APPLICATION OF MULTIPLE CRITERIA DECISION MAKING FOR THE DESIGN AND ANALYSIS OF GREENHOUSE CROPPING SYSTEMS

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Abstract

Greenhouse cropping systems have various objectives and can be controlled in various ways. Selection or design of an optimal cropping system requires weighing of the objectives as well as proper understanding of the input-output relations of the system. The field of Multiple Criteria Decision Making (MCDM) provides a set of mathematical techniques that may help to reach a decision in optimisation problems in which more than one objective play a role. Two examples of the use of MCDM are given. The benefit of simulation models to generate quantified production systems is shown using the model CHRYSIM for year-round chrysanthemum production. In the second example, Interactive Multiple Goal Linear Programming, an MCDM approach, is introduced and illustrated in the optimisation of water and nutrient use of rockwool-grown tomato.

1. Introduction

Modern production systems in protected cultivation should meet a broad scope of objectives from farm economic profitability and quality production to socio-political issues like minimisation of influence on environment and on human health. To realise these objectives many decisions have to be taken to control the cultivation process. Also other, less controllable or non-controllable factors are involved. Figure 1, adapted from Challa and Pluimers (1997), illustrates this from a systems perspective. The output of the system is defined as the relevant set of system features, in this case not only crop yield, but also, among others, consumption of energy. The output is determined by the system, the system control and the interference by random factors.

In figure 1 five groups of control variables are distinguished. Climate control factors are light, temperature, CO_2 concentration and humidity. Rooting environment factors are type of soil or substrate and its characteristics, such as nutrient and water availability, EC, pH, and organic matter content. Crop protection factors refer to pest and disease management (biological control or use of chemical biocides). Cultivation practices may vary among crops, such as density of planting, choice of cultivar, pruning, etc.

Multiple Criteria Decision Making (MCDM) methods can be helpful to manage the greenhouse cropping system by supplementing the (empirical) expertise of the grower with quantitative information on planned decisions and on alternatives. Aim of the paper is to discuss the possible application of MCDM techniques in greenhouse cultivation. First, MCDM techniques will be briefly discussed, followed by the presentation of a planned application in the year-round cultivation of chrysanthemum. Subsequently, Interactive Multiple Goal Linear Programming, a special case of MCDM, is introduced and its possible application in optimizing nutrient and water use in tomato cultivation will be presented.

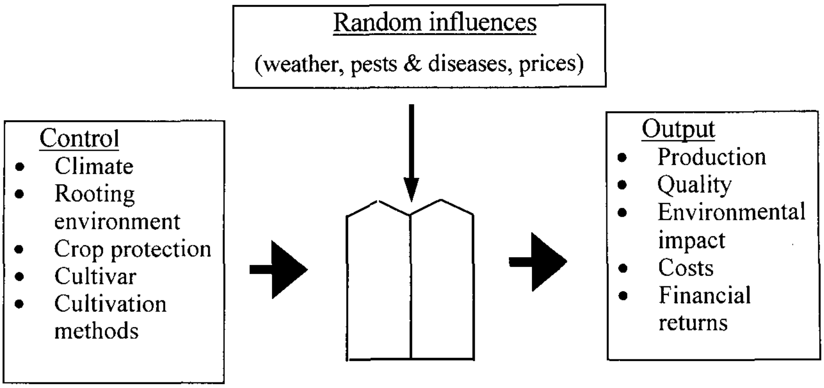

Figure 1. Schematic representation of a greenhouse cropping system

2. Multiple criteria decision making

MCDM is a branch of the Operations Research tree that develops tools that may help to explore options for choice situations in which multiple, and often conflicting, goals and objectives play a role. Such tools give decision support; they do not solve decision making problems, because this suggests that one and only one (ideal) solution exists. Moreover, it is the decision maker, not a mathematical model, that has to make the decision. Zeleny (1984) says in this respect in his preface:

> *"The alternatives of choice do not usually present themselves nicely ordered and clearly differentiated. Very rarely can we simply choose by saying: "I'll take....that one!". But as we invest more in our personal 'models' and learn more about our values, needs, and possibilities, our criteria of choice become more reliable and less confusing and we are able to make our choices with greater confidence and understanding"*

In MCDM an important term is attribute. Attributes are system features that are relevant to the overall assessment of the system. They are therefore a subset of the system output. Attributes can have target values or target value ranges attached to them. The combination of the two is then called a goal. An attribute of which the value is to be maximised or minimised is called an objective.

In MCDM a number of techniques can be distinguished. For example, iterative approaches as opposed to approaches in which all objectives get a fixed weight and in this way are turned into one single objective, that can be optimized. The choice of the most appropriate technique depends on a number of factors. Do only goals play a role in the choice situation or are there also objectives to be maximised? Is more than one stakeholder involved? Can goals be easily ranked, according to their importance? Romero and Rehman (1989) present a theoretical framework of MCDM in agriculture as well as some applications.

To apply MCDM techniques, a number of requirements have to be met. First, the consequences of system control on system output should be quantitatively described. The data comprising this quantitative description are called "technical coefficients", as they refer to the way the system works technically. The coefficients are assumed to give objective information. To generate these coefficients, databases and models can be used, that form a so called technical coefficients generator (TCG). Next, the objectives and/or targets of the cropping system should be made explicit. Furthermore, knowledge about the consequences of disturbances on system output and of their probability distributions is needed. If the latter requirement is not met, then one can still analyse the problem using average conditions.

3. CHRYSIM - a TCG for year-round cultivation of Chrysanthemum

A methodology is being developed that aims at optimisation of the control of greenhouse production systems. Year-round chrysanthemum cultivation is used as a first case. Objectives of year-round chrysanthemum can be grouped into: quality, yield, environmental impact, financial returns. Some quality aspects of cut flowers are vase life duration, form and colour of leaves and flowers. Yield is expressed as the number of cuttings per unit area per year. The duration of a crop cycle (period from planting to harvest) is therefore an important aspect of the cropping system. Environmental impact parameters are use of fossil energy, emission of greenhouse gases (CO_2), use and emission of chemical biocides, and the production of waste. As for financial returns, chrysanthemum cut flower prices at any time vary according to their quality. In a first approximation, cut flower weight is used as the only quality indicator. The product value is the sum product of the production per weight category and the corresponding prices. Although the list of objectives is not complete, it contains already many aspects that are difficult to quantify, especially those on quality.

The quantitative basis for the analysis is a simulation model, called CHRYSIM (Van de Ende, 1997). This model can therefore be considered as the TCG (figure 2). CHRYSIM is adapted from REF95 (Heuvelink, *et al.*, 1995), but in which the possibility for supplementary light explicitly is included following De Koning (1996). REF95 is a model that simulates dry matter production in a greenhouse for a reference crop, and is based in turn on SUCROS (Spitters, *et al.*, 1989) and the work of Gijzen (1994).

In CHRYSIM, CO_2 concentration and air temperature inside the greenhouse are fixed for the whole growing period. For assimilation light, strategies can be used in which every hour on the basis of natural light intensity is decided whether to switch lights on or off. Because switching on the assimilation light is expensive, the number of times this is done is a criterion for the evaluation of assimilation light strategies. At present, the model uses average light data (varying per hour and per month). Optimisation of the control of temperature, CO_2 concentration, plant density and assimilation is performed as a first step. In first instance only financial returns and energy use are regarded as the objectives to be maximised and minimised, respectively.

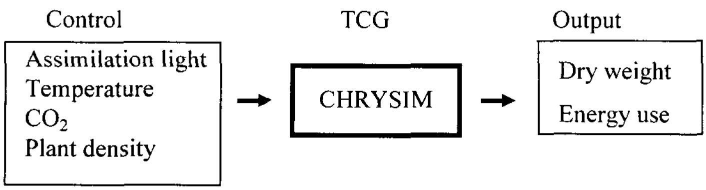

Figure 2. CHRYSIM simulation model for chrysanthemum production.

4. Interactive Multiple Goal Linear Programming

Interactive Multiple Goal Linear Programming (IMGLP) is a multiple criteria optimisation approach combined with linear programming (LP). The method has been proposed by De Wit, *et al.* (1988) for analysis and planning of regional agricultural development and applied by the Netherlands Scientific Council for Government Policy for the study of future rural land use in the European Community (WRR, 1992). It has been successfully applied at the farm level as well, e.g. to dairy farming (Van de Ven, 1996), integrated arable farming (Habekotté & Schans, 1996; Schans, 1996) and flower bulb production (Rossing, *et al.*, 1997). IMGLP uses linear programming to model the cropping system. An LP-problem consists of decision variables or activities, constraints, which determine feasible combinations of decision variables, and an objective function describing the aim of optimisation. Input-output coefficients describe the contribution of different activities to the realisation of objective and constraints. Optimisation software is used to solve the problem. In the examples mentioned above, technical coefficients generators (TCG) have been used to quantify these coefficients by means of extraction from databases or calculation using simulation.

In an IMGLP model various objective functions are defined, but in each model run only one objective function is optimised, the other objectives being used as constraints with target values or ranges put on them (goals). In the first set of runs the optimal solution for each objective is calculated with minimum targets put on the other objectives. Thus a so-called 'playing field' is obtained. Next, the goals are tightened one after the other until a 'satisfactory' solution is reached (figure 3). This iterative process is performed in interaction with the stakeholders involved (growers, policy makers, ...) and subject to the scenario and/or time horizon under examination. The process not only generates the optimal combination of activities but, more importantly, explicitizes the exchange values among objectives and demonstrates the consequences of different priorities that may be given to objectives.

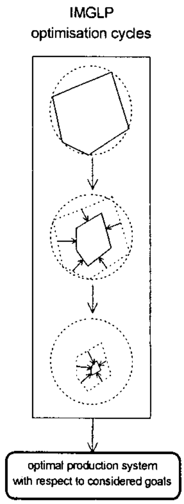

Figure 3: The IMGLP iterative process towards an optimal production system

It might help the grower in weighing his decisions in terms of objectives he wants to reach or are imposed on him.

Apart from decision support, the method can also be used in an explorative manner to search for new options for protected cultivation. The possible impact of 'futuristic' production techniques on the degree of attainment of the various objectives may be 'tested'. The method can also be applied to analyse or design new opportunities for (regional) horticultural development and to support restructuring the sector.

5. Optimisation of water and nutrient use

Greenhouse horticulture in the Netherlands is faced with strict regulations with respect to pollution of surface waters. In cultivation on substrate, recirculation of nutrient solution and storage and use of rainwater is compulsory. Drainage out of the system is only allowed when the nutrient solution has reached a crop-specific maximum sodium concentration. Soil-grown crops are subject to comparable restrictions. Other legislation and government-sector agreements demand sharp reductions in fossil energy consumption, in emission of CO_2 and in chemical crop protection. On the other hand, international competition forces the grower to aim at the highest quality produced at minimal costs. This multi-objective optimisation problem can be tackled using the

IMGLP approach because of the different stakeholders involved (grower, government policymakers, environmentalist organisations, ...) and the 'subjective' nature of the weighing of goals and targets.

A project is started that aims at the optimisation of water and nutrient management in a cropping system of rockwool-grown tomato on recirculating nutrient solution. In a later stage other 'environmental' aspects may be included. Since the variation among growers in nutrient use efficiencies and water use is found to be large, there seems to be 'scope' for optimisation. The objectives of the optimisation of the cropping system are, in addition to maximising financial result, to minimise use of water and to minimise emission of nutrients.

Decisions are made at the operational level, the tactical level and the strategic level. At the operational level important decision variables are the amount of water and nutrients to be supplied and the strength of the solution in terms of its electrical conductivity (EC). These variables not only determine the impact on the environment when drainage is required, but also crop growth rate and quality of produce. In recirculating nutrient solution some nutrients will be depleted (N), while others will accumulate (Na). Maximum/minimum nutrient concentrations and EC are to be set as constraints. Quantification of growth, production and water use and the effect of nutrients and EC on yield and fruit quality is obtained from simulation models, experimentation and expert knowledge (e.g., Gijzen, 1994; Heuvelink, *et al.*, 1995; Sonneveld & Welles, 1988; Van de Sanden & Uittien, 1995). At the tactical level crop and cultivar choice is relevant with respect to salt tolerance, i.c. the capacity to accumulate sodium (Blom-Zandstra, 1996). Planting date (earliness) is another choice to be made at this level. At the strategic level (investments in) in greenhouse size and equipment have to be considered, like the use of rainwater storage pools, different type of fertigation systems, substrate type, etc. (Van Os, *et al.*, 1991; Van Os, 1994).

Different scenarios may be distinguished that determine the context of the optimisation problem: from present day cultivation to future technological development under anticipated new legislation or from today's farm size (distribution) to a restructured sector. An uncertainty analysis should be part of the exercise, since weather data and prices are input to the problem. Output of the optimisation might be the seasonal course of EC combined with optimal planting date and optimal fertigation system.

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References

Blom-Zandstra M., 1996. Ophoping vereist andere spoelstrategie. [Accumulation requires an other strategy with respect to drainage.] Groenten + Fruit/Glasgroenten (29): 8-9.

Challa H. and Pluimers,J., 1997. Efficiënt en verantwoord produceren onder glas: Naar een bewuste synthese van doelstellingen. [Efficient and sound greenhouse crop production: Towards a conscious synthesis of objectives]. *In*: L.F.M. Marcelis & A.J. Haverkort (Eds). Kwaliteit en milieu in de glastuinbouw: stimulans tot vernieuwing. [Quality and environment in protected cultivation: incentive for innovation]. AB-DLO Thema's 4. DLO Research Institute for Agrobiology and Soil Fertility, Wageningen, pp. 109-122.

De Koning J.C.M., 1996. Voorspelling van gewasgroei in relatie tot assimilatiebelichting. [Predicting crop growth in relation to assimilation light intensity]. Internal Report. Wageningen Agricultural University, Department of Horticulture, 35 pp.

De Wit C.T., van Keulen H., Seligman N.G. and Spharim, I., 1988. Application of Interactive Multiple Goal Programming Techniques for Analysis and Planning of Regional Agricultural Development. Agricultural Systems 26: 211-230.
Gijzen H., 1994. Ontwikkeling van een simulatiemodel voor transpiratie en wateropname en van een integraal gewasmodel. [Development of a simulation model for transpiration and water uptake and of an integrated crop model]. AB-DLO report 18, Wageningen, the Netherlands, 90 pp.
Habekotté B., and Schans J., 1996. Modelmatige verkenningen van mogelijkheden voor geïntegreerde akkerbouw. [Model-based explorations of integrated arable farming]. Rapport 64. DLO Research Institute for Agrobiology and Soil Fertility, Wageningen, 68 pp.
Heuvelink E., de Koning J.C.M. and Gijzen H., 1995. REF95: A reference model for simulation of dry matter production in greenhouses. Internal Report. Wageningen Agricultural University, Department of Horticulture, 8 pp.
Romero C., and Rehman T., 1989. Multiple criteria analysis for agricultural decisions. Elsevier, Amsterdam, 257 pp.
Rossing W.A.H., Jansma J.E., de Ruijter F.J. and Schans J., 1997. Operationalizing sustainability: exploring options for environmentally friendly flower bulb production systems. European Journal of Plant Pathology 103: 217-234.
Schans J., 1996. MGOPT_CROP, a multiple goal linear programming model for optimisation of crop rotations, version 1.0. Report 69. DLO Research Institute for Agrobiology and Soil Fertility, Wageningen, 48 pp.
Sonneveld C. and Welles G.W.H., 1988. Yield and quality of rockwool-grown tomatoes as affected by variations in EC-value and climatic conditions. Plant and Soil 111: 37-42.
Spitters C.J.T., van Keulen H., and van Kraalingen D.W.G., 1989. A simple and universal crop growth simulator: SUCROS 87. *In*: R. Rabbinge, S.A. Ward & H.H. van Laar (Eds), Simulation and system management in crop protection. PUDOC, Wageningen, The Netherlands, 147-81.
Van de Ende, K., (1997). Assimilatie belichting in de jaarrond teelt van chrysanten. [Assimilation light in year-round production of chrysanthemum]. MSc thesis, Dept of Horticulture, Wageningen Agricultural University (forthcoming).
Van de Sanden,P.A.C.M., and Uittien J.J., 1995. Root environment water potential and tomato fruit growth. Acta Horticulturae 401: 531-536.
Van de Ven G.W.J., 1996. A mathematical approach to comparing environmental and economic goals in dairy farming on sandy soils in the Netherlands. Ph.D.thesis Wageningen Agricultural University, Wageningen, 239 pp.
Van Os E.A., 1994., Closed growing systems for more efficient and environmental friendly production. Acta Horticulturae 361: 194-200.
Van Os E.A., Ruijs M.N.A. and van Weel P.A., 1991. Closed business systems for less pollution from greenhouses. Acta Horticulturae 294: 49-57.
WRR [Netherlands Scientific Council for Government Policy], 1992. Ground for choices. Four perspectives for the rural areas in the European Community. Reports to the Government nr. 42, The Hague, 149 pp.
Zeleny M., 1982. Multiple Criteria Decision Making, McGraw-Hill, New York, 453 pp.