

Canada's salt tolerance testing laboratory

H. STEPPUHN and K.G. WALL

Semiarid Prairie Agricultural Research Centre, Agriculture and Agri-Food Canada, P.O. Box 1030, Swift Current, SK, Canada S9H 3X2. Received 7 December 1998; accepted 8 July 1999.

Steppuhn, H. and Wall, K.G. 1999. **Canada's salt tolerance testing laboratory.** *Can. Agric. Eng.* **41**:185-189. Soil salinity refers to a state where dissolved constituents in interstitial water concentrate beyond the needs of the plants rooted in the soil. Salinity levels in western Canadian soils can range from very slight to very severe within a few metres. Such variability makes it impossible to evaluate the salt tolerance of crops in the field. Canadian engineers have overcome this difficulty by fabricating an environmentally-controlled testing facility near Swift Current, Saskatchewan. Plants growing in sand tanks and irrigated with hydroponics can be evaluated from emergence through maturity. A programable logic controller actuates the facility's lighting, heating, ventilation, and ambient temperature monitoring. The controller also automatically triggers irrigation, replacement of supply water lost by evapotranspiration, and maintenance of brine concentration. Salt tolerance response functions have been determined for wheat, barley, alfalfa, kochia, quinoa, and perennial forage grasses. The facility can serve private companies and producer organizations through the Western Region Business Development Office of Agriculture and Agri-Food Canada. **Keywords:** salinity testing, salt tolerance, salinity laboratory.

La salinité du sol réfère à un état où la concentration des composés en solution dans l'eau interstitielle dépasse les besoins des plantes enracinées dans ce sol. Les niveaux de salinité des sols de l'Ouest canadien peuvent varier de très faible à très élevé sur une profondeur de quelques mètres. Cette variabilité ne permet pas d'évaluer directement au champ la tolérance à la salinité des plantes. Des chercheurs canadiens ont apporté une solution à ce problème en construisant, près de Swift Current Saskatchewan, des bancs d'essai dont l'environnement est contrôlé. Les plantes qui poussent dans des bacs de sable et qui sont irriguées avec un système hydroponique peuvent être suivies de l'émergence jusqu'à la maturité. Un contrôleur logique actionne l'éclairage, le chauffage, la ventilation et le système de suivi de la température. Le contrôleur déclenche automatiquement l'irrigation, remplace l'eau perdue par évapotranspiration et maintient la concentration de sel dans l'eau du sol. On a déterminé les fonctions qui décrivent la tolérance à la salinité du blé, de l'orge, de la luzerne, du kochia, du quinoa et des plantes fourragères vivaces. Les entreprises privées et les groupes de producteurs peuvent utiliser les installations en s'adressant au centre de Développement des Affaires de la région Ouest d'Agriculture et Agro-Alimentaire Canada. **Mots-clés:** expériences sur la salinité, tolérance à la salinité, laboratoire de mesures de la salinité

INTRODUCTION

Salinity levels and salinity problems

Salinity is that property of water which indicates the concentration of the water's dissolved constituents. All natural waters, including those occurring in the interstices of soil and

subsoil, contain dissolved solids and gases and, therefore, possess a degree of salinity. In fact, the growth of vegetative agricultural crops depends on the dissolved nutrients contained within soil solutions.

Unfortunately, problems develop when the concentrations of dissolved salts in root zones exceed those required by the plants. Ayers and Westcot (1985), writing for the Food and Agriculture Organization of the United Nations, defined the problem as: "A salinity problem exists if the salts in a soil accumulate to concentrations that cause reductions in growth and crop yield for plants rooted in the soil." Thus, agricultural salinity refers to the effect of salinity (primarily those of root-zone solutions) on crop plants. Furthermore, the severity of the plant damage, or crop loss, defines the magnitude of the salinity problem. Conversely, the degree to which the plant growth and crop yield remain unaffected by the root-zone salinity defines the salt tolerance of the plants. This technical paper reports on an effort initiated by Canadian engineers to address the salinity problem. The objective was to design and fabricate a world-class, salt-tolerance testing facility primarily for Canadian crops.

The accumulation of white crusts on soil surfaces, especially at seeding time, usually indicates that the crop will produce less due to salinity. White crusts commonly appear only when the average root zone salinity reaches the moderately saline level. Many Canadian crops, such as field pea, flax, and even barley, sustain considerable reduction in productivity when grown in moderately saline root zones. Some crops, spring wheat for example, rarely grow in these soils and suffer significant loss in production when rooted in only slightly saline soils where the telltale white crusts rarely show.

Salinity levels in western Canadian soils can range from very slight to very severe within a few metres (Eilers 1998). The level of root-zone salinity can also vary with time and with changes in the weather. Root-zone salt concentrations increase or decrease in response to infiltration of water from rainfall or snowmelt and to the loss of soil water by evapotranspiration. Such variability makes it impossible to evaluate the salt tolerance of crops in the field. Canadian engineers have overcome this difficulty by fabricating an environmentally-controlled testing facility near Swift Current, Saskatchewan. Plants growing in sand tanks and irrigated with hydroponics can be evaluated from emergence through maturity.

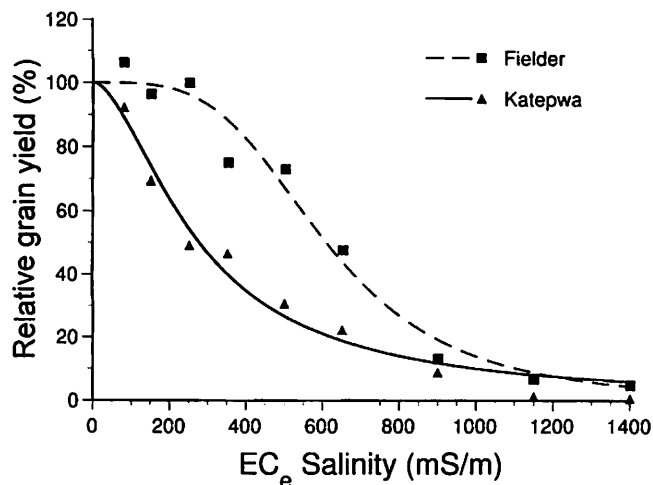


Fig. 1. Responses in relative grain yield (%) produced by 'Katepwa' hard red and 'Fielder' soft white spring wheat varieties grown in saline rooting media (Steppuhn and Wall 1997).

Salinity measurements

The response of test plants to saline environments is determined by measuring plant emergence, survival, growth, phenology, maturity, above-ground biomass, and commodity yields. These measurements are usually replicated, averaged, and related to the electrical conductivities of the test solutions (EC_{sol}) dimensioned in Siemens per metre, S/m (or milliSiemens per metre, mS/m). In the field, EC_{sol} is very difficult to measure. To overcome this difficulty, the United States Salinity Laboratory Staff (1954) outlined a soil chemistry procedure using the electrical conductivities of water-saturated soil paste extracts (EC_e). This measure has proven very consistent and has become the world standard for classifying levels of soil salinity. As reported by Maas (1990), experience in most soils has shown that the two conductivities are approximately related:

$$EC_e \approx 0.5EC_{sol} \quad (1)$$

The right side of this equation assumes that the solutions fill the soil pores to field capacity. This relationship was substantiated for a southern Alberta soil salinized in the laboratory by Janzen and Chang (1988) and for various prairie soils in the field by Kohut and Dudas (1994). White surface crusts rarely occur on Canadian prairie soils until their average EC_e salinity reaches 400 or 500 mS/m.

Canadian crops and varieties

In the past, when growers asked which plant crops or varieties to seed into saline soils, answers relied on published tables listing the salt tolerance data from controlled tests conducted in other countries with foreign varieties (Ayers and Westcot 1985; Maas and Hoffman 1977). These answers were sometimes tempered with data gleaned from field tests at specific locations on the Prairies (Holm 1983; McKenzie 1988); unfortunately, because of the large temporal and spatial variability associated with salinity in the field plus confounding effects from varying soil water volumes, this information was not precise enough to associate inherent production losses to specific salinity levels.

For example, controlled tests conducted in the United States and India placed the threshold EC_e for declining wheat yields at 600 mS/m (Maas 1990). Recent tests in Canada's Salt Tolerance Testing Laboratory (Salt Lab) showed that yield losses for 'Katepwa' hard red spring wheat begin near 150 mS/m and for 'Fielder' soft white wheat near 250 mS/m (Steppuhn and Wall 1997). At 400 mS/m, grain production dropped to 80% of that from the control plants for 'Fielder' and 35% for 'Katepwa' (Fig. 1). These tests confirmed the common observation of Prairie farmers that spring wheat produces very poorly in saline soil.

TESTING OBJECTIVES

Tests have shown that plants respond to saline rooting gradients by following genetically-controlled patterns. Unless a plant possesses specific adaptive mechanisms to grow under saline conditions, salinity hinders growth and productivity. The extent of this hindrance forms the response measured in controlled salt-tolerance testing. The primary objective is to determine the reductions in growth and the losses in production sustained by a vegetative crop when subjected to specific levels of root-zone salinity. The design of the Salt Lab minimizes variations in growth caused by drought, temperature, gas exchange, and other factors except that of salinity. The facility permits control over these side influences so that they affect the test crop uniformly at all salt levels. Such control is impossible to obtain under field conditions.

Crop responses to salinity often vary with different plant growth stages, among varieties, and for each measure of plant growth, development, and product yield. The trend of these responses is typically

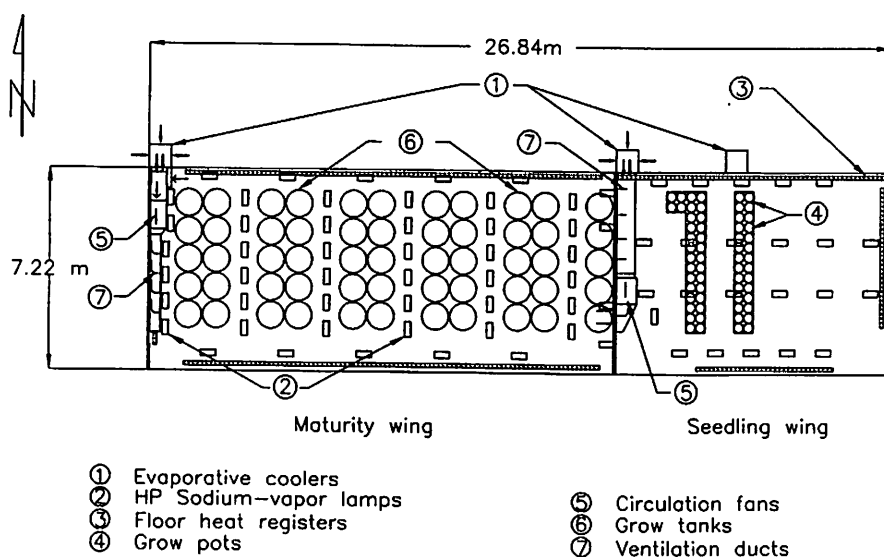


Fig. 2. Plan view, Salt Tolerance Testing Laboratory (Salt Lab) at Swift Current, Saskatchewan.

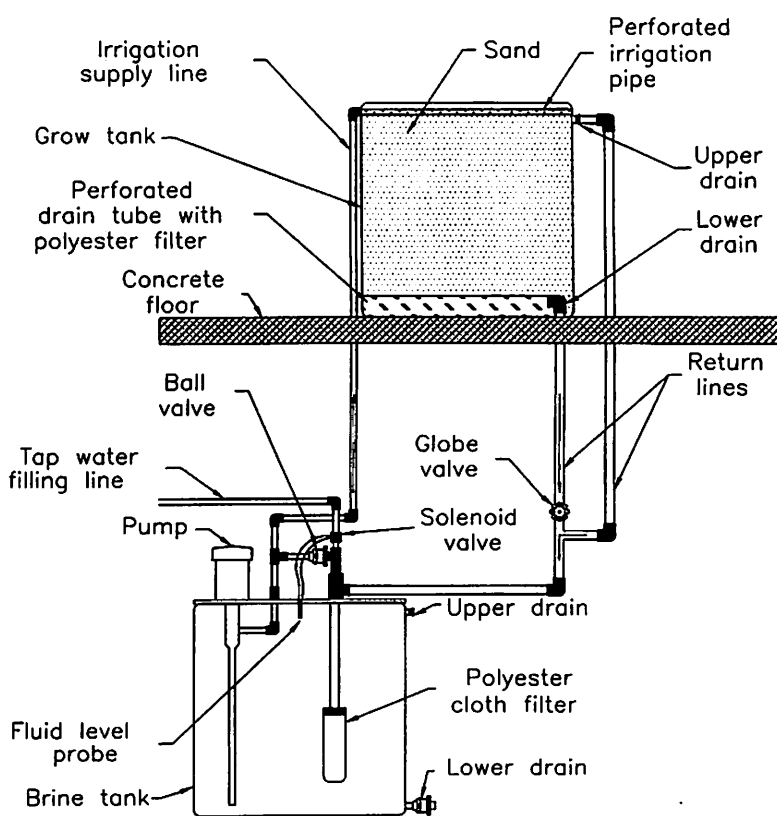


Fig. 3. Side view of grow (sand) tanks and nutrient-brine supply tanks (0.7 m^3) used to test crops grown to maturity.

negative as root-zone salinity increases. The shape of these functions, which commonly follow non-linear, downward curves, has become very important in crop growth modelling. Test results from the Salt Lab define the shapes and slopes of these curves.

GENERAL LABORATORY DESCRIPTION

The tolerance of agricultural crops to salinity relates in large measure to genetics. Specific crops, or varieties, often produce better than others when growing in saline environments because they possess the ability to better cope with the adverse conditions imposed by the dissolved salts. Depending on the plant, the adversity relates, at least in part, to salt-reduced osmotic gradients by which dissolved substances move from the soil into the roots. Adverse salt balances within the soil, roots, or shoots can also cause chemical problems wherein specific ions may become either limiting or toxic. The Swift Current Salt Lab uses large and medium-size sand tanks to evaluate the sensitivity of plants to adverse rooting environments (Fig. 2).

The Salt Lab forms a component of the Semiarid Prairie Agricultural Research Centre, Agriculture and Agri-Food Canada, at Swift Current, Saskatchewan. The facility offers simultaneous testing of crops at three different growth stages: germinating seeds in a growth chamber, seedlings in sand pots, and maturing plants in sand tanks. Seeds are placed in quartz sand where the roots develop and anchor the plants. Nutrients and salts in solution periodically bathe the roots following

preset irrigation and drainage schedules. The entire facility is housed in a thermally-controlled greenhouse which permits year-round testing. Large lamps hang overhead and complement the natural solar radiation and feature adjustable cycling to mimic natural illumination of the test plants during selected growing seasons. The mature plant component of the Lab is large enough to compare seed production from tall crops such as corn, reed grass, and shrubs.

PLANT GROWTH STAGES

Maturing plants

The plants are grown to maturity in open-top, upright, polyethylene cylindrical tanks 1.0 m tall and 0.95 m in diameter (Fig. 3); the grow tanks are filled with high-grade quartz sand (99.8% pure) with nominal particle diameters of 0.3 to 1.0 mm. Each tank provides a surface growing area of 0.7 m^2 , and holds approximately 0.65 m^3 of sand, solution, and root volume. Fifty-five grow tanks are surface irrigated, bottom drained, and supplied with solutions delivered individually from 55 separate storage vessels. Flow meters monitor the quantity of water evapotranspired from each tank. Tests can be conducted following any desired statistical design. The large size of these tanks is essential in order to minimize the effect of open areas and root zones surrounding test crops. Crop plants in the open tend to develop differently than those grown within a stand of plants as in the field.

Seedlings

The plants are grown to seedling size in polyethylene pots, 250 mm tall, with 250 mm top, and 200 mm bottom diameters (Fig. 4). The grow pots are filled with high-grade quartz sand (0.3 to 1.0 mm nominal particle diameter). A total of 60 pots arranged in a randomized block of ten replications are irrigated with hydroponic nutrient and test solutions under clockwork control. Each of six solution-supply vessels feed ten replicate pots.

Seed germination

An environmentally-controlled growth cabinet houses 54 germination dishes. Each dish is placed within a system designed to maintain the concentration of its test solution. Filling the dishes with fine sand and covering the sand with filter paper to hold the seed has proven to be effective in the testing of seeds germinating from varying levels of saline substrata.

SALT LAB STRUCTURAL SPECIFICATIONS

Salt Lab test crops are grown in a greenhouse constructed of double-wall, acrylic sheeting hung on a galvanized metal frame. The clear plastic sheeting passes diffuse solar radiation with a transmissivity of approximately 0.8. The growing areas of the greenhouse occupy the top floor resting on a concrete slab poured across metal decking supported by a steel structure and a reinforced concrete foundation. Two wings split the greenhouse into two growth rooms (to test seedlings and mature plants) having a combined floor area of 195.6 m^2 , with heights

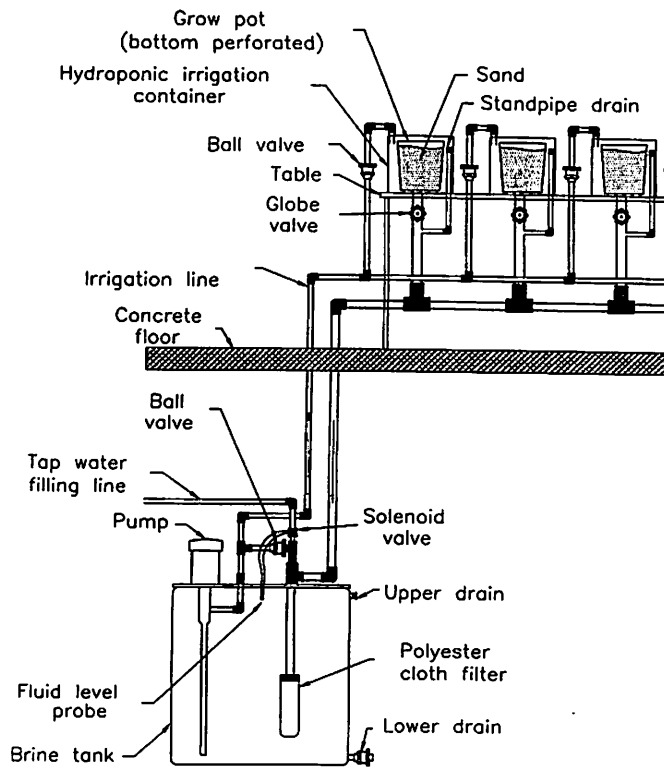


Fig. 4. Side view of grow (sand) pots (0.04 m³) and nutrient-brine supply tanks (0.7m³) used to test emergence and seedling growth.

from the floor of 3 m at the north and south sides to 4.9 m at the gable-centre (Fig. 2).

Test plants are irradiated with natural and artificial light. High pressure sodium-vapor lights are fixed 2.5 m above the

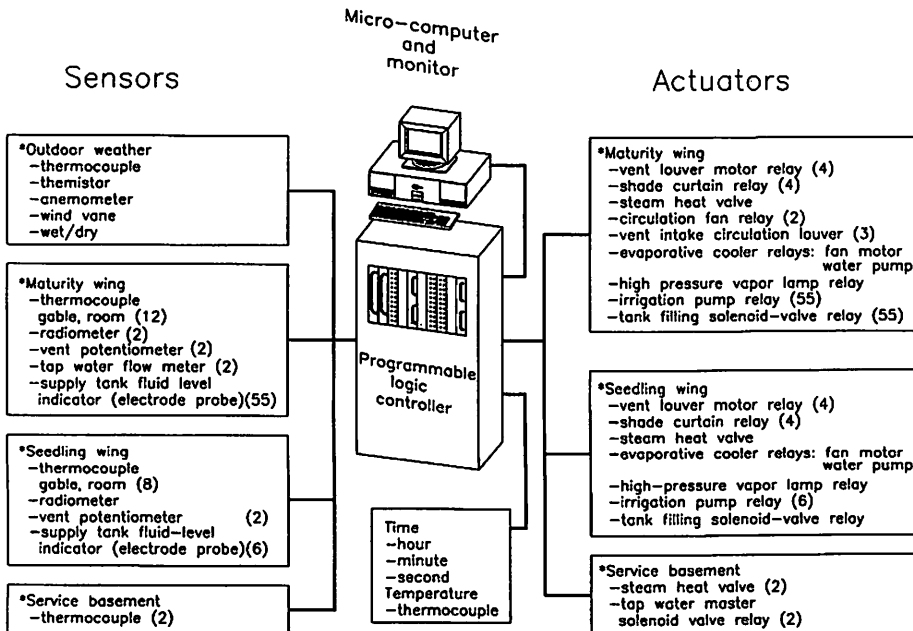


Fig. 5. Block diagram of the Salt Lab scheme for environmental and operational control; numbers in parentheses indicate the number of units located within each compartment.

floor and engineered to deliver 400 W/m² of supplemental radiation with a uniformity coefficient of 0.9 within one vertical metre of the sand surface. The Salt Lab also features automated shade and temperature control. An overhead solar shield consisting of 50% porous-woven, reflective aluminum strips and a 50%-translucent curtain hung on the south wall, block excessive radiation. The shield and curtain automatically retract when radiation intensity becomes normal.

The greenhouse is ventilated by: (1) full length, gable-top louvers which open and close in relation to setpoint temperatures, outside wind speed and direction, and gable-to-outside temperature differences; (2) inside air circulation fans; and (3) automated fans and evaporative coolers drawing outside air when needed.

The basement serves as a storage and service centre. It houses the test-solution supply tanks, pumps, germinator, electronic control centre, steam distribution service, water purification unit, hydraulic and electrical systems, preparation bench, etc. It also contains a small chemical wet laboratory for mixing test solutions.

ENVIRONMENTAL and OPERATIONAL CONTROL

A programmable logic controller (General Electric Series Six and 90-30) automatically monitors environmental conditions in the growth rooms and signals actuators according to programmed setpoints and an internal clock (Fig. 5). Ambient air temperature, outside weather, and radiation intensity are continuously scanned from which the controller excites electrical relays for powering circulating fans, evaporative coolers, solar curtains, gable vents, supplemental lighting, and steam valves, etc. Reference and setpoints are adjustable depending on desired objectives and preset environmental conditions. Irrigation scheduling of the salt and hydroponic solutions along with daily evapotranspiration monitoring are

also programmer controlled. Controls for the germinator are part of the growth cabinet and provide adjustment over chamber illumination, temperature, and humidity.

TESTING TOLERANCES

Estimates of the tolerances associated with testing to determine response functions for crops grown in the Salt Lab are based on spatial variations from setpoints (Table I). In addition, barley (cv: Bonanza) was grown at various times during the test year in the maturity and seedling wings to assess the uniformity in crop growth and production. June and July proved to be the most unfavorable time of year for salt tolerance testing. The long day lengths at that time of year limited testing if shorter days were required. Also, tall crops grown in the front tanks can, at times, shade adjacent tanks causing non-uniform

Table I. Uniformities and tolerances (spatial variation from set points).

<u>Growth Rooms</u>	
Artificial light	intensity $\pm 5\%$; day length $\pm 1\%$; quality $\pm 0.1\%$
Air temperature at plant canopy	$\pm 1.0^\circ\text{C}$
Carbon dioxide concentration	$\pm 1.0\%$, approximately equal to outside atmosphere
Nutrient concentration	$\pm 0.5\%$ estimate
Salt and specific ion concentration	$\pm 2\%$ estimate
Water supply	$\pm 0.5\%$ in wet-dry cycles
Humidity	approximately $\pm 3\%$ uniformity
<u>Germinator</u>	
Artificial light	intensity $\pm 8\%$; day length $\pm 0.5\%$
Temperature	$\pm 1.5^\circ\text{C}$
Humidity	$\pm 5\%$ at 90% relative humidity
Salt concentration	$\pm 2\%$ estimate

irradiation among the different grow tanks. Comparisons of barley yields in chi-square tests for homogeneity of variances showed a production bias favoring tanks near the south wall during November, December, and January ($p = 0.011$, 40 degrees of freedom). This bias diminished at other times during the year.

Two strategies have been instituted to overcome this difficulty in uniformity of growth: response tests are scheduled so as to avoid steep growth rates during June and July; and, the south row of tanks have been reserved for growing the test plants subjected to the highest salt concentrations. These strategies resulted in minimum chi-square homogeneity probabilities for barley grain yields of 0.15, giving statistical assurance that the entire test crop comprises but one homogeneous population. These data also indicated that the mean yields of above-ground biomass and grain yields fell within a confidence interval (0.05 error probability) of ± 4.5 and $\pm 5.9\%$, respectively.

CONCLUSIONS

Canadian engineers have designed and fabricated an environmentally-controlled salt-tolerance testing facility for agricultural field and horticultural crops. Located near Swift Current, Saskatchewan, the facility features large, hydroponic grow tanks which can evaluate crops from emergence through maturity. A programable logic controller actuates the facility's lighting, heating, ventilation, and ambient temperature monitoring. The controller also automatically triggers fertigation, replacement of supply water lost by evapotranspiration, and maintenance of brine concentration.

With this facility, salt-tolerance response functions have already been determined for various Canadian crop varieties. These include barley, spring wheat, durum, canola, field pea,

pinto bean, quinoa, kochia, flax, alfalfa, sweetclover, and a number of perennial grasses. Opportunity exists for many more crops and different varieties. The facility can serve private companies and producer organizations through the Western Region Business Development Office of Agriculture and Agri-Food Canada.

Very few testing facilities of this calibre exist throughout the world. The design and operational concepts used in the Canadian Salt Lab were based on those proven so successful at the United States Salinity Laboratory. However, in comparison to the U.S. Laboratory, the Canadian Laboratory, although smaller in capacity and in the number of different crops or cultivars that can be tested at the same time, ranks superior in the use of automatic electronic controls.

REFERENCES

- Ayers, R.S. and D.W. Westcot. 1985. Water quality for agriculture. Irrigation and Drainage Paper 29 (Rev.1), Rome, Italy: Food and Agriculture Organization.
- Eilers, W.D. 1998. Soil salinity trends in the 90's. In *Proceedings of the 1998 Workshop, Soils & Crops '98*, 125-132. Saskatoon, SK: Saskatchewan Advisory Council on Soils & Agronomy and Extension Division, University of Saskatchewan.
- Holm, H.M. 1983. Soil salinity, a study in crop tolerances and cropping practices. Publication 25M/3/83. Regina, SK: Saskatchewan Agriculture, Plant Industries Branch.
- Janzen, H.H. and C. Chang. 1988. Cation concentration in the saturation extract and soil solution extract of soil salinized with various sulfate salts. *Communications in Soil Science and Plant Analyses* 19:405-430.
- Kohut, C.K. and M.J. Dudas. 1994. Comparison of immiscibly displaced soil solutions and saturated paste extracts from saline soils. *Canadian Journal of Soil Science* 74:409-419.
- Maas, E.V. 1990. Crop salt tolerance. In *Agricultural Salinity Assessment and Management*, ed. K.K. Tanji, 262-304. New York, NY: American Society of Civil Engineers.
- Maas, E.V. and G.J. Hoffman. 1977. Crop salt tolerance--current assessment. *Journal Irrigation & Drainage Division*, American Society of Civil Engineering 103(IR2):115-134.
- McKenzie, R.C. 1988. Tolerance of plants to soil salinity. Soil and Water Program, 1987. Pamphlet 88-10. Brooks, AB: Alberta Special Crops and Horticultural Research Centre.
- Steppuhn, H. and K.G. Wall. 1997. Grain yields from spring-sown Canadian wheats grown in saline rooting media. *Canadian Journal of Plant Science* 77:63-68.
- United States Salinity Laboratory Staff. 1954. Diagnosis and improvement of saline and alkali soils. Handbook 60. Washington, DC: United States Department of Agriculture.