18 - SADREG, A DSS FOR SURFACE IRRIGATION

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Abstract: The DSS software SADREG has been developed and applied to an irrigation district in Fergana, Central Asia, to support design and management decisions relative to farm irrigation systems. SADREG generates and ranks alternative improvement scenarios according to user criteria. It 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 for selection. The decision-maker expresses his (her) 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 that 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 parameterized 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 field length adjustments and runoff water reuse. The evaluation analysis includes cost and benefit calculations, and attributes relative to environmental impacts. The paper describes the DSS tool and its application to furrow irrigation in Fergana. Results show the usefulness of this tool when searching for feasible improvements in surface irrigation systems.

Keywords: Furrow irrigation, Irrigation performances, Central Asia, Irrigation design, Multicriteria analysis, Decision support system (DSS).

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Introduction

The improvement of farm irrigation systems in large surface irrigation projects can be well supported by DSS tools which application may be performed at field level or at sector level when linked with a GIS. This is the case for the Central Asia where a new version of SADREG (Gonçalves *et al.*, 1998; Gonçalves and Pereira, 1999) is developed and applied. It is a DSS aimed to assist designers and managers in the process of design and planning improvements in farm surface irrigation systems. SADREG includes a database, simulation models and user-friendly interfaces; and allows for ranking and selection of design alternatives through a multicriteria decision process.

The SADREG application scope comprises: (a) a single field analysis relative to 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; (b) an irrigation sector analysis, when a spatially distributed database relative to the 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 and assess improvements on demand and delivery at sector level (Gonçalves *et al.*, 2005). The links between SADREG and SEDAM through the GIS are described by Gonçalves *et al.* (2005).

SADREG is an helpful tool to search and analyse modernization solutions for surface irrigation because designing surface irrigation systems imply the selection among 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 and ranking through a DSS tool. When several fields within an irrigation district are considered, then the task becomes only feasible if a spatially distributed database is also available. In addition, SADREG is conceived in such a manner that the user may learn through the application process.

In case of Central Asia, crop irrigation scheduling is obtained from ISAREG simulations, including with the GISAREG version (Fortes *et al.*, 2005), which is validated for the main crops in the area (Cholpankulov *et al.*, 2005). Field experiments carried out at Fergana provided for appropriate parameterisation of the surface irrigation simulation model (Horst *et al.*, 2005a, b) used in the DSS. This paper refers to the single field analysis and describes both the DSS model and its application to furrow irrigation in Fergana, Uzbekistan.

DSS Model

SADREG comprises two components: design and selection (Fig. 1). The first one applies database information and produces a set of alternative designs, which characterization data is used for ranking and selection. The selection component is based on a multicriteria analysis in which the project alternatives are ranking allowing the decision-maker to 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.

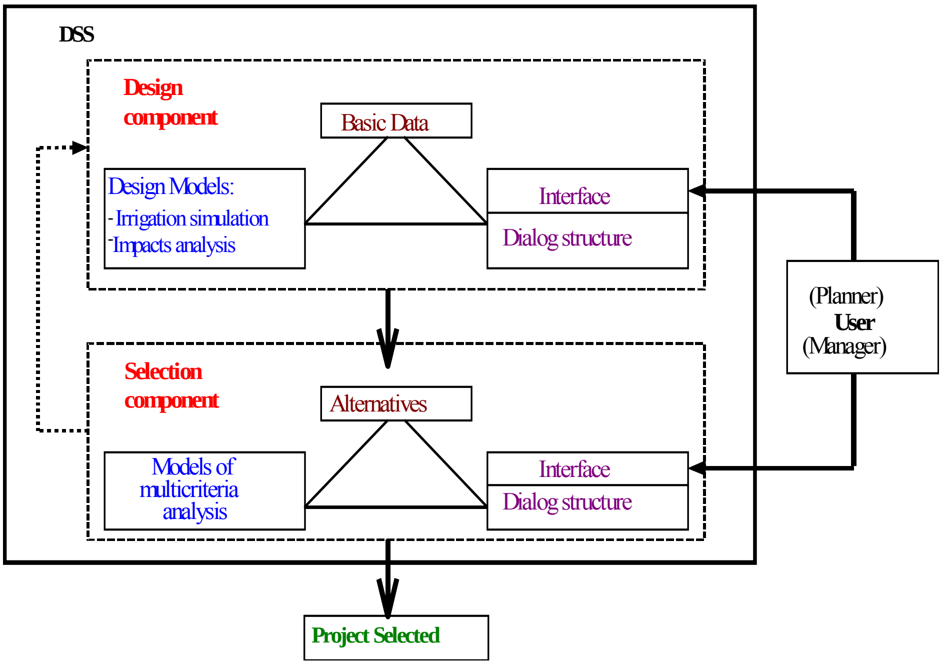


Fig. 1. Conceptual structure of SADREG.

The modular components of DSS include a database, which may be accessed through GIS, simulation models and the multicriteria analysis model (Fig. 2). The database concerns field sizes and topography, soil intake rates, soil water holding capacity, economic data, crop data, and irrigation management data created through interactive simulations with the ISAREG model.

SADREG 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 delivers the water from a given hydrant, which has specific hydraulic characteristics, like the maximum discharge and head. These data may be referring to an existing system, or values may be selected by user.

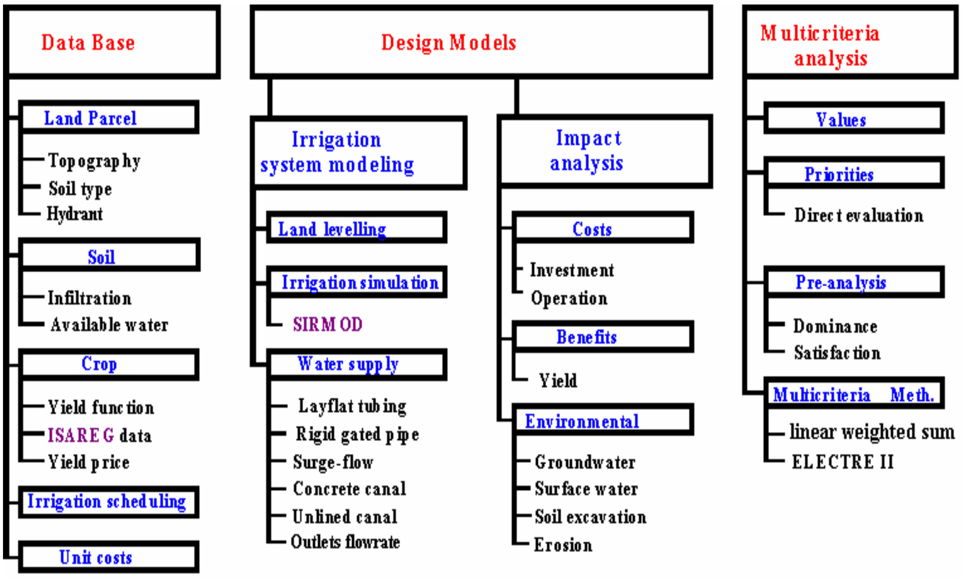


Fig. 2. Modular components of SADREG.

The surface irrigation models include a land levelling module, that applies an iterative optimization of landforms with minimal soil movement (Fig. 3), and the SIRMOD simulation model (ISED, 1989) for surface irrigation design (Fig. 4).

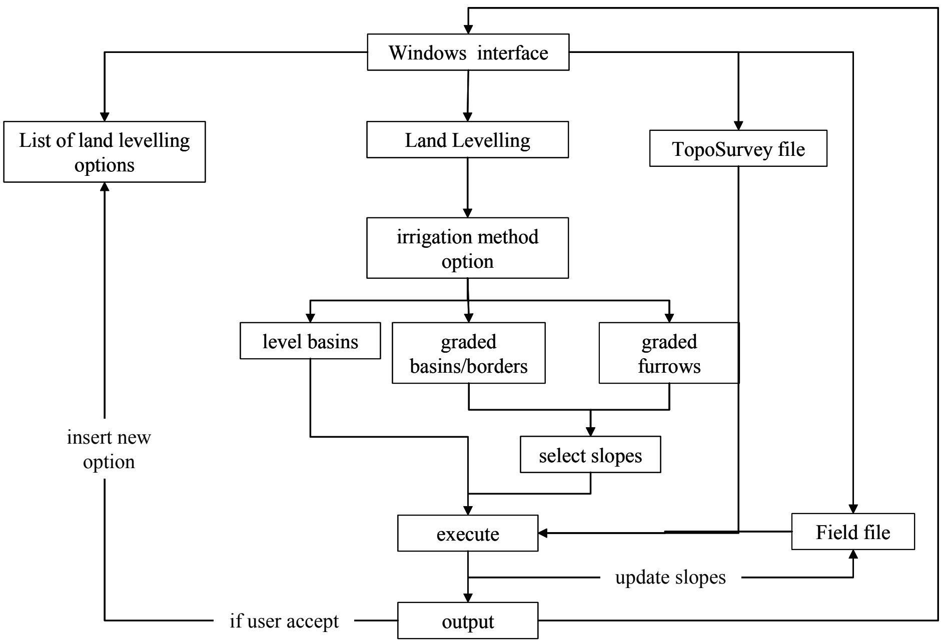


Fig. 3. Land levelling module flowchart.

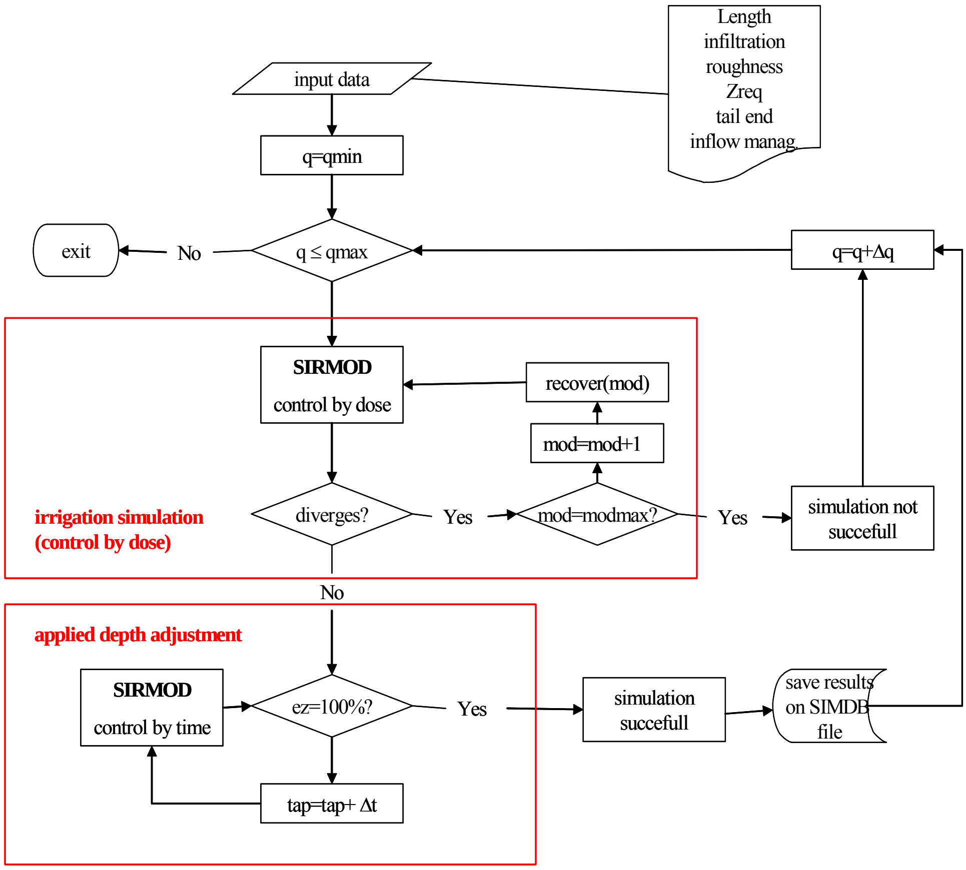


Fig. 4. Flowchart relative to the execution of the SIRMOD application procedure.

The farm surface irrigation systems refer to basin, border and furrow irrigation. The later concerns continuous and surge-flow, automatic or manually controlled. 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 several design options, including relative to runoff water reuse and field length adjustments. The option of length adjustment could be interesting for long fields by comparing gains in the application efficiency against increased labour and operation costs. The evaluation analysis refers to cost and benefits as well as to environmental and performance indicators.

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 referring to 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 using both design models referred above (Fig. 2) relative to the considered scenarios (item 2 above);
5) Ranking and selection of alternative designs using multicriteria analysis where weights are defined according the user priorities.

To carry out this sequence of operations is necessary to understand the main concepts and the hierarchy of the elements that compose the SADREG data structure. Main concepts:

- **Field -** is an rectangular shape on-farm land parcel, with a well known geographical location, with an uniform soil intake characteristics and a water supply hydrant; it is an element of a farm enterprise and belonging to a Water Use Association area;
- **Hydrant** - is a gate on the network delivery system that supply the field;
- **Outlet** - is a discharge point, inside the field, connected to the field distribution system; a field can have several outlets.

The SADREG data structure can be described as follows (Fig. 5):

- **Workspace** - is the basic element of SADREG data structure; corresponds to an individual Field and include all its data files. The information for each Field include: location; dimension; agronomic data; topographic survey, etc;
- **Project -** each Project is a Field Scenario to develop a design for the selected field. Several projects can be created for each Workspace receiving different names;
- **Alternative -** is a complete design solution for the selected field;
- **Group of alternatives** - a cluster that are differentiated by structural decision variables (e.g. land levelling, irrigation method, equipments); within a group, the alternatives are differentiated by the operative values (unitary inflow rate and application time) and the number of sub-units;
- **Unit** – it is a field subdivision irrigated by a single outlet; it is assumed that all units of a field are similar;
- **Sub-unit** – it is the fraction of a unit that is irrigated at the same time.

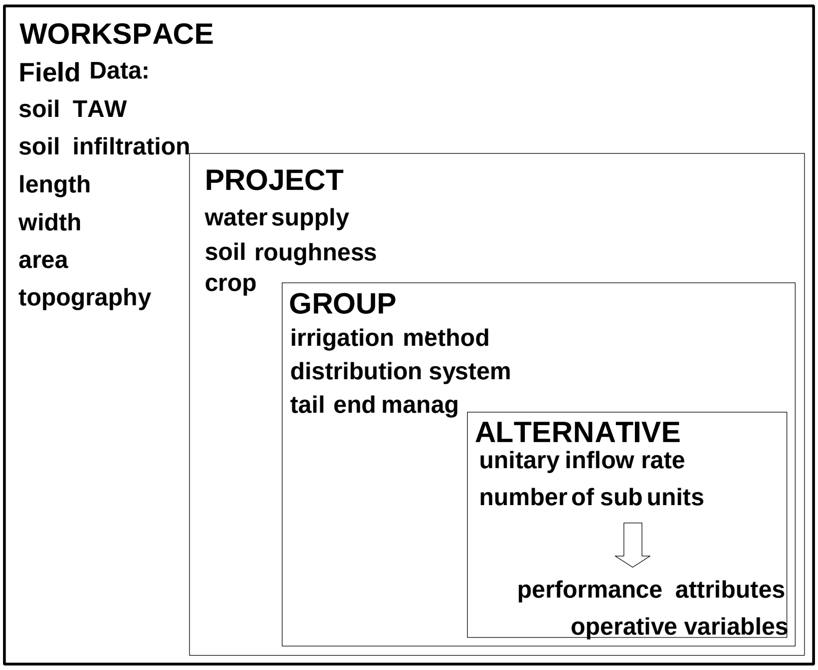


Fig. 5. SADREG data structure elements.

To construct the different alternatives of one project is necessary to have in mind the existing relations between the several irrigation design options (Fig. 6). Thus, the generation of alternatives has to be made as described in the following:

1. To select the irrigation method: flat level basin, graded basins or border, or graded furrows.
2. To choose the inflow supply regime, that for basins and borders is continuous constant flow, while for graded furrows it can be surge-flow.
3. To select the water distribution system among rigid pipe, lay-flat pipe, earth canal, or lined canal; if the surge-flow is chosen, then the control system is also to be selected between manual or automated control.
4. To select the tail water management: for basins the option is diked, while for borders and furrows it may be diked, open without reuse, reuse with pumping, and gravity reuse.

Once the design options are selected, the programme generates the design alternatives as indicated in Fig. 7.

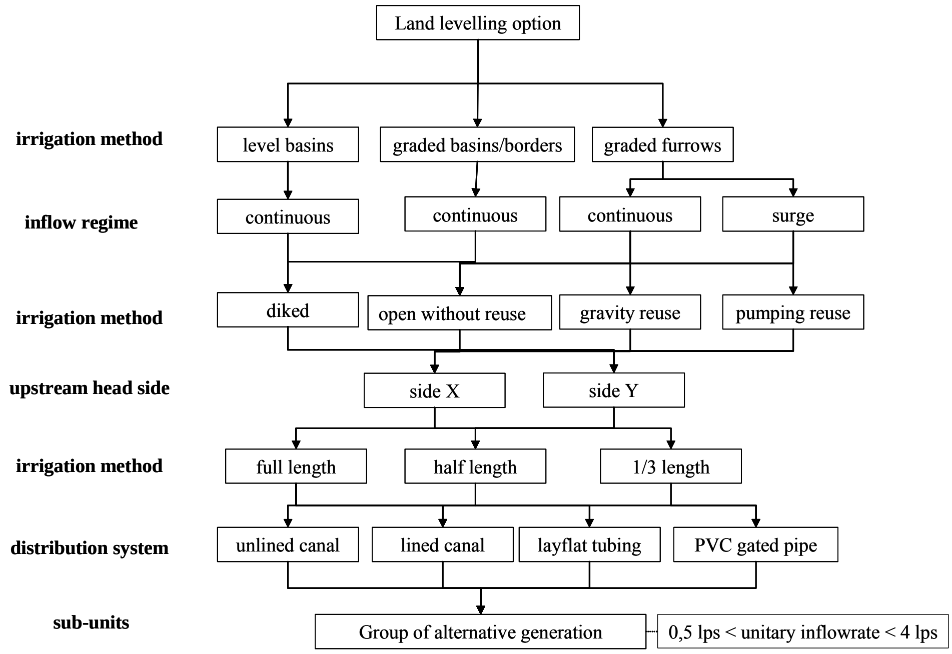


Fig. 6. Design variables for the alternatives generation procedure.

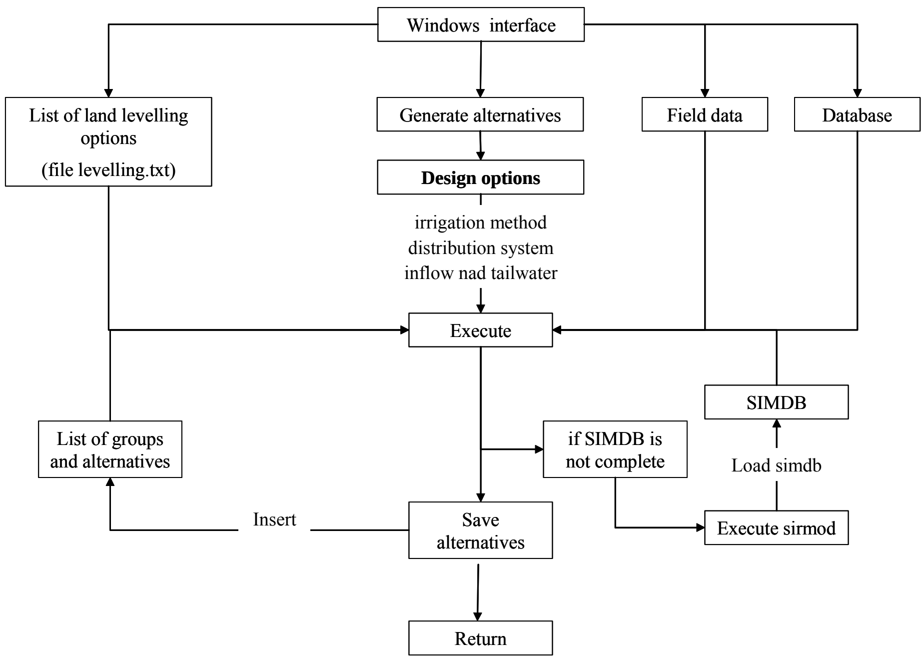


Fig. 7. Flowchart of the alternatives generator module.

The user design options to generate alternatives for furrow irrigation (Table 1) are described as follows:

- Field outlets or hydrants: number per field and respective discharge and head; 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;
- Land levelling: cross and longitudinal field slopes;
- Length adjustment: full, 1/2 or 1/3, i.e. not adjusting or reducing the length to the half or the third of the actual length (Fig. 8);

Table 1. Design variables.

	Decision variables
topographic	- supply side (X or Y)
(land levelling options)	- field length (adjustments)
	- transversal slope
	- longitudinal slope
supply system	- number of outlets
	- outlet discharge and head
distribution system	- canal, layflat, rigid pipe
reuse system	- reuse by pumping
	- gravity reuse on other fields
operation	- inflow rate (nr. of sub-units)

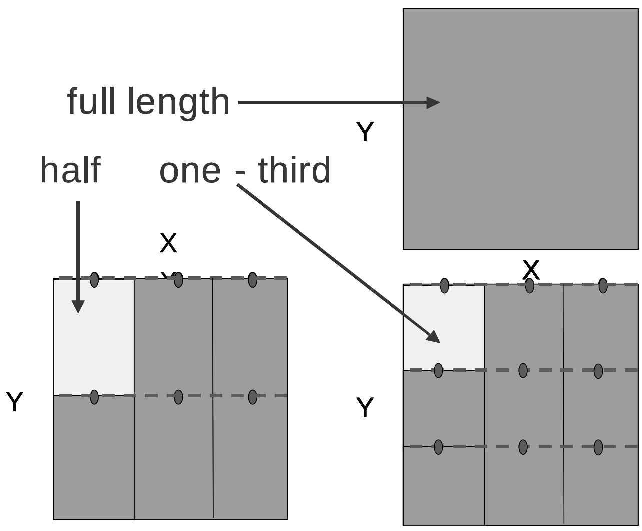


Fig. 8. Schematic representation of field length adjustment, including multi-tier.

- Distribution system: rigid pipe, lay-flat pipe, earth canal, or lined canal (Fig. 9);
- Inflow supply regime: continuous or surge-flow; operated by an automatic or a manual valve;
- Tail-end flow management: diked, free drainage, or water reuse by pumping or gravity to downstream fields;
- Crops irrigation scheduling, with every furrow or alternate furrow irrigation.

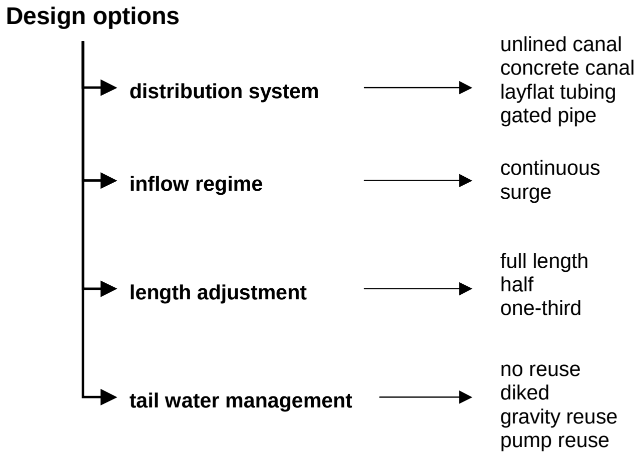


Fig. 9. Design options.

The decision criteria refer to the following: total water use (m^3 $ha^{-1}year^{-1}$), 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 $year^{-1}$), soil impacts of land levelling (cm) and soil erosion index.

The impact analysis includes the crop yield estimation based upon the total water use during the irrigation season and adopting an user selected yield function relating the relative yield with the relative water application (Fig. 10). Three functions are available: the quadratic one, with an adjusted decreasing branch where the user selects the parameter dw relative to the deviation relative to the quadratic function, and a fitting function where the user provides the decreasing branch through a table.

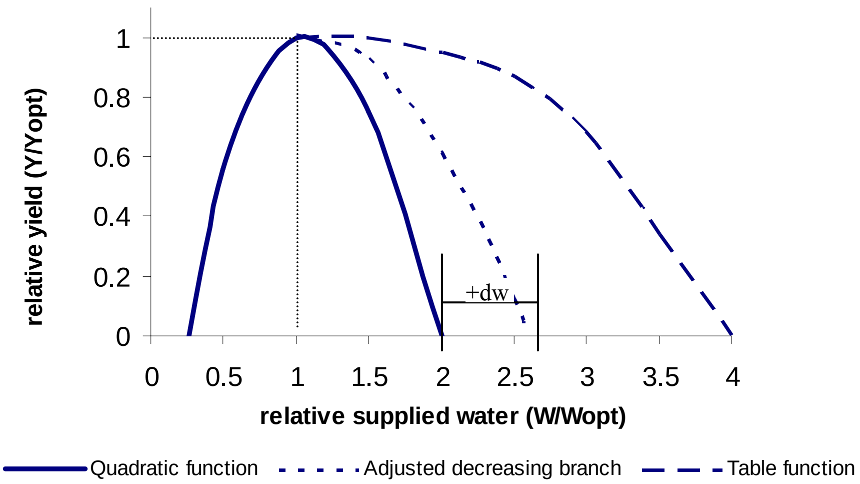


Fig. 10. Irrigation water-yield function.

The multicriteria analysis applies linear utility functions for benefits, costs and environmental criteria; the weights for every criterion are user defined and the global utility value to rank alternatives is computed by a linear weighing method.

The programme generates a large number of alternatives in consequence of combination of design variables; however, it is very difficult for user to view and analyse, one by one, the existing alternatives on database. Thus, the multicriteria analysis module has a very important role on automatic management of large amount of data. It screens the alternatives, removing the not satisfactory and dominated alternatives, selecting the most adequate one, by groups and by projects.

Application of SAGREG to cotton furrow irrigation in Fergana

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 (Cholpankulov *et al.*, 2005; Horst *et al.*, 2005a, b). The typical infiltration curves for Fergana are identified in Table 2 and the curves are shown in Fig. 11.

The most representative field types in Fergana Valley have the characteristics given in Table 3. For the application, 9 typical fields or "*workspaces*" (Wi, with i = 1, 2, …9) have been established combining field sizes and infiltration classes (Table 4).

Table 2. Identification of the infiltration curves for Fergana.

Soil-infiltration classification	Irrigation event				
	1st	2nd	3rd	4th	5th and following
I (high)	F1	F2	F2	F3	F3
II (medium-high)	F1	F2	F3	F4	F4
III (medium)	F2	F3	F3	F4	F4
IV (medium-low)	F2	F3	F3	F4	F5
V (low)	F2	F3	F4	F5	F5
VI (very low)	F3	F4	F5	F5	F5

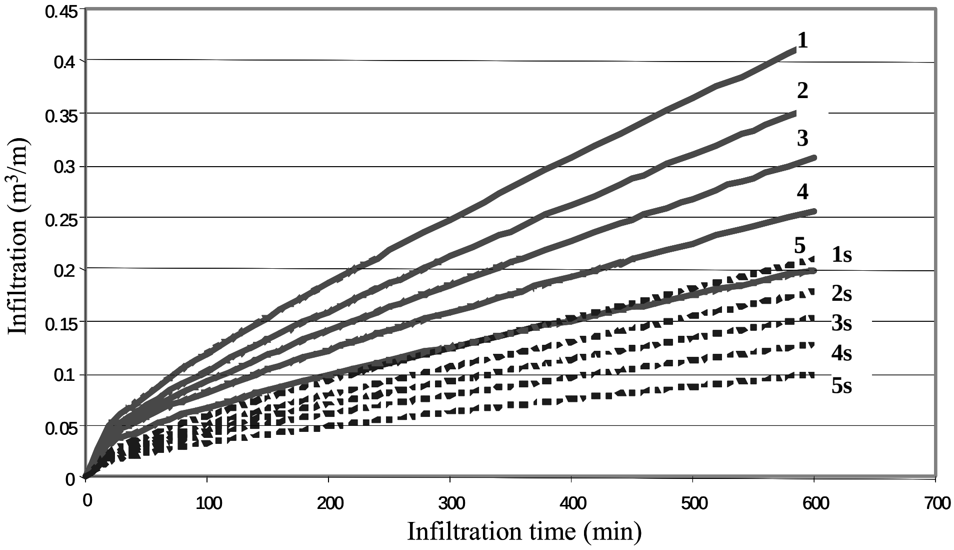


Fig. 11. Soil infiltration curves for continuous (▬▬) and surge flow (– – –).

Table 3. Most representative field types.

Field sizes	Area (ha)	Length (m)	TAW (mm/m)	Width (m)	Longitudinal. Slope (%)
large	20	400	150	500	0.25
medium	10	400	150	250	0.25
small	6	300	150	200	0.25

As referred in Table 3, the following three field sizes are applied:

- 6 ha, 300 x 200 m, with a length of 300 m
- 10 ha - 400 x 250 m, with a length of 400 m
- 20 ha - 400 x 500 m, with a length of 400 m

Table 4. *Workspaces* relative to the main field types.

Infiltration	Field sizes		
	large	medium	small
High (I)	W4	W5	W6
Medium (III)	W1	W2	W3
Low (VI)	W7	W8	W9

Comparing results for fields of 6 ha and 10 ha (Table 3), one may observe the response to the furrows length (300 and 400 m) and field area, while comparing the fields of 10 and 20 ha, one may analyze the impact of the field area since furrows have the same length.

The length adjustment option was considered because the "multi-tier" approach (Horst *et al.*, 2005a) has a large potential to increase the application efficiency. However this technique is labour consuming; because SADREG has not any constraint on labour, results relative to length adjustment must be carefully observed and analyzed before to achieve final conclusions.

The field scenarios refer to a progressive implementation of improved technical solutions relative to irrigation scheduling, land levelling, inflow management and runoff control. Each scenario represents a step in the improvement process and corresponds to a "*project*" object. In SADREG each *project* is generated by the user by selecting a specific combination of design variables. The alternatives included in each project refer to different operative variables, e.g. the inflow rate and the application time. Scenarios (*projects*) were built considering cotton as the main crop; they are identified in Table 5.

Table 5. Summary of projects considered for the decision process.

Projects	Crop	Irrigation scheduling	Furrow spacing (m)	Land levelling	Inflow regime	Condition
P0	cotton	present (over irrigation)	0.90	no	continuous	present
P1	cotton	MAD = 0.4	0.90	no	continuous	improved **
P2	cotton	optimal	0.90	yes	continuous	improved
P3	cotton	optimal	1.80*	yes	continuous	improved
P4	cotton	deficit	0.90	yes	continuous	improved
P5	cotton	deficit	1.80*	yes	continuous	improved
P6	cotton	optimal	0.90	yes	surge	improved
P7	cotton	optimal	1.80*	yes	surge	improved
P8	cotton	deficit	0.90	yes	surge	improved
P9	cotton	deficit	1.80*	yes	surge	improved

(*) wider furrow spacing refers to the adoption of alternate furrow irrigation
(**) the improvement refers only to reducing the cut-off times.

The scenario relative to "present" is described by a project without any improvement, so with the actual scheduling, without land levelling; and continuous inflow, however well managed thus corresponding to the potential performance of actual systems without changing the irrigation scheduling. To build the improvement scenarios for Fergana Valley the factors listed in Table 6 were considered: The scenarios or "projects" are shown in Table 7.

Table 6. Irrigation improvement factors.

Technical issues	Levels for scenarios generation	Level of changes
1. Field water supply	Actual hydrant maximum discharge and number of outlets	no changes
2. Crop	Cotton	no changes
3. Furrow water application	Every furrow (0.90 m) Alternate furrow (1.80 m)	a b
4. Irrigation scheduling	Over irrigation (present) Improved irrigation (MAD=0.4) Optimal situation (MAD=0.6) Deficit irrigation (MAD=0.8)	a b c d
5. Inflow regime	Continuous-flow Surge-flow	a b
6. Field water distribution	earth canal flexible pipe gated pipe	a b c
7. Length adjustment	full length half length 1/3 length	a b c
8. Tail water management	open diked reuse with pumping	a b c

Table 7. On-farm irrigation improvement scenarios (SADREG projects).

Scenarios (projects)	Design factors and respective levels of improvement*							
	1	2	3	4	5	6	7	8
P0	n. c.	n. c.	a	a	a	a	a	a
P1	n. c.	n. c.	a	b	a	a	a	a
P2	n. c.	n. c.	a	c	a	a, b, c	a, b, c	a, b, c
P3	n. c.	n. c.	b	c	a	a, b, c	a, b, c	a, b, c
P4	n. c.	n. c.	a	d	a	a, b, c	a, b, c	a, b, c
P5	n. c.	n. c.	b	d	a	a, b, c	a, b, c	a, b, c
P6	n. c.	n. c.	a	c	b	a, b, c	a, b	a, b, c
P7	n. c.	n. c.	b	c	b	a, b, c	a, b	a, b, c
P8	n. c.	n. c.	a	d	b	a, b, c	a, b	a, b, c
P9	n. c.	n. c.	b	d	b	a, b, c	a, b	a, b, c

***** levels a, b and c (Table 6) for factors 6 to 8 depend upon the field characteristics. Symbol n.c. indicates that no improved design factors were considered.

The rank number of projects is related with the level of complexity of the system, including its operability. The application of surge-flow, deficit irrigation and alternated furrows irrigation, increase the potential for water savings but is more demanding in terms of irrigation management control.

When SADREG is applied to an irrigation sector, demand and the water distribution require that the irrigation scheduling for each crop and soil type follow the same approaches, so the field projects are typified and the application is relates given scenarios for water delivery.

Decision making prioritization

The decision maker may express his preferences and priorities for ranking and selection of alternative designs through the weights given to each criterion. Among all possible combinations of weights, those considered in this study are listed in Table 8.

Table 8. Types of decision maker priorities (weights in %).

Criteria	Attributes	Types of prioritization		
		Balanced priorities	Priority to environment and water saving	Priority to economic issues
Benefits	Land Productivity	6	3	7
	Land Economic Productivity	5	3	7
	Water Productivity	6	4	6
	Water Economic Productivity	5	3	7
	Beneficial Water Use ratio	6	4	6
	Yield Value - Total Cost ratio	6	3	7
	Total	**34**	**20**	**40**
Cost	Total Cost per Water Use	11	6	14
	Fixed Cost per Water Use	11	7	13
	Variable Cost per Water Use	11	7	13
	Total	**33**	**20**	**40**
Environmental impacts	Total Water Use	7	20	4
	Runoff Ratio	7	15	4
	Salinization Risk	6	15	4
	Levelling Soil Impact	6	5	4
	Soil Erosion Index	7	5	4
	Total	**33**	**60**	**20**

The combinations in Table 8 refer to the following criteria for prioritization:

1. *Balance between economic and environmental issue*s, when equal weights are attributed to all groups of criteria (benefits, costs, environmental impacts);

2. *Priority to environmental and water saving issues*, when more importance is given to criteria relative to environmental impacts, mainly water use;
3. *Priority to economic issues*, when higher weights are given to the economic results.

To carry out a further sensitivity analysis of the decision-making priorities, these three different types of prioritization were applied.

Performance indicators

To analyze the results the following performance indicators are considered:

- *Land productivity* (LP) - it is the amount of yield (cotton crop) per unit area (kg ha^{-1}), expressing irrigation performance on crop benefice point of view;
- *Water productivity* (WP) - this indicator expresses the yield per unit volume of irrigation water (kgm^{-3}); it is very important to qualify the irrigation performance relative to water when this factor is scarce and expansive;
- *Total water cost* (TWC) - it is the total cost relative to irrigation (€ ha^{-1});
- *Total water use* (TWU) - it is the annual amount of irrigation water applied per unit area (mm);
- *Salinization risk* (SR) - it is the volume of water that deep percolates (mm), meaning the potential of groundwater salinization;
- *Global Utility* (U) - it is the aggregated utility characteristic of alternatives, being dependent of irrigation performance, criteria weights and utility functions;
- *Distribution uniformity* (DU) – it is the ratio between the average low-quarter depth of water received and the average depth of water received in the field (%);
- *Application efficiency* (Ea) – it is the ratio between the average depth of water added to the root zone storage and the gross depth of water delivered to the field (%).

The analysis of next topics was done according the following procedure:

a) the more representative field types (*workspaces*) were considered (Table 4);
b) alternatives were generated for each field type (*workspace*) and scenario for improvement (*project*) as referred in Tables 5 to 7;
c) these alternatives were ranked according the three types of prioritization (criteria weights) defined in Table 8;
d) The alternative selected for each improvement scenario (*project*) was analyzed and its attributes and indicators were used to its characterization.

Field lengths were adjusted as referred before in case of adopting criteria weights reflecting a balance among economic and environmental impacts (see Table 8). The adjusted lengths are listed in Table 9 for each field type and project alternative. Furrow lengths were assumed equal to the field lengths; the multi-tier option (Horst *et al.*, 2005a) was adopted only for the project alternative 6 and for fields with 400 m length.

Table 9. Field lengths adopted for each field type (Wi) and project alternative (Pi).

Field types (workspaces)	Actual field length (m)	Adjusted field lengths (m) for project alternatives									
		P0	P1	P2	P3	P4	P5	P6	P7	P8	P9
W1	400	400	200	200	400	200	400	200	200	200	200
W2	400	400	400	200	400	200	400	133	400	400	400
W3	300	300	300	300	300	300	300	150	300	300	300
W4	400	400	200	200	400	400	400	133	200	200	200
W5	400	400	400	200	400	200	200	133	400	400	400
W6	300	300	150	150	300	150	300	150	300	300	300
W7	400	400	400	400	400	400	400	200	400	400	400
W8	400	400	400	400	400	400	400	200	400	400	400
W9	300	300	300	300	300	300	300	300	300	300	300

Results comparing alternative furrow irrigation strategies

Irrigation performances as related with field sizes

Results shown in the following were selected with the objective of assessing how irrigation performances relative to different improvement scenarios (*projects*) are influenced by the field sizes; they concern:

i. Fields cropped with cotton, soils with medium infiltration (curve III) and TAW = 150 mm/m, and an average longitudinal slope = 0.25%;
ii. On-farm priorities representing a balance among economic and environmental impacts.

Seasonal water use

There is a higher water use comparing the present scenario P0 with the improved project scenarios, including the simple adjustment of cutoff times P1 (Fig.12).

When the length adjustment option is considered (Fig. 12a), similar seasonal water use are predicted for all improved solutions with slightly worst results for fields with 6 ha. Without length adjustment, the continuous flow with every furrow irrigation (P2 and P4) show better performance than continuous flow in alternate furrows (P3 and P5) for 10 and 20 ha, but for the 6 ha field alternate furrows present slightly better results than continuous flow. The best results are for surge-flow both for every and alternate furrow irrigation.

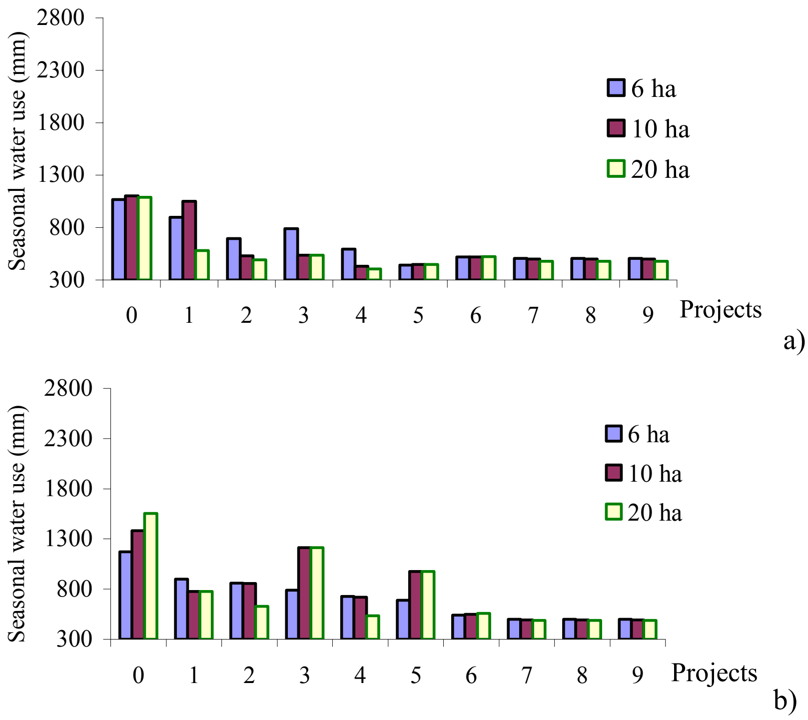


Fig. 12. Seasonal water use in relation to progressive improvements as affected by field sizes for fields where length is adjusted (a) or actual length is kept (b).

Distribution uniformity

The distribution uniformity DU shows very good results for all projects (Fig. 13); one can notice a trend for improving DU when technical improvements are considered, mainly with surge-flow (P6 to P9).

Results for DU are similar with and without length adjustment. Without length adjustment the option for alternate furrow irrigation, P3 and P5, have similar results to the surge-flow projects for furrows with larger length (400 m).

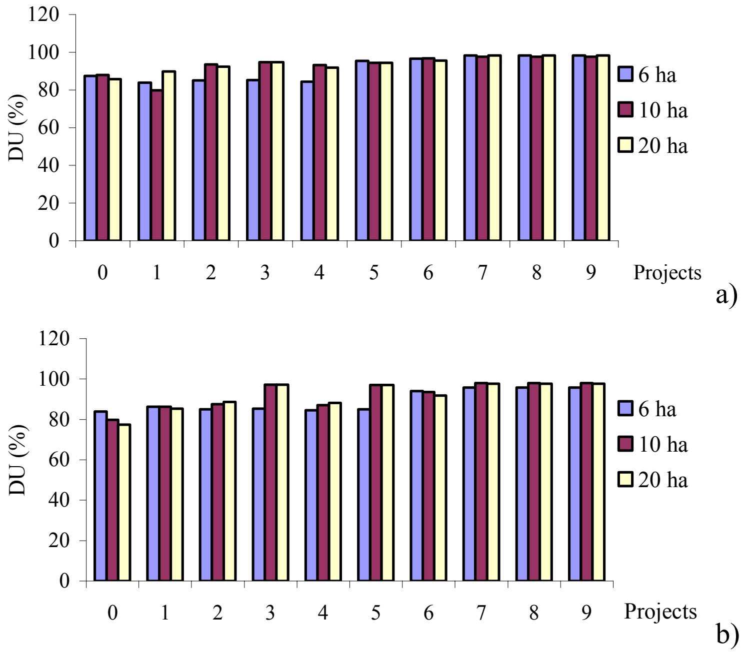


Fig. 13. Distribution uniformity in relation to progressive improvements as affected by field sizes for fields where length is adjusted (a) or actual length is kept (b).

Application efficiency

For present scenario P0 the application efficiency shows poor results. Application efficiency (Ea) values (Fig. 14) are less good than those for DU but it is noticeable that Ea increases relative to present for all scenarios including P1, when only the cutoff times are improved. For fields where the length is adjusted, there are similar results comparing continuous and surge-flow; however, continuous every furrow (P2, P3) and surge every furrow (P6) show better results.

It is evident that surge-flow presents the highest Ea values when the actual length is kept. For this case, the fields with smaller sizes (6 ha) show the best results, contrarily to the case when the length is adjusted. P1 (continuous) presents results similar to surge-flow.

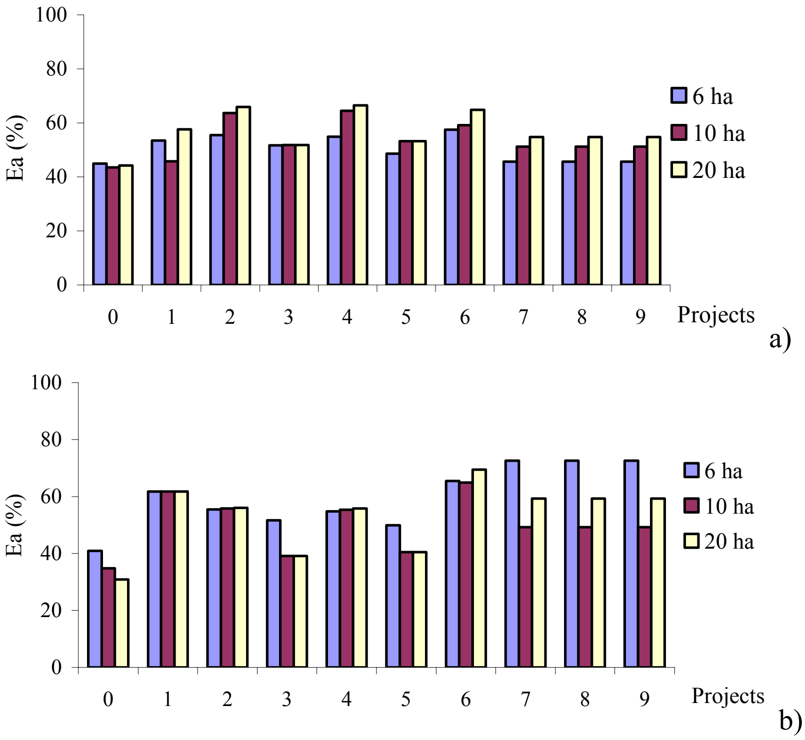


Fig. 14. Application efficiency in relation to progressive improvements as affected by field sizes for fields where length is adjusted (a) or the actual length is kept (b).

Percolation and risk for salinization

The present scenario (P0) shows a high salinization risk due to the great amount of total percolation, mainly in larger fields without length adjustment option.

Figure 15 shows that a good control of deep percolation is achievable with surge-flow whenever the length is or not adjusted.

For continuous flow, the worst results are for the 6 ha field when continuous flow irrigation is adopted.

Water use costs

Adopting the length adjustment option, the projects P2 and P4 (continuous flow in every furrow) have slightly higher costs (Fig. 16), due to more labour requirements for the multitier technique.

Without length adjustment the costs show a much reduced variability for all the projects; however, a slightly higher cost for surge-flow is expected due to higher investment on the valve and pipes.

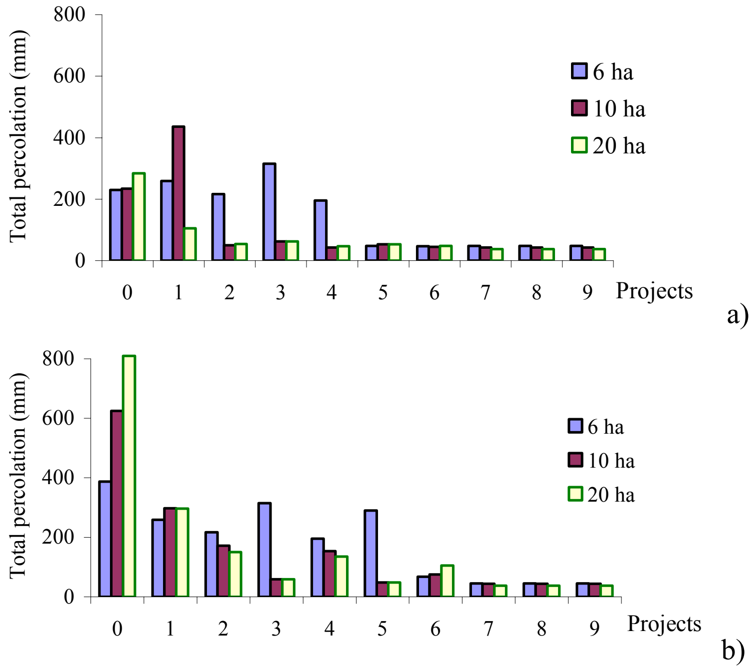


Fig. 15. Salinization risk – Total percolation in relation to progressive improvements as affected by field sizes for fields where length is adjusted (a) or actual length is kept (b).

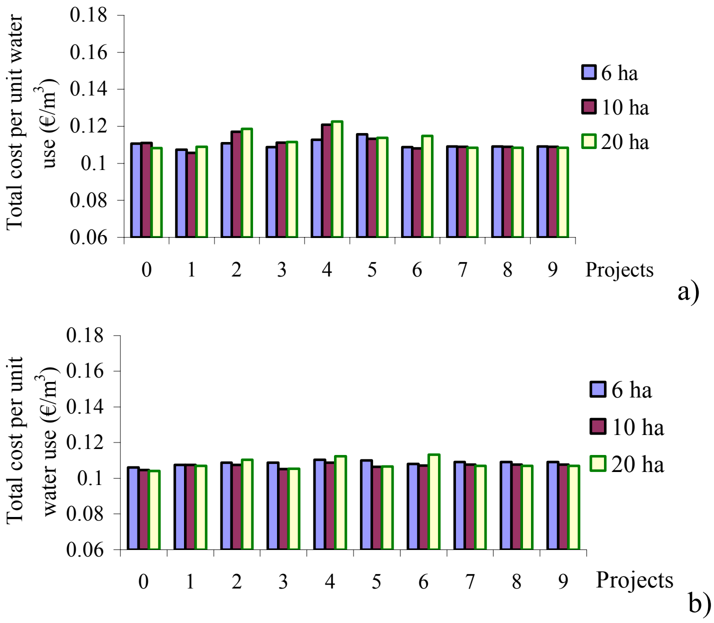


Fig. 16. Total cost per unit water use in relation to progressive improvements as affected by field sizes for fields where length is adjusted (a) or actual length is kept (b).

Water productivity

Concerning Fig. 17, when the length adjustment option is adopted, higher water productivity (WP) are foreseen for all improved solutions with a trend for better results with surge-flow. This fact relates with the smaller water used identified above. The 6 ha fields present lower values for continuous flow but similar to the other when surge flow is considered (P6 to P9). The best results concern continuous flow in every furrow (P4) and alternate-furrows (P5).

Without length adjustment, the surge-flow scenarios P6 to P9 have the better WP results; this can be explained by a more sensitivity of continuous irrigation to length adjustment.

For all cases, WP improves relative to present scenario (P0).

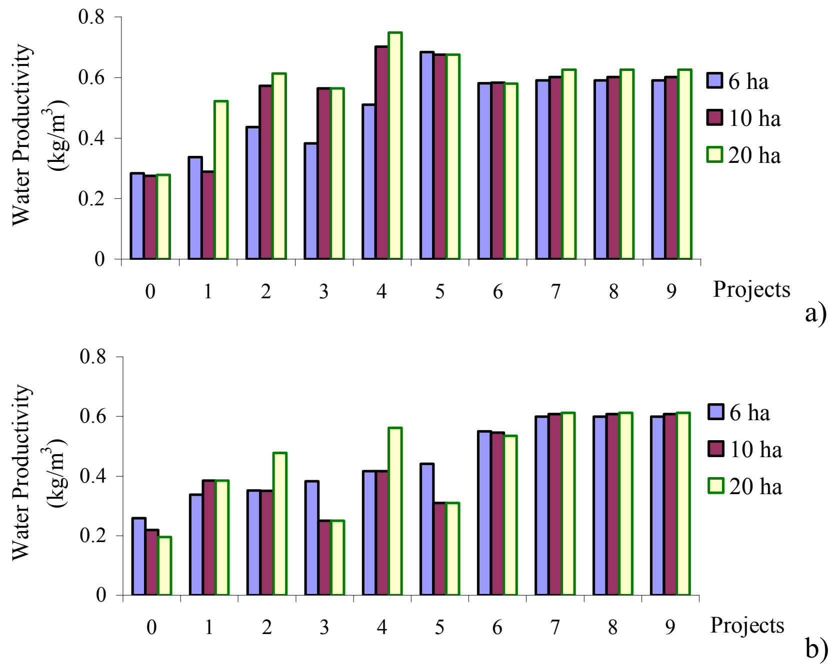


Fig. 17. Water productivity in relation to progressive improvements as affected by field sizes for fields where length is adjusted (a) or the actual length is kept (b).

Land productivity

Results in Fig. 18 show that land productivity (LP) is not responsive to improvements in farm irrigation. On the one hand, agronomic cultivation practices and cotton varieties were assumed the same for all scenarios and following the present ones, which are considered adequate; on the other hand, over irrigation as practiced at present is not producing waterlogging and salinity since fields are drained and drainage systems are working properly. In addition, the deficit irrigation strategy adopted refers to a mild deficit that barely affects yields.

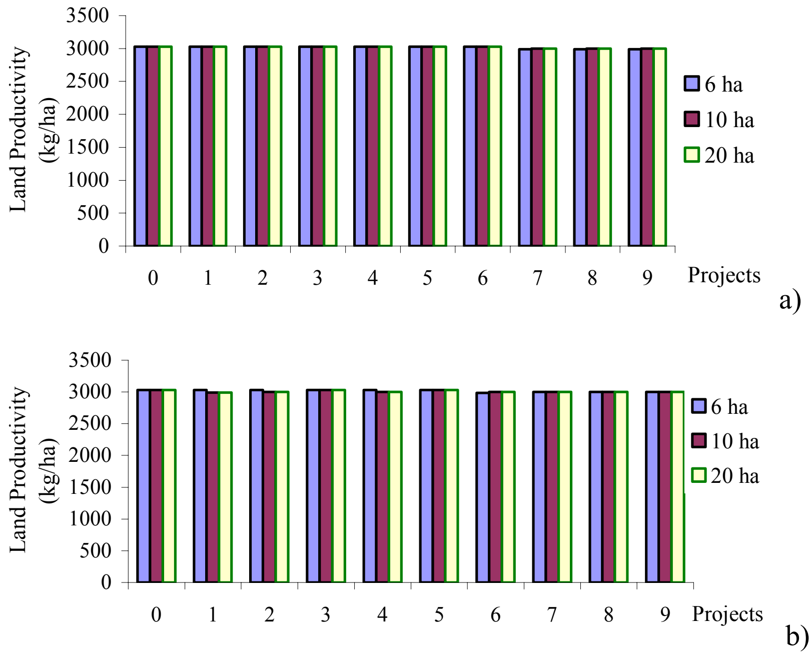


Fig. 18. Land productivity in relation to progressive improvements as affected by field sizes for fields where length is adjusted (a) or the actual length is kept (b).

Irrigation performances as affected by soil infiltration characteristics

In the analyses of the irrigation performance related with soil infiltration characteristics, the following conditions were fixed:

i. Fields cropped with cotton, medium size fields (W2: 10 ha, 400 x 250 m), soil with TAW = 150 mm/m, and a longitudinal slope = 0.25%;

ii. On-farm priorities relative to the balance between economic and environmental impacts

Seasonal water use

A higher water use among scenarios P0 and those for improved projects is observed.

Results in Fig. 19 show that, with the length adjustment option, there are similar seasonal water uses for all improved solutions (P2 to P9) but slightly higher water use in low infiltration soils due to higher runoff. Without length adjustment, surge-flow (P6 to P9) has better results than continuous irrigation.

Seasonal water use does not depend on soil infiltration for surge-flow; but it is sensitive to low infiltration for continuous irrigation when adopting the length adjustment option.

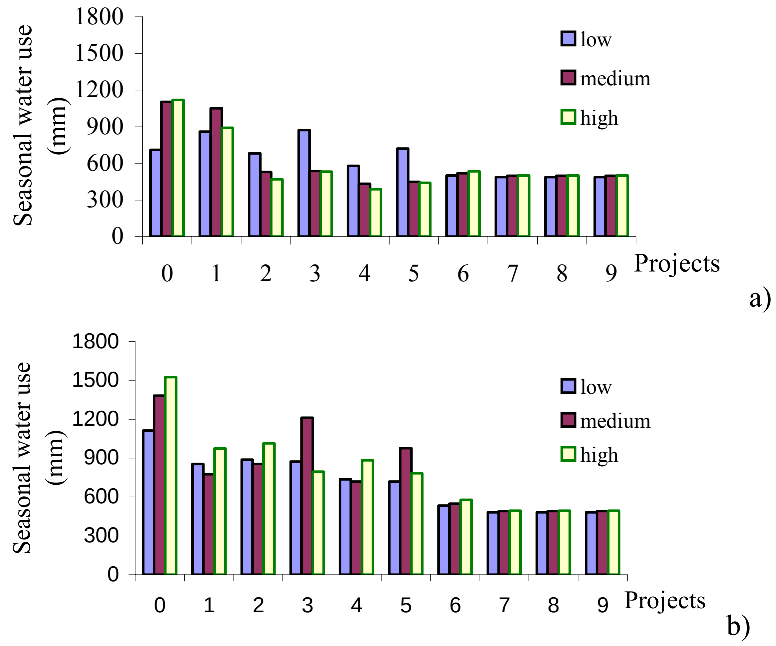
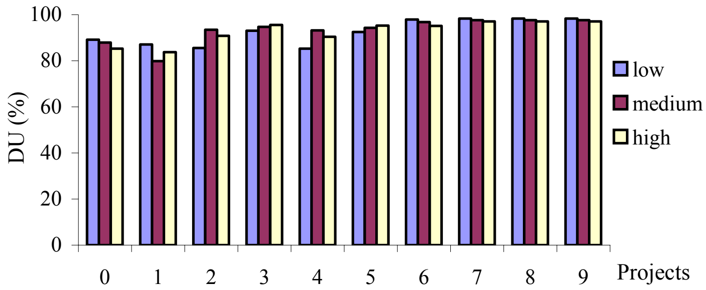


Fig. 19. Seasonal water use in relation to progressive improvements as affected by soil infiltrability for fields where length is adjusted (a) or actual length is kept (b).

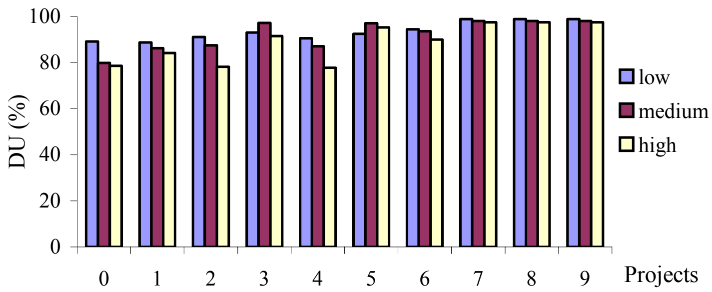
Distribution uniformity

Distribution uniformity shows very good results for all projects, including for present, with the surge-flow projects having the best results (Fig. 20).

Without length adjustment, the alternate-furrow irrigation strategies, projects P3 and P5, have similar results to the surge projects. The worst results are for every-furrow irrigation with high infiltration soil.



a)



b)

Fig. 20. Distribution uniformity in relation to progressive improvements as affected by soil infiltration characteristics for fields where length is adjusted (a) or actual length is kept (b).

Application efficiency

For present scenario P0 the application efficiency shows the lower results, not influenced by the soil infiltration characteristics for fields where furrows length is adjusted.

Results in Fig. 21 show that the Ea values are less good as it would be expected from the DU values. With length adjustment option Ea present similar results when comparing continuous and surge-flow; however, the alternate furrows are slightly worst than every furrow. The best results are for the soils with highest infiltration and the worst for those with low infiltration, which relates with runoff production.

When keeping the actual length, the surge-flow scenarios present the highest Ea values especially for the high infiltration soil, where surge is significantly more efficient than the others. Best results are foreseen for surge with every-furrow irrigation.

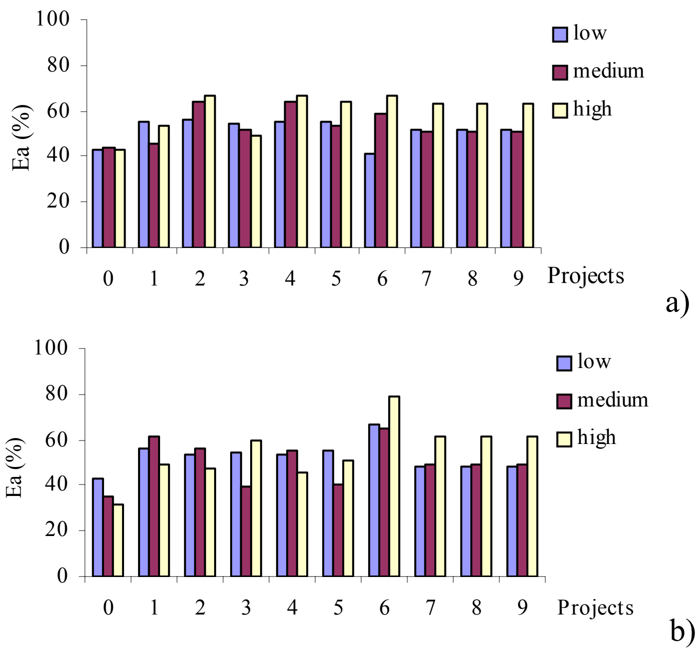


Fig. 21. Application efficiency in relation to progressive improvements as affected by soil infiltrability for fields where length is adjusted (a) or actual length is kept (b).

Percolation and risk for salinization

There is a great amount of deep percolation and salinization risk for the present scenario P0 when the actual length is kept, mainly for the high infiltration soils. For all cases, this situation is improved for all scenarios considered, mainly when the furrow lengths are adjusted (Fig. 22a). However, for high infiltration soils and adopting the actual furrow lengths percolation remains high for continuous flow and every-furrow irrigation (P1, P2 and P4).

Continuous flow irrigation in alternate furrows (P3 and P5) controls well the deep percolation. However, the best results are achieved with surge-flow whenever adopting or not furrow length adjustment (Fig. 22).

Water use costs

The total cost of water use is less dependent on soil infiltration but tends to be higher for high infiltration soils when furrow lengths are adjusted and continuous flow in every furrow is adopted. The projects P4 and P5 (deficit irrigation), with length adjustment option, have slightly higher costs for high infiltration soils due to the shorter furrows, what induces more labour.

The water use costs have a much reduced variability for all the projects when the actual length is kept (Fig. 23b).

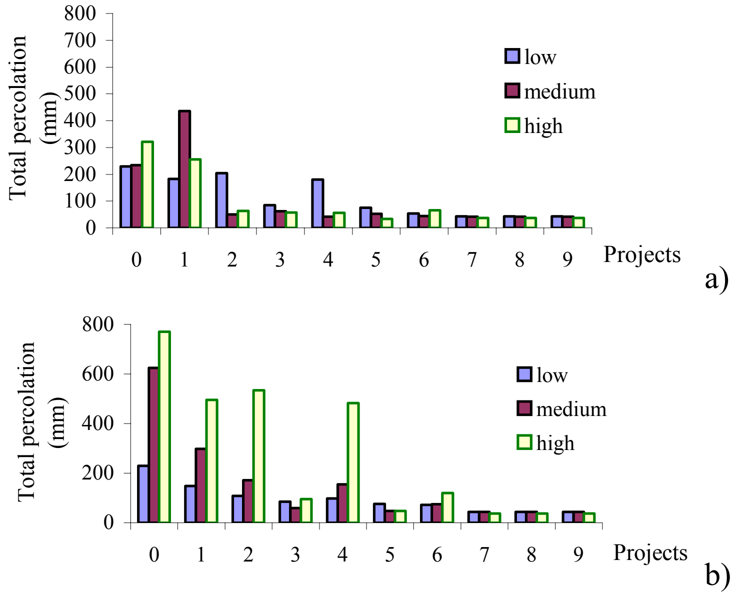


Fig. 22. Salinization risk and percolation relative to improved scenarios as affected by soil infiltration for fields where length is adjusted (a) or actual length is kept (b).

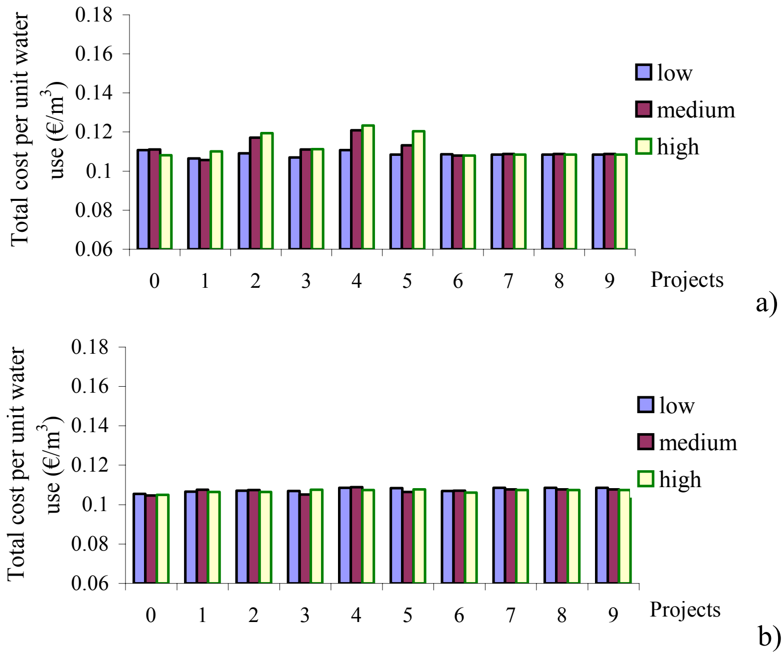


Fig. 23. Total water use cost in relation to progressive improvements as affected by soil infiltrability for fields where length is adjusted (a) or actual length is kept (b).

Water productivity

As referred before, the present WP has low results but highly increases if improved scenarios are implemented.

With length adjustment, the worst results are for the low infiltration soils (Fig. 24), which relates with higher runoff. On the contrary, the best results are for high infiltration soils with continuous flow in every furrow (P2 and P4), which relates to better controlling runoff and infiltration in shorter (200 m) fields. Surge-flow (P6 to P9) shows good results for all the three infiltration classes, both for every- and alternate furrows.

Adopting the actual furrow length, the higher WP concern surge-flow independently of soil infiltration, with an increase from 0.3-0.4 kg/m^3 for continuous to 0.6 kg/m^3 for surge).

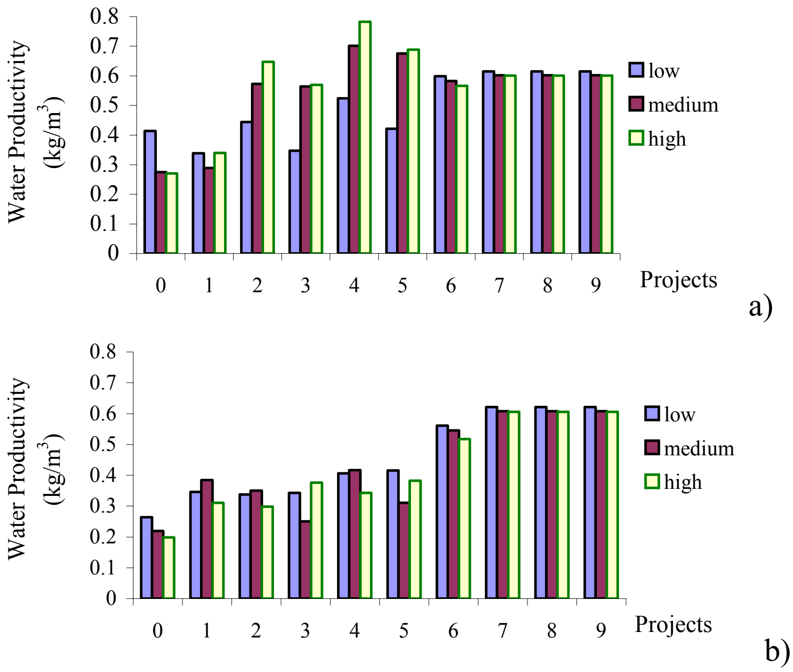


Fig. 24. Water productivity in relation to progressive improvements as affected by soil infiltration for fields where length is adjusted (a) or actual length is kept (b).

Land productivity

Results do not show significant differences in LP among the several projects, exception for P0 and P1 for soils with low infiltration, where a slightly reduction of LP occurs due to waterlogging (Fig. 25). Results with and without length adjustment is similar due to the fact that agronomic practices are the same for all scenarios and deficit irrigation is quite mild, so not affecting significantly the yields.

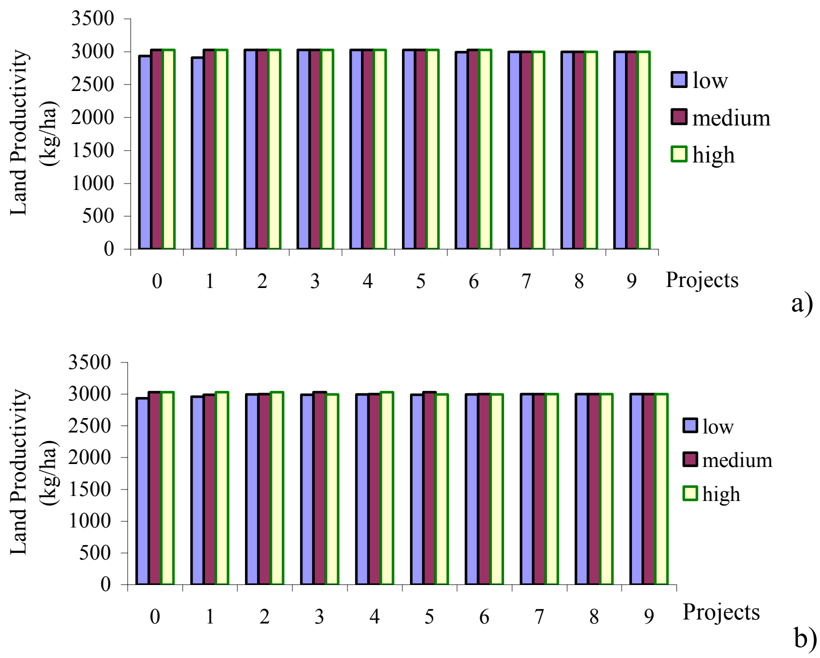


Fig. 25. Land productivity in relation to progressive improvements as affected by soil infiltration for fields where length is adjusted (a) or actual length is kept (b).

Global Utility analysis

In the analysis relative to the global utilities relative to the considered scenarios, the type of prioritization adopted is that aimed at a balance among economic and environmental issues. The analysis herein concerns soil infiltrability only.

Results show (Fig. 26) that the global utility value U increases from the present condition to the improved ones, with generally higher values when surge flow is adopted.

With length adjustment the best results concern surge flow (P6 to P9), mainly for low and secondly for high infiltration soils.

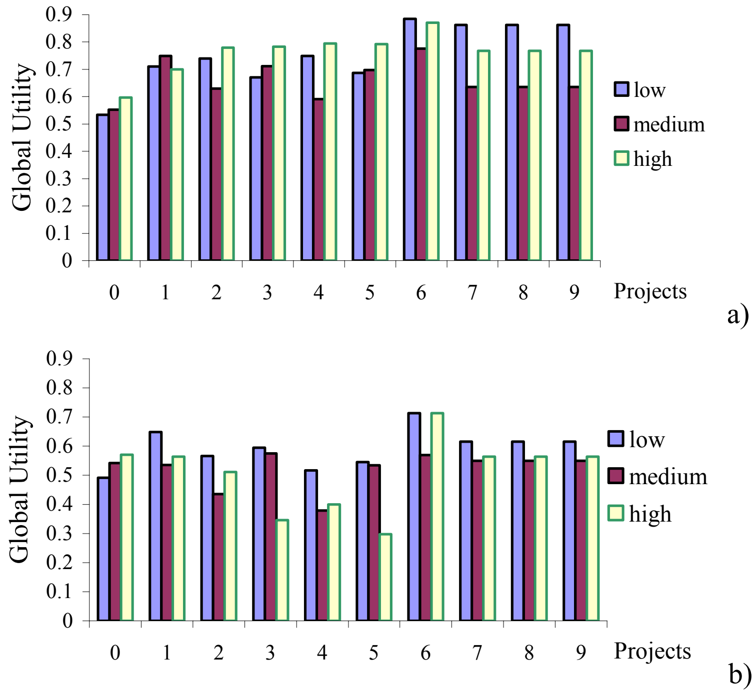


Fig. 26. Global Utility in relation to improved scenarios as affected by soil infiltration for 10 ha fields (W2) where length is adjusted (a) or the actual length is kept (b).

Sensitivity analysis relative to the criteria for prioritization

In the sensitivity analyses relative to the variation of the global utility as impacted by the prioritization criteria (Table 8), the following conditions were set:

i. medium soil infiltration;

ii. medium field size (W2: 10 ha, 400 x 250 m).

Results in Fig. 27 show that generically the present system (P0) has worst results comparing with P1 (actual system but with improved cut-off time) and with the improved project scenarios (P2 to P9). The best results are for P5 and P6 when field lengths are adjusted and the surge flow scenarios if actual lengths are kept.

Higher values for U are obtained when priorities are assigned to water saving and environmental impacts. Contrarily, smaller U corresponds to priorities given to economic issues. Results are not very different when a balance among economic and environmental issues is foreseen.

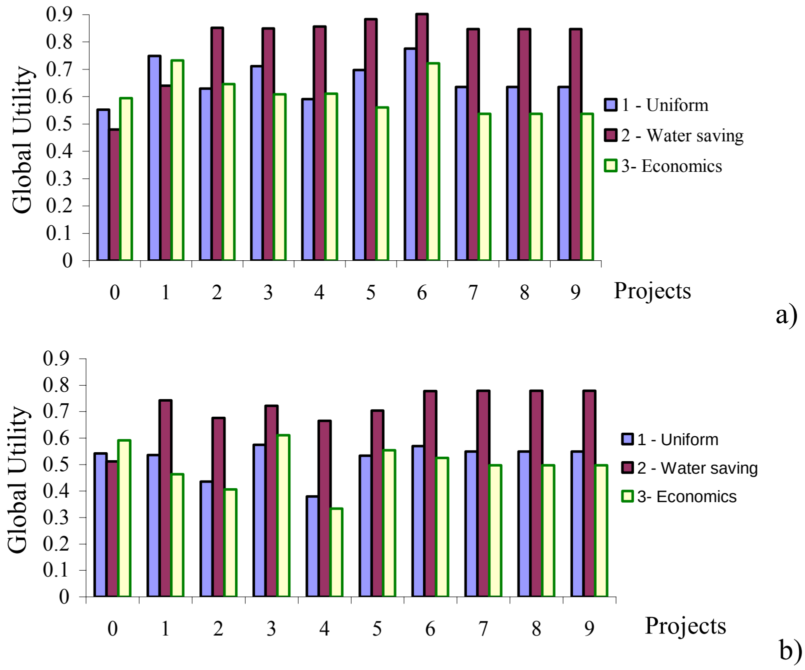


Fig. 27. Project global utilities referring to different priority criteria for fields where length is adjusted (a) or the actual length is kept (b).

Conclusions and future issues

The application of SADREG to the case study area in Fergana, Uzbekistan, where furrow irrigation is the dominant method revealed successful. Difficulties to extend the use of the model to other areas refer to the need for basing design calculations on field-tested variables and parameters and to the database requirements.

Assessing the improved scenarios (*Projects* P2-P9), the following conclusions were drawn: surge-flow (P6-P9) leads to less water use, in particular for full length furrows; continuous flow in every furrow (P2 and P4) shows a water use closer to surge flow than continuous flow in alternate furrows (P3 and P5). Surge-flow has a higher water productivity (kg m^{-3}), and is less sensitive to soil infiltration; in addition it shows to better control deep percolation, allowing a large potential to prevent the groundwater salinization.

The Project/scenarios performances are very sensitive to the prioritization criteria. This evidences the importance of an adequate construction of the decision maker priorities types. Generally, the differences of global utility between continuous and surge-flow are not expressive. But surge-flow seems to be more efficient when the water savings and the control of groundwater salinization are the major on-farm priorities. Surge has a higher capability to improve water productivity, maintaining the standard of economic performance of the system (yield benefice and costs).

The DSS application reported in this paper shows the feasibility of this approach to the design practice. First, the DSS allows a rational generation, evaluation, and ranking of design alternatives. Second, design alternatives are more easily associated with attributes of technical, economic and environmental nature, which allows an appropriate dialog between the designer and the user. Third, the ranking is defined using multicriteria analysis and criteria are weighted according to the perspectives of the designer and users. Fourth, the DSS provides for the learning by doing of the decision-maker involved. These aspects are evident advantages for using a DSS in surface irrigation design.

The application of the DSS to Uzbekistan also shows that the feasibility for application of a DSS largely depends on the quality of data utilized. It is therefore evidenced that the quality of the design when more sophisticated approaches are used still is highly influenced by the field data available. In other words, a good modelling approach does not replace the lack of field data.

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