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2009 Irrigated Crop and Forage Test
Annual Report
Tongue River Information Project

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Foreword

The Irrigated Crop and Forage Test Report is a companion report to the Agricultural Protection and Monitoring Program (AMPP) Report and the Tongue River Hydrology Report, produced under the auspices of the Tongue River Information Program (TRIP). The Montana Board of Oil and Gas Conservation (MBOGC), a division of the Montana Department of Natural Resources and Conservation, has funded this program since 2006. The AMPP program was originally launched in 2003 by Fidelity Exploration & Production Company, a subsidiary of MDU Resources Group, Inc., in response to concerns by Tongue River irrigators over whether crop yield, soils or water quality were being affected by discharges from the coal bed methane industry. Soil scientists William Schafer and Kevin Harvey of Bozeman, Montana, and agronomist Neal Fehringer of Billings, Montana developed the scientific methodology and implementation of the AMPP.

The principal author of this report is Dina Brown, Certified Professional Soil Scientist with KC Harvey, Inc. The TRIP scientists mentioned above, along with Tom Osborne of HydroSolutions, and Karen Brown of Energy Strategies and Solutions, LLC provided technical reviews. HydroSolutions Inc, a Montana based environmental science and engineering firm administered the 2007-2008 TRIP contract. The web site for the Montana Board of Oil and Gas Conservation (located at http://www.bogc.dnrc.mt.gov) contains current and past TRIP reports. The interpretations provided herein are solely those of the authors.

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2.0 Introduction

Irrigators that rely on Tongue River water for crop and forage production have expressed concern about potential adverse impacts that coal bed natural gas (CBNG) development may have on irrigation water quality. Currently, the Tongue River possesses good quality water that is used to irrigate over 20,000 acres of land while supporting a healthy fishery within and just below the Tongue River Reservoir.

This report contains results of testing conducted under the Tongue River Information Program (TRIP), which was initially commissioned and funded by Fidelity Exploration and Production Company in 2003 and since 2006, has been supported by the Montana Department of Natural Resources, Board of Oil and Gas Conservation. The objective of TRIP is to collect and analyze scientific information on soils and crops in the Tongue River basin, provide agronomic assistance to participants, help irrigators better understand potential effects of CBNG development on their irrigated fields, and document regional trends in irrigated soil characteristics. TRIP consists of three tiers of sampling. Tier 3, which is covered in this report, is more specifically named the Irrigated Crop and Forage Test. The objective of this test is to evaluate the potential effects of irrigating with blended CBNG produced water and Tongue River water.

CBNG operators have developed numerous water management strategies to store, utilize, or discharge CBNG produced water. Some water management strategies may entail discharge of produced water into surface waters, provided that the receiving water can comply with irrigation water quality standards and non-degradation limits. Consequently, irrigators would not be applying undiluted CBNG produced water except in special circumstances where 'managed irrigation' programs are developed near the CBNG fields in cooperation with the landowner.

Irrigators using water from the Tongue River may experience slight changes in electrical conductivity (EC) and sodium adsorption ratio (SAR) in their water supply due to CBNG expansion in the Tongue River Basin. However, EC and SAR must not exceed prescribed water quality limits adopted by the State of Montana, which were developed to protect irrigation uses of water. For the Tongue River at the USGS gauging station below the Tongue River Dam in 2007, total CBNG discharges comprised a maximum of 6.4 percent of the river flow in February 2007, with untreated discharge being 4 percent. During the April-September irrigation season, total CBNG discharges comprised from 0.3 to 1.6 percent of river flow, with untreated discharge ranging from 0.1 to 0.8 percent (HydroSolutions, 2008).

In order to evaluate the potential effects associated with various blends of CBNG produced water and Tongue River water, a series of test plot experiments began in the spring of 2004. The following report documents these experiments and comprises four sections including this introduction (Section 1), study methodology (Section 2), test results and discussion (Section 3), and references cited (Section 4).

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3.0 Methods

Flood and sprinkler irrigated test plots were used to assess changes in soil and crop properties resulting from irrigation using various blends of Tongue River water and CBNG produced water.

3.1 Study Site Selection

Researchers selected a privately owned ranch in the Tongue River Drainage for the Irrigated Crop and Forage Test. The legal description of the test plot area is Section 21 of Township 58 North, Range 83 West, Sheridan County, Wyoming. The site is adjacent to the Tongue River floodplain near the Wyoming-Montana state line. Researchers initiated the Irrigated Crop and Forage Test at this location in April 2004, and completed its fifth season of testing in fall 2008.

3.2 Experimental Treatments and Design

The experimental treatments for this project consisted of four irrigation water mixtures, two sets of cropping sequences, and two irrigation methods. These variables combine to create 16 unique treatments. Each unique treatment was replicated three times, resulting in a total of 48 experimental units.

Researchers established plots in mid-April 2004. They divided a 0.50-acre area into 48plots to represent each experimental unit as shown in Figure 1. They then divided the entire experimental area lengthwise, with the east and west portions representing separate cropping systems. They also divided the entire area crosswise, with the north and south portions representing flood and sprinkler irrigation respectively, thus creating four blocks with each block representing a unique cropping system and irrigation method combination. Each block contained 12 plots, with three replicates of four different water mixtures, randomly applied within the block using a split-plot design (Figure 1). (Note – it is unusual to separate the different irrigation and cropping practices spatially as we did because pre-existing spatial differences could account in part for observed differences in yield or soil chemistry. This potential drawback should probably be mentioned, and provide a rationale for the separation of treatment blocks – e.g. necessary to build irrigation infrastructure and to facilitate tillage/planting, etc. The water type treatment is truly randomized within each block so the main effects associated with water type are fully valid while effects associated with irrigation method or cropping system are harder to separate from soil spatial variability)

3.2.1 Irrigation Water

To test the effects of irrigating with Tongue River water containing CBNG produced water on crops, forages, and soils, researchers applied four irrigation water treatments to test plots. Table 1 describes the water treatments. Table 2 presents chemical analysis results for CBNG produced water and Tongue River water. Table 3 presents the calculated water quality results for each of the four water treatments.

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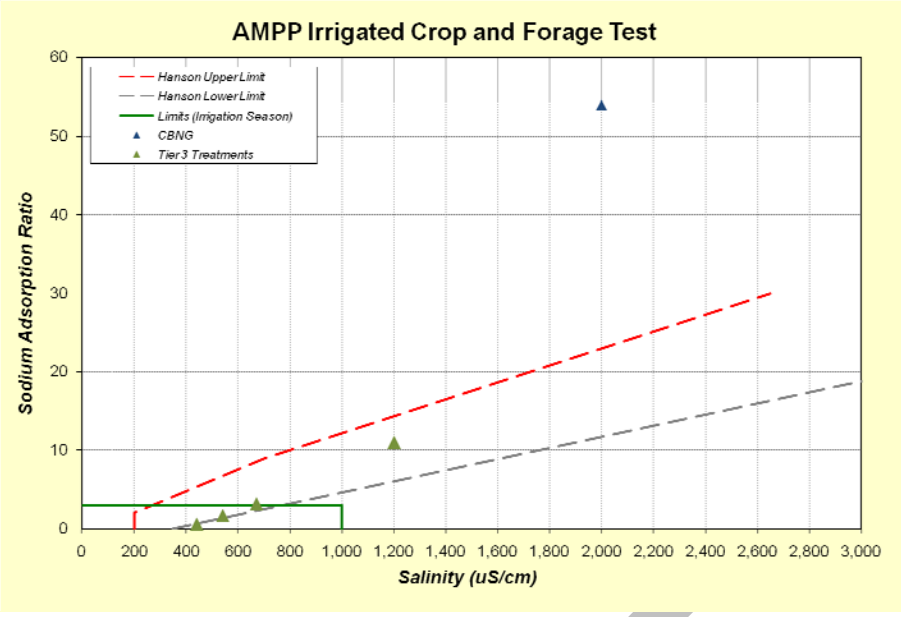

3.2.2 Crops

To determine the effects on crop and forage yield of irrigating with Tongue River water containing CBNG produced water, the four irrigation water treatments were applied to two crop plantings each irrigation season (Figure 1). Bean, barley, and alfalfa crops were rotated between the two plots on a yearly basis (Table 4).

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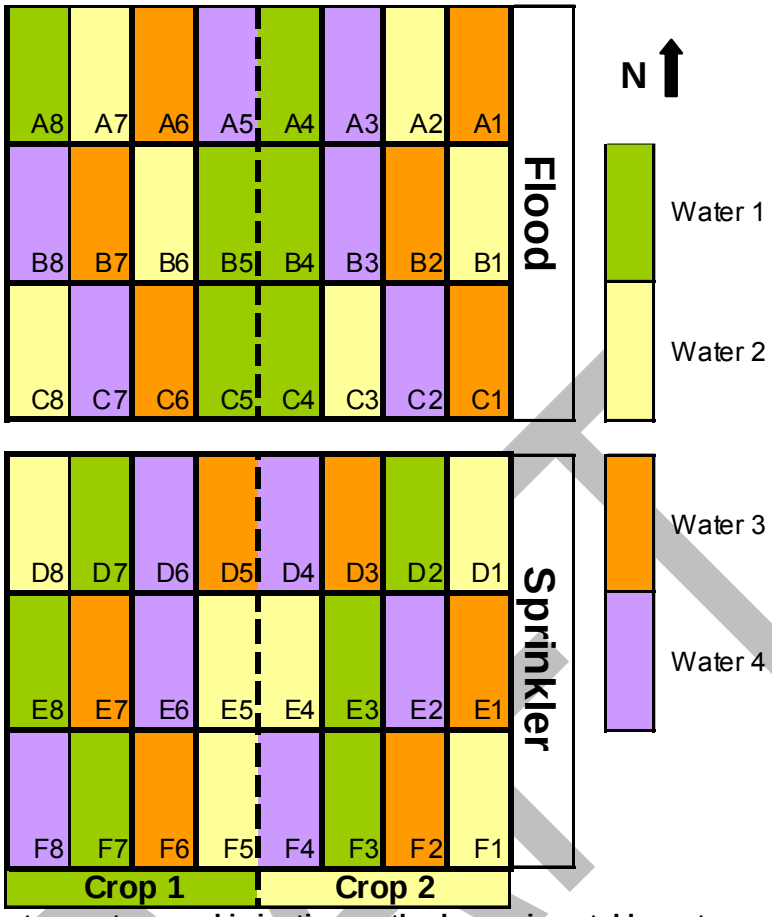

Figure 1. Water treatment, crop type and irrigation method experimental layout

Table 1. Irrigation water treatments consisting of Tongue River and CBNG produced waters.

Water Number	Tongue River Water	CBNG Produced Water
1	100%	0%
2	93%	7%
3	85%	15%
4	50%	50%

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Table 2. CBNG produced water quality and spring and fall Tongue River water quality used in the Tier 3 field test.

Analyte[1]	Units[2]	CBNG Produced Water	Tongue River, Spring[3]	Tongue River, Fall[4]
pH	*s.u.*	8.6	8.2	7.9
Electrical Conductivity (EC)	*dS/m*	2	0.23	0.64
Sodium Adsorption Ratio (SAR)		54	0.35	0.8
Anions				
Bicarbonate	*mg/L*	1290	145	270
Chloride	*mg/L*	20	4	5
Sulfate	*mg/L*	56	38	122
Cations				
Calcium	*mg/L*	4	31	41
Magnesium	*mg/L*	2	11	39
Sodium	*mg/L*	523	8.8	30

Notes:

1. Samples were analyzed by Energy Laboratories, Inc.
2. Abbreviations used are as follows: s.u. = standard units; dS/m = decisiemens per meter; mg/L = milligrams per
3. Sample was collected on May 9, 2004.
4. Sample was collected on September 23, 2004.

Table 3. Calculated water quality of water mixtures used in irrigation water treatments

Constituent	Units	CBNG Produced Water	Average Tongue River Water	Tongue River Composition			
				Water 1	Water 2	Water 3	Water 4
				100%	93%	85%	50%
Electrical Conductivity (EC)	*dS/m*	2	0.44	0.44	0.54	0.67	1.2
Calcium	*mg/L*	4	36	36	33.8	31.2	20
Magnesium	*mg/L*	2	25	25	23	22	14
Sodium	*mg/L*	523	19	19	55	95	271
Sodium Adsorption Ratio (SAR)	-	54	0.6	0.6	1.7	3.2	11

Notes:

1. Abbreviations used are as follows: dS/m = deciSiemens per meter; mg/L = milligrams per liter.
2. Average Tongue River water quality was calculated by averaging the spring and fall results from Table 2.
3. Tongue River Composition was calculated using a flow weighted average of the CBNG produced water and the average Tongue River water.

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Table 4. Test plot crop rotations during irrigation seasons 2004 – 2008

Irrigation Season	Crop 1	Crop 2
2004	Barley	Beans
2005	Beans	Barley
2006	Barley	Alfalfa
2007	Beans	Alfalfa
2008	Barley	Alfalfa

3.2.3 Irrigation Method

To determine whether the effects of the irrigation treatments are dependent upon irrigation method, researchers applied water using two methods, sprinkler and flood. They divided the study area in half from east to west, with each half receiving a different irrigation method (Figure 2). Sprinkler heads attached to steel posts located at the edges of each plot comprised the sprinkler irrigation system (Figure 3). Setting sprinkler head pressure to 10 psi limited cross contamination between plots. The sprinkler treatment applied water at a rate of one inch in 2.75 hours.

Constructing the flood irrigation treatment areas using an earthen double dike system limited cross contamination between plots (Figure 3). The system applied three inches of water to the flood plots every nine days during the growing season, requiring 0.75 hour. Normally, flood irrigation to crop fields requires six total inches of water per acre and assumes a maximum of 50 percent application efficiency maximum. Thus, the net amount of water normally applied to flood irrigated crops is three inches. Less than 100 percent efficiency is attributed to tail water losses off the end of the field and/or leaching through the soil profile. However, this is not the case with the double dike system used in this study; because water is contained, the flood system is assumed to have 100 percent application efficiency. Figure 3 illustrates the design of the double diked system. Table 4 lists water applied per crop for 2004 through 2008.

Figure 2. Irrigation system overview, with the flood treatment on the right and sprinkler treatment on the left. Tanks in the upper right of this photo hold Tongue River water (right tank) and CBNG produced water (left tank)

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Figure 3. Sprinkler irrigation system design. Sprinkler heads are attached to steel posts at the corners of each plot.

Figure 4. Example of fold irrigation plot using a double dike design. Water escaped first border dike but was trapped by second border dike

3.3 Treatment Implementation

Researchers began treatment implementation in April 2004. The following methods were used to prepare study plots for seeding, implement seeding, and maintain plots:

- Fertilizer. To determine fertilizer requirements, a soil scientist collected soil samples in 2004, prior to water application. Using a hand-held Oakfield probe, they collected samples from the 0 to 6 and 6 to 24 inch depths, and composited them by depth for analysis. Energy Laboratories, Inc. (Billings, MT) conducted the soil analysis. Neal E. Fehringer, Certified Professional Agronomist, C.C.A. used analysis results to recommend fertilizer application rates. He applied fertilizer prior to seeding and according to soil tests for each crop.

- Tilling and Leveling. A three-point tractor mounted unit roto-tilled the entire plot to a depth of eight inches. A standard agricultural land plane leveled the test area with two passes.

- Seeding. Seeding occurred annually in accordance with the crop rotations listed in Table 3 and employed the following methods:

  Hay barley. Both drill and broadcast seeding equipment applied hay barley seed at a rate of 100 pounds per acre. The drill seeder placed seeds at a depth of 1.5 inches using either seven inch row spacing (International double disk small grain drill) or 12 inch row spacing (Tye Estate drill). When broadcast seeding, a Brillion was used.
  Beans. A John Deere planter seeded beans at a rate of 65 pounds per acre to a depth of 2.0 inches. Row spacing was 22 inches.
  Alfalfa. A Brillion broadcast seeder applied alfalfa seed at a rate of 20 pounds per acre. Operators lightly hand raked the seed, then pressed it into the soil by running over each plot with an ATV pulling a sod roller filled with water.

- Weed Control. Operators implemented weed control prior to seeding and/or as needed throughout the growing season. Appendix A details weed management techniques used in this study.

3.3.1 Irrigation Timing and Application Rates

Average weekly water consumptive use data developed by the University of Nebraska Research Station (Scottsbluff, Nebraska) allowed determination of water use demands. Researchers periodically monitored soil moisture by probing the soil to three feet and determining soil moisture by feel in each crop and irrigation system. Daily consumptive use rates and available soil moisture determined adjustments to water application intervals.

Sprinkler irrigated plots received one inch of water every three to four days, depending upon crop growth stage. Each flood replication plot received three inches of water every nine to twelve days, depending upon consumptive water use (Figure 4).

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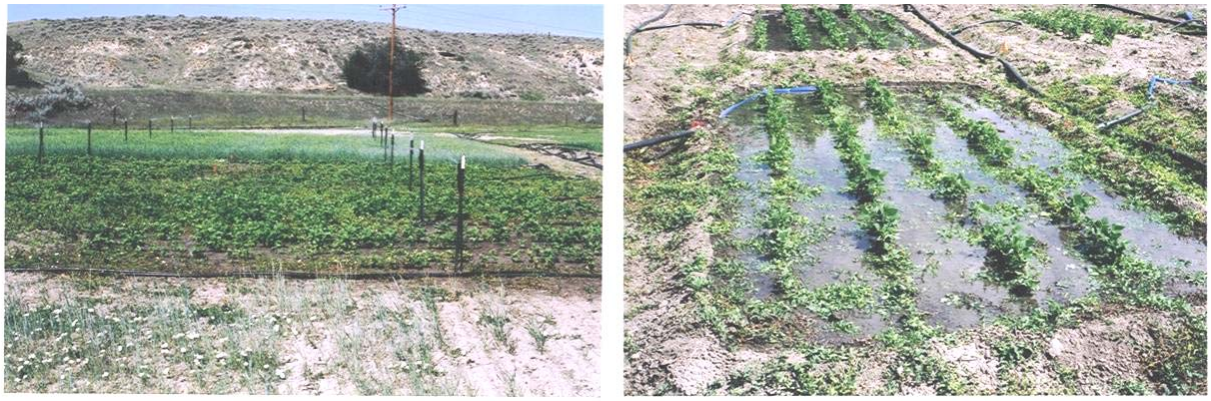

Figure 5. Plots receiving sprinkler irrigation (left photo), and double diked plot following flood irrigation (right photo)

3.3.2 Soil Sample Collection and Analysis

A soil scientist collected soil samples from each replication prior to initial water application (referred to as year 0), and following each irrigation season (years 1 through 4). A truck mounted Giddings Probe (Giddings Machine Company, Inc., Windsor, Colorado) collected samples at five depths: 0 to 6, 6 to 12, 12 to 24, 24 to 36, and 36 to 48 inches. Operators collected three sub-samples in each replication and composited them by depth for analysis. They delivered samples to Energy Laboratories, Inc. (Helena, Montana), for analysis of pH, EC, SAR, saturation percentage, calcium, magnesium, sodium, cation exchange capacity, exchangeable sodium percentage (ESP), and lime content (0 to 6 inch samples only). The laboratory also determined soil texture (percent sand, silt, and clay) for samples collected prior to initial irrigation.

3.3.3 Crop Yield Determination and Quality

An agronomist conducted annual forage harvests within each replication plot. For hay barley and alfalfa, samples were collected, allowed to dry, then weighed and processed through a chipper-shredder. Olsen Agricultural Laboratory, (McCook, Nebraska) analyzed representative samples for complete feed and total mineral analyses. For beans, samples were collected, dried, and processed using a stationary thresher. Following threshing, bean samples were cleaned and weighed. The agricultural laboratory did not analyze bean samples for feed quality or mineral content.

3.4 Statistical Analysis

3.4.1 Soil Data

The experiment followed a split-split-split-plot design with four factors. The factors and levels were four irrigation water treatments, two crops, two irrigation methods, and five years of sampling, giving a total of 80 treatments. An initial plotting of the data, examining soil chemical changes by water treatment through time revealed that two potential patterns fit the data (Appendix B). The first pattern is that the data either increases or decreases from baseline conditions but then remains fairly constant, or flat, with time. The second pattern was that the response variable either increased or decreased with time in a definite trend pattern (interaction of time and water treatment). Therefore two linear mixed effects models, the “flat” model and the “trend” model, were fit using restricted maximum likelihood (REML) by means of procedure lme using R version 1.1.1 (Ihaka & Gentleman, 1996; RDCT, 2006). Both models included grouping for the split-split-split plot design used. In the flat model irrigation water, crop type, and irrigation

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method were considered fixed effects and time was considered a random effect. For the trend model irrigation water, crop type, irrigation method, and time were considered fixed effects. In both models the plots were considered random effects.

An "information based" approach was then used to determine which model was most appropriate for a specific data set. Calculations of Akaike's Information Criteria (AIC) analyzed the complexity of an estimated model against how well the model fits a data set (Burnam and Anderson, 2002). Low AIC results indicate that a model provides a better fit; therefore, the model with the lowest AIC was chosen.

3.4.2 Crop Data

Crops were rotated on a yearly basis between plots (Table 4). Three crops rotated between two plots; therefore, no one crop has five years of continuous data. Additionally, individual crops grown in succession years were not grown on the same plots under the same conditions. These factors limit the use of statistical analysis on crop yield data. As an alternative, yearly crop yields will be plotted and compared against the mean crop yield for the 100% Tongue River water treatment for each irrigation treatment. Crop yields were statically analyzed per year using one-way ANOVA comparisons.

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4.0 Results

Mean baseline soil chemical conditions determined from soil samples collected prior to initial water application (in year 0) are presented in Table 5. Overall differences in soil chemical properties and crop yields as affected by crop type, water treatment, irrigation method, and year are provided in Table 6. Mean soil sample pH, EC, and SAR values and standard errors for each crop type, water treatment, and irrigation method for each depth measured are provided in Figures 6 through 14. For the water treatment means, results followed by different alphabetical letters are significantly different. Finally, for the water treatment by year interaction, statistically significant trends for the 6 to 12 and 12 to 24 inch depth increments are shown in Figure 15. All results were determined to be statically significant at a p value of 0.05 or less.

4.1 Soil Chemistry

Crop type, water treatment, and irrigation method significantly affected many of the soil chemical parameters (Table 6). A significant interactive effect between water treatment and irrigation method was experienced for soil pH, SAR, and ESP, at most sample depths. Also, a significant interactive effect between water treatment and time was present for SAR and ESP in the 6 to 12 and 12 to 24 inch depth increments.

4.1.1 Soil pH

Soil pH is perhaps the most important soil chemical characteristic and indicates the intensity of the acidic or basic condition. Soil pH serves as a general index of the availability of plant nutrients, potential toxicity problems, and sodic soil conditions. A soil pH of 6.0 to 7.5 is ideal for most forage crops; however, surface soil pH typically ranges from 7.0 to 8.0 in eastern Montana (Dinkin and Jones, 2007). As pH increases above or decreases below this ideal range, availability of phosphorus, calcium, magnesium, iron, manganese, zinc, copper, cobalt, and boron may be yield limiting.

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Table 5. Means and standard errors (in parenthesis) for the TRIP Tier 3 baseline soil conditions.

Soil Depth	pH	Electrical Conductivity	Sodium Adsorption Ratio	Calcium	Magnesium	Sodium	ESP	Lime	Saturation Percentage	Sand	Silt	Clay
in.	s.u.	dS/m		mg/L			%					
0 to 6	7.6 (0.012)	0.80 (0.028)	0.46 (0.027)	4.8 (0.17)	2.0 (0.082)	0.83 (0.047)	1.6 (0.077)	9.1 (0.11)	50 (0.38)	20 (1.04)	54 (0.75)	26 (0.45)
6 to 12	7.7 (0.012)	0.81 (0.056)	0.69 (0.069)	4.5 (0.18	2.6 (0.22)	1.4 (0.22)	1.8 (0.085)	-	50 (0.45)	17 (0.52)	55 (0.35)	27 (0.43)
12 to 24	7.9 (0.018)	2.8 (0.38)	1.9 (0.17)	9.4 (1.1)	16 (2.9)	7.8 (1.4)	3.5 (0.19)	-	49 (0.30)	14 (0.45)	59 (0.35)	27 (0.43)
24 to 36	8.0 (0.026)	7.3 (0.57)	3.9 (0.31)	14 (0.97)	59 (5.9)	25 (2.8)	5.3 (0.27)	-	49 (0.51)	19 (0.86)	53 (0.49)	28 (0.63)
36 to 48	8.2 (0.026)	5.8 (0.36)	5.4 (0.32)	7.4 (0.80)	37 (3.1)	25 (2.0)	6.5 (0.33)	-	43 (0.94)	35 (2.6)	44 (1.8)	21 (0.90)

Notes:

1. Samples were collected on by KC Harvey, Inc. soil scientists and Neal Fehringer, using a Giddings probe. During sample collection, three sub-samples were collected from within each plot and composited for analysis. All samples were analyzed by Energy Laboratories, Inc., Helena, MT.
2. For all means calculated, n = 48.
3. Abbreviations are: in. = inches; s.u. = standard units; dS/m = deciSiemens per meter; mg/L = milligrams per liter; % = percent; and, "-" = sample not analyzed for given parameter.

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Table 6. F-values and significance from analyses of variance for the effects of crop, water treatment, irrigation method, and time on soil chemical properties and crop yield.

Variable	Source of Variation (df)						
Depth (in)	Crop (2)	Water Treatment (3)	Irrigation Method (1)	Year (1)	Water Treatment x Irrigation Method (3)	Water Treatment x Year (3)	Water Treatment x Irrigation Method x Year (3)
pH (s.u.)							
0-6	**15.2**	**26.5**	2.0		**2.7**		
6-12	**3.1**	**18.0**	**9.4**		**3.1**		
12-24	**5.8**	**7.5**	**26.0**		**5.1**		
24-36	2.75	0.74	**86.88**		**3.17**		
36-48	0.32	**3.59**	**30.09**		**3.81**		
EC (dS/m)							
0-6	3.6102	8.3884	9.0182		3.2984		
6-12	**9.93**	**3.21**	**8.38**		2.25		
12-24	0.49	**3.42**	2.32		1.59		
24-36	**13.3**	0.49	**13.3**	**76.76**	1.07	0.11	1.34
36-48	**17.73**	1.1	**23.43**	**35.49**	**3.75**	0.09	0.89
SAR							
0-6	**10.54**	**219.84**	1.58		0.69		
6-12	**25.18**	**128.67**	1.23	**13.81**	**7.70**	**20.13**	1.98
12-24	**8.32**	**48.54**	**5.02**	2.51	**8.43**	**7.23**	0.96
24-36	2.22	2.43	**14.53**		**2.70**		
36-48	**10.73**	**6.65**	2.91		**7.08**		
ESP (%)							
0-6	**5.12**	**114.76**	0.25	0.39	1.91	0.95	0.63
6-12	**4.62**	**92.57**	0.08	**5.79**	**4.18**	**7.52**	0.86
12-24	**3.67**	**30.40**	3.09	0.21	**4.11**	**4.04**	0.41
24-36	0.45	1.83	**4.12**		**3.85**		
36-48	0.07	**4.16**	**3.96**	1.1	**7.04**	0.69	0.08
Calcium (mg/L)							
0-6	**16.07**	**54.2**	**19.71**	**47.65**	2.25	1.37	0.69
6-12	**72.36**	**62.93**	**59.72**		**3.27**		
12-24	**4.62**	**3.46**	0.49	**28.77**	1.08	0.35	0.74
24-36	**11.57**	1.14	**63.80**	**26.77**	1.91	0.56	0.97
36-48	**21.49**	**2.83**	**35.74**	**44.10**	0.42	0.75	0.8
Magnesium (mg/L)							
0-6	**10.39**	**59.66**	**39.97**		2.25		
6-12	**69.31**	**63.84**	**68.91**		2.12		
12-24	**10.65**	**8.02**	**6.78**		0.33		
24-36	**4.86**	1.66	**18.41**	**30.377**	0.62	0.07	1.24
36-48	**6.71**	1.48	**36.95**	**11.02**	**3.81**	0.37	0.69
Sodium (mg/L)							
0-6	**9.59**	**161.37**	**22.56**		1.65		
6-12	**16**	**132.62**	**4.73**	**10.42**	**6.12**	**13.49**	**3.13**
12-24	**6.46**	**25.87**	2.43	0.67	2.31	0.52	1
24-36	1.18	0.62	**4.59**	**17.15**	0.59	0.07	1.07
36-48	**11.12**	1.75	**4.24**	**15.35**	2.39	0.55	1.35
Saturation (%)							
0-6	**15.30**	**8.42**	**96.21**		0.43		
6-12	1.63	**4.87**	**30.38**		2		
12-24	1.30	0.69	**50.26**		0.17		
24-36	0.81	0.55	**101.06**	**18.89**	**2.78**	0.96	1.14
36-48	0.25	0.5	**123.85**	**10.77**	**2.99**		
Lime (%)							
0-6	**13**	1.23	**5**		1.57		
Yield	1.29	**4.03**	1.72		2.35		

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Baseline soil sample pH in the Irrigated Crop and Forage Test plots are as expected for soils of irrigated fields along the Tongue River. Mean soil sample pH was 7.6 in the 0 to 6 inch surface horizon and gradually increased to 8.2 in the 36 to 48 inch subsurface horizon (Table 5).

4.1.1.1 Crop Type Effects on Soil pH

The type of crop planted produced consistent results in soil pH for all depths sampled (Figure 6). Mean soil sample pH values and standard errors for each crop type and for each depth measured are provided in Figure 6. Mean soil sample pH was always lowest for the plots planted to alfalfa and was always highest for plots planted to barley. As in the baseline soil data (Table 5), soil sample pH increases with depth. Mean pH values for each crop type for all depths are equal to or less than the mean baseline pH values. Although there is a significant effect this effect possible is a result of differing crop management (i.e. tillage) and not the the actual crop effecting soil pH.

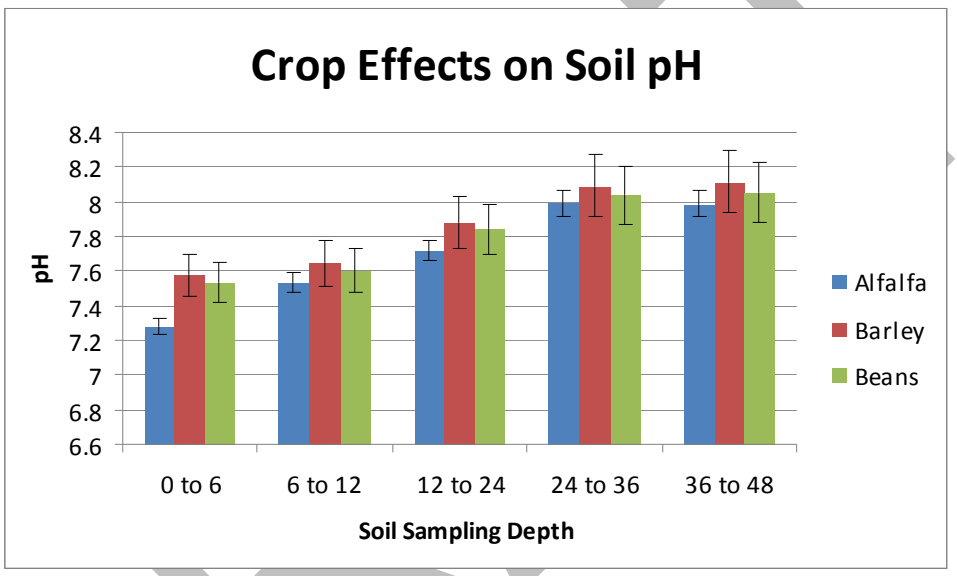

Figure 6. Effects of crop type on mean soil pH (error bars represent standard error).

4.1.1.2 Water Treatment Effects on Soil pH

The irrigation water treatment produced somewhat consistent results in soil pH for all depths sampled (Figure 7). Mean soil sample pH values and standard errors for each water treatment and for each depth measured are provided in Figure 7. Results followed by different alphabetical letters are significantly different. Mean soil sample pH was always lowest for water treatment 1, the 100% Tongue River water treatment, and mean soil sample pH was always second lowest for water treatment 2, the 93% Tongue River water treatment, for all depths sampled. For the three depths where statistical significance was present, the 0 to 6, 6 to 12, and 12 to 24 inch depths, water treatments 1 and 2 were considered statistically the same. In the 0 to 6 inch depth samples, pH values were significantly higher in water 3 than in water treatments 1 and 2; however, water treatment 3 was considered to be the same as water treatment 4 and water treatment 4 was considered to be the same as water treatment 2. In the 6 to 12 and 12 to 24 inch depth samples, water treatments 2, 3, and 4 were statistically the same.

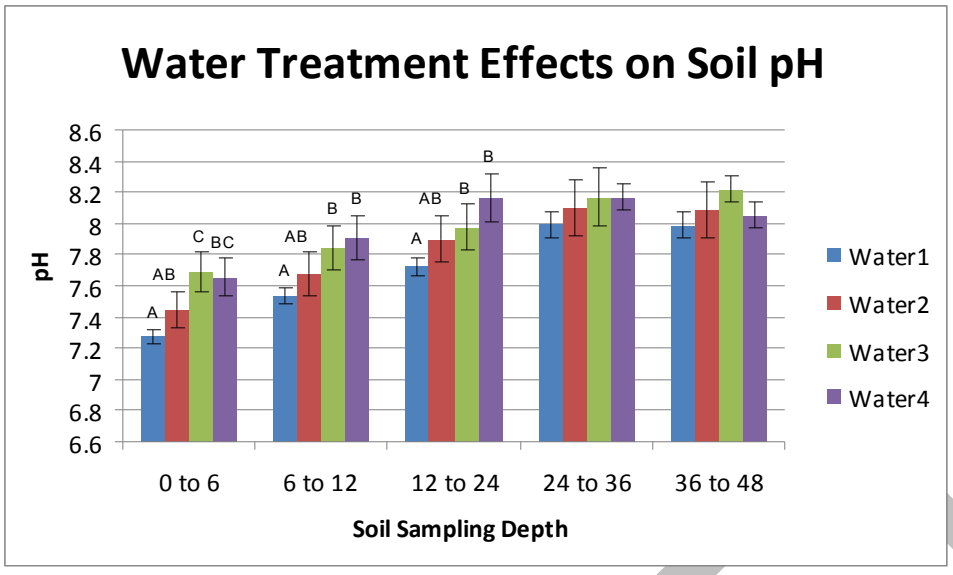

Figure 7. Effects of water treatment on mean soil pH (error bars represent standard error).

As in the baseline soil data (Table 5), soil sample pH increases with depth. Mean pH values for each crop type for all depths are equal to or less than the mean baseline pH values.

4.1.1.3 Irrigation Method Effects on Soil pH

The type of irrigation method employed produced consistent results in soil pH for all depths sampled (Figure 8). Mean soil sample pH values and standard errors for each irrigation method and for each depth measured are provided in Figure 8. Mean soil sample pH was always lowest for the plots irrigated using flood irrigation methods and was always highest for plots irrigated using sprinkler methods. Mean pH values for each irrigation method for all depths are equal to or less than the mean baseline pH values.

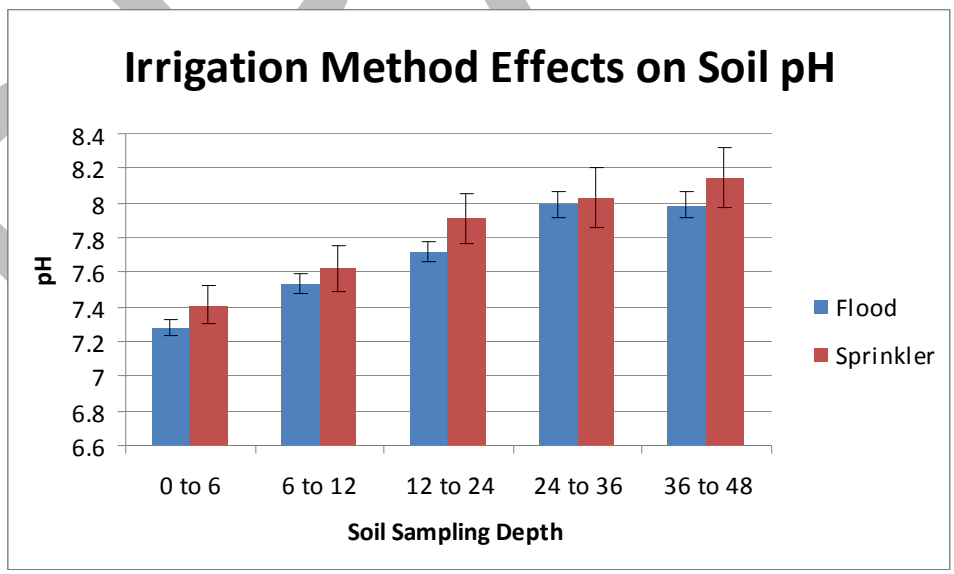

Figure 8. Effects of irrigation method on mean soil pH (error bars represent standard error).

4.1.2 Soil Salinity

Soil salinity is simply the amount of soluble salts in a soil, and is measured by the EC of the saturated paste extract. The salinity of a soil is important because high salt levels make it

difficult for plants to obtain water (Bohn, et al., 1985). Saline soils are conventionally defined as having EC values of greater than 4 dS/m, however sensitive plants can be affected at EC levels less than 4dS/m and highly tolerant plants may reach 100 % yield potential at EC levels greater than 8 dS/m. In the arid western United States, naturally occurring saline soils are more typical because arid regions are subject to high evaporation rates, thus causing salt concentration to occur naturally (Soil Improvement Committee, California Plant Health Association, 2002).

Baseline soil sample EC in the Irrigated Crop and Forage Test plots are as expected for soils of irrigated fields along the Tongue River. Mean soil sample EC was 0.80 and 0.81 dS/m in the 0 to 6 and 6 to 12 inch surface horizons, respectively (Table 5). Mean EC was higher in the subsurface horizons and peaked in the 24 to 36 inch horizon at 7.3 dS/m (Table 5). Likely the 24 to 36 inch depth represents the depth of irrigation and zone of maximum salt accumulation from past irrigation practices.

4.1.2.1 Crop Type Effects on Soil Salinity

The type of crop planted produced no clear consistent differences in soil EC for the depths sampled (Figure 9). Mean soil sample EC values and standard errors for each crop type and for each depth measured are provided in Figure 9. For the top three depths measured, mean soil sample EC was similar in all three crop types, even though there was a statistically significant difference in the 6 to 12 inch sampling depth (Table 6). Statistically significant differences were present in the 24 to 36 and 36 to 48 inch sampling depths (Table 6), however the high degree of variability in the results makes the differences seem less important. There is no consistent pattern in the crop effects between the 24 to 36 and 36 to 48 inch samples.

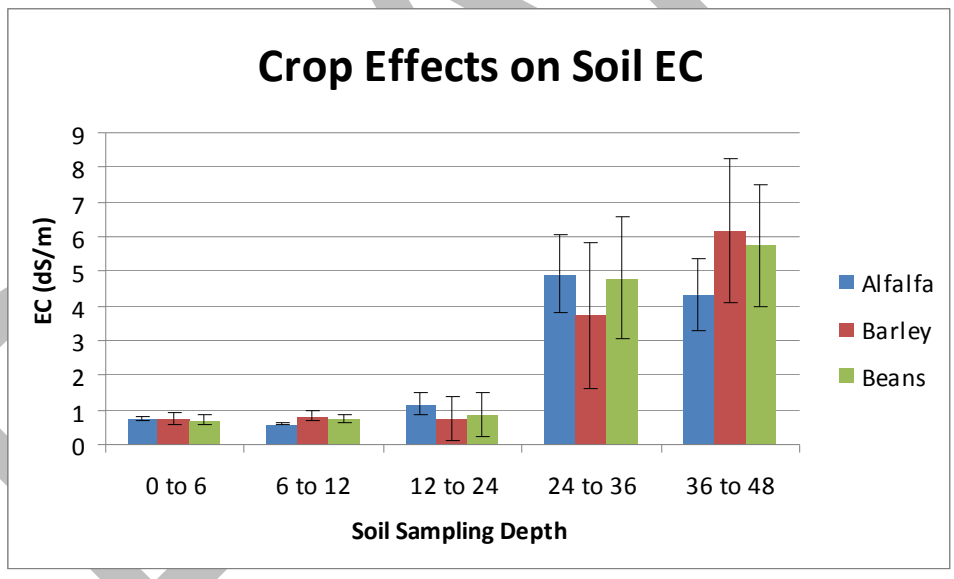

Figure 9. Effects of crop type on mean soil electrical conductivity (EC) (error bars represent standard error).

Except for the 36 to 48 inch sample collected from the barley plots, mean soil EC for all depths was always equal to or lower than mean baseline EC values (Table 5), suggesting that leaching was occurring in all of the plots. Mean soil EC in the 36 to 48 inch sample collected from the barley plots was 6.2 dS/m compared to a 36 to 48 inch depth baseline EC of 5.8 dS/m.

4.1.2.2 Water Treatment Effects on Soil Salinity

The irrigation water treatment produced somewhat consistent results in soil EC for the depths sampled (Figure 10). Mean soil sample EC values and standard errors for each water treatment

and for each depth measured are provided in Figure 10. For the top three depths measured, mean soil sample EC was similar in all four water treatments, even though there were statistically significant differences in the 6 to 12 and 12 to 24 inch sampling depths (Table 6). While not statistically significant, in the 24 to 36 and 36 to 48 inch sampling depths, mean soil sample EC was always lowest for water treatment 2, the 93% Tongue River water treatment, and was always highest for water treatment 3, the 85% Tongue River water treatment (Figure 10). This pattern is interesting given that the EC of the irrigation water treatments are neither the lowest nor the highest and are quite similar for treatments 2 and 3 (Table 3). It may be that leaching is keeping the surface sample results similar but in the 24 to 36 and 36 to 48 inch sampling depths, treatment patterns may be emerging.

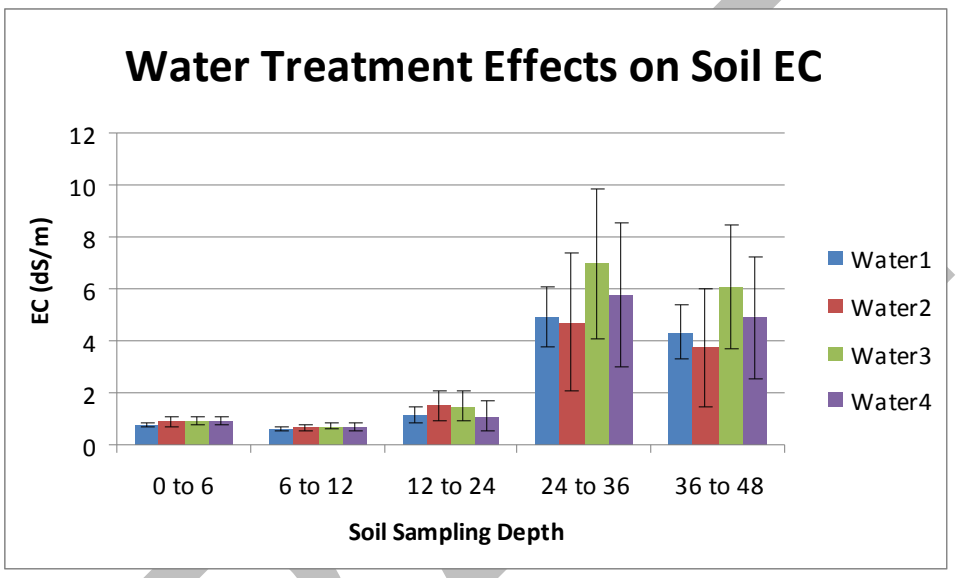

Figure 10. Effects of water treatment on mean soil electrical conductivity (EC) (error bars represent standard error).

For most samples, mean soil EC was equal to or lower than mean baseline EC values. When mean soil EC was higher there was always less than a 20% increase over baseline values. Mean soil EC in the 0 to 6 inch samples collected from the water treatment 2, water treatment 3, and water treatment 4 plots was 0.90, 0.93, and 0.91 dS/m, respectively, compared to a 0 to 6 inch baseline EC of 0.80 dS/m. From an agricultural perspective, these changes in mean EC are insignificant to crop performance.

4.1.2.3 Irrigation Method Effects on Soil Salinity

Mean soil sample EC values and standard errors for each irrigation method and for each depth measured are provided in Figure 11. The type of irrigation method employed produced little apparent difference in mean soil EC for all depths sampled (Figure 11), even though samples from three depths, 6 to 12, 24 to 36, and 36 to 48 had statistically significant differences (Table 6).

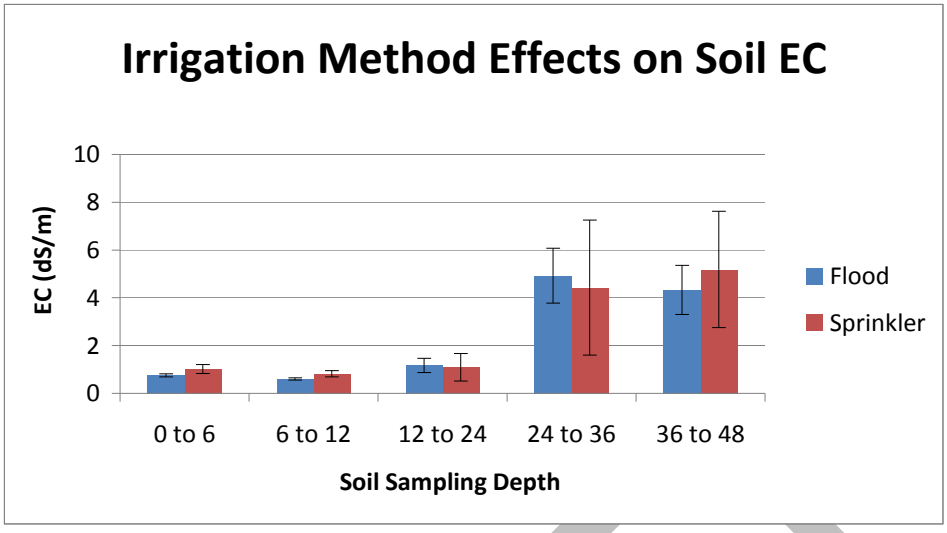

Figure 11. Effects of irrigation method on mean soil electrical conductivity (EC) (error bars represent standard error).

Mean EC values for the flood treatments were always lower than baseline whereas the sprinkler treatments in the 0 to 6 and 6 to 12 inch depths were greater or equal to mean baseline EC. The flood treatments may likely be causing more leaching in the surface horizons.

4.1.3 Soil Sodicity

Sodic soils are "nonsaline soils containing sufficient exchangeable sodium to adversely affect crop production and soil structure" (Soil Science Society of America, 2001). High levels of sodium tend to disperse soil particles thereby sealing the soil. The result can produce hard surface crusts, reduced infiltration rates, and reduced oxygen diffusion rates, all of which interfere with or prevent plant growth. By definition, sodic soils are those that have an exchangeable sodium percentage (ESP) of more than 15 or a sodium adsorption ratio (SAR) of at least 13, an EC less than 4 dS/m, and a pH between 8.5 and 10 (U.S. Salinity Laboratory Staff, 1954; Soil Science Society of America, 2001).

SAR is the ratio of the dissolved sodium concentration divided by the square root of the average calcium plus magnesium concentration. SAR can be calculated from the sodium, calcium and magnesium concentrations via the formula:

SAR = [sodium] / (([calcium] + [magnesium])/2)1/2

where the concentrations are in milliequivalents per liter (meq/L). To measure calcium, magnesium, and sodium concentrations in soil, a saturated paste is prepared and allowed to equilibrate for approximately eight hours. Soil water from the sample is then extracted and analyzed for the calcium, magnesium, and sodium ion concentrations. Typical SAR values for soils in eastern Montana range from less than 1 up to about 5.

The SAR formula indicates that if calcium and magnesium concentrations are low and sodium is high, then SAR will be high. Conversely, if calcium and/or magnesium concentrations increase relative to sodium, then SAR will decrease.

Clay minerals in soils are negatively charged and consequently attract ions with a positive charge such as sodium, calcium and magnesium. When sodium comprises more than about

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15% of the exchangeable ions, clays begin to repel one another causing soil structure to degrade. Continued swelling and dispersion of clay minerals and subsequent degradation of soil structure can reduce water infiltration rate of the soil and permeability of water through the soil. In general, soils with moderately high, to high, clay contents are at higher risk. Further, those soils where swelling type clays (i.e., smectitic clays) are abundant are at highest risk.

Baseline soil sample SAR in the Irrigated Crop and Forage Test plots are as expected for soils of irrigated fields along the Tongue River. Mean soil sample SAR was 0.46 and 0.69 in the 0 to 6 and 6 to 12 inch surface horizons, respectively (Table 5). Mean SAR increased with depth to 5.4 in the 36 to 48 inch horizon. Clay content ranges from 21 to 28% in the baseline samples, representing a moderate clay content

4.1.3.1 Crop Type Effects on Soil Sodicity

The type of crop planted produced no clear consistent differences in soil SAR for the depths sampled (Figure 12). Mean soil sample SAR values and standard errors for each crop type and for each depth measured are provided in Figure 12. Statistically significant differences were present in all depths sampled except for the 24 to 36 inch depth (Table 6). For the top three depths measured, mean soil sample SAR was lowest for the barley plots, while in the bottom two depths mean soil sample SAR was highest for the barley plots (Figure 12).

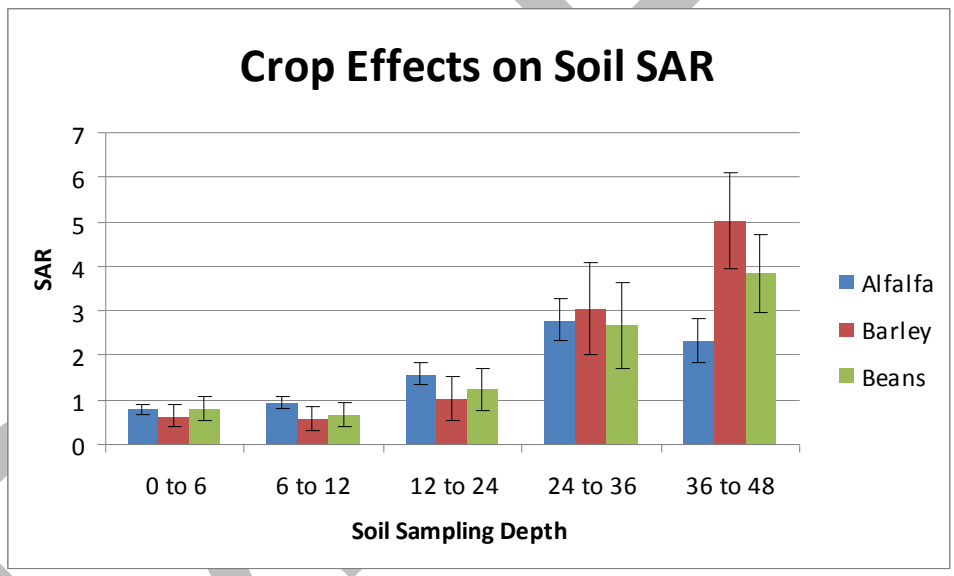

Figure 12. Effects of crop type on mean soil sodium adsorption ratio (SAR) (error bars represent standard error).

Except for the 0 to 6 inch samples from all crops and the 6 to 12 inch soil samples from the alfalfa plots, mean soil sample SAR for all depths were always lower than mean baseline SAR values (Table 5). Mean soil sample SAR in the 0 to 6 inch horizon was 0.79, 0.65, and 0.81 in the alfalfa, barley, and beans plots, respectively, compared to a 0 to 6 inch baseline mean SAR of 0.46.

4.1.3.2 Water Treatment Effects on Soil Sodicity

The irrigation water treatment produced consistent results in soil SAR for the depths sampled (Figure 13). Mean soil sample SAR values and standard errors for each water treatment and for each depth measured are provided in Figure 13. Results followed by different alphabetical letters are significantly different at the $p \leq 0.001$ level. For the four depths where statistical significance was present, the 0 to 6, 6 to 12, 12 to 24, and 36 to 48 inch depths, mean soil

sample SAR was always lowest for water treatment 1, the 100% Tongue River water treatment, and mean soil sample SAR was always highest for water treatment 4, the 50% Tongue River water treatment. Also in the four depths with statistical significance, mean soil sample SAR for water treatment 2, the 93% Tongue River water treatment, was always considered to be the same as mean soil sample SAR for water treatment 3, the 85% Tongue River water treatment.

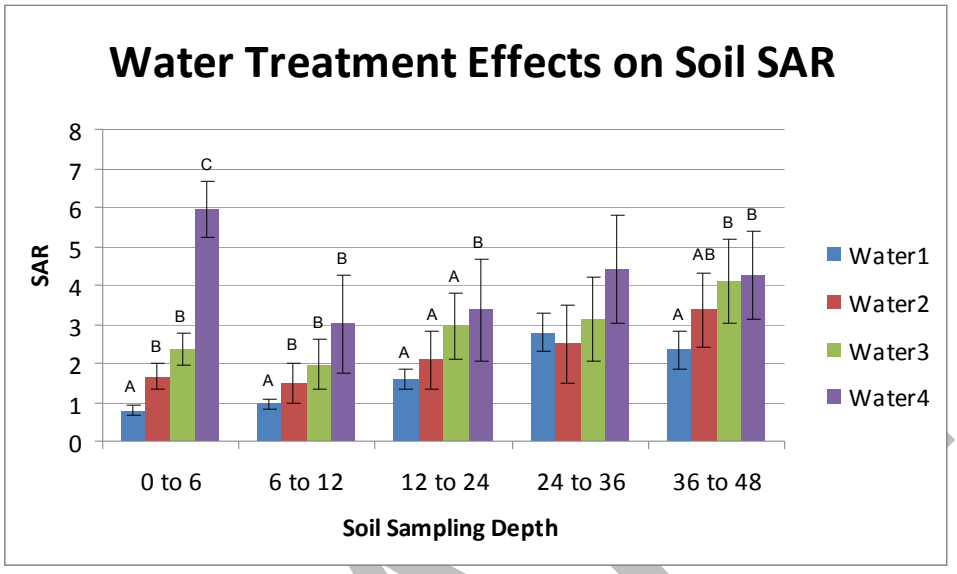

Figure 13. Effects of water treatment on mean soil sodium adsorption ratio (SAR) (error bars represent standard error).

For the top two sampling depths, 0 to 6 and 6 to 12 inches, mean treated soil sample SAR was always greater than mean baseline soil sample SAR. Mean treated SAR in the 0 to 6 inch samples collected from the water treatment 1, water treatment 2, water treatment 3, and water treatment 4 plots was 0.79, 1.7, 2.3, and 6.0, respectively, compared to a 0 to 6 inch mean baseline SAR of 0.46. For the 12 to 24 inch depth, mean treated SAR was higher than mean baseline SAR in the water treatment 2, water treatment 3, and water treatment 4 plots. For the 24 to 36 inch depth, mean treated SAR was higher than mean baseline SAR in the water treatment 4 plots. For the 36 to 48 inch depth, all mean treated SAR values were lower than mean baseline SAR values. It appears that after continued irrigation in all treatments, the SAR will continue to increase throughout the soil profile, likely until the soil profile is in equilibrium with the SAR of the irrigation water. Even irrigation with water treatment 1, the 100% Tongue River water treatment, increased soil sample SAR.

4.1.3.3 Irrigation Method Effects on Soil Sodicity

Mean soil sample SAR values and standard errors for each irrigation method and for each depth measured are provided in Figure 14. Only samples from two depths, 12 to 24 and 24 to 36 inches had statistically significant differences (Table 6). In both depths, flood irrigation resulted in higher soil sample SAR.

Mean treated soil sample SAR values were higher than mean baseline soil sample SAR in the 0 to 6 inch surface horizon regardless of irrigation method. For the flood irrigated plots, mean treated SAR was also higher than mean baseline SAR in the 6 to 12 inch horizon.

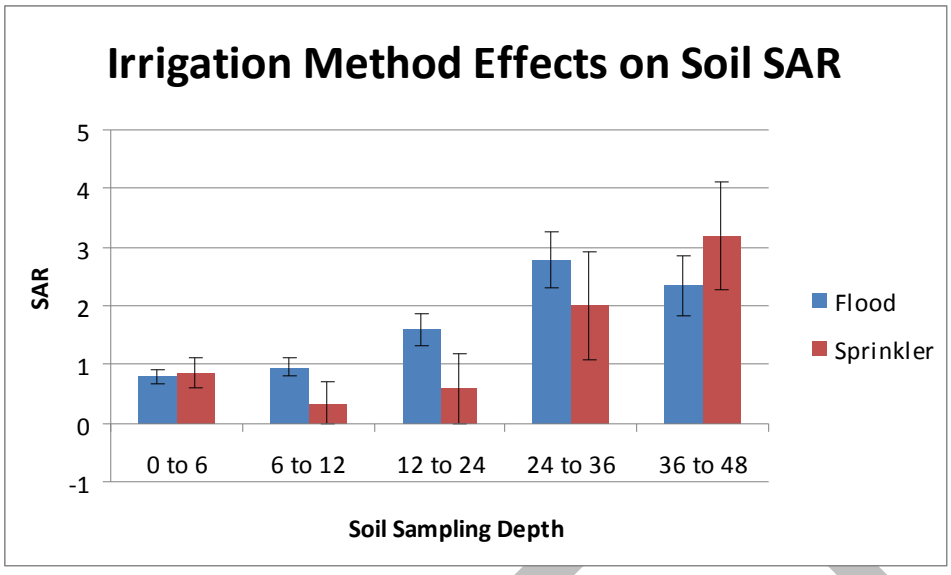

Figure 14. Effects of irrigation method on mean soil sodium adsorption ratio (SAR) (error bars represent standard error).

4.1.3.4 Water Treatment by Year (Trend) Effects on Soil Sodicity

There was a significant trend effect in SAR for the irrigation water treatments in the 6 to 12 and 12 to 24 inch depth increments (Table 6). Mean soil sample SAR is shown in Figure 8 for each year of the study for each irrigation water treatment. Year zero presents the mean baseline SAR of the soil. (Only the 6 to 12 and 12 to 24 inch depth increments are meaningful; a trend effect in SAR did not exist for the other depths sampled (Table 6).) For all irrigation water treatments mean soil sample SAR increases with time. Mean soil sample SAR is increasing at the greatest rate in water treatment 4, the 50% Tongue River water treatment, when compared to the other water treatments. In the 6 to 12 inch depth, water treatment 2 and water treatment 3 appear to be increasing at the same rate and water treatment 1 appears to be increasing at the lowest rate. In the 12 to 24 inch depth, water treatments 1, 2, and 3 all appear to be increasing at the same rate.

4.2 Crop Yield

To make comparisons of crop yields across years all yields were normalized based on average yield for the 100% Tongue River water treatment for both the sprinkler and flood irrigation methods. Normalized yields were calculated to minimize differences in yields due to growing season changes. Crop data is shown with respect to water type and irrigation method in figures 16 through 21.

Based on statistical analysis water treatments did not significantly decrease crop yields (Table 6 shows a significant F value for water treatment). Although there were no significant differences in crop yields some key trends did appear to emerge. In general the relative mean yields decreased as CBNG produced water increased. This was especially the case as the salinity tolerance of the crops decreased. In other words the most sensitive species (beans) had the lowest relative mean yields when the salinity of the water treatment was increased. In addition the decrease in relative mean yields, although not significant, was usually less under sprinkler irrigation than under flood irrigation.

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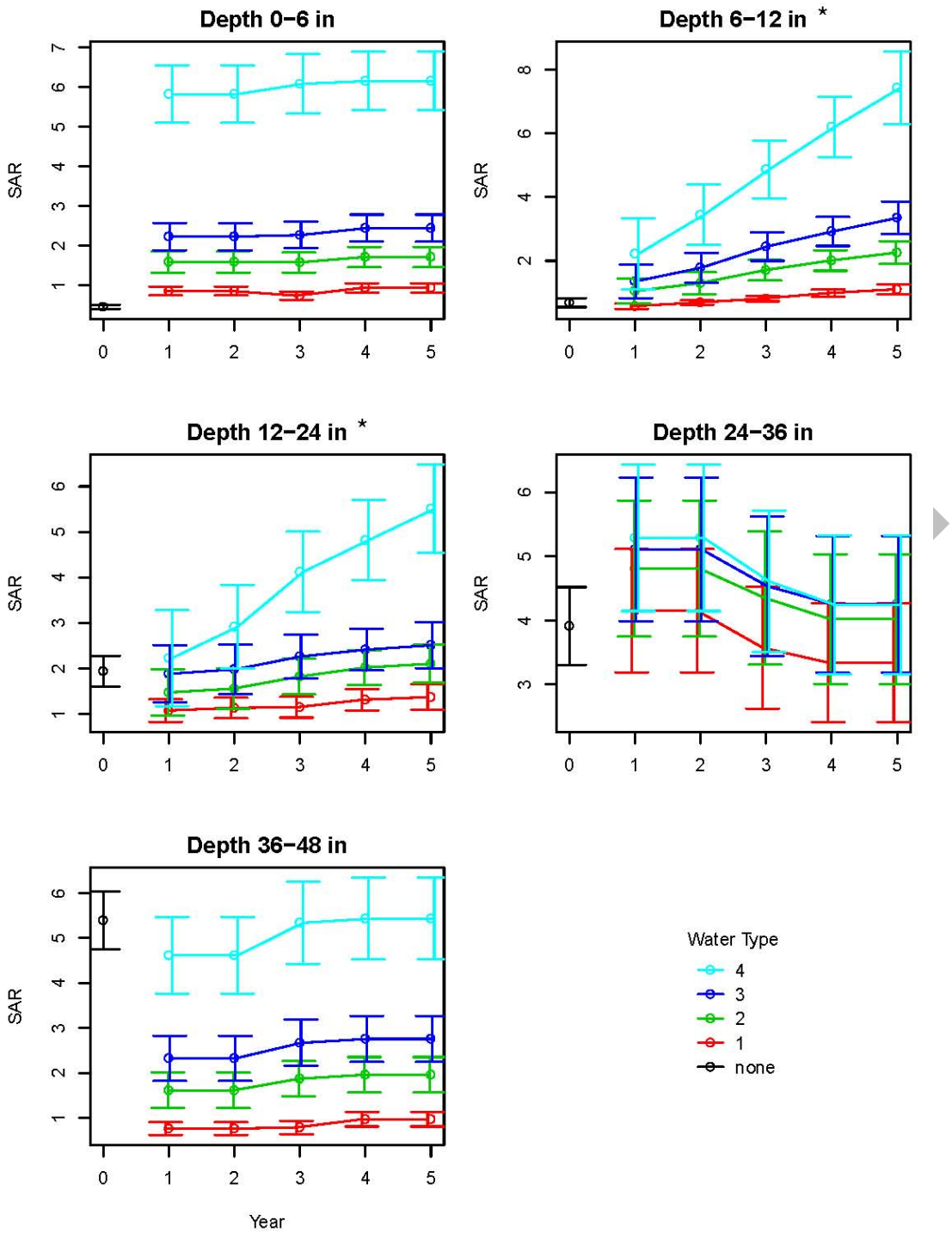

Figure 15. Trend effects in mean soil sample SAR for each irrigation water treatment. *Significant

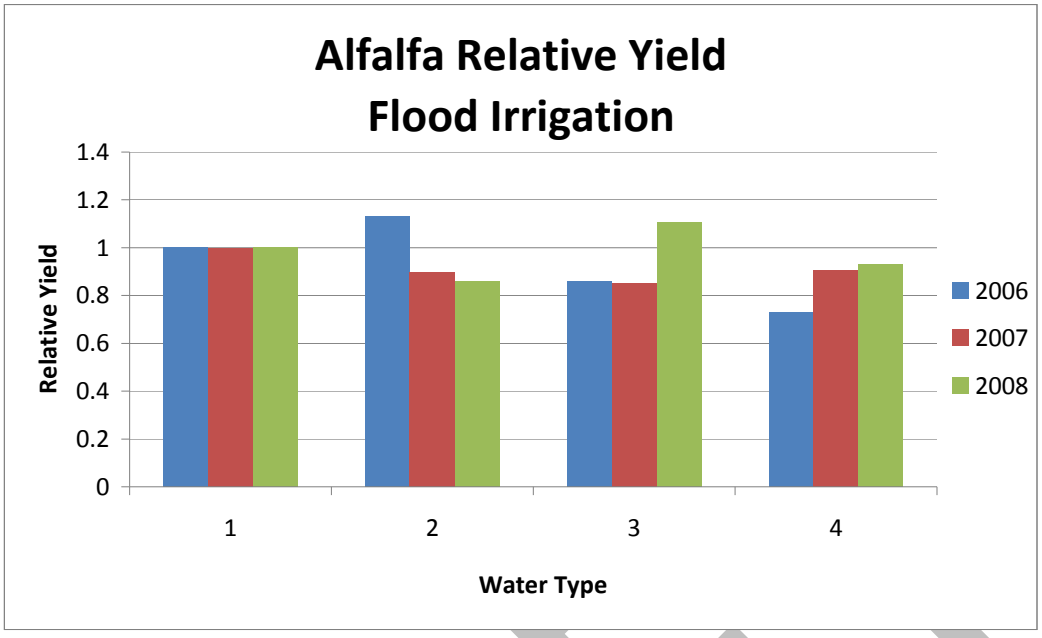

Figure 16. Alfalfa relative yield under flood irrigation (Alfalfa was grown only in the years shown).

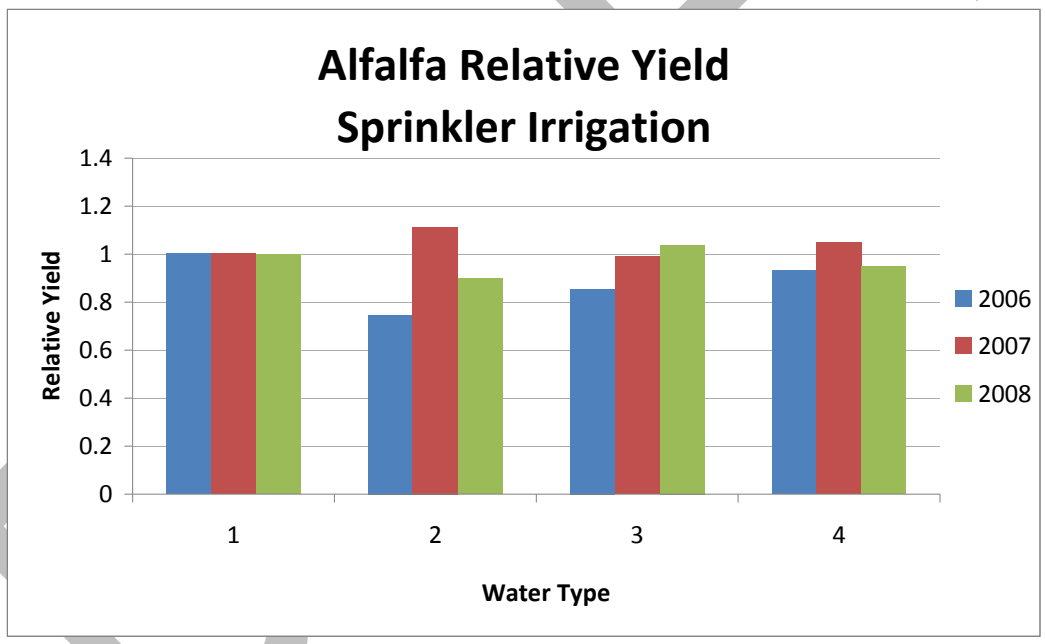

Figure 17. Alfalfa relative yield under sprinkler irrigation (Alfalfa was grown only in the years shown).

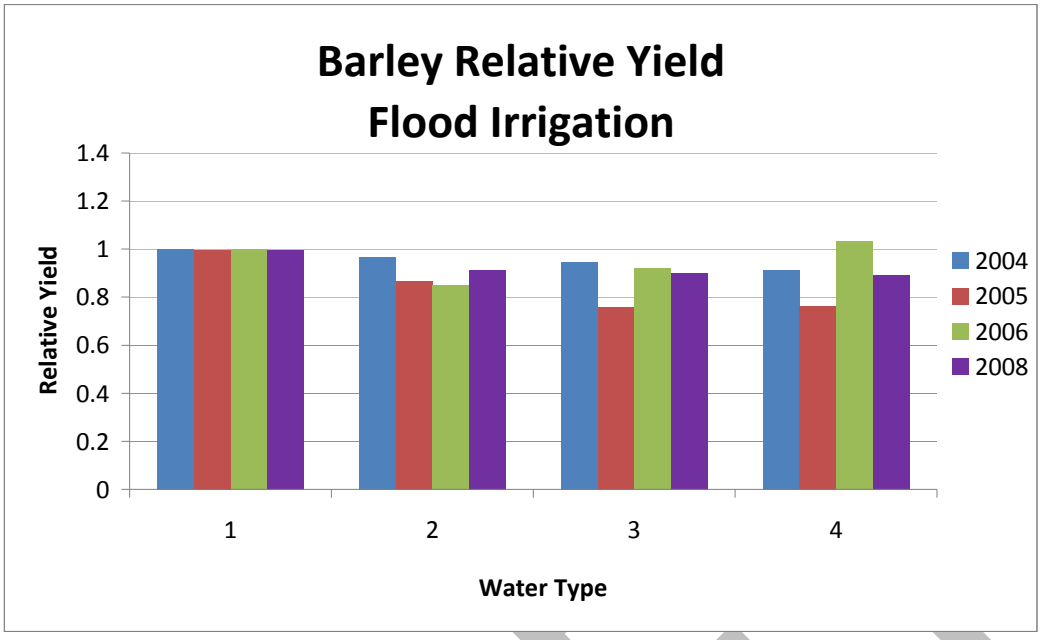

Figure 18. Barley relative yield under flood irrigation (Barley was grown only in the years shown).

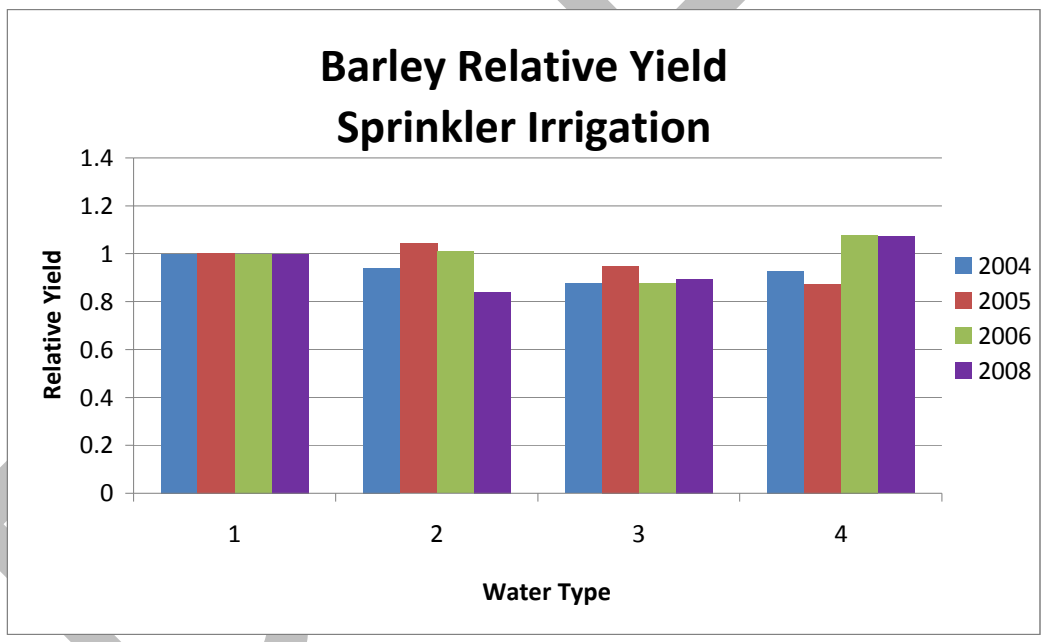

Figure 19. Barley relative yield under sprinkler irrigation (Barley was grown only in the years shown).

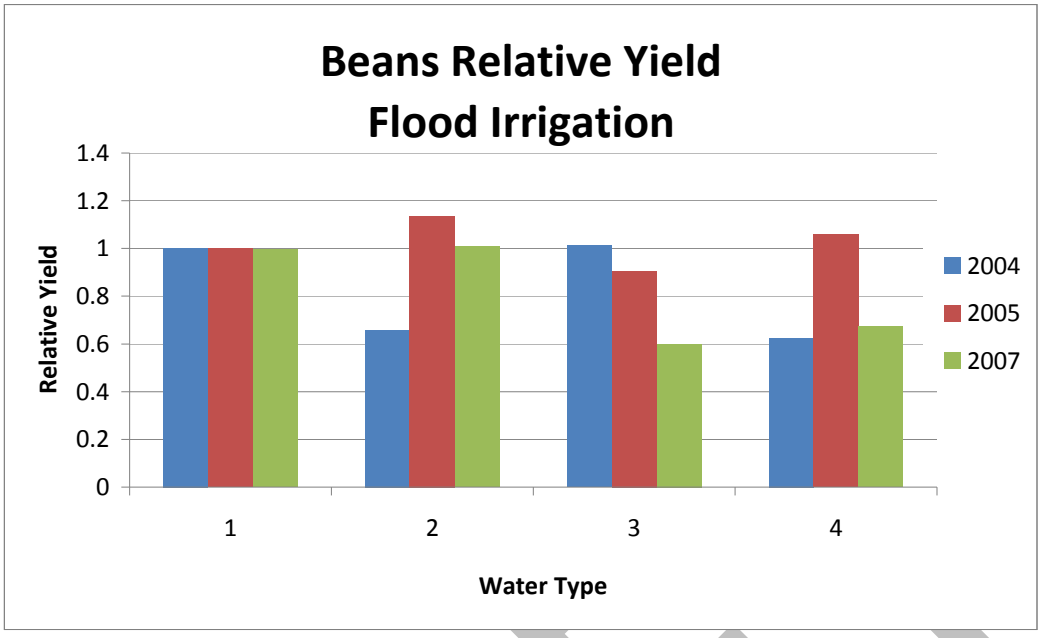

Figure 20. Beans relative yield under flood irrigation (Beans were grown only in the years shown).

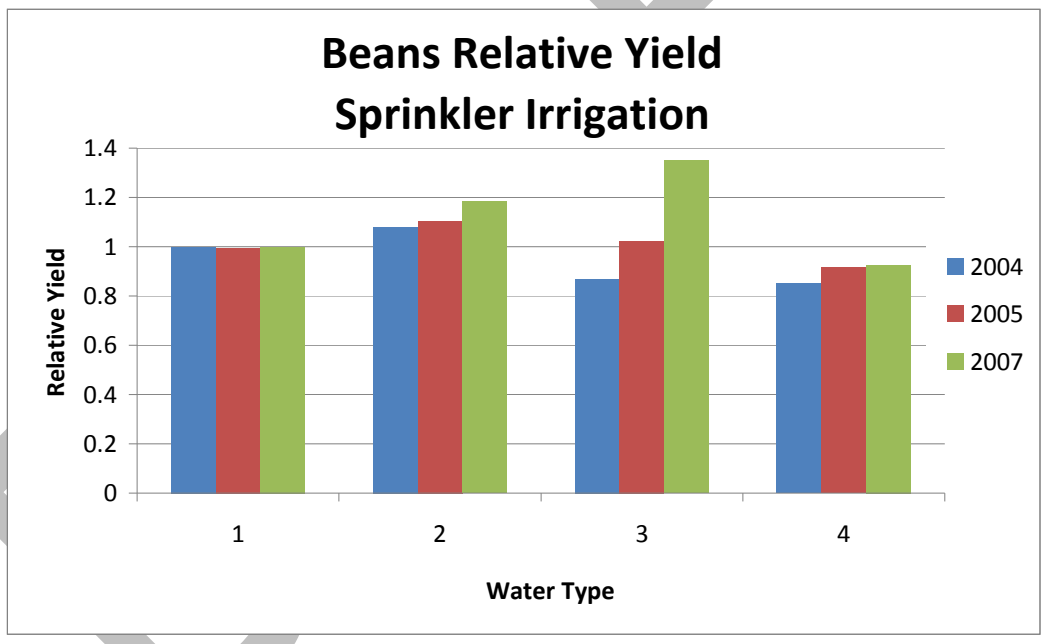

Figure 21. Beans relative yield under sprinkler irrigation (Beans were grown only in the years shown).

5.0 Summary

- After five years of irrigation soil pH increased at the 6 to 12, 12 to 24, and 24 to 36 inch depth increments when compared to the 100% Tongue River water treatment, but never exceeded a pH of 8.2.

- Soil pH is greater under sprinkler irrigation at all depths except the 0-6 inch depth.

- After five years of irrigation, soil EC has significantly increased under all water treatments, irrigation methods, and crop species. However, the increase in soil EC likely did not increase enough to affect the yields of crops grown at the site.

- Soil EC increased statistically under sprinkler irrigation at the 6-12 and 36-48 inch depth, while soil EC decreased at the 24-36 inch depth. The differences in soil EC is likely a result of leaching timing and quantity differences between the irrigation methods.

- Soil SAR significantly increased at the 0-6, 6-12, 12-24, and 36-48 inch sampling depth compared to the 100% Tongue River water treatment. However, the increase in soil SAR was not enough to reduce crop yield in any treatment.

- The flood irrigation method resulted in a significantly greater soil SAR than the sprinkler irrigation method at the 12-24 and 24-36 inch depths.

- Relative crop yields were NOT significantly changed based on water treatments.

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Appendices

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Appendix A: Weed management techniques used on the Tier 3 test plots.

Management Type	Method (s)	Rate	Plot	Growth Stage
Chemical	Unison®	1 pt/acre	Barley	Post-emergence
	Outlook®	1 pt/acre	Beans	Pre-planting
	Prowl® 3.3 EC	3 pt/acre	Beans	Pre-planting
	Basagran®	2 pt/acre	Beans	Post-emergence
	Crop oil	Per label Instructions	Beans	Post-emergence
	Ammonia sulfate	Per label Instructions	Beans, Alfalfa	Post-emergence
	Round-up®	1-2 qt/acre	All	Post-emergence
	Raptor®, surfactant	4 oz/acre, per label instructions	Alfalfa	Post-emergence
Mechanical	Hoeing	As needed	Beans	Post-emergence
	Hand pulling	As needed	Beans	Post-emergence

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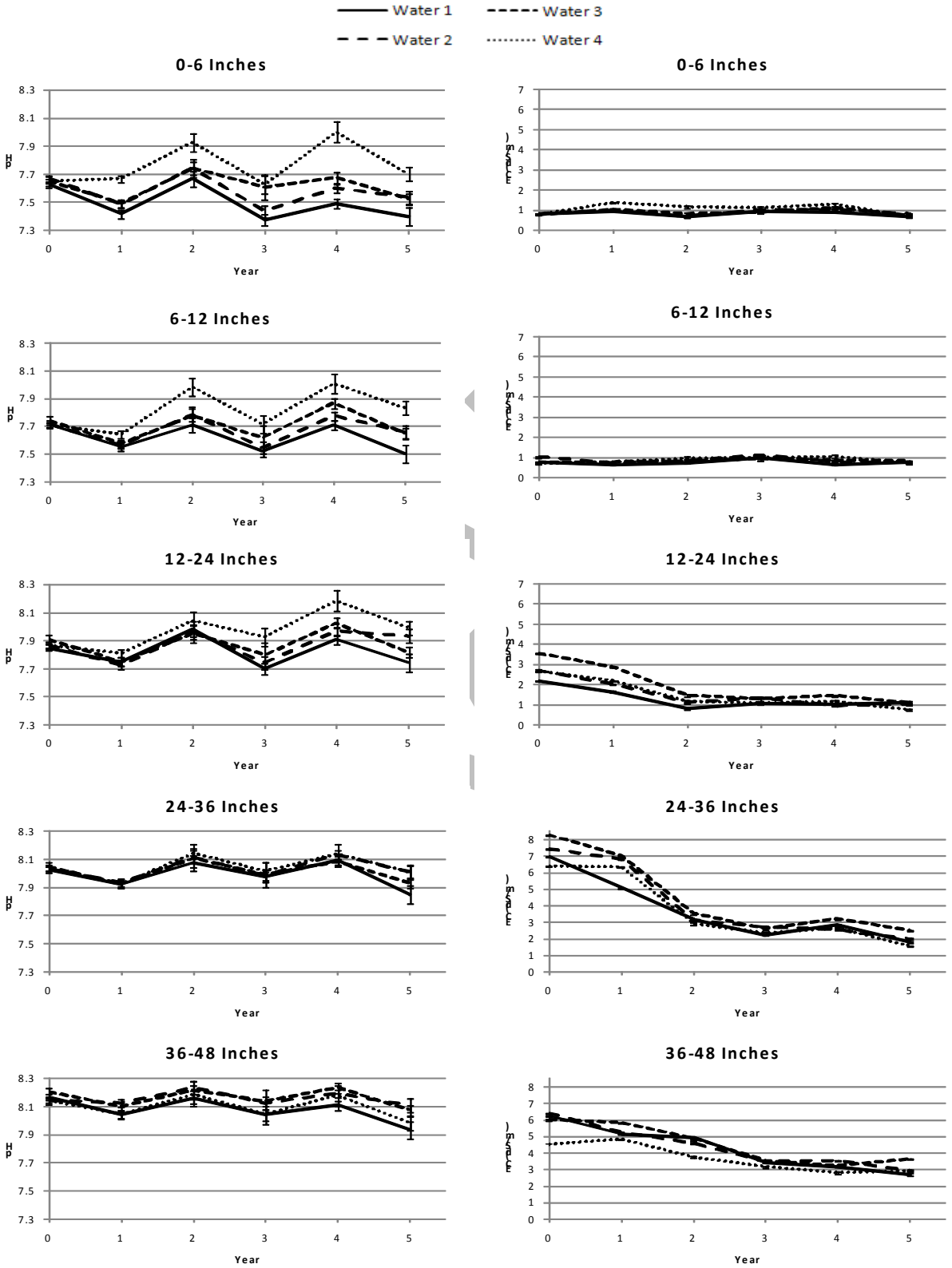
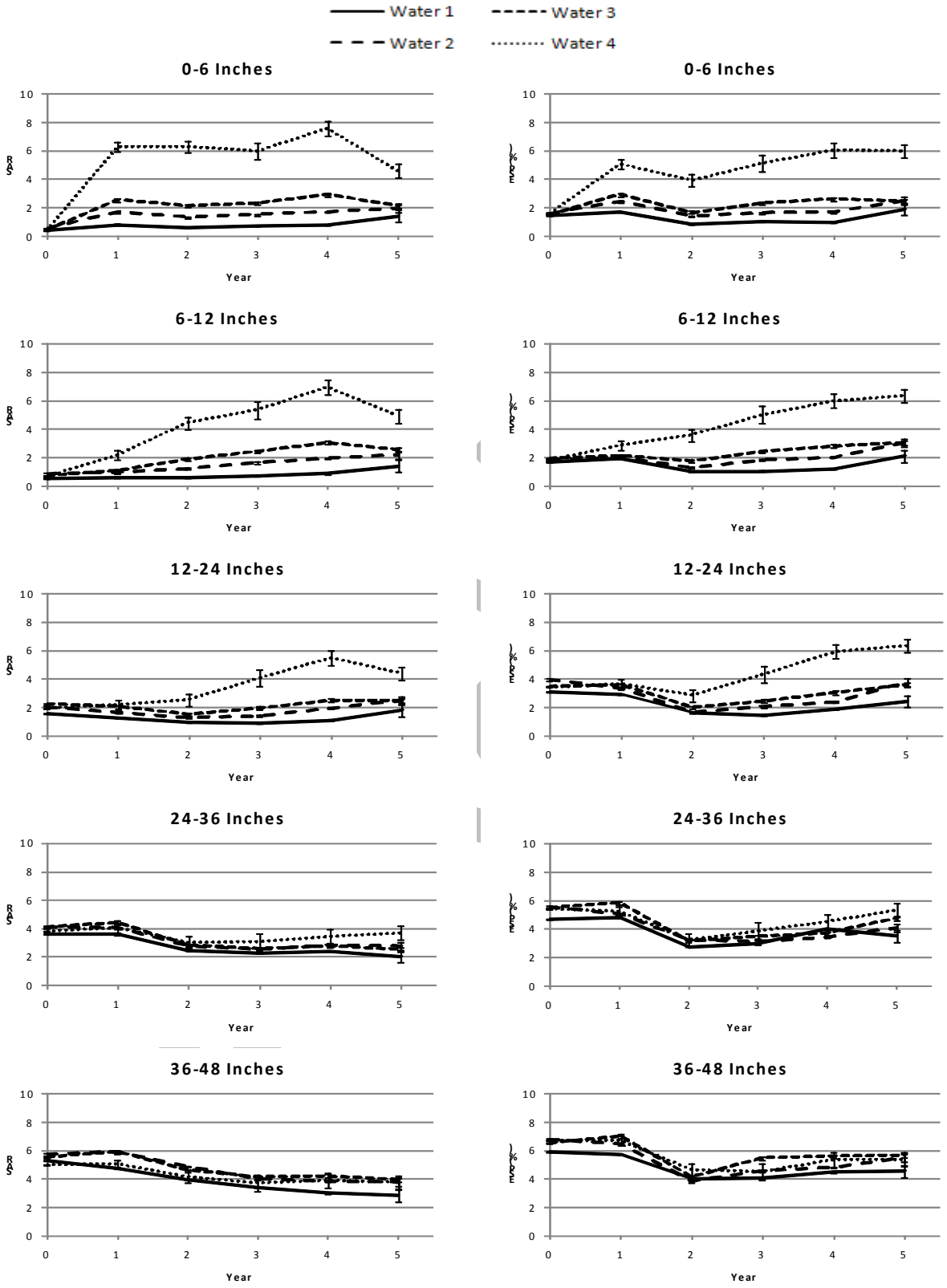
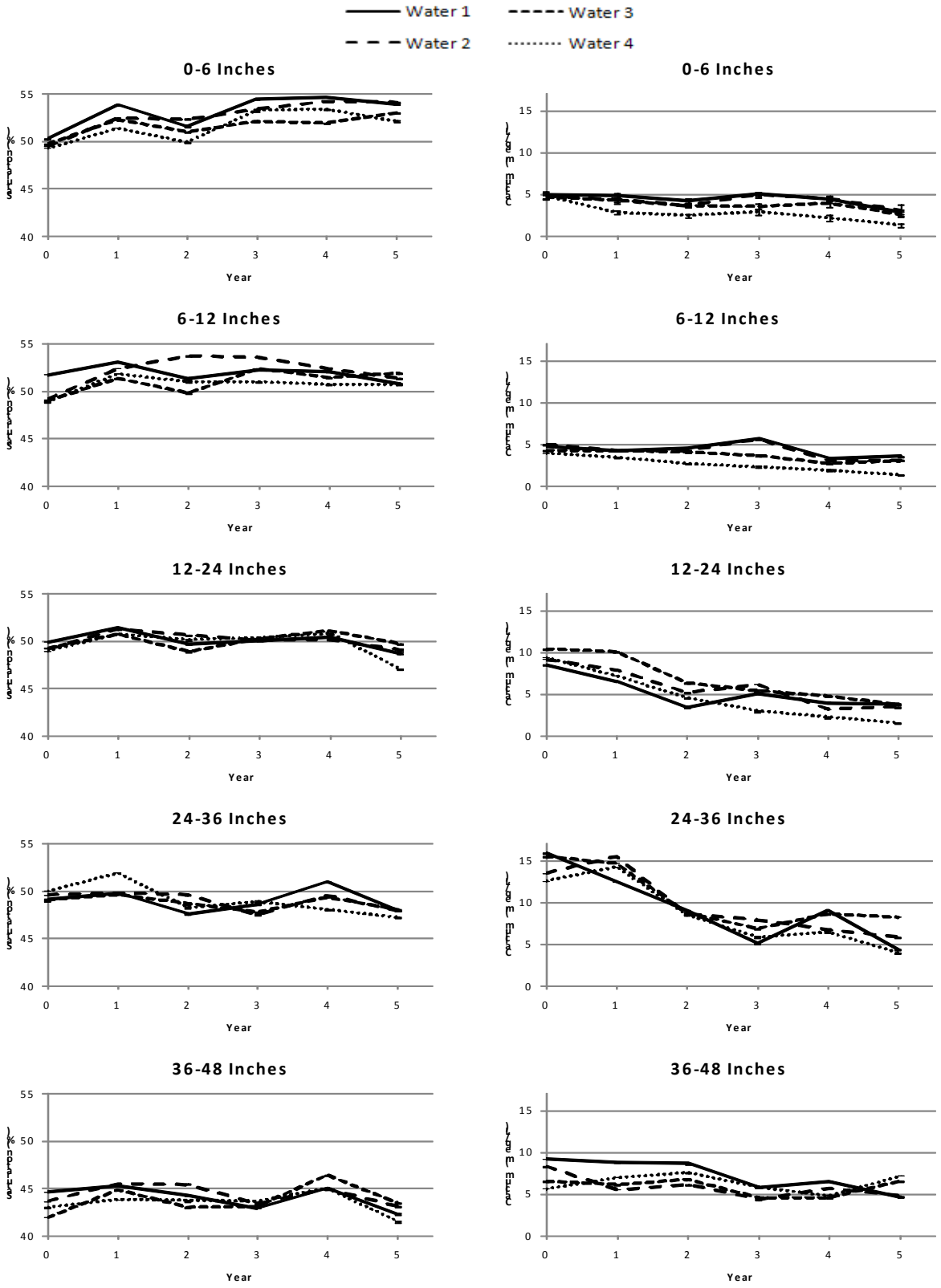
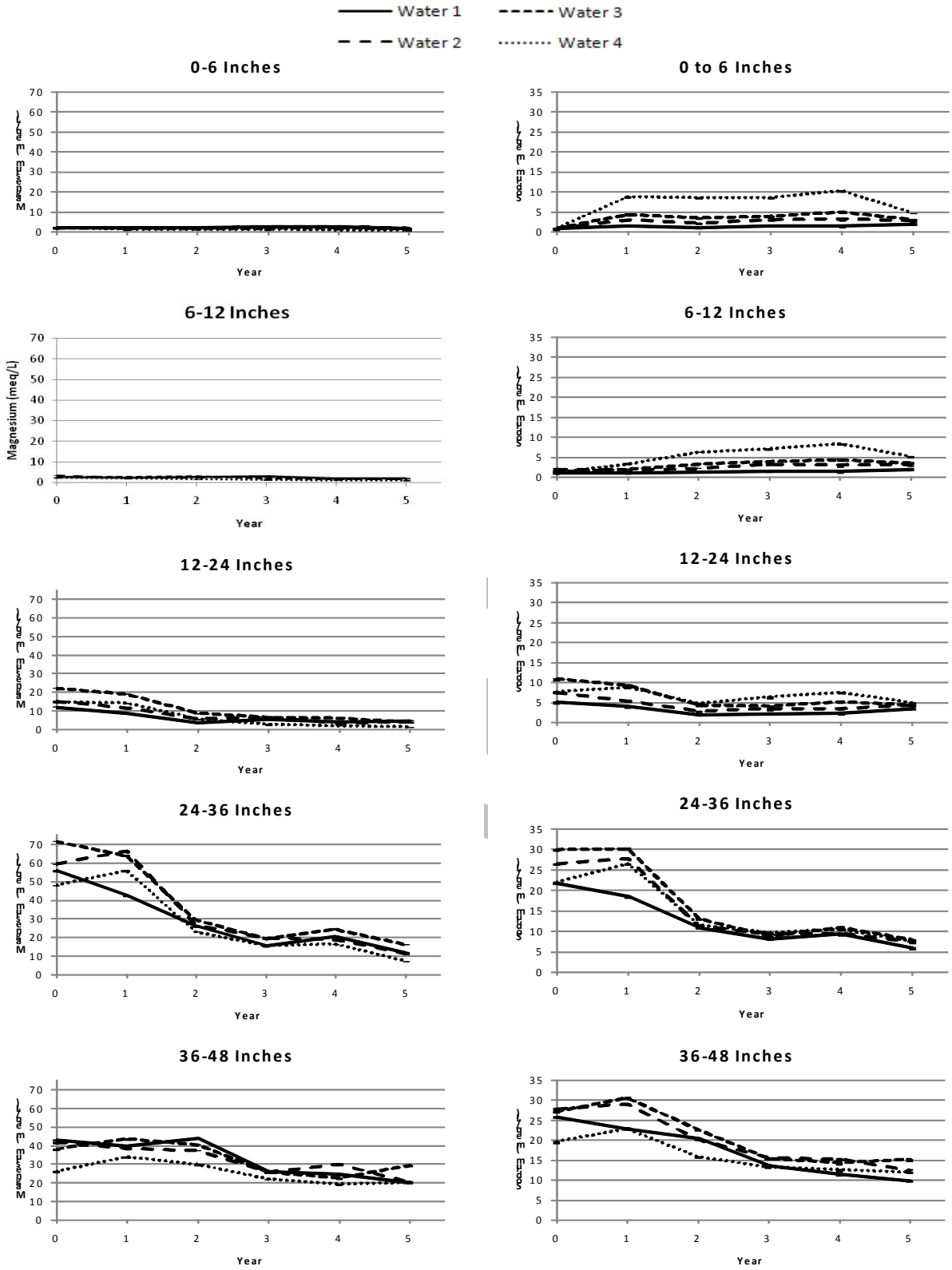
Appendix B: Soil Chemistry Data




Water 1
Water 2
Water 3
Water 4
0-6 Inches
6-12 Inches
12-24 Inches
24-36 Inches
36-48 Inches
Year


Water 1
Water 2
Water 3
Water 4
0-6 Inches
6-12 Inches
12-24 Inches
24-36 Inches
36-48 Inches
Year


Water 1
Water 2
Water 3
Water 4
0-6 Inches
0 to 6 Inches
6-12 Inches
6-12 Inches
12-24 Inches
12-24 Inches
24-36 Inches
24-36 Inches
36-48 Inches
36-48 Inches
Magnesium (meq/L)
Year