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DECISION-MAKING PROCESS FOR THE DESIGN, SELECTION, AND OPERATION OF MANURE MANAGEMENT SYSTEMS: A REVIEW

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Abstract

For centuries, livestock manure has been utilized as an invaluable soil amendment and fertilizer for crops. The continuing growth of the livestock industry in both developed and developing countries coupled with the implementation of more rigorous environmental regulations and protocols are increasing the importance of appropriate manure management systems and practices. A systematic approach to manure management must involve the identification and evaluation of criteria that are necessary for the design and selection of optimal manure management systems. The purpose of such a decision-making process is to analyze the system parameters and to recommend site specific and need-based parameters that result into an optimized manure management strategy. In this article, efforts have been made to identify decision-making criteria related to manure management practices. Decision-support tools for manure management systems have also been reviewed. Not surprisingly, environmental considerations have been found to top the list of the most important manure management criteria. Most of the existing decision-support tools are based on very specific aspects, such as nutrient management. The need to develop whole-farm decision-support tools that address all the major components of manure management systems, such as collection, storage, treatment, and land application, has been identified. Integrated decision support systems (DSS) should be an important part of management approach to identify the suitable system (liquid, semi-solid or solid manure management, composting, bio-energy production) of manure management.

1. Introduction

Manure has always been considered as an invaluable input to the soil for crop production. In a broad sense, manure management relates to the use of animal manure in ways that are appropriate to the capabilities and goals of the farm while enhancing soil quality, crop nutrition, and farm profits (Nowak et al., 1998). Manure management is defined as a decision-making process aiming to combine profitable agricultural production with minimum nutrient losses from manure, for the present and in the future (Brandjes et al., 1996). Appropriate manure management systems (MMS) are becoming increasingly important, firstly because of the increasing population of livestock animals and the growth of the livestock industry, and secondly as a result of the implementation of environmental regulations and protocols. Increasing environmental and sustainability concerns lengthen planning horizons and increase the number of decision variables that must be considered in management planning (Li et al., 1994). The selection of manure management and treatment options increasingly depends on environmental regulations for preventing pollution of land, water and air. For example, regulated reductions in ammonia emissions could influence the housing management, the storage and treatment of manure, and methods of land application (Westerman and Bicudo, 2005)

The Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC) was adopted in 1997 and became international law in 2005 (Bohem, 2005). Under this protocol, parties agreed to legally-binding greenhouse gas (GHG) emission reduction targets intended to reduce global GHG emissions to about 5% below 1990 levels during the first commitment period, which covers the years 2008 to 2012. In livestock production, manure management constitutes a potential area for reducing GHG emissions. Greenhouse gases are generated at all stages of manure management: collection, handling/storage, treatment, land application, etc. The use of an appropriate decision support system (DSS) could assist livestock operators in identifying MMS or components that have a positive impact on the reduction of GHG emissions.

A number of criteria determine the suitability of a given MMS components. The main purpose of the research on the systematic approach to manure management is to identify and assess the relative importance of such criteria, which are required for the design, evaluation, and selection processes of alternate MMS (Laguë et al., 2000). Decisions related to the design, selection, and operations of MMS are difficult and complex because of the heterogeneity of manure, options for managing in different forms with different end uses, cost factors, related soil and crop factors, etc. (Stonehouse, 1991). The objectives of this article were: (1) to identify the criteria required for the selection, design, and operation of livestock MMS; (2) to review some of the available decision support systems (DSS) for manure management: (3) to suggest ways for integrating different options and their components.

2. Criteria for DSS in Manure Management

Traditionally, manure has been directly recycled into soil-crop agricultural systems as an amendment and a fertilizer. However, an increasing number of constraints must now be considered when designing, selecting, and operating MMS. To make a bridge between the increasing animal production and high-scale regulations on environment, the Livestock-Environment- and Development (LEAD-FAO, 2003) initiative is emphasizing a decision support tool (DST) on manure management to facilitate the identification, evaluation and selection of manure management options for confined pig production in rapidly growing economies. Design and operation of a MMS requires the simultaneous consideration of environmental and economic outcomes (Ogilvie et al., 2000). Magette et al. (2002) developed a list of '*Best Available Techniques'* for the Irish pig and poultry producers that meets integrated pollution prevention control (IPPC) regulations. Recommended techniques for the overall waste management mainly focused on environmental management systems (EMS) incorporating modifications on feed composition and manure handling from production facilities. Criteria used in formulating manure management guidelines for the Western Washington region of the USA included water quality, local support and application, and economic feasibility (Peterson, 1995).

Classification systems for hog manure management technologies were reported by CETAC-WEST (1999) with the objective to facilitate the identification of components for proposed systems. Criteria for the classification included application area, economy, limiting features, technology type, and end products. Application area included building design, manure storage, manure application, soil capacities for agronomic practices, and manure processing. Limiting features included geography, infrastructure, land use, energy utilization, etc. Technology types covered solid-liquid separator, manure handling and land application, odour control, solids management, liquids management, digestion processes, etc., while end products were examined in terms of value and marketability, land application, useful gases (e.g. methane for electricity generation), useful liquids (e.g. flush water recycling), animal re-feeding, etc.

Laguë (2002) conducted a study to evaluate the relative importance of 37 criteria in five different categories (agronomic, economic, environment, social / health & safety, and technical) for a systematic approach to the design, evaluation, and selection of MMS. Environmental criteria were identified as the most important ones, followed by the social / health and safety criteria. System developers have been urged to provide detailed information about the performances of a particular MMS with respect to environmental and human criteria, in addition to the traditional economic and technical elements. Design criteria should therefore include the maximization of nutrient recycling, the protection of natural (air, soil and water) resources, the control of manure application rates, the minimization of capital and operating costs, as well as, social acceptance and human health and safety issues (Laguë et al., 2005).

Farm decision-makers must balance the technical (bio-physical) aspect of manure as a source of plant nutrients with the environmental aspect of avoiding damage and thus decisions should be based on a three-way tradeoff perspective amongst (1) technical aspects, (2) environmental aspects and (3) economic aspects (Stonehouse et al., 2002). Unterschultz et al. (2004) studied the economic evaluation of manure management considering the environmental aspect in the Alberta's livestock sector. This review study reported the effect of manure on four sub-criteria of environmental impacts including water pollution, air pollution, climatic change (global warming), and soil degradation. During the first workshop on current research across Canada on GHG emissions from animal production and manure management, a special emphasis was given to the best management practice development and assessment of manure management strategies that would reduce methane and nitrous oxide emissions (France et al., 2005). Environmental aspect was given utmost priority in manure management.

3. An Overview of Decision Support Systems

A Decision Support System is an interactive computer-based system or subsystem intended to help decision makers use communication technologies, data, documents, knowledge and/or models to identify and solve problems, complete decision process tasks, and make decisions (Power, 1997). An accurate evaluation of the various criteria is necessary when assessing the overall performance of a particular MMS. A decision support system is basically in the form of a long questionnaire that also includes procedures for problem resolution. This can be achieved by analytical methods or more efficiently by using interactive computer programs. With the advent of new technologies and programming languages, manure management planning tools are now based on interactive software packages. Computer programs help users with decisions about the choice of all the major components of the management system. There exist many examples towards developing decision support systems for manure management. Decision support systems that are available commercially and that have been adopted by producers to various degrees are listed in Table 1. Some of them are described in the following sections.

Table 1. Decision support systems (DSS) for manure management.

3.1 Analytical approach

Early days DSS used to depend on procedural and analytical approaches. Comparison matrix and critical path methods were popular tools in decision-making processes. These methods involve comparing the variables set in a matrix form for finding the weighting factors of the criteria chosen for a particular system. Optimization techniques have also been used for analytical tools for decision-making.

Preston (1967) used Network Diagrams and Critical Path Scheduling to optimize the system components of piggery housing, including manure handling and storage. Ogilvie et al. (1975) and Safley et al. (1977) also worked on the same method as an extended work including the component of manure distribution focusing on cost-effectiveness of the system for swine and dairy manure. Laguë et al. (2000) exemplified a hypothetical manure management system using comparison matrix as a decision support tool. The selection process consisted of integrating the results from ranking of the different potential solutions for each chosen criteria with their relative importance.

Analytical Hierarchy Process (AHP) is an approach designed to assist in the decision making process for problems associated with multiple criteria (Saaty, 2000). It can effectively consider complex and unstructured decisions. The process involves carrying out simple pair-wise comparisons that are then used to develop overall priorities for ranking the alternatives. Huang et al. (2003) used AHP for odour management strategy selection. A basic AHP model was used to evaluate the efficiency of four management strategies including manure depth reduction, finishing building type (deep pit vs. shallow pit), air treatment, and feed type (ground vs. pelleted) for their relative importance on odour reduction.

A self-guiding decision support system was applied to evaluate the criteria for hog manure system in Minnesota (Bergh et al., 2005). The evaluation system comprised a large interdisciplinary team consisting of farmers utilizing alternative hog production systems, an agricultural economist, agricultural lender, agricultural engineer, agricultural ecologist, a farm management educator, extension educator, rural sociologist and staff from the Minnesota Institute for Sustainable Agriculture (MISA) and the Sustainable Agriculture Program (SAP) of the Minnesota Department of Agriculture. Analysis and review of the results were carried out by a small evaluation team consisting of five members group that visited eight farms at least twice during the fall and the next spring (1996-97), toured of the production areas, and made follow up phone calls. The result of this evaluation was then reviewed and commented by the larger team.

3.2 Computer support systems

A computerized environment for decision making has cost and time saving benefits, particularly when the opportunity for more formal analysis is unavailable or quick responses are needed. In order to be well accepted by livestock operators and other users, a computer-based DSS should incorporate: (a) a whole farm focus along with comparative business analysis, (b) integration of data sources, program modules, and budgets, (c) the capability of direct interaction with experts, especially through wide area networks (*WAN*s) during the decision process; and (d) the ability to interface with a range of expert system (ES) and operations research (OR) models to move towards more optimized decisions (Li et al., 1994).

Computer based management began with linear programming (LP), and spreadsheet application using commercial packages such as Lotus 1-2-3™, QuattroPro™, MS Excel™. Computer based programs are basically of the following three types (Jackson, 1986):

1. Level 1 assistance: There is no knowledge built-in to this type of programs. Results are obtained based on some mathematical functions that are applied to the input data.

2. Level 2 assistance: It involves a built-in database as a memory for the purpose of comparison with the analysis of user input data.
3. Level 3 assistance: In this advanced system, the program needs a knowledge base from which it yields solutions given certain responses from the user. This is often termed an expert system (ES) or knowledge-based-system (KBS). Such programs are developed from the integrated knowledge of experts for solving problems of a certain nature. Basically, such programs analyze the information from a range of alternatives and provide responses to user questions based on its built-in knowledge combined with user input.

3.2.1 *DSS focusing on nutrient management*

Jones et al. (1994) in Purdue University (USA) developed a nutrient management program (AMANURE) using QuattroPro™ for DOS spreadsheet and compiled with BALER software. This program provides support in managing the nutrient value of the manure for estimating the application rate that matches the crop to be grown. The program can be used for swine, dairy and poultry manure.

WISPer (Wisconsin Interactive Soils Program for economic recommendations), an interactive software, was developed as a whole farm manure allocation plan based on optimum manure application rates on environmentally acceptable sites and prioritized fields based on crop nutrient needs (Bullington and Combs, 1994). The program first estimates the amount of manure available for application based on herd numbers, management and manure handling/storing methods. It then calculates manure application rates, identifies fields for manure application considering a combination of cropping practices, landscape parameters and nutrient needs ranked by N, P_2O_2 or K_2O. This decision support tool is used widely in the state of Wisconsin for nutrient management.

VMNM (Vermont Manure Nutrient Management), a nutrient management planner, was developed at the University of Vermont, Burlington (Jokela et al., 1995). This spreadsheet software is used for dairy and other livestock farms for recommending manure application rates based on the user's choice of N, P, or K as the limiting nutrient and it provides the most cost-effective and environmentally sound use of the manure. The program also keeps a running tally of the total amount allocated to all fields on the farm and compares it to the amount available for spreading. It also estimates an economic value of manure to be applied.

OMAFRA (Ontario Ministry of Agriculture Food and Rural Affairs, Canada) developed ‘NMAN’, a nutrient management computer program as a tool to assist farmers, contractors and advisors to develop a nutrient management plan for farms using livestock manure (Hilborn and Brown, 1995). One of the challenges related to the program is interpreting output information using environmental, economic, and common sense parameters. The program is especially of interest as a planning tool for large livestock or poultry operations having large volumes of manure to handle. It performs manure storage sizing and manure nutrient application rates based on the estimated amount of manure production and recommended nutrient needs.

MAGMA, a hybrid dynamical system (HDS) using both continuous and discrete-valued variables, was developed to simulate management of livestock manure production and utilization (Guerrin, 2001). The main goal that is pursued is the utilization of stocks according to constraints depending upon various scenarios and to assist in choosing alternative management strategies. Decision rules allow one to work out on scheduling manure application based production cycles (crops, compost) and availability of necessary resources (e.g. equipment, volume of manure stocks, etc.). It supports decision-making to help better manage manure at the farm level with the aims of environmental risk minimization, agricultural efficiency, and farming sustainability. Depending on the preferred criterion between environmental risk and labor usage, it can predict how such an approach may highlight alternative strategies, and help decision-making by farmers or public policy makers.

Nutrient Management planner for Minnesota (Version 2.1) is a computer program designed to assist in developing field-specific crop nutrient management plans for crop and livestock farms (USDA-NRCS, 2001). It provides guidance for making sound management decisions on location, rate, timing, form and method of nutrient application based on crop history and past management.

EWEES (European Waste Engineering Expert System) is based on several European conditions for a vast region ranging from the UK and Ireland through Greece (Walok and Carton, 2002). The main objective of this program is to solve farm pollution problem through the selection of appropriate remediation strategies. While recommending manure application rates based on relevant circumstances, the model accounts for limits in manure application considering its pollution potential. The most economical commercial fertilizer, which may be needed in addition to animal manure, can also be selected.

A geographic information system (GIS) based manure application plan was developed for site-specific manure application in the southeast Queensland region of Australia (Basnet et al., 2002). Sites suitable for animal waste application were identified using a GIS based weighted linear combination (WLC) model. The degree of land suitability for manure application was determined using a range of social, economic, environmental, and agricultural factors. Recommendations were made for manure management practices to minimize the socio-environmental risks and increase the nutrient use efficiency of the applied manure.

MANMOD, a simple spreadsheet-based model was developed to estimate the main nutrient losses during manure production and storage that would impact on the final manure nutrient content. Thus, a user can see how management (e.g. storing slurry or manure with or without a cover) will impact nutrient losses. Shepherd and Webb (2002) implemented two tools for manure nutrient planning, one being the use of look-up tables to assess nutrient content, and the other being the development of a decision support tool for describing nutrient transformations during cattle manure management.

Compost Wizard©, a computer program, was developed to design a composting operation based on scientific and regulatory recommendations (Governo et al., 2002). The program uses critical user-inputs to develop a preliminary design of the composting process and facility, and an estimate of capital and operating costs. It helps generate many different design scenarios that can be used to estimate the feasibility of composting as a waste management option.

To aid farmers in planning, a computer model created in Microsoft Excel, called “Co-Composter,” was developed as a planning and management tool for large composting facilities (Harrison, 2003). The model, basically prepared for composting dairy manure, generates a detailed logistical and economic analysis to help compost managers look at facility planning, equipment, efficiency and feasibility.

Agriculture Environmental Management and Information System (AEMIS), developed at Utah State University, is an online decision support tool that provides efficient and accurate access to the latest information about manure management theories, methods, and tools for the livestock and poultry industry (Harrison et al., 2005). The system helps producers and their advisors facilitate planning, controlling, monitoring, steps to corrective action, auditing, and review activities to ensure that both the environmental policy is complied with and that the agriculture environment management system remains appropriate. The enterprise served valuable information addressing the issues of manure management and environmentally sensitive methods of on-site reduction, reuse, and recycling. The information has been developed, peer reviewed, and pilot tested by agricultural experts across the United States.

A Windows-based computer program called ‘Manure Management Planner (MMP)’ was developed at Purdue University. This application package was adopted by the Government of Alberta (Canada) incorporating the local system parameters. This planner is a software program where the user enters information about the operation's fields, crops, storage, animals, and application equipment. MMP helps the user allocate manure (where, when, and how much) on a monthly basis for the length of the plan (1-10 years). This allocation process helps determine if the current operation has sufficient crop acreage, seasonal land availability, manure storage capacity, and application equipment to manage the manure produced in an environmentally responsible manner. MMP is also useful for identifying changes that may be needed for a non-sustainable operation to become sustainable, and determine what changes may be needed to keep an expanding operation sustainable.

The Manure Application Rate Calculator (MARC, 2005) is a manure management planning software for the provinces of Manitoba and Saskatchewan, Canada. MARC can contain land, crop, and manure information specific to Manitoba and Saskatchewan. This provides the capability of developing manure management plans in both Prairie provinces. MARC 2005 is a more advanced version of MARC98, which was adapted from NMan97 software for Ontario. It provides improved record keeping for crop and livestock producers, gives users more flexibility in the types of manure they apply and the methods of application they can use. Distinctively, it automatically fills out and print manure management plan reports; and assists producers in fulfilling regulatory requirements.

3.2.2 *DSS focusing on whole farm manure management*

A knowledge base expert system of waste management alternatives was created with PDC prolog™ for IBM™ compatible PCs and was used by extension personnel responsible for pig waste management in Taiwan (Chen, 1994). The system considers information about the farm location, land area, scale of production, methods of manure collection and cleaning, fertilizer needs of the farm and treatment efficiencies of different processes. There are 21 different recommendations that can be provided by the DSS based on the user interface and knowledge-based procedures ranging from the simplest discharge/recycle MMS to the most complicated solid/liquid separation-anaerobic digestion- solid/liquid separation-aerobic treatment-discharge system.

DAFOSYM, a dairy forage system model (developed at Michigan State University), was revised and used for the management of dairy manure incorporating sub-models for manure production, collection, storage and land application (Borton et al., 1995). This integrated model provided a tool for evaluating and comparing the long-term performance and economics of alternative manure systems for diary farms and their interaction with feed production. It was observed that manure systems using long-term storage with spreading, injection, or irrigation have greater direct cost to the farmers than the daily haul system. Considering environmental benefits, adapting a long-term storage system increased the cost of the manure handling system.

A DSS for managing swine manure was developed using a nutrient balance method based on user-defined system parameters (Ma, 1997). Overall manure management is accomplished by performing five functions including estimation of manure production & storage space, nutrient needs for crops & manure field application rate, cost of the manure handling system, and system rating and environmental indices. The rating scheme for the manure management system is based on five criteria including cost, labor, odor, nutrients and environment. The upgraded version (MCLONE4, 1999) of the DSS software originally developed by Flaming (1988) assess environmental risks over five major factors of odour, ammonia losses, phosphorus impact, nitrogen leaching, and bacterial contamination. It can be used for liquid and solid swine manure. However, nutrient calculations in the program are based on Ontario crop recommendations guide.

An optimal whole farm plans for four different sizes of hog finishing enterprises in Ontario was developed using mixed integer programming (MIP) models (Stonehouse et al., 2002). The emphasis was placed on the economic criterion, which was coupled with environmental and nutrients aspects. Management plan involved identifying the most profitable ways to formulate hog feed rations and to utilize cropland, hog production and manure-handling facilities, and farm labor and capital resources. Linear programming (LP) models were selected to have the mixtures of systems components in pursuit of their bid to maximize objective function values (maximization of farm net returns). It was observed that considerable differences existed between the best ways to feed livestock, to collect and handle manure economically with a combination of environmental issues.

4. Future needs and perspectives

It has been observed that computer-based decision support systems for manure management are mainly focusing on nutrient management. Very few have considered the whole farm manure management options. However, for proper monitoring and management of manure, a decision support tool should encompass all the relevant phases of manure management including manure collection, storage and land application. Besides this, a DSS of whole farm manure management should also be able to look into different alternatives of the uses of manure considering user-defined criteria on agronomic, environmental, economic, and social & health. For example, the nutrient content of manure is influenced by the type of collection and storage facilities. If manure management practices are changed to reduce ammonia emissions (by cover on the storage), the nitrogen content of the operations' manure will increase. If manure applications to the land remain unchanged, the risk of nitrogen runoff to water resources increases (Aillery, 2005). This may also cause imbalances in the nutrient uptake of the crop. Thus, an overall evaluation of a manure management system based on defined criteria is required for the benefit of livestock producers as well as of society in general. The management alternatives could be conventional or non-conventional use of manure for energy production. Such a decision support system can be visualized as shown in Fig. 1.

Fig. 1. Conceptual model of integrated decision support system for manure management.

An integrated DSS should be capable of investigating the feasibility of different management alternatives by evaluating systems rating based on weighted factors of user defined criteria from the perspective of systems approach. The whole system can be categorized as intra-system and inter-system. The integrated DSS needs to evaluate various management options for all the components (collection, storage and application/end use) of a particular management system (liquid, semi-solid, solid, composting or bio-energy system) i.e., intra-system evaluation. In case of inter-system evaluation, the DSS repeats the same procedure for different management systems. Such a system has been outlined in Fig. 2. During the evaluation process, user defined criteria are used for performance evaluation and systems ranking.

Fig. 2. Systems approach for integrated manure management.

A good DSS should be interactive in terms of weighting factors of decision criteria for system evaluation and rating. This provision would help make a proper decision that is suitable at different locations and for different users like farmers, producers, agrologists, environmentalists and government agencies. For example, if the MMS has to be located near a populated area, odour intensity associated with the social, health and safety issues need to be given more weight. These situation-based weight factors for decision criteria can be generated during the early stage of systems rating in the DSS program. One approach could be a comparative matrix as shown in Table 2. For the five chosen criteria, the users can specify values based on their specific situation. Thus an integrated DSS is envisaged to serve the purpose of choosing varying weight factors for different locations and end uses and then evaluate the system with respect to other possible management options on a systems approach.

Table 2. Weight factor module for decision criteria.

5. **Conclusions**

Not surprisingly, environmental considerations have been found to top the list of manure management criteria. As a result, computerized decision-support systems that focus on environmental criteria are becoming increasingly popular and effective management tools. The second most important criterion has been found to be agronomic considerations for nutrient management. Environmental issues are coupled with social and health considerations. Recent research trend on manure management systems closely matches with the criteria obtained from the survey studies in the Canadian Prairies (Laguë, 2002). Surface and ground water contamination and odour reduction have been identified as priority areas in manure management.

Because of the growing demand for the appropriate evaluation of an increased number of management criteria, several approaches have been proposed to assist the decision-making process around the world. Two types of evaluation practices have been identified. One is the overall evaluation of the management system while the other is focused on a specific criterion of the whole process with respect to its variables. Computer-based decision support systems for manure management are mainly focusing on nutrient management. However, very few systems have been developed to address whole farm decision-making needs involving all major system components. Another feature with the commercially available DSS packages is that most of them are based on local needs. Their application and databases are focused on either a particular country or for a particular province, state, or region. This can be attributed to the uniqueness of each facility as each of the manure management systems are site-specific with respect to government policies and regulations, agronomical variations, and other related engineering parameters, evaluation and recommendation for the optimum system.

Manure management system has been conceptualized as the integration of management components and management alternatives. A user-friendly approach for the selection and design of the weightage factors of respective criterion has also been suggested for integrated manure management.

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Table 1. Decision support systems (DSS) for manure management.

Name/source	Type/framework	Animal	Criteria	Management Goal
AMANURE, Purdue University	Spreadsheet	Livestock	Agronomic	Nutrient
WISPer, University of Wisconsin	Procedural/Interactive software	Swine and dairy	Agronomic, environmental	Nutrient
DAFOSYM, Michigan State University	Simulation	Dairy	Economy, environmental	Whole farm
MCLONE4, University of Guelph	Expert System/ Interactive software	Swine	Cost, labor, agronomy, environment	Whole farm rating
MAGMA, France	Dynamic Simulation	Swine, poultry	Environmental	Manure treatment and application
MANMOD, UK	Spreadsheet	Dairy	Agronomy	Nutrient loss from practices
MMP, Purdue University	Interactive software	Swine and dairy	Agronomy, environmental	Nutrient
NMP for Minnesota, University of Minnesota	Interactive software	Livestock	Agronomy	Nutrient
EWEES, UK & Ireland	Expert system, data base/ software	Livestock	Agronomy, environment	Nutrient
MNAN (OMAFRA), Ontario, Canada	Interactive software	Livestock and poultry	Agronomy, economy, environment	Nutrient
VMNM, University of Vermont	Spreadsheet	Swine and Dairy	Agronomy	Nutrient
AEMIS, Utah State University	Online navigation system/ Information Technology	Livestock and poultry	Environment	Information system
MARC, Saskatchewan and Manitoba Agriculture	Expert system, database	Livestock	Agronomy, economy, environment	Nutrient
Co-Composer, Cornell Waste Management Institute	Spreadsheet	Dairy	Agronomy, cost	Nutrient
Compost-Wizard, University of Georgia	Expert system	Livestock	Agronomy, cost	Nutrient

Table 2. Weight factor module for decision criteria

	Criterion1	Criterion2	Criterion3	Criterion4	Criterion5	Sum_Row
Criterion1	F_1=1	F_6	F_{11}	F_{16}	F_{21}	S_1
Criterion2	F_2=1 or 0	F_7=1	F_{12}	F_{17}	F_{22}	S_2
Criterion3	F_3=1 or 0	F_8=1 or 0	F_{13}=1	F_{18}	F_{23}	S_3
Criterion4	F_4=1 or 0	F_9=1 or 0	F_{14}=1 or 0	F_{19}=1	F_{24}	S_4
Criterion5	$F_{5=}$1 or 0	F_{10}=1 or 0	F_{15}=1 or 0	F_{20}=1 or 0	F_{25}=1	S_5
						Sum_WF=Σ (S_1:S_5)

Factors in the upper half of the matrix table attain values (0 or 1) according the users' input values for the shaded region.

Choose '1': if corresponding criteria in column is less important
Choose '0': if corresponding criteria in column is more important

Weight factors in percentage:

WF-C1=(Sum_WF/S_1)*100
WF-C2=(Sum_WF/S_2)*100
WF-C3=(Sum_WF/S_3)*100
WF-C4=(Sum_WF/S_4)*100
WF-C5=(Sum_WF/S_5)*100

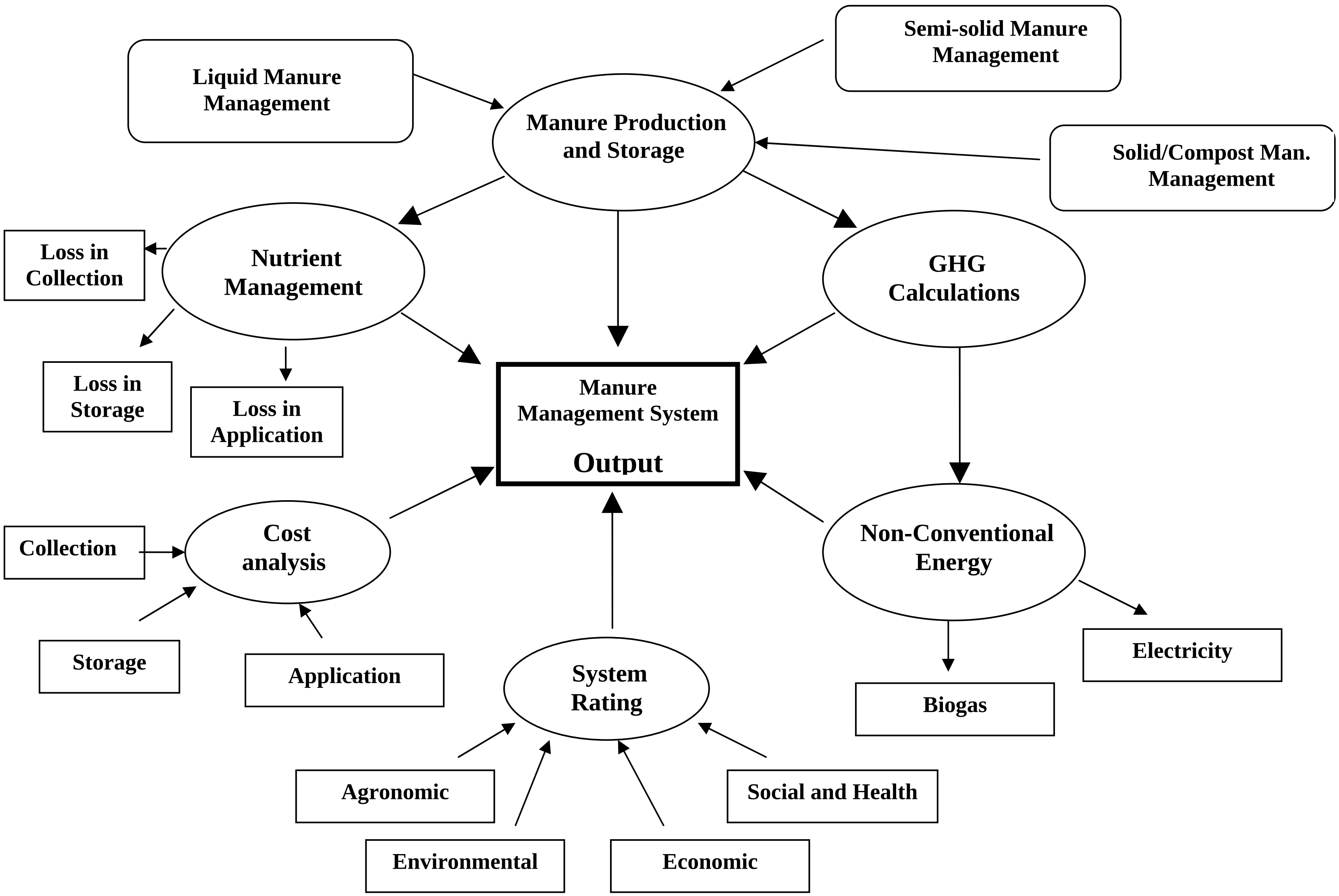

Fig. 1. Conceptual model of integrated decision support system for manure management.

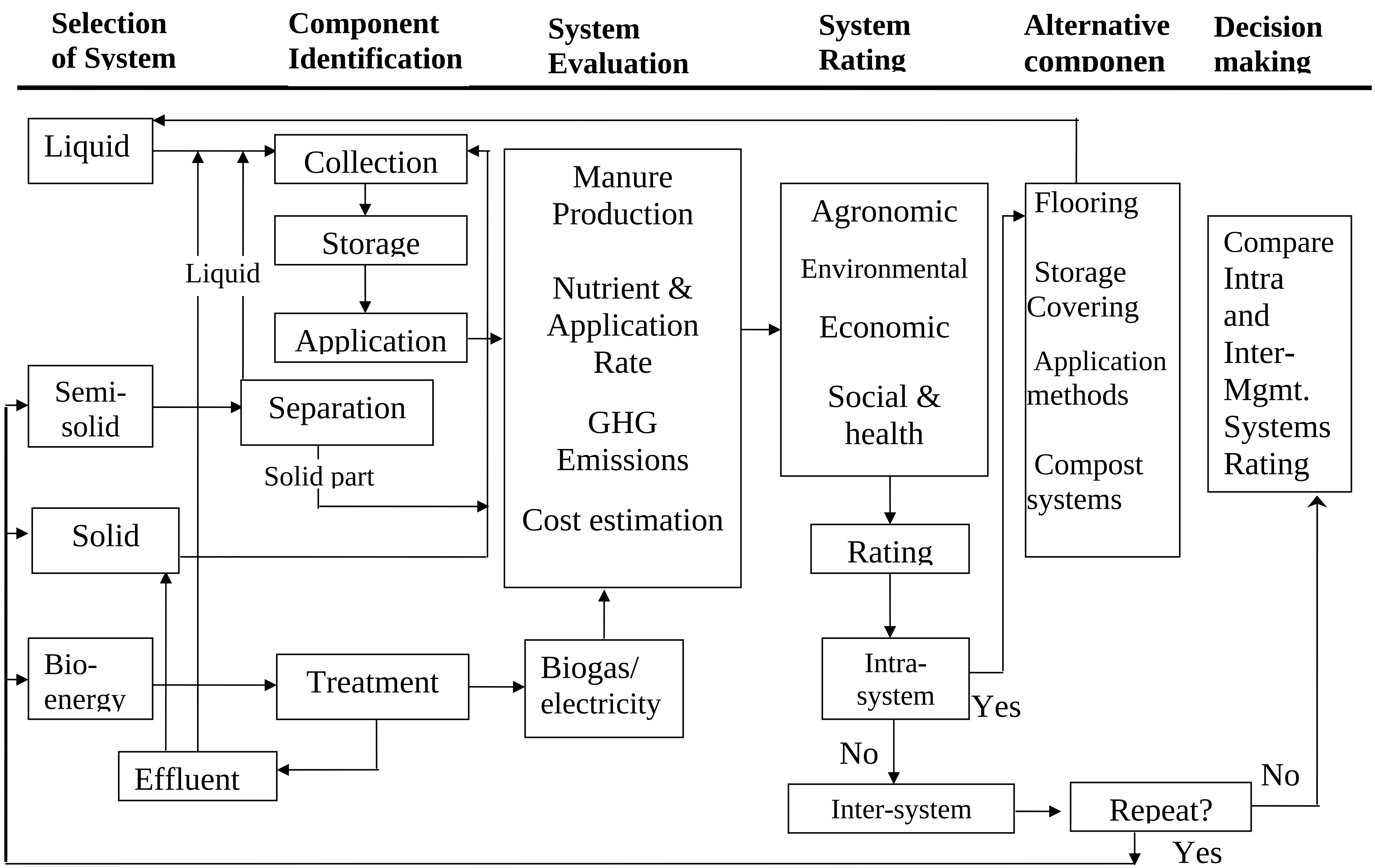

Fig. 2. Systems approach for integrated manure management.