SADREG, a DSS for Improving Surface Irrigation Systems

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Abstract

To support design and management decisions relative to alternative solutions aimed at improving farm irrigation systems, the DSS software SADREG has been developed and applied to an irrigation district in Fergana, Central Asia. It allows generating and ranking alternative improvement scenarios according to user criteria. SADREG comprises two components: design and selection. The first one applies database information including GIS and produces a set of alternative design solutions, which performance characteristics are used in selection. The decision-maker participates in all decision process by expressing preferences and priorities for selection through interface dialog structures. SADREG is applied to rectangular shape fields, with assumed uniform soil intake characteristics. The modular components of DSS include a database, which may be accessed through GIS, simulation models and the multicriteria analysis model. The database concerns field sizes and topography, soil intake rates, soil water holding capacity, crop data, irrigation management data created through interactive simulations with the ISAREG model, and economic information. The surface irrigation models include: a land levelling module that applies an iterative optimisation of land forms with minimal soil movement, and the SIRMOD simulation model for surface irrigation design. Both the ISAREG and SIRMOD models were validated and parameterised before the application using appropriate field experiments and trials. The on-farm distribution systems refer to continuous and surge-flow (automatic or manually controlled) with layflat tubing with gates, gated pipes, concrete canal with lateral holes, and unlined canals with or without siphons. The user may consider other design options like relative to field length adjustments and runoff water reuse. The evaluation analysis includes cost and benefit calculations, and the determination of attributes relative to environmental impacts. The paper describes the DSS tool and its application to furrow irrigation in Fergana.

Key words: Furrow irrigation, Irrigation performances, Central Asia, Irrigation design, Multicriteria analysis.

1 Introduction

The improvement of farm irrigation systems in large surface irrigation projects may be well supported by DSS tools which application may be performed at field level, or at spatial level when linked with a GIS. This is the case for the Central Asia where a new version of SADREG (Gonçalves \textit{et al.}, 1998; Gonçalves and Pereira, 1999) is developed and applied. It is a DSS for on-farm surface irrigation system design and planning to assist designers and managers in the process of design and planning on-farm surface irrigation systems. It supports the design phase through a database, simulation models and user friendly interfaces; and allows for the alternatives ranking and selection applying a multicriteria methodology. It allows an user knowledge learning by doing process, i.e., through getting a progressive understanding by analyzing successive DSS results.

The SADREG application scope comprises:
A single field analysis to plan, design and evaluate alternative design options for furrow, basin or border irrigation considering several decision variables such as field slopes, water delivery methods and equipments, as well as reuse options;

An irrigation district or sector supplied by a collective system, when a spatially distributed database on farm systems is available through GIS, and where improvement alternatives are assessed jointly with modernization options relative to the conveyance and distribution network. This is the case when the model SEDAM is used, which is a DSS to simulate demand and delivery at sector level and to evaluate improvement scenarios. The links between SADREG and SEDAM through the GIS are also described by Gonçalves et al. (2005).

SADREG is an helpful tool to search and analyse modernization solutions for surface irrigation because:

- There are a large number of combinations of main factors such as soil infiltration and water holding capacity, field sizes, slopes and topography, crop irrigation requirements, and inflow rates, which become easier to manipulate through a GIS.
- Crop irrigation scheduling can be obtained from ISAREG simulations using the GISAREG version (Fortes et al., 2005). ISAREG is validated for the main crops in the area (Cholpankulov et al., 2004)
- The field experiments carried out at Fergana provided for appropriate model parameterisation (Horst et al., 2005)
- It allows a deep analysis of irrigation alternatives, with a focus on economic and environmental criteria, as well as an integrated operation with a demand and delivery analysis DSS model applied to the irrigation Sector, the SEDAM model (Gonçalves et al., 2005).

2 DSS Model

SADREG comprises two components: design and selection. The first one applies database information and produces a set of alternative designs, which produce the input data required for ranking and selection. The selection component is based on a multicriteria analysis in which the project alternatives are ranking allowing the decision-maker or the decision group select the best alternative. The decision-maker participates in all decision process through interface dialog structures, expressing its preferences and priorities required for ranking and selection of alternatives.

The modular components of DSS include a database, which may be accessed through GIS, simulation models and the multicriteria analysis model (Fig. 1). The database concerns field sizes and topography, soil intake rates, soil water holding capacity, crop data, irrigation management data created through interactive simulations with the ISAREG model, and economic information.

![Fig. 1. Modular components of SADREG.](image-url)
SADR EG is applied to a Field assumed with rectangular shape, uniform soil intake characteristics and cultivated with a single crop. The water is supplied from a collective conveyance system, that deliver the water from an hydrant. It has specific hydraulic characteristics, like the maximum discharge and head. These one can be an existent system, with values pre-fixed, or values selected by user, for design of a new system evaluation purposes.

The surface irrigation models include a land levelling module, that applies an iterative optimization of land forms with minimal soil movement, and the SIRMOD simulation model (ISED, 1989) for surface irrigation design. The farm surface irrigation systems concern continuous and surge-flow, automatic or manually controlled, and farm distribution systems refer to layflat tubing with gates, gated pipes, concrete canal with lateral holes, and unlined canals with or without siphons. The user may consider other design options relative to field length adjustments and/or runoff water reuse. The evaluation analysis refers to cost and benefits as well as to environmental and performance indicators.

3 SADREG Application

The main steps on a SADREG application are:
1) Identification of field characteristics;
2) Scenario development relative to decision variables such as field water supply, crop irrigation, furrow spacing, management allowed depletion (MAD), and furrows inflow regime (continuous vs. surge irrigation);
3) Data input including soil water data, infiltration and roughness parameters based on field experiments and/or databases, crop data, operation and equipment costs, labour and machine time durations, and water supply characteristics such as the hydraulic head and number and discharge of field outlets;
4) Design procedure to create alternatives with both design models referred before (Fig. 2) relative to the scenarios mentioned under item 2 above; and
5) Selection (and ranking) of alternative designs using multicriteria analysis where the user selects the weights according his priorities.

Fig. 2. Flowchart of the alternatives generator module.

The design options to generate alternatives are:
- Irrigation method: basins, borders or furrows.
- Field outlet: its number, discharge and head are user selected; it is assumed that all outlets are identical and each one irrigates the same area, named unit.
• Upstream supply side: side X or Y or both, according user choice.
• Land leveling: cross and longitudinal field slopes.
• Length adjustment: full, 1/2 or 1/3 or original length.
• Distribution system: earth canal, rigid pipe, flexible pipe or lined canal.
• Inflow supply regime: continuous or surge-flow; operated by an automatic or a manual valve.
• Tail end flow management: diked, free drainage, reuse by pumping or gravity (downstream fields).
• Crops, irrigation scheduling, with every furrow or alternate furrow irrigation.

The decision criteria refer to the following: total water use (m$^3$/ha/year), land productivity (kg/ha), land economic productivity (€/ha), water productivity (kg/m$^3$), water economic productivity (€/m$^3$), beneficial water use ratio, yield – cost ratio (kg/€), total cost – water use ratio (€/m$^3$), fixed (and variable) cost – water use ratio (€/m$^3$), runoff ratio, salinization risk (m$^3$/ha/year), soil impacts of land leveling (cm) and soil erosion index.

The impact analysis include the crop yield calculation, based on intake distribution during irrigation season, applying a yield function: a function relating relative water and crop yield is applied (Fig. 3).

\[
\begin{align*}
\text{Fig. 3. Irrigation water-yield function.}
\end{align*}
\]

The multicriteria analysis applies linear utility functions for benefit, cost and environmental criteria. Adopting user defined weights for every criteria, the global utility value is computed by the linear weighted method, getting the rank alternatives.

3 Central Asia application. Scenarios for farm irrigation improvement

Field studies and experiments were carried out on Fergana Valley. Both the ISAREG and SIRMOD models were validated and parameterized before the application using appropriate field experiments and trials (e.g. Horst et al., 2005).

The most representative field types of Fergana Valley have the following characteristics (Table 1 and 2):

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Area (ha)</th>
<th>Length (m)</th>
<th>TAW (mm/m)</th>
<th>Width (m)</th>
<th>Longit. Slope (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>large</td>
<td>20</td>
<td>400</td>
<td>150</td>
<td>500</td>
<td>0.25</td>
</tr>
<tr>
<td>medium</td>
<td>10</td>
<td>400</td>
<td>150</td>
<td>250</td>
<td>0.25</td>
</tr>
<tr>
<td>small</td>
<td>6</td>
<td>300</td>
<td>150</td>
<td>200</td>
<td>0.25</td>
</tr>
</tbody>
</table>
Nine typical fields ("workspaces" on SADREG model) have been established from field dimensions and infiltration classes:

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Infiltration</th>
</tr>
</thead>
<tbody>
<tr>
<td>large</td>
<td>High (I)</td>
</tr>
<tr>
<td></td>
<td>W1</td>
</tr>
<tr>
<td>medium</td>
<td>Medium (III)</td>
</tr>
<tr>
<td></td>
<td>W2</td>
</tr>
<tr>
<td>small</td>
<td>Low (VI)</td>
</tr>
<tr>
<td></td>
<td>W3</td>
</tr>
</tbody>
</table>

The field scenarios refers to the implementation of technical solutions to solve on-farm irrigation problems, related with scheduling, land leveling, inflow management and runoff control. More advanced solutions require farmer support actions, in a dynamic process that it develops on a time scale. Each "field scenario" step is represented in SADREG by a "project" object.

Each project is generated by the user by selecting a specific combination of design variables. The alternatives included in each project are differentiated by operative variables, like the inflow rate and the application time. Table 3 summarizes the different projects constructed. The projects that represent the improved conditions consider the several options of field distribution system, length adjustment and tail water management.

<table>
<thead>
<tr>
<th>Projects</th>
<th>Crop</th>
<th>Schedule</th>
<th>Furrows spacing (m)</th>
<th>Land levelling</th>
<th>Inflow regime</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>cotton</td>
<td>over irrigation</td>
<td>0.90</td>
<td>no</td>
<td>continuous</td>
<td>present situation</td>
</tr>
<tr>
<td>P2</td>
<td>cotton</td>
<td>optimal</td>
<td>0.90</td>
<td>yes</td>
<td>continuous</td>
<td>improved</td>
</tr>
<tr>
<td>P3</td>
<td>cotton</td>
<td>optimal</td>
<td>1.80</td>
<td>yes</td>
<td>continuous</td>
<td>improved</td>
</tr>
<tr>
<td>P4</td>
<td>cotton</td>
<td>deficit</td>
<td>0.90</td>
<td>yes</td>
<td>continuous</td>
<td>improved</td>
</tr>
<tr>
<td>P5</td>
<td>cotton</td>
<td>deficit</td>
<td>1.80</td>
<td>yes</td>
<td>continuous</td>
<td>improved</td>
</tr>
<tr>
<td>P6</td>
<td>cotton</td>
<td>optimal</td>
<td>0.90</td>
<td>yes</td>
<td>surge</td>
<td>improved</td>
</tr>
<tr>
<td>P7</td>
<td>cotton</td>
<td>optimal</td>
<td>1.80</td>
<td>yes</td>
<td>surge</td>
<td>improved</td>
</tr>
<tr>
<td>P8</td>
<td>cotton</td>
<td>deficit</td>
<td>0.90</td>
<td>yes</td>
<td>surge</td>
<td>improved</td>
</tr>
<tr>
<td>P9</td>
<td>cotton</td>
<td>deficit</td>
<td>1.80</td>
<td>yes</td>
<td>surge</td>
<td>improved</td>
</tr>
</tbody>
</table>

The rank number of projects is related with the level of complexity of the system, including it operability. The application of surge-flow, the deficit irrigation and the alternated furrows irrigation, increase the potential for water savings but they have more requirements to control the scheduling and the inflows. Because the risks of crop damage by water stress are bigger, mainly when the farmers have the common practice of over irrigate to avoid these same problems.

The SADREG integration on a sector demand and delivery model is an useful application. The decisions at collective network supply system level refers to the district management authority and generally correspond to the establishment of delivery rules, the discharge and time of supply to the fields. The SADREG application to an irrigation sector to model the demand and the water distribution require the following procedure: (a) the irrigation scheduling for each crop and soil type has a centralised plan, related with groups of homogenous fields; and (b) the field projects are typified ant their application is related with sector scenarios for water delivery improvement.

4 Results and conclusions

SADREG application generated a large number of alternatives for field irrigation, correponding to the multiple combinations of design options, fields and projects. Focusing the performance of field projects, the specific results for average field (W5, with 400 x 200 m size) are presented and analysed.

To carry out the sensitivity analysis of the decision-maker priorities, three different scenarios are applied:

1. Balance between economic and environmental impacts –balance situation where is attributed equal weights to all groups of criteria (benefits=1/3, costs=1/3, enviromental impacts=1/3);
2. Priority to Environmental and water saving impacts – in this scenario importance is given to environmental impacts mainly to the water consumption (benefits=1/5, costs=1/5, environmental impacts=3/5);

3. Priority to Economic impacts – importance is given mainly to the economic results (benefits=2/5, costs=2/5, environmental impacts=1/5).

The projects performances expressed by global utility were calculated for each priority scenario (Fig 4). These results allow the following conclusions:

a) The project 5 shows the better performance, according the several criteria. It means that the irrigation improvement with land levelling, continuous irrigation with alternated furrows is a very feasible solution.

b) The present scenario (P1) has a lower performance in the environmental priority scenario, because this solution has very low irrigation efficiency. The reasonable economic performance is explained by the very low price of the water. This result proves that present scenario is not feasible if water saving will be a strong priority on water management.

c) The comparison between continuous and surge-flow is not conclusive, because the length adjustment option allows an increase of efficiency of continuous irrigation for shorter length of run furrows. This option only is accepted in practice is the incremental labor is available. In fact, the multitier technic is more labor required. If labor will be more expansive or limited for irrigation operation, the surge-flow would be more competitive rather than continuous one.

4 References


