Utilization of Fuzzy Computing in Agrophysics
(review)

D. A. Kurtener¹ & V. P. Yakushev²

¹European Agrophysical Institute, Amriswil, Switzerland
²Agrophysical Research Institute, St. Petersburg, Russia

Correspondence: D. A. Kurtener, European Agrophysical Institute, Alpenstr. 1, 8580 Amriswil, Switzerland, e-mail: dmitrykurtener@hotmail.com

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Abstract
Traditionally decision of agrophysics problems was evaluated with problem-oriented models. Utilization of fuzzy computing gives new dimension for agrophysics. It is well known that in agricultural sciences there exists much fuzzy knowledge, that is, knowledge which is vague, imprecise, uncertain, ambiguous, inexact, or probabilistic in nature. Fuzzy Computing is power tools for dealing with randomness and uncertainties. This paper reviews exploitation of fuzzy computing in agrophysics. The emphasis is on the achievements of Agrophysical Research Institute, St. Petersburg, Russia, especially in the fields of soil tillage, crop management, precision agriculture, melioration, and agricultural engineering.

Keywords: agrophysics, fuzzy computing

1. Introduction

Traditionally decision of agrophysics problems was evaluated with problem-oriented models. Application of fuzzy modeling gives new dimension for agrophysics.

It is well known that in agrophysics there exists much fuzzy knowledge, that is, knowledge which is vague, imprecise, uncertain, ambiguous, inexact, or probabilistic in nature. Fuzzy models are powerful tool for dealing with randomness and uncertainties.

Human can use such information because the human thinking and reasoning frequently involve fuzzy information, possibly originating from inherently inexact human concepts and matching of similar rather than identical experiences.

The computing systems, based upon classical set theory and two-valid logic, can not answer to some questions, as human does, because they do not have completely true answers (Chakrabort, 2010).

The fuzzy computing systems makes possible to do that. They give human like answers but also describe their reality levels. These levels calculate using imprecision and uncertainty of fact and rules that were applied.

The Fuzzy Computing can handle qualitative values instead of quantitative values. It can define the so called linguistic variables, instead of the classical numeric variables, and can perform computing with these variables, using fuzzy rules, simulating in a certain way the human reasoning processes (Caversan, 2009).

Fuzzy computing has made a great impact in capturing human domain knowledge and modeling non-linear mapping of input-output space (Chen & Mathe., 2012).

Fuzzy Computing is based on two main achievements: fuzzy set theory and fuzzy logic.

Fuzzy set theory was introduced by Lofti Zadeh (Zadeh, 1965), as an alternative approach to solve problems when the classical set theory and discrete mathematics.

In classical set theory, the membership of elements in a set is assessed in binary terms according to a bivalent condition — an element either belongs or does not belong to the set. By contrast, fuzzy set theory allows the gradual assessment of the membership of elements in a set. Herewith a membership function varies in the real unit interval [0, 1].

Fuzzy set theory generalize classical sets, since the indicator functions of classical sets are special cases of the membership functions of fuzzy sets, if the latter only take values 0 or 1. In fuzzy set theory, classical bivalent sets are usually called crisp sets.

The term "fuzzy logic" was introduced with the development of the theory of fuzzy sets by Lotfi Zadeh (1965). Fuzzy logic deals with reasoning that is approximate rather than fixed and exact. Compared to traditional binary sets (where variables may take on true or false values) fuzzy logic variables may have a truth value that ranges in degree between 0 and 1.

Because of the potential importance of fuzzy computing to solve the agricultural research problems Agrophysical Research Institute, St. Petersburg, Russia, began to develop applications of FC in
agrophysics several years ago. Many problems in soil tillage, crop management, precision agriculture, melioration, and agricultural engineering have been solved through fuzzy computing.

2. Fuzzy indicator modeling

The theory of fuzzy sets is a mathematically intuitive method of quantifying imprecision and uncertainty by grouping individuals into classes that do not have sharply defined boundaries. The central concept of fuzzy set theory is the membership function, which represents the relationship of an element to a set. The membership function of a fuzzy set is expressed on a continuous scale from one (full membership) to zero (full non-membership). One of the principal benefits of the application of fuzzy set theory in real world situations is that majority of characteristics of farming technologies can be estimated by fuzzy indicators, which are built on the basis of an expert opinions, which realized using the appropriative membership functions.

Thus, fuzzy indicator is defined as a number in the range from 0 to 1, which reflected an expert concept and modelled by appropriate membership function. The choice of a membership function is somewhat arbitrary and should mirror the subjective expert concept.

Recently, several models of fuzzy indicators have been developed to address a variety of questions and problems related to land evaluation. These include models for soil survey and land evaluation (Burrough, 1986, 1989; Burrough et al., 1992; for fuzzy reliability assessment of differences between resistance of ecosystem and anthropogenic load (Bogardi et al., 1996), managing fuzzy indicators (Krueger-Shvetsova & Kurtener, 2003), and land suitability indices for cropping systems (Baja 2002, 2007). Examples where fuzzy indicators have been successfully applied include zoning of territory contaminated by heavy metals (Kurtener et al., 1999; Kurtener & Badenko, 2002), multi-dimensional assessment of urban areas after flooding (Kurtener et al., 1999), assessment of polluted agricultural fields to develop strategies for remediation (Kurtener et al., 1999), and assessment of burned forest areas for land restoration planning (Kurtener et al., 2000). Other successful applications include assessing land suitability for agricultural experimentation (Kurtener & Badenko, 2000b), assessing agricultural lands for site-specific residue management (Kurtener & Badenko, 2000c), and multi-dimensional evaluations of areas for land markets (Yakishev et al., 2000).

Also, fuzzy indicator models were applied successfully for evaluation of yield maps (Krueger et al., 2010a), evaluation of agricultural land suitability (Kurtener et al., 2008), assessment of soil quality (Torbert et al., 2008), evaluation of resources of agricultural lands (Torbert et al., 2009), zoning of an agricultural field (Kurtener et al., 2011).

For assessment of resources of agricultural field two types of fuzzy indicators was developed (Kurtener & Sukhanov, 2014). These two types were the individual fuzzy indicators (IFI) and the combined fuzzy indicators (CFI). The IFI shows the degree of accordance of “n” category of land resource, the “j” attribute characterizes the land resource, the “i” characterizes the user group, and the “k” characterizes the task of land resource evaluation.
As an example, a “j” attribute could be: (a) attributes related to crop productivity; (b) attributes related to domestic animal productivity; or (c) attributes related to management and inputs. Examples of “i” user groups may be: (a) farmers, (b) government managers, or (c) market traders. Examples of “k” task of evaluation could be: (a) use in agricultural activities, (b) applications in teaching, or (c) utilization on land markets.

3. Combination of fuzzy indicator models with Geographical Information System (GIS)


GISFM is applied for solution of the problem of investment allocation into worse part of the land drainage systems located in the Saint-Petersburg suburbs (Kurtener & Badenko, 2004). In the design of transformation of land drainage systems it is necessary to solve the problems of allocation of investment between parts of the system that need renovations. In other words, each land drainage system can contain some elements that need to be improved, and funds for their transformation and rehabilitation are limited in most cases. Thus, it is necessary to solve the following problem: how to allocate the available investment between these parts. Figure 1 shows a structure of GISFM adopted for decision of this problem. Using GISFM approach several thematic maps have been elaborated (Figure 2).

![Fig. 1: Structure of GIS FKM adopted for complex evaluation of land drainage systems](image)

66
GISFM is applied for assessment of soil contamination by heavy (Badenko et al., 2014). Figure 3 shows thematic map displaying the spatial distribution of soil contamination indicator (SCI) by arsenic.

Fig. 1. The combined fuzzy indicators (Kurtener & Badenko, 2004).

Fig. 3. Thematic map displaying the spatial distribution of soil contamination indicator (SCI) by arsenic (Badenko et al., 2014).
4. Fuzzy multi-criteria evaluation of agricultural technologies

A suitable method for examining problems of fuzzy multi-criteria evaluation of agricultural technologies is the tool for fuzzy multi-attributive comparison of alternatives (Krueger-Shvetsova & Kurtener, 2003; Kurtener et al., 2009, 2009a). The developed tool was applied effectively to compare ways of reducing the cementation of the surface layers of the soil and choosing the best option (Busscher et al., 2007), for analysis of different combinations of soil cultivation methods with crop systems (Torbert et al., 2007), for evaluation of tillage systems for grain sorghum and wheat yields and total nitrogen uptake in the Texas Blackland Prairie (Torbert et al, 2009), with aim to evaluate different N management strategies (Krueger et al, 2010).

5. Utilization of Adaptive Neuro-Fuzzy Inference System (ANFIS)

Contrasted against conventional mathematics, fuzzy logic provides a formal mathematical structure for analyzing complex processes. A fuzzy inference system (FIS) and its adaptive version Adaptive Neuro-Fuzzy Inference System (ANFIS) employs fuzzy if-then rules to model the qualitative aspects of human knowledge and reasoning processes without employing precise quantitative analyses (Jang, 1993; Jang & Sun, 1995). One of the advantages of ANFIS, compared to the traditional regression approach, is that it does not require an a priori regression model, which generally is very difficult to justify (Dubois and Prade, 1980; Schaap et al., 1998).

Recently ANFIS has been applied in many agricultural and environmental settings, and represents a useful framework to deal with various issues, such as: 1) complexity of the soil compaction processes and qualitative knowledge associated with site-specific soil compaction evaluation (de Araújo & Saraiva, 2003); 2) soil science (Akbarzadeh et al., 2009; Lee et al., 2003; McBratney & Odeh, 1997); 3) estimating soil erosion (Akbarzadeh et al., 2009a); 4) predicting daily reference evapotranspiration (Cai et al., 2004; Cai & Mu, 2005; Lin et al., 2007), daily irrigation water demand (Atsalakis and Minoudaki, 2007), and wind forecasts (Potter et al., 2004); 5) hydro-environmental research (Azamathulla et al., 2009; Peschel et al., 2002); 6) estimating fluvial nutrient loads in watersheds (Marce, 2004); 7) behavioral interest identification in farm mechanization development (Tooy & Murase, 2007); 8) modeling of crop yield prediction (Arkhipov et al., 2008, 2012; Kurtener et al., 2005, 2006; Stathakis et al., 2006); and 9) agricultural robots (Stathakis et al., 2006; Xie et al., 2007).

In particular, ANFIS is applied for study of correlation between Normalized Difference Vegetation Index (NDVI), maize yield and management zones (MZ) (Krueger et al., 2010). By using ANFIS, a two-input FIS was constructed to define the relation between MZ, NDVI, and yield (figures 4 and 5). The information gained about this relationship is of practical significance for management decision making.
Fig. 4. ANFIS surface after training describing the relationship between management zones (MZ), NDVI, and yield (MZ are defined as 1=low, 2=medium, and 3=high) (Krueger et al., 2010).

Also ANFIS is applied for exploring relationships between characteristics of root distribution, and CO2 treatments (Krueger et al., 2011). Root-soil relationships are pivotal to understanding crop growth and function in a changing environmental. By using ANFIS, several fuzzy inference system (FIS) were built for exploring complex root distribution patterns under field conditions (figures 6 and 7). Simulation shows that the ANFIS technique gives plausible results, indicating that the fuzzy method offers a viable alternative to more traditional statistical techniques.
Application of microfertilizer HUMIN PLUS in combination with magnetic treatments of seed and water was evaluated by Ostrovskiy et al., (2014). By using ANFIS several fuzzy inference system (FIS) were built to define the contiguous relationships between the energy of seed germination, different HUMIN PLUS solution concentrations, and magnetic treatment of seeds and water (figure 8). Results from ANFIS simulations gave reasonable results, offering a feasible alternative to more traditional
statistical techniques for evaluation of relations between characteristics of seed germination energy, emulsion of sapropel concentrations, magnetic treatment of seeds and water, and time after sowing.

Fig. 8. FIS surface describing the relation between seed germination energy, which are sprayed by a solution of emulsion of sapropel with magnetic seed treatment but with no magnetic water treatment, and time after sowing (Ostrovskij et al., 2014).

6. Application of fuzzy logic

These include the work (Ambuel et al, 1994), which describes the fuzzy simulation to predict crop yield. Article (Modern irrigation systems towards fuzzy, 2008) describes a new irrigation system based on fuzzy logic (FL), which allows taking into account the knowledge and experience of the traditional farmer. Article (Oyekale, 2012) devoted sustainable land management using fuzzy indicator. Yang et al. (2000) used FL model to manage dose of entering of herbicides for field crops. This simulation showed that the proposed strategy can potentially reduce the consumption of herbicides from 5 to 24%. Article (Mansor et al., 2010) focused on the development and application of FL controller to manage the humidity of the grain. In 2010 a review on development of soft computing and applications in agricultural and biological engineering was published (Huang et al., 2010). Fuzzy logic was applied for assessing conditions for sowing (Arkhipov et al., 2012). Network of fuzzy controllers is developed. For the practical use a computer program was designed.

7. Conclusion

In conclusion, it may be said that applications of fuzzy computing in agrophysics has expanded in the last decade faster than any other divisions of agrophysical science. Agrophysical Research Institute,
St. Petersburg, Russia, published book in this topic (Applications of soft computing in agricultural field experimentations, 2010). The book contents: 1) utilization of tool for fuzzy multi attributive comparison of alternatives in soil and crop experimentations, 2) application of Adaptive Neuro-Fuzzy Inference System (ANFIS), and 3) development and utilization of fuzzy indicator models.

Publications show that the fuzzy computing technique gives plausible results, indicating that the fuzzy method offers a viable alternative to more traditional statistical techniques. This technique could be integrated into spatial computer tools (e.g., Geographical Information System). The results of this study illustrate the potential benefits of fuzzy set computing in agricultural research.
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