# The rough set theory applied for the evaluation of irrigation systems design and economics

M. S. Abuarab*; V. Sardo**; A. Hamdy***;

## ABSTRACT

The general goal was to critically analyze the irrigation systems as a whole, namely in the context of the farms, considering also the economic and practical aspects of their management rather than limiting the investigation to the hydraulic aspects as it is generally the case. In order to achieve such a goal, the new technique of the so-called "rough sets" was applied in the evaluation of the data resulting from field investigations and the interviews with the land tenants. The investigation was conducted in sixteen citrus farms in Sicily and a number of "conditional" criteria, corresponding to independent variables, were applied in the evaluation (Average gross profit, Water cost, Energy cost, Field emission uniformity, Design emission uniformity, Direct, Indirect and Total energy input, Operation and Maintenance costs, Variable, Fixed and Total System costs). All such criteria were elaborated against a "decisional" parameter, namely Satisfaction of the Farmer, corresponding to the independent variable in classical statistics. The rough set analysis, partly supported by traditional statistical analysis, evidenced those threshold values that in selected parameters must be respected to achieve a "medium" or a "high" level of satisfaction by the farmers; also the considerable influence of content in Ca, Mg and Na in water on emission uniformity was highlighted through the multiple regression analysis. The results also gave useful information on the optimization of direct and indirect energy input, which translates into the possibility of associating environmental to economic aspects in the optimization process of the design and management stages.

*Demonstrator at Agric. Eng. Dept., Faculty of Agric., Cairo University, Egypt.
** Professor at Agric. Eng. Dept., Faculty of Agric., Catania University, Sicily, Italy.
*** Chairman of Science at Mediterranean Agronomic Institute, Bari, Italy.

# INTRODUCTION

It is well known that fresh water resources are becoming ever more reduced in vast areas of the world and that access to water of good quality is a critical issue in most arid and semi-arid zones, to the extent that international and inter-regional relationships are ever more often put under strain. Out of the three major categories of water uses, domestic, industrial and agricultural, the former is obviously the most important while the second permits to obtain from water an estimated added value about 70 times higher than that of agriculture (**Clarke, 1993**).

On the other side, agriculture uses the largest share of water, with peaks in excess of 90%, and uses it quite inefficiently since it is estimated that cases of efficiencies as low as 50% are not uncommon (**Hamdy *et al*., 2001**). It is remarkable, furthermore, that with very few exceptions whenever the highest percentages of water are dedicated to agricultural uses, then the highest percentages of water waste are recorded: there is therefore ample room for improving existing irrigation methods, both in the structures and in the management.

Of course any suggestion for improvement must be based on a previous appraisal of the operating conditions and then on an evaluation of the systems and their operation: "evaluation is the analysis of any irrigation system based on measurements taken in the field under the conditions and practiced normally used. It also includes on-site studies of possible modifications such as changing sprinkler pressures, having larger or smaller streams in furrows, and changing duration of application. Measurements needed for an analysis include: soil moisture deficiency prior to irrigation, rate of inflow, uniformity of application and infiltration, duration of application, rate of advance, soil conditions, rates of infiltration, and adequacy of irrigation" (**Merriam and Keller, 1978**).

We actually felt that it can be useful to conduct a thorough appraisal work, aimed at reviewing, sorting and ranking irrigation systems and at supplying guidelines for their selection; this must be based on the assessment not only of the hydraulic characteristics of the systems, their application uniformity, the irrigation efficiency and adequacy, but should also include such aspects as the management and the operation and maintenance. The goal of the present research was to critically analyze one typical, representative irrigation system (sprayer system) as operating in a number of different citrus farms, in order to work out a set of information to be used as a guideline in design and management. To do that, the new technique of the so-called "rough sets" was applied, which permits to rank the variables according to pre-fixed criteria.

The reason why uniform irrigation systems (sprayers) and crops (citrus) were selected is the need to have a homogeneous database from which to extract the variables selected and analyzed in order to rank the systems. It will be apparent from the description of the work below that the final outcome was the evaluation not of the irrigation system itself, as a standalone component, but rather of the irrigation system as an organic component of the farm and accordingly the approach to the evaluation results totally new.

It seems appropriate to introduce some preliminary information on rough set theory. The rough sets theory introduced by **Pawlak, Z. 1982 and 1991**, has often proved to be an excellent mathematical tool for the analysis of a vague description of objects (called actions in decision problems). The adjective vague, referring to the quality of information, means inconsistency or ambiguity, which follows from information granulation. The rough sets philosophy is based on the assumption that with every object of the universe there is associated a certain amount of information (data, knowledge), expressed by means of some attributes used for object description. For example, if the objects are firms applying for a bank mortgage, the information given concerns their financial, economic and technical characteristics, that constitute their description. Objects having the same description are indiscernible (similar) with respect to the available information. The *indiscernibility relation* thus generated constitutes a mathematical basis of the rough sets theory; it induces a partition of the universe into blocks of indiscernible objects, called elementary sets that can be used as "bricks" to build knowledge about a real or abstract world. The use of the *indiscernibility* relation results in information granulation.

Any subset X of the universe may be expressed in terms of these bricks either precisely (as a union of elementary sets) or approximately only. In the latter case, the subset X may be characterized by two ordinary sets, called *lower* and *upper approximations.* A rough set is defined by means of these two approximations, which coincide in the case of an ordinary set. The lower approximation of X is composed of all the elementary sets included in X (whose elements, therefore, certainly belong to X), while the upper approximation of X consists of all the elementary sets, which have a non-empty intersection with X (whose elements, therefore, may belong to X). Obviously, the difference between the upper and lower approximations constitutes the boundary region of the rough set, whose elements cannot be characterized with certainty as belonging or not to X, using the available information. The information about objects from the boundary region is, therefore, inconsistent or ambiguous. Clearly, in ordinary sets the boundary region is empty. The cardinality of the boundary region states, moreover, to what extent it is possible to express X in exact terms, on the basis of the available information. For this reason, this cardinality may be used as a measure of vagueness of the information about X. The rough sets theory, dealing with representation and processing of vague information, presents a series of intersections and complements with respect to many other theories and mathematical techniques dealing with imperfect information, like probability theory, evidence theory of Dempster-Shafer, fuzzy sets theory, discriminant analysis and mereology (**Dubois, D. and Prade, H.1990 and 1992; Krusinska, E., Slowinski, R. and Stefanowski, J., 1992; Pawlak, Z., 1985; Polkowski, L. and Skowron, A., 1994; Skowron, A. and Grzymala-Busse, J.W., 1994; Slowinski, R., 1995**).

Some important characteristics of the rough set approach make of this a particularly interesting tool in a number of problems and concrete applications. With respect to the input information, it is possible to deal with both quantitative and qualitative data and inconsistencies need not to be removed prior to the analysis. With reference to the output information, it is possible to acquire a posteriori information regarding the relevance of particular attributes and their subsets to the quality of approximation considered in the problem at hand, without any additional inter-attribute preference information. Moreover, the final result in the form of "*if..., then...*" decision rules, using the most relevant attributes, is easy to interpret.

## MATERIALS AND METHODS

### 1. Scrutiny Irrigation Systems

The area cultivated to citrus in Sicily is approximately 160.000 ha, the commonly applied irrigation system is microirrigation with sprayers. The need for an in-depth analysis, as required for the comprehensive approach depending on the selected methodology, obliged to limit the field appraisal to sixteen farms; for the sake of operating under uniform conditions, only citrus farms were examined, irrigated with localized or semi-localized systems. The analysis included the appraisal of the main features of the farms, as reported figure 1. To better appreciate the results it must be outlined that out of the 16 farms under scrutiny, 11 were producing fresh fruit (oranges) whereas in 5 of them (farm 10 to 14) plants were grown and sold as ornamentals: this explains the higher costs and inputs required by them as well as the higher gross income. From all the criteria's included in appraisal form we reformalizing all of these parameters under two main branches, the first one is the economic and energetic evaluation and the other is the hydraulic evaluation to have a precise overall view for how good are the applied irrigation systems.

**2. Economic and Energetic Evaluation**

The economic evaluation requires a rather complex procedure since it is based between to orders of trade-off, namely A trade-off at the design stage, when the land tenant and the designer decide together the level of application uniformity of the system, in the assumption that a higher

Figure 1: Farm appraisal form

**Farm Appraisal Form**

- Date:
- Farm Name: Owner Name:

**Farm**

- Surface area (ha):
- Crop:
- Average Production (q/ha):

**Management**

- Capitalistic ( ) Capitalistic/Laborer ( ) Prevalently entrepreneur( )
- Manager age:
- Education: Primary School ( ) Diploma ( ) University degree ( )

**Water Supply**

- Public collective system ( ) Private collection system ( ) Private ( )
- Large artificial reservoir ( ) Farm reservoir ( ) Well ( ) Other(Spring, Water course)( )
- Cost (€/$m^3$): Hours/Week Total yearly volume ($m^3$):
- Flow rate (l/sec): Total hours/year:

**Irrigation System**

- Method:
- Designed by: Professional designer ( ) Commercial designer ( ) Farmer ( )
- Installed by: Commercial Installer ( ) Farmer himself ( )
- Fertigation: Yes ( ) No ( )
- Filter:
- Pumping System
- ♦ Pump Type: Electric ( ) Thermal ( )
- ♦ Power: Flow Rate (l/sec): Pressure (m):
- ♦ Yearly hours of operation:
- ♦ Mean interval of application (day): Duration (hour):
- Energy cost (€/year):
- Labor Required for O&M (emitters inspection, filters cleaning, flushing, etc.) (hour/year):

**Specific Irrigated Section**

- Surface (ha): Number of trees: Crop (cultivars, species):
- Distances among plants (m * m): Pattern (Square, Triangle, Rectangle):

- Emitter: Dripper ( ) Sprayer ( ) Sprinkler ( ) Commercial brand:
- Distance (m * m): Emitters/plant: Emitter flow rate (l/h):
- Pressure (m): $CV_t$ (%):
- Laterals: PVC ( ) PE ( )
- Diameter (mm): Length (m):
- Sub mains: PVC ( ) PE ( )
- Diameter (mm): Length (m):
- Main Line: PVC ( ) PE ( )

  Diameter (mm): Length (m):

Main problems encountered:

Farm satisfaction degree: High ( ) Medium ( ) Low ( )

uniformity implies a higher initial cost but permits savings in water and energy when running the system, as well as a better and more uniform plant development, and A trade-off at the operation stage, when a more accurate maintenance requires higher labor costs but permits a better and more uniform water application, thus saving water and energy costs and, again, offering better conditions to plant development.

Both selection procedures are influenced by specific farm conditions: e.g. saving energy cost has no meaning for the farmers to whom water is delivered under pressure by gravity; saving water can be unimportant for farmers deriving water from their own wells, unless energy costs for lifting water are considered. Furthermore, high maintenance costs can be fully justified in those farms with a high gross profit (e.g. in nurseries), whereas there is no point in operating and maintaining very accurately irrigation systems where water is cheap and abundant and profit is low.

To proceed to the economic evaluation several parameters were analyzed, including:

- ✓ Average gross profit (€/ha/year)
- ✓ Energy cost (€/ha/year)
- ✓ Water cost (€/ha/year)
- ✓ Operation and maintenance cost (€/ha/year)
- ✓ System fixed costs (€/ha/year)
- ✓ Variable costs (resulting from ii + iii + iv)

All those costs are not directly referring to irrigation, such as those for cultivation, pruning, pest control etc. were not considered because out of scope: that is the reason why farm gross profit rather than net profit was considered. Parallel to the economic evaluation, an energy evaluation was conducted, in order to assess energy inputs to the systems: such information was believed of importance to estimate the relationship between the economic and the environmental optimization. It has been remarked in fact that energy input to a system can be assumed as an indicator of environmental sustainability, while on the other hand it has been noted that the too often overlooked energy aspects in irrigation systems are to some extent parallel to economic aspects. Estimating direct and indirect energy in the irrigation systems carried out the energy appraisal.

Direct energy input (in kW/h per year) was estimated by multiplying the power in the pumping stations (in kW) by the yearly time of operation (hours). No attempt was done to estimate the human energy for operation and maintenance, due to the well known difficulties of this procedure, which is highly debated and to the fact that its amount is negligible compared to that required to lift and pressurize water (**Sardo, 1982**).

Indirect or embodied energy was estimated through the research of the total weight of pipelines in the system, then by multiplying such weight by the appropriate coefficient (44.45 for polythene and 33.34 for polyvinyl chloride). The resulting value was prorated on the estimated useful life of the system, namely 20 years; no salvage value was applied since it is customarily to abandon all the system components at the end of the cycle (**Sardo, 1982**).

The interest in energy aspects stems also from the consideration that in a multicriteria decision making process it can be of interest to the decision maker (the farmer, in this case) to ponder also those factors that impact environment conservation; it is also possible to imagine that in a near future economic tools for encouraging conservation strategies will be implemented by governments, thus shifting the decision-makers preferences towards energy-saving solutions.

## 3. Hydraulic Evaluation

In the course of every field visit the pressure and flow rate variations were assessed in nine selected points for every sector. Pressures were measured by applying a large-dial precision manometer to the 16 mm polyethylene pipe bearing the emitters, while flow rates from the selected emitters were assessed measuring the amount of water accumulated in a graduated cylinder during 36 seconds (one hundredth of an hour). Such data were subsequently processed to obtain the various uniformity coefficients, including EUfield, EUBralts, EUct, EUdesign, Maximum pressure difference, and Maximum discharge difference, as reported below. Also the emitters were closely inspected with special consideration to their pressure/flow rate relationship (and consequently to the value of the x exponent in the equation $Q = a * H^x$) and their coefficient of technological variation as reported by the manufacturer. From the elaboration of measures collected in the field, the following indicators were calculated:

(I) The emission uniformity of the emitters tested in the field (%), calculated by using the Keller and Karmeli equation:

$$EU = \frac{\text{the average discharge of the low quarter emitters}}{\text{The average discharge of all tested emitters}} \times 100 \qquad (1)$$

(II) The design emission uniformity (%) (**Keller and Karmeli, 1975**),

$$EU = 100*(1-1.27(CVt/n^{0.5}))(q_{min}/q_{max}) \qquad (2)$$

Where:

| | |
|---|---|
| EU | = Design emission uniformity (%) |
| $C_{Vt}$ | = Manufacturer coefficient of variation |
| n | = The number of emitters per plant |
| $q_{min}$ | = The minimum discharge rate (l/h) |
| SD | = The standard deviation of the flow rate |
| $Q_{ave}$ | = The average flow rate of all emitters (l/h) |

(III) The emission uniformity of Capra and Tamburino (%) (**Capra and Tamburino, 1995**).

$$EU_{CT} = 100\ (\frac{Dr_{1/4min}}{Dr_a})\ *\ (\frac{H\ min}{H\ a})^x \quad (3)$$

$$EU_{CT} = 100\ (\frac{Dr_{1/4min}}{Dr_a})\ *\ (\frac{H_{1/4min}}{H\ a})^x \quad (4)$$

Where:

$Dr_{1/4min}$ = The mean discharge of the low quarter (l/h),
$Dr_a$ = The mean discharge for all emitters (l/h),
Dr = Flow rate ratio of each emitter tested in the field (l/h).
$H_{min}$ = The minimum head in meter
$H_a$ = The average head in meter
$H_{1/4\ min}$ = Average head of the low quarter in meter
X = Flow rate exponent

(IV) The maximum head difference (%)

$$\text{Max. Press. Diff.} = (\frac{Pmax - Pmin}{Pmax}) \times 100) \quad (5)$$

Where:

$P_{max}$ = Maximum head (m)
$P_{min}$ = Minimum head (m)

(V) The maximum discharge difference (%)

$$\text{Max. Disch. Diff.} = (\frac{Qmax - Qmin}{Qmax}) \times 100 \quad (6)$$

Where:

$Q_{max}$ = Maximum flow rate (l/h),
$Q_{min}$ = Minimum flow rate (l/h.

(VI) The statistical coefficient of uniformity or The Bralts emission uniformity (%) (**Bralts *et al*., 1987**).

$$EU_{bralts} = 100 \times \left(1 - \frac{SD}{Q_{Ave}}\right) \quad (7)$$

Where:

$EU_{bralts}$ = Emission uniformity of Bralts
SD = Standard deviation of flow rate for emitters tested
$Q_{Ave}$ = Average flow rate

## 4. Procedure and methods of analysis

Water and soil in every farm were also sampled and analyzed in the laboratory according to the standard methodology as illustrated down.

### 4.1. Water analysis

**Physical parameters**

- The total suspended solids in mg/l, were determined by using (AOAC Official Methods of Analysis).
- Water pH using AMEL model pH meter

- EC in dS/m, by using the EC meter type (Delta OHM conductivity meter HD 8706).

**Chemical parameters**
Water chemical analysis was made to determine the soluble cations ($Ca^{++}$, $Mg^{++}$, $K^{+}$, $Na^{+}$) and anions ($Cl^{-}$, $CO_3^{--}$, $HCO_3^{-}$, $SO_4^{--}$) as follows:

- Carbonate and bicarbonate were estimated volumetrically by titration with a standard solution of sulfuric acid, using phenolphthalein and methyl orange as indicators for each element respectively.
- Chloride was determined with silver nitrate according to (**U.S.S.L., 1954**)
- Calcium and magnesium were estimated by titrating with versenate method using ammonium purporate as an indicator for calcium and Eriochrome Black T as an indicator for calcium and magnesium according to (**U.S.S.L., 1954**)
- Sodium and potassium were determined photometrically by using flame photometer (JENWAY PEP7) according to (**U.S.S.L., 1954**)
- Sulfate was estimated by the difference between total anions and $Cl^{-}$ plus $HCO_3^{-}$.

### 4.2. Soil Analysis

For the analysis of the soil the same parameters were applied except the total suspended solids (TSS) plus the soil texture for each farm.

### 4.3. The statistical analysis

The conventional statistical analysis of data was conducted through the use of a dedicated, advanced software, “STATGRAPHICS”, which has a number of convenient and useful functionalities and a larger flexibility than most other software’s. STATGRAPHICS was used to search simple and multiple correlations among the parameters considered, as well as to draw the correlation diagrams.

### 4.4. The application of the rough set theory

The analysis of data was conducted by using both the traditional statistical analysis and the analysis by the application of the rough set theory; a short description of this relatively novel theory has been given in introduction. The rough set analysis was obtained through the application of special, dedicated software, JAMM, not in commerce, obtained through the courtesy of professor B. Matarazzo of the University of Catania.

## RESULTS AND DISCUSSION

### 1. General comment

The considerable amount of data and information collected in the field and through the interviews to the farmers, as well as by means of the subsequent laboratory analysis and desk elaboration permits to formulate a number of general considerations on the conditions of the farms sampled and observed. First it is necessary to keep present that out of the sixteen citrus farms analyzed, eleven were addressing production of orange fruits while five were nurseries, trading citrus plants as ornamentals. Below the data collected are reported: out of them only a part has been processed because the other part was redundant.

Table 1: The costs items

| Farm | Water Cost (€/ha/year) | Direct energy (KW.h/year) | Indirect energy (KW.h/year)) | yearly Energy cost (€/kW.h/ha) | Operation and maintenance cost (€/ha/year) | variable costs (euro/ha/year) | fixed yearly costs (euro/ha/year) | Total Costs (€/ha/year) |
|---|---|---|---|---|---|---|---|---|
| 1 | 2431 | 650 | 871.2 | 228 | 75 | 2734 | 300 | 3034 |
| 2 | 0 | 5000 | 1139 | 921 | 300 | 1221 | 400 | 1621 |
| 3 | 0 | 6000 | 1190 | 1079 | 400 | 1479 | 380 | 1859 |
| 4 | 365 | 950 | 1110 | 309 | 300 | 974 | 280 | 1254 |
| 5 | 0 | 0 | 5950 | 892 | 125 | 1017 | 550 | 1567 |
| 6 | 4336 | 1500 | 1083 | 387 | 300 | 5024 | 320 | 5344 |
| 7 | 353 | 700 | 928.1 | 244 | 100 | 698 | 380 | 1078 |
| 8 | 427 | 750 | 821.3 | 236 | 125 | 788 | 300 | 1088 |
| 9 | 703 | 800 | 1005 | 271 | 175 | 1148 | 320 | 1468 |
| 10 | 0 | 10000 | 1215 | 1682 | 200 | 1882 | 350 | 2232 |
| 11 | 0 | 10000 | 2140 | 1821 | 400 | 2221 | 250 | 2471 |
| 12 | 0 | 6440 | 3272 | 1457 | 450 | 1907 | 500 | 2407 |
| 13 | 0 | 5350 | 4247 | 1440 | 350 | 1790 | 430 | 2220 |
| 14 | 0 | 14600 | 2237 | 2526 | 500 | 3026 | 250 | 3276 |
| 15 | 799 | 3000 | 1409 | 661 | 75 | 1536 | 300 | 1836 |
| 16 | 2372 | 4000 | 1703 | 855 | 75 | 3302 | 350 | 3652 |

- As illustrated in table 1. the water cost ranges from a minimum of zero for those farms endowed with their private wells to a maximum of 4336.08 euro/ha/year in a farm with particular problems in water supply.
- The direct energy ranged from zero, in one farm where water is supplied under pressure by gravity, up to a maximum of 14.600 kW/h/ha per year, in dependence of the depth from which water is lifted and of the volumes of application.
- Indirect energy, which is a measure of the system sizing (it is also called embodied energy), was expressed in terms of kW/h/ha/year and ranged between the values of 871 and 5.949. The largest value depended not on a more generous size of the system itself but rather on the length of the supplying pipeline. One further parameter was the yearly energy cost, paralleling direct energy input and therefore redundant.
- Operation and maintenance were expressed in terms of labor hours per year; as expected, they were highest in nurseries (with only one exception) where the high gross income obliged to a more careful O&M activity. Oddly, it resulted very high (80 hours/ha/year) also in farm 3, with a very poor EUfield (45 %), where the good quality of water, lifted from a well, dictated no particular attention to clogging problems; also in farm 6 a poor EUfield (40 %) was associated to high O&M values (60 hours/ha/year).
- Fixed, variable and total costs were unrelated to farm activities, namely no sharp distinction was apparent between costs in nurseries and in fruit producing farms, opposite to what could be expected, based on water, energy and O&M inputs.
- As shown in figure 2. the field emission uniformity, EUfield, ranges from a low of 40.33% to a maximum of 94.38%; it is remarkable that the maximum value was recorded in a fruit-producing farm rather than in a nursery.

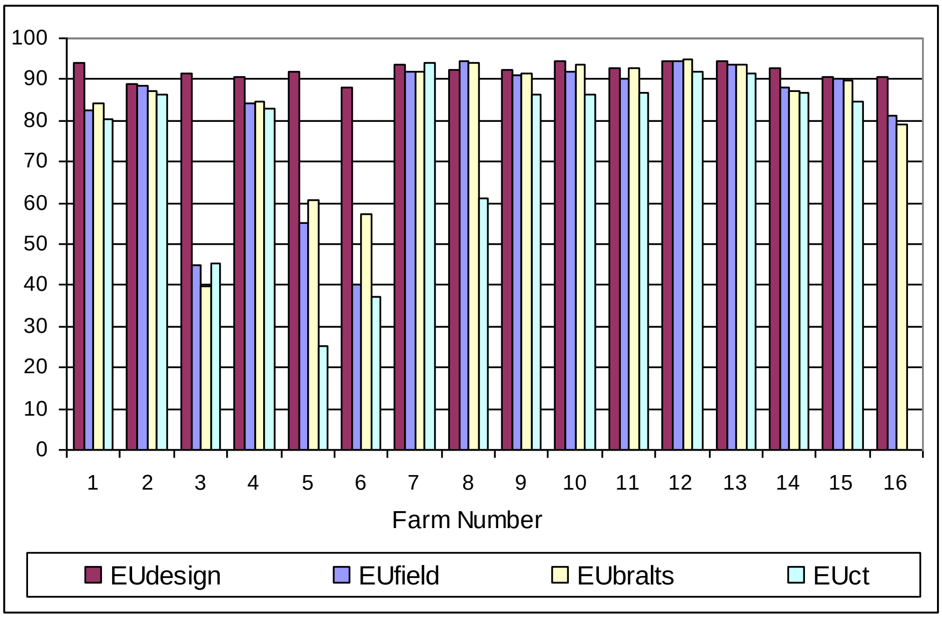


Figure 2: The uniformities parameters.

- The design emission uniformity (EUdesign) only in one single case was below 90% (88.97%, in farm 2), while in the other cases ranged between 90% and 94%, with the highest values corresponding to the nurseries.
- The other emission uniformity indicators (EUcapra-tamburino; Eubralts, maximum pressure difference; maximum discharge difference) are strictly correlated between them (figure 3) and to EUfield (e.g. EUbralts and EUfield have a correlation index of 96.49 %), therefore they have been considered redundant in the following elaboration.

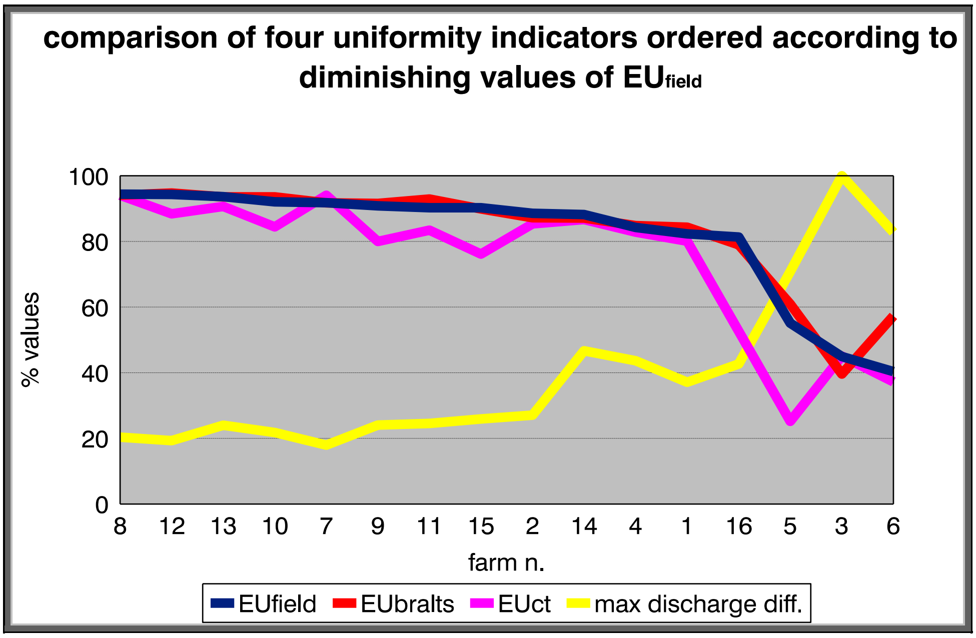


Figure 3: A comparison of four indicators ordered according to diminishing values of EUfield

- As shown in table 2. the gross profit data are scattered within a wide range of values; actually they can be subdivided into two major groups, one (3.150 to10.500 euro/ha/year) referring to orange fruit production, the other (75.294 to 200.000 euro/ha/year) referring to nurseries). Of course the relevant differences would be considerably mitigated if net profits were considered, due to the high costs for running nurseries, but the analysis was limited to gross profits for the considerations exposed above.

Table 2: The average gross profit & The Satisfaction degree of the farmer

| Farm | Average gross profit (€/ha) | Satisfaction of the farmer |
|---|---|---|
| 1 | 5250 | High |
| 2 | 3150 | Medium |
| 3 | 3150 | Medium |
| 4 | 4515 | Low |
| 5 | 5250 | High |
| 6 | 8400 | Medium |
| 7 | 4200 | Medium |
| 8 | 4200 | Medium |
| 9 | 4200 | Medium |
| 10 | 177778 | Medium |
| 11 | 200000 | Medium |
| 12 | 75294 | High |
| 13 | 200000 | Medium |
| 14 | 160000 | Medium |
| 15 | 10500 | High |
| 16 | 8400 | High |

## 2. Data analysis

Two kinds of procedures were applied in the elaboration of data collected in the field, namely the "conventional" statistical analysis and the rough set analysis, the parameters used in the analysis are reported in table 4.30; below the results of such elaborations are exposed.

### 2.1. The statistical analysis

A number of parameters were considered and the correlation among them was explored; they included:

- ✓ Gross profit
- ✓ EUfield
- ✓ EUdesign
- ✓ Direct energy
- ✓ Total costs
- ✓ Indirect energy
- ✓ Total energy
- ✓ Variable costs
- ✓ Fixed costs
- ✓ Operation & Maintenance

A few were significantly correlated. As resulting from the matrix of coefficients of determination reported below in table 3 ($R^2$ values for only significant correlation are reported).

Table 3. Matrix of coefficients of determination $R^2$.

| | Gross Profit | EUfield | EUdesign | Direct Energy | Indirect energy | Total Energy | O&M* | Variable Costs | Fixed Costs | Total Costs |
|---|---|---|---|---|---|---|---|---|---|---|
| Gross profit | X | | 26.97 | 61.76 | | 67.87 | 21.85 | | | |
| EUfield | | X | 31.76 | | | | | | | |
| EUdesign | | | X | | | | | | | |
| Direct energy | | | | X | | | 47.02 | | | |
| Indirect energy | | | | | X | | | | 50.32 | |
| Total Energy | | | | | | X | 47.98 | | | |
| O&M | | | | | | | X | | | |
| Variable costs | | | | | | | | X | | |
| Fixed Costs | | | | | | | | | X | |
| Total costs | | | | | | | | | | X |

* Operation & Maintenance

The strongest coefficients of determination ($R^2$ = 61.76 % and 67.87 %) were found between gross profit and direct and total energy, respectively, whereas no significant correlation was found with indirect energy; this result is rather unexpected since a higher input in terms of pipeline sections was to be expected in those farms with a higher budget. However fixed costs, which are related to indirect energy, being its equivalent in economic terms (actually are the yearly amortization of the invested capital), are significantly linked to indirect energy, as observed below. Gross profit was also significantly ($R^2$ = 21.85 %) linked to O&M; the comparatively loose correlation is explained by the fact that those farms with the highest input (the nurseries) had the possibility of deriving water of drinking quality for their systems, which of course largely reduced O&M costs, largely dependent on emitter inspection and unplugging.

It is also of interest to highlight the highly significant correlation found through the multiple regression analysis between EUfield (strictly linked to it, with a 96.48 % correlation coefficient) and chemical components in irrigation water. The models resulting from the analysis are:

EUfield = 96.338 – 4.1524 x Ca – 8.7776 Mg + 3.6620Na ($R^2$ = 58.97 %)

Such results evidence the negative action of calcium and magnesium (with a negative sign) and confirm the positive action of sodium (positive sign) on emitter uniformity, due to flocculation of colloids in water brought about by Ca and Mg, with a consequent clogging action, and an opposite action of colloids peptization due to Na.

Strangely, such close relationship is not maintained when analyzing water SAR action on EUfield values (it could be expected in fact that SAR, which results from the ratio of $Na^+$ to the square root of $Ca^{++}$ and $Mg^{++}$ was able to lump in one single value the effect of the three ions): the correlation coefficient of EUfield versus SAR resulted a deluding 5.96 %.

To conclude the statistical analysis, we can note the interesting link found between gross profit and O&M versus direct and total energy, both strictly and positively correlated, highlighting the larger energy and labor requirements in the more intensively managed farms; this finding was confirmed by the correlation between farm intensity and design uniformity. It is also of interest that the systems fixed costs are highly correlated to the indirect energy input, which permits to link economic and environmental aspects in the optimization process, due to the parallel pathway of the two variables.

Finally, it is worthwhile to note that almost 60 % of variation in EUfield can be predicted by the model based on Ca, Mg and Na content in irrigation water: it can be proposed to integrate the EUdesign indicator with water content in such elements in order to get a more complete prevision of the system performance.

### 2.2. The rough set analysis

The nine conditional criteria (equivalent to the independent variables of multiple regression in statistical analysis) taken into consideration in the rough set analysis were the following (symbols used in the JAMM software processing are reported)

- as1 = Average gross profit
- as2 = Water cost
- as3 = EUfield
- as4 = Direct energy

- as5 = Indirect energy
- as6 = Yearly energy cost
- as7 = Operation and maintenance hours
- as8 = Variable yearly costs
- as9 = Fixed yearly cost
- as10 = was the decisional criterion (equivalent to the dependent variable), and expressed the farmer's satisfaction.

Through the processing with Jamm the following results were achieved:

3 Reducts were found, namely
- Reduct 1: as2; as3; as5; as7
- Reduct 2: as1; as2; as4; as5
- Reduct 3: as1; as2; as5; as6

- The core is formed by criteria as2 and as5, the most important, present in the three reducts.
- Criterion as1 is present in 2 out of 3 reducts, which testifies of is significance in explaining farmer's satisfaction.
- Criteria as7, a4 and as3, also present in the reducts, have their own bearing, although less significant than the others.
- Criteria as8 and as9 are never included in the reducts, which means that they have no direct impact on farmer's satisfaction.
- The quality of sorting is 1, namely at the highest possible level; this demonstrates that the available information enables us to totally explain and sort the problem we are analyzing.

- The most significant rules (as reported in the annex labeled RULES), with a confidence level ≥ 90%, are the following:
  - ✓ Rule n. 44: as 1≥ 5250 => as10 => M
  - ✓ Rule n. 46 as 2 ≤ 353 => as10 => M
  - ✓ Rule n. 52 as 5 ≤ 1083 => as10 => M

- The three rules above explain a satisfaction level at least medium; a high level of satisfaction is best explained by the three following rules
  - ✓ Rule n.61: as 4 ≤ 650 => as10 => H
  - ✓ Rule n. 63: as 7 ≤ 75 => as10 => H
  - ✓ Rule n.65: as1 ≥ 5250 & as7 ≤ 125 =>as10 => H

In conclusion the highest confidence for the rules to obtain a level of farmer's satisfaction at least medium is given by the a level of gross income not less than 5.250 euro/ha/year, linked to a water cost not higher than 353 euro/ha/year and to an indirect energy input equal or lower than 1.083 kW/h/ha/year. The highest confidence for the rules to obtain a high level of satisfaction is given by a gross income not less than 5.250 euro/ha/year, linked to O&M costs not higher than 75 euro/ha/year (which can grow to 125 euro/ha/year with rule n. 65) and a direct energy input not higher than 650 kW/h/ha/year.

The fact that conditional criteria as8 and as9 (variable and fixed yearly costs, respectively) have no impact on farmers satisfaction does not mean, of course, that farmers are insensitive to the system cost, but rather that within the experimental conditions they fell within a rather homogeneous group with a range of values not enough distinct to have a bearing on the final outcome.

Such conclusions give useful information in design and management, since they can be used in the research for the trade-offs illustrated above, namely trade-off in system design (between costs for the irrigation system purchase and installation vs. costs for operation and maintenance and water procurement.) and in system management: the rules disclose in fact which threshold in gross income must be respected while fixing limits to O&M and water costs and to indirect energy input, if a level of satisfaction at least medium is to be achieved. Of course the indirect energy input is a parameter to be used by the designer when sizing the pipeline system. More indications are given for achieving a high user's satisfaction, regarding also direct energy input. It must be remarked that emphasis put by the analysis results on direct and indirect energy input as factors of optimization is particularly interesting because it encompasses both economic and environmental aspects.

## CONCLUSION

- One of the main problems that irrigation system designers are facing is to find out a reasonable trade-off between system cost and O&M costs, usually inversely correlated: the results of the analysis suggests which threshold value in gross income should be secured and which costs of water supply, O&M and indirect energy input should not be exceeded to achieve at least a medium level in farmers satisfaction.
- Values of direct energy input not to be exceeded are also given for the event that a high level in farmers' satisfaction is desired.
- The above points give also useful guidelines in finding out a reasonable trade-off between costs for operating and maintaining the system (O&M) and the reduction in water and direct energy input, which are inversely correlated.
- The integrated analysis conducted through the rough set technique permits to link the economic and the environmental optimization, since indications are given about which threshold value for direct and indirect energy input must be considered in designing the system, which translates in indications on the most economic system sizing.
- A case of particular relevance is that of the adoption of self-compensating emitters: although not present in the farms inspected, the results of the analysis permit to determine which is the maximum level of direct energy input not to be exceeded to secure farmers satisfaction (it is known that the inherent risk of systems with self-compensating emitters is to reduce the system pipeline size and cost at the expense of a high direct energy input).
- An indication given by the statistical analysis refers to the model linking emitter clogging and therefore field emission uniformity to chemical water characteristics: since the content of water in Ca, Mg and Na explains almost 60% of the variations in emission uniformity it seems thoroughly reasonable to propose to add this model to the indicator of design uniformity as generally adopted.
- The indications of the statistical analysis, although corresponding to single point values and not structured as those of the rough set analysis, confirmed and gave support to the latter

## REFERENCES

**Barlts, V. F., Edwards, D. M. and Wu, I-Pai, (1987).** Drip irrigation and evaluation based on the statistical uniformity concept. In Hillel, D. (ed), *Advances in Irrigation*, vol. 4. Academic Press, Orlando, pp. 67-117.

**Capra, A. and V. Tamburino 1995.** Evaluation and control of distribution uniformity in farm irrigation systems. Proceeding of 46th International Excutive Council Meeting. ICID, CIID, Special Technical Session, Rome, Italy.

**Chapman, H.D. and P.F. Pratt 1961.** Methods of analysis for soils, plants, and wastewaters. University of California, Division of Agricultural Science, Berkeley, California.
**Clarke, R. 1993.** Water. The International Crisis. The MIT Press, Cambridge, Massachussets.
**Dubois, D. and H. Prade 1990.** Rough fuzzy sets and fuzzy rough sets. Int. J. of General Systems 17: 191-200.
**Dubois, D. and H. Prade 1992.** "Putting rough sets and fuzzy sets together". In: R. Slowinski (ed): *Intelligent Decision Support, Handbook of Applications and Advances of the Rough Sets Theory*. Kluwer, Dordrecht, pp.203-233.
**Hamdy, A., C. Lacirignola and G. Trisorio-Liuzzi 2001.** Water Saving and Increasing Water Productivity: Challenges and Options. In *Water Saving and Increasing Water Productivity*: *Challenges and Options*. University of Jordan, Faculty of Agriculture.
**Keller, J. and D. Karmeli 1975.** Trickle irrigation design. Rain Bird Sprinkler Manufacturing Corporation, Glendora, CA, 133p.
**Krusinska, E., R. Slowinski and J. Stefanowski 1992.** Discriminant versus rough set approach to vague data analysis. Applied Stochastic Models and Data Analysis 843-56.
**Merriam, J. L. and J. Keller 1978.** Farm Irrigation System Evaluation: A guide for Management. Dept. Agric. Irrig. Eng., Logan, Utah St. University.
Pawlak, Z. 1982. Rough sets. International Journal of Information & Computer Sciences 11: 341-356.
**Pawlak, Z. 1985.** Rough probability. Bull. Polish Acad.. Scis., Technical Sci. 339-10.
Pawlak, Z. 1985. *Rough Sets. Theoretical Aspects of Reasoning about Data*. Kluwer, Dordrecht 1991.
**Polkowski, L. and A. Skowron 1994.** "Rough mereology". *Proc. Symp. on Methodologies for Intelligent Systems*, Lecture Notes in Artificial Intelligence, vol. 869, Springer-Verlag, Berlin, pp. 85-94.
**Sardo, V. 1982.** Energy economics and the choice of irrigation method.L'Irrigazione, n° 1.
**Skowron, A. and J.W. Grzymala-Busse 1994.** "From the rough set theory to the evidence theory". In: M. Fedrizzi, J. Kacprzyk, R.R. Yager (eds): *Advances in the Dempster-Shafer Theory of Evidence*. John Wiley and Sons, New York, pp. 193-236.
**Slowinski, R. 1995.** "Rough set processing of fuzzy information", In: T.Y.Lin, A.Wildberger (eds): *Soft Computing: Rough Sets, Fuzzy Logic, Neural Networks, Uncertainty Management, Knowledge Discovery*. Simulation Councils, Inc., San Diego, CA, pp. 142-145.
**US. Salinity Laboratory Staff 1954.** Diagnosis and improvement of saline and alkali soils. In: *Handbook no. 60*. Dept. of Agriculture, Washington, 160 p.

# الملخص العربى

## تقييم أداء نظم الري من الناحية التصميمية والاقتصادية باستخدام نموذج Rough Set

م/ محمد السيد أبوعرب     أ.د. / فيتو صاردو     أ.د./ عاطف حمدي

يهدف البحث إلى تقييم نظم الري المطبقة في مزارع الموالح بجزيرة صقلية بإيطاليا من الناحية الفنية والاقتصادية من خلال اختيار عينة عشوائية تتكون من ستة عشر مزرعة و باستخدام استمارة تقييم تتضمن مجموعة من المعايير الاقتصادية والفنية بالإضافة إلى أجراء مجموعة من القياسات الحقلية للضغط والتصرف. وقد تم تطبيق أحد أنظمة اتخاذ القرار متعدد المعايير ويطلق علية Rough Set على المعايير الآتية ( متوسط الإنتاجية، تكاليف المياه، تكاليف الطاقة، انتظامية التوزيع الحقلية، انتظامية التوزيع التصميمية، الطاقة المباشرة، الطاقة غير المباشرة، الطاقة الكلية، تكاليف التشغيل والصيانة، التكاليف المتغيرة، التكاليف الثابتة، التكاليف الكلية) وذلك بهدف تحديد أكثر هذه العوامل تأثيرا في عملية التقييم بالإضافة إلى درجة اكتفاء صاحب المزرعة كمعيار أساسي للحكم. ومن خلال هذه الدراسة تم التوصل إلى النتائج الآتية:

- ❖ من أهم المشاكل التي تواجه العاملين بتصميم شبكات الري هي إيجاد علاقة معنوية بين تكاليف النظام وتكاليف التشغيل والصيانة والتي تكون غالبا علاقة عكسية. من خلال النتائج المتحصل عليها من التحليل الرياضي والتي تحدد القيمة التي يجب المحافظة عليها لتوفير مستوى أمن من الدخل وكذلك القيمة المبدية التي يجب ألا تقل عنها كل من تكاليف المياه، تكاليف التشغيل والصيانة والطاقة غير المباشرة لتحقيق مستوى متوسط من الاكتفاء للمزارع.
- ❖ من خلال الدراسة تم التوصل إلى تحديد القيمة المطلوبة من الطاقة المباشرة واللازمة لتحقيق مستوى عالي من الاكتفاء للمزارع.
- ❖ من خلال النقطتين السابقتين تم التوصل إلى إيجاد علاقة عكسية بين كل من تكليف التشغيل والصيانة وكل من تكاليف المياه والطاقة المباشرة.
- ❖ من خلال التحليل المتكامل والذي تم التوصل إليه باستخدام Rough Set تم تحديد القيمة المبدئية لكل من الطاقة المباشرة وغير المباشرة والتي تحدد أقصى مساحة اقتصادية عند تصميم نظم الري.
- ❖ من خلال التحليل الإحصائي تم التوصل إلى معادل رياضية تربط بين كل من درجة انسداد النقاطات وبالتالي انتظامية التوزيع ومحتوى مياه الري من العناصر الكيميائية من الكالسيوم، المغنيسيوم والصوديوم والتي تؤثر على انتظامية التوزيع بمقدار 60%.
- ❖ من خلال الدراسة وجد أن التحليل الإحصائي له تأثير ضعيف في عملية التقييم مقارنة بـ Rough Set إلا انه أعطى تأكيد وتدعيم للأخير.