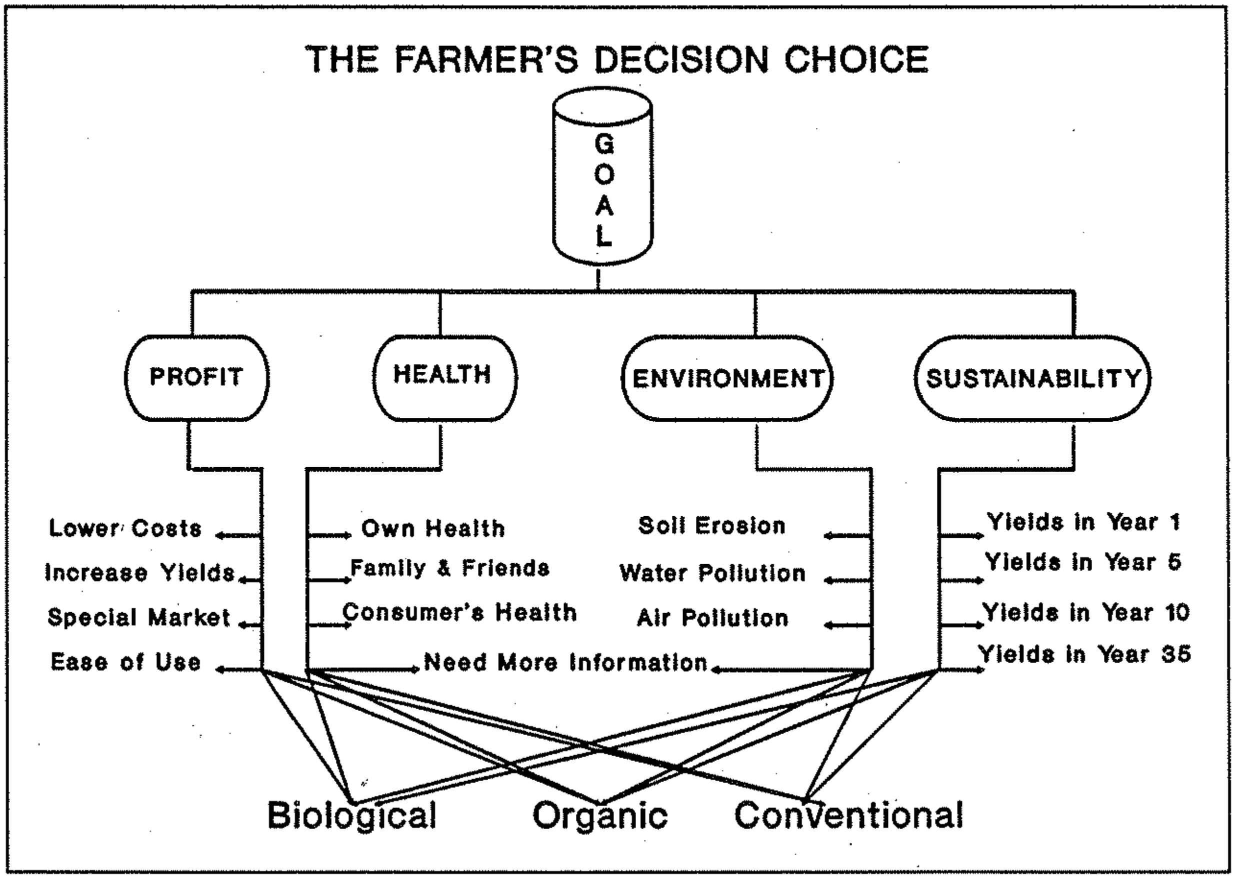

Figure 1. The Structure of the Farmer's Decision Problem

Farmers have more concerns than in the past when choosing a farming system that may affect the environment and the health of the public in ways that may not be fully known except over a number of years. The Analytic Hierarchy Process is specifically designed to take into account uncertain, often subjective, information in the decision making process.

To incorporate the varying and even conflicting aspects of this complex decision problem, the farmer can construct a hierarchy that reflects that individual's understanding and interpretation of the decision choice problem (Figure 1). AHP requires that the most important decision or goal be identified first.

Lower levels of the hierarchy contain decision attributes that contribute to the quality of the decision. Attributes become more detailed at lower levels in the hierarchy. At the bottom, the decision alternatives or selection choices are found (Beaumariage, Zahedi).

Level II of the hierarchy contains the four objectives pursued by the farmer in selecting the most appropriate farming system. These objectives include profit maximization, the enhancement of the health of family members, workers and consumers, overall environmental enhancement, and the maintenance or improvement of long term productivity of the farming operation (Table 1).

Table 1. Level II Objectives and their Attributes in Level III

Objectives (Level II)	Attributes or Sub-objectives (Level III)
1.- Profit Maximization:	
	1.1.- Reduce Production Costs
	1.2.- Increase Yields
	1.3.- Access Special Market Outlets
	1.4.- Ease of Use
2.- Health Concerns:	
	2.1.- Farmer's Own Health
	2.2.- Family and Friend's Health
	2.3.- Consumer(Customer)'s Health
	2.4.- Need More Information to Decide
3.- Environmental Concerns:	
	3.1.- Reduce Soil Erosion
	3.2.- Reduce Water Contamination
	3.3.- Reduce Air Pollution
	3.4.- Need More Information to Decide
4.- Sustainability:	
	4.1.- Next Season's Yields
	4.2.- Yields in the Next Five Years
	4.3.- Yields in the Next Ten Years
	4.4.- Yields in the Next Generation

Level III depicts attributes or characteristics of the preceeding level's sub-goals or objectives. In our example, level III contains 16 attributes or characteristics. Some attributes help the farmer achieve the objectives or sub-goals defined at level II. Others, however, may impede the achievement of certain objectives. The farmer's problem is structured such that all four sub-goals have four attributes each in level III, i.e. a total of 16 attributes all depicted in Table 1.

The three alternative farming systems comprising the farmer's choice set make up the lowest level of the hierarchy. These are conventional farming, biological farming, and organic farming. Of course, each farmer can construct a different hierarchy reflecting a unique understanding of the decision problem. A farmer may include more alternative choices and/or pursue additional or fewer objectives.

Table 2. A Description of The Three Alternatives

Farming Systems	Weed Management	Pest Management	Fertility Management	Land Management
Conventional	Chemical Herbicides	Chemical Pesticides	Chemical Fertilizers	Conventional Tillage
Biological	Intercropping, Rotations, Biological agents, Few chemicals	Rotations, Planting Dates, Biological agents, Chemical Pesticides used as a last resort	Animal and Green Manure, few chemical fertilizers if nothing else can be used	Conservation tillage
Organic	No chemical Herbicides	No chemical pesticides	No chemical Herbicides	Zero tillage or Plow-plant

Data Collection by Pairwise Comparisons

The second major step of an AHP model is to collect input data through pairwise comparisons of the different decision elements included in the hierarchy. At each level of the hierarchy, an evaluation is made of the relative importance of pairs of factors. This is accomplished by using the 9-point scale (Table 3). Each pairwise comparison then fits into a square matrix.

Instead of assigning arbitrary weights, AHP gives the farmer performing the evaluation a solid basis to reveal preferences to avoid inaccuracies and inconsistencies. This is accomplished by using the judgement scale outlined in Table 3. Inconsistencies can be reduced by conducting a consistency test. If the result is above a certain acceptable limit, say 10 percent, the decision maker is given the opportunity to repeat the pairwise comparisons.

Saaty provided the following reasons or explanations to justify the use of Table 3 as a judgement scale for performing the pairwise comparisons:

(1) Qualitative distinctions are meaningful in practice and have an element of precision when the items being compared are of the same order of magnitude or close together with regard to the property used to make the comparison.

Table 3. Scale of Judgements.

Intensity of Judgements	*Definition*	*Explanation*
1	Equal importance	Two activities contribute equally to a given objective.
3	Weak importance of one over another	There is evidence favoring one activity over another but it is not conclusive.
5	Essential or strong importance.	Good evidence and logical criteria exist to show that one activity is more important.
7	Demonstrated importance	Conclusive evidence exist and show the importance of one activity over another.
9	Absolute importance	The evidence of the importance of one activity over another is of the highest possible order of affirmation.
2, 4, 6, 8	Intermediate values	When compromise is required. between two adjacent judgements.
Reciprocals of above non-zero numbers	If activity i has one of the above non-zero numbers assigned to it when compared with activity j, then j has the reciprocal value when compared with i	
Rationals	Ratios arising from the scale	If consistency were to be forced by obtaining n numerical values to span the matrix

(2) Human ability to make qualitative differences or meaningfull comparisons is well represented by five attributes: equal, weak, strong, very strong, and absolute. Compromises between adjacent attributes can be made when greater precision is needed.

(3) A practical method used to evaluate items is the classification of stimuli into a trichotomy of regions: rejection, indifference, and acceptance. For more refined classification, each one is subdivided into a trichotomy of low, medium, and high which produces a total of nine shades of meaningful distinctions. And those nine shades provide the basis for the AHP's scale of judgements (Saaty, 1990).

A scale of pairwise comparison from zero to infinity has not been useful in practice. An extremely wide scale assumes that humans are somehow capable of comparing the relative dominance of any two objects, which is not always the case. Experience has shown that human ability to discriminate is highly limited in range, and when there is considerable disparity, guesses tend to be arbitrary and usually far from actual reality (Saaty, 1990).

In this step, the question to be answered by the decision maker (farmer in our case) is of the following generalized form: For the best choice of a farming system, which objective is, according to your personal understanding, more important; and how strongly do you favor it?

The farmer must ask this question at each level of the decision hierarchy, and all pairwise comparisons are performed likewise. Each level has k pairwise comparison matrices with $n(i)$ rows and columns each; n is the number of decision attributes, i is the level in the decision hierarchy; and $k = [n(i-1) \times \text{(the number of elements at level } i)]$.

For example, in ranking alternative farming systems with respect to the sub-objective of increasing productivity in the next generation, one of the farmers interviewed for this study assigned equal weights to conventional and biological farming, which were subsequently ranked twice and five times more important than organic farming.

Table 4. Illustrative Sample of a Pairwise Comparison Matrix.

	Conventional	*Biological*	*Organic*
Conventional	1	1	2
Biological	1	1	5
Organic	1/2	1/5	1

When compared with itself, each element has equal importance. Therefore, diagonal elements of the pairwise comparison matrix always equal 1 and lower triangle elements of the matrix are the reciprocal of upper triangle elements. Thus, pairwise comparison data are usually collected for only half of the matrix excluding diagonal elements.

Calculations to Generate Weights

The decision maker, in applying AHP, uses an eigenvalue method to estimate the relative weights of different decision elements included in any pairwise matrix similar to the one illustrated below. Since this method is based on pairwise comparisons, the procedure also includes an analysis of the consistency (transitivity) of judgements, which allows possible revisions.

In this third step, the solution technique of AHP uses the pairwise comparison matrix created in step 2 as input and produces as output the relative weights of elements at each level. To better understand the AHP eigenvalue method of step 3, suppose one wishes to compare $n = 1,..., N$ elements in pairs according to their weights.

Suppose the evaluator knows the weights of those n elements, which are denoted as A_1, A_2,... ,A_n for the elements and w_1, w_2, ... ,w_n for the weights. The matrix of pairwise comparisons is

$$A = \begin{array}{c|ccccc} & 1 & 2 & 3 & \cdots & n \\ 1 & w_1/w_1 & w_1/w_2 & w_1/w_3 & \cdots & w_1/w_n \\ 2 & w_2/w_1 & w_2/w_2 & w_2/w_3 & \cdots & w_2/w_n \\ 3 & w_3/w_1 & w_3/w_2 & w_3/w_3 & \cdots & w_3/w_n \\ \vdots & \vdots & \vdots & \vdots & \ddots & \vdots \\ n & w_n/w_1 & w_n/w_2 & w_n/w_3 & \cdots & w_n/w_n \end{array}$$

The pairwise comparison matrix above is created using the following procedure (Saaty 1980, Beaumariage). Row criterion or attribute A_i is compared to a column criterion or attribute A_j. If A_i is greater than A_j, then a numerical value greater than 1 is placed in the (A_i,A_j) position in matrix A. If A_j is more important than A_i, the reciprocal of (A_i,A_j), a number smaller than 1, will be entered instead. In any case, the reciprocal of the value entered in the (A_i,A_j) position is entered in the (A_j,A_i) position (Saaty 1986*a*, 1986*b*), while 1 is entered in all the diagonal positions.

It is important to note that the evaluator uses ordinal rankings that AHP transforms into cardinal rankings. These cardinal rankings are ultimately converted into weights.

Aggregation into Priority Vectors of Composite Weights

The fourth step of the AHP model consists of aggregating the simple relative weights of the decision elements to produce a set of ratings or composite weights for the decision alternatives or outcomes. In contrast to the simple relative weights of step 3, which are based on a single criterion, these composite weights are calculated by Expert Choice® using a process that takes into account all elements of the decision hierarchy.

The final priorities are obtained by weighting the relative values through the hierarchy by summing the totals for each decision alternative, and normalizing the results (Beaumariage; Saaty, 1990). Given the pairwise comparisons in matrix A (step 2), the relative weights could be trivially obtained from each of the n rows of matrix A. In other words, matrix A has rank 1 and the following relationship holds:

$$A \cdot W = n \cdot W,$$

where $W = (w_1, w_2, \ldots .w_n)^T$ is the vector of actual real weights, and n is the number of elements. The equality can only hold if n and W are, respectively, the eigenvalue and the right eigenvector of matrix A, and also if and only if A is a consistent matrix (Zahedi).

AHP posits that the evaluator does not know W and, is therefore unable to accurately produce the pairwise relative weights of the A matrix. Consequently, the observed matrix A contains inconsistencies. The estimate of W, $\hat{W}$ could be obtained from:

$$A^h \circ \hat{W} = \lambda_{max} \circ \hat{W},$$

where A^h is the observed matrix of pairwise comparisons, λ_{max} is the largest eigenvalue of A^h and $\hat{W}$ is its right eigenvector.The composite relative weight vector of elements at the k^{th} (bottom) level with respect to that of the first (top) level is obtained from:

$$C[1,k] = \prod_{i=2}^{k} B(i),$$

where $C[1,k]$ is the vector of composite weights of elements on level 1; and $B(i)$ is the $n(i-1)$ by $n(i)$ matrix with rows consisting of estimated $\hat{W}$ vectors; $n(i)$ represents the number of elements at level i and is the same elsewhere except that it is subscripted to show that it belongs to level i (Beaumarriage; Zahedi).

Eigenvalue λ, is used in the construction of the consistency index $CI = (\lambda_{max} - n)/(n-1)$ and the consistency ratio $CR = (CI/ACI)*100$, where ACI is the average index of randomly generated weights (Saaty 1988, 1990). As a rule of thumb, a consistency ratio (CR) of 10 percent or less is acceptable. If not, it is recommended that A^h be re-observed to solve inconsistencies in pairwise comparisons. This 10 percent upper-limit value was determined based on the understanding that there is an acceptable 10 percent probability that the decision maker made all judgements in a purely random fashion (Harker and Vargas).

An Illustrative Application of Expert Choice®

Several methods can be used to estimate W. Expert Choice®, a computational algorithm capable of performing all the computations required by AHP, including consistency checks for pairwise comparison matrices, has recently been introduced. Until Expert Choice® was developed, the calculations in steps 3 and 4 were done manually to convert the ordinal rankings made by the decision maker into cardinal rankings. The cardinal rankings are arranged in a non-symmetric matrix from which eigenvalues are computed and weights assigned.

For example, the weights assigned by one of the farmers interviewed for this study originated from the following pairwise comparisons (Table 5). On the first line health concerns were indicated to be slightly more important than profit maximization. In the AHP jugement scale, that choice becomes 2, as highlighted on the right hand side of Table 5, implying that health concerns are twice as important as profit maximization for this farmer.

Table 5. Sample Pairwise Comparison Entry Form from the Survey Questionnaire

1	PROFITABILITY	9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9	HEALTH
2	PROFITABILITY	9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9	THE ENVIRONMENT
3	PROFITABILITY	9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9	LONG TERM PRODUCTIVITY
4	HEALTH	9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9	THE ENVIRONMENT
5	HEALTH	9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9	LONG TERM PRODUCTIVITY
6	ENVIRONMENT	9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9	LONG TERM PRODUCTIVITY

Three types of comparisons are used in Expert Choice®: *importance, preference* or *likelihood*. The type expresses the decision maker's perspective of the comparisons being made at a particular point, but it does not affect in any way the calculations performed by Expert Choice® (Decision Support Software Inc. & Expert Choice®).

The term *importance* is appropriate when comparing one criterion with another. For example, farmers indicated how much more important profit is relative to other objectives such as health concerns. The term *preference* is appropriate when comparing alternatives. This term was used by farmers as the basis for comparing alternative farming systems by specifying how much more preferable one farming system is to another with respect to achieving a given objective (such as profit), or sub-objective (such as reducing production costs). The term *likelihood*, which is appropriate when comparing uncertain events with a probability of occurrence which is unknown and at least less than 1.

There are three modes to enter pairwise comparison judgements into the software (Expert Choice®): verbal mode, graphical mode, and numerical mode. The farmers interviewed for this study used a combination of both the verbal and numerical modes to enter their judgements.

After processing the pairwise comparison data in Table 5, the software derives priorities from the simple pairwise comparison judgements in Table 4 and translates them into the weights shown in column 6 of Table 6. To produce the simple weights in Table 6, four methods are available for computing a vector of priorities or weights from any given matrix of pairwise comparisons. Each method uses the same matrix of pairwise comparisons formed by the first four rows and columns of Table 6.

Method one is applied by summing the elements in each row of the pairwise comparison matrix (column 5). Each sum is then normalized by dividing it by the total of all sums so that the resulting weights add to one. The first entry of the resulting vector in column 6 of Table 6 is the corresponding weight that represents the priority of profit, the first objective.

Method Two takes the sum of the elements in each column of the matrix of pairwise comparisons, and forms the reciprocals of these sums. The reciprocals are then entered in the second row below the pairwise comparison matrix. Each reciprocal is divided by the sum of the reciprocals for purposes of normalization. The resulting vector of weights is then entered in the fifth column of Table 6.

Method Three is applied as follows. First, divide the elements of each column by the sum of that column (i.e., normalize the column) and then add the elements in each resulting row and enter the results in column 5. Then, divide each sum by the number of elements in the row. This is a process of averaging over the normalized columns. The matrix formed by the bottom portion of the first four columns of Table 6 under this method is the result of this normalization process. The sums of the rows of the new matrix are entered in the fifth column. After dividing these sums by 4, the resulting weights are entered in a vector formed by column 6.

Table 6. A Comparison of Weights Using Alternative Calculation Methods

Method One:

Objective	Profit	Health	Envir'nt	L.T. Prod.	Totals	Weights	%Δ from Expert Choice
Profit	1	1/2	2	1/4	3.75	0.148	3.33
Health	2	1	5	2	10.0	0.396	-8.15
Environment	1/2	1/5	1	1/4	1.95	0.077	0.00
L.T. Productivity	4	1/2	4	1	9.50	0.376	8.36
					25.2		

Method Two

Objective	Profit	Health	Envir'nt	L.T.Prod.	Weights	%Δ from Expert Choice
Profit	1	1/2	2	1/4	.139	3.4%
Health	2	1	5	2	.475	9.9%
Environment	1/2	1/5	1	1/4	.087	13.0%
L.T.Productivity	4	1/2	4	1	.299	13.8%
Column Sum	15/2	11/5	12	7/2		
Reciprocals	.133	.454	.083	.286	Total = .956	

Method Three:

Objective	Profit	Health	Environment	Long Term Productivity
Profit	1	1/2	2	1/4
Health	2	1	5	2
Environment	1/2	1/5	1	1/4
L.T.Productivity	4	1/2	4	1
Column Total	7.5	2.2	12	3.5

Objective	Profit	Health	Envir'nt	L.T.Prod	Totals	Weights	%Δ from Expert Choice
Profit	.133	.227	.167	.078	.605	.151	4.9%
Health	.267	.455	.417	.571	1.71	.426	-1.4%
Environment	.067	.091	.083	.078	.319	.078	1.3%
L.T.Productivity	.533	.227	.333	.286	1.38	.359	3.5%

Method Four:

Objective	Profit	Health	Envint	L.T.Prod	Product	Weights	%Δ from Expert Choice®
Profit	1	1/2	2	1/4	0.707	.144	0
Health	2	1	5	2	2.115	.431	-0.2
Environment	1/2	1/5	1	1/4	0.398	.081	5.3
L.T.Productivity	4	1/2	4	1	1.682	.343	-1.2
Total					4.902		

Method Four is the most tedious to apply.First, multiply the *n* elements (i.e. the four objectives) in each row and take the n^{th}(i.e. the 4^{th}) root and enter that result in column 5. After normalization, the resulting numbers are entered in column 6 which is the vector of weights resulting from this method.

Compared with those obtained by Expert Choice®, the manually computed weights appear to show substantial improvement from the first to the fourth method. However, to get the exact solution, Expert Choice® raises the matrix of pairwise comparisons to arbitrarily large powers and divides the sum of each row by the sum of the elements of the matrix. If the matrix in table 8 were consistent, all four methods would yield the same results as Expert Choice®. Although the estimates provide a good approximation, as the accuracy improves the computations become more tedious.

After all the pairwise comparison judgements have been entered, the software synthesizes and combines all local priorities to produce the overall priorities for the three alternative farming systems at the lowest level of the hierarchy.

The Survey

Data used in this study was collected through a field survey. Thirty questionnaires were mailed to selected farmers in western Kentucky to be completed under the supervision of extension agents. The response rate was 60 percent. The questionnaire was pre-tested with graduate students and faculty of the college of agriculture at the university of Kentucky in Lexington, plus farmers and extension agents from Fayette County. Because the questionnaire was mailed in early spring, when farmers were busy with planting, it took more time to return the questionnaires. Most questionnaires were received within a month although some took up to two months, and follow-up phone calls.

In order to obtain a representative sample of farmers, the choice was not done randomly. Like most previous studies using AHP, a purposive survey was used [Beaumariage, Ikedi, Harker]. Only farmers with enough experience in the types of decisions included on the questionnaire were selected by the county extension agents. Some have been using sustainable farming practices, and are therefore more knowledgeable about those practices while others use only conventional farming techniques.

The average age of the respondents was 46 years, close to the average of 52 years for US farmers, and identical to the average age of Kentucky farmers. For the 13 counties in which respondents were located, the average age of farmers is 51 years (1987 US Census of Agriculture). The age distribution of respondents included only a few young farmers (less than 30 years, about 6.6 percent), and a considerable number of older farmers (above 60 years, 13.3 percent). Only one of the respondents was a female. This reflects both US and Kentucky farm populations where, respectively 6 and 7 percent of farm operators are females, according to the 1987 US census of agriculture. In the thirteen counties, women operate 6 percent of the farms.

Although half of the respondents were full-time farmers, most (77 percent) acknowledged having used sustainable farming practices . Also, fifty percent have been farming between 10 and 35 years. Only three respondents had been farmers for less than 10 years. Approximately 40 percent have been involved in farming for more than one generation. Most respondents (72 percent) have had some formal or informal education dealing with sustainable farming techniques and are therefore familiar with sustainability issues.

Empirical Results

The simple arithmetic mean of the weights from all 18 individual farmers (Table 7) interviewed for the survey was calculated.

Table 7. Priority Vector for Alternative Farming Systems, Survey Data, Means for 18 Farmers

Objective	Weight	Rank
Biological	0.42	1
Organic	0.31	2
Conventional	0.27	3

Previous studies have used the geometric mean or groupings in which a consensus from a diverse group was first reached before the pairwise comparison data were entered into the software for processing. Such an approach was not used in this study because the farmers were scattered over a wide area of western Kentucky and also because preserving each individual farmer's independence of judgement was as important as the group consensus. The cost of bringing all the farmers together for the Expert Choice® sessions was also a consideration.

Biological farming(0.42) was the one farming system most preferred by the farmers interviewed for this study (Table 7). Conventional farming was ranked second (0.31), followed by organic farming (0.24).

On average, the most important of the four objectives pertaining to the choice of a farming system remains the concerns for health (Table 8). The objective of enhancing health (0.37) outweighed profit maximization (0.29) which was ranked second followed by sustainability concerns to maintain long-term productivity (0.20) and environmental concerns in fourth position (0.14).

Table 8. Priority Vector for Objectives

Objective	Weight	Rank
Health	0.37	1
Profit	0.29	2
Sustainability	0.20	3
Environment	0.14	4

Table 9 presents the surveyed farmers' rankings of different sub-objectives or attributes within their respective parent objectives. Within the *profit maximization* objective, there are two top-ranked sub-objectives (those scoring above 0.30) and two less important ones. Increasing yields is ranked at the top (0.36) followed by reducing production costs which is second (0.32). The weight of Access to Special Market Outlets (0.17), the third sub-objective, is not significantly different from the weight of Ease of Use (0.15), the last sub-objective. The coefficients of variation of these average weights increase with the ranks of the attributes, which means that they increase in inverse order with the weights, i.e., from 0.47 for the first attribute to 0.80 for the fourth.

The sub-objectives of *Health* concerns are ranked by farmers within the context of that parent objective, as follows: family member's health (0.30) is first, own health (0.29) is second, followed by consumer's health (0.21) in third place, and need for more information (0.13) is at the bottom of the priority vector. Within the context of the concerns for the *Environment* parent objective, the farmers' rankings of its sub-objectives assigned the top spot to the reduction of soil erosion (a weight of 0.38). Reducing water contamination is second (0.30), air pollution reduction is third (0.20) while the need for more information is last (0.12).

The surveyed farmers' ranking of the sub-objectives of *Sustainability* as a parent objective assigned the highest weight (0.33) to the next generation's productivity. The second position is held by the productivity ten years from now, but with a weight of 0.25, it barely outweighs next season's productivity which scored 0.24 in the hierarchy. Productivity 5 years from now is the last sub-objective with the lowest score of 0.18. Though the rules of discounting future returns may suggest otherwise, it is important to keep in mind that those same rules are based on the assumption that short-term profit maximization is the single most important objective of the farmer. But when the ranking is done with respect to sustainability and long-term profit maximization the result may be quite different.

Table 9. Farmer's Normalized Rankings of Sub-Objectives with respect to Objectives.

Objective	Sub-Objective	Rank	Weight	Coefficient of Variation
Profit Maximization	Increase Yield	1	0.36	0.47
	Lower Costs	2	0.32	0.48
	Special Market	3	0.17	0.72
	Ease of Use	4	0.15	0.80
Health Concerns	Own Health	2	0.29	0.42
	Family Health	1	0.37	0.40
	Consumer Health	3	0.21	0.50
	More Information	4	0.13	1.1
Environmental Concerns	Soil Erosion	1	0.38	0.44
	Water Pollution	2	0.30	0.36
	Air Pollution	3	0.20	0.76
	More Information	4	0.12	1.1
Sustainability	Production of Year 1	3	0.24	0.82
	Production of Year 5	4	0.18	0.48
	Production of Year 10	2	0.25	0.31
	Production of Year 35	1	0.33	0.53

That biological farming is the preferred farming system among the farmers surveyed is obvious in Table 10 where, on average, it was ranked first with respect to all four major objectives or sub-goals. The weights assigned by farmers to biological farming ranged from 0.37 with respect to health concerns to 0.51 with respect to sustainability or concerns for long term productivity.

With respect to the other two objectives, concerns for the *Environment* and *Sustainability*, the farmers assigned an equal weight of 0.44 to biological farming. Conventional farming is ranked second with respect to profit-related objectives, i.e., profit maximization and long term productivity. As illustrated in Table 10, organic farming is in second place with respect to the *health* and *environment* objectives.

Table 10. Farmer's Normalized Rankings of Alternatives with respect to Objectives.

Objective	Alternative	Rank	Weight	Coefficient of Variation
Profit Maximization	Conventional	2	0.38	0.49
	Biological	1	0.44	0.40
	Organic	3	0.18	0.50
Health Concerns	Conventional	3	0.28	0.67
	Biological	1	0.37	0.41
	Organic	2	0.35	0.60
Environment	Conventional	3	0.26	0.83
	Biological	1	0.44	0.40
	Organic	2	0.30	0.49
Sustainability	Conventional	2	0.32	0.68
	Biological	1	0.51	0.37
	Organic	3	0.17	0.60

The surveyed farmers' preferences for biological farming over conventional farming coupled with the fact that concerns for health were assigned, if not a significantly higher weight, at least an equal weight with profit maximization, has economic meaning. At least among those surveyed, farmers are willing to forgo some short-term profits in exchange for better health and environment.

Another interpretation is that, if after everything is taken into account, after guaranteeing the farmers' health, there may be some optimal profit level that may satisfy the public's concerns about the environment. This is consistent with previous findings by Foltz, where farmers, using all attributes, preferred a set of three alternative farming systems with profit levels of $ 182.99 per acre, $ 238.01 per acre and $ 241.86 per acre. Since the first alternative was within the preferred set of the environmentalists, if the farmer chose to adopt it as proof of concern for the environment, the opportunity cost of not employing either of the other two farming systems would be respectively $55.02 per acre and $ 58.87 per acre.

Conclusion

The main objective in using the analytic hierarchy process in the decision problem of choosing a farming system was to determine the weights and resulting ranks assigned by farmers to alternative farming systems and the different sub-objectives. The surveyed farmers clearly preferred biological farming, followed in order of decreasing importance by conventional and organic farming. This is consistent with the choice of enhancing health as the most important objective above profit maximization, sustainability and environmental protection. This result suggests that farmers may be more concerned about the impact of their production systems on public health than has been widely believed.

Our analysis reveals that AHP can be used to model complex decision making processes in agricultural economics. Theoretically, other interests including health of consumers, should take precedence over the health of anyone else in the mind of a profit maximizing entrepreneur including farmers. However, by ranking one's family's health above the consumer's, results from the AHP analysis suggests that at least the respondents (farmers) are internally consistent in the sense that neither conventional farming nor profit maximization were the preferred choices. This result could not possibly be reached within the traditional framework where profit maximization has a much larger weight due to the fact that health, environmental, and other objectives are relegated to the background role of constraints.

Furthermore, by ranking both personal and family health above the consumers' health, (a conclusion from our AHP modelling), farmers may be sending two additional messages. One is that if a farming technique is not good enough for a farmer's personal health, then it would not be desirable from the perspective of consumers' health, either. The second is that enhancing personal health may be a *prerequisite* to profit maximization which was ranked second behind health.

In this AHP analysis, the surveyed farmers assigned a higher rank to soil erosion because they are more directly affected by erosion when compared with water or air pollution. These AHP results are consistent with results obtained employing other multi-objective modelling techniques. Foltz reached a similar conclusion and ordering of attributes (in order of decreasing importance) i.e. profit > soil erosion > ground water contamination > surface water contamination. Biological farming, the preferred farming system is probably less prone to water pollution than conventional farming employing large amounts of chemicals.

Farmers prefer to reduce soil erosion because it affects the productive capacity of the land, not only in the long-term, but perhaps even in the short-run. To the extent that a farmer relies on a farm well as a source of water, concern for the quality of drinking water from that well should take precedence over the concern for surface water quality. In fact, because of the negative externality the farmer imposes on the rest of society, our analysis suggests that the farmer's concern about ground water contamination may not be as great as that of society at large.

As soil erodes, there is a direct cost to the farmer in the form of reduced productivity of the land. However, in the case of water contamination, even though farmers may be paying the same high cost of water as others, the general public is relatively more sensitive to water quality than land quality the degradation of which more directly impacts farmers' livelihoods.

The choice of a farming system is typical of several farm management decisions a farmer faces every day. Contrary to this example, the alternatives in practice are many and the choice among them depends on a multiplicity of factors some of which are highly subjective. The AHP was designed to help guide decision making in this type of situation. This and previous applications in other fields suggest that AHP will prove to be a valuable farm management tool by enabling farmers, farm managers, agricultural economists, and policy makers to make better and more logically consistent farm management decisions.

References

Alexander, J.M. 1983. Priorities and Preferences in Conflict Resolution. *Mathematics and Computers in Simulation,* 25(2)108-119.

Downey, W. David, and Steven, P. Erickson. 1987. *Agribusiness Management.* McGraw-Hill, New York, NY.

Arrington, C.E., Jensen, R.E., and Toukani, M. Scaling of corporate multivariate performance criteria: Subjective composition vs. the analytic hierarchy process. *Journal of Accounting and Public Policy*, 1982.1(2)95-123.

Bahmani, N., Javalgi, R.G., and Blumburg, H. An Application of the Analytic Hierarchy Process for a consumer choice problem. *Development in Marketing Science*, 1986, 9, pp. 402-406.

Bahmani, N., Yamoah, D., Basser, P., and Revzani, F. Using the Analytic Hierarchy Process to select investment in a heterogenous environment. *Mathematical Modelling*, 1987, 8, pp. 157-162.

Beaumariage, G. Terrence. Investigation of an Object Oriented Modeling Environment for the Generation of Simulation Models, Ph. D. Thesis, Oklahoma State University, Stillwater, OK. 1990.

Debertin, David L. 1992. Sustainable Agriculture: Concepts, Definitions and Myths in *Agribusiness News for Kentucky*; No. 81; Feb 1994. UK-College of Agriculture-CES.

Decision Support Software, Inc., and Expert Choice®, Inc. 1992. Expert Choice® Version 8: User Manual.

Dolan, J.G., Clinical Decision Making Using the Analytic Hierarchy Process: Choice of Antibiotic Treatment for Community-Acquired Pyelonephritis. *Clinical Research*, 1987, 35(3)738.

Dougherty, H.J., and Saaty, T.L., 1982. Optimum Determination of Hospital Requirements. In T.L. Saaty & L.G. Vargas (Eds) *The Logic of Priorities: Applications in Business, Energy, Health and Transportation*, Kuwer-Nijhoff Publishing, Boston, MA.

Foltz, John Clark. 1991. Economic and Environmental Implications of Alternative Agricultural Systems in the Eastern Corn Belt: A Multiple Criteria Decision Approach. Unpublished Ph. D. Thesis. Purdue University.

Golden, Bruce L., Wasil E.A., and Levy D.E., 1989. Applications of the Analytic Hierarchy Process: A Categorized Annotated Bibliography, in *The Analytic Hierarchy Process: Applications and Studies*, Golden, B.I, Wasil, E.A., and Harker P.T. (Eds) Springer-Verlag, Berlin.

Granatsein, David. 1988. *Reshaping the Bottomline: On-Farm Strategies for Sustainable Agriculture*. Land Stewardship Project. Stillwater, Minesota.

Harker, P. and L. Vargas, The Theory of Ratio Scale Estimation: Saaty's Analytic hierarchy Process; *Management Science*, 33, pp:1383-1403.

Hughes, W.R. 1986. Deriving Utilities Using the Analytic Hierarchy Process. *Socio-Economic Planning Sciences*, 20(6), pp. 393-95.

Ikedi, C. Ehie. 1989. An Integrated Multi-Objective Decision Model for Industry In a Less Developing Country. Unpublished Ph. D. University of Missouri-Rolla.

Jensen, R.E. 1987. A Dynamic Analytic Hierarchy Process Analysis of Capital Budgeting under Stochastic Inflation Rates and Risk Premiums. *Advances in Financial Planning and Forecasting*, 2, pp. 269-302.

Liberatore, M.J. An Extension of the Analytic Hierarchy Process for Industrial R&D Project Selection and Resource Allocation. *IEEE Transactions on Engineering Management*, 1987. EM-34(1), pp. 12-18.

Neim, A.J., and Teed, S.A. Assessing Inherent Risk in EDP applications: An Instrumental addition to the Auditor's toolbox. *CA magazine*, 1986, 119(2) pp. 42-48.

Peniwati, K., and Hsiao, T. 1987. Ranking countries according to economic, social, and political indicators. *Mathematical Modelling*, 9(3-5), pp. 203-209.

Saaty, T.L., A new Macroeconomic Forecasting and Policy Evaluation Method Using the Analytic Hierarchy Process., *Mathematical Modelling*, 1987, 9(3-5) pp. 219-231.

Saaty, T.L., Absolute and Relative Measurement with the AHP; the most livable cities in the United States. *Socio-Economic Planning Sciences*, 1986(6) pp. 327-331.

__________. 1986_a. Axiomatic Foundation of the Analytic Hierarchy Process", Management Science, Vol. 32, No. 7.

__________. 1986_b. "Exploring Optimization Through Hierarchies and Ratio Scales." Socio-Economic Planning Science, Vol. 20, No. 6, pp: 355-360.

Saaty, T.L. Risk - It's priority and probability: The Analytic Hierarchy Process. *Risk Analysis*, 1987, 7(2), pp. 159-172.

Saaty, T.L., The Sudan Transport Study. *Interfaces*, 1977, 8(1) pp. 37-57.

Saaty, T.L., and Mariano, R.S. Rationing Energy to Industries: Priorities and Input-Output Dependence. *Energy Systems and Policy*, 1979, 3(1) pp. 85-111.

Saaty, T.L., and Wong, M.M. Projecting Average Family Size in Rural India by the Analytic Hierarchy Process. *Journal of Mathematical Sociology*, 1983, 9(3) pp. 181-201.

Schaller, Neil. 1990. Building a Better Agriculture. *Proceedings of the Philadelphia Society for Promoting Agriculture* 1990-1991. Philadelphia PA. The Philadelphia Society for Promoting Agriculture.

Schwartz, R.G., and Oren, S. Using Analytic Hierarchy Process for Consumer Research and Market Modelling. *Mathematical and Computer Modelling*, 1988, 11, pp. 266-271.

________, and R. W. Whitaker. "Editorial", *The European Journal of Operations Research*, 48:(1990)1.

Wind, Y. An Analytic Hierarchy Process Based Approach to the Design and Evaluation of a Marketing Driven Business and Corporate Strategy. *Mathematical Modelling*, 1987, 9(3-5), pp. 285-291.

Wind, Y., and Saaty, T.L. Marketing Applications of the Analytic Hierarchy Process. *Management Science* , 1980, 26(7), pp. 641-658.