GMDH-based decision-making support for ecological processes

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Abstract. *The paper considers the issues concerning the decision-making support on the basis of GMDH modeling and qualitative assessment applied for environmental tasks in agriculture. As an example, the task of irrigation of forest plant species under different conditions was studied here for the purpose to understand behavior of the plant species and select the best irrigation conditions. This task implies four main stages of the decision-making support: 1) Stage of experimental study; 2) Stage of making the conclusion about the possibility to implement the results of study into the real-word applications; 3) Stage of the development of monitoring and control techniques; 4) Stage of implementation. The GMDH was applied to estimate different aspects of plant species behavior, provide the basis for qualitative assessment, obtain general models that describe combinations of irrigation regimes, as well as to establish the control procedures for suitable or optimum irrigation processes. Qualitative assessment was intended to facilitate clear understanding of the experimental results, easily classify different irrigation/plant species cases and identify the best ones.*

Keywords

GMDH, qualitative assessment, decision-making, environment, agriculture, irrigation, wastewater.

1 Introduction

The paper considers the issues concerning the decision-making support on the basis of GMDH modeling and qualitative assessment of environmental tasks in agriculture. Those issues stem from the necessity to convert the modeling and analysis results into the valid conclusions and implement them into real-world applications.

A number of modeling works with use of GMDH and qualitative assessment methods have been carried out to understand behavior of various agricultural and forest plant species grown under different conditions: mechanical properties of trees (axial compression and bending) depending on concentrations of chemical elements contained in wastewater [1], growth dynamics of trees irrigated with wastewater (development of tree height and mortality over time) [2, 3]. In addition, qualitative analysis techniques were applied to assess plant species behavior under different conditions: irrigation of forest species with wastewater and sludge [4], heavy metals impact on agricultural species cultivated near the highway [5, 6], etc.

For the considered area, there are four main stages for which the decision-making support is required:

1) Stage of experimental study. This stage (design of experiments, planting of species, measurements, data processing and analysis) is a multiphase process due to complex nature of ecological interactions and slow growth of plant species. Design of the next-phase experiments implies making the decisions about what kind of experiments shall be carried out to decrease the degree of uncertainty of currently available results. In addition, at each phase, reliability and completeness of the experimental results shall be considered to make decision whether to continue the experiments or stop them.

2) Stage of making the conclusion: if the results of experimental study are successful or not, i.e. if it is possible to implement them into the real-word applications or not.

3) Stage of the development of monitoring and control techniques. At this stage, the decisions shall be made about what monitoring and control techniques to be used in a real-world application, are the most suitable.

4) Stage of implementation. At this stage, the decisions shall be made if it is reasonable to apply the results to the specific area.

Some of those issues are discussed in the paper on the example of the following task: irrigation of four forest trees species with five irrigation regimes applied for each tree species [4]. Here, the decision-making process implies three main steps:

1) Define the criteria of acceptability and suitability (optimum) in order to evaluate different cases (tree species and irrigation regimes);

2) Select a subset of the acceptable cases;

3) Within the subset of the acceptable cases, select the most appropriate (optimum) case(s), according to the criteria.

Two criteria, the mortality rates and height growth of trees, were chosen here as the criteria to select the acceptable cases and make the decision on the best appropriate cases. Five irrigation regimes are different combinations of normal irrigation water, wastewater, and sludge.

The GMDH method has been applied to obtain individual models for each tree species and irrigation regime. The models have been used to qualitatively in terms of High, Medium, Low) assess each case, select the subset of acceptable cases, and rank them according to the stated criteria. This approach makes it possible to select the best case to apply, make decision about "good/bad" trees for different irrigation conditions, etc.

2 Experiments and methods

Four forest species (*Cupressus Arizonica Green*, *Cotoneaster Integerrimus Med.*, *Pinus Halepensis Mill.*, and *Pinus Pinea L.*) were cultivated in the greenhouse in Agrinion area, Greece, and irrigated under five different irrigation regimes.

Wastewater for irrigation and sludge for fertilization were used from the Wastewater Treatment Plant. Sludge was used during the planting phase inside the plastic bags in a percentage of 20 % of the substratum (80% soil and 20 % sludge).

In order to examine the impact of wastewater and sludge on various aspects of tree growth, the experiments were designed with five irrigation regimes (treatment cases). They are as follows:

Treatment case 1: Irrigation with control (irrigation) water only (*CW*)

Treatment case 2: Irrigation with control and waste water (*CWW*)

Treatment case 3: Irrigation with waste water and application of sludge (*SWW*)

Treatment case 4: Irrigation with control water and application of sludge (*SCW*)

Treatment case 5: Irrigation with waste water and application of 20% diluted sludge (*SCW20*)

The criteria of acceptability, suitability. From the forestry point of view, the following aspects were monitored: height growth, mortality rates, impacts of the different treatments on soil, impacts of the different treatments on flora, silvicultural issues (roots and crown development), and assimilation behavior of the plant for different chemical elements. As an example, we will take here the mortality rates and height growth of trees as the criteria to select the acceptable cases and make the decision on the best appropriate cases.

Design of estimation models. For the criteria of tree growth and mortality, estimation models based on COMBI algorithm were obtained, and a technique of qualitative assessment of these characteristics was proposed. With only 3 time points of measurements, at this stage we will use the simplest linear models for preliminary rough estimation of tree growth. We need to structure the problem in such a way that we could obtain explicit estimations of growth characteristics for each tree species irrigated under different treatment cases, over the measurement period. Therefore, it is reasonable to design individual models for each tree/treatment case, and further analyze and compare individual models by qualitative assessment. The example of estimation for *Cupressus Arizonica* (*CW* case, height growth) is:

$$y(t)=-17.833+49.650*t \tag{1}$$

where the input variable (t) is the growth time, and output variable is the height growth.

Total number of obtained linear models for tree height estimated with COMBI, is 20: number of tree species x number of treatment cases.

Qualitative assessment. The purpose of qualitative assessment is to facilitate reasoning about dependencies between input and output variables. The variables take a form of qualitative features meaningful for the investigator (low or high value, increase or decrease, etc.). Therefore, it is required to extract qualitative features of output variables, classify them and associate with those of input variables in a manner enabling efficient assessment of dependencies.

Since the results of represented experiments reflect the early stage of investigations, we will make a rough qualitative assessment of trees behavior, by partitioning the range space of output variables into crisp intervals, proceed from the experience of agricultural specialists. For example, in case of *Cupressus Arizonica*, the range of height values is partitioned into three equal intervals, [0,60], [61,80], and [>81], with respectively assigned qualitative values Low, Medium, and High. The range of mortality values can be partitioned in a similar way. Proceed from the experience, the mortality below 30% can be considered as the allowable one, and unallowable otherwise. Therefore, we will partition the range of mortality values into two crisp intervals, up to 30% and above 30%, and assign them qualitative values Low and High respectively.

Let us make qualitative assessments of trees grown under each treatment case, where G is height growth, R is mortality rate, H is High, M is Medium and L is Low. Below is the example of qualitative description for the behavior of *Cupressus Arizonica* irrigated with Control Water, given over the whole measurement period $t = \{t_1 = \text{June}, t_2 = \text{October}, (t_3 = \text{December}\}$:

$$t_1\text{: (G=L)^(R=L); } t_2 \text{ : (G=M)^(R=L); } t_3\text{: (G=H)^(R=L)} \quad (2)$$

Let us make qualitative descriptions of the measurement results obtained at the end of measurement period (t_3), in order to qualitatively assess and make the decisions about final results of experiments. The total set of possible cases is below:

Cupressus Arizonica: *CW*:(G=H)^(R=L); *CWW*:(G=H)^(R=L); *SWW*:(G=H)^(R=H); *SCW*:(G=H)^(R=L); *SCW20*: (G=H)^(R=H);

Cotoneaster Integerrimus: *CW*:(G=M)^(R=L); *CWW*:(G=H)^(R=L); *SWW*:(G=H) ^(R=H); *SCW*:(G=H)^(R=H); *SCW20*:(G=H)^(R=H);

Pinus Halepensis: *CW*:(G=H)^(R=H); *CWW*:(G=H)^(R=H); *SWW*:(G=H)^(R=H); *SCW*:(G=H)^(R=H); *SCW20*:(G=H)^(R=H);

Pinus Pinea: *CW*:(G=M)^(R=L); *CWW*:(G=M)^(R=L); *SWW*:(G=H)^(R=H); *SCW*:(G=H)^(R=H); *SCW20*:(G=H)^(R=H).

Select now the subset of acceptable cases, taking the high mortality rates as unacceptable ones (i.e., excluding the items with the R=H term):

Cupressus Arizonica: *CW*:(G=H)^(R=L); *CWW*:(G=H)^(R=L); *SCW*:(G=H)^(R=L);

Cotoneaster Integerrimus: *CW*:(G=M)^(R=L); *CWW*:(G=H)^(R=L);

Pinus Pinea: *CW*:(G=M)^(R=L); *CWW*:(G=M)^(R=L).

As we can see, *Pinus Halepensis* has been excluded from the list due to high mortality rates for all treatment cases.

Decision-making on suitable and best cases. In order to provide more comprehensive ranking to make decisions about suitability of the remaining cases, let us rank the combinations of qualitative values of output variables, as follows: {(G=H)^(R=L)}=+3; {(G=M)^(R=L)}=+2; {(G= L)^(R=L)}=+1; {(G=H)^(R=H)}=-1; {(G=M)^(R=H)}=-2; {(G= L)^(R=H)}=-3.

Proceed from the ranking values above, we can rank the trees/treatment cases, e.g., by simple summation of ranking values for different cases. Therefore, the total ranking value for all acceptable cases of trees is the following: *Cupressus Arizonica*: +9; *Cotoneaster Integerrimus*: +5; *Pinus Pinea*: +4.

In a similar way, the total ranking value for all acceptable cases of treatments is the following: *CWW*: +8; *CW*: +7; *SCW*: +3. Therefore, the most stable tree for different treatments is *Cupressus Arizonica*, while combination of control and waste water is the most suitable irrigation source.

For the combined assessment tree/treatment, the best options ((G=H)^(R=L)) are *Cupressus Arizonica* with treatments "control water", "control and waste water", and "control water + sludge"; and *Cotoneaster Integerrimus* with treatment "control and waste water".

Stage of the development of monitoring and control techniques. At this stage, the best selected options shall be considered as a process. Each step of the process shall be analyzed to decide what monitoring and control techniques would be used to provide the final results. In addition, application of different irrigation cases at different steps could be considered at this stage. This extends the basis of solutions to find more efficient irrigation regimes not considered directly at the stage of experimental study. For example, the combined irrigation "control and waste water" was applied with some constant ratio control/waste water. Each individual irrigation case is associated with constant values of concentrations of chemical elements in the control or waste water. The technique of merging two models into a general model [3] allows us to obtain a model that describes the growth dynamics at varying chemical content of irrigation water with different proportions of control and waste water. In order to build the general model, we shall associate the models of individual irrigation cases with some indices *Q(t)* of water content. This would enable us to make the explicit assessment of the effect of water quality on tree growth characteristics, as well as to solve optimum value of water content maximizing the tree species growth by a given criterion. Then, by optimal irrigation condition we will understand such *Q(t)* that maximizes "tree height" while minimizes "tree mortality". Hence, the general merged models can be used to find optimal irrigation conditions.

This stage may require carrying out the additional experiments to verify the control modeling results and ensure reliable control techniques.

Stage of implementation. At this stage, the decisions shall be made if it is reasonable to apply the results to a specific area. Here, the analysis shall be carried out how successfully the experimental and modeling results can be adapted for a specific area, in what extent the environmental and other conditions are similar to those at the experimental plot, etc.

3 Conclusion

The purpose of the paper was to analyze the possibilities and advantages of GMDH and qualitative assessment techniques to provide the basis for decision-making support in the field of complex environmental tasks in agriculture. Four main stages of decision-making support were considered.

The GMDH was applied to estimate different aspects of plant species behavior, provide the basis for qualitative assessment, obtain general models that describe combinations of irrigation regimes, as well as to establish the control procedures for suitable or optimum irrigation processes. Qualitative assessment was intended to facilitate clear understanding of the experimental results, easily classify different irrigation/plant species cases and identify the best ones.

In general, the application of GMDH-methods together with deductive qualitative assessment techniques provides a consistent basis for the development of integrated tools intended to cover the modeling, analysis, and decision-making tasks in the field of environment and agriculture.

References

[1] Kalavrouziotis I. K., Stepashko V. S., Vissikirsky V. A., Drakatos P.A.: Group Method of Data Handling (GMDH) application for modelling of mechanical properties of trees irrigated with wastewater. *International Journal of Environment and Pollution,* p. 589-601, 18 (6), 2002.

[2] Kalavrouziotis I. K., Stepashko V. S., Vissikirsky V. A., Drakatos P.A.: Group Method of Data Handling (GMDH) in modelling of growth dynamics of tress irrigated with wastewater. *International Journal of Environment and Pollution*, p. 350-364, 21 (4), 2004.

[3] Vissikirsky V.A., Stepashko V.S., Kalavrouziotis I.K., Drakatos P.A.: Growth Dynamics of trees Irrigated with wastewater: GMDH Modeling, Assessment and Control Issues. *Instrumentation Science and Technology,* p. 229-249, 33 (2), 2005.

[4] Kalavrouziotis I. K., Pantazis V. N., Vissikirsky V. A., Stepashko, V. S.: Irrigation of Forest Species with Wastewater and Sludge: Experiments, Modeling, and Qualitative Assessment, *Instrumentation Science and Technology,* p. 727–742, 34, 2006.

[5] Vissikirsky V.A., Stepashko V.S., Kalavrouziotis I.K., Varnavas S.P.: The Road Pollution Impact on Zea mays: Inductive Modeling and Qualitative Assessment. *Water, Air & Soil Pollution*, Published online: 3 June 2008, 2008.

[6] Vissikirsky, V.A., Stepashko, V.S., Kalavrouziotis, I.K.: Application of GMDH to the Environmental Modeling with Short Samples, *Proceedings of International Workshop on Inductive Modeling (IWIM 2007), Prague, 22-26 September*, pp. 18-25, 2007.