Netherlands Journal of Agricultural Science 45 (1997) 219-228

Simulation and optimization of the logistics of biomass fuel collection

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Received 23 September 1996, accepted 21 March 1997

Abstract

Biomass is a renewable energy source which gains an increasing interest. The costs depend for a great part on the costs of the logistics of biomass fuel collection. The logistics, including the pre-treatments, from source locations to the energy plant can be modelled by means of a network structure. Nodes correspond with source locations, collection sites, transshipment sites, pre-treatment sites or the energy plant and arcs correspond with transport. Two models have been developed to gain insight into the costs and energy consumption of the logistics: a simulation model and an optimization model. Both models are described, together with some results of an example, and the differences are discussed. The model choice depends mostly on the objectives of the user.

Keywords: biomass, logistics, models, simulation, optimization

Introduction

Biomass is a renewable energy source which can be used as fuel in energy plants. Interest in biomass as an energy source is increasing for several reasons. The use of biomass is CO_2 neutral and therefore does not contribute to global warming. It is an alternative for fossil fuels (with limited resources) and as an energy crop it is an alternative for arable farmers. Several types of biomass can be distinguished: rest-products (like demolition wood and waste paper), agricultural by-products (like straw and tops) and energy crops (like willow, poplar and miscanthus).

In The Netherlands there are plans for energy plants fed with biomass. The costs for biomass as a fuel are divided into three parts: the purchase prize, the logistic costs for the collection, and the costs for establishing and running the energy plant. The costs of the logistics of the biomass fuel collection may determine for a major part the feasibility of these plans, especially when the purchase prize is low as may be expected when rest-products or by-products are used. The logistics, which include transport, storage, handling and pre-treatment can be set up in many ways. Thus, it is difficult to estimate the logistical costs. Two models have been developed to gain insight into these costs: a simulation model and an optimization model. The models and some results are described in this paper.

Literature on network flows, modelling logistics and facility location problems is extensive. On this topic, books and survey articles have been published (Ahuja *et al.*, 1993; Sussams, 1992; Aikens, 1985). Literature on models for biomass logistics is less extensive.

Simulation models are described in Mantovani & Gibson (1992) of the harvest and transport of maize residues, low-quality hay and wood chips to a biomass conversion plant. Comparisons of systems for collecting, processing, storing and transporting biomass (field crop residues, orchard prunings and forest slash) to be used in energy systems are made in Jenkins *et al.* (1984). A logistical model for the harvest of Miscanthus, with special emphasis on workability, is described in Huisman (1994). The total logistical chain is considered in Becher & Kaltschmitt (1994), where logistical chains for biomass are analysed according to labour requirements. A simulation model for the biomass logistics is described in the next section.

Optimization of biomass logistics can be carried out by using dynamic programming (DP). A DP approach to optimize the harvest (and the resulting inventory policy) in a model consisting of a plantation, a harvest and a manufacturing component is described in Grado & Strauss (1995). DP is also used in Jenkins & Arthur (1983) to select biomass utilization options. Optimization with mixed integer linear programming to minimize the costs for the logistics is described in the next section.

Material and methods

Network structure

The biomass fuel collection is a logistical process consisting of flows originating in source locations directed towards the energy plant. There can be direct transport or transport via collection, pre-treatment or transshipment sites. The logistics of the collection include transport, storage, handling and pre-treatment. These can be modelled by a network structure (see Figure 1). A node corresponds with a location and an arc with transport. Usually there are three transport options: road, water or rail transport. The arcs in Figure 1 show the possibilities for biomass to get from the source location to the energy plant.

Nodes can correspond with:
- a source location, where biomass becomes available;
- a collection site, where biomass from several source locations is collected;
- a transshipment site, needed when different kinds of transport means are used;
- a pre-treatment site, included in case of more complex pre-treatments, like pelleting of waste paper;
- the energy plant, the target location for all biomass.

Pre-treatments, like size reduction and drying of biomass, are involved to improve

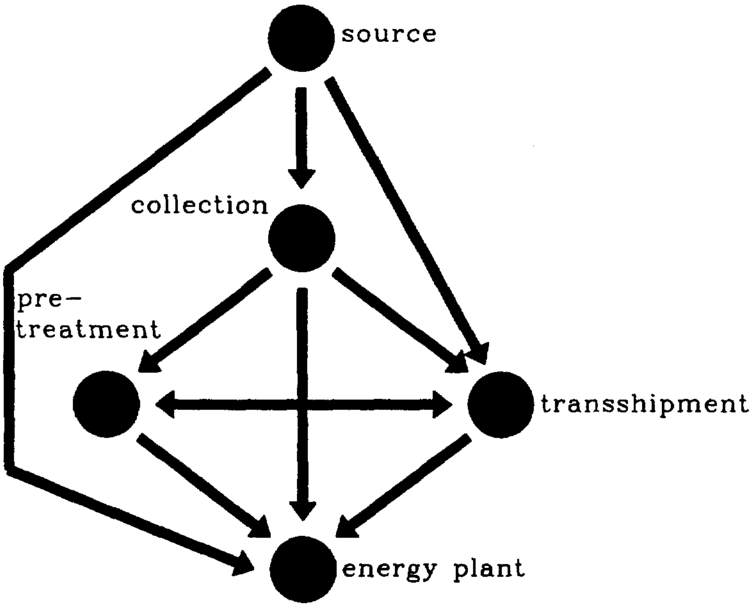

Figure 1. Network structure of the logistics of biomass fuel collection.

transport and storage characteristics or when the biomass characteristics do not correspond with the requirements set by the energy plant. Pre-treatments are possible in every type of node, a separate pre-treatment site is included only when specialized equipment is needed that can not be placed at all locations in the logistic chain.

Like other agricultural products, biomass may have losses during storage. These can have positive effects (moisture losses) or negative effects (dry matter losses). The losses have influence on the logistics, for example: the total flow to the energy plant may be less than the total flows originating from the source locations, the actual weight depends on the storage period.

All data concerning possible network structures are stored in a database. A user-friendly interface has been developed to work with these data. The network structures are divided into cases with variants. A case can for example be an energy plant fed with forest thinnings. Variants of this case may have different transport means, locations of the energy plant or involved pre-treatments. The interface has been developed with the DataBase Management System DataFlex (Anonymous, 1988). All items of a network structure can be changed successively: biomass types, pre-treatments, nodes, transport means and arcs. It is also possible to check the network structure for consistency. All data of a case or variant can be transferred to the simulation or optimization model by writing them to ASCII files (see Figure 2).

The simulation model

The simulation model Biologics (BIOmass LOGIstics Computer Simulation) has

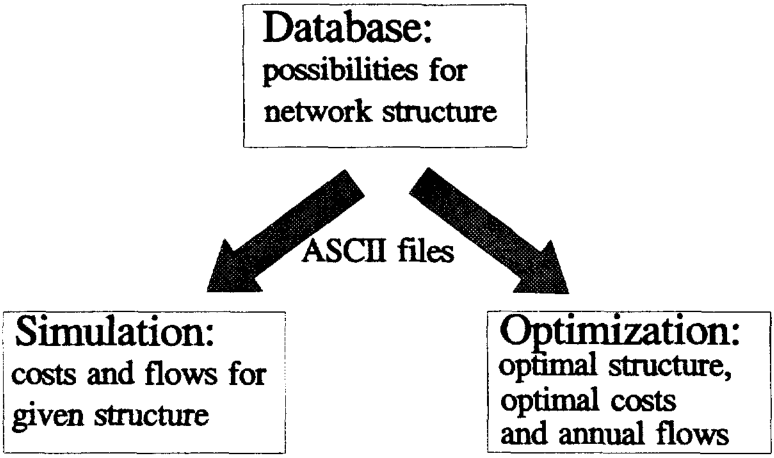

Figure 2. Relationship between database and simulation and optimzation model.

been developed to calculate the costs and energy consumption of the biomass logistics. Energy consumption is included to be able to judge the energy balance of the biomass utilization. This model is implemented with the simulation package PROSIM (Anonymous, 1993). The biomass flows during a certain time period (mostly a year) are simulated and the results are used to calculate the cost figures of a variant.

Input for Biologics is a network structure with all relevant parameters. These parameters can be costs figures (e.g. transport costs per km), but also capacities or parameters describing the storage losses or seasonalities in supply or demand. Files with all input data originate from the database (Figure 2).

For the simulation, the biomass in the network is divided into lots. Each lot is followed on its way through the network from source location to energy plant. Results, like costs, energy consumption, losses, are calculated for each lot and are totalized as cumulatives during the simulation. Each load for transport consists of an integer number of lots, this can be one for a truck load and more for transport means with a greater capacity.

The biomass flows are based on a pull model. The demand of the energy plant activates flows of lots in the network. News lots are ordered when the stock in the energy plant gets below a threshold (taking a safety stock into account). New lots are ordered in a preceding node in the network. The preceding node with the greatest stock is selected. The ordering rule is further based upon the 'fifo' principle (first in, first out) which implies that older lots are selected first for transport.

The ordering of biomass to the energy plant can lead to a chain reaction of flows in the network up to the source locations, because other nodes also order in one of their preceding nodes when their stock gets below a threshold. Each collection site, transshipment site or pre-treatment site will keep the stock at a certain level to be prepared for transports needed for orders from following nodes in the network. This is only possible when preceding nodes have enough stock available. Biomass at source locations is available for following nodes.

The characteristics of the biomass lots that are taken from a stock may have changed during storage, losses of dry matter, moisture or calorific value are taken into account.

The main results of the simulation model Biologics are:

- input and output of biomass (tonnes, tonnes of dry-matter) and calorific value;
- costs (total and per tonne dry-matter) with a sub-division into costs for transport, for pre-treatment and for handling;
- energy consumption (total and per tonne dry-matter) with a sub-division into energy consumption for transport, for pre-treatment and for handling;
- number of transports to the energy plant.

More detailed results, like stocks during the simulation period or number of transport or pre-treatment equipment needed, are also available after the simulation.

The optimization model

An optimization model has been developed in a follow-up research (Jogems *et al.*, 1996). It is used to optimize both the network structure: inclusion/exclusion of possible nodes, situation of pre-treatment; and the mixture of biomass types supplied to the energy plant, given the available quantities as a restriction.

A mixed-integer linear programming (MIP) model gives the annual flows of biomass with minimal costs. This MIP model is divided into three sub-models, each restricted to biomass types with certain pre-treatment options:
Sub-model 1: biomass flows without pre-treatments, e.g. prunings or waste wood;
Sub-model 2: biomass flows with pre-treatments in a separate pre-treatment site, e.g. waste paper with pelleting in a pelleting factory as pre-treatment;
Sub-model 3: biomass flows with pre-treatments possible in every node, e.g. chipping of thinnings.

Within each sub-model the binary variables show whether or not a site for an energy plant is chosen in the optimal solution, and whether or not a pre-treatment is chosen at a site. Continuous variables are related to biomass flows in the network. The optimization function is built up from the costs of biomass flows (variable costs) and fixed costs related to pre-treatments:

$$\min\{cx + dy : Ax + By \leq b\} \tag{1}$$

In equation (1) x denotes a non-negative vector and y an integer vector with 0-1 elements. Each element of x corresponds with the biomass flow of a biomass type along an arc during a period. Each element of y is a binary decision variable reflecting wether or not a potential location for the plant, or a pre-treatment option at a node, is used.

The objective function reflects the costs of transport, pre-treatment and handling (components of c) and fixed costs for decisions (components of d).

The restrictions on x and y in equation (1) reflect:

- the restrictions on supply in each source location and on demand of the energy plant;
- the mass balances for each collection, pre-treatment or transshipment site;

- the limitation that only one of the possible energy plants may be chosen;
- the possibilities of flows in case of pre-treatments as defined by the binary variables (only in Sub-model 2 and 3).

The overall problem was too big to solve with the available version of the MIP package OMP (Anonymous, 1994). Therefore it was solved by integrating the sub-problems into a knapsack model. This is possible because each sub-model is restricted to different non-overlapping groups of biomass types. The total input of the energy plant is a mixture of the three sub-models. A knapsack model is used to determine the contribution of each sub-model to the total input.

This is depicted in Figure 3: solutions for each sub-model are calculated with the demand for the sub-model being a percentage of the total demand. These solutions give the optimal structure when a sub-model fulfils 0%, 10% ... 100% of the total capacity. The knapsack model determines the optimal combination of solutions from sub-models for the total capacity. This method gives a good approximation with minor efforts.

Differences between simulation and optimization model

Both the simulation and the optimization model are directed to the logistics of biomass fuel collection. They use the same data which are stored in a database (Figure 2). There are some major differences:

The simulation model assumes a given network structure, the optimization model calculates the optimal network structure.

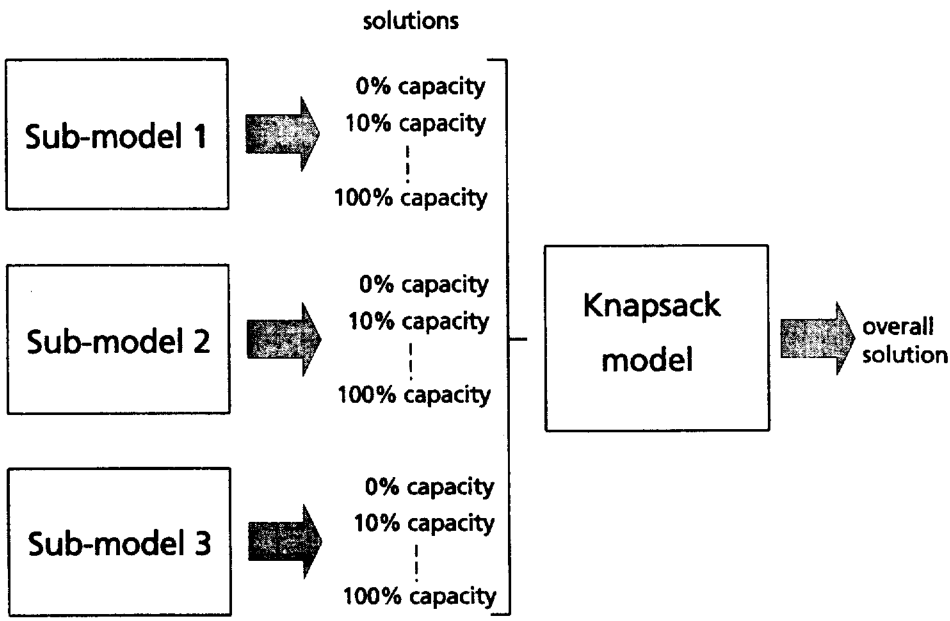

Figure 3. Relationship between sub-models and knapsack model.

The simulation model takes dry-matter and moisture losses into account. This is possible because the actual transports are simulated. The optimization model does not include these effects, because it only gives the annual flows.

The simulation model shows the flows in the course of time, it is difficult to include time-dependent effects (like storage balances) in the optimization model.

The energy consumption for the collection is included in the simulation, but excluded in the optimization.

The model choice depends mostly on the objectives of the user. Some of these differences may disappear by model adaptations. But it will not be possible to take away all differences. Typical elements of the simulation model like losses during storage or seasonal fluctuations in supply or demand can only be approximated by the optimization model. Optimization of the logistics structure is difficult with the simulation model, only comparison of pre-defined structures is possible.

Results

An energy plant fed with biomass is planned in the province of North-Holland in the Netherlands. There are several degrees of freedom for the realization of this plant:

- biomass types: thinnings and restwood, prunings, waste wood, sewage sludge or waste paper;
- transport means: road, rail or water transport;
- pre-treatment of biomass: particle size reduction, drying;
- location of the energy plant: four possibilities are given.

Both the simulation model as well as the optimization model have been used to get insight into the logistics of biomass fuel collection for this plant.

The simulation model

Five cases have been taken in the simulation model, each case corresponds with one biomass type. For each case several variants have been examined which differ in location of the energy plant, and transport means or pre-treatment involved. The number of variants per case varies from 12 (4 locations, 3 transport means, no pre-treatments) to 36 (3 additional options for pre-treatment). Calculating the results for all variants shows the effects of choices. For each case all variants were compared with a base variant; the results of the base variants of each case are given in Figure 4. Cases with pre-treatments involved (thinnings and waste paper) give the highest costs and energy consumption. Waste paper gives high costs because pelleting in the pelleting factory (as is assumed in the base variant) is expensive. A cheaper alternative is pelleting in the energy plant.

Some of the conclusions that can be drawn by comparing the variants are (Feenstra *et al.*, 1995):

- a central location for the energy plant results in the lowest costs;
- road transport is the cheapest option on shorter distances, water transport is an alternative on longer distances;

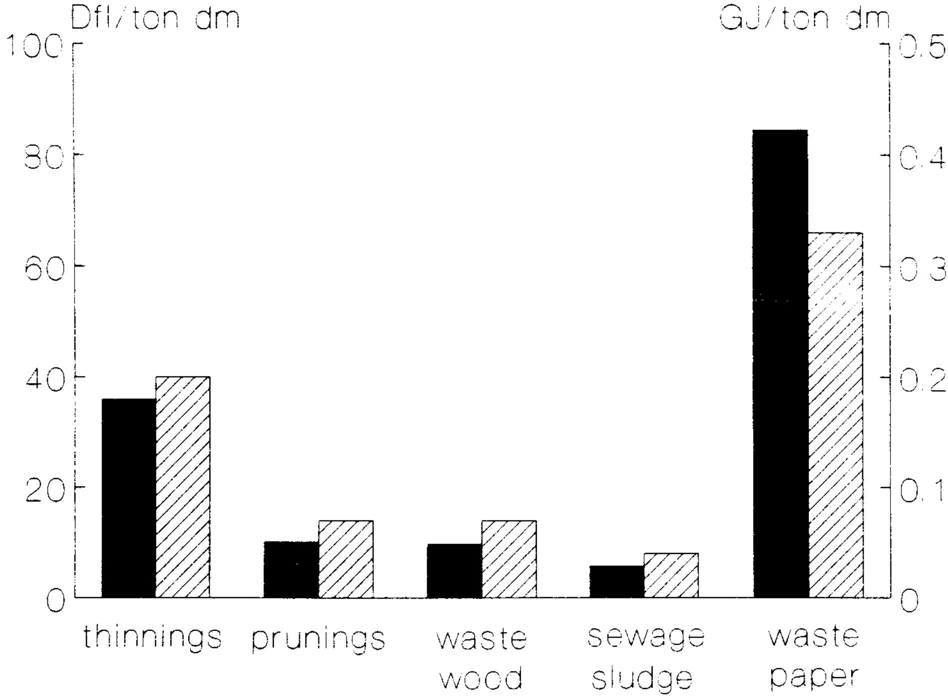

Figure 4. The costs (solid blocks) and energy consumption (striped) of the logistics of biomass fuel collection for different biomass types in North-Holland.

- chipping can best be done at the energy plant, drying at the lower landing reduces the costs and energy consumption;
- the costs and energy consumption due to the logistics may be a major part of the costs for biomass fuels.

Another application of the simulation model can be found in Gigler *et al.* (1996).

The optimization model

Combining biomass types is possible in the optimization model. The optimal network structure and mixture of biomass types is determined. The same variants as for the simulation are given as input for the optimization model. First, the solution of each sub-model was calculated, the problem sizes are given in Table 1.

The solutions of the sub-models are used in the knapsack model to get a overall solution. This was done successively for each location of the energy plant. The total results as determined by the knapsack model are given in Table 2.

Location C for the energy plant gives the lowest total costs (slightly less than Location A). Sub-model 3 is excluded in each case the demand is mostly fulfilled with biomass types included in Sub-model 1 and partly with biomass types included in Sub-model 2. This means that in the optimal solution prunings, waste-wood,

Table 1. Problem size and calculation time in OMP for each sub-model of the optimization model.

	Sub-model 1	Sub-model 2	Sub-model 3
Number of continuous varables	784	480	4256
Number of binary variables	4	6	43
Calculation time MIP (sec)	13	1	13

Table 2. Used capacities of each sub-model and total optimal costs and for each possible location of the energy plant.

Location of energy plant	Capacity of Sub-model 1 (%)	Capacity of Sub-model 2 (%)	Capacity of Sub-model 3 (%)	Optimum Logistical costs [NLG]
A	80	20	0	1,618,497
B	80	20	0	2,714,572
C	80	20	0	1,617,656
D	80	20	0	1,687,619

sewage sludge and waste paper (pelleted in the energy plant) are used as fuels. Thinnings are excluded, because of the high pre-treatment costs.

The results of the optimization model lead to the following conclusions:

- the optimal location is one centrally located, other central locations give only a small increase in costs;
- transport is a mixture of road transport (shorter distances) and water transport (longer distances);
- chipping is done at the energy plant;
- only biomass types that are free are used in the optimal solution.

Discussion

Both the simulation model and the optimization model can be used to gain insight into the costs of the logistics of biomass fuel collection. These figures are needed to be able to judge the feasibility of plans for energy plants fed with biomass, because the logistics costs are a major cost component. The logistics costs are also needed to judge plans for the introduction of energy crops as an alternative for arable farmers.

Although there are differences between the models, the conclusions drawn from the results of the simulation model are comparable to those of the optimization model. Model adaptations should decrease the influence of these model differences. The use of a mixture of biomass types should be possible in the simulation model. The optimization model should take energy consumption into account (multiple criteria optimization), as well as losses during storage. The losses can be estimated when the storage period is known, the number of periods (now four quarters) should increase and inventory equations are needed to model storage in a node longer than one period.

These adaptions can reduce the differences but the results will never be exactly the same. The optimization model can be used to select the best network structure or the optimal mixture of biomass types. It may be used for decisions on the strategic level. The simulation model will be preferred when the network structure is fixed or when only a small number of possibilities is taken into account. Simulation gives more detailed results on the biomass logistics. These can be useful for tactical decisions. Further detailing of the simulation model can also make it applicable for operational decisions.

The model choice depends on the objectives of the user. Practical experiences sofar show a preference for the simulation model. It is easy to understand and the results appear to be useful for the users.

References

Ahuja, R.K., T.L. Magnanti, & J.B. Orlin, 1993. Network flows: theory, algorithms, and applications. Prentice Hall, Englewood Cliffs,, 846 pp.

Aikens, C.H., 1985. Facility location models for distribution planning. *European Journal of Operational Research* 22: 263–279.

Anonymous, 1988. The DataFlex user's guide (Revision 2.3). Data Access Corporation, Miami, 538 pp.

Anonymous, 1993. PROSIM user guide. Sierenberg & De Gans bv, Waddinxveen, 134 pp.

Anonymous, 1994. OMP-Manual. Beyers Innovative Software N.V., Brasschaat, 363 pp.

Becher S. & M. Kaltschmitt, 1994. Logistic chains of solid biomass – classification and chain analysis. In: Ph. Chartier, A.A.C.M. Beenackers & G. Grassi (Eds.), Biomass for energy, environment, agriculture and industry, Proceedings of the 8th European Biomass Conference. Pergamon, Oxford, pp. 401–408.

Feenstra, F., J.K. Gigler, R.M. De Mol & A.H. Bosma, 1995. Logistics of the collection of biomass (In Dutch). IMAG-DLO, Wageningen, Report 95–3, 44 pp.

Gigler, J.K., R.M. De Mol & A.P.W.M. Curvers, 1996. Logistics of biomass fuel collection. To be published in Proceedings of the 9th European Bioenergy Conference, 6 pp.

Grado, S.C., & C.H. Strauss, 1995. Using an inventory control model to establish biomass harvesting policies. Solar Energy 54: 3–11.

Huisman, W., 1994. Logistics of harvest of *Miscanthus sinensis* Giganteus. In: Ph. Chartier, A.A.C.M. Beenackers & G. Grassi (Eds.), Biomass for energy, environment, agriculture and industry. Proceedings of the 8th European Biomass Conference. Pergamon, Oxford, pp. 361–371.

Jenkins, B.M., & J.F. Arthur, 1983. Assessing biomass utilization options through network analysis. *Transactions of the American Society of Agricultural Engineers* 26(5), 1557–1560.

Jenkins, B.M., J.F. Arthur, G.E. Miller, & P.S. Parsons, 1984. Logistics and economics of biomass utilization. *Transactions of the American Society of Agricultural Engineers* 27(6). 1898–1904, 1910.

Jogems, M.A.H., R.M. De Mol & P. Van Beek, 1996. Optimization of the collection and pre-treatment of biomass as an energy source. *European Journal of Operational Research* (submitted).

Mantovani, B. & H. Gibson, 1992. A simulation model for analysis of harvesting and transport costs for biomass based on geography, density and plant location. In: R.M. Peart & R.C. Brook (Eds.), Analysis of agricultural energy systems. Energy in world agriculture, Vol. 5. Elsevier, Amsterdam, 253–280.

Sussams, J.E., 1992. Logistics Modelling, Pitman Publishing, London, 200 pp.

Editor's acknowledgement

In 1996, the persons listed below have served the Netherlands Journal of Agricultural Science by refereeing one or more submitted manuscripts. They are highly commended for their contribution to the maintenance of the scientific standard of our journal. On behalf of the Editorial Board, I thank them all.

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