PLANNING LENGTH OF LONG -TERM FIELD EXPERIMENTS THROUGH DECISION SUPPORT SYSTEMS – A CASE STUDY

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Abstract. Long-term field experiments are the conventional means for developing; evaluating and demonstrating site-specific land/water use plans. However, it has been often observed that at times they are unable to propose sustainable practices, when planned for shorter time durations (say 2-3 years) or become cost-ineffective and obsolete, when planned for longer time durations (say more than 15 years or so). Hence, what should be the ideal length of such long-term experiments has always been a debatable issue. The present study attempts to demonstrate application of one indigenously developed decision support system (DSS) for planning appropriate length of long term conjunctive water use experiments on a test salt affected farmer's field. Before application the proposed DSS was extensively validated on several farmers and controlled experimental fields in Haryana (India). Validation of DSS showed its potential to give realistic estimates of root zone soil salinity; sodicity and salt stress induced relative crop yield reductions under local resource management conditions. Long term impact assessment of varied conjunctive water use strategies, on the test farmer's field, with the so validated DSS showed that the time required for achieving stable crop yields could be treated as a good measure of the minimum length of such experiments. For the test (rice-wheat growing) farmer's field, this time ranged between 5.5 – 6.0 years. It was observed that at shorter time scale (i.e. 2 years), though application of 50% canal waters (CW) blended with 50% tube well waters (TW), was as productive and superior as cyclic applications of (2CW, 1TW, 1CW); (1CW, 1TW, 2CW) and (CW: TW) during wheat cropping season yet it could not maintain its superior performance at DSS proposed time duration of 6 years or more. Similarly irrigation practice of (4CW, 5TW) during rice cropping season, though beneficial at shorter time scale, was much inferior to the cyclic application of canal and tube well waters (i.e. CW: TW) at longer time scales (i.e. at ≥ 6 years). Hence, limiting the proposed long-term conjunctive water use experiment to the DSS proposed minimum time duration of 6 years lead to the selection of the most stable and sustainable irrigation practice(s) for the test farm.

Keywords: *sustainability, long term studies, environmental impact assessment, water use planning*

Introduction

Maintenance of long-term productivity and environmental conservation are the pre-requisites for sustainable agriculture. This requires proper use of natural resources. Planning proper use of natural resources presents several challenges before a decision maker. Appropriate land and water use decisions require the ability of a decision maker to understand their long-term impacts on soil health and crop production. Long-term field experiments, lasting 2 to several years, are the conventional means for the development, evaluation and demonstration of potentially sustainable practices as they provide a primary source of information about agricultural sustainability as a function of time [19].

A long-term field experiment is considered to be the one in which the original treatments are repeated on the same plots, year after year, for many years [8]. The classical experiments at Rothamsted, England [14] is a typical example. Such experiments play an important role in understanding the complex interaction of plants, soils, climate and management problems, and their effects on sustainable crop production. Although such experiments are essential for developing (site-specific) suitable land/ water use plans yet when planned for shorter time durations (say 2-3 years) they are unable to propose sustainable practices. Further, when planned for longer time durations (say more than 15 years or so) they become cost-ineffective and obsolete due to changes in agricultural practices with time. Hence what should be the ideal length of such long-term field experiments has always been a debatable issue.

Well-validated decision support systems with potential to evaluate time required for achieving stable crop yields, under varied agricultural systems, can be very effective tools for planning length of long-term field experiments. A Decision Support System (DSS) is infact an integrated assembly of models, data, interpretive routines and other relevant information that efficiently processes input data, runs the models, and displays the results in an easy-to-interpret format [10]. It comprises a hardware and a software to assist decision-makers in comprehensively looking at the relatively unstructured and complex environmental problems, try out different solutions and visualize the probable (short as well as long-term) impacts of adopting the solution, all through a computer. For planning purposes, this ability to dynamically change information, forecast and perform sensitivity analysis is exteremely useful.

The present study attempts to demonstrate the application of one such indigenously developed decision support system, named IMPASSE [15], for planning length of long term conjunctive water use experiments on a (test) rice-wheat growing salt affected farmer's field in Haryana (India).

Materials and methods

Proposed DSS

IMPASSE (IMPact Assessment and management of Saline/ Sodic Environments) is a user-friendly field scale-DSS designed for managing saline/ sodic soils and waters in freely draining irrigated and rainfed agricultural lands. It comprises of a set of well established subroutines for assessing short / long term impacts of a range of (geo) hydrologic conditions, water management options and crop rotation schedules on root zone-soil salinity / sodicity build ups and crop yield reductions [15]. By selecting appropriate time criteria it can even generate crop-specific irrigation schedules.

Under the assumption of no capillary rise from deep ground water tables in freely draining soils and no contribution of salts by rainfall, the change in soil root zone salt content (i.e. ΔZ in dS/m -mm or meq/l -mm) in the proposed DSS is based on the following equation proposed by [28]:

$$\pm \Delta Z = \{IS_i - (1\text{-}f)\ DS_i - (fD/\ W_{fc})\ Z_{t\text{-}\Delta t}\}/\ \{1 + fD/\ 2W_{fc}\} \qquad \text{(Eq. 1.)}$$

While change in root zone soil moisture content (ΔW in mm) in a given time step Δt (= 1 day) is expressed as:

$$(\pm)\ \Delta W = (I + P) - (E_a \text{ or } ET_a + R + D)$$

Where, $Z_{t\text{-}\Delta t}$ is initial salt content (in dS/m-mm or meq/l-mm) of soil root zone, S_i is salt concentration (in dS/m) or Na^+, Ca^{2+}, Mg^{2+} concentration (in meq/l) of irrigation water, 'f' is leaching fraction, W_{fc} is field capacity moisture content (mm), I is the amount of applied irrigation water (mm), D is deep percolation loss (mm), P is precipitation (mm), E_a is actual evaporation (mm) under fallow conditions, ET_a (= $E_a + T_a$) is actual evapo-transpiration (mm) under cropped conditions and R is surface runoff (mm). In the proposed DSS, daily actual evaporation and actual evapo-transpiration rates are computed through "square-root-of-time relation" [26] and Doorenbos and Pruitt [7] methods respectively.

Estimation of deep percolation loss (D) from soil root zone, under fallow/ upland conditions, is based on the following procedures:

$$D = \{(WC_t – WC_{fc}) / 100\} * RZD \text{ When } WC_{sat} > WC_t > WC_{fc} \text{ or}$$

$$D = \{(WC_{sat} - WC_{fc}) / 100\} * RZD \text{ When } WC_{sat} \le WC_t > WC_{fc} \text{ or}$$

$$D = 0 \text{ When } WC_t = WC_{fc}$$

Where, WC_{sat} is root zone soil moisture contents at saturation (mm), RZD is root zone soil depth (mm) and WC_t is root zone soil moisture content (mm) at a particular time 't'.

For deep percolation losses under lowland (puddle) conditions, soil root zone is assumed to comprise of both the muddy layer and plow sole (responsible for impeded drainage) and the un-puddle soil, characterized with actual soil drainage rate [29]. Under such conditions, deep percolation is assumed to occur only when ponded water depth (Pond, in mm) is greater than zero. Ponding of water on the soil surface is assumed to take place only when root zone soil moisture at a particular time 't' (WC_t) is either greater than or equal to soil moisture content at saturation (WC_{sat}). When $WC_t > WC_{sat}$ then change in ponding depth in a given time interval Δt (= 1 day) i.e. ΔPond (in mm) is set to $\{((WC_t - WC_{sat}) / 100) * RZD\} + P + I$. While, when $WC_t = WC_{sat}$ then $\Delta Pond = P + I$. Thus on days with Pond > 0, deep percolation losses under lowland/ puddle conditions are computed as follows:

$$\text{If Pond} \ge (K_s/ 5) \text{ then } D = (K_s/ 5) \text{ Else } D = \text{Pond}$$

Setting up of deep percolation losses (D) to $1/5^{th}$ of the saturated hydraulic conductivity values ($K_{s,}$ in mm/day) in the above equation is in fact based on the findings of Fujioka [9] and Van de Goor [27], who observed that soil percolation rates of puddle soils are about $1/5^{th}$ of the same un-puddle soils.

Daily amounts of surface runoff (R) in the proposed DSS, depending upon upland/ fallow or lowland conditions, are computed as:

$$R = (I – Bund) \text{ When } I > Bund, \text{ or } R = (P – Bund) \text{ When } P > Bund, \text{ or}$$

$$R = (Pond – Bund) \text{ When } Pond > Bund$$

Where, 'Bund' is field bund depth (in mm) and 'Pond' is ponded water depth (in mm) under lowland conditions.

The so computed final root zone soil saturation extract-salt concentrations, obtained through Eq. 1, were adjusted for ion pair/ complex formation as per Sposito and Mattigod [25] method and expressed as Exchangeable Sodium Percentage (ESP, [4]) and Electrical Conductivity (EC) values.

Mechanistic simulation of salt stress induced crop yield reductions requires realistic information on root growth and water/ nutrient uptake distribution patterns, under varying salt stresses, for different crops [5]. However, non-availability of such (crop and location specific) information generally limits wide-scale applicability of these mechanistic approaches. Hence in the proposed DSS, daily relative crop yield reductions due to salinity (EC_i) or sodicity (ESP_i) stresses (i.e. RYR_{si} and RYR_{ai}, respectively) are estimated through the following widely applicable empirical simulation procedure of Maas et al. [20]:

$$RYR_{si} = S_{ec} * (EC_i - EC_t)$$
$$RYR_{ai} = S_{esp} * (ESP_i - ESP_t) \qquad \text{(Eq. 2.)}$$

While, daily (i.e. RYR_{cdi}) and seasonal (i.e. RYR_{cg}) relative crop yield reductions due to both salinity and sodicity stresses are expressed as:

$$RYR_{cdi} = MAX\ (RYR_{si}, RYR_{ai})$$
$$RYR_{cg} = MAX\ (RYR_{cd1}, RYR_{cd2}, \ldots\ldots\ldots, RYR_{cdi}) \qquad \text{Eq. 3.)}$$

Where, EC_t and ESP_t are threshold salinity / sodicity levels, and S_{ec} and S_{esp} are slopes of salinity/ sodicity response functions for 30 different local crop types ranging from cereals, pulses, and oilseeds to vegetables [11, 12] .

The conceptualization of this salt transport and its impact on crop yield reductions is based on several theoretical assumptions such as: (1) no soil mineral dissolution, (2) no lateral/ upward capillary movement of water and salts, (3) incomplete mixing of root zone soil solution to account for bypass and (4) no direct crop yield reductions due to moisture, nutrient or pest stresses.

The proposed DSS was designed keeping in mind the relative simplicity of its operation to promote its use by field technicians and project planners. It contains a set of default soil/ crop characteristics, which can be selected and adjusted for various soil/ crop types. It basically requires two types of input-parameters. Type-I inputs comprise of daily weather data, crop data (viz. crop type and salinity/ sodicity response factors), soil data (viz. soil type, moisture contents at saturation, field capacity and wilting point, saturated hydraulic conductivity, initial soil moisture content and initial EC, Na^+, Ca^{+2}, Mg^{+2} concentrations of soil root zone) and water data (viz. irrigation depth, application dates and EC and Na^+, Ca^{+2}, Mg^{+2} concentrations). These parameters can be determined through actual resource surveys. While type-II inputs comprising of leaching fractions, whose direct determination is generally very cumbersome, are determined through calibration procedure.

DSS calibration & validation

The proposed DSS was validated on several farmers as well as controlled experimental fields in Gurgaon and Karnal districts of Haryana, India. Before validation, firstly the calibrated values of leaching fractions under both actual farmers fields and controlled experimental field conditions were obtained. For this, soil type specific-default leaching fraction values [23] in the DSS were increased or decreased in steps till good correlation coefficients (R) between the observed and simulated EC and ESP values were obtained. The so calibrated leaching fraction values, along with the other type-I parameters, were then used for its validation. As per the recommendations of ASCE [2], both visual (graphical) and statistical comparisons in terms of correlation coefficient, mean relative error and root mean square prediction difference were used for this purpose.

On farmer's fields

For validation on actual farmer's fields, a detailed inventory on weather, farming practices, soils and waters of 11-farmer's fields was prepared. Figure 1 illustrates the location of these fields in 6-villages of Gurgaon district of Haryana, India.

Test area weather data was acquired from Indian Meteorological Department (IMD) while farming practice information on crops cultivated, their sowing/ harvest dates, actual/ potential yields and water management practices was obtained through personal interviews of farmers.

Physico-chemical characteristics of the soils and waters of the test fields were determined through primary (farm-level) surveys, scheduled during the *Kharif* (June to September) and *Rabi* (October to March) seasons of 2000-03. During these surveys, bulk soil samples (1 Kg) from the top (0-30 cm) and the sub-soil (30-60 cm) horizons of 4 random spots, in each test farm, were extracted and mixed together to form one-composite top/ sub-soil sample. These composite soil samples were crushed and ground with a wooden mortar-pestle, passed through a 2-mm sieve and divided into three replicates. Simultaneously, bulk (250 ml) surface (i.e. Canal, C) and sub-surface (i.e. Tube Well, TW) water samples were also collected in labeled plastic bottles and partitioned into three equal portions. EC, pH, calcium, magnesium, sodium [13] and carbonate and bi-carbonate concentrations [22] of these (triplicate) soil/ water samples from each test farm were determined, as per the standard laboratory procedures. The so determined sodium, calcium, magnesium, carbonate and bi-carbonate concentrations in the soil saturation extracts and/ or water samples were then transformed to Sodium Adsorption Ratio (SAR), Exchangeable Sodium Percentage (ESP; [4]) and Residual Sodium Carbonate (RSC) values (meq/l), as per the standard procedures. Saturated hydraulic conductivities of non-destructive soil core samples [17], soil texture [3] and volumetric soil moisture contents at 0.05, 0.33 and 15 bars [16] were also determined.

The so determined actual (local) resource management conditions for the *Kharif* and *Rabi* seasons of 2000-01 were used for the proposed DSS-calibration while those for 2001-02 and 2002-03 seasons were used for its validation on 11- farmer's fields.

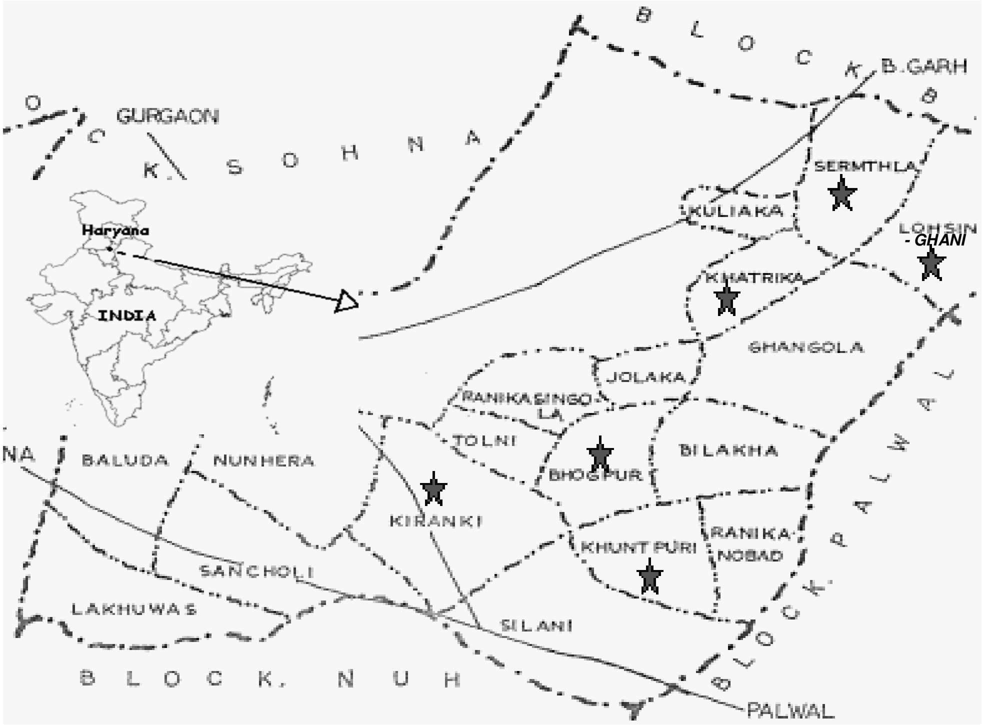

Figure 1. *Location of test farms in Sohna block of Gurgaon district, Haryana (India)*

On controlled experimental fields

For this controlled (randomized block) experimental field data of Sharma et al. [24] was used. This experiment under fixed Wheat-fallow rotation (Nov., 1986 to Apr., 1989) comprised of 5-replications of 5-irrigation treatments viz. EC = 0.7 dS/m (Canal water, CW), 6 dS/m, 9 dS/m, 12 dS/m and 18 – 27 dS/m (Drainage water, DW). The first year (i.e. 1986-1987) experimental data was used for the calibration of the proposed DSS while the remaining 2-years data (for 1987-89 period) was used for its validation. For this study, actual soil salinization (EC) and economic yields under only first four irrigation treatments were considered. The economic yields obtained under 6, 9 and 12 dS/m - saline water irrigation treatments were divided with those under canal water irrigation (i.e. no salt stress) treatment to obtain actual relative crop yield reductions under varying salt-stress levels.

DSS application

The so validated-DSS was then used for planning length of varied conjunctive water use experiments on a salt affected farmer's field in Khatrika village of district Gurgaon, Haryana (India). For this, long-term (10 years) impacts of varied (existing/ alternative) conjunctive water use strategies on the test field's root zone soil salinization/ sodification and relative crop yield reductions were simulated with the proposed DSS. While simulating long-term impacts of these conjunctive water use strategies, the test field was subjected to the long-term weather conditions (for the years 1990 – 1999) of the study area.

The test field, with Rice-Wheat cropping sequence, was characterized with cyclic application of good quality canal (EC: 0.9 dS/m, SAR: 3.1 and RSC: 0.6 meq/l) and poor quality tube well waters (EC: 4.3 dS/m; SAR: 12.7 and RSC: 4.1 meq/l). Existing conjunctive water use practice during *Kharif* (i.e. Rice crop) season comprised of 9-irrigations comprising of (3-TW, 3-CW and 3-TW). While that during *Rabi* (i.e. Wheat crop) season comprised of 4-irrigations with (2-CW, 1-TW, and 1-CW). Alternative (*Kharif* and *Rabi* season) conjunctive water use strategies simulated by the proposed DSS comprised of:

- *Kharif* season irrigation treatments; *4-cyclic modes* i.e. (1-CW, 1-TW, 1-CW, 1-TW, 1-CW, 1- TW, 1-CW, 1-TW, 1-CW i.e. CW: TW); (1-TW, 1-CW, 1-TW, 1-CW, 1-TW, 1-CW, 1-TW, 1-CW, 1-TW i.e. TW: CW); (4-CW, 5-TW); (1-CW, 2-TW, 3-CW, 3-TW) and *2-blending modes* i.e. (50%CW + 50%TW i.e. 1:1) and (25%CW + 75%TW i.e. 1:3).
- *Rabi* season irrigation treatments: *3-cyclic modes* i.e. (1-CW, 1-TW, 2-CW); (2-CW, 2TW); (1-CW, 1-TW, 1-CW, 1-TW i.e. CW: TW); and *3-blending modes* i.e. (25%CW + 75%TW i.e. 1:3); (50%CW + 50%TW i.e. 1:1) and (75%CW + 25%TW i.e. 3:1).

While assessing long-term impacts of any conjunctive water use strategy during a particular season, the water use strategy for the subsequent season was kept as that existing for the test farm.

The so simulated long-term relative crop yield reductions under above (existing/ alternative) conjunctive water use strategies for *Kharif* and *Rabi* seasons were then subjected to a one way classified ANOVA analysis [6]. During this analysis, simulation years were assumed as classificatory variables while conjunctive water use strategies for a particular cropping season were assumed as more than one observation for a particular simulation year. This was basically aimed at determining the number of years in which a set of conjunctive water use strategies (or treatments) for a particular cropping season (or agricultural system) became sustainable.

Results and discussions

DSS validation on actual farmer's fields

The proposed DSS was calibrated and validated on 11-actual farmer's fields in 6-villages of Gurgaon district of Haryana state in India (Fig. 1). The study area experiences sub-tropical, semi-arid, continental and monsoonal type of climate. Paddy-Wheat in Lohsinghani, Sermethla, Khatrika, Bhogpur villages and Fallow-Wheat/ Barley in Kiranki-Kherli and Khuntpuri villages were the dominant crop rotation practices for the study area (Table 1). All test farms, excepting the one with no canal water supplies in Bhogpur village, used both canal and tube well waters for irrigation.

Table 1. *Local crop/water management practices for test farmer's fields*

Village/ Farm	**LOHSINGHANI**		**SERMETHLA**		**KHATRIKA**		*KHUNTPURI*		**BHOGPUR**	**KIRANKI-KHERLI**	
	Farm 1	Farm 2	Farm 1	Farm 2	Farm 1	Farm 2	Farm 1	Farm 2	Farm 1	Farm 1	Farm 2
Area (ha)	0.16	0.20	0.60	0.40	0.60	0.10	0.60	0.40	0.16	0.20	0.80
					RABI SEASON						
Crop	Wheat	Wheat	Wheat	Wheat	Wheat	Wheat	Barley	Wheat	Wheat	Wheat	Wheat
Irrigation Source	CW & TW	CW & TW	CW & TW	TW	CW & TW	CW & TW	TW	CW	TW	CW	CW & TW
Irrigation No.	5	5	4	4	4	4	4	4	4	5	4
Irrigation Sequence	2CW,TW, CW, TW	2CW,TW, CW, TW	2TW, CW, TW	4TW	2CW,TW, CW	CW, TW, 2CW	4TW	4CW	4TW	4CW, TW	4CW
					KHARIF SEASON						
Crop	Paddy	Paddy	Paddy	Paddy	Paddy	Paddy	Fallow	Fallow	Paddy	Fallow	Fallow
Irrigation Source	CW & TW	CW & TW	CW & TW	TW	CW & TW	CW & TW	N/A	N/A	TW	N/A	N/A
Irrigation No.	9	9	9	9	9	9	N/A	N/A	10	N/A	N/A
Irrigation Sequence	2CW, 2TW, 3C W, 2TW	3CW, 2TW, 4CW	3TW, 2CW, 4TW	9TW	3TW, 3CW, 3TW	1CW, 1TW, 2CW, 3TW, 2CW	N/A	N/A	10TW	N/A	N/A

Soils of farms in Lohsinghani, Khuntpuri, Bhogpur and Kiranki-Kherli villages were of sandy loam texture while those in Sermethla and Khatrika villages were of sandy clay loam texture. Their bulk density and gravimetric moisture contents at saturation, field capacity and wilting point ranged between 1.4 - 1.8 g/cm^3 and 29 - 39%; 16 to 24% and 7 to 11%, respectively. About 50% of the test farms were salt affected. Khuntpuri and Khatrika farms (with ESP: 33 -14 % and EC: 7- 4 dS/m) were observed to be the most salt-affected. Sermethla and Kiranki-Kherli farms (with ESP: 20-17% and EC: 3 dS/m) were moderately salt-affected while Lohsinghani and Bhogpur farms (with ESP: 15-10% and EC: 1-3 dS/m) were marginally salt affected. Sodicity was observed to be the major problem in the test farms.

Quality of canal waters of the study area was in general good (EC: 0.5-1.1 dS/m, pH: 6.8-8.4; SAR: 2.0-4.3 and RSC: 0.0-5.5 meq/l) while that of the tube-well waters was poor. Tube well waters of the test farms in Kiranki-Kherli and Khatrika villages were of the poorest quality (EC: 3.8-4.9 dS/m; SAR: 6.6-24.4 and RSC: 0.0-4.3 meq/l). These were followed by the tube-well waters in Khuntpuri (with EC: 3.0 dS/m; SAR: 4.1 and RSC: 3.0 meq/l); Lohsinghani (with EC: 1.4-2.1 dS/m; SAR: 3.2-16.2 and RSC: 0.0-3.9 meq/l); Bhogpur (with EC: 1.1-1.9 dS/m; SAR: 6.6-8.0 and RSC: 0.4-3.9 meq/l) and Sermethla (with EC: 0.8-1.4 dS/m; SAR: 2.0-15.4 and RSC: 0.0-3.8 meq/l) villages.

This information on actual local resource management conditions of 11-test farms, during *Kharif* and *Rabi* seasons of 2000-01, was used for the calibration of soil leaching fraction values in the proposed DSS. It was observed that the test farms with lowland paddy cultivation were associated with lower leaching fraction (f) values (ranging from 0.02 – 0.04) than the fallow (with 'f' ranging between 0.35 – 0.40) and Wheat/ Barley cultivated farms (with 'f' ranging between 0.20 – 0.40). Figure 2 shows that the so calibrated soil leaching fraction values (f, ranging between 0.02 - 0.40) could yield good correlation coefficients between the observed and simulated EC (0.96) and ESP (0.99) values of the test farms. Incorporation of these (calibrated) leaching fraction values, along with other (actually determined) type-I parameters for the test farms, into the proposed DSS resulted into EC and ESP predictions with Pearson correlation coefficients (R), absolute mean relative errors (AMRE) and root mean square prediction errors (RMSPD) ranging between 0.94 – 0.99; 0.02-0.06 and 0.51-0.84 respectively (Fig. 3) for the validation period (2001-03). It was observed that these root mean square prediction errors were in general lesser than the standard (measurement) errors (STD) associated with their observed EC and ESP values (EC_STD: 0.21- 1.76 dS/m and ESP_STD: 0.40-2.94%). Even the temporal profiles of soil root zone EC and ESP, for all test farms, could be quite realistically simulated by the proposed DSS.

DSS validation on controlled experimental fields

Besides actual farmer's fields, the proposed DSS was calibrated and validated on several controlled experimental fields in Sampla experimental station of CSSRI, Karnal also. The soils of controlled experimental fields were of sandy loam texture with bulk density and gravimetric moisture contents at field capacity and saturation ranging between 1.48 -1.55 g/cm^3, 8 - 21 % and 35 - 41 % respectively. Initial root zone (0-60 cm) soil salinity of these experimental fields (before Wheat crop sowing in Nov. 1986) ranged between 1.5 – 1.9 dS/m.

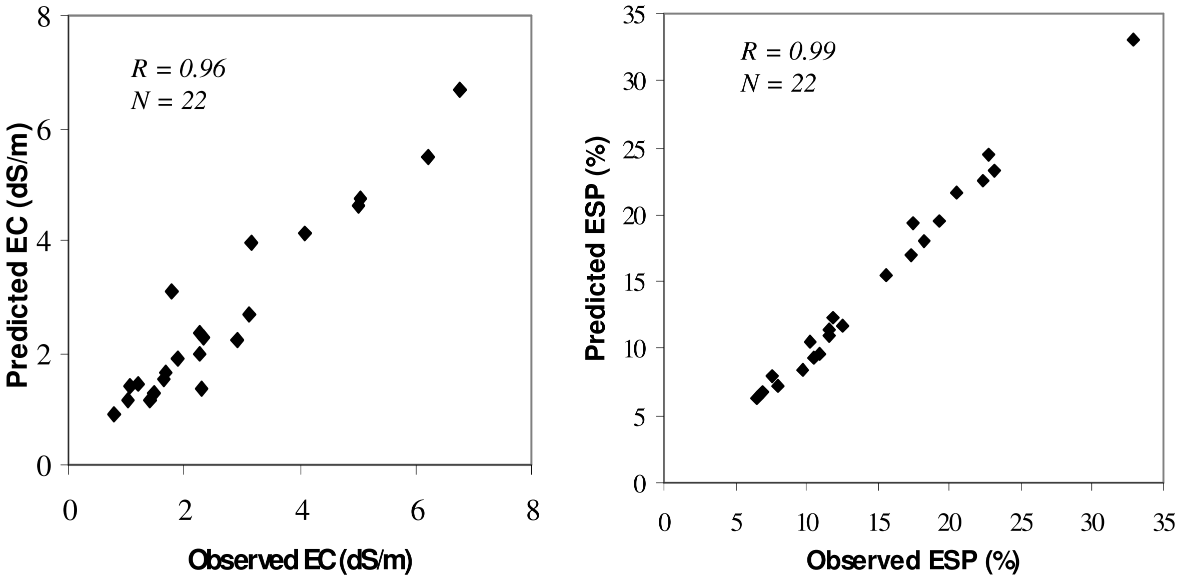

Figure 1. *Observed vs. predicted EC and ESP values for farmer's fields during (2000-01) calibration period*

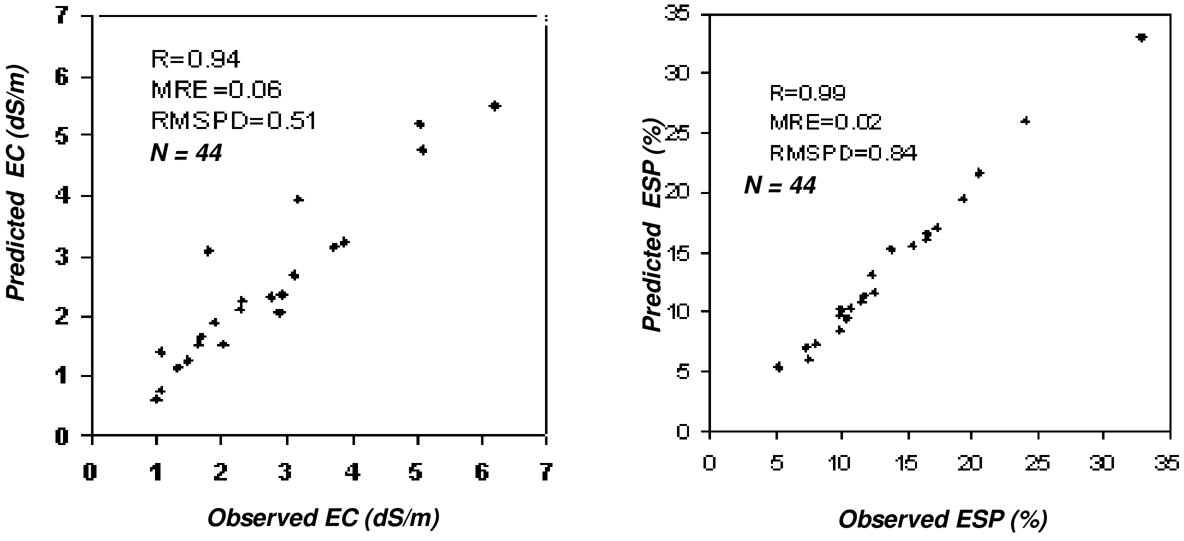

Figure 2. *Overall correlation coefficients (R), mean relative errors (MRE) and root mean square prediction errors (RMSPD) for DSS simulated EC and ESP values for farmer's fields during (2001-03) validation period*

Calibration of proposed DSS on the controlled experimental field data for 1986-1987 showed (Fig. 4) that soil leaching fraction value of 0.5 could yield reasonably good correlation coefficient (0.86) between the observed and predicted EC values for the test fields. Incorporation of these calibrated leaching fraction values, along with other (known) type-I parameters, into the proposed DSS showed that simulated root zone electrical conductivities (under 4-saline water irrigation treatments) for (1987-89) validation period were associated with correlation coefficients (R), and root mean square prediction errors (RMSPD) ranging between 0.84 - 0.96 and 0.42 - 1.30 respectively (Table 2). Pooling of validation results for all 4 - irrigation treatments showed that absolute mean relative errors associated with the DSS-predicted root zone soil salinities were well within 15%.

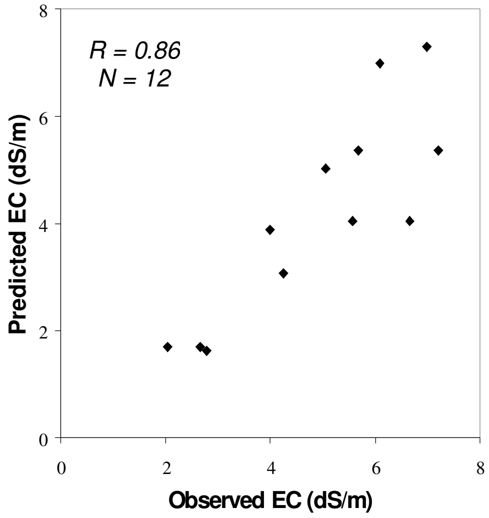

Figure 3. *Observed vs. predicted electrical conductivities (EC) of controlled experimental fields during (1986-87) calibration period*

Table 2. *Observed (Obs.) vs. DSS-predicted (Pred.) electrical conductivities (EC, dS/m) of controlled experimental fields during validation period (1987-89)*

Dates	**CW (< 0.7 dS/m)**		**6(dS/m)**		**9 (dS/m)**		**12 (dS/m)**	
	Obs.	**Pred.**	**Obs.**	**Pred.**	**Obs.**	**Pred.**	**Obs.**	**Pred.**
13/11/87	1.50	1.46	2.75	3.33	4.15	4.37	5.00	5.66
10/02/88	1.59	1.49	2.95	4.13	4.25	5.61	5.97	7.32
09/03/88	2.05	1.46	4.61	4.7	6.23	6.51	8.35	8.54
24/03/88	1.87	1.44	5.20	5.25	6.56	7.38	8.47	9.72
09/04/88	1.52	1.53	5.46	6.17	7.34	8.79	8.96	11.59
16/11/88	0.68	0.28	0.63	0.82	0.50	1.12	0.48	1.45
09/04/89	1.24	0.51	5.07	3.55	5.99	5.26	7.34	6.99
R	0.84		0.88		0.95		0.96	
RMSPD	0.42		0.81		0.90		1.30	

The above controlled experimental field data (for 1987-89 period) was also used for testing the proposed decision support system's potential to realistically simulate relative crop yield reductions under varying salinity levels. In contrast to the actual relative wheat yield reductions of about 5.94, 19.93 and 22.07%, under 6, 9 and 12 dS/m-irrigation treatments, the proposed DSS predicted about 6.25, 18.03 and 38.61% relative crop yield reductions respectively. These DSS simulated relative wheat yield reductions were associated with absolute mean relative error of 24%.

Hence validation of proposed DSS on both farmer's and controlled experimental fields showed that it was indeed capable of giving near-realistic estimates of both root zone soil salinity/ sodicity and relative crop yield reductions.

Assessing length of conjunctive water use experiments with DSS

Average rice and wheat crop yield reductions, at initial mean salt concentrations of 5.2-dS/m (EC) and 16.0% (ESP) under varied conjunctive water use strategies, on the test farm were about 39% and 28% respectively. Long-term impacts of varied *Kharif* season-conjunctive water use strategies with the proposed DSS (Table 3) showed about 17% improvement in mean rice crop yields over 10 years duration. However it was observed that these average rice crop yields had no significant improvement beyond fourth year. On the contrary, mean wheat crop yield reductions (Table 4), under varied *Rabi* season-conjunctive water use strategies, stabilized at about 14% in the eighth year of the long-term impact assessment study. Hence, the proposed DSS could clearly show that the length of rice crop based long-term conjunctive water use experiments, associated with larger water inputs (Table 1) and hence faster leaching of root zone salts, should be shorter than the wheat crop based conjunctive water use experiments.

Table 3. *DSS-simulated long-term impacts of varied Kharif season-conjunctive water use strategies on test farm's rice crop yield reductions*

Simulation year	**Rice crop yield reductions (%) under individual conjunctive water use strategies**							
	CW: TW	TW: CW	4CW, 5TW	1CW, 2TW, 3CW, 3TW	3TW, 3CW, 3TW **(Existing)**	25%CW + 75%TW	50%CW + 50%TW	MEAN
1	38.1	38.4	42.1	38.4	38.4	39.9	38.1	39.1 (a)[#]
2	29.0	32.7	30.2	33.2	33.9	34.6	26.6	31.5 (b)
3	19.3	22.7	20.9	24.1	24.3	25.5	19.2	22.3 (d)
4	20.4	23.2	23.2	25.1	25.3	27.5	20.9	23.7 (c, d)
5	20.7	23.4	24.2	25.5	25.7	28.5	21.7	24.3 (c)
6	20.7	23.3	24.8	25.8	25.8	28.9	22.1	24.5 (c)
7	20.7	23.4	25.1	27.1	25.9	29.1	22.3	24.8 (c)
8	19.2	22.0	27.1	26.7	27.2	24.1	20.9	23.9 (c)
9	20.4	22.4	26.6	24.2	23.1	27.0	21.8	23.6 (c, d)
10	20.4	22.4	26.0	26.8	24.5	28.1	21.7	24.3 (c)

#: Means with the same letter are not significantly different at $\alpha = 0.05$ with Critical t-Value = 2.0 and Least Significant Difference = 1.4

Table 4. *DSS-simulated long-term impacts of varied Rabi season-conjunctive water use strategies on test farm's wheat crop yield reductions*

Simulation year	**Wheat crop yield reductions (%) under individual conjunctive water use strategies**							
	2CW, 1TW, 1CW **(Existing)**	1CW, 1TW, 2CW	2CW, 2TW	CW: TW	25% CW + 75% TW	50% CW + 50% TW	75% CW + 25% TW	MEAN
1	28.3	27.7	28.8	28.1	28.6	27.7	26.9	28.0 (a)[#]
2	21.2	20.9	26.0	21.3	24.6	21.2	19.7	22.1 (b)
3	18.1	18.4	22.5	18.2	21.7	21.2	18.1	19.7 (c)
4	16.2	16.0	21.6	16.1	20.5	19.5	15.2	17.9 (d)
5	15.1	14.8	19.2	15.0	19.5	18.2	14.6	16.6 (e)
6	14.2	14.3	18.5	14.3	18.7	17.3	14.2	15.9 (e)
7	13.4	13.5	17.3	13.4	17.9	17.1	13.0	15.1 (f)
8	13.1	13.1	15.8	13.1	15.7	15.1	12.7	14.1 (g)
9	13.1	12.5	14.9	12.9	15.4	14.2	12.0	13.5 (g)
10	13.2	12.2	14.7	13.3	15.1	13.9	11.7	13.4 (g)

#: Means with the same letter are not significantly different at $\alpha = 0.05$ with Critical t-Value = 2.0 and Least Significant Difference = 0.9

It was further observed that DSS proposed mean annual root zone salt concentrations of the rice-wheat growing test farm, exposed to varied conjunctive water use strategies, decreased exponentially with time (Fig. 5a, b). Fitting of these mean annual EC and ESP values to an exponential model showed that the test farm was associated with mean salt decay rates of -0.023 dS/m and -0.016% per annum at 95% confidence interval. It was estimated that at these decay rates, time required for the test farm's root zone EC/ ESP values to stabilize at (all treatment) mean values of 4.6 dS/m or 14.5 %, from an initial mean levels of about 5.2 dS/m or 16.0%, is about 5.5 to 6.0 years.

The present study could thus clearly show that the time required for achieving stable root zone salt concentrations, as revealed from stable crop productivities, under individual Rice / Wheat cropping seasons is quite different from that required by combined Rice-Wheat system. In fact in a combined Rice-Wheat system, the time required for achieving stable root zone salt concentrations was about average (i.e. 5.5 – 6.0 years) of both quickly (i.e. in about 4 years)-stabilizing rice and slowly (i.e. in about 8 years)- stabilizing wheat sub-system. These results were in complete confirmation with those obtained through actual long-term conjunctive water use experiments of All India Co-ordinated Research Projects [1] on Rice-Wheat cropping sequence. The proposed DSS could hence quite realistically mimic the natural tendency of a faster sub-system (i.e. Rice) to force the total (i.e. Rice-Wheat) system's stabilization time to lower than that of a slower sub-system (i.e. Wheat) and vice-a-versa.

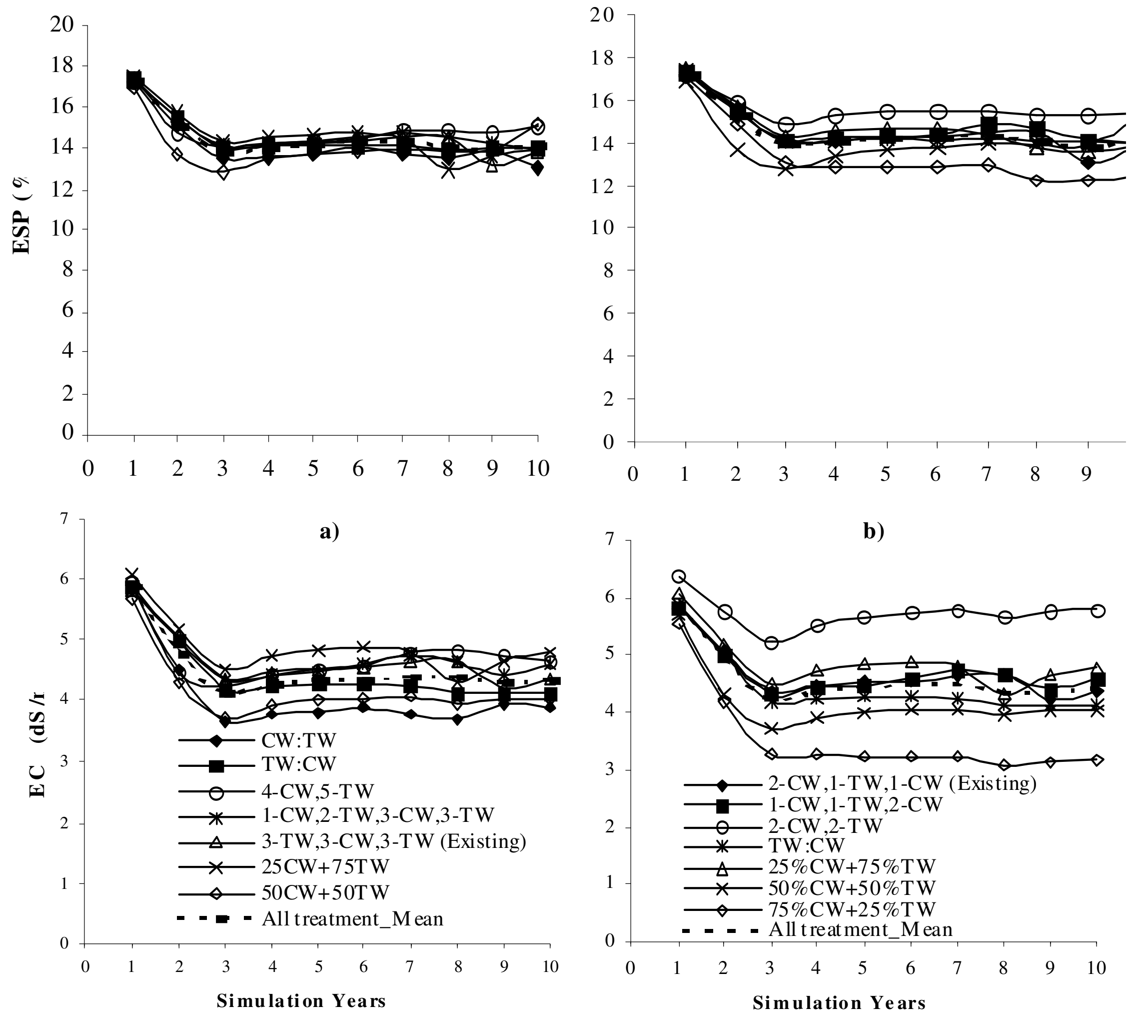

Figure 4. *Long-term average annual root zone salt concentrations under (a) Kharif and (b) Rabi season - conjunctive water use strategies for the test farm*

Impact of length of long term experiments on the consistent performance and hence appropriate selection of most stable and sustainable conjunctive water use strategies for the test farm was also attempted. Table 3 shows that at shorter time scales (eg. 2 years) (50% CW + 50% TW); (CW:TW) and (4CW,5TW) conjunctive water use strategies appeared to be superior to the rest of the *Kharif* season-conjunctive water use strategies. However at DSS proposed stabilization time for the (test) Rice-Wheat system (i.e. 6 years) or at longer term scales, cyclic application of (4CW,5TW) appeared to be much inferior to (50% CW + 50% TW); (CW:TW) and (TW:CW) strategies. In fact it was observed that, at longer time scales (i.e. at ≥ 6 years), cyclic application of canal and tube well waters (i.e.CW:TW) was consistently more productive than anyother *Kharif* season conjunctive water use strategy for the test farm.

Similarly, on comparing various conjunctive water use strategies for *Rabi* season (Table 4), it was observed that although on shorter time scale (i.e. 2 years) application of 50% CW blended with 50% TW (i.e. 50% CW + 50% TW) was as productive and superior as cyclic applications of (2CW, 1TW, 1CW); (1CW, 1TW, 2CW) and

(CW:TW) yet on long term scales (i.e. at ≥ 6 years) it could not maintain its superior performance. In fact, at longer time scales, (75%CW + 25% TW); (1-CW, 1-TW, 2-CW); (CW: TW) and (2-CW, 1-TW, 1-CW, i.e. existing) irrigation practices appeared to be the most stable and consistent strategies for the test farm. It was further observed that during any cropping season, cyclic conjunctive water use strategies were in general more (long-term) stable and sustainable than the blending options. These results were in complete confirmation with those obtained through several actual long-term conjunctive water use experiments [21, 18] on similar soils.

Conclusions

The present investigation could demonstrate tremendous application potential of such pre-validated decision support tools in planning appropriate lengths of various long-term field experiments. It could clearly demonstrate that different agricultural systems, as generated by different sets of conjunctive water use treatments, are characterized with different time periods for achieving stable/sustained crop yields. Limiting an infinitely long conventional field experiment to this time duration not only leads to the selection of most appropriate and sustainable agricultural practice(s) but also increases its cost, time, energy and information-efficiency and hence chances to be planned for many other diverse locations within the same limited budget.

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