ANNUAL REPORT
COMPREHENSIVE RESEARCH ON RICE
January 1, 1997 - December 31, 1997

PROJECT TITLE: Salinity Studies in Rice

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LEVEL OF FUNDING: $30,820

OBJECTIVES AND EXPERIMENTS CONDUCTED TO ACCOMPLISH OBJECTIVES:

I. Identify and verify soil and water salinity levels where yields and economic returns are reduced.

II. Quantify and verify rice grain yield, shoot biomass and plant density as it relates to soil and water salinity in a replicated trial conducted in the Sacramento Valley under commercial field conditions.

III. Propose crop water management strategies that are consistent with current practices (e.g.: extended water holding periods) and constraints but avoid salinization of fields.

IMPORTANCE OF RESEARCH TO INDUSTRY:

Researchers from the USDA/ARS and the University of California Cooperative Extension have gathered strong evidence that suggests that salinity is reducing rice yields in several locations in Colusa and Glenn counties (Rhoades, 1995, personal communication; Scardaci et al., 1995 and 1996). Of the 27 fields that were monitored, these investigators found that rice yields decreased in a linear fashion as the electrical conductivity (EC) of the soil water increased. The electrical conductivity of the water is an indicator of the salinity hazard and increases in direct proportion to the salt concentration in the water. Perhaps of greater importance was the rapid decrease in seedling density (number of plants per area) with relatively small increases in salinity. The literature also indicates that rice is extremely sensitive to salinity during the seedling and early-development stage (Maas, 1990). Therefore it is unclear to what extent yields are being reduced by reductions in plant growth or overall reductions in stand establishment.

The investigators of the salinity survey found that although the salinity of the water in top basins was about the same as the irrigation water source, the salinity of lower basins was substantially higher. They also showed that soil EC increased from top to bottom basins. These differences indicate that salt concentrations in the lower basins are increasing by evapoconcentration and are consistent with the fact that water inflows and outflows were lower in the lower basins.

The salinity problems that have been observed in the Sacramento Valley over the past several years may have been enhanced by water management practices that have shown to reduce pesticide concentrations in the Sacramento River. The water quality of the river has been improved substantially by holding the water in pesticide-treated fields for extended periods and by using closed irrigation systems. However these practices while decreasing the pesticide concentration of the receiving river may increase the potential for field salinization.

In light of the recent survey conducted by Scardaci et al. (1995 and 1996), salinity studies are needed to quantify the relationship between salinity, seedling survival, crop growth and yield. The current salinity guidelines for rice are based on limited research and indicate that rice is relatively sensitive to salinity (Maas, 1990). The guidelines indicate that crop yields are reduced 12% for every unit increase in EC above 3.0 dS/m. The preliminary data collected by Scardaci et al. (1995 and 1996) indicate that reduced yields were correlated with soil salinity in excess of only 2.0 dS/m and seedling establishment was adversely affected at even lower levels. Since climate and environmental factors are known to affect salt tolerance (Maas, 1990), it was important to conduct field salinity experiments in the Sacramento Valley to modify the guidelines for this area. Furthermore, most salinity studies have been conducted where salinity is imposed after the crops have been well established, bypassing the salt-sensitive seedling stage, which may inflate their apparent tolerance to salinity. Therefore, we have now completed two years of field research to quantify salinity's effect on stand establishment, growth, and yield and determine whether Sacramento Valley-grown rice is more sensitive to salinity than the existing guidelines indicate.

SUMMARY OF 1997 RESEARCH:

Methods

The 1997 field salinity trial was conducted at the same site where the study was conduced in 1996. The site was located west of Hwy. 45, just south of Tule Road. In 1996, the field was planted to a very early variety of rice, M-103, while in 1997 it was planted to the early variety, M-202.

Saline irrigation water was prepared as it was in 1996 and stored in large (1000 gal) tanks. Small plots within rings were flooded using irrigation waters that vary in salinity (i.e. targeted EC values of 0.4 (grower water), 1, 2, 4, 6, 8 and 10 dS/m). Saline irrigation water was prepared by adding known quantities of salt of various types in proportions that produced water close to the same ionic composition to that in rice growing areas currently affected by salinity. $NaCl$, $CaCl_2$, $MgSO_4$ and Na_2SO_4 was added in a molar ratio of 10:1:2:1. These 7 salinity treatments were replicated 4 times in a randomized block design and plots were monitored 2-3 times weekly for EC and water depth. Water of either an equal or lower salinity was added to the plots to maintain water levels and EC values as close to the targeted level/value as possible.

We improved upon the small-plot method that we used in 1996. In 1996 we used large aluminum-ring basins (8-ft diameter) that were flooded using irrigation waters that vary in salinity. The rings were installed in the field and pushed into the soil to the depth of the plow pan after flooding but the aluminum walls were flimsy and it was difficult to maintain the targeted salinities within the rings. Consequently, this year we used rings made by cutting a 5-ft diameter culvert pipe into 2-ft sections. Before the field was flooded we manually installed each ring in the field to a depth of 6-8 inches using shovels and a sledge hammer to drive the ring into the plow pan to prevent leaks. Unlike last year, we plumbed each of the rings so that each would have its assigned water-treatment source. Using this modified method we were better able to control both the water level and salinity within each of the rings.

Another difference in methodology we employed this year was pre-salinization of the plots prior to seeding. Unlike last year, all plots were flooded with their respective treatment water before seeds were sown in order to determine salinity's affect on stand establishment. To ensure uniform seeding density, we aligned our plots with the flight path of the plane dropping the seed. Initial seed density counts in the rings confirmed that this alteration was effective at obtaining uniform seed density.

The leaders and investigators in this proposal acknowledge the difficulty and pioneering nature of performing this type of field study and of maintaining targeted salt concentrations in small plots throughout the season. Small-plot studies are accepted as ideal methodology in salinity research carried out in the field. Small plots are necessary not only because salinity plots require numerous measurements and intense management but also the amount of salt needed to establish and maintain large scale plots is prohibitive. Carefully maintained small plots under field conditions along with extensive measurements of stand density, shoot growth, ion accumulation, yield, and yield components as they relate to soil and water salinity allow us to carefully study the response of rice to salinity. We found that this improved ring method was an effective experimental method . It allowed us to study the response of field-grown rice to salinity and to test the appropriateness of the current salinity tolerance guidelines for rice grown in the Sacramento Valley.

OBJECTIVES I AND II

Using the improved "ring method" described above, we developed time-weighted average salinity levels (ECw) that ranged from 0.4 to 11.9 dS/m. This was a suitable range of salinity treatments because a number of treatments fell both above and below the current published salinity threshold guideline for rice (i.e. 3.0 dS/m). The salinity threshold is the maximum level of salinity beyond which yields decline. Soil samples were also collected at several times throughout the season but data from the analytical laboratory are still pending. Therefore the data presented in this report are in relation to the time-average EC of the standing water in each ring. Presentation of data in relation to EC of the standing water, mud or soil all produced high correlation coefficients with plant variables (Shannon et al., unpublished data) where standing water in relation to biomass gave the highest correlation (r= -0.86).

At 28 days after seeding (DAS), visual observations showed that severely salt-stressed seedlings were smaller, had fewer tillers, less root mass, and had shorter, thinner, and often chlorotic leaves compared to non-stressed plants. Moreover, the data indicate that salinity had a profound influence on both plant and tiller density (i.e. number/area) (Figure 1). Reductions in plant and tiller density followed a natural log function (r^2 = 0.75 and 0.85, respectively). At an EC of 3.0 dS/m, the currently published salinity threshold for rice, plant and tiller densities were reduced by roughly 50% compared to those in non-salinized controls (EC = 0.4 dS/m). These data support the claim by Maas (1990) that rice is very sensitive during seedling and early development stage. No significant differences in tillering or stand density were observed at 28 DAS in 1996 presumably because treatments were not imposed until after seedlings were established.

Not only did salinity reduce plant and tiller density at 28 DAS, but also reduced the number of tillers per plant (Figure 2). The number of tillers per plant decreased in a linear fashion (r2 = 0.72) with increasing salinity.

At 62 DAS plant and tiller density still declined with increasing salinity. However, early high seedling mortality decreased the number of plants/area at higher salinities which lead to prolonged tillering on individual plants (up to 7 dS/m) later in the season. On the other hand, plants at higher stand densities (i.e. low salinity levels) only had two or three tillers/plant (Figure 3). We believe that the increase in tillers per plant as salinity increased to 7 dS/m is related to decreasing plant density (i.e. lower plant density, less competition, more tillering). As salinity increased above 7 dS/m, salinity stress was severe and became the major factor affecting tillering, rather than reduced plant competition.

Salinity also delayed heading. We found a relatively good second-order relationship ($r^2 = 0.75$) between salinity and days after seeding to 50% heading (Figure 4). At 10 dS/m salinity, it took plants roughly 6 additional days to reach 50% heading compared to those in non-saline controls. Data collected in 1996 also showed delayed heading by salinity.

Biomass data collected at the end of the season indicated that salinity had profound effects on shoot and root growth as well as grain yield. Dry shoot and root biomass data are presented in Figure 5. As with nearly all crops, salinity reduced shoot growth more than root growth. Unlike many other crops, however, salinity reduced straw yield in direct proportion to grain yield (Figure 6). This suggests that salinity did not affect the harvest index (the fraction of the total shoot biomass comprised of grain) in 1997. This was not the case in 1996. In 1996, we found that salinity had little influence on straw yield, but substantially reduced grain yield, thereby decreasing the harvest index.

The discrepancy in harvest index between years can be partly explained by salinity's differential response on sterility. In 1996, salinity increased the percentage of sterile florets in a given panicle such that % sterility increased with increasing salinity. Results in 1996 agreed well with results from greenhouse studies conducted in the UK. It is known that salinity increases sterility in rice but little is known of the underlying cause (Khatun and Flowers, 1995). Greenhouse studies showed that salinity delayed flowering, reduced the number of productive tillers, the number of fertile florets per panicle, the weight per grain and overall grain yield (Khatun et al. 1995). This year, however, salinity did not have much influence on % sterility (data not shown).

The reduction in grain yield in 1997 by salinity was attributed to the reduction of panicles per area (Figure 7), an overall reduction in the number of filled grains per area, and the individual seed size (Figure 8). In 1996, an increase in the number of sterile florets and a reduction in grain size were the primary factors responsible for yield reduction under saline conditions. In both years, very good linear relationships were found between increasing salinity and decreasing seed size (i.e. decreasing 1000 grain weight; $r^2 = 0.94$ and 0.79 for year 1996 and 1997, respectively). In both years it seemed apparent that salinity, below the current salinity-threshold guideline of 3.0 dS/m, was reducing seed size.

In order to determine whether the existing salt-tolerance guidelines for rice are appropriate for rice grown in the Sacramento Valley, grain yield must be converted to a relative basis, combined with previous years studies and then plotted in relation to the seasonal average salinity. We did this for 1996 and 1997 (Figure 9). The NLIN (non-linear) procedure in SAS was used to fit the Maas and Hoffman Piecewise Linear response model. The NLIN procedure fits non-linear regression models by least squares. The NLIN procedure in this case is used in a segmented linear model combination. From this preliminary assessment using data from the 1996 and 1997 years, we found that a threshold of 1.9 dS/m and slope of 9.1% best fit our combined data set.

Our data thus far support the finding by Scardaci et al. (1995 and 1996) that the salinity threshold for rice grown in the Sacramento Valley is less than the current guidelines indicate, suggesting that rice is adversely affected by salinity at a lower level. At this particular point in time, however, we are not in a position to advocate these new threshold and slope values. The methodologies for 1996 and 1997 were different in that we were unable to pre-salinize the plots in 1996 due to time constraints but we did pre-salinize in 1997. This difference in methodology resulted in differences in stand density among treatments in 1997, but this was not evident in 1996. In order to increase our confidence in these "threshold" and "slope" values, it is appropriate that we conduct this study an additional year where plots are again pre-salinized as they were this year. In the interim, we suggest that a tentative threshold of 2 dS/m be used since this value is also consistent with the observations by Scardaci et al. (1995 and 1996). Verification of these guidelines are particularly important should these be used in water policy decisions regarding salinity standards or for water allocations.

OBJECTIVE III

We are still not in the position to suggest alternative water management practices for rice production that are consistent with current practices (e.g.: extended water holding periods) and constraints but avoid salinization of fields. However, our data, as well as those by others (Scardaci, 1995 and 1996; Khatun and Flowers, 1995 ; Khatun et al., 1995) suggest that salinity stress in rice should be avoided during seedling establishment and early growth, due to salinity's profound influence on stand establishment, as well as during inflorescence and grain filling, due to salinity's potential adverse effect on sterility. Therefore modified water management practices should take these important factors into account.

Acknowledgment:

The investigators of this project would like to express their appreciation for the valuable work by James A. Poss, Soil Scientist, USDA/ARS Salinity Laboratory in Riverside for running the statistical program on our data.

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Scardaci, S.C., A.U. Eke, J.E. Hill, J.D. Rhoades, and M.C. Shannon. 1996. Water and soil salinity studies on California rice, 1993-1995. University of California, Cooperative Extension, Colusa, California, Rice Publication No. 2. 12pp

PUBLICATIONS AND REPORTS: None to date.

GENERAL SUMMARY OF CURRENT YEAR'S RESULTS

Irrigation management practices in rice that have improved water quality in receiving rivers in relation to pesticides may be creating a different problem. In a recent salinity survey conducted in Colusa and Glenn counties between 1993 and 1995, researchers at the University of California and the USDA/ARS Salinity Lab have gathered strong evidence that suggests that salinity is reducing rice yields in several locations within the Sacramento Valley. Apparently these new water management practices while decreasing the pesticide concentration of the receiving river may increase the potential for field salinization by allowing salts to evapo-concentrate in lower basins.

Rice is known to be very sensitive to salinity. The current salinity guidelines for rice are based on limited research and indicate that crop yields are reduced 12% for every increase in unit of electrical conductivity (EC) above 3.0 dS/m. The EC of the water is an indicator of the salinity hazard and increases in direct proportion to the salt concentration in the water. The preliminary data collected in 1993-1995 indicate that yields were affected by soil salinity in excess of only 2.0 dS/m and seedling establishment was adversely affected at even lower levels. Since climate and environmental factors are known to affect salt tolerance it was necessary to conduct field salinity experiments in the Sacramento Valley to modify the guidelines for this area.

We conducted a salinity experiment for a second year at the same site in Colusa county. We used 5-ft diameter rings to establish 28 salinity plots, arranged in four randomized blocks, where the time-averaged seasonal EC varied from 0.4 (growers field) to 11.9 dS/m. Small plots are necessary not only because salinity plots require numerous measurements and intense management but also the amount of salt needed to establish and maintain large scale plots is prohibitive.

Small increases in salinity had a profound influence on stand establishment and overall plant density (number of plants per area). We found that moderate levels of salinity delayed tillering but that eventually the number of tillers per plant increased with increasing salinity up to 7 dS/m, due to reduced plant competition, which partially compensated for salinity's devastating effect on stand establishment.

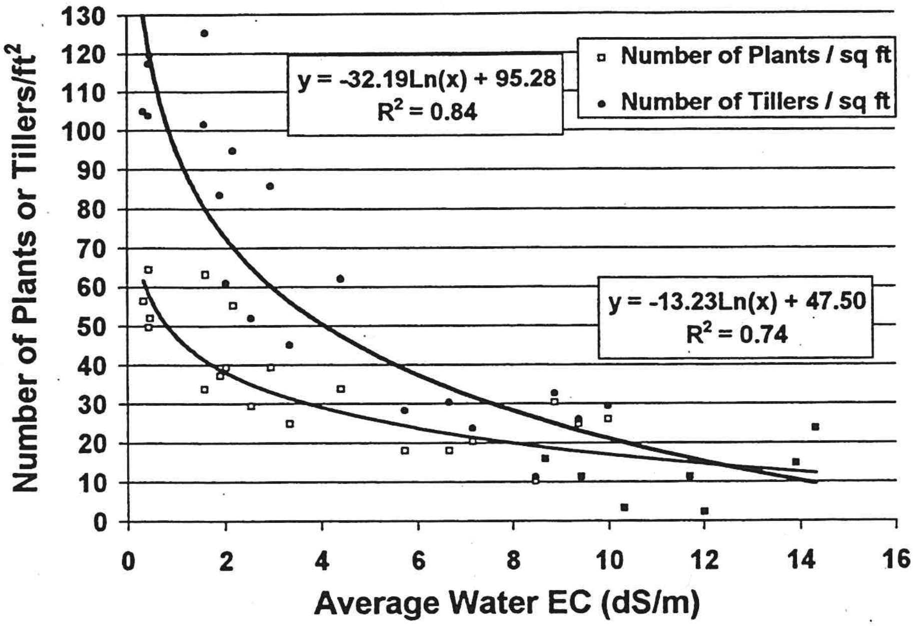
Salinity reduced shoot and root biomass as well as grain yield. This year, salinity reduced grain yield primarily by reducing the number of panicles per area as well as reducing individual grain size. We also found that salinity delayed heading, but did not appreciably increase the percent of sterile florets as it did last year.

We converted actual grain yield to a relative basis for both 1996 and 1997, combined the data, and plotted them as a function of average seasonal EC of the standing water. This allowed us to use a statistical method to best fit the data and determine a new salinity threshold and % slope. Our preliminary analysis indicates that a salinity threshold of 1.9 dS/m and slope of 9.1% best fit our combined data. The important difference between our values and those reported by Maas (1990) is a lower salinity threshold. The "salinity threshold" based on our 1996 and 1997 data are consistent with the results from the salinity surveys conducted in 1993 and 1995.

At this particular point in time, however, we are not in a position to advocate these new threshold and slope values. The methodologies for 1996 and 1997 were different in that we were unable to pre-salinize the plots in 1996 due to time constraints but we did pre-salinize in 1997. This difference in methodology resulted in differences in stand density among treatments in 1997, but this was not evident in 1996. In order to increase our confidence in these "threshold" and "slope" values, it is appropriate that we conduct this study an additional year where plots are again pre-salinized as they were this year. In the interim, we suggest that a tentative threshold of 2 dS/m be used since this value is also consistent with the observations by Scardaci et al. (1995 and 1996). Verification of these guidelines are particularly important should these be used in water policy decisions regarding salinity standards or for water allocations.

Soil and water EC's over the season averaged by treatment.

REP	Target EC	Treatment Mean Across Reps	Water Ec Weighted Average 28 DAS	Treatment Mean Across Reps	Water Ec Weighted Average 62 DAS	Treatment Mean Across Reps	Water Ec Weighted Average Season	Treatment Mean Across Reps	Soil EC 8 DAS	Treatment Mean Across Reps	Soil Ec at Harvest 0-3"	Treatment Mean Across Reps
						dS/m						
1	0		0.47		0.47		0.47		1.49		1.1	
2	0		0.45		0.43		0.46		1.35		1.2	
3	0		0.34		0.38		0.41		0.83		1.3	
4	0	0	0.45	0.43	0.45	0.43	0.46	0.45	0.67	1.09	1.4	1.25
1	1		1.91		1.60		1.37		2.61		3.4	
2	1		1.58		1.35		1.23		1.73		2.3	
3	1		1.62		1.39		1.23		1.87		2.9	
4	1	1	2.03	1.78	1.83	1.55	1.57	1.35	1.99	2.05	3.2	2.95
1	2		2.97		2.42		2.11		5.20		5.3	
2	2		2.55		2.33		2.14		3.30		4.4	
3	2		2.18		2.17		2.10		2.18		4.4	
4	2	2	3.35	2.76	2.91	2.46	2.49	2.21	3.40	3.52	4.4	4.63
1	4		5.73		5.11		4.62		5.40		5.1	
2	4		4.41		3.82		3.50		3.80		5.9	
3	4		6.66		5.53		4.90		6.40		5.8	
4	4	4	7.17	5.99	6.44	5.23	5.40	4.61	6.40	5.50	6.8	5.90
1	6		9.43		8.24		7.11		1.02		8.2	
2	6		9.99		8.22		7.02		8.80		8.8	
3	6		8.88		7.79		6.84		7.10		8.7	
4	6	6	8.48	9.20	7.01	7.82	6.11	6.77	7.80	6.18	9.3	8.75
1	8		12.01		10.99		9.83		14.60		16.4	
2	8		8.69		7.99		7.67		7.00		12.1	
3	8		9.37		8.16		7.12		7.80		9.7	
4	8	8	11.70	10.44	11.01	9.54	9.90	8.63	9.80	9.80	10.8	12.25
1	10		14.63		13.24		11.71		16.10		19.1	
2	10		10.32		9.45		8.88		11.80		10.4	
3	10		14.33		13.64		11.90		10.10		10.8	
4	10	10	13.91	13.30	13.18	12.38	11.69	11.04	12.60	12.65	15.1	13.85

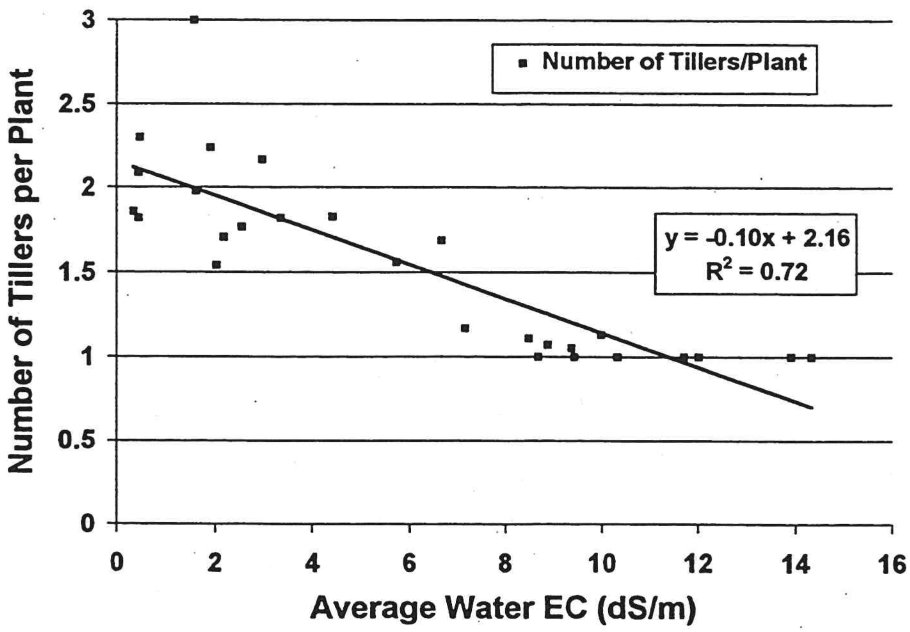


1997, M-202

EC is Weighted Average to 28 DAS

Figure 1. Plant and tiller density (number/ft2) in relation to the average salinity (EC, dS/m) of the standing water 28 DAS.

Figure 2. Number of tillers per plant in relation to the average salinity (EC, dS/m) of the standing water 28 DAS.



1997, M-202

EC is Weighted Average to 28 DAS

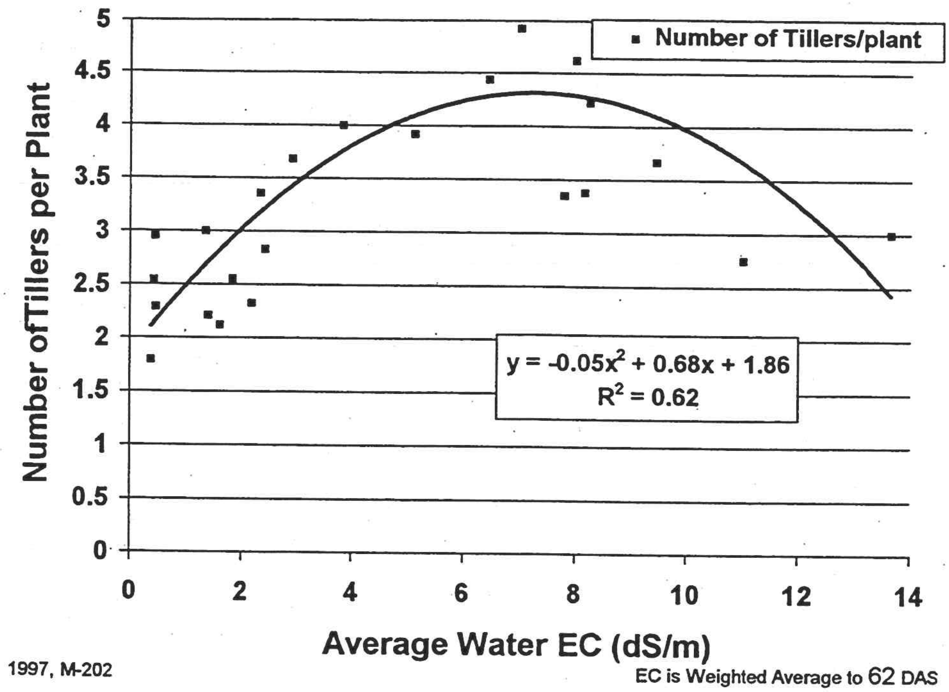
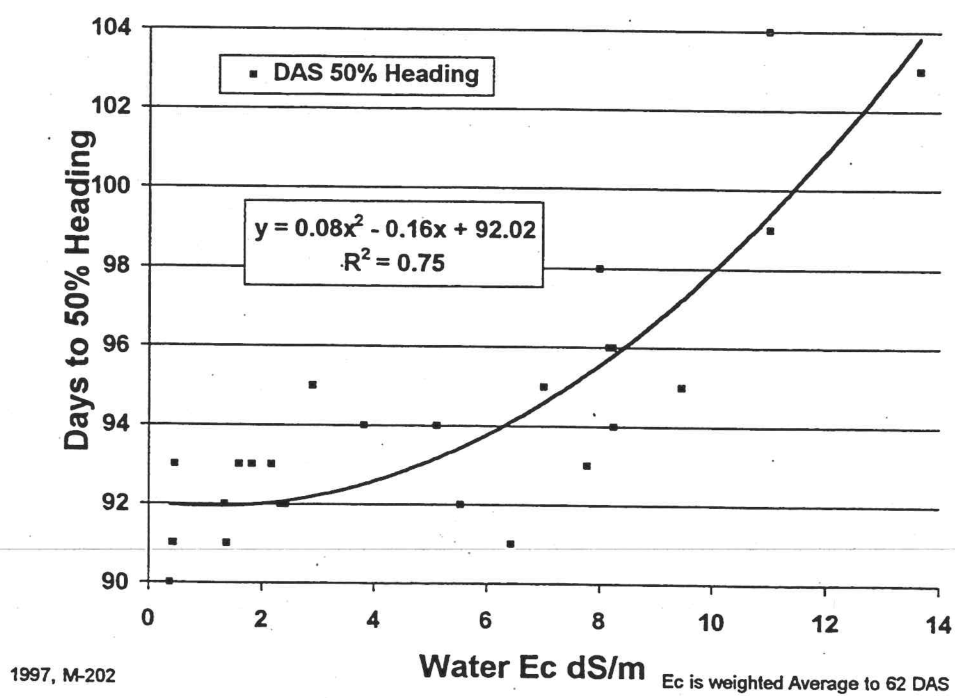


Figure 3. Number of tillers per plant in relation to the average salinity (EC, dS/m) of the standing water 62 DAS.

Figure 4. Days after seeding (DAS) to 50% heading in relation to the average salinity (EC, dS/m) of the standing water.



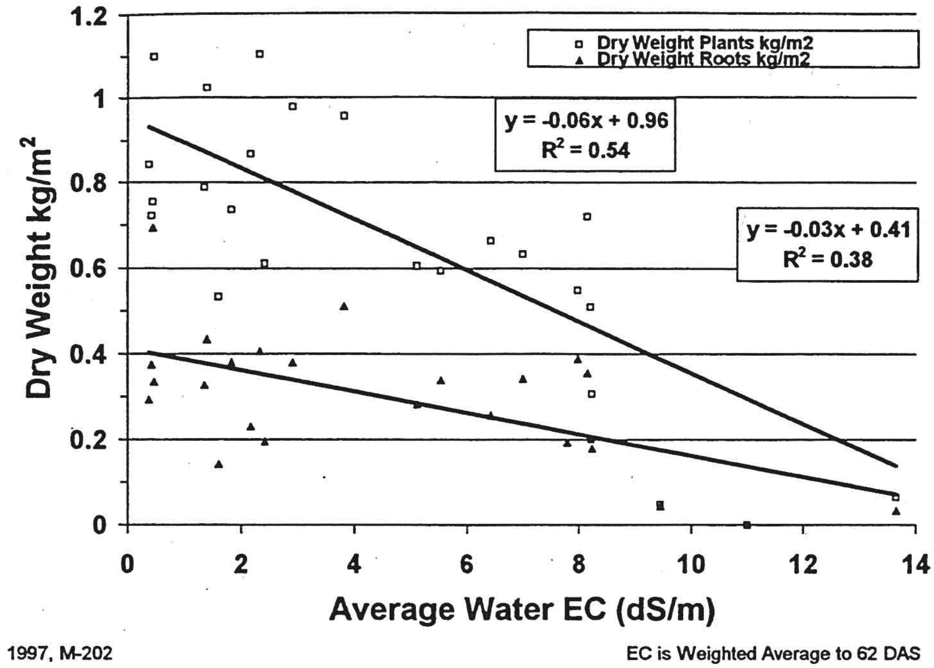
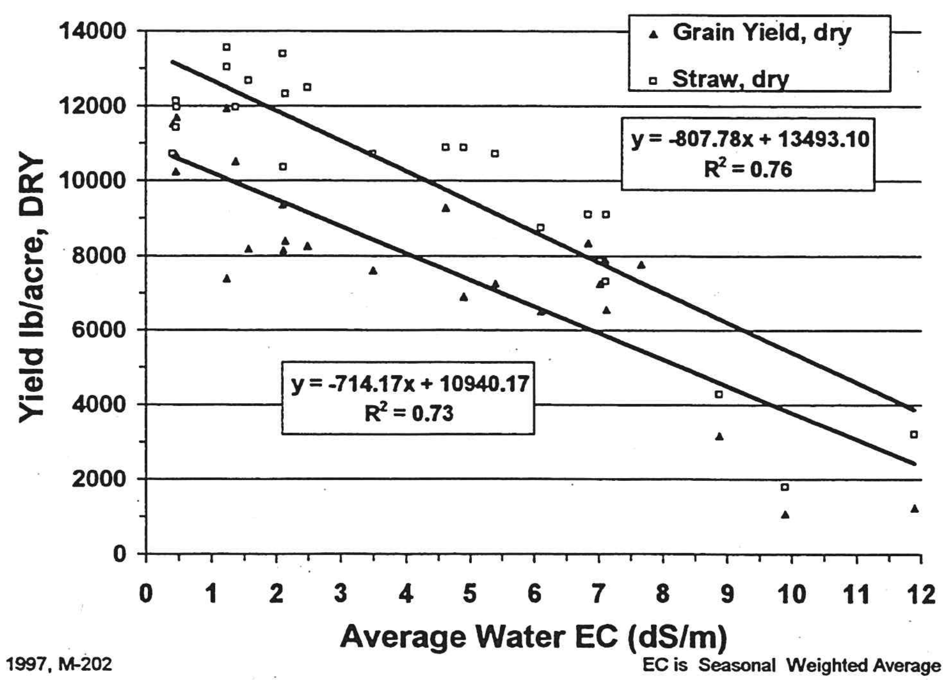
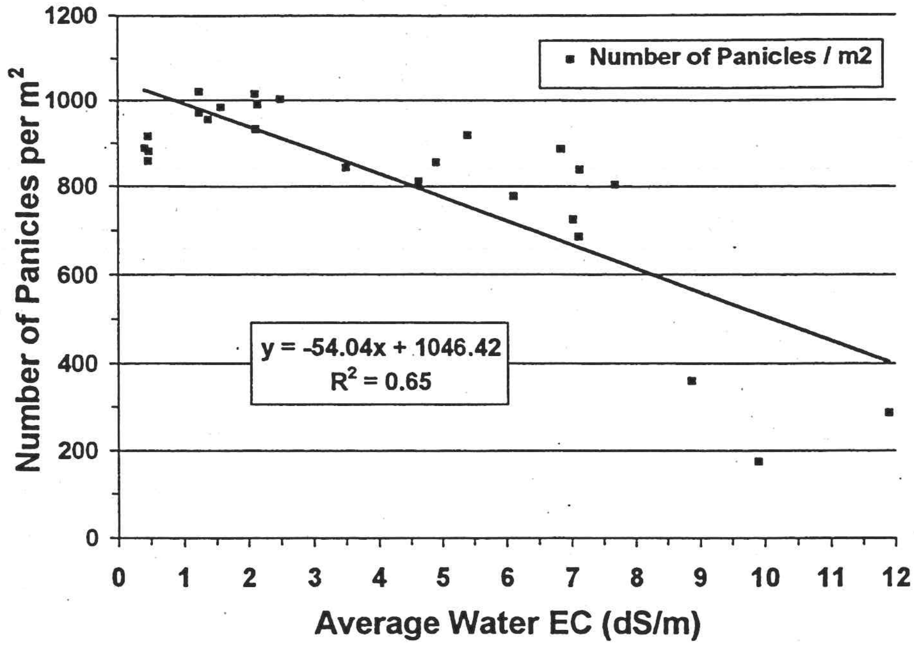


Figure 5. Dry shoot and root weight (kg/m2) in relation to salinity (EC, dS/m) of the standing water.

Figure 6. Dry straw and grain yield (lbs/ac) at the end of the season in relation to the average seasonal salinity (EC, dS/m).

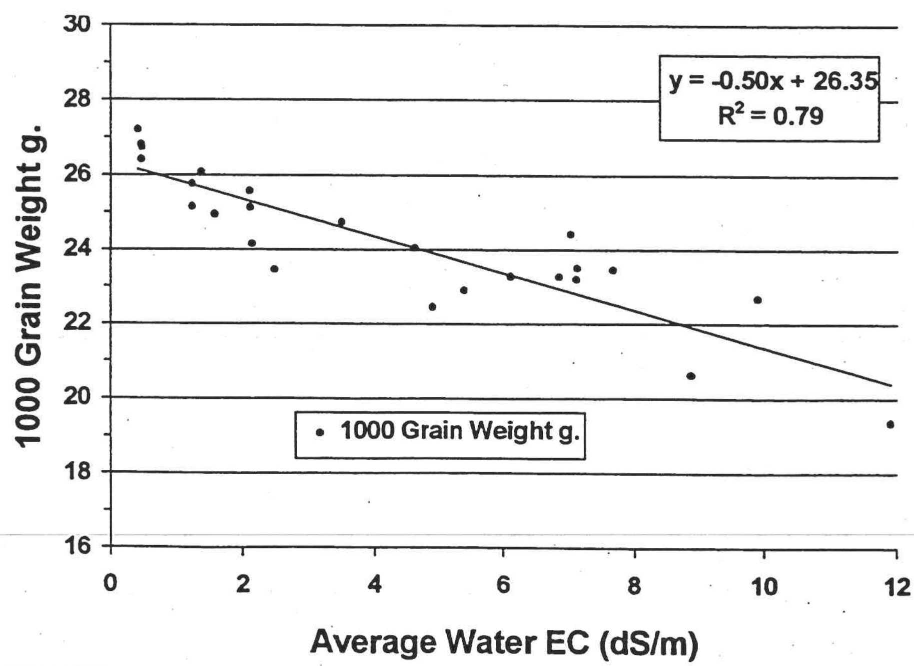




1997, M-202 EC is Seasonal Weighted Average

Figure 7. Number of panicles per m2 in relation to the seasonal average salinity (EC, dS/m).

Figure 8. Thousand grain weight in relation to the average seasonal salinity (EC, dS/m).



1997, M-202 EC is Seasonal Weighted Average

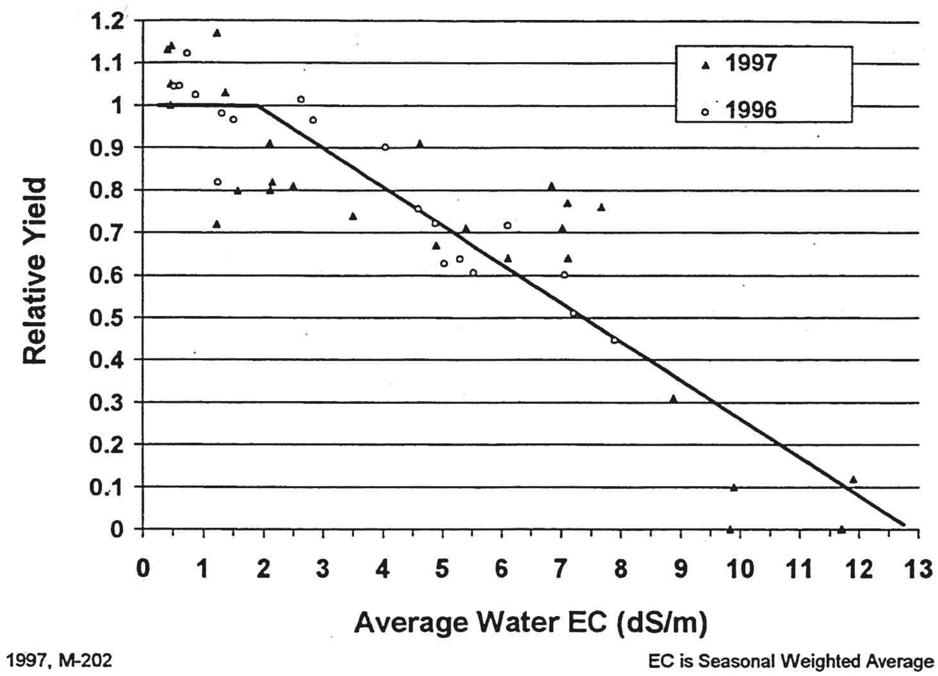


Figure 9. Relative grain yield in relation to the seasonal average salinity (EC, dS/m) of the standing water for 1996 and 1997 years combined.