Reprinted from *Agronomy Journal*
Vol. 90, No. 4

SALTDATA: A Database of Plant Yield Response to Salinity

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ABSTRACT

Crop salt-tolerance data are crucial for the effective management of salt-affected agronomic systems in arid and semiarid regions. Numerous field and laboratory experiments have been conducted over the years to obtain these data, leading to generalized salt-tolerance lists used by growers and researchers. Plant response to salinity is affected by several factors, including crop variety, soil texture, climate, and irrigation or other cultural practices. Consideration of these factors in growth-response models would permit a more realistic and site-specific prediction of crop yield as a function of soil salinity. A computerized salt-tolerance database management program, SALTDATA, was developed to store experimental data relating observed crop yields to average rootzone salinity and other parameters affecting plant growth. The information was selectively retrieved from a large collection of published references on salt tolerance. The data were stored in their original reported units, but conversion equations were included to allow comparison of salinity and yield data of different experiments reported in different units. Thus, a comprehensive data set can be built for retrieval, export, and subsequent analysis by various crop salt-tolerance models.

Salt-affected soils reduce crop yields in many arid and semiarid regions, as well as in coastal areas subject to seawater intrusion or salt sprays. Excess salts also inhibit plant growth in greenhouses when soils and planting media are either inadequately irrigated or overfertilized. Successful management of salt-affected agronomic systems is largely dependent on information about crop salt tolerance, or the relative yield expected for a given rootzone salinity. The amount of work done on this subject is astounding; countless salinity studies have been carried out over the years in many parts of the world. Thousands of publications stemming from these studies have been compiled and indexed (Francois and Maas, 1978, 1984). Despite this abundance of information, application of available data has often been of limited value, since plant response to salinity is mediated and/or influenced by cultural, soil and water management practices, and environmental factors (Maas, 1993). In addition, many studies suffer from inadequate experimental controls, or lack pertinent information on important environmental variables and yield components. Some experiments are conducted over a range of salinities that proved to be too narrow or too broad, and the number of treatments was often inadequate for reliable estimation of salt-tolerance parameters. These considerations, while perhaps evident to scientists familiar with salinity research, may not be intuitive to less-experienced readers engaged in a literature search. For example, among the most critical elements of a salt-tolerance experiment is the maintenance of adequate soil moisture and soil fertility, so that salinity effects on plant growth are not confounded by matric or nutrient stresses. Other important considerations that should be reported include the composition of the saline solutions, the quality of water used to germinate the seeds, and the rate of salinization after transplanting or during seedling establishment.

Another perplexing problem for readers is the different ways in which salinity can be measured. Soil salinity in crop salt-tolerance studies is most commonly measured in terms of the saturated-paste extract electrical conductivity (EC_e), since this value is reproducible and easily measured (USSL, 1954). The EC_e can be estimated from other measures of soil and solution salinity, including osmotic potential and chemical concentration. Ideally, an effective salt-tolerance experiment would include the measurement of critical environmental variables and would have a range of six or more rootzone salinity levels, producing different yield values (Maas, 1993). In many cases, however, this range of salinity treatments is reduced, to save expense and labor.

Consolidation of previous salt-tolerance studies into a comprehensive database will allow for a more effective evaluation of past work. By combining similar experiments on the same crop, conducted under approxi-

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Published in Agron. J. 90:556–562 (1998).

Abbreviations: EC_e, electrical conductivity of the saturated-paste extract.

mately the same conditions (e.g., field or greenhouse environment, soil or nutrient solution), a larger and more complete composite data set can be derived and used to quantify a particular crop's response to a particular type of salinity. Another potential use for a plant salt-tolerance database is the opportunity to compare results across different crop genotypes and different types of experiments, e.g., evaluating the effects of different growth media (sand, soil, or solution) or irrigation types (sprinkling, drip, or flood) on crop salt tolerance. One of the issues in salinity research is the response of plants to specific ions or salts; for example, reviews of crop salt-tolerance data indicate that plants respond differently to anions (such as chloride and sulfate) and cations (like sodium and calcium) (USSL, 1954). To facilitate further investigation of this subject, the database includes information on the specific salt type used in each treatment, and how salinity was measured. Queries based on salt type allow the user to compare and select data sets for specific salts.

Our objectives for this project were to design and build a computerized database of plant response to salinity. The database was designed to provide specific quantitative information on marketable and vegetative yield as a function of average rootzone salinity, separated by the environmental and management conditions affecting growth.

MATERIALS AND METHODS

Microsoft Visual FoxPro[1] relational database software was used to build the database and develop an executable program for distribution to a variety of users in research and management. The database system requires a personal computer using a 386 or higher microprocessor with the MS-DOS operating system version 3.1 or later, and the Microsoft Windows operating system version 3.0 or later running in 386 enhanced mode. The system requires 8 MB of memory, and a monitor of VGA resolution or higher.

The Design Process

Design of the crop salt-tolerance database structure and system required a multidisciplinary approach including input from plant, soil, and computer scientists. The first step in the design process was to define user needs and the purpose for this data set. After discussions with research scientists, extension agents, farmers, and students, the database was planned to function both as a reference tool for applied extension activities (providing bibliographic and experimental information) and as a resource of raw and standardized salt-tolerance data for use in various growth-response modeling efforts. Possible salt-tolerance models include the familiar two-piece yield-threshold model of Maas and Hoffman (1977), and other one- and two-parameter sigmoidal or exponential functions (van Genuchten and Hoffman, 1984). Vegetative and marketable yields have been shown to be especially appropriate response variables for growth-response models (van Genuchten, 1983), although other growth parameters, such as plant height, leaf area, or root yield, may serve as alternative yield variables.

In addition to bibliographic information, the database contains easily accessible, quantitative information on crop and management parameters, including actual plant yield results for given salinity levels separated by different experimental variables. A general review of the salt-tolerance literature revealed the factors known to affect plant response to salinity, and most of these factors were incorporated into various database tables (Table 1).

The database design was based on a relational approach, which required that the data be input as tables (Date, 1991). Tables are composed of records, with each record containing several fields of various types (character, numeric, logical, or date), size, and purpose (Table 1). The records comprise the rows in a table and the named columns are the fields. The order of fields and records in a table is irrelevant, but duplicate entries in a table are not allowed. Data must be partitioned into normalized tables, denoting that all fields within that table are elemental and cannot be decomposed without loss of meaning.

To support the relational approach, relevant data from each appropriate publication were partitioned into natural groupings, using normalized tables such as bibliographic, plant, environmental and management information. Hence, crop, salt, location, dates, and water and nutrient applications were all placed in different tables. This systematic organization of information into individualized tables eliminated redundancy in the database and increased efficiency in storing the data. This design also clarified what information was available or lacking in the existing literature. The only deviation from the normalized approach concerned the storage of the salinity and plant yield data. Due to the varying nature of this data (i.e., the number of reported yield–salinity pairs differs substantially from experiment to experiment), storage of the data in a normalized linear form would have been inelegant and cumbersome. Thus, plant yield response and salinity data were stored in comma-delimited strings as sets of numbers.

Results of crop salt-tolerance studies are stored in the database as they were reported in the literature, even though some of the units of measurement are now uncommon or outdated. The database is composed of 14 tables or files containing crop, management, and yield data extracted from the original publications, and several *lookup* or reference tables that contain commonly used information. The data files and their individual fields are listed and described in Table 1.

Lookup reference tables in the database are lists used in conjunction with specific data files. The tables currently include the following information:

1. methods of salinity measurement and salt species,
2. texture of the soil or growth medium,
3. irrigation methods,
4. conversion equations to estimate EC_e (mostly from USSL, 1954), and
5. salt tolerance rating of various crops (Maas, 1993).

One of the benefits of the relational database design is that additional tables can be added as user needs change or become more evident, and as future publications address salinity issues in a new way. For example, the first version of the database contained only information on plants grown in fairly constant salinity, thus ignoring growth stage effects and the influence of salts on germination, flowering, or other potentially sensitive periods. There is growing interest in this subject (Maas and Gratten, 1998); hence, as a more consistent method of reporting the results becomes accepted, a growth stage table could be added to the existing database structure. Climate is another factor that strongly influences plant response to salinity (Maas and Gratten, 1998) and should be included in this database. However, a standardized format of reporting climatic variables has not been established, and this information

[1] Mention of particular products does not constitute endorsement by the USDA, or the U.S. federal government.

Table 1. Bibliographic and experimental parameters stored in database (.dbf) files.

Field	Field name	Type†	Field length	Examples
				Publication data (Tables 1 to 14)
1. BIBLIO.dbf (bibliographic information; complete once for each publication)				
1	Pub_no	Num	5	Publication number, unique for each paper
2	Title	Char	250	Title of paper or report
3	Authors	Char	250	All authors listed on the paper
4	Citation	Char	80	Journal or report; volume: page range
5	Pub_Year	Num	4	Year of publication
6	Comments	Char	70	Reference to other publications, unusual features, ...
2. CROP.dbf (common and scientific crop names, plus identifiers for subgroups of crops)				
1	Pub_no	Num	5	Publication number, unique for each paper
2	Crop_id	Num	2	Values > 0 indicate more than one crop type
3	Crop_var	Char	40	Variety, cultivar, accession, hybrid, label, ...
4	Family	Char	40	Gramineae, Leguminosae, ...
5	Gen_spp	Char	50	*Zea mays, Medicago sativa*, ...
6	Common	Char	40	Corn, alfalfa, ...
3. EXPT.dbf (experimental parameters)				
1	Pub_no	Num	5	Publication number, unique for each paper
2	Expt_id	Num	1	Values > 0 indicate more than one experiment
3	Env_system	Char	30	Field, greenhouse, growth chamber, ...
4	Gro_media	Char	50	Soil, sand, solution, tissue culture, ...
5	Plot_size	Char	30	Dimensions of field plots, beds, pots
6	Plant_den	Char	25	No. of plants per square meter, or per pot
7	Germ_salt	Num	2	Quality of water used to germinate seeds: 0 = good; 1 = saline; −1 = not reported
8	Salt_rate	Num	2	Rate of salt application: 0 = gradual or stepwise; 1 = abrupt; −1 = not reported
4. DATE−FAC.dbf (dates and duration of the various experiments)				
1	Pub_no	Num	5	Publication number, unique for each paper
2	Date_id	Num	1	Values > 0 indicate more than one season
3	Sow_date	Date	8	Planting or sowing date (mm/dd/yy)
4	Transplant	Date	8	Date transplanted (mm/dd/yy)
5	Salt_app	Date	8	Date of 1st salt application (mm/dd/yy)
6	Harvest	Date	8	Date of harvest (mm/dd/yy)
7	Salt_dap	Char	15	Days after planting (when salt applied)
8	Harv_dap	Char	25	Days after planting (when harvested)
5. LOC−FAC.dbf (location where experiments conducted; latitude and longitude are not typically reported)				
1	Pub_no	Num	5	Publication number, unique for each paper
2	Loc_id	Num	1	Values > 0 indicate more than one location
3	Location	Char	40	City, field station, university, agency, ...
4	State	Char	20	State or province
5	Country	Char	20	Country (USA, Israel, Canada, Egypt, ...)
6. SALT_FAC.dbf (the type of salinity imposed and how it was measured)				
1	Pub_no	Num	5	Publication number, unique for each paper
2	Salt_id	Num	2	Values > 0 indicate more than one salt type
3	Sal_unit	Num	2	EC, OP, m*M*, ... (from lookup table)
4	Sal_type	Char	40	NaCl, seawater, $CaCl_2$, ...
5	Ratio	Char	17	Numeric ratios of salts in salt_type
6	Sel_cation	Num	2	Refer to CATION.dbf; to facilitate queries
7	Sel_anion	Num	2	Refer to ANION.dbf; to facilitate queries
8	Comp_info	Logical	1	Irrigation water composition reported? (Y/N)
7. ENVIRON.dbf (environmental factors that were tested or varied with salinity)				
1	Pub_no	Num	5	Publication number, unique for each paper
2	Env_id	Num	1	Values > 0 indicate more than one environmental factor
3	Env_fac	Char	55	RH%, ozone, $CaCO_3$, light intensity, ...
8. AMEND.dbf (amendments or fertilizers that varied with salinity)				
1	Pub_no	Num	5	Publication number, unique for each paper
2	Amend_id	Num	2	Values > 0 indicate more than one amendment
3	Texture	Num	2	Growth medium texture from reference table
4	Border	Logical	1	Y = borders around plots or space between pots
5	N_form	Char	30	Nitrate, ammonium, manure, ...
6	N_amt	Char	30	Quantity or rate of nitrogen application
7	P_added	Char	30	Quantity and form of phosphorus applied
8	Micronutr	Logical	1	Y = micronutrients applied; N = not applied or no info
9	Pesticides	Logical	1	Y = pesticides applied; N = not applied or no info

Table 1 cont. next page.

is often missing from the literature. The location and dates of experiments may help compensate for the lack of climatic data, but this information is also often unreported.

A unique identification number is assigned to each publication. This number, or primary key, is subsequently included in every record and every table containing information from that publication. Thus, all sets of data are keyed to their publication identification number and, in addition, are related to the specific environmental, management, and varietal parameters of individual experiments by a secondary key.

Secondary keys in the various crop, environment, and management tables are a combination of the publication identification number and one or, in certain cases, two digits that indicate variations in experimental procedures, crops, or other factors. Two digits are required for the crop, salt, and amendment tables, since one manuscript may report more than nine different crops, salts, or fertilizers. A digit of zero in any secondary key indicates that only one factor in that table was reported for that publication and that there was zero variation in the experiments for that particular property. For example,

Table 1. Table 1 cont.

Field	Field name	Type†	Field length	Examples
9. MGMT.dbf (irrigation type; i.e. sprinkler, flood, drip, etc.)				
1	Pub_no	Num	5	Publication number, unique for each paper
2	Water_id	Num	1	Values > 0 indicate more than one irrigation type
3	Treatmnt	Num	2	From irrigation type reference table
10. MATRIC.dbf (irrigation and water scheduling: a subset of MGMT.dbf)				
1	Pub_no	Num	5	Publication number, unique for each paper
2	Matric_id	Num	4	Water_id + Date_id + Loc_id + Amend_id
3	Irr_amt	Char	40	Amount of each irrigation or season total
4	Irr_freq	Char	40	Frequency of irrigation
5	Matr_pot	Char	40	Matric potential used to guide irrigation
11. UNITS.dbf (salinity and yield units reported in publication)				
1	Pub_no	Num	5	Publication number, unique for each paper
2	Unit_id	Num	1	Values > 0 indicate more than one set of units
3	Saltunit	Char	20	Units for salinity (e.g., dS m^{-1}, bar, atm, m*M*, ...)
4	Veg_econ	Logical	1	Vegetative = marketable yield? (Y/N)
5	Conv_fac	Num	2	Conversion equation to EC, in reference table
6	Veg_yld	Char	26	Vegetative yield (shoot, roots, total dry matter)
7	Veg_unit	Char	20	Vegetative units (g $plant^{-1}$, g $plot^{-1}$, kg ha^{-1}, ...)
8	Econ_yld	Char	20	Marketable yield (bolls, fresh fruit, grain, ...)
9	Econ_unit	Char	20	Market units (kg $plant^{-1}$, ton ac^{-1}; no. $plant^{-1}$, ...)
10	Alt_yld	Char	20	Alternate yield (plant height, fresh wt., ...)
11	Alt_unit	Char	20	Alternate units (m, kg $plant^{-1}$, %, ...)
12	Est_yield	Logical	1	Is yield data estimated from graphs or figures?
13	Goto_abs	Logical	1	Maximum values available in ABSOLUTE.dbf
14	ion_comp	Logical	1	Inorganic analysis of plant tissue reported?
15	Othr_yld	Char	100	Other yields reported in paper
12. RESULTS.dbf (reported results)				
1	Pub_no	Num	5	Publication number, unique for each paper
2	temp_id	Char	13	2crop + expt + date + loc + 2salt + env + 2amend + water + unit
3	Num_reps	Num	2	Number of replicate treatments in experiment
4	Num_vals	Num	2	Number of data points (salt–yield pairs)
5	Salinity	Char	60	Values of saline treatments (numerals separated by commas)
6	Veg_yield	Char	80	Values of vegetative yield (numerals separated by commas)
7	Eco_yield	Char	80	Values of economic yield (numerals separated by commas)
8	Alt_yield	Char	60	Values of alternate yield (numerals separated by commas)
9	Is_lr	Logical	1	Is linear response calculated? (If Y, go to MODEL.dbf for yield-threshold results)
13. MODEL.dbf (yield-threshold model results)				
1	Pub_no	Num	5	Publication number, unique for each paper
2	temp_id	Char	13	Same as temp–id in RESULTS.dbf
3	Ct_veg	Num	00.00	Threshold salinity for vegetative yield
4	Decr_veg	Num	00.00	Slope of model: % yield reduction
5	Ct_econ	Num	00.00	Threshold salinity for marketable yield
6	Decr_econ	Num	00.00	Slope: % yield reduction for marketable
7	Class	Char	2	Salinity class: s, ms, m, mt, t
8	Comments	Char	80	Averaged treatments to calculate model parameters
14. ABSOLUTE.dbf (contains the real values when results are reported as % control or % max)				
1	Pub_no	Num	5	Publication number, unique for each paper
2	temp_id	Char	13	Same as temp_id in RESULTS.dbf
3	Control	Logical	1	Are relative yields % of control? (Y) or % of max? (N)
4	Salt_abs	Num	7	Salinity value associated with 100% yield
5	Veg_abs	Char	25	Value and units associated with 100% vegetative yield
6	Eco_abs	Char	25	Value and units associated with 100% economic yield
7	Alt_abs	Char	25	Value and units associated with 100% alternate yield
Lookup or reference (Tables 15 to 21)				
15. PARA_LUT.dbf (salinity measurements)				
1	Ch	Num	2	Selected in SALT_FAC.dbf, Sal_unit field
2	Salinity	Char	10	Labels of salinity types (ECe, OPe, TDS, Conc., ...)
3	Salt_unit	Char	100	Explanation of the salinity types listed above

Table 1 cont. next page.

Francois (1994) measured the response to salinity of two canola species, *Brassica campestris* (crop 01) and *B. napus* (crop 02) (Fig. 1a). These crops were grown in the same location (loc 0), using the same salt (salt 00), experimental and cultural practices (expt. 0, amend. 00, water 0, and units 0) for two years, 1989 and 1990 (date 1 and 2). The secondary keys for each table are composited, in the specific order shown in Fig. 1a, to form a 12-character key in the RESULTS.DBF table, thus providing a link between yield data and specific parameters listed in the crop, experimental, and management data tables. The normalized data sets are represented by the bottom row of boxes in Fig. 1a,b.

Queries based on various experimental parameters (e.g., crop, N form, irrigation type, etc.) will provide users with sets of salinity and yield data. If more than one data set fits the prescribed query conditions, the user can delete undesirable sets (e.g., when there is inadequate information in fields other than those queried) and combine the remaining data files to form a composite yield–salinity data set. Although the sets are character strings, they contain only numbers, separated by commas, and can be converted to ASCII files for use in other programs, models, or spreadsheets, either as individual or composite data sets.

When the initial design of the database structure was complete, data from a subset of published papers were entered into the database. This prototype dataset was used to test the

Table 1. Table 1 cont.

Field	Field name	Type†	Field length	Examples
16. IRR_LUT.dbf (type of irrigation used in experiment)				
1	Choice	Num	2	Selected in MGMT.dbf, Treatmnt field
2	Irr_type	Char	40	Irrigation types (flood, sprinkle, drip, ...)
17. TEX_LUT.dbf (texture of the growth medium used in experiment; not just soil texture)				
1	Ch	Num	2	Selected in AMEND.dbf, Texture field
2	Tex	Char	20	Sand to clay to gravel to no texture (solution)
18. CONVERT.dbf (conversion equations to estimate ECe from other salinity measurements)				
1	Eqn_no	Num	2	Selected in UNITS.dbf, Conv_fac field
2	Conv_eqn	Char	35	Equations for conversion
3	Con_note	Char	40	Explanations, notes, definitions, etc.
19. CATION.dbf (list of cations used in experiment)				
1	Pos_ion	Num	2	Selected in SALT_FAC.dbf, Sel_cation field
2	Cations	Char	40	Full names of potentially used cations
3	Cat_sym	Char	15	Chemical symbols that match the cation list box
20. ANION.dbf (list of anions used in experiment)				
1	Neg_ion	Num	2	Selected in SALT_msFAC.dbf, Sel_anion field
2	Salt_fam	Char	40	Full names of potentially used anions
3	An_sym	Char	15	Chemical symbols that match the anion list box
21. RATING.dbf (list of plants by their common and botanical names with salt tolerance rating by Maas, 1993)				
1	Bot_name	Char	50	Botanical (genus species) crop name
2	Com_name	Char	40	Common crop name
3	Maas_rate	Char	2	Sensitive to tolerant rating, as published by Maas

† Field types are numeric (Num), character (Char), logical, and date.

design of the database and its ability to accept the many different types of experimental data that would eventually be included in the database. A reiterative process resulted in several modifications to the database design and tables to accommodate variable data sets. Individual field sizes were modified to fit the stored information and reference tables were added as necessary.

Minimum Requirements for Publications to be Included in the Database

Whereas thousands of experiments have been conducted and published on salinity-related issues, individual manuscripts vary tremendously in quality and often do not report enough experimental or yield information. In addition, many high-quality salt-tolerance studies reported unique data on genetics, plant disease, physiology, and other factors but did not include vegetative or economic yield values as a function of varying salinity. These experiments, as well as those focusing on germination and early seedling growth, were not included in the current version of the database.

Ideally, only quantitative data from publications and technical reports that met certain format requirements and minimum experimental criteria were included in the database. Yield results that were not reported as a specific function of salinity, but for example were averaged over several treatments, generally could not be included because they did not fit the structure of the Results database table, which requires numerical salin-

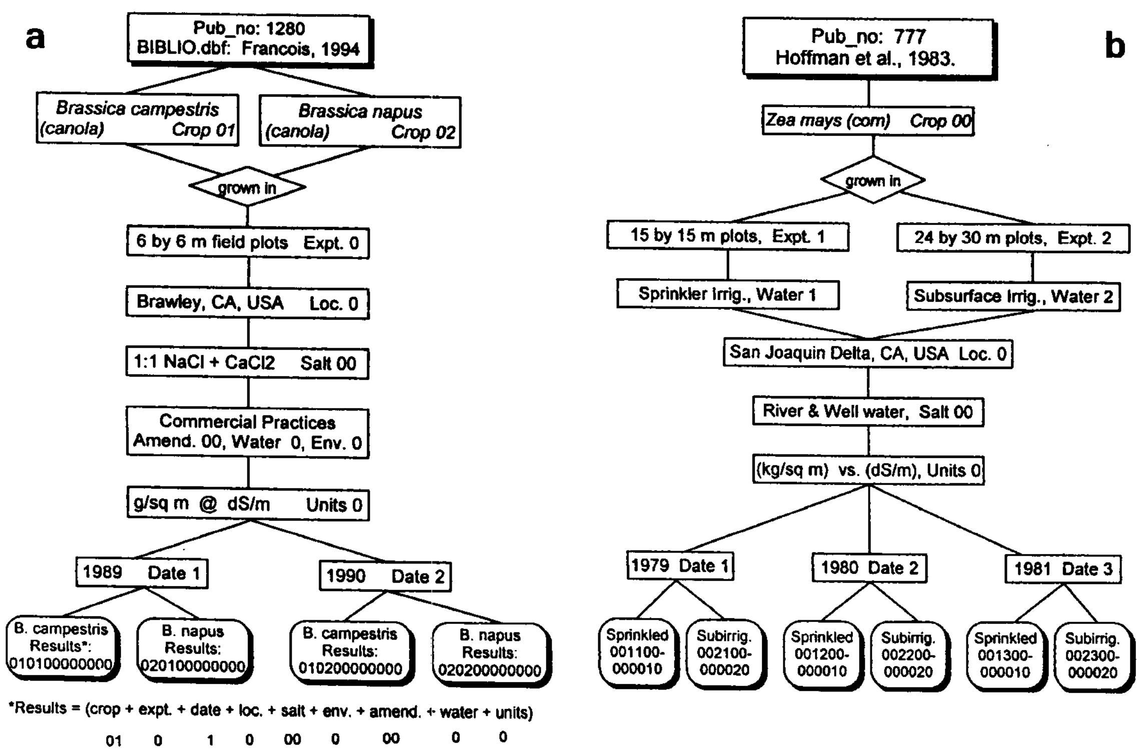

Fig. 1. Data flowcharts demonstrating the variability of experimental design and the numbers of yield records that can be extracted from just two publications (Francois, 1994; Hoffman et al., 1983). All of the information shown in this figure is accessible through the database system.

ity–yield pairs. In addition to the proper data format, a minimum description of certain experimental parameters was required for the inclusion of a manuscript in the database. These parameters included the control (or background) salinity; numerical values of the imposed salinity treatments rather than such qualitative terms as low, medium, and high; quantitative information about environmental parameters that covaried with salinity; and quantitative plant yield as a function of salinity.

One important by-product of the database design process was our realization of the need for standardized procedures for salt-tolerance experiments, as well as a need for better methods to report the data. Quite often, relevant or even critical experimental parameters were not included in the publications. For example, few papers fully described water management practices, including the method, frequency, or amount of irrigation. Many studies also failed to report the soil matric potential, which has a major influence on apparent crop salt tolerance, since salt stress lowers the water potential and mimics water stress. At low soil matric potentials (high tension), root water uptake can quickly exacerbate both the osmotic and toxic components of salt stress (Shannon et al., 1994; Cardon and Letey, 1992).

Another fundamental property that is often not reported in salt-tolerance papers is the rootzone salinity. In many cases, only the irrigation water quality, or the rate of salt application is reported, often without any relevant information on leaching fractions and soil or matric properties. However, in order to include as many salinity–yield data pairs as possible, publications reporting minimal experimental information were used, but then with special codes to indicate missing information or that the study lacked an accepted conversion of the irrigation water salinity values to EC_e of the rootzone. Thus, the user still has the opportunity to view and evaluate these data, and could use conversion equations from sources other than the USSL (1954) handbook that might allow comparison of these data with other studies. These issues are of particular interest because the abundance of published work on salt tolerance may give the impression that this subject has been exhaustively researched; however, only about 10% of the papers in the indexed bibliographies, which include 3500 to 5000 references, were found to contain the minimum information, and in the appropriate format, required to adequately describe plant yield response to salinity. Even so, many database fields remained empty or the choices selected from reference tables were "unknown."

DATABASE FEATURES AND STRUCTURE

Flowcharts were used to demonstrate the variability in experimental design and number of yield records (separated on the basis of experimental parameters) that can be derived from just one publication (Fig. 1a,b). As an example, consider the study by Francois (1994), who reported data from four experiments in which two cultivars of canola were grown in two different years, each having a seed and vegetative yield as a function of soil salinity (represented by the shadowed boxes at the bottom of Fig. 1a). All other experimental and management parameters were the same, as indicated by the nondiverting line of boxes.

In another study, the flowchart structure branches to indicate different experimental methods (Hoffman et al., 1983) (Fig. 1b). The six yield–salinity data sets reported in that paper represented one cultivar of corn (*Zea mays* L.) grown under two different irrigation regimes (each with a corresponding plot size) for three different years (Fig. 2). Note that if the data had been directly averaged over all three years, the study would have yielded only two sets of results, and some of the information would have been lost. In this particular case, combining all of the data into one large or composite data set resulted in unique model predictions for the yield-threshold values and percent decline (van Genuchten, 1983) (Fig. 3). However, different values for these parameters would have been obtained for each of the three years if the data had not been combined. This example points out the usefulness of providing experiment-specific information, thereby allowing the user to delete or combine individual data sets as desired to compare various environmental, crop, or management parameters.

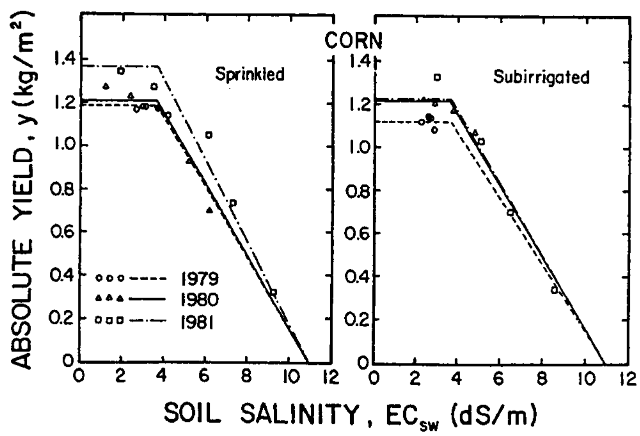

Fig. 2. Observed salt-tolerance response yield-threshold functions for corn for two irrigation types and three growing seasons over a range of soil water electrical conductivity (EC_{sw}). The fitted curves were calculated by van Genuchten (1983) (data from Hoffman et al., 1983).

FUTURE DIRECTIONS AND AVAILABILITY

In addition to the database, an executable management program that will run independently of the com-

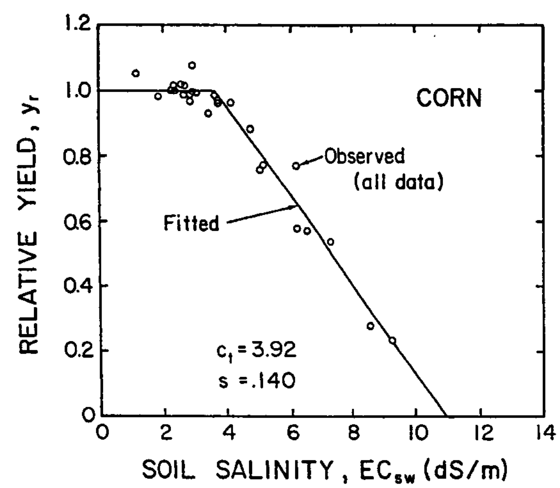

Fig. 3. Plot of the relative salt-tolerance response yield-threshold function for corn as determined from all of the data in Fig. 2 calculated by van Genuchten (1983) (data from Hoffman et al., 1983). The threshold of soil salinity (c_t) at which yield begins to decline is 3.92 dS m^{-1} and the slope (s) of yield decrease over increased salinity is 14%.

mercial database software is under development. A graphical user interface, consisting of a set of windows that allows queries of the database for specific data elements, analysis of the data in terms of different crop salt-tolerance response functions, retrieval (export) of the data, and plotting or reporting the results, are being added to the database application. When this package becomes available, it will be announced on the U.S. Salinity Laboratory Web site (http://www.ussl.ars.usda.gov). Inquiries may also be directed to Michael C. Shannon (mshannon@ussl.ars.usda.gov) or Martinus Th. van Genuchten (rvang@ussl.ars.usda.gov).

Some of the features in the USSL crop salt-tolerance application package, SALTDATA, include conversion routines (USSL, 1954) that will standardize reported salinities to the electrical conductivity of the saturated paste extract (EC_e), and calculate relative yields from the reported absolute yields in various units. The software package will also permit analysis of the data in terms of linear and nonlinear crop salt-response models, and optionally will provide graphs of raw, converted, or analyzed data.

CONCLUSIONS

A database management system was designed and built in Microsoft Visual FoxPro containing quantitative plant yield response data and other relevant experimental information that could be extracted from an extensive collection of published literature. SALTDATA is composed of several normalized and nonnormalized data and reference tables containing bibliographic, crop, management, and environmental information. If there is a sufficient amount of normalized data that can be compared and combined into one or more data sets, then quantitative relationships between salinity and other experimental variables may be revealed without conducting expensive and difficult experiments. One important result of the design, and the review of the literature for this database, was increased awareness of the need for better and more standardized experimental methods, more focused research, and improved documentation and reporting of the research results. The size, precision, and completeness, or lack thereof, of the database will indicate gaps in the literature and in our understanding, and thus, provide direction for future crop salt-tolerance research.

ACKNOWLEDGMENTS

The authors thank the entire staff at the U.S. Salinity Laboratory for their valued suggestions and input in designing this database. In addition, special thanks are made to Jirka Simunek, William Alves, and to the students who helped enter the data: Marlene Fonseca, Devin Slaven, Lynn Phu, Lara Lagos, and Kathleen Masuga.

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