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# A multi-criteria analysis approach

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# Managing nitrate pollution in a Tunisian irrigated area
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*Abstract*--- **In Tunisia, the extension of irrigated area is justified by its important role in the development and diversification of agricultural production. Nevertheless, the strong intensification of the agricultural activities may lead to the pollution of underground water resources due to an excess use of fertilisers and other chemical products. In fact, the high nitrate concentrations observed in some Tunisian irrigated areas, are related to the excessive use of nitrate fertilizers in intensive agriculture. The objective of the present study is to implement decision-making methods allowing a better combination of factors production by optimization of an economic objective and an environmental objective.**

**This research is based on multi-criteria modelling through the optimization of two conflict objectives: an economic objective as settled by farmer in the short or medium-run (Gross margin), and an environmental objective (nitrate pollution reduction) as a long-run objective of the decision maker in order to ensure the continuity of agriculture activities and ecosystems sustainability.**

**Data were collected through a survey conducted in the irrigated area of Kalaât El Andalous in Tunisia with a sample containing 57 farms. Efficient solutions were obtained and compared through the "*constraints*", "*NISE*" and "*compromises*" methods.**

**Main results obtained indicate a significant degree of conflict between these two objectives. Indeed the maximization of the total gross margin involves an increase in the degrees of nitrate pollution and conversely. Finally, some policy implications are presented.**

*Keywords*--- **Nitrate pollution, environmental impact, multicriteria analysis**

## I. INTRODCUTION

In Tunisia, Agriculture is the principal user of water resources and it will still remain so beyond the 2030 horizon, even if the extension of the irrigated areas is will follow a slow growth during the 2010-2030 period. The expansion of the irrigated crops is justified by its important role in the development and diversification of agricultural production, especially for areas that are more dependent on climatic conditions. The irrigated sector represents 35% in the value of the total agricultural production while aiming to reach 50% into 2009.

Nevertheless, the high intensification of the agricultural activities may lead to the pollution of underground water resources due to the use of fertilisers and other chemicals. The high nitrate concentrations observed in some Tunisian irrigated areas, are due to an excessive use of nitrogen fertilizers in intensive agriculture where farmers are seeking an increase of soil productivity.

The issue is that farmers, as economic agents, are characterized by their individual rationality by seeking the maximization of their income using the best combination of inputs according to the available technology, but to the detriment of water and soil quality. However, the economic objective of farmers in the short or medium run, aiming at profit maximization involves a massive use of fertilizers according to the requirement of an none respectful intensive agriculture regarding the environment which can lead to nitrate pollution of both water and soil and consequently environment degradation.

On the other hand, decision makers aim at minimizing nitrate pollution, to achieve an environmental protection in order to ensure the continuity of Tunisian agriculture and ecosystems sustainability.

The purpose of the paper is to establish a plan allowing the simultaneous optimization of two conflict objectives, to minimise the environmental pollution and to maximise the economic income (agronomic gross margin) using multi-objective-programming as a support decision tool [1].

## II. METHODOLOGICAL APPROACH

The model approaches the problem of determining the efficient solutions under a set of two conflict objectives and constraints imposed by the production system. This is achieved by a multi-objective-programming. The set of efficient solutions was obtained using the constraints method, then the *NISE* method and complemented by compromise programming method. The study was conducted on a public irrigated area in the region of Kalaât El Andalous in the North of Tunisia.

### *A. Data sources*

Data were collected through a survey conducted on a sample of 57 farms located in the irrigated of area of Kalaât El Andalous (Tunisia). The sample used represented 10% of the total farms. Farms were classified in to three groups Through a cluster analysis. The first group contains 21 farms and corresponds to farmers who cultivate only cereals, considered as specialized farms. The second group includes farmers who cultivate only vegetables also considered as specialized farms and contains 8 farms. The third group is that of farmers who are practising cereals and vegetables, considered as diversified farms, and are about 28 farms.

### *B. Multiobjective modelling*

Multi-objective-programming (MOP) is used to find the efficient set among two conflict objectives: an economic objective and an environmental objective.
The objective function: The economic objective is addressed through the total gross margin (MBG) is written:

$$MBG = \sum_{j=1}^{n} (r_j p_j - cv_j) * x_j \; ; \qquad (1)$$

The environmental objective (pollution reduction): POLLUTION is written:

$$POLLUTION = \sum_{j=1}^{n} lost_j * x_j \qquad (2)$$

The model is expressed as follows (equation 3):

$$Max\ MBG = \sum_{j=1}^{n} (r_j p_j - cv_j) * x_j \qquad (3)$$

$$Min\ POLLUTION = \sum_{j=1}^{n} pertes_j * x_j$$

Subject to;

$$\sum_{j=1}^{n} x_j \le SAU + TL$$

$$\sum_{j=1}^{n} MO_j * x_j \le MOD + MOC$$

$$\sum_{j=1}^{n} Be_j * x_j \le EAUDISP + APPORT$$

$$\sum_{j=1}^{n} Bm_j * x_j \le MEC + ML$$

$$\sum_{j=1}^{n} Cinv_j * x_j \le Fonds$$

$$x_j \ge 0, \qquad j = 1, 2, \cdots, n$$

$r_j$ : output of the crop j; $p_j$ : price of the crop j; $cv_j$ : variable cost ; $x_j$ : activity level; Lost j : losses of nitrogen per crop j; $Cinv_j$ : investment cost of the crop j; Fonds: treasury ; MBG : Total Gross Margen ; SAU : Total agricultural area ; TL : Rented area ; MOj : Labour for crop j ; MOD : Disposable Labour ; MOC : Occasional labour ; Bej : Water required by crop j ; EAUDISP : Available water ; APPORT : Water imported ; MEC : Mechanisation available.

## III. RESULTS AND DISCUSSION

All the models developed were solved using GAMS (General Algebraic modelling System)
The 1st group of farmers is specialized in producing cereals: barley (ORG), oats (AV) and Lucerne (LUZ). The rotation restriction is expressed generally as follows: $\sum Following\ areas \le \sum previous\ areas$. The model takes into account the frequency restriction:

$$x_{ORG} + x_{AV} \le x_{LUZ} \; ; \qquad (4)$$

$$x_{ORG} \le 0.5 * SAU \qquad (5)$$

$$x_{AV} \ge 0.25 * SAU \qquad (6)$$

A device frequently used within the MOP approach is the payoff matrix. The elements of that matrix are obtained by optimizing the objectives under consideration and then computing their value in each one of the optimal solutions. The payoff matrix is very useful to illustrate the degree of conflict between the objectives under consideration. In this problem the ideal point related to the first group is **I** (3785.333, 80.250)**.** The anti-ideal is **I***(3000.000, 91.650).

The 2nd farmers group is specialized in producing vegetables: Tomato (TOM), Melon (MEL), artichoke (ARTCH) and other vegetables (LEG). Rotation restriction is expressed as follows:

$$x_{TOM} \leq 0.33 * SAU; \qquad (7)$$

$$x_{MEL} \leq 0.25 * SAU; \qquad (8)$$

$$x_{ARTCH} \leq 0.25 * SAU; \qquad (9)$$

$$x_{LEG} \leq 0.25 * SAU; \qquad (10)$$

The resolution generated: Ideal point: **I (16610.300, 634.453);** Anti-ideal: **I * (15800.0, 738.324)**

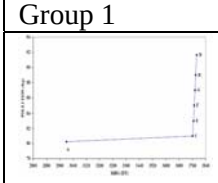
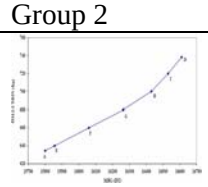
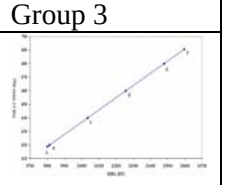
The 3rd farmers group is risk averse and tends to practise cereal crops as well as vegetables. Main crops cultivated by these farmers are durum wheat, barley, oats, bersim and artichoke indicated respectively by: BD, ORG, AV, BERS and ARTCH. By security measure the farmer always chooses to make durum wheat at least more than the 1/3 of the area. This restriction is presented by following equation: $x_{BD} \geq 0.33 * SAU$ (11)

The ideal point is I (10597.800, 618.829) and the anti-ideal point is I *(9800.000, 690.720).

For this farmers group, the MBG is relatively reduced compared to the others groups. However, pollution is less intense because of the nature of the cultivated crops.

*A. Constraint method*

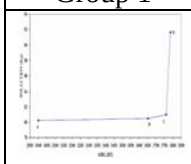
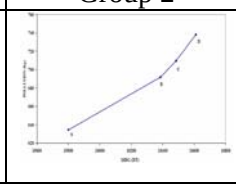
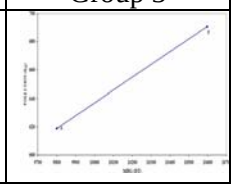
Table 1 Efficient solutions generated by constraints method

| Group 1 | Group 2 | Group 3 |
|---|---|---|
|  |  |  |

The efficiency zone is throughout the trade-off curve between the points, A (3000.000, 80.250) and D (3785.333, 91.650) for the Group 1, between A (15800.000, 634.453) and D (16610.300, 738.324) for the Group 2 and between A (9800.000, 618.829) and F (10597.800, 690.720) for the Group 3. The points which do not belong to this border constitute a lower solution or no efficient.

*B. NISE method*

Table 2 Efficient solutions generated by Nise method

| Group 1 | Group 2 | Group 3 |
|---|---|---|
|  |  |  |

- Group 1: The passage from B to C is characterized by an increase of 0.62% in the nitrogen pollution and an increase of 3% the total gross margin.
- Group 2: The passage from A to B is accompanied by an increase of 3.7% in the total gross margin and 9% in the nitrogen pollution. The increase of 0.6% in the profit starting from the point B generates an increase of 2.6% in the nitrogen pollution.
- Group 3: the solution is again the segment [A F] connecting the two efficient extreme solutions A and F. Noting that the passage from A to F is characterized by an increase of 8.25% in the total gross margin which generates an increase of 11.6% in the nitrate pollution level.

*C. Compromise method*

The compromise method is used with an aim of determining the efficient solutions. For the metric $L_1$ (p=1) the solutions are presented in the table 3.

Table 3 Solution generated by the Compromise method

| | *Solution* | | Point |
|---|---|---|---|
| | Gross Margin (TD) | Pollution | |
| Group 1 | 3760.000 | 81.000 | C |
| | 3760.730 | 81.071 | I |
| Group 2 | 3760.140 | 80.313 | J |
| | 3121.727 | 80.265 | K |
| Group 3 | 9800.000 | 618.829 | A |

## IV. CONCLUSIONS

This study aims at implementing methods of decision-making aid particularly adapted to the farms by ensuring a better combination of the production factors of making it possible of the kind to confront the maximization of the total gross margin with the minimization of the level of the nitrogen pollution.

The results obtained prove a high degree of conflict between these two objectives: the maximization of the gross margin (economic objective) and the minimisation of nitrogen pollution (environmental objective). It is shown that the vegetables, characterized by a high productivity, are the most polluting activities at a rate of 738.324 kg and are specific to the small-scale farming whose cultivated area lies between 5 and 10 ha . This reveals a high potential for such crops, that require an important nitrate fertilisation, but this needs an improvement at a practical level in order to avoid nitrate pollution.

MOP techniques used allowed addressing a specific problem within an agricultural irrigated area, with applicability in a decision problem not only for the farmer but also for the policy maker. CP was found to be useful to handle these kinds of problems. In such situations, the decision maker is interested in finding a compromise among several objectives rather than in optimising a single objective.

## REFERENCES

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