AEPAT: Software for Assessing Agronomic and Environmental Performance of Management Practices in Long-Term Agroecosystem Experiments

Mark A. Liebig
Northern Great Plains Research Laboratory

Martin E. Miller
University of Houston

Gary E. Varvel
University of Nebraska-Lincoln, gevarvel@windstream.net

John W. Doran
University of Nebraska-Lincoln, jdoran1@unl.edu

Jon D. Hanson
Northern Great Plains Research Laboratory

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ABSTRACT

Approaches to assess the effects of management practices on agroecosystem functions are needed. This paper describes a computer program designed to assess the relative sustainability of management practices using agronomic and environmental data. The program, entitled AgroEcosystem Performance Assessment Tool (AEPAT), utilizes performance-based index methodology to derive a relative ranking of agroecosystem performance among management practices for functions and indicators included in the procedure. The program is organized into eight major steps: Introduction, Input Files, Assign Indicators to Functions, Describe Indicators, Assign Weights, Select Output File, Calculate Agroecosystem Performance Scores, and Save Agroecosystem Project. Help windows as well as a tutorial are provided within the program to assist users through each step. Users must keep in mind the assumptions and drawbacks inherent to performance-based indices while using AEPAT. Additionally, the program requires data on many indicators to provide useful information on agroecosystem performance. Therefore, its use is intended primarily for clientele conducting long-term agroecosystem experiments.

Methods to assess the sustainability of agricultural management systems are in their infancy. Challenges with such assessments extend from the lack of a commonly accepted definition of sustainable agriculture to the inherent complexity of sustainability itself, which encompasses economic, social, and environmental dimensions. Frameworks for sustainability assessments vary based on the emphasis given to each of the dimensions within the sustainability triumvirate (Stockle et al., 1994; Smyth and Dumanski, 1995). For the environmental dimension, the use of agroecosystem functions has proven useful in providing an organizational template by which researchers can group and categorize indicators for analysis (Costanza et al., 1997). Once categorized, indicators can be evaluated through a number of different approaches to describe their effect on agroecosystem performance. Liebig et al. (2001) outlined three approaches for this purpose: single indicator–single response relationships, multivariate statistical techniques, and performance-based indices. Of the three, performance-based indices were considered to be the most appropriate for assessing the impact of management practices on multiple agroecosystem functions.

Performance-based indices employ multiobjective analysis principles to quantitatively assess agroecosystem performance (Yakowitz et al., 1992; Edwards and Newman, 1982; Stillwell et al., 1981). These indices use expert opinion or principal-component analysis to select indicators representative of specific agroecosystem functions. Once selected, indicators are scored from 0 to 1 (with 1 reflecting improved performance) based on their relative difference from a standard or optimum value using either linear or nonlinear mathematical functions. The relative performance of one management practice to another within an agroecosystem function is determined by summing indicator scores within functions. Likewise, scores for individual agroecosystem functions—which are aggregated scores of multiple indicators—are typically summed across functions, resulting in an overall score that reflects a relative ranking of agroecosystem performance among management practices evaluated in the procedure.

Performance-based indices have been used extensively to evaluate the effects of management practices on agroecosystem functions (Liebig and Varvel, 2003; Andrews et al., 2002; Glover et al., 2000; Ericksen and McSweeney, 1999; Karlen and Stott, 1994). These evaluations have typically utilized traditional spreadsheet programs for the calculation of agroecosystem performance scores. In this paper, we describe a computer software program specifically designed to calculate agroecosystem performance scores following the index approach outlined above. The program, AEPAT, calculates scores using agronomic and environmental data and scoring function descriptions provided by the user.

PROGRAM DESCRIPTION

AEPAT was developed using Microsoft Visual Basic 6, Service Pack 5 (Microsoft Corp., Redmond, WA).[1] The tutorial and help windows in AEPAT were created in Microsoft FrontPage 2002 and Gimp (Free Software Foundation, Boston, MA). AEPAT was written for 32-bit versions of Microsoft Windows running ×86 processors (e.g., updated versions of Windows 98 and later). The program is loaded onto a user's hard drive from a compact disc, which contains the necessary installation file (AgroEcosystem.msi). Version 1.1 of AEPAT requires 4.93 MB of hard drive space.

The calculation procedure performed by AEPAT is organized into eight major steps: Introduction, Input

M.A. Liebig and J.D. Hanson, USDA-ARS, Northern Great Plains Res. Lab., P.O. Box 459, Mandan, ND 58554-0459; M.E. Miller, 4800 Calhoun Rd. Dep. of Comput. Sci., Univ. of Houston, Houston, TX 77204-3010; and G.E. Varvel and J.W. Doran, USDA-ARS, Soil and Water Conserv. Res. Unit, 119 Keim Hall, Dep. of Agron., Univ. of Nebraska, Lincoln, NE 68583-0934. The USDA-ARS is an equal opportunity/affirmative action employer, and all agency services are available without discrimination. Received 27 Feb. 2003. *Corresponding author (liebigm@mandan.ars.usda.gov).

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[1] Mention of commercial products and organizations in this article is solely to provide specific information. It does not constitute endorsement by USDA-ARS over other products and organizations not mentioned.

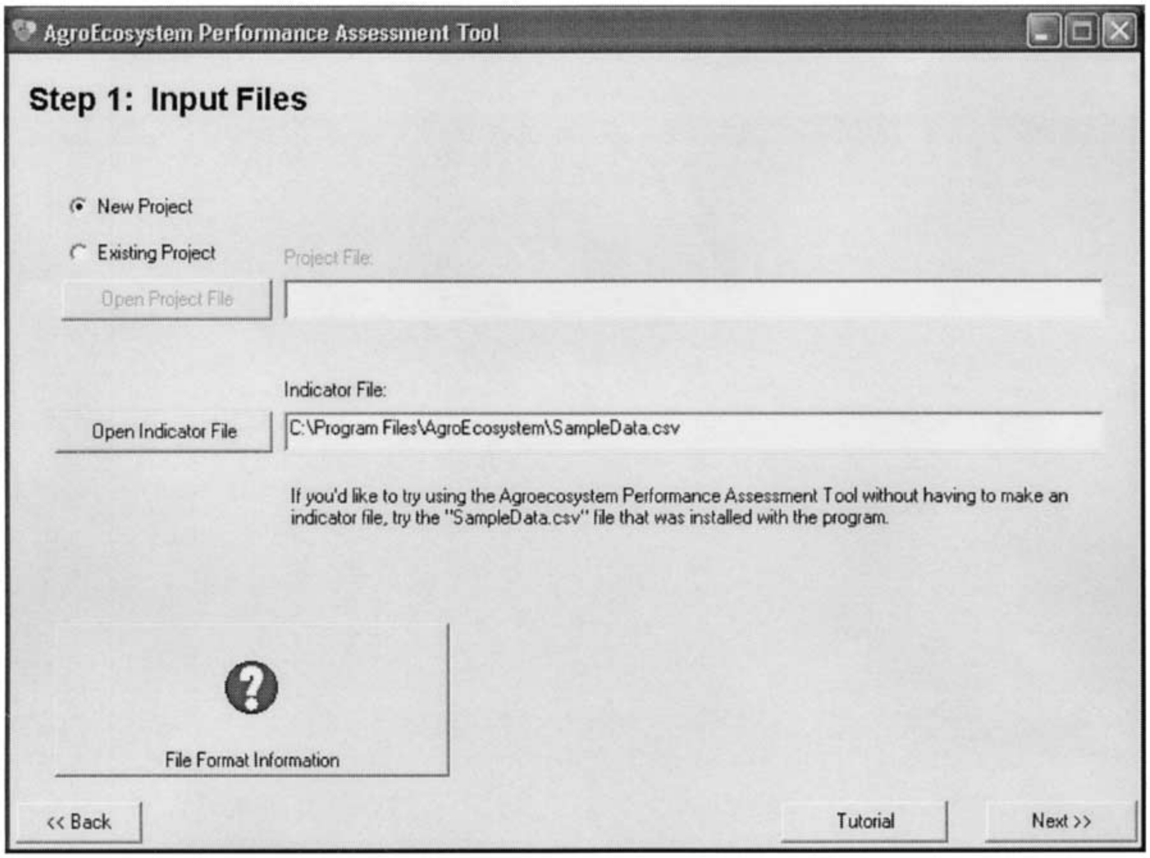

Fig. 1. Input file screen for AEPAT. First-time users may select an indicator file installed with the program (SampleData.csv).

Files, Assign Indicators to Functions, Describe Indicators, Assign Weights, Select Output File, Calculate Agroecosystem Performance Scores, and Save Agroecosystem Project. Each step will be briefly reviewed.

Introduction

After accepting the terms and conditions of AEPAT in an opening window, users have the option of reviewing a self-directed slide set that provides a brief review of performance-based index methodology. Users may bypass the introduction and open a tutorial, which will guide them through the calculation procedure using a sample data set. Tutorial windows are accessible within each step by clicking the appropriate button within the main program. It is strongly recommended first-time users of AEPAT review both the introduction and tutorial. Should users choose to review neither, however, they may simply click the Get Started button to input files.

Table 1. An example of an indicator file in comma-separated-value (*.csv) spreadsheet format.

Treatment	Grain yield (Mg/ha)	Residual soil nitrate (kg/ha)	Soil organic C (Mg/ha)
A	3.46	52.7	55.28
B	6.31	63.4	58.32
C	6.55	180.6	60.46
D	5.32	52.0	56.03
E	7.59	60.3	57.81
F	7.11	79.7	51.28
G	7.08	54.3	61.32
H	7.92	58.5	57.04
I	8.17	112.8	62.84
J	6.23	48.1	55.16
K	7.00	54.0	53.59
L	7.87	104.8	56.11

Input Files

When inputting files for the program, users have the option of selecting a new or existing project (Fig. 1). This option is provided as we anticipate AEPAT to be used with the same scoring functions and weight assignments but with updated data sets. Project files possess an *.AgEco extension and are opened via a standard Microsoft open-file dialog. Indicator files (i.e., data files) are opened in a similar manner. Indicator files must be in comma-separated-value (*.csv) spreadsheet format and should not contain quotation marks or extraneous commas. Spreadsheets are organized such that the first row provides a list of indicators and the first column provides the names of treatments to be compared. The resulting grid lists indicator values for each of the respective treatments (Table 1).

New users can become familiar with AEPAT without creating project or input files by opening SampleData.csv. The indicator file was installed with the program and is the same data set used in the tutorial.

Assign Indicators to Functions

Within this step, indicators included in the data set are assigned to agroecosystem functions (Fig. 2). A subset of

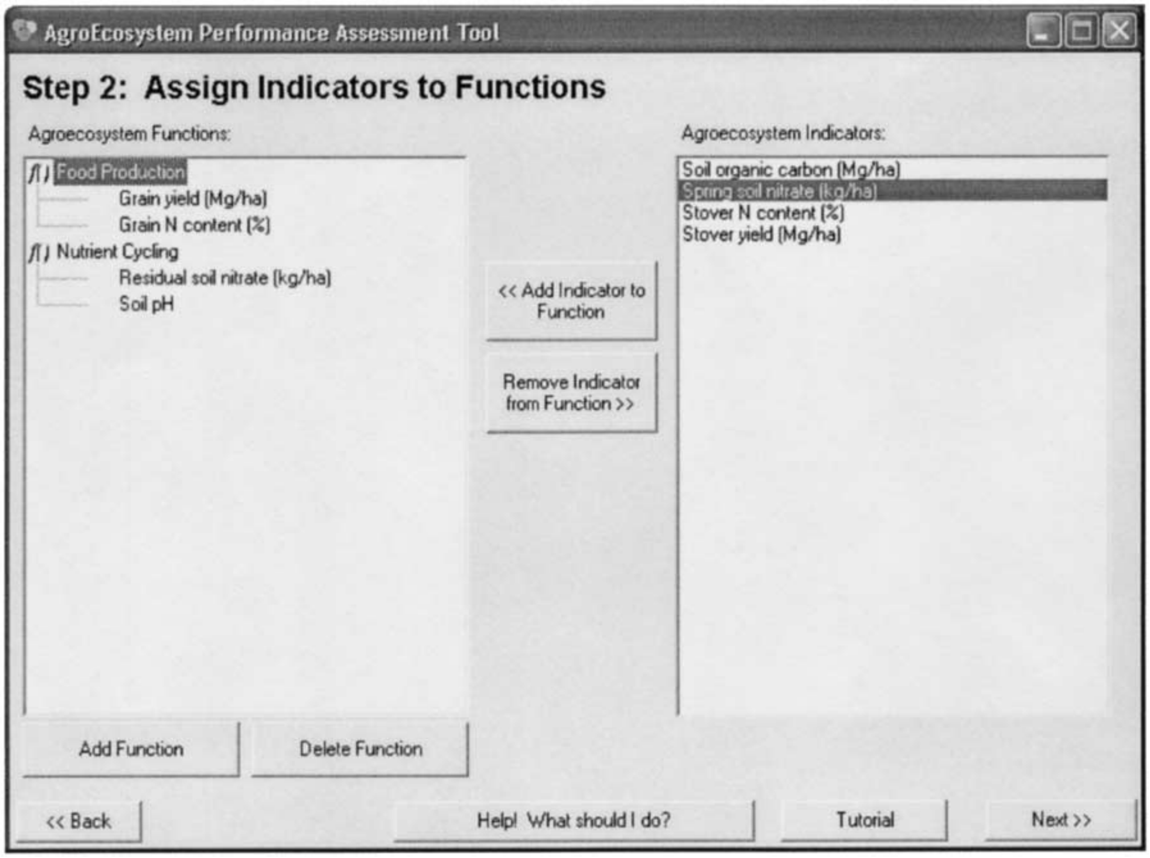

Fig. 2. Screen for assigning indicators to functions. In this screen, grain yield and grain N content are assigned to food production, and residual soil nitrate and soil pH are assigned to nutrient cycling.

agroecosystem functions from Costanza et al. (1997) is provided within the program (e.g., erosion control, food production, greenhouse gas regulation, nutrient cycling, raw-materials production, waste treatment, and water regulation). Additional agroecosystem functions may be added to more appropriately categorize indicators in the data set. Conversely, agroecosystem functions for which there are no representative indicators may be deleted. Data for indicators not assigned to agroecosystem functions are not included in the assessment procedure.

Describe Indicators

Relationships between indicators and their associated agroecosystem functions are described in this step (Fig. 3). The nature of a relationship is characterized by a concept of what is better and a mathematical formula, or scoring function, for a line or curve of appropriate shape to reflect the concept. For each indicator, users first decide how it is related to agroecosystem performance based on *more is better*, *less is better*, or *threshold value* criteria. These criteria are associated with relationships where a higher, lower, or threshold value for an indicator is indicative of enhanced performance within a specified agroecosystem function. Users then select one of four scoring functions (linear, exponential, sigmoidal, or logarithmic) to best describe the relationship between the indicator and agroecosystem function as values for the indicator become more or less optimal. As such, users are required to enter an optimal value for each indicator, along with lower and upper bounds, depending on the type of indicator selected. The optimal value of an indicator equates to a perfect score of 1, whereas the lower and upper bounds are values of an indicator that would receive a score of 0. Obviously, the lower and upper bounds selected by the user should encompass values in the data set. If the sigmoidal function is selected, additional information on the shape of the curve is required in the form of inflection points (where the value of the indicator would equate to a score of 0.5). Slopes for the exponential and sigmoidal functions are calculated by clicking an Auto-Calculate Slopes button. Line graphs of each curve (a model curve and the curve created by the user) are provided to give the user a visual representation of the relationship for each indicator.

To assist the user in selecting values for the scoring functions, the minimum, maximum, mean, median, and standard deviation of each indicator is provided. Additionally, a histogram and point plot for each indicator can be accessed by clicking on the View More Analysis of the Indicator button.

Next to assigning weights to indicators and functions, describing relationships between indicators and their associated agroecosystem functions is the most subjective step of the calculation procedure. Some indicators

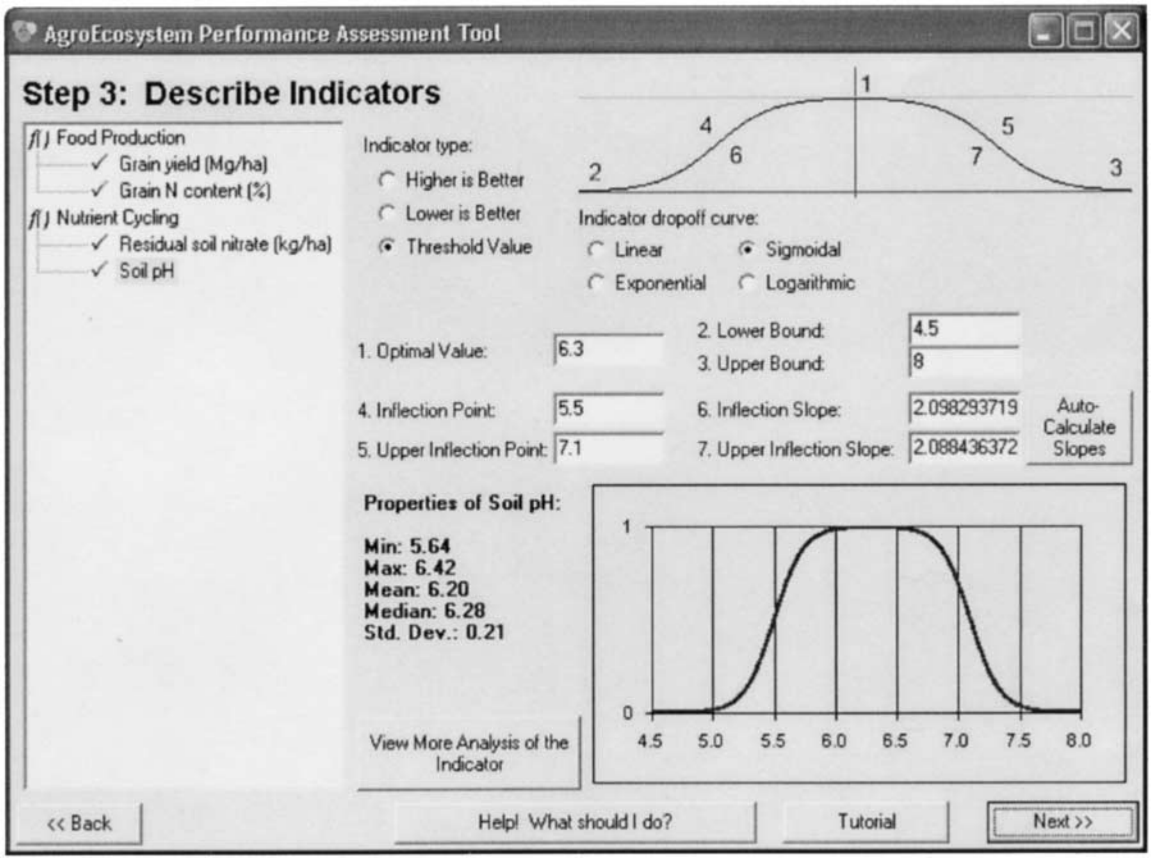

Fig. 3. Screen for describing indicators. For soil pH, a threshold value is selected using a sigmoidal scoring function. Lower and upper bounds as well as inflection points are selected by the user. The slope of the curve is generated by clicking the Auto-Calculate Slopes button.

may not have published information regarding how their status influences agroecosystem performance. As a result, users may be required to make assumptions when describing indicators in their data set. However, uncertainty regarding assumptions made in describing an indicator can be tempered by assigning the indicator in question a lower weight in the assessment procedure.

Assign Weights

Each agroecosystem performance score is a weighted sum of a set of agroecosystem function scores. Likewise, each agroecosystem function score is a weighted sum of a set of indicator scores. In this step, users select weights for the agroecosystem functions and indicators included in the assessment procedure. Each weight reflects a percentage (between 0 and 100%) that will determine how much an agroecosystem function will contribute to the final performance score, or how much indicators will contribute to an agroecosystem function score.

Weights for agroecosystem functions are inputted in the left column of the window while weights for associated indicators are inputted in the right column (Fig. 4). Percentages must add up to 100% across agroecosystem functions and for all indicators within functions before continuing to the next step.

Select Output File

Before calculating agroecosystem performance scores, users are required to designate an output file to save the results of their analysis. Like the indicator file, output files are saved in comma-separated-value (*.csv) format, thereby making them easy to open in spreadsheet programs. The output file contains the scored values of the indicators, functions, and overall performance for each treatment, as well as a summary of the weights assigned to the indicators and functions.

Calculate Agroecosystem Performance Scores

Calculation of agroecosystem performance scores is performed by the program by simply advancing to the next step after selecting an output file. Performance scores are presented in tabular and graphical formats (Fig. 5). The table is organized in the same manner as the output file, with treatments in the first column, followed by scores for indicators and agroecosystem functions in the subsequent columns. The final agroecosystem performance score for each treatment is shown in the rightmost column. Final scores are scaled to 100 to present them in a more familiar context. Weights assigned to indicators, and agroecosystem functions are presented below their respective headings. A graph showing agroecosystem performance scores on the ver-

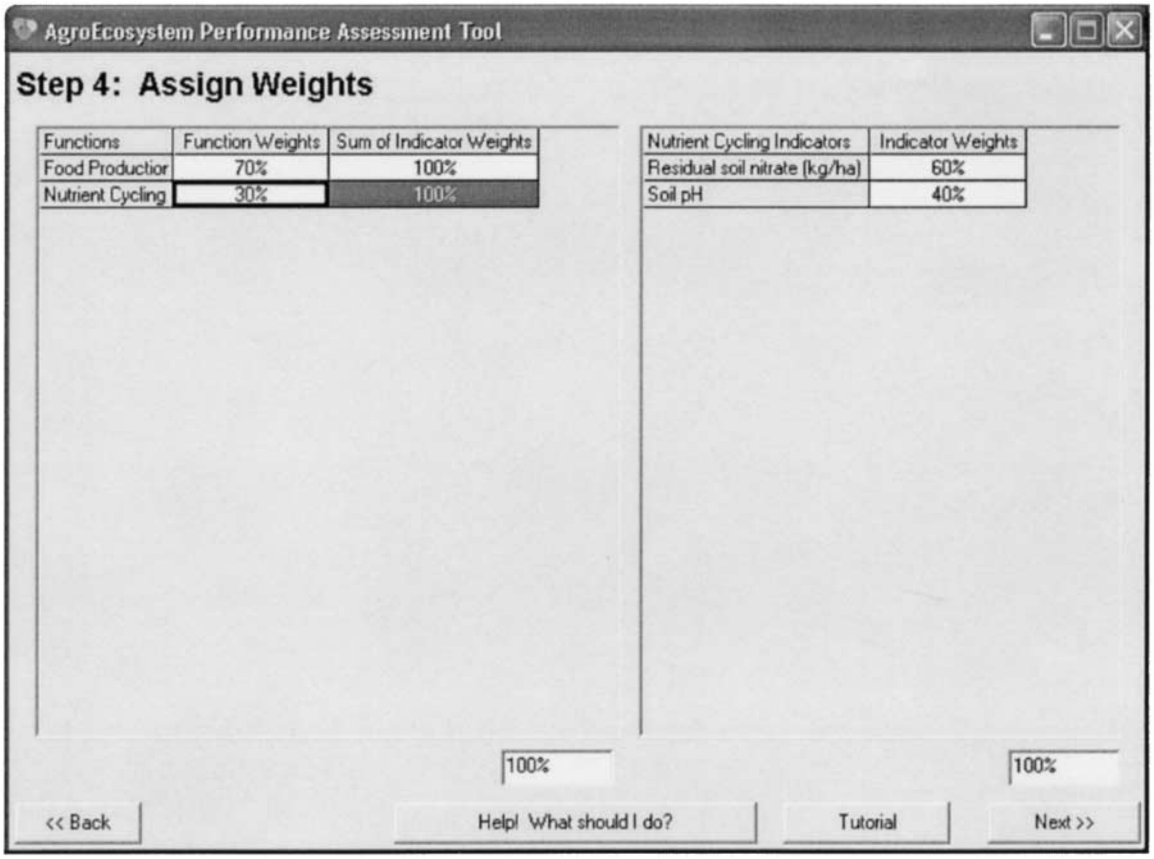

Fig. 4. Screen for assigning weights to agroecosystem functions and indicators.

tical axis and treatment designations on the horizontal axis is provided as a visual representation of the output.

If desired, users can recalculate agroecosystem performance scores before proceeding to the last step by changing how indicators are described as well as altering weight assignments to agroecosystem functions and indicators. If changes are made, updated performance scores are calculated by simply clicking the Recalculate button.

Save Agroecosystem Project

The final step allows users to save program settings for later use as AgroEcosystem project files (*.AgEco). This file allows users to quickly repeat calculations with the same scoring functions and weight assignments for agroecosystem functions and indicators. After saving the program settings, users may modify the project they were most recently working on, start a new project, or exit from the program.

Help Features within AEPAT

Help windows are accessible throughout the program by clicking on the Help! What Should I Do? button. Help is provided through a combination of written guidelines, mathematical formulae, and diagrams. The most complicated step—Describe Indicators—possesses a supplementary help window with detailed mathematical descriptions of each of the four scoring functions included in the program. To assist users further, links to the help windows are provided within the tutorial.

DISCUSSION

AEPAT was created to provide users with a tool to assess the relative effects of management on agronomic and environmental dimensions of agricultural sustainability. As such, evaluations with AEPAT are representative of the middle level of the agricultural sustainability hierarchy outlined by Andrews (1998) (Fig. 6) where functions supporting soil, water, and air quality are consistent with the agroecosystem functions included in the program. This hierarchy provides a useful conceptual framework by which to organize efforts focused on designing tools for sustainability assessment.

Because the calculation procedure used in AEPAT is patterned after a performance-based index, users must accept the assumptions and drawbacks inherent to this assessment approach (see Wagenet and Hutson, 1997). Users must also accept the somewhat restrictive data requirements inherent to performance-based indices. In general, a large amount of high quality data ideally collected over multiple years is needed for output to be useful. Consequently, we consider data from long-term agroecosystem experiments to be most suitable for use with AEPAT. In general, long-term agroecosystem experiments have been conducted for a minimum of 20 yr, possess replicated treatments/plots sufficiently large

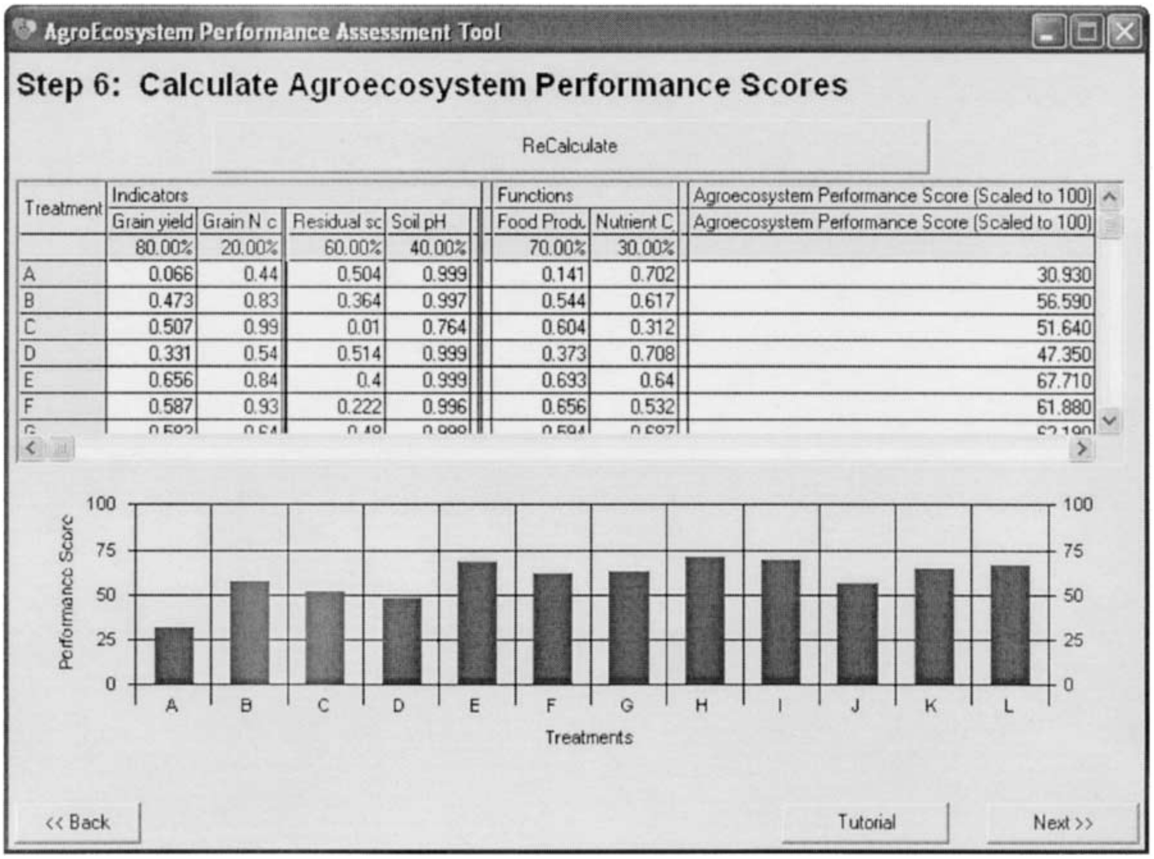

Fig. 5. Output screen displaying calculated scores for indicators, agroecosystem functions, and overall performance. Results are presented in a table and bar graph.

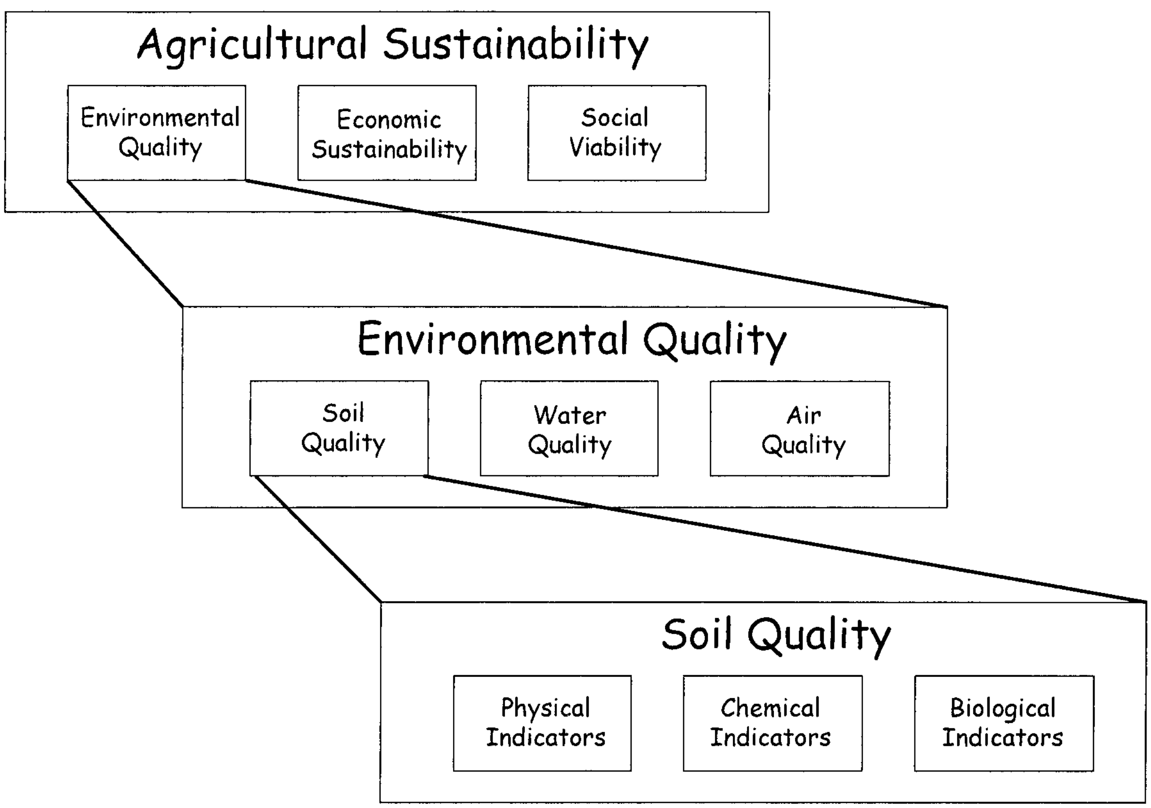

Fig. 6. An agricultural sustainability hierarchy (adapted from Andrews, 1998). Evaluations with AEPAT are representative of the middle level of the hierarchy.

enough to allow for repeated within-plot sampling, and are characterized by exceptional documenting, archiving, and data management systems (Rasmussen et al., 1998; Richter and Markewitz, 2001).

The usefulness of AEPAT as a tool for assessing the sustainability of agricultural management systems will improve with refinements based on constructive input from users. Version 1.1 of AEPAT can be ordered through the USDA-ARS Northern Great Plains Research Laboratory website at www.mandan.ars.usda.gov (verified 6 Oct. 2003) or by contacting Mark Liebig, USDA-ARS, P.O. Box 459, Mandan, ND 58554; (701) 667-3079 (office); (701) 667-3054 (fax); or liebigm@mandan.ars.usda.gov (email).

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