Wheat Yield Responses to Slightly and Moderately Saline Rooting Media

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INTRODUCTION

Farmers often observe that spring wheat produces poorly in saline soils. Field trials have verified these observations, but are not precise enough to associate actual production losses to specific salinity levels. Researchers at the United States Salinity Laboratory (1954) identify wheat as possessing medium salt tolerance. They also suggest that the electrical conductivity of water-saturated soil paste extract (EC_e) provides the most consistent measure of salinity. They arbitrarily classify soils having ECe-values between O-2 dS m-1 as "non-saline", between 2-4 "slightly saline", 4-8 "moderately saline", and above 8 dS m^{-1} as "severely saline." The telltale white crusts on soil surfaces rarely occur in Prairie soils whose average salinity remains less than 4 or 5 dS m^{-1}.

The salinity identifiable by white crusting characterizes soils on 2,240,000 ha in western Canada, reducing crop production by an average of 25% (1992 Dryland Salinity investigations Manual). Also, using data from soil testing labs, we estimate that approximately another 10,000,000 ha are slightly salinized ($1 > EC_e \leq 4$ dS m-l), although this condition often goes undetected because the salinity is not readily visible.

van Genuchten (1983) suggested that a descending-type function would best describe the inherent yield response of crops growing in saline rooting media. The yield (Y) depends on the strength of the salinity expressed as either salt concentration or electrical conductivity (c):

$$Y = \frac{Ym}{1 + (c/c_{50})^p} \qquad [1]$$

and

$$Y_r = 100(Y/Y_m) \qquad [2]$$

where:

Ym = crop yield obtained where salinity has no influence on yield,
c_{50} = the salinity at which the yield is reduced by 50%,
p = an empirical constant, and
Yr = relative yield (%).

Katepwa, Biggar, Fielder (Triticum aestivum L.), and Kyle (T. turgidum L.) are wheat varieties sown in spring throughout the Canadian Prairies. These varieties have been bred to produce flour for different food products. This suggests possible genetic variation such that they may also differ in their inherent responses to salinity. The objective of this study was to assess and compare the grain yield responses of these wheats when grown in saline rooting media.

TESTING METHODS

The Salt Tolerance Testing Laboratory at Swift Current features control over irrigation, fertility, root-zone salinity, and temperature under an electronic, programmable logic controller (Steppuhn 1995). The test reported here was conducted in this facility using sand tanks housed within a greenhouse. The plastic tanks (cylinders 0.85 m dia. x 1 .O m deep) contained washed silica sand having an average bulk density of 1.5 Mg m^{3} and a mean volumetric water content of 31.3% at saturation. The tanks were flushed four times daily with a modified Hoagland nutrient solution which included Mn, Zn, Cu, Si, and MO. Solutions were salinized by adding NaCl and CaC12 (1: 1 by mass) resulting in pH values of 7.5-7.9. Each irrigation continued for five minutes until the sand was completely saturated after which the solutions drained into 612-litre reservoirs for the next irrigation. Water lost by evapotranspiration was replenished weekly or when necessary to maintain the concentrations of salts in solution. The electrical conductivity of each solution was checked initially, biweekly, and at harvest.

Nine treatment solutions were prepared with target electrical conductivities equalling 1.6, 3, 5, 7, 10, 13, 18, 23 and 28 dS m-l. The 1.6, 3, 5 and 7 dS m^{-1} treatments were replicated at least two times, and the remaining treatments consisted of one tank each. Full complements of salt were added to the irrigation water supplies prior to seeding.

Fifty seeds per tank from one of four wheat varieties (Katepwa, Biggar, Fielder and Kyle) were sown 40 mm deep into the sand separated by 80 mm within rows spaced 125 mm apart. The resulting plants were not thinned. The tank arrangement followed a randomized block design with respect to varieties, but was modified slightly to eliminate any bias caused by taller plants blocking solar radiation associated with low sun angles. Day lengths were adjusted during the growing period by using 475 W sodium lamps positioned 1.5 m above the sand surfaces to mimic a typical field seeding date of May 1st along the 50th parallel north. Setpoint temperatures equalled 220C daytime and 18oC nighttime resulting in maximum daily ambient air temperature ranging from 21 o to 270C and the minimum between 15o and 190C.

Within each variety, the response of the plants to the salinity treatments was determined at harvest by measuring plant height, above-ground biomass, number of seedheads, oven-dried grain yield, and the number of live plants per tank. These measurements were averaged and related to electrical conductivities of water-saturated soil paste extracts (EC_e) derived from the electrical conductivities of the test solutions (EC_s) using the conventional relationship followed by the U.S. Salinity Laboratory (Maas 1990): $EC_e = 0.5\ EC_s$ [3]

This equality assumes that the solutions fill the soil pores to field capacity and 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). The electrical conductivities were also adjusted for differences in the effects of NaCl and Na_2SO_4 on osmotic pressure (U.S. Salinity Lab. Staff 1954).

The usual procedure for converting absolute yield to relative yield employs a scaling divisor based on the production where salinity has little or no influence on yield (Maas 1990). This divisor normalizes the data set, and for non-halophytes, equals the maximum yield (Ym) associated with the response function. A Ym-value was determined for each variety using Equ. [1] in a non-linear regression with each data set. With Ym determined, the relationship between Yr and EC_e could be estimated by regression using Equ. [2] and the response model to obtain the parameter estimates. Standard errors, residual sum-of-squares, coefficient-of-determination, and X^2-probability that a random sample could give no better fit were determined using the maximum neighborhood method of Marquardt (1963), which is based on an optimum interpolation between the Taylor series method and the method of steepest descent.

RESULTS AND DISCUSSIONS

Plant Height

Plant heights at maturity declined linearly with increasing salinity in all varieties; the Kyle heights decreased the most among the varieties (Figure 1). Height reductions in response to salinity were evident in all varieties growing in media with an EC_e of 2 dS m^{-1} or greater.

Number of Plants Harvested

Although most plants which emerged grew to maturity, a tendency existed for some plants subjected to the greatest salinity to either fail to emerge or to die before producing seed; Fielder plants were the exception (Table 1).

Grain Yield

The quantity of grain produced generally decreased non-linearly with increasing root-zone salinity (Figure 2). The scaling divisors (Ym) calculated to convert absolute gram production to relative yields equalled 455, 607, 492 and 549 g m^{-2} for Katepwa, Biggar, Fielder and Kyle, respectively.

The regressions for the relative grain yields of each variety fit the descending function well with r^2-values ranging from 0.94 through 0.99 and residual error of 1% or less. The c_{50}-values were 3.5, 3.8, 6.6 and 7.5 dS m^{-1} for Katepwa, Biggar, Fielder, and Kyle, respectively. Based on standard errors for c_{50} and t-distributions at 5% error, Fielder and Kyle exhibited significantly greater salt tolerance than Katepwa and Biggar.

The most important result from our test is the tendency for grain production to begin decreasing at very low EC_e-values (Figure 2). Grain yield losses for Katepwa and Biggar began near 1.5 dS m^{-1} and for Fielder and Kyle near 2.5 dS m^{-1}. This classifies these wheats as sensitive and moderately sensitive

Table 1. Average number of plants harvested from 50 seeds sown per tank, sorted by wheat variety and electrical conductivity (EC_e).

EC_e dS m^{-1}	Katepwa	Biggar	Fielder	Kyle
1	47.3	41	49.3	46
2	45	46.5	50	45
3.2	47	45.5	49.5	44.7
4.4	48.5	37	49	44.5
6.2	47	44	48	42
8	48	44	48	44
11	48	41	49	38
14	43.1	34	49	40
17	42	43	48	38
Mean	46.2	41.8	48.9	42.5
Stand. Dev.	2.32	4.06	0.72	3.09

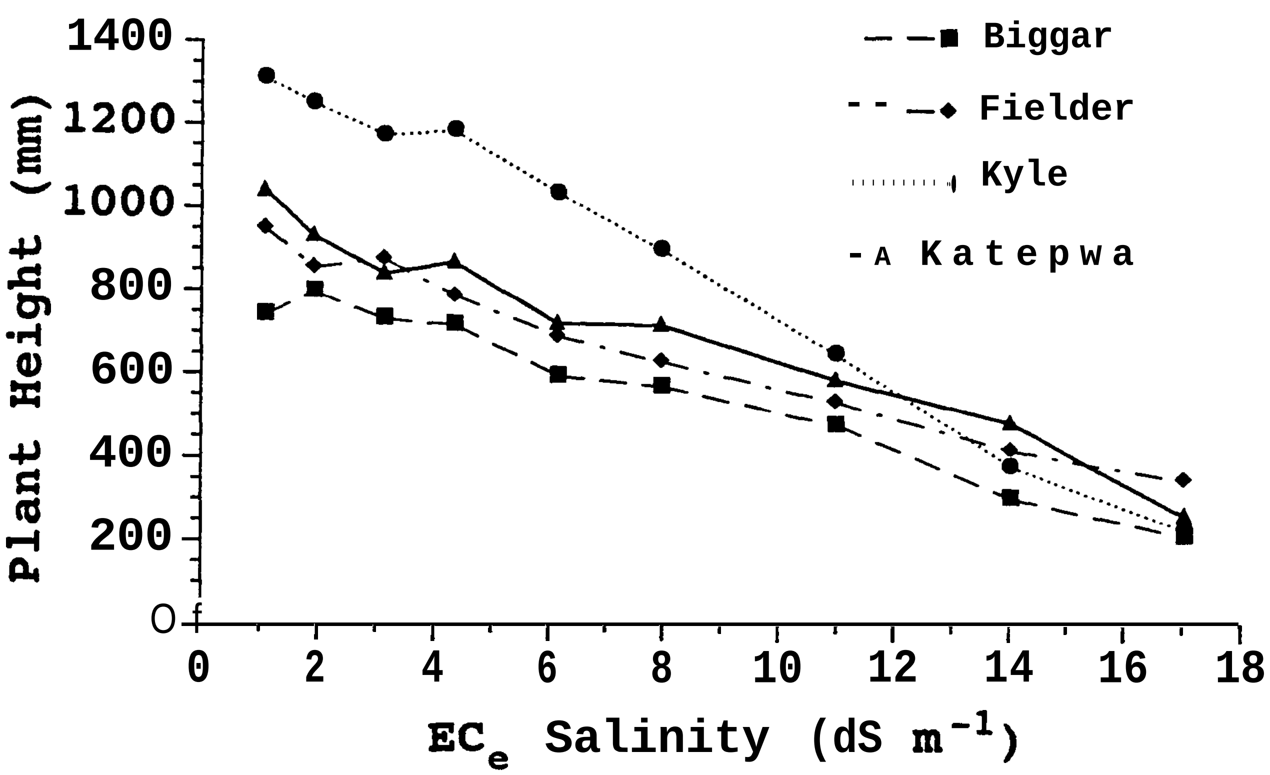

Figure 1. Average plant height (at harvest) related to root-zone salinity (measured as electrical conductivity, EC_e).

to salinity (Ayers and Westcot 1985). At 4 dS m-l, grain production dropped to 90% of that from the control plants for Fielder and Kyle and 45% for Katepwa and Biggar. This agrees with Fowler and Hamm (1980) whose field data averaged 4.1 dS m-l for threshold EC_e when grain yield losses due to salinity could be detected during a two-year study in Saskatchewan.

The corresponding value reported by Maas and Hoffman (1977) for wheat in general is 6.0 dS m-l, with an average decline in yield beyond the threshold of -7.1% (dS $m^{-1})^{-1}$. This rate of decline amounts to only about half of those measured in our test. One possible explanation for these differences relates to the different times in growth stages when rooting media were salinized. Another explanation stems from possible inherent variability in salt tolerance among wheat varieties.

Root-zone salinity affects grain production primarily by reducing the number of fertile seedheads per plant (Maas and Grieve 1990). This reduction occurs early in the plant's life when the salt hinders the development of primordia which determine the number of tillers produced by the plant (Grieve et al. 1993). In our test, the number of heads per plant dropped immediately with the first increment of salt, decreased non-linearly with additional salinity, and at 11 dS m-l was reduced to one (on the mainstem) (Figure 3). Although salinity in our test increased to 17 dS m-l, the single mainstem kept producing grain. These results guide our search for remedial technologies which favor a greater population of mainstems in slightly and moderately saline soils.

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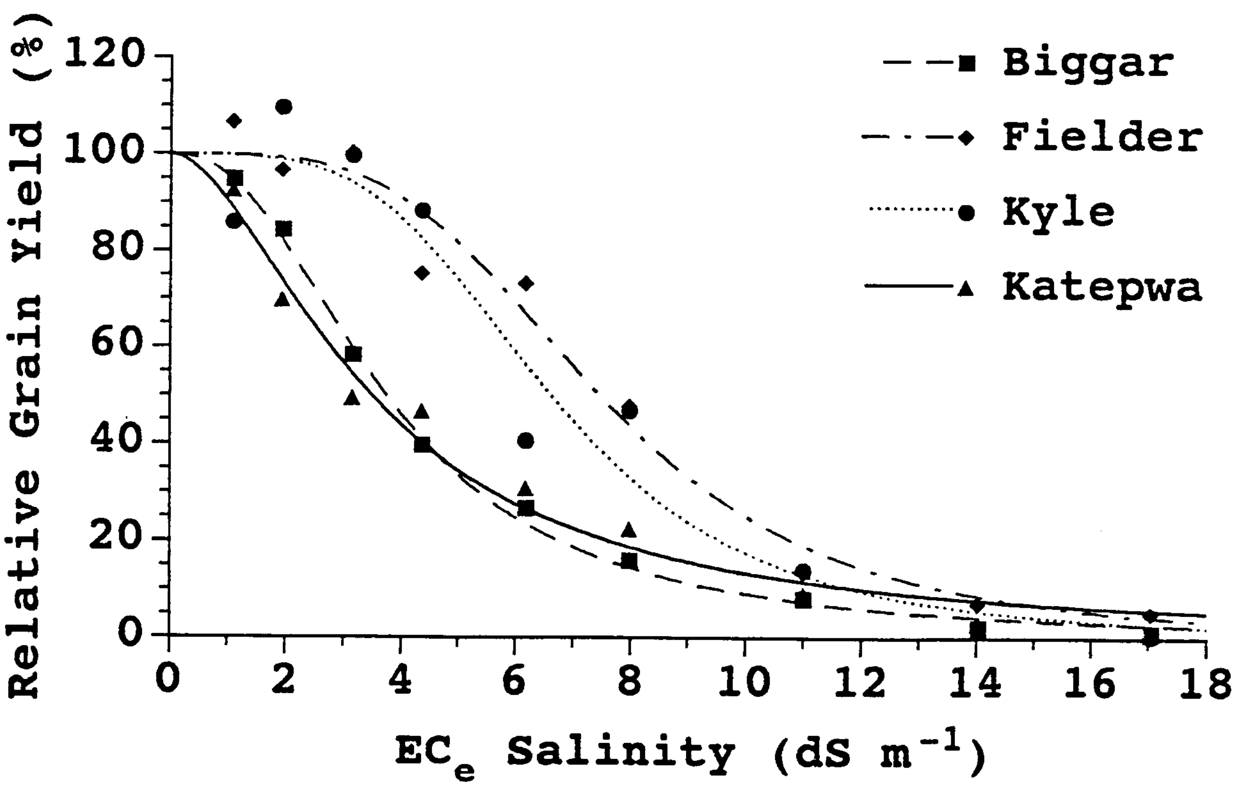

Figure 2. The response in relative grain yield (%) related to root-zone salinity.

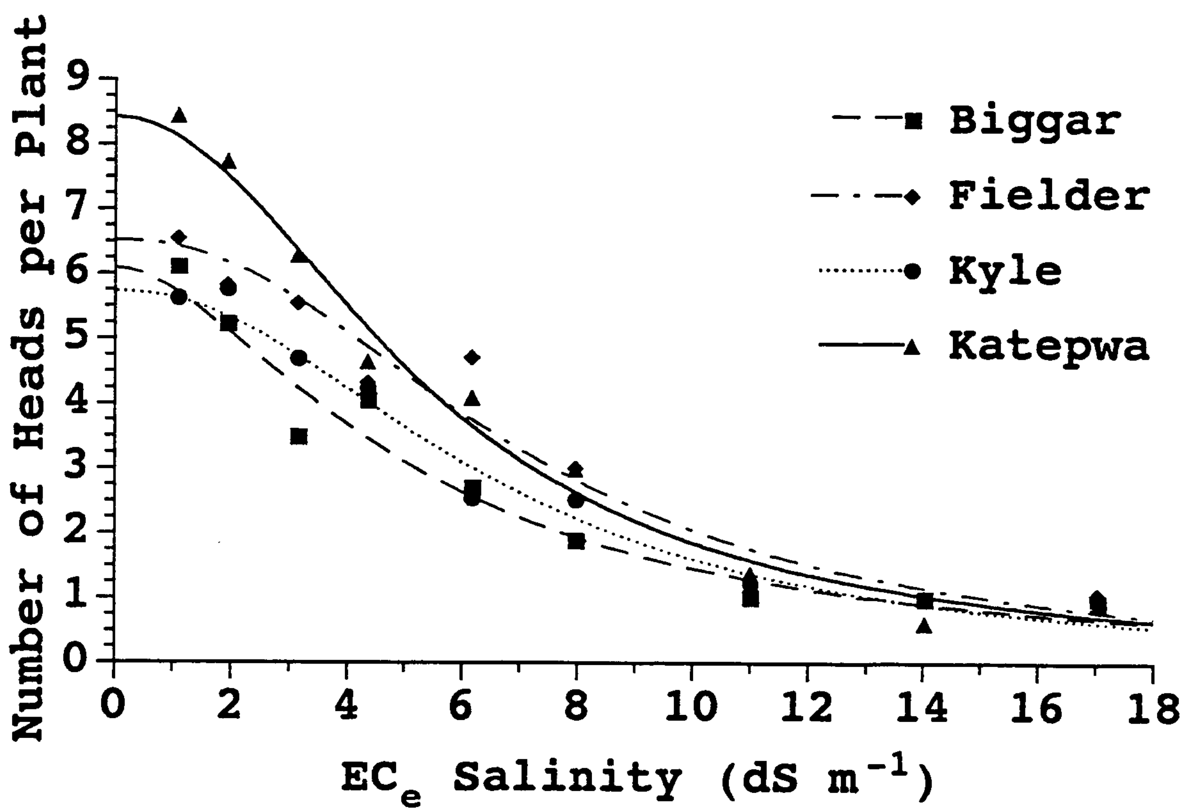

Figure 3. Average number of fertile seed heads per plant related to root-zone salinity.

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