PRE-IRRIGATION OF A SEVERELY-SALINE SOIL WITH IN-SITU WATER TO ESTABLISH DRYLAND FORAGES

H. Steppuhn[1], K.G. Wall[1] and W. Helgason[2]
[1] Semiarid Prairie Agricultural Research Centre, Agriculture and Agri-Food Canada, P.O. Box 1030, Swift Current, SK S9H 3X2; [2] Department of Agricultural and Bioresource Engineering, University of Saskatchewan, Saskatoon, SK S7N 5A9

Abstract

Alfalfa serves as one of the most important forage plants in North America. It is also the recommended remedial crop for dryland salinity control. But, because of its limited salt tolerance, it does not establish satisfactorily in severely or moderately saline soils. A series of irrigations with the in-situ ground water located beneath a severely-saline site were delivered across seedbeds prepared within the same site prior to seeding 'Beaver' alfalfa (Medicago sativa) and ' AC Saltlander' green wheatgrass (Elymus Hoffmannii). In this field study conducted in semiarid Saskatchewan, fall irrigations with 4.6 dS/m-water from a shallow, on-site, backhoe-dug well fitted with a solar-powered pump preceded spring seeding. Irrigation treatments ranged from zero to 2530 mm in total applied water. Plant emergence, spacing, height, cover, and forage yield of the alfalfa were significantly improved following pre-irrigation. Mean plant emergence increased from 20 to 79% for the alfalfa. The wheatgrass height and forage yield also improved significantly, but showed only an upward trend in emergence, spacing, height, and cover. The mean plant height in July increased from 90 to 159 mm for the wheatgrass and from 35 to 140 mm for the alfalfa. Based on linear regression of irrigated volume, every 119.3 mm of irrigated, in-situ water up to 2530 mm increased alfalfa forage yield by 10 g/m^2.

Introduction

Dryland forage growers know that plant establishment in saline soils can be difficult (Heinrichs and Lawrence 1956; Lawrence and Troelsen 1964; Tremblay 1997). Emergence and plant establishment is important for all seeded crops and has been linked to crop genetics, depth of seeding, seed-soil contact, temperature, and water relationships (Kilcher and Lawrence 1970; Doering and Sandoval 1981; Helms et al. 1996). Hadas and Russo (1974) studied water imbibition by seeds and found that plants of each species require a critical volume in seed water content for germination and that germination does not occur until the seed water content is greater than this critical value. Irrigation eases attainment of this germination requirement (Fapohunda 1986; Shmueli and Goldberg 1971). However, seeding on dryland ranches and farms depends on natural rainfall and/or snowmelt to achieve plant establishment, a process further hindered in saline seedbeds.

Water relationships within saline soils and subsoils influence dryland forage production in arid and semiarid climates to such an extent that the difficulties which arise are often referred to as "dryland saline seep problems" (Miller et al. 1981; Brown et al. 1983; Halvorson 1990). In dry climates, subsoils provide a ready source of soluble salts which, as solutes, move to seedbeds during soil-surface evaporation (Bresler et al. 1982; Steppuhn 1992). Near-surface ground water and potentiometric levels (within two metres of the surface) typically accelerate the salinization process, because subsurface water volumes conveyed upward by soil-energy gradients in relation to evapotranspiration tend to exceed snowmelt and rainfall volumes infiltrating downward (Gardner and Fireman 1958; Hoffman 1990). This imbalance, favouring net upward migration of salts, deters plant emergence and establishment. A major dryland salinity control strategy seeks to lower ground-water levels by growing alfalfa (Medicago sativa L.) and grass hay crops in order to transpire large quantities of subsurface water, thereby, reversing net salt fluxes downward (Brun and Worcester 1975; Halvorson 1984). Poor plant establishment on severely-saline seedbeds limits the success of this strategy. The challenge investigated in this study was to engineer a technique to sufficiently advantage perennial forage seedbeds on severely-saline dryland fields to attain better plant establishment.

Study Site

The site selected for this study forms part of a dryland grain field located 5 km southwest of Swift Current, Saskatchewan (50.3^{o}N, 107.8^{o}W). Mean annual precipitation (up to the year 2001) from measurements during 114-years at the federal climatological station 8 km east of the field equalled 361 mm, with up to one-third falling as snow. Growing season (May, June, July, August) precipitation and Class A pan evaporation averaged 211 and 977 mm over 114 and 40 years, respectively, reflecting the semiarid climate of the site. Winter-to-summer air temperatures can range from -40 to +40^{o}C. The field surface slopes about 3% southeastward along which major changes in the nature and texture of the subsurface material slow and accumulate subsurface water moving downhill. The “accumulated” waters are released naturally during the course of the growing season and move slowly downslope through the soil, subsoil and stratigraphic contacts (Steppuhn and Wall 1997).

A one-hectare area of severely-saline land (the North Parcel) associated with a zone of near-surface “accumulated” water was selected for experimentation. The topsoil of the field developed from a partially-eroded veneer of loess (now approximately 150 mm thick where it exists) overlying glacial till. Ayres et al. (1985) mapped the soil as a salinized Swinton silty-loam to loam merging into a Haverhill loam to clay loam; it is classified as a Saline Brown Chernozem in Canada and a Saline Aridic Haploboroll in the USA. The soil bulk density and saturated subsoil hydraulic conductivity average 1500 kg/m^{3} and 2.6 (10^{-7}) m/s, respectively. The weathered Cretaceous Bearpaw Formation underlies the till at depths below land surface measuring from 5 m along the west boundary of the saline parcel to 1.5 m on the east side.

Study Methods and Materials

Treatments

During the fall of 1997, a shallow well was dug with a backhoe in the North Parcel. An open-ended, corrugated, galvanized-steel casing, 0.76 m in diameter, 4.0 m long, and perforated along the bottom half of its length, was placed on a gravel bed in the well. Commercial, “three-quarter-inch”, washed gravel provided the gravel-pack adjacent the perforations. The well was pumped to completion during July and August, 1998.

In August of 1999, a 25 m by 15 m area within the severely-saline parcel, located 15 m east of the well, was disced, harrowed, surveyed, and staked to delineate twelve separately-spaced plots (Figure 1). Six of the twelve plots, each measuring 2.44 m by 0.9 m and arranged in two north-south-oriented rows, 6 m apart, were prepared for randomized irrigation treatments with in-situ ground water pumped from the North Parcel well. The six remaining plots, also measuring 2.44 m by 0.9 m each, two in the west row and four in the east row, received no irrigated water, A submersible, direct current, Sunmotor[1] pump, capable of lifting 15 litres/minute against a 4-m water head, was powered by a 75 W Siemens[1] solar panel. The electrical conductivity of the pumped water maintained an average value of 4.6 dS/m within a range of ±0.1 dS/m during the pumping period from 15 September to 23 October 1999; neither rain nor snow fell during this irrigation period. Solar-regulated, daily-pumped water was stored in a 4500-liter, black-plastic storage tank from which it was metered by an Omega[1] turbine flow meter and Campbell Scientific[1] data logger. Each irrigated plot received the in-situ water delivered under pressure (103 to 310 kPa) provided by a SHURflo[1] 90 W, solar-powered pump via two parallel 13.7 mm (inside diameter) trickle irrigation conduits, surface-placed 457 mm apart and transecting the length and centre of each plot. Twelve emitters (Rainbird Dripline[1]) spaced 305 mm apart along the drip-lines each released a pressure-compensating 2.3 litres per hour with automatic salt-flushing actions at daily startup and shutdown. Water volumes delivered to each plot were calculated and totalled from the flow measurements for Plots 1 through 12: 1181, 0, 1855, 0, 2193, 2530, 1012, 0, 1349, 0, 0, and 0 mm.

Forage Seeding

After irrigation in the fall, the irrigation lines were removed, and the plots left over-winter until seeded on 9 May 2000. Prior to seeding, weeds growing across the plots were hoed by hand. One row each of 'Beaver' alfalfa, a dryland variety, and a strain of 'AC Saltlander' green wheatgrass (*Elymus Hoffmannii* K.B. Jensen & K.H. Asay), a salt-tolerant grass hybrid, was carefully seeded with a no-till forage plot seeder; the two rows were spaced 305 mm apart and aligned between the locations of the two parallel irrigation drip-lines. The rest of the experimental site was seeded with a grass seed mix to serve as crop filler. As the seeded forages emerged, weeds were controlled by hand-rouging, a practice continued throughout the growing season. No additional irrigation water was applied. Also, no spring frost damage occurred during the plant emergence period.

Observations and Measurements

Soil root zones were sampled before and after irrigation in the fall and before seeding in the spring using a truck-mounted Giddings[1] mechanical core sampler. Cores were sectioned into 150 mm lengths and analyzed for soil water content (gravimetrically) and electrical conductivities of saturated soil-paste extracts (EC_e) following Rhoades (1982).

Rainfall volumes during the growing season were measured at the site using a standard Canadian Precipitation Gauge (provided by the Canadian Atmospheric Environment Service). Water-equivalents in snow falling across the study field were estimated by transposing volume measurements obtained from a Nipher-shielded weighing gauge located at the federal climatological station 8 km east.

The forage harvest on 22 August 2000 terminated the experiment after plant responses to plot treatments were measured on July 7th and August 17th, 2000. Response measurements were obtained along a one-meter length of each seed-row of each forage sampled near the middle of each plot during each measurement. On July 7th, each 20-mm segment along the length of the measurement meter (50 segments) was checked and marked if it contained at least one emerged

---

[1][1] Product names are provided for information only and do not infer endorsement.

plant; fifty marks along the meter length inferred 100% emergence. Also, the tallest plant growing within each segment was measured for height; if the segment lacked plants, no height was recorded. The frequency in changing from a mark to no mark and visa verse while moving from segment to segment along the 50 segments in each seed-row divided by the number of segments recorded without a plant provided a measure of spatial uniformity in emergence. This ratio defined a dependent variable termed the spacing ratio.

On August 17th, the number of 50-mm segments within which at least one plant was growing out of 20 segments along the measurement meter identified the degree of plant cover. The mean height of each segment's plants specified a seasonal growth variable. The above-ground forage cut along each meter length of seed-row per plot was oven-dried (40^oC) and massed giving the forage yield. For each forage and each plot, the mean plant emergence, spacing ratio, height, cover, and forage yield were derived and analyzed as dependent variables. Statistical analyses comparing these variables in response to irrigated and non-irrigated treatments utilized unpaired t-tests and model regression fits executed with JMP software (SAS Institute 1995). Significance was set at $\forall = 0.05$ probability or less. Linear regressions based on irrigated water volumes as the independent variable provided empirical relationships.

Results

Soil Salinity and Water

A soil is considered severely-saline if its EC_e equals 8 dS/m or greater (US Salinity Laboratory Staff 1954). On 1 September 1999, before irrigation was initiated, a vertically-decreasing salinity profile existed in all the plots from a mean of 13.5 dS/m in the top 150 mm to 4.6 dS/m in the 600-900 mm depth layer (Table 1). On 23 November 1999, after irrigation ceased, the non-irrigated plot cores averaged 14.1 dS/m in the surface layer and 3.8 dS/m in the deepest layer probed (Table 1); this reflected preservation of the pre-irrigation vertically-decreasing salinity profile. Soil cores obtained from the irrigated plots, however, indicated a change in this profile with the average surface layer decreasing to 5.3 dS/m and the 600-900 mm layer increasing to 6.8 dS/m. Soil cores obtained from the plots during the following spring (28 April 2000) just before seeding retained these post-irrigation profile differences between the irrigated and non-irrigated plots with the irrigated plots displaying a more uniform vertical salinity profile following irrigation (Table 1).

The weighted-mean soil water percentages (mass basis) to 900 mm just after irrigation were 18.3% and 20.2% for the non-irrigated and the irrigated plots, respectively (Table 2). Estimated over-winter precipitation from 1 November 1999 to 28 April 2000 totalled 91 mm. Following over-winter recharge, just before seeding, respective non- and -irrigated mean soil water percentages equalled 20.3% and 20.3%; the net non-irrigated soil water contents increased by 2%, but those of the irrigated plots remained the same. Precipitation amounts accumulated during the growing season from seeding through forage harvest equalled 267 mm.

Forage Emergence and Spacing

'Beaver' alfalfa and 'AC Saltlander' green wheatgrass plants began to emerge on most of the plots by 19 May 2000, ten days after seeding. By May 23rd, the rates of emergence observed in the irrigated plots visually exceeded those in the non-irrigated plots. These differences persisted and increased as the growing season progressed. By July 7th, mean emergence percentages for both forages significantly favoured those pre-treated with irrigation (Table 3).

Emergence percentages associated with the irrigation increased 41.3% for the wheatgrass and 300.4% for the alfalfa over the non-irrigation emergence. Alfalfa emergence among the irrigated plots correlated with increasing irrigated volumes in an ascending array: 36, 46, 96, 96, 98, and 100%.

Spatial uniformity in emergence along the seed row, as measured by the spacing ratio, significantly favoured the irrigated over the non-irrigated Beaver plots but not with the wheatgrass plots (Table 3). Irrigation improved uniformity by 400% for the alfalfa but had no significant effect on the wheatgrass spacing. Statistical tests with plant-cover measurements taken on August 17th result in similar inferences (Table 4). Based on an ∀-0.05 probability threshold, irrigation made no difference in the percent plant cover for the wheatgrass but significantly improved the coverage observed for the alfalfa.

Plant Height and Forage Yield

Mean plant heights for both the wheatgrass and the alfalfa differed significantly among the treatments with the irrigated plants measuring the tallest (Tables 3 & 4). On July 7th, wheatgrass heights due to pre-irrigation differed by 77%, and alfalfa heights differed three-fold. By August 17th, these differences increased for the wheatgrass (to 119%) and decreased for the alfalfa (to 206%). Similar differences showing the greater heights in the pre-irrigation plants for both forages also resulted from statistical tests when combining all the measurements by each treatment across all the plots (Tables 3 & 4).

Forage yields for both species during the plant establishment year significantly favoured the practice of pre-irrigation (Table 4). The above-ground wheatgrass biomass at harvest grown on the pre-irrigated plots averaged 958% greater than that from the same forage grown without the irrigation. Mean alfalfa yields (above-ground biomass) produced following pre-irrigation exceeded those determined for the non-irrigated alfalfa by 2560%.

Regressions with Irrigated Volumes

The total volume of in-situ water applied to each irrigated plot varied from 1012 to 2530 mm. Together with the six non-irrigated plots, these volumes formed the independent variable for which regressions could determine any dependence of the forage response variables. Statistical results from these linear regressions indicated that the response in plant emergence, spacing, height, and forage yield by the green wheatgrass to increasing irrigation volumes could explain only 45% or less of the measured variation (Table 5). However, the responses by the alfalfa in the four dependent variables resulted in adjusted r^2-values of 0.75 or greater and the following empirical relationships:

$$\text{Alfalfa emergence (\%)} = 19.1 + 35.6 \text{ Irrigation Volume (m)} \quad [1]$$

$$\text{Alfalfa spacing ratio} = 0.238 + 0.766 \text{ Irrigation Volume (m)} \quad [2]$$

$$\text{Alfalfa height (mm)} = 166.3 + 156.2 \text{ Irrigation Volume (m)} \quad [3]$$

$$\text{Alfalfa yield (g/m}^2\text{)} = 5.27 + 83.85 \text{ Irrigation Volume (m)} \quad [4]$$

Discussion and Conclusions

Salinity control in irrigated agriculture depends in large measure on water applications in sufficient quantities before seeding to satisfy leaching requirements (US Salinity Laboratory Staff 1954; Bernstein and Francois 1973). Irrigation also provides the water necessary to ensure emergence of irrigated crop plants (Shmueli and Goldberg 1971; Fapohunda 1986). Similarly, salinity control in dryland agriculture could relate to leaching-water irrigations applied before seeding remedial crops, a practice herein called pre-irrigation. The lack of adoption for such pre-irrigation practices in dryland salinity control likely reflects limitations in available water supplies.

Dryland saline sites typically harbour near-surface, excess ground waters, which contribute to the soil salinization processes (Miller et al. 1981). The drawbacks to extracting and using this in-situ ground water include: its salinity, the lack of low-cost water extraction and utilization technology, and timeliness of the pre-irrigations. The strategy tested in this study addresses the second and the third of these drawbacks. If saline ground water is applied in the irrigation of field crops growing on non-saline soil, root-zone salinization concerns dominate (Rhoades et al. 1992). If, however, the saline water is applied to land whose soil-solution salt-concentrations are greater than that of the applied water, the strategy can decrease root-zone salinity (Meiri and Plaut 1985). Further, if the seedbed salinity can be reduced sufficiently to initiate the establishment of remedial crops, such as alfalfa, the first drawback is also overcome.

The advent of solar-powered pump and trickle irrigation technologies offers the possibility of countering the second drawback. Portable pump irrigation systems are envisioned which, in turn, could serve different sites in establishing remedial vegetation. The results presented herein support the merits of pre-irrigating severely-saline soils with in-situ water to establish dryland forages.

Before irrigation, the mean salinity values for the 0-900 mm soil profiles for the non-irrigated and irrigated plots equalled 8.1 and 8.5 dS/m, respectively. Compared again after irrigation and just before seeding, these values decreased to 7.7 and 7.0 dS/m, respectively. This implies that the irrigation waters (of a lower solution salinity) tended to move the salts in the surface layers of the soil downward out of the measured soil profile and, together with the over-winter snowmelt-recharge, diluted root-zone salt concentrations by about 12%.

The soil salinity and water data further confirm that both the fall pre-irrigation and the over-winter recharge affected primarily the upper soil layers. This is likely due to the interactions of many factors. The first is that, although saturating soil solutions tend to move salts downward enriching the lower layers, their movement slows, may stop, or even reverse within frozen soils. The irrigation in this study, having occurred before winter freeze-up, lowered the salt concentrations of the soil solutions and increased the soil water contents in the 0-300 mm layer within the irrigated plots. From previous studies at this site, mass-based soil water contents in the 20-25% range define the field capacity for the top 300 mm of the root zone (Steppuhn and Wall 1997). Over-winter, up to 91 mm of non-saline, recharge water became available to the upper layers in all the plots. Mean soil water contents in the surface layer recorded a 3.2% over-winter increase in the non-irrigated plots and a 3.1% decrease in the irrigated plots. The gain likely reflected the mean maximum over-winter recharge that could have been stored in the non-irrigated upper soil layers. Whereas the average irrigated surface layers entered the winter with their water contents already above their storage maxima, they most likely lost water as drainage and as vapour to the atmosphere.

Another factor relates to the in-situ residence times as the irrigation waters percolated through the root zone. Residence times tend to decrease as soil water contents increase and approach field capacity (Hillel 1971). Again, frozen soil solutions would have slowed or stopped this movement. The ample water existing in the upper layers of the irrigated plots would have favoured short residence times before freeze-up. It would have also hindered infiltration of snowmelt recharge and suggests that drought likely did not limit plant emergence. While thawing in the spring, soil water solutions above the upper thawing front would have moved salts upward in response to the usual salinization processes. This could explain the mean 1.5% dS/m increase in seedbed salinity measured over winter in the irrigated plots.

Fall irrigation with in-situ water significantly promoted emergence of both green wheatgrass and alfalfa when seeded into the irrigated seedbeds the following spring. Also, the pre-irrigation benefited the areal uniformity (spacing) of the emerging alfalfa but not the wheatgrass plants. The spacing achieved by the wheatgrass without the aid of pre-irrigation already proved satisfactory and was not improved by the irrigation treatment. This occurred, because the wheatgrass is much more salt-tolerant than the alfalfa (Bernstein and Francois 1973; Maas 1990). Without the pre-irrigation, salinity reduced the number of emerging plants of both forages, but less so for the wheatgrass resulting in a spatial uniformity (and plant cover) very similar to that achieved following pre-irrigation. The alfalfa, on the other hand, required the pre-irrigation to help overcome the seedbed salinity.

Responses in plant heights and forage yields of both forages when treated with pre-irrigation significantly exceeded those resulting when irrigation was withheld (Tables 3 & 4). Plant heights were measured twice, at 60 and 100 days following seeding. The differences in mean heights measured in the non-irrigation and irrigation plots increased for the wheatgrass but decreased for the alfalfa during the 40 days separating the dates of measurement. The greater genetic growth potential of the alfalfa compared to the wheatgrass coupled with timely rainfalls during the growing season likely caused these results. The benefits of lower salinity in the pre-irrigation plots took longer for the wheatgrass to exploit than for the alfalfa. At harvest, the capability of alfalfa to produce significantly more hay than that possible from the wheatgrass prevailed but only within the irrigated plots (Table 4). Without irrigation, the mean quantity of forage produced by either of the two forages verged on nil.

The significant response in growth to the pre-irrigation treatment by the Beaver alfalfa was also evident in the regression results (Table 5). Eighty-five percent or more of the variation in alfalfa yields measured among the plots in response to the volumes of irrigated water applied were explained by the independent variable. With the wheatgrass, this regression value dropped to 35% or less. Measured plant heights showed similar results. Also from the regressions in this experiment, every 28 mm of pre-irrigated, in-situ water up to 2273 mm total increased alfalfa emergence by 1%. With 2273 mm, the regression yielded 100% emergence.

Throughout western North America, producers of dryland hay prefer to include alfalfa among their forage stands (Barnes and Sheaffer 1995). Consequently, growers have followed recommendations to grow alfalfa for hydrologic control of saline seeps (Halvorson and Reule 1980; Brown et al. 1983). The utilization of saline waters to irrigate alfalfa growing on land with slight to no salinity has also been tested (Noble et al. 1987). The experiment reported herein combines pumping excess ground water from a dryland saline site and using the water to establish remedial alfalfa plants directly in the severely saline soil of the site to further de-water and reclaim the soil by the usual hydrologic control techniques (transpiration). The conclusion, based on this study, is that this combination can result in the establishment of remedial alfalfa plants (along with the more salt-tolerant green wheatgrass) in severely-saline seedbeds in order to transpire subsurface water and control salinization. Further studies will be necessary to determine how long the established alfalfa plants can survive in such saline environments.

A**cknowledgements**

Many people contributed to this study, and their assistance is gratefully appreciated. Special thanks go to Murray Smith, Doug Smith, Stuart Smith, Ken Deobald, Don Sluth, Gary Winkleman, Evan Powell, Rod Ljunggren, Jane Holzer, Eric Jensen, Marvin Miller, and Kay Asay.

Rreferences

Ayres, K.W., D.F. Acton, and J.G. Ellis. 1985. The soils of the Swift Current map area 72J Saskatchewan. Sask. Institute Pedology, Publ. 481, Extension Div., Univ. of Saskatchewan, Saskatoon, Sask.

Barnes, D.K. and C.C. Sheaffer. 1995. Alfalfa. Chap. 16, pp. 205-216 In Forages: An Introduction To Grassland Agriculture (R. F. Barnes, D.A. Miller and C.J. Nelson, eds.), Vol. I, Part 2, Forage Legumes and Grasses. Iowa State University Press, 5th Edition, Ames, Iowa.

Bernstein, L. and L.E. Francois. 1973. Leaching requirement studies: Sensitivity of alfalfa to salinity of irrigation and drainage waters. Soil Science Soc. of America Proc. 37: 931-943.

Bresler, E., B.L. McNeal, and D.L. Carter. 1982. Saline and Sodic Soils. Springer-Verlag, Berlin Heidelberg, Germany.

Brown, P.L., A.D. Halvorson, F.H. Siddoway, H.F. Mayland, and M.R. Miller. 1983. Saline-seep diagnosis, control and reclamation. U.S. Dept. Agric. Conservation Research Report No. 30.

Brun, L.J. and B.K. Worcester. 1975. Soil water extraction by alfalfa. Agronomy J. 67: 586-589.

Doering, E.R. and F.M. Sandoval. 1981. Chemistry of saline seep drainage in southwestern North Dakota. Soil Science 132: 142-149.

Fapohunda, H.O. 1986. Crop emergence as affected by soil and irrigation. Plant and Soil 92: 201-208.

Forsberg, D.E. 1953. The response of various forage crops to saline soils. Canadian J. of Agricultural Science 33: 542-549.

Gardner, W.R. and M. Fireman. 1958. Laboratory studies of evaporation from soil columns in the presence of a water table. Soil Science 85(5): 244-249.

Hadas, A. and D. Russo. 1974. Water uptake by seeds as affected by water stress, capillary conductivity, and seed-soil contact: I. Experimental study. Agronomy J. 66: 643-647.

Halvorson, A.D. and C.A. Reule. 1980. Alfalfa for hydrologic control of saline seeps. Soil Science Soc. America J. 44: 370-374.

Halvorson, A.D. 1984. Saline-seep reclamation in the northern Great Plains. Transactions of the ASAE 27: 773-778.

Halvorson, A.D. 1990. Management of Dryland Saline Seeps. Chapter 17, pp. 372-394 In Agricultural Salinity Assessment and Management (K.K. Tanji, ed.) American Soc. Civil Engineers Manual on Engineering Practice No. 71.

Heinrichs, D.H. and T. Lawrence. 1956. Russian wild ryegrass. Publ. 991, Information Division, Canada Dept. Agric., Supply and Services Canada, Ottawa, Ontario.

Helms, T.C., E. Deckard, R.J. Goos, and J.W. Enz. 1996. Soil moisture, temperature and drying influence on soybean emergence. Agronomy J. 88: 662-667.

Hillel, D. 1971. Soil and Water: Physical Principles and Processes. Academic press, New York.

Hoffman, G.J. 1990. Leaching Fraction and Root Zone Salinity Control. Chapter 12, pp. 237-261 In Agricultural Salinity Assessment and Management (K.K. Tanji, ed.) American Soc. Civil Engineers Manual on Engineering Practice No. 71.

Kilcher, M.R. and T. Lawrence. 1970. Emergence of Altai wild ryegrass and other grasses as influenced by depth of seeding and soil type. Canadian J. of Plant Science 50: 475-479.

Lawrence, T. and J.E. Troelsen. 1964. An evaluation of fifteen grass species for forage crops for southwestern Saskatchewan. Canadian J. Plant Science 44: 301-310.

Maas, E.V. 1990. Crop Salt Tolerance. Chapter 13, pp. 262-304 In Agricultural Salinity Assessment and Management (K.K. Tanji, ed.) American Soc. Civil Engineers Manual on Engineering Practice No. 71.

Meiri, A. and Z. Plaut. 1985. Crop production and management under saline conditions. Plant and Soil 89: 253-271.

Miller, M.R., P.L. Brown, J.J. Donovan, R.N. Bergatino, J.L. Sonderegger, and F.A. Schmidt. 1981. Saline seep development and control in the North American Great Plains–Hydrological aspects. Agric. Water Management 4: 115-141.

Noble, C.L., C.C. Hunter, and R.A. Wildes. 1987. Irrigation of lucerne with saline groundwater on a slowly permeable, duplex soil. Irrigation Science 8: 35-48.

Rhoades, J.D. 1982. Soluble Salts. pp. 167-179 In Methods of Soil Analysis. Part 2: Chemical and Microbiological Properties, 2nd Edition (A.L. Page, ed.), American Soc. of Agronomy, Soil Science Soc. America, Madison, Wisconsin,

Rhoades, J.D., A. Kandiah and A.M. Mashali. 1992. The use of saline waters for crop production. FAO Irrigation and Drainage Paper 48, Rome.

SAS Institute. 1995. JMP, Statistical Discovery Software, Version 3.1. SAS Institute Inc., Cary, North Carolina.

Shmueli, M. and D. Goldberg. 1971. Emergence, early growth, and salinity of five vegetable crops germinated by sprinkle and trickle irrigation in an arid zone. HortScience 6(6): 563-565.

Steppuhn, H. 1992. Approaches toward controlling salinity. pp. 174-183 In Proc. Salinity and Sustainable Agriculture Workshop, Prairie Salinity Network Publ. No. 1. Swift Current, Sask.

Steppuhn, H. and K.G. Wall. 1997. Combining subsurface drainage and windbreak technologies to abate salinity. Vol. A, Edited Proc. of the Joint Conference, "Agriculture, Food and Biosystems Engineering" (D.I. Norum & P. Savoie, eds.), Canadian Societies of Civil and Agricultural Engineering, A: 152-161. Sherbrooke, Quebec.

Tremblay, M.E. 1997. Saskatchewan Forage Crop Production Guide 1997. Saskatchewan Agriculture and Food, Advisory Council on Forage Crops, Regina, Sask.

US Salinity Laboratory Staff. 1954. Diagnosis and improvement of saline and alkali soils. (L.A. Richards, ed.) USDA Handbook No. 60.

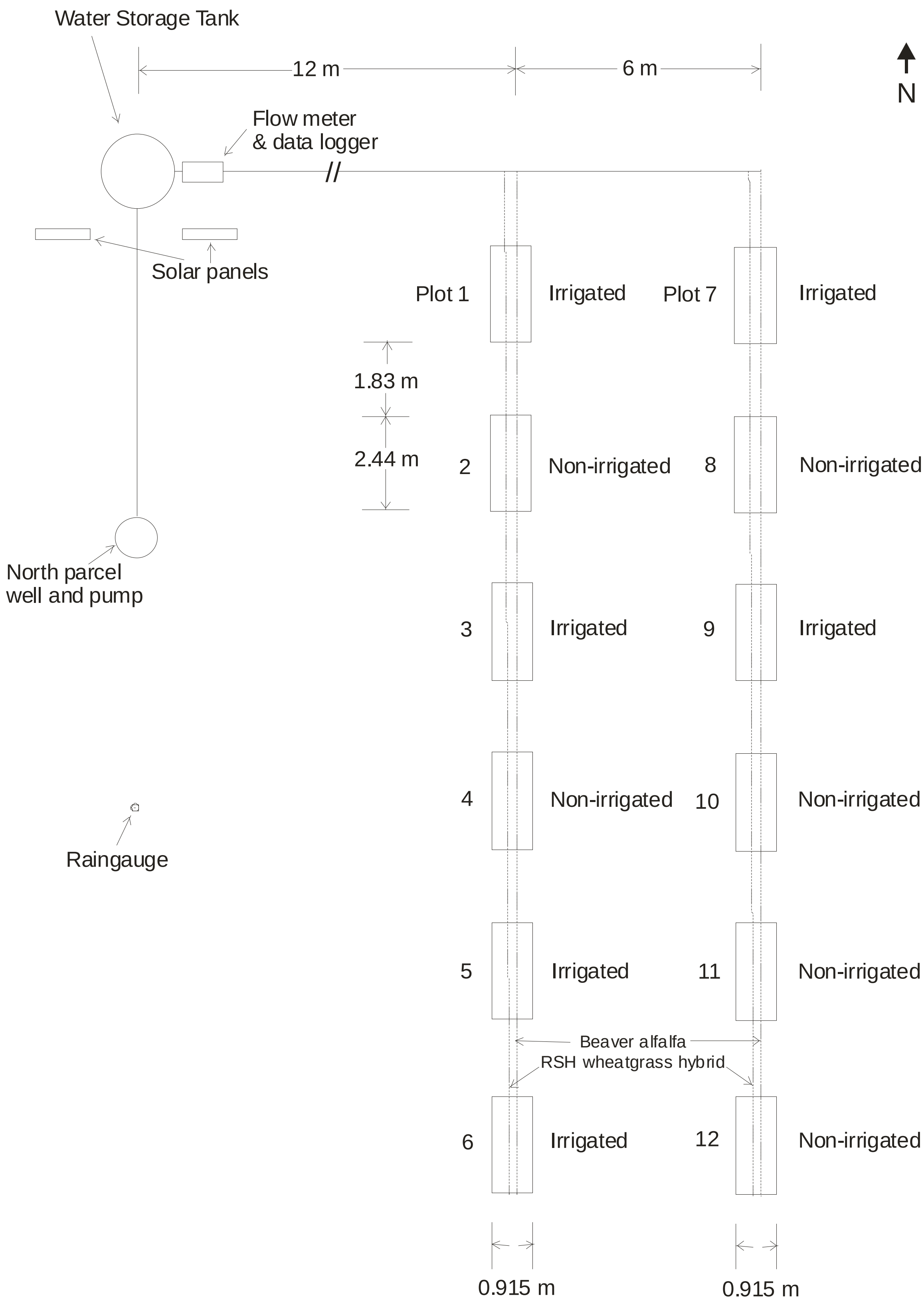

Figure 1. Surface view of the North Parcel experimental plots, water-supply well, water delivery and routing, and forage seedings; near Swift Current, Saskatchewan.

Table 1. Mean salinity values derived from irrigated and non-irrigated plots before and after irrigation and before seeding, arrayed by soil depth-layer.

	Mean EC_e [z] (Standard Deviation)					
	Before irrigation[y]		After irrigation[x]		Before seeding[w]	
	Non-irr	Irr	Non-irr	Irr	Non-irr	Irr
(mm)	(dS/m)					
0-150	13.5 (5.5)	14.2 (5.8)	14.1 (3.4)	5.3 (0.8)	13.8 (3.7)	6.8 (1.4)
150-300	12.4 (5.5)	13.3 (5.5)	13.3 (5.5)	5.6 (1.2)	12.9 (5.9)	6.8 (2.1)
300-600	6.8 (3.2)	7.0 (3.3)	6.4 (2.3)	7.1 (3.3)	5.5 (1.0)	7.2 (4.1)
600-900	4.6 (1.0)	4.8 (0.9)	4.3 (0.4)	6.8 (3.4)	4.2 (0.3)	6.9 (3.5)
900-1200	-------	-------	3.8 (0.7)	5.7 (3.1)	-------	-------

[z] Electrical conductivity of saturated soil-paste extract (EC_e)
[y] One soil core per plot obtained 1 Sep 1999, six plots irrigated (Irr) and six plots non-irrigated (Non-irr)
[x] Two soil cores per plot obtained 23 Nov 1999, six plots irrigated (Irr) and six plots non-irrigated (Non-irr)
[w] Two soil cores per plot obtained 28 Apr 2000, six plots irrigated (Irr) and six plots non-irrigated (Non-irr)

Table 2. Mean soil water contents derived from irrigated and non-irrigated plots after irrigation and before seeding, arrayed by soil depth-layer.

	Mean Soil Water[z] (Standard Deviation)			
	After irrigation[y]		Before seeding[x]	
Depth layer	Non-irr	Irr	Non-irr	Irr
(mm)	(%)			
0-150	21.5 (2.3)	28.3 (5.1)	24.7 (3.2)	25.2 (4.4)
150-300	21.1 (2.5)	20.1 (1.2)	21.5 (1.8)	20.0 (1.6)
300-600	17.2 (2.0)	19.0 (2.4)	20.3 (1.5)	19.9 (2.4)
600-900	16.5 (1.9)	17.3 (0.7)	17.4 (1.8)	18.4 (1.6)
900-1200	16.2 (1.6)	16.7 (1.2)	-------	-------

[z] Based on soil mass
[y] Two soil cores per plot obtained 23 Nov 1999, six plots irrigated (Irr) and six plots non-irrigated (Non-irr)
[x] Two soil cores per plot obtained 28 Apr 2000, six plots irrigated (Irr) and six plots non-irrigated (Non-irr)

Table 3. Statistical summary for emergence, spacing ratio, and plant height from t-tests for forages seeded following non-irrigation (Non-irr) and pre-irrigation (Irr) treatments, measured on 7 July 2000.

Forage	DF[z]	(Prob.>t)[y]	Mean (Standard Error) Non-irr	Irr
Emergence			- - - - - - - - - (%) - - - - - - - -	
Wheatgrass[x]	10	0.0290	46.0 (4.5)	65.0 (5.9)
Alfalfa[w]	10	0.0017	19.7 (6.9)	78.8 (12.0)
Spacing ratio				
Wheatgrass	10	0.4080	0.92 (0.16)	1.11 (0.15)
Alfalfa	10	0.0059	0.28 (0.10)	1.48 (0.33)
Plant height			- - - - - - - - (mm) - - - - - - - -	
Wheatgrass	10	0.0002	89.9 (6.2)	159.4 (10.3)
Alfalfa	10	<0.0001	35.3 (6.8)	139.7 (11.4)
Plant height [v]			- - - - - - - - (mm) - - - - - - - -	
Wheatgrass	331	<0.0001	87.2 (3.2)	163.3 (4.2)
Alfalfa	312	<0.0001	32.9 (3.0)	147.8 (3.2)

[z] Degrees of freedom
[y] Probability of obtaining a larger absolute t-value by chance
[x] Green Wheatgrass *Elymus hoffmannii* (cv. AC Saltlamder)
[w] Alfalfa (cv. Beaver)
[v] All plant height measurements from all plots combined by treatment

Table 4. Statistical summary for plant cover, height, and forage yield from t-tests for forages seeded following non-irrigation (Non-irr) and pre-irrigation (Irr) treatments, measured on 17 August 2000.

Forage	DF[z]	(Prob.>t)[y]	Mean (Standard Error) Non-irr	Irr
Plant Cover			- - - - - - - - - (%)	- - - - - - - -
Wheatgrass[x]	10	0.0730	90.0 (5.0)	100.0 (0.0)
Alfalfa [w]	10	0.0006	39.2 (12.4)	100.0 (0.0)
Plant height			- - - - - - - - (mm)	- - - - - - - -
Wheatgrass	10	0.0002	175.3 (27.5)	383.3 (22.9)
Alfalfa	10	<0.0001	146.7 (23.7)	449.3 (25.5)
Forage yield			- - - - - - - (g/m^2)	- - - - - - -
Wheatgrass	10	0.0042	3.8 (2.3)	40.2 (9.6)
Alfalfa	10	0.0005	5.5 (3.8)	146.5 (67.2)
Plant height [v]			- - - - - - - - (mm)	- - - - - - - -
Wheatgrass	226	<0.0001	177.7 (8.8)	383.4 (6.3)
Alfalfa	166	<0.0001	161.2 (11.7)	449.4 (6.0)

[z] Degrees of freedom
[y] Probability of obtaining a larger absolute t-value by chance
[x] Green Wheatgrass *Elymus hoffmannii* (cv. AC Saltlamder)
[w] Alfalfa (cv. Beaver)
[v] All plant height measurements from all plots combined by treatment

Table 5. Statistics associated with liner regressions for emergence, spacing ratio, plant height, and forage yield dependent on irrigation volume.

				(Prob.> t)[z]	
Variable[y]	DF[x]	(Adj. r^2)[w]	RMSE[v]	Slope	Intercept
Emergence (%)					
Wheatgrass[u]	11	0.374	12.50	0.0200	<0.0001
Alfalfa[t]	11	0.791	17.56	<0.0001	0.0190
Spacing ratio					
Wheatgrass	11	-0.059	0.389	0.5480	<0.0001
Alfalfa	11	0.746	0.426	0.0002	0.1820
Plant height (mm)					
Wheatgrass	11	0.444	92.22	0.0107	0.0002
Alfalfa	11	0.793	76.56	<0.0001	0.0002
Forage yield (g/m^2)					
Wheatgrass	11	0.338	20.33	0.0280	0.3180
Alfalfa	11	0.868	31.44	<0.0001	0.6760

[z] Probability of obtaining a larger absolute t-value by chance
[y] Emergence and spacing ratio data measured in July 2000; plant height and forage yield data measured in August 2000
[x] Degrees of freedom
[w] Coefficient of determination adjusted for different degrees of freedom
[v] Root mean square error
[u] Green Wheatgrass *Elymus hoffmannii* (cv. AC Saltlamder)
[t] Alfalfa (cv. Beaver)