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AGRICULTURAL FLEET MANAGEMENT: A SYSTEM APPROACH

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ABSTRACT The structural development and the imposed requirements within agriculture together with the introduction of sensors, actuators, software, on-board networking and auto-steering technology is gradually transforming conventional agricultural vehicles into supervised semi-autonomous machines which can traverse fields, turn at headlands and control implements automatically. Therefore, it is both imperative and technologically feasible to plan and coordinate the execution of field operations by fleets of modern agricultural machines optimally. In order to analyse the complex situation of how to develop an effective fleet management system, a conceptual model was developed. This involved using soft systems methodology (SSM) and a participatory approach involving users and stakeholders as providers of expected requirements for a proposed fleet management system (FMS) of tomorrow. The proposed system involves a management system on a farm/contractor level to support real-time management decision-making of mobile units, by means of automated acquiring and contextualising of operations data and external parameters to form a foundation for decision-making improvement of the quality of decision-making and reduce the time efforts. A holistic view and scope of the system is presented together with the system's constraints.

Keywords: Participatory approach, soft methodology, system analysis, requirements specification

INTRODUCTION The structural development and the imposed requirements within agriculture imply that innovative technology and knowledge management are decisive for the future arable farmer. Especially, the maximisation of the agricultural machine productivity is an important element in the continued efforts of planning and controlling resource input in arable farming. Furthermore, the introduction of sensors, actuators, software, on-board networking and auto-steering technology is gradually transforming conventional agricultural vehicles into supervised semi-autonomous machines which can traverse fields, turn at headlands and control implements automatically. That together with the large amounts of capital invested in such high-efficiency agricultural machinery and the computing and communication platforms they carry, makes it both imperative and technologically feasible to plan and coordinate the execution of field operations by fleets of modern agricultural machines in an optimal manner. Such planning has the potential to lower operational cost by reducing fuel consumption and the number of required machines and operators, to reduce emissions and to increase machine utilisation.

Large scale operations like harvesting or other "material-handling" operations are especially requiring complex planning efforts due to the uncertainties that it is subjected to (*e.g*. yield, weather, machine performance). The planning of such operations, typically involves four stages that are highly interconnected. These are: harvesting, out-of-field removal of biomass, rural road transportation and public road transportation. The corresponding machinery system includes: harvesters, transport units, medium and high capacity transport trucks, and unloading equipment between each pair of successive stages. All these comprise a complex system in which the individual efficiency of each machine unit depends on the performance of the system as a whole or the supply chain.

Different forms of driving instructions and advice on optimising the execution of field operations provide the possibility of influencing a number of factors pertaining to the operational efficiency (e.g. Palmer, 2003; Sørensen & Nielsen, 2005; Bochtis and Sørensen 2009; Bochtis and Sørensen 2010). The operational efficiency expresses the ratio between the actual in-field productivity and the maximum theoretical productivity defined by the maximum operating speed and maximum working width (Witney, 1988). Especially for larger machines, it is important to maintain a high efficiency as the non-productive time elements represents a greater proportional loss in potential machine production (Søgaard & Sørensen, 2004; Sørensen, 2003).

Fleet management systems have been available in the industrial domain, such as the transport business, for a number of years. The first generation of fleet management systems was relatively simple software applications coping with a number of simple functionalities such as the vehicle tracking components as a basic function (e.g. Crainic & Laporte, 1998; Mele, 2005). Currently, these systems have evolved into complete enterprise management tools linking together all parts of the business. However, the inherent biological and dynamic nature of agricultural operations together with an experienced lesser general user acceptance have proven to inhibit a habitual transferable and integration of current fleet management systems into the agricultural domain (*e.g*. Gelb and Offer, 2005).

The objective of this study is to use the soft systems methodology (SSM) and a participatory approach to derive the contextual guidelines for optimised decision making concerning e.g. resource allocation, scheduling, routing, real time monitoring of vehicles and materials and timely conducting field operations. The concept will include the decision support and optimization of operations executed by a fleet of agricultural machines (non-autonomous or autonomous).

METHODOLOGY As a first step in the derivation of requirements on systems for integrated fleet management, a study involving relevant actors and stakeholders was carried out. This involved a participatory approach and analysis extracting current operations management challenges facing farmers and contractors in terms of increased productivity demands as well as increased compliance requirements from society. The study was carried out as an interview survey involving 3 Danish companies (The Danish Association of Machine Contractors, Danish Agricultural Advisory Service, and DataLogisk Inc) and an Austrian company, PROGIS Software GmbH, which all work with development and maintenance of planning tools for agriculture. The surveys included targeted questionnaires administered by an experienced researcher during each interview. The questionnaires included both closed and open-ended questions and followed established guidelines for surveys (Fink & Kosecoff, 1998). Efforts were made to avoid any bias in the process of interviewing farmers by introducing standardised lists of options to be answered. A non-random sampling method was considered feasible as the interviews targeted an explorative pilot (Lohr, 1999). The interview itself included the following themes and checklist given in Figure 1.

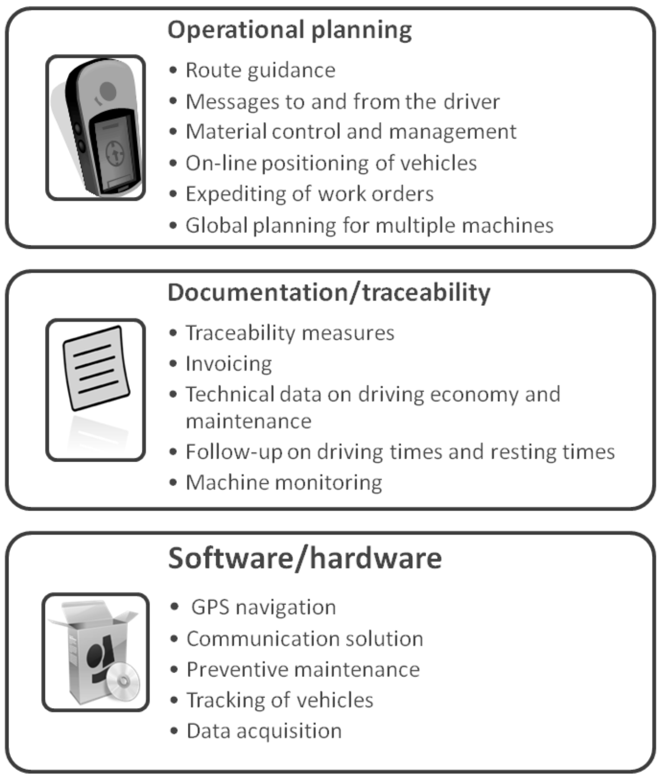

Figure 1. Interview components

Based on the derived user requirements, the complex and soft-systems situations of a FMS was analysed using the soft systems methodology (SSM) (Wilson, 2001). This approach has been used in multiple applications (*e.g*. Macadam *et al.*, 1990; Kasimin *et al.*, 1996) and involves identification of the scope of the system, integration of user requirements, conceptual modelling, and information needs as a preliminary step before any detailed system development and technology application. The boundaries and scope of a system can be described in terms of users and use-cases, where users are entities interfacing with the system (*e.g.* managers, software, databases) and the use-cases describe the functionality of the system or what the users want the system to do.

The conceptual model was tailored to the elements of CATWOE, a mnemonic concept representing the terms Customers (C), Actors (A), Transformation process (T), Weltanschauung (W), Ownership (O) and Environmental constraints (E) (Checkland & Scholes, 1999). The core elements are the T and the W, where the weltanschauung depicts the world view for which the system has meaning and the transformation depicts functionality on the system level. Customers are influenced by the transformation in terms of benefitting and suffering from it and the Actors are the entities that carry out the system activity and the Ownership belongs to the entities with the power to initiate or terminate system activities. Finally, the Environmental constraints represent elements, which are external to the system and imposed on the system. Checkland & Scholes (1999) argue that the CATWOE transformation is more elaborated since it includes additional and related elements and when included, will lead to enriched root definitions and hence, better models.

In summary, the applied approach expresses the current status quo of the system including inherent problems, derives the actual goal of the targeted system ("root definition"), and next, constructs a plausible conceptual model containing the proposed system amendments. The continuous and incremental elaborations and modifications of these procedural steps will provide an action plan for the system design.

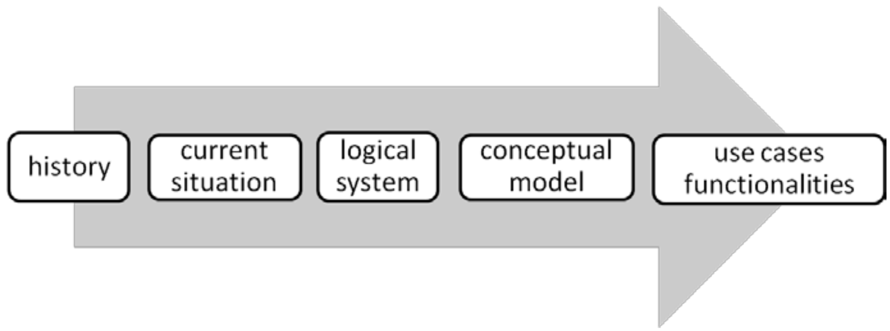

Figure 2. Principles of system analysis and conceptual modelling (adapted from Checkland (1988))

The applied systems analysis has a number of stages (Figure 2). The process starts with a description of the current system and situation, continues with the current logical system, the proposed conceptual model integrating future demands and finally with the proposed use cases or functionalities. For the first stage, the description of the current systems and situation, soft systems methodology was used to analyse the complex environment (Checkland, 1988). During the design phase of the conceptual model, a logical system was constructed for the proposed FMS and later the functionalities were derived, which can used to develop the functional prototype.

RESULTS AND DISCUSSION The derived expected functionalities for the FMS involved the voiced requirements from the various stakeholders. The requirements put forward by the machine contractors clearly embrace a fleet management solution, which can fulfil the information need for transport administration and control. The focus is on transport control, route guidance in connection with visited customers, invoicing, data acquisition as regards technical and operational data concerning the individual machine, *etc.* The voiced requirements from farmers more concentrate on on-farm functionalities such as on-line monitoring, route guidance, operations scheduling, *etc.* (Figure 3).

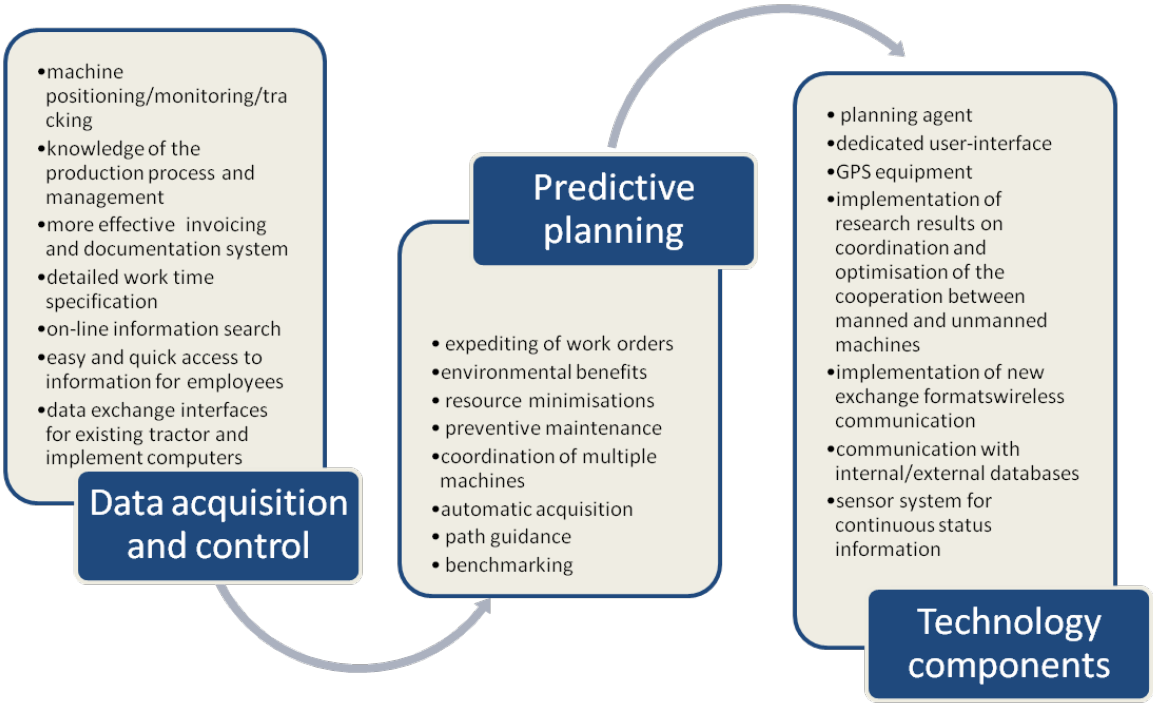

Figure 3. Voiced requirements for the FMS

Derived competences for model development efforts include route planning, analysis and decomposition of machine operations and various resource optimisation and decision support.

Based on the derived requirements, the precise definition of the FMS was established within the context of the CATWOE definition:

Customers: The primary customer of the proposed FMS is the farm manager or machine contractor manager and the management system as the demanders of data for production and operations management.

Actors: The actor is the one operating the FMS, which in this case is the farm/contractor manager or other farm staffs.

Transformation process: The transformation process involves the transformation of operational field data into a form, which can provide the foundation for decision making in crop production, specifically the management of mobile units.

Weltanschauung: The weltanschauung is the hypothesis that drives the FMS development. In this case, the view is that operational data is easily acquired and can be use to improve the management of mobile units.

Ownership: The farm/contractor manager is the owner of the FMS in terms of every day decision maker responsibility and as the decider on whether the system is of use or not.

Environmental constraints: The constraints influencing the usability and performance of the FMS includes the expectations of the managers, the required data quality, the reliability and used information technology (communication devices, server, databases, *etc*.)

In summary, the applied CATWOE approach expresses the actual goal of the targeted system. In compressed form, the root definition defines the purposeful activity handled here as: "*a FMS (owned and operated on farm/contractor level) to support real-time management decision-making of mobile units, by means of automated acquiring and contextualising of operations data and external parameters to form a foundation for decision-making. In order to improve the quality of decision-making and reduce the time efforts*". In this way, a FMS serves several purposes. A dedicated and well-designed FMS must be able to collect, process and store the required data and be capable of producing aggregate data and documentation as well as providing information planning and control purposes. It must be integrated into enterprise and management systems as a way to reduce duplication of data-entries and producing data for reporting requirements, both for internal and external purposes.

In a general approach to attain operations efficiency in an agricultural FMS, a number of operational functionalities must be acquired. These include on-line positioning of vehicles, machine monitoring/tracking, improved general knowledge of the production process and management, automatic invoicing and documentation system, detailed work time specification measures, automatic expediting of work orders, resource minimisations (*e.g*. labour, fuel), coordination of multiple machines (farmers, contractors), route and path guidance, *etc*. The complement of proposed functionalities is associated with a number of derived requirements securing an efficient operational performance of the proposed FMS. These requirements and capabilities include robustness, a balance between optimality and decision process time, a balance between extensibility and flexibility, efficient allocation measures, heterogeneity, changeability, and adaptation.

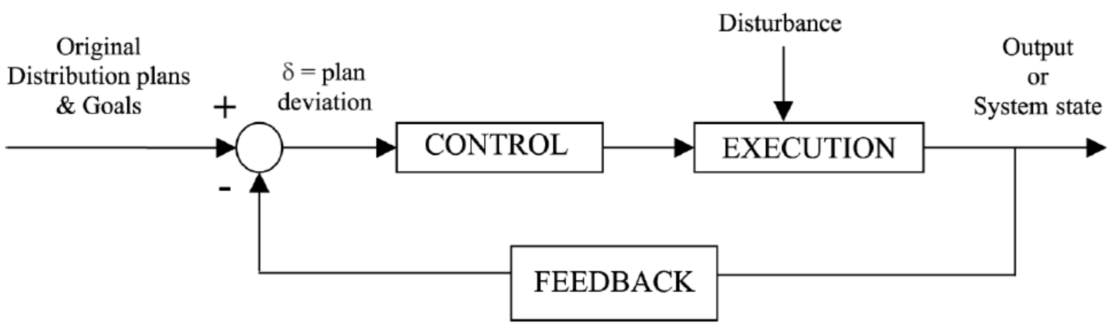

Figure 4. Schematic representation of closed-loop management system (Giaglis et al., 2004)

In order to incorporate the dynamic nature of the field operation, and the inherent uncertainties of many of its parameters (*e.g*. unknown yield distribution), the adoption of a closed loop control system, which results in a sequence of planning, execution and re-planning, is suggested (Figure 4). As indicated, plan generation and execution must be linked in a system monitoring effects of actions, unexpected events and any new information that can attribute to a validation, a refinement, or a reconsideration of the plan. An important aspect is that supplementary knowledge from observations, databases, sensors, *etc*., can be incorporated in order to revise plans. The closed loop approach makes feasible the implementation of an on-line decision support system for the coordination of mobile machinery units operating in a field or in a number of geographically dispersed fields.

Selecting the proper balance between the uses of centralized or de-centralized approach constitutes a difficult task varying form application to application. Of central importance is the determination of the acceptable level of team performance. Centralized management systems provide the key advantage of globally optimal plans due to the fact that decision maker (human or automated system) can take into account all the relevant information conveyed by the members of the team. However, centralized approaches often involve intrinsic difficulties such as intractable solutions for large machinery teams due to the complexity of the required algorithms for the global planning systems. Also, the requirements in terms of extensive inter-machine and centre-machine communication often mean that the real-time response is not feasible. On the other hand, a de-centralized management approach to agricultural fleet management architecture provides the advantages of a fast response to dynamic conditions and decreased communication requirements. In this way, an improved adaptation of the machines to the changing operational conditions is achieved, since this adaptation is carried out by locally sensing and responding to the environment.

Algorithms for scheduling, task allocation, machinery assignment, area coverage and route and path planning, should be distributed efficiently in terms of the balance between communication and computational requirements. For example, dynamic planning tools for area coverage planning for main units – *e.g*. harvesters, fertilizers, seeders- path planning for in-field service units- *e.g*. material transport carts- and routing for inter-field transport units – *e.g*. transport carts- (Figure 5) should be placed on-board in order to plan using both the a priory information provided by the centralized GIS system as well as the updated information of the local sensing measures.

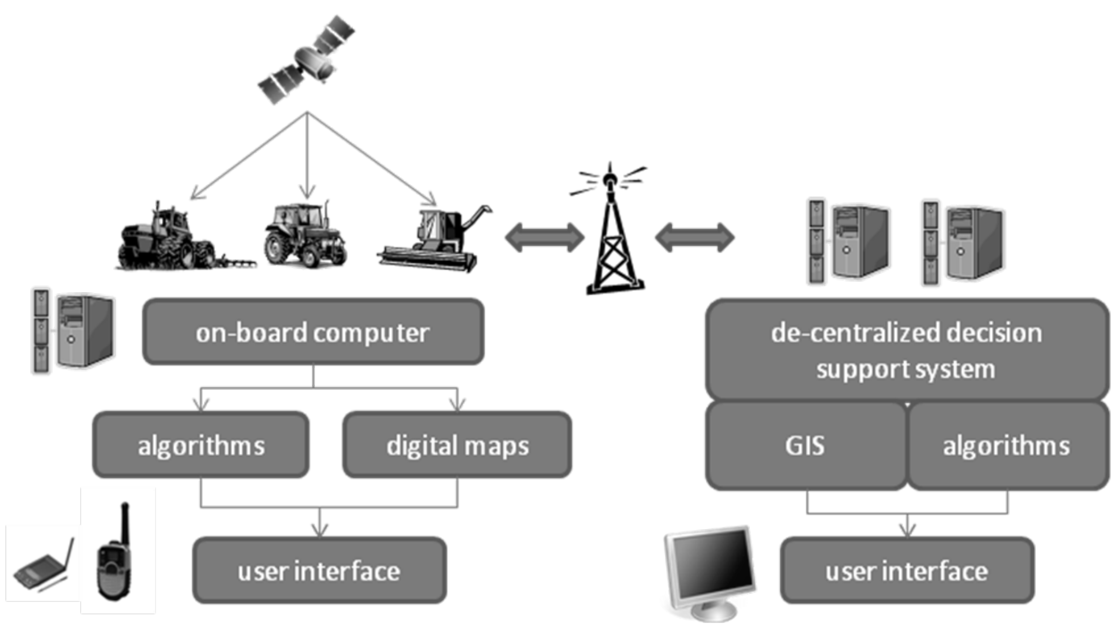

Figure 4. De-centralized vs. centralized planning distribution

CONCLUSIONS This research has shown the benefit of using dedicated system analysis methodologies as a initial step to the actual design and conceptualisation of a dedicated fleet management system for agriculture. The soft systems methodology has been used to target organisational business and process modelling through a participatory approach involving users and stakeholders as providers of expected requirements for a proposed fleet management system that will fulfil the user requirements of tomorrow. The proposed system involve "a FMS (owned and operated on farm/contractor level) to support real-time management decision-making of mobile units, by means of automated acquiring and contextualising of operations data and external parameters to form a foundation for decision-making. In order to improve the quality of decision-making and reduce the time efforts".

Selected derived functionalities of the conceptual fleet management model include on-line positioning of vehicles, machine monitoring/tracking, improved general knowledge of the production process and management, automatic invoicing and documentation system, detailed work time specification measures, automatic expediting of work orders, resource minimisations (*e.g*. labour, fuel), coordination of multiple machines (farmers, contractors), route and path guidance, *etc*. The complement of proposed functionalities is associated with a number of derived requirements securing an efficient operational performance of the proposed fleet management system. These requirements and capabilities include robustness, a balance between optimality and velocity, a balance between extensibility and flexibility, efficient allocation measures, heterogeneity, changeability, and adaptation.

The central elements of the conceptual fleet management model involve an elaborated division between centralised and de-centralised management measures. Planning tools for scheduling, task allocation, machinery assignment, area coverage and route and path planning, should be distributed efficiently in terms of the balance between communication and computational requirements utilizing both the a priory information provided by the centralized GIS system as well as the updated information of the local sensing measures.

REFERENCES

Bochtis D.D., and C.G. Sørensen. 2009. The vehicle routing problem in field logistics Part I. Biosystems Engineering, 104(4), 447-457.

Bochtis D.D., and C.G. Sørensen. 2010. The vehicle routing problem in field logistics: Part II. Biosystems Engineering, 105(2), 180-188.

Checkland, P. B. 1988. Information-Systems and Systems Thinking - Time to Unite. International Journal of Information Management.8 (4), 239-248.

Checkland, P. and J. Scholes. 1999. Soft Systems Methodology in Action, John Wiley & Sons Ltd, Chichester.

Crainic, T. G. and G. Laporte. 1998. Fleet Management and Logistics, Springer, 1998, pp. 251

Fink, A. and J. Kosecoff. 1998. How to Conduct Surveys: A Step-by-Step Guide. Sage Publications, Thousand Oaks, USA

Gelb, E. And A. Offer (Eds.). 2005. ICT in Agriculture: Perspectives of Technological innovation. E-book samengesteld onder de auspiciën van, en gesteund door de European Federation for Information Technologies in Agriculture, Food and the Environment (EFITA) en het Samuel Neaman Institute for Advanced Studies in Science and Technology.

Giaglis G.M., I. Minis, A. Tatarakis, and V. Zeimpekis. 2004. Minimizing logistics risk through real-time vehicle routing and mobile technologies, International Journal of Physical Distribution & Logistics Management Vol. 34 No. 9, pp. 749-764.

Kasimin, H. and M. Yusoff. 1996. The use of a soft systems approach in developing information systems for development planning: An exploration in regional planning. Computers, Environment and Urban Systems. 20, 165-180.

Lohr, S. 1999. Sampling: Design and Analysis. Duxbury Press,, USA

Macadam, R., I. Britton, D. Russell, W. Potts, B. Baillie, and A. Shaw. 1990. The use of soft systems methodology to improve the adoption by Australian cotton growers of the siratac computer-based crop management system. Agricultural Systems. 34, 1-14.

Mele, J. 2005. Fleet Management Systems: The future is here. Fleet Owner, August 1, 2005

Palmer, R. J. D. Wild, and K. Runtz. 2003. Improving the Efficiency of Field Operations. Biosystems Engineering (2003) 84(3), 283-288

Søgaard, H. T. and C.G. Sørensen. 2004. A model for optimal selection of machinery sizes within the farm machinery system. *Biosystems Engineering* 89(1), 13-28.

Sørensen, C. G. 2003. A Model of Field Machinery Capability and Logistics: the Case of Manure Application. Agricultural Engineering International: *The CIGR Journal of AE Scientific Research and Development*, Vol 5, ISSN 1682-1130

Sørensen, C. G. and V. Nielsen. 2005. Operational Analyses and Model Comparison of Machinery Systems for Reduced Tillage. *Biosystems Engineering*, 92(2): 143-155

Wilson, B. 2001. Soft Systems Methodology. John Wiley & Sons Ltd.

Witney, B. 1988. Choosing & using farm machines. Longman Scientific & Technical, England, 412 pp.