2008 Irrigated Crop and Forage Test Report

Tongue River Information Project

Prepared for:

Montana Board of Oil & Gas Conservation

Montana Department of Natural Resources and Conservation

Prepared by:

Dina Brown, M.Sc., CPSS
and
Kevin Harvey, M.Sc., CPSS

KC HARVEY, LLC
SOIL AND WATER RESOURCE

Neal Fehringer, CPAg

Fehringer Agricultural Consulting

and HydroSolutions Inc

Hydro Solutions Inc

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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 yields, soils or water quality were being affected by discharges from the coal bed methane industry. The scientific methodology and implementation of the AMPP was developed by soil scientists, William Schafer and Kevin Harvey of Bozeman, Montana, and agronomist Neal Fehringer of Billings, Montana. Tier 3 crop testing and irrigation management has been performed by Neal Fehringer.

The principal author of this report is Dina Brown, certified soil scientist with KC Harvey, Inc. Technical reviews of the report were provided by the other TRIP scientists mentioned above, along with Tom Osborne of HydroSolutions, and Karen Brown of Energy Strategies and Solutions, LLC. The 2006-2007 TRIP contract was administered by HydroSolutions Inc, a Montana based environmental science and engineering firm. This report and other TRIP reports may be found on the web site for the Montana Board of Oil and Gas Conservation: http://www.bogc.dnrc.mt.gov. The interpretations provided herein are solely those of the authors.

1.0 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.

Numerous water management strategies have been developed by CBNG operators 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 2007 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 preliminary report documents these experiments and comprises four sections including this introduction (Section 1), study methodology (Section 2), test results and discussion (Section 3), crop yield (Section 4), summary (Section 5), and references cited. This report contains preliminary Tier 3 project results, with a limited evaluation of selected soil parameters and crop yield and quality data. A more comprehensive report containing presentation of all data collected and full data analysis will be provided in 2009. The 2009 report will have results from five years of irrigation with blended CBNG produced water and Tongue River water.

2.0 Methods

The following methods were employed to analyze changes in soil and crop properties resulting from irrigation using various blends of Tongue River water and CBNG produced water.

2.1 Study Site Selection

A privately-owned ranch in the Tongue River Drainage was selected for the Tier 3 study. 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. The Irrigated Crop and Forage Test was initiated at this location during April 2004, and will be entering its fifth season of testing in summer 2008.

2.2 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. When combined, 16 unique treatments were created. Each unique treatment was replicated three times, resulting in a total of 48 experimental units.

The test location was established in mid-April 2004. The total area (0.50 acre) was divided into 48 plots to represent each experimental unit as shown in Figure 1. The entire experimental area was divided lengthwise, with east and west portions representing separate cropping systems, the entire area was divided 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. (**Error! Reference source not found.**).

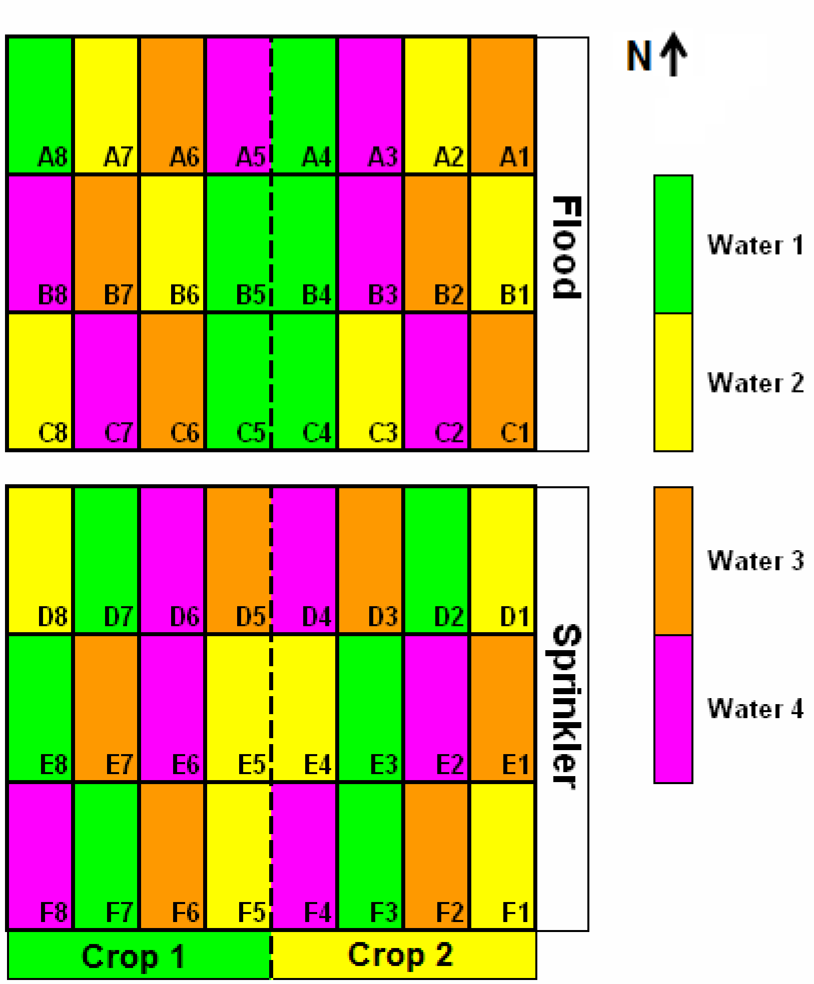

Figure 1. Water treatment crop type and irrigation method experimental layout.

2.2.1 Irrigation Water

To test the effects of irrigating with Tongue River water containing CBNG produced water on crops, forages, and soils, four irrigation water treatments were applied to test plots. The four irrigation water treatments are described in **Error! Reference source not found.**. Chemical analysis results for CBNG produced water and Tongue River water are presented in **Error! Reference source not found.**. Calculated water quality parameters for the four mixtures are provided in Table 3.

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

Water Number	Tongue River Water	CBNG Produced Water	Purpose
1	100%	0%	Control
2	93%	7%	Chosen to indicate what effects will occur if the percentage of CBNG water in the Tongue River increases
3	85%	15%	Chosen to approximate maximum Tongue River irrigation SAR & EC standards of 3.0 and 1,000 mmhos/cm, established by the Montana Board of Environmental Review. Water 3 had an approximate SAR of 2.95 and EC of 844 umhos/cm in 2004
4	50%	50%	Chosen to quantify soil and/or crop yield changes, if any, with a blend that far exceeds the numerical standard

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	0.23	0.64
Sodium Adsorption Ratio (SAR)		54	0.35	0.80
Anions				
Bicarbonate	*mg/L*	1290	145	270
Chloride	*mg/L*	20	4.0	5.0
Sulfate	*mg/L*	56	38	122
Cations				
Calcium	*mg/L*	4.0	31	41
Magnesium	*mg/L*	2.0	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 liter; and, nd = analyte not detected at the given reporting limit.
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[1]	CBNG Produced Water	Average Tongue River Water[2]	Tongue River Composition[3]			
				Water 1	Water 2	Water 3	Water 4
				100%	93%	85%	50%
Electrical Conductivity (EC)	*dS/m*	2.0	0.44	0.44	0.54	0.67	1.2
Calcium	*mg/L*	4.0	36	36	34	31	20
Magnesium	*mg/L*	2.0	25	25	23	22	14
Sodium	*mg/L*	523	19	19	55	95	271
Sodium Adsorption Ratio (SAR)		54	0.60	0.60	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.

2.2.2 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. The study plot was divided in half from north to south, with each half receiving a unique crop planting (**Error! Reference source not found.**). Bean, barley, and alfalfa crops were rotated between the two plots on a yearly basis (Table 4).

Table 4. Test plot crop rotations during irrigation seasons 2004 – 2007.

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

2.2.3 Irrigation Method

To determine whether the effects of the irrigation treatments are dependent upon irrigation method, water was applied using two methods, sprinkler and flood. The study plot was divided in half from east to west, with each half receiving a different irrigation method. The sprinkler irrigation system consisted of sprinkler heads attached to steel posts located at the edges of each plot. Sprinkler head pressure was set to 10 psi to limit cross contamination between plots. The sprinkler treatment applied water at a rate of one inch in 2.75 hours. The flood irrigation treatment areas were constructed using an earthen double dike system to limit cross contamination between plots (Figure 2). Three inches of water is applied to the flood plots every nine days during the growing season, which takes 0.75 hour. In a typical flood irrigated field, a single irrigation event will apply approximately six inches of water per acre at a 50 % application efficiency. Thus the net water applied for crop use is three inches, with the remaining water either draining off the field as tail water or leaching through the soil profile below the root zone. In these test plots, with the double dike system, there was no off-site tail water drainage. Therefore the experimental flood system has a very high level of efficiency. Figure 3 illustrates the design of these two systems.

Figure 2. Water escaped first border dike but trapped by second border dike.

Figure 3. 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).

2.3 Treatment Implementation

Treatments were first implemented in April 2004. The following methods were used to prepare study plots for seeding, implement seeding, and maintaining plots:

- Fertilizer. To determine fertilizer requirements, soil samples were collected in 2004, prior to water application. A hand-held Oakfield probe was used to collect samples from the 0 to 6 and 6 to 24 inch depths, which were composited by depth for analysis. Samples were analyzed by Energy Laboratories, Inc. (Billings, MT). Fertilizer recommendations were made by Neal E. Fehringer, Certified Professional Agronomist, C.C.A. Fertilizer was applied prior to seeding according to soil tests for each crop.

- Tilling and Leveling. The entire plot was roto-tilled using a three-point tractor mounted unit to a depth of eight inches. The area was then land leveled twice using a standard agricultural land plane.

- Seeding. In 2004, hay barley was seeded at 100 pounds per acre at a depth of 1.5 inches with an International double disk small grain drill with seven inch row spacing. In 2005, a Brillion broadcast seeder was used and in 2006, a Tye Estate seeding with 12 inch row spacing was used. Hay barley seeding rates for 2005 and 2006 remained at 100 pounds per acre. For each year planted, beans were seeded at a rate of 65 lbs/acre at a depth of 2.0 inches using a John Deere planter, row spacing was 22 inches.

  In April 2006, alfalfa was broadcasted at 20 pounds per acre after seedbed preparation. The seed was lightly hand raked and then pressed into the soil by running over each plot with an ATV pulling a sod roller filled with water.

- Weed Control. Weed control was implemented prior to seeding and as needed throughout the life of the project to control field bindweed and other weedy species. Herbicides used for the beans have been Outlook (one pint per acre) + Prowl 3.3 EC (three pints per acre) applied preplant and incorporated with the roto-tiller and Basagran (2 pints per acre) with labeled rates of crop oil and ammonium sulfate (AMS) post emergent for bindweed and Canada thistle control, Round-up (1-2 quarts per acre + labeled AMS rate), and Unison 2 4-D (one quart per acre) were used for bindweed, Canada thistle, and general weed control in replications as well as between replications. Unison (one pint per acre) was used for weed control in growing barley. Raptor (four ounces per acre) + labeled rates of surfactant and AMS were used for weed control in the alfalfa. Weed control by hoeing and hand pulling has also occurred in the beans.

2.3.1 Irrigation Timing and Application Rates

Water use demands were determined by average weekly water consumptive use data developed by the University of Nebraska Research Station at Scottsbluff, Nebraska (Agricultural Engineering Group, 1980). Soil moisture was monitored periodically by probing the soil to three feet and determining soil moisture by feel in each crop and in both irrigation systems. Water application intervals were adjusted based on daily consumptive use and available soil moisture.

One inch of water was applied every three to four days to the sprinkler replications, depending upon crop growth stage (Figure 4). Each flood replication had three inches of water applied every 9 to12 days, depending upon consumptive water use (Figure 4). Table 5 lists water applied per crop for 2004 through 2007.

Figure 4. Plots receiving sprinkler irrigation (left photo), and double diked plot following flood irrigation (right photo).

Table 5. Annual and total irrigation water applied to the test plots.

Year	Cropping System		Inches of Water Applied to Each Irrigation Area[1]			
			Flood		Sprinkler	
	Crop 1	Crop 2	Crop 1	Crop 2	Crop 1	Crop 2
2004	Barley	Beans	18	24	14	21
2005	Beans	Barley	15	6	13	4
2006	Barley	Alfalfa	19.6	25.6	13	17
2007	Beans	Alfalfa	16.5	13.5	13	15
		Total Water Applied:	69.1	69.1	53	57

Notes:

1. Irrigation areas are as shown in the experimental layout in Figure 1.

2.3.2 Soil Sample Collection and Analysis

Prior to initial water application (referred to as year 0) and following each irrigation season (years 1 through 4), soil samples were collected from each plot. Samples were collected at five depths: 0 to 6, 6 to 12, 12 to 24, 24 to 36, and 36 to 48 inches using a truck mounted Giddings Probe (Giddings Machine Company, Inc., Windsor, Colorado). Three sub-samples were collected in each plot and composited by depth for analysis. Samples were delivered to Energy Laboratories, Inc., Helena, Montana, and analyzed for pH, EC, SAR, saturation percentage, calcium, magnesium, sodium, cation exchange capacity, and exchangeable sodium percentage (ESP). In addition, surface soil samples (0 to 6 inches) were analyzed for lime content. Samples collected prior to initial irrigation were also analyzed for texture.

2.3.3 Crop Yield Determination and Quality

The harvest area in each replication has been 8.71 ft^2 for hay barley and alfalfa. Forage from each replication was harvested yearly. Samples were collected, allowed to dry, then weighed and processed through a chipper-shredder. A representative sample was then sent to Olsen Agricultural Laboratory, McCook, Nebraska, for a complete feed and total mineral analyses. For beans, area harvested has been 18.33 ft^2 (two rows x five feet each x 22 inch row spacing).

Beans were dried and processed using a stationary thresher. Beans were cleaned and weighed. Beans were not analyzed for feed quality or mineral content.

2.4 Statistical Analysis

Data were analyzed using the R statistical program (RDCT 2006). Data were highly variable for each response parameter and for each depth sampled; therefore, simple linear models could not be used to explain relationships between parameters. Separate statistical models were developed for each response parameter, i.e. pH, EC, and SAR, at each soil depth sampled, based on the amount of data variability observed and trends across years. Three models, “trend”, “jump”, and “null”, were used in the analysis of the three response parameters. The three response parameters, pH, EC, and SAR were chosen based on the level of influence they have on plant growth and their likelihood to be impacted by produced water application. Additional soil parameters were measured during the study, including calcium, magnesium, sodium, saturation percentage, lime percentage, citation exchange capacity, and ESP, and are not discussed in this report. The additional parameters will be included in the more comprehensive 2009 report.

An “information based” approach using Akaike Information Criteria (AIC) was used to determine which model, trend, jump or null, was most appropriate for a specific data set. AIC were used to compare the complexity of an estimated model against how well the model fit the particular data set (Burnam and Anderson, 2002). AIC results were calculated for each estimated model and then models with the smallest AIC values were chosen as the “best” models to apply to each data set. The model choices were as follows:

- Trend Model. A trend model was used to describe the data in cases where treatment effects accumulate over time. The trend model uses a regression equation to assign a separate slope and intercept for each water type, omitting baseline (year = 0) data. The slope indicates an interaction between time and water types, and allows for a comparison of whether or not effects accumulate at the same rate for each treatment.

- Jump Model. A jump model was used in cases where treatments affect a mean response during the first year, creating a ‘jump’, or initial increase in the data. Following the initial increase, means remain similar throughout years 1 through 4. The jump model applies an analysis of variance (ANOVA) using water type as the categorical predictor, omitting baseline (year = 0) data. Different jumps are expected for each water type, and comparisons were made with the 100% TRW water (control) data to determine treatment effects.

- Null Model. The null model was used to describe the data when treatments have no effect on mean responses. For these data sets, no statistical model was applied.

Regression and ANOVA analyses assume data exhibit equal variance. Soil data collected for this study exhibited increasing variance as mean values increased, thus failing the assumption of equal variance. Therefore, a Weighted Least Squares (WLS) regression approach was applied to the development of both trend and jump models. The WLS method models variance as a power of the mean response, and assigns less importance, or weight, to more variable data.

3.0 Preliminary Results and Discussion

To determine the effects of irrigating with blended CBNG produced water and Tongue River water, soil chemical analysis and crop yield results for the four irrigation water treatments were compared. Soil pH, EC, and SAR data are displayed in Figures 5 through 7. In Figures 5 through 7, irrigation year is represented on the x axis, the response values are given on the y axis, four separate graphs, one for each water treatment, are displayed cross-wise, and each soil depth is provided incrementally down the figure. Treatment means for soil pH, EC, and SAR are provided in Table 6. Crop yields are provided in Table 7 and Figure 8. When discussing soil analytical results, statistical significance corresponds to a p-value less than or equal to 0.05.

3.1 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, the availability of phosphorus, calcium, magnesium, iron, manganese, zinc, copper, cobalt, and boron may be yield limiting.

3.1.1 0 to 6 Inch Depth

The jump model was used to evaluate pH data within the 0 to 6 inch depth based on the AIC results, implying that mean soil sample pH changed from year 0 to year 1 depending on water treatment, and then remained stable during years 1 through 4 (Figure 5). There was no statistically significant change in mean pH as the percentage of CBNG produced water increased from 0 to 7%, i.e. when comparing water Treatment 1, 100% TRW, with water Treatment 2, 93% TRW. There were small, but statistically significant, increases in mean pH as CBNG water percentage increased to 15%; mean pH increased from 7.42 in the plots irrigated with 100% TRW to 7.56 in the plots irrigated with 85% TRW. When compared to baseline (100% TRW) values, mean soil sample pH significantly increased to 7.87 when water containing 50% CBNG water was applied (Table 6). While increases in Treatment 3 and Treatment 4 waters were statistically significant, all surface soil pH values are within the typical range for eastern Montana soils.

Crop type and irrigation method employed had a significant effect on soil sample pH at the 0 to 6 inch depth. When compared to alfalfa, barley and bean crops significantly increased soil sample pH by 0.12 and 0.18, respectively, and sprinkler irrigation decreased soil sample pH by 0.09.

3.1.2 6 to 12 Inch Depth

The jump model was used to evaluate pH data within the 6 to 12 inch depth, implying that mean soil sample pH changed from year 0 to year 1 depending on water treatment, and then remained stable during years 1 through 4 (Figure 5). Similar to the top depth, there was no significant change as the percentage of CBNG produced water increased from 0 to 7%. The soil sample pH of plots irrigated with water Treatment 1 was 7.71 and the soil sample pH of plots irrigated with water Treatment 2 averaged 7.76. There were small, but statistically significant, increases in mean soil sample pH as the percentage of CBNG water increased to

15%, with mean pH of the water Treatment 3 irrigated plots at 7.79. When compared to baseline (100% TRW) values, mean soil sample pH significantly increased to 7.92 when water containing 50% CBNG water, Treatment 4, was applied (Table 6).

Crop type and irrigation method employed had a significant effect on soil sample pH at the 6 to 12 inch depth. When compared to alfalfa, barley decreased soil sample pH by 0.09, and beans produced a non-significant change. Sprinkler irrigation decreased soil sample pH by 0.18 when compared to flood irrigation.

3.1.3 12 to 24 Inch Depth

The jump model was used to evaluate pH data within the 12 to 24 inch depth, implying that mean soil sample pH changed from year 0 to year 1 depending on water treatment, and then remained stable during years 1 through 4 (Table 6). One small, but statistically significant increase in mean soil sample pH occurred as the percentage of CBNG produced water increased from 0 to 50%; mean pH increased from 8.01 in water Treatment 1, 100% TRW, to 8.15 in water Treatment 4, 50% CBNG water (Table 6).

Crop type and irrigation method employed had a significant effect on soil sample pH at the 12 to 24 inch depth. When compared to alfalfa, barley and beans decreased pH by 0.13 and 0.07, respectively, and sprinkler irrigation decreased pH by 0.18 when compared to flood irrigation.

3.1.4 24 to 36 and 36 to 48 Inch Depths

Soil pH data within the 24 to 36 and 36 to 48 inch depth increments were highly variable with no discernable trend (Figure 5). This is likely due to 1) irrigation water had less effect at these depths, or 2) soil chemistry was naturally more variable at these depths and masked small changes in pH. Therefore no statistical model, or the null model, was applied to these data.

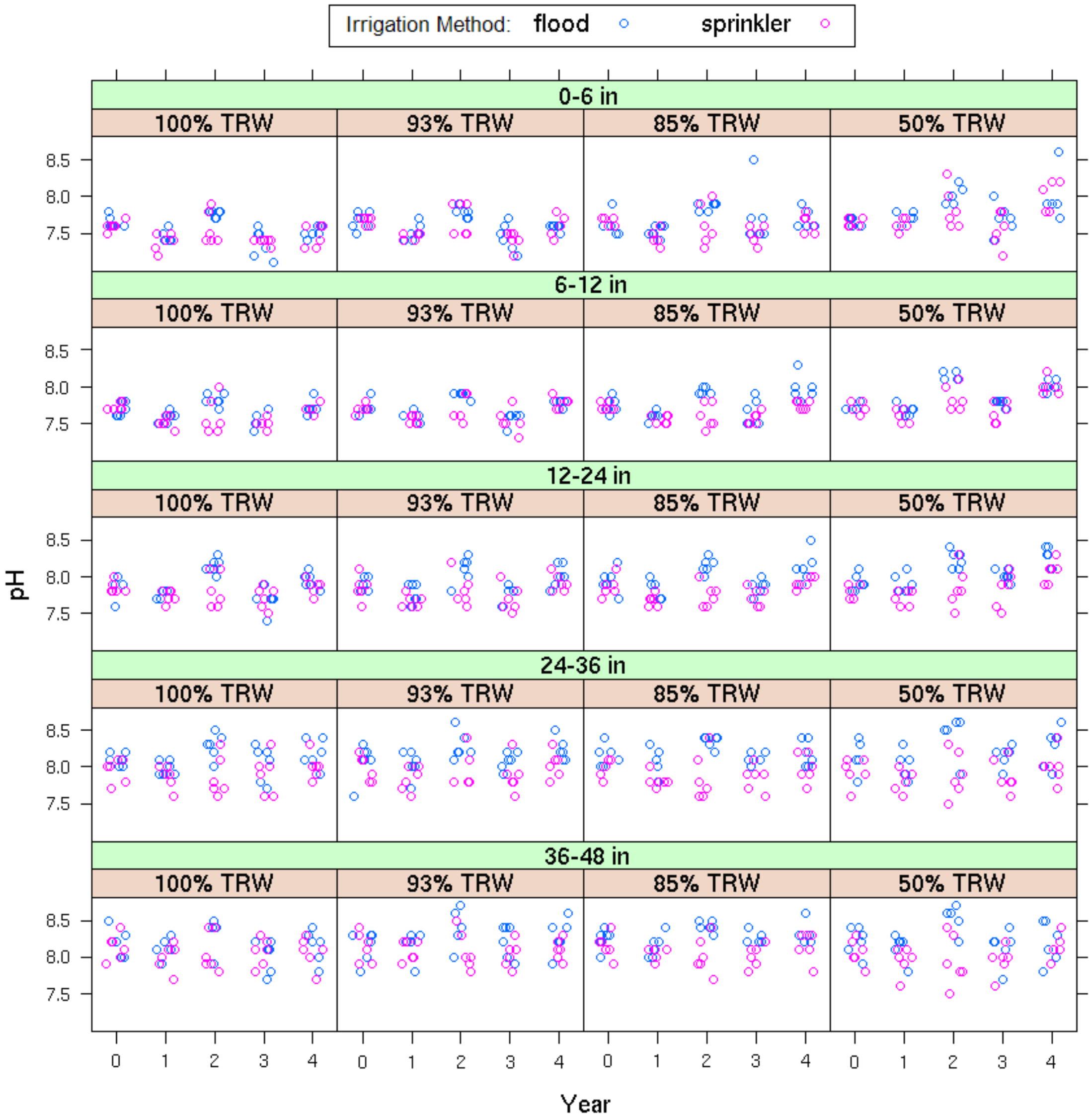

Figure 5. Change in mean soil sample pH over time; a separate graph is provided for each soil depth and water treatment combination. Year 0 measurements were taken the spring before application of treatments.

Table 6. Mean soil pH, EC, and SAR for irrigation water types based on model used (jump, trend or null). Only one mean value is reported for parameters analyzed using the jump model, which indicates that mean values remain stable during years 1 through 4. For the trend model, mean values are observed to increase with each year sampled; therefore the model predicts a unique mean value for each year/water type combination. When the null model was used, data were too variable to fit within a statistical model; therefore, mean values cannot be predicted

Parameter	Depth (inches)	Model Used	Water 1 (100% TRW)				Water 2 (93% TRW)				Water 3 (85% TRW)				Water 4 (50% TRW)			
			Year				Year				Year				Year			
			1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
pH	0-6	Jump	7.42				7.50				7.56 *				7.73 *			
	6-12	Jump	7.71				7.76				7.79 *				7.92 *			
	12-24	Jump	8.01				8.02				8.05				8.15 *			
	24-36	Null	--				--				--				--			
	36-48	Null	--				--				--				--			
EC (dS/m)	0-6	Jump	0.94				1.01 *				1.06 *				1.31 *			
	6-12	Jump	0.64				0.72 *				0.72 *				0.79 *			
	12-24	Null	--				--				--				--			
	24-36	Null	--				--				--				--			
	36-48	Null	--				--				--				--			
SAR	0-6	Jump	0.81				1.63 *				2.52 *				6.60 *			
	6-12	Trend	0.95	0.96	0.97	0.98	1.08	1.34	1.59	1.85†	0.81	1.43	2.05	2.67†	0.95	3.6	4.25	5.90†
	12-24	Trend	1.96	1.82	1.68	1.54	2.11	2.1	2.09	2.08†	2.3	2.37	2.44	2.51†	1.7	2.6	3.54	4.46†
	24-36	Null	--				--				--				--			
	36-48	Null	--				--				--				--			

* Modeled mean is significantly ($p<0.05$) different when compared to control (Water 1).
† The slope of modeled means over time, within water type, is significantly ($p<0.05$) different when compared to control (Water 1).

3.2 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 may be affected at 2 dS/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).

3.2.1 0 to 6 Inch Depth

The jump model was used to evaluate EC data within the 0 to 6 inch depth, implying that mean soil sample salinity increased from year 0 to year 1, and then remained stable during years 1 through 4 (Figure 6). When compared to water Treatment 1, Treatments 2 through 4 had statistically significant differences in mean soil sample EC, with EC increasing as the percentage of CBNG water increased. When compared to a baseline (100% TRW) soil sample EC of 0.94 dS/m, soil sample EC increased to 1.01, 1.06, and 1.31 dS/m when water containing 7%, 15%, and 50% CBNG water, respectively, was applied (Table 6). All mean soil sample EC values are below the 2.0 dS/m threshold for sensitive plants and below the 4.0 dS/m threshold for classification as saline soils.

Crop type and irrigation method employed had a significant effect on soil sample EC at the 0 to 6 inch depth. When compared to alfalfa, barley and beans decreased soil sample EC by 0.16 and 0.19 dS/m, respectively, and sprinkler irrigation, when compared to flood irrigation, increased soil sample EC by 0.09 dS/m.

3.2.2 6 to 12 Inch Depth

The jump model was also used to evaluate EC data within the 6 to 12 inch depth, implying that mean soil sample salinity increased from year 0 to year 1, and then remained stable during years 1 through 4 (Figure 6). There were small, but statistically significant, differences between means for all treatments, with EC increasing as the percentage of CBNG water increased. When compared to a baseline (100% TRW) soil sample EC of 0.64 dS/m, soil sample EC increased to 0.72, 0.72, and 0.79 dS/m when water containing 7%, 15%, and 50% CBNG water, respectively, was applied (Table 6). All mean soil sample EC values are below the 2.0 dS/m threshold for sensitive plants and below the 4.0 dS/m threshold for classification as saline soils.

Crop type and irrigation method employed had a significant effect on soil sample EC at the 6 to 12 inch depth. When compared to alfalfa, barley increased soil sample EC by 0.16 dS/m and beans had a non-significant effect. Sprinkler irrigation, when compared to flood irrigation, increased soil sample EC by 0.12 dS/m.

3.2.3 12 to 24, 24 to 36, and 36 to 48 Inch Depths

EC data within the 12 to 24, 24 to 36, and 36 to 48 inch depth increments were highly variable with no discernable trend (Figure 6). This is likely due to 1) irrigation water had less effect at these depths, or 2) soil chemistry was naturally more variable at these depths and masked any changes in EC. Therefore no statistical model, or the null model, was applied to these data.

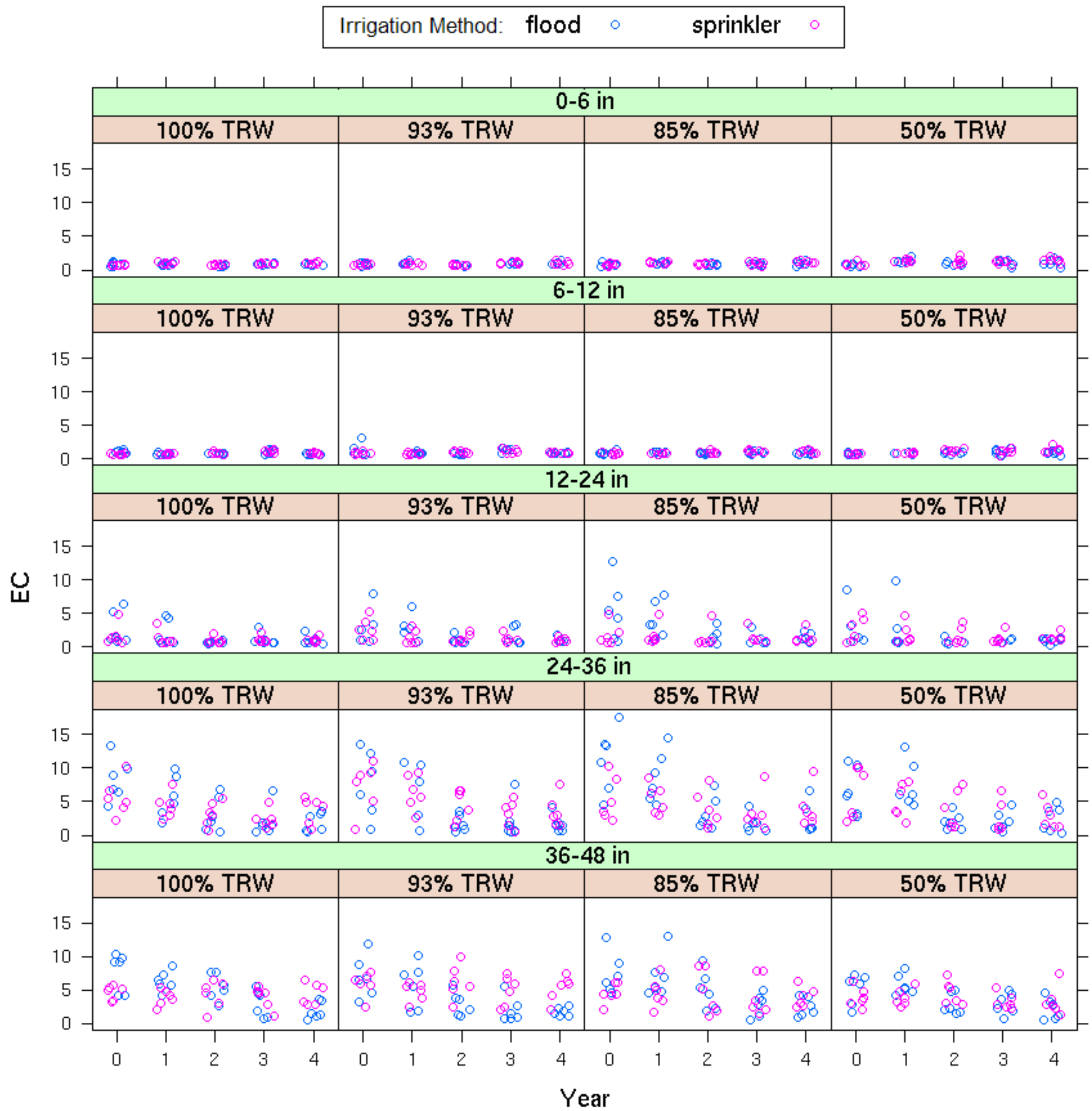

Figure 6. Change in mean soil sample EC (dS/m) over time; a separate graph is provided for each soil depth and water treatment combination. Year 0 measurements were taken the spring before application of treatments.

3.3 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).

The SAR is the ratio of the dissolved sodium concentration divided by the square root of the average calcium plus magnesium concentration. The 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 the calcium, magnesium, and sodium concentrations in soil sample, 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 the 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 15% of the exchangeable ions, the clays can begin to repel one another causing the soil structure to degrade. The continued swelling and dispersion of clay minerals and subsequent degradation of soil structure can reduce the rate of water infiltrating the soil and the 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 higher risk.

3.3.1 0 to 6 Inch Depth

The jump model was used to evaluate SAR data within the 0 to 6 inch depth, implying that mean soil sample SAR increased from year 0 to year 1, and then remained stable during years 1 through 4 (Figure 7). There were statistically significant differences between means for all treatments, with soil sample SAR increasing as the percentage of CBNG water increased. When compared to a baseline (100% TRW) soil sample SAR of 0.81, soil sample SAR increased to 1.63, 2.52, and 6.60 when water containing 7%, 15%, and 50% CBNG water, respectively, was applied (Table 6). Soil samples from all four water treatments were below a SAR of 13 and would not be considered non-sodic.

Crop type had a significant effect on soil sample SAR at the 0 to 6 inch depth. Irrigation of barley and beans decreased soil sample SAR by 0.16 and 0.04, respectively, when compared to alfalfa. Irrigation method had no statistically significant effect on SAR within the 0 to 6 inch depth.

3.3.2 6 to 12 Inch Depth

The trend model was used to evaluate SAR data within the 6 to 12 inch depth increment, implying that mean soil sample SAR increased in a linear fashion over time for years 1 through 4 (Figure 7). SAR is increasing over time at a rate of 0.01, 0.26, 0.62, and 1.64 per year, for water Treatments 1, 2, 3, and 4, respectively even for Treatment 1, 100% Tongue River water. SAR is increasing over time. When compared to Treatment 1, all increases in SAR over time were statistically significant. The rate of SAR increase is greater when higher percentages of CBNG water were applied, indicated by an increase in mean soil sample SAR for each water type over time (Table 6). Application of increasing percentages of CBNG produced water resulted in greater changes in SAR over the four years of data. It should be noted that soil SAR could not continue to increase over time, as ultimately an equilibrium will be reached with the SAR of the applied irrigation water. Soil samples from all four water treatments were below a SAR of 13 and would not be considered sodic.

Crop type had a significant effect on soil sample SAR at the 6 to 12 inch depth. Irrigation of barley and beans decreased soil sample SAR by 0.39 and 0.32, respectively, when compared to alfalfa. Irrigation method had no statistically significant effect on SAR within the 6 to 12 inch depth.

3.3.3 12 to 24 Inch Depth

The trend model was used to evaluate SAR data within the 12 to 24 inch depth increment, implying that mean soil sample SAR increased in a linear fashion over time for years 1 through 4 (Figure 7). SAR is increasing over time at a rate of -0.14, -0.01, 0.07, and 0.92 per year, for water Treatments 1, 2, 3, and 4, respectively; when compared to Treatment 1, all changes in SAR over time were statistically significant. Negative slopes indicate a decrease in mean soil sample SAR over time (Table 6). Similar to the 6 to 12 inch depth increment, the rate of SAR increase is greater when higher percentages of CBNG water were applied.

Crop type and irrigation method employed had a significant effect on soil sample SAR at the 12 to 24 inch depth. When compared to alfalfa, barley and beans decreased mean soil sample SAR by 0.54 and 0.42, respectively. Sprinkler irrigation decreased mean soil sample SAR by 0.27 when compared to flood irrigation.

3.3.4 24 to 36 and 36 to 48 Inch Depths

SAR data within the 24 to 36 and 36 to 48 inch depth increments were highly variable with no discernable trend (Figure 7). This is likely due to 1) irrigation water had less effect at these depths, or 2) soil chemistry was naturally more variable at these depths and masked any changes in SAR. Therefore no statistical model, or the null model, was applied to these data.

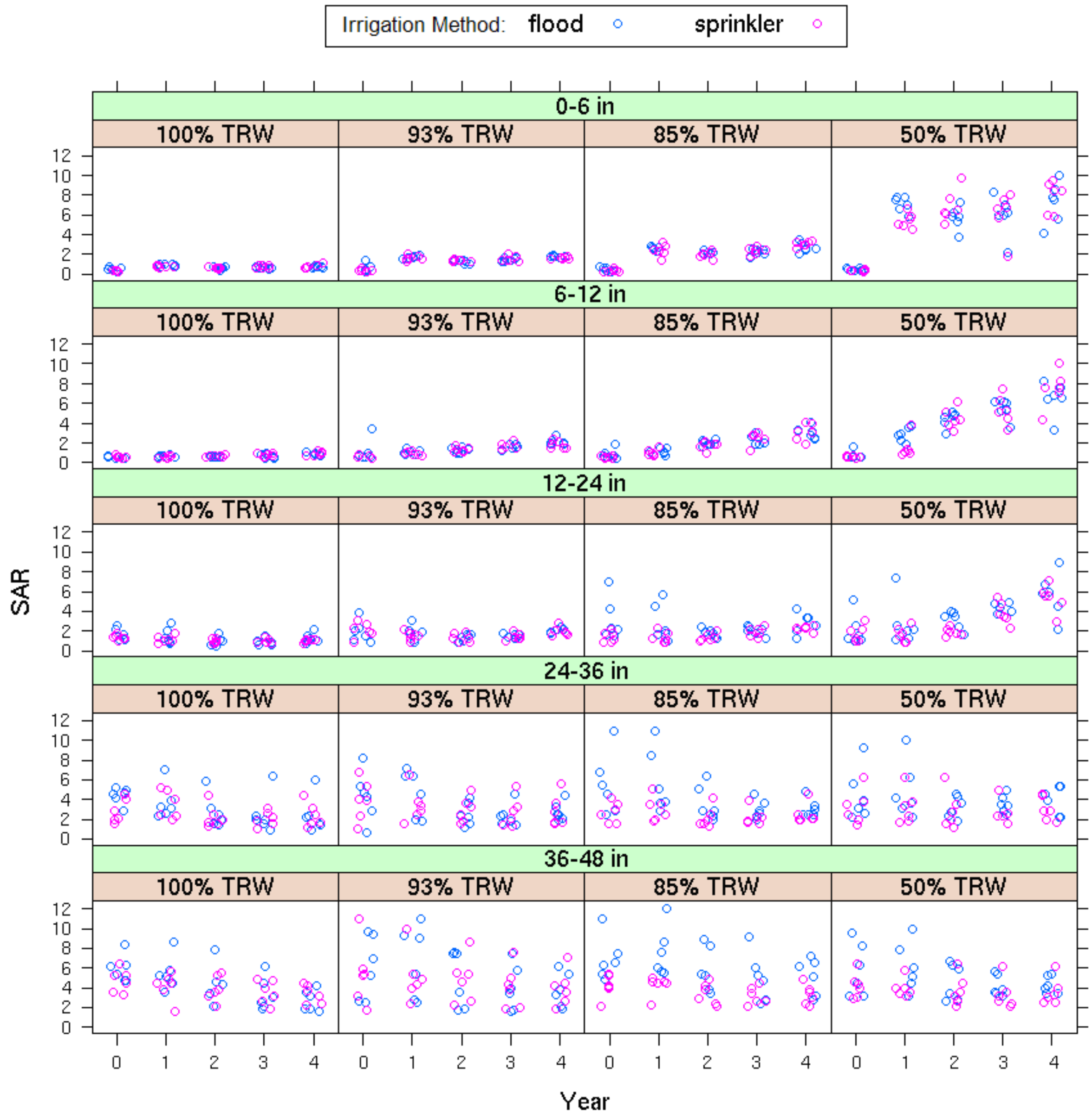

Figure 7. Change in mean soil sample SAR over time; a separate graph is provided for each soil depth and water treatment combination. Year 0 measurements were taken the spring before application of treatments.

4.0 Crop Yield

Annual and average crop yields for the three crops grown in the Irrigated Crop and Forage Test are provided in Table 7; averages include both flood and sprinkler irrigation plot yields. The annual and average sodium content for the forage crops, alfalfa and hay barley are also provided in Table 7. A complete presentation of all forage mineral results will be included in the 2009 report. For the three seasons that hay barley was grown, average yields were 2.62, 2.49, 2.31, and 2.41 tons per acre, for water Treatments 1 through 4, respectively. Average hay barley sodium content (in percentages) was 0.14, 0.19, 0.24, and 0.43% for water Treatments 1 through 4 respectively. For the three seasons that pinto beans were grown, average yields were 22.51, 23.18, 21.12, and 18.63 hundred weight (cwt) per acre, for water Treatments 1 through 4, respectively. The 2005 and 2007 pinto bean yields are comparable to county average yields in South Eastern and South Central Montana. For the two seasons that alfalfa has been planted, average yields have been 1.90, 1.95, 1.85, and 2.02 tons per acre for water Treatments 1 through 4, respectively. Average alfalfa sodium content was 0.05, 0.09, 0.12, and 0.31% for water Treatments 1 through 4, respectively.

Table 7. Crop yields and forage sodium content for the Irrigated Crop and Forage Test Plots.

Hay Barley

Water	Yield @ 12% Moisture(T/A)					Sodium Content (%)				
	2004	2005	2006	2007	AVE	2004	2005	2006	2007	AVE
1	1.64	3.55	2.68	n/a	**2.62**	0.11	0.16	0.15	n/a	**0.14**
2	1.56	3.38	2.53	n/a	**2.49**	0.12	0.17	0.28	n/a	**0.19**
3	1.50	3.02	2.40	n/a	**2.31**	0.19	0.22	0.3	n/a	**0.24**
4	1.50	2.90	2.84	n/a	**2.41**	0.31	0.33	0.66	n/a	**0.43**

Pinto Beans

Water	Yield (cwt/acre)					Sodium Content (%)				
	2004	2005	2006	2007	AVE	2004	2005	2006	2007	AVE
1	18.95	21.04	n/a	27.53	**22.51**	n/a	n/a	n/a	n/a	n/a
2	16.23	23.54	n/a	29.78	**23.18**	n/a	n/a	n/a	n/a	n/a
3	17.92	20.44	n/a	25.01	**21.12**	n/a	n/a	n/a	n/a	n/a
4	13.88	20.63	n/a	21.38	**18.63**	n/a	n/a	n/a	n/a	n/a

cwt: hundred weight @ air dried moisture.
Beans were not tested for sodium content

Alfalfa

Water	Yield @ 12% Moisture(T/A)					Sodium Content (%)				
	2004	2005	2006	2007	AVE	2004	2005	2006	2007	AVE
1	n/a	n/a	0.47	3.32	**1.90**	n/a	n/a	0.06	0.04	**0.05**
2	n/a	n/a	0.43	3.46	**1.95**	n/a	n/a	0.09	0.08	**0.09**
3	n/a	n/a	0.41	3.28	**1.85**	n/a	n/a	0.13	0.11	**0.12**
4	n/a	n/a	0.40	3.64	**2.02**	n/a	n/a	0.33	0.28	**0.31**

Due to yearly crop rotations between plots, statistical evaluations of crop yield over time were not possible for all plots. Comparisons are possible in Plot 1, where alfalfa was grown in years 3 and 4. Alfalfa yields increased the second season after planting, which is expected as the stand matures (Figure 8). In Plot 2, barley was planted in years 1 and 3, with no apparent shift in production over time. Bean production can also be compared in Plot 2, with increased production observed between years 2 and 4 (Figure 8). For all three crops, there is no evidence of any drop in yield over time regardless of water treatment.

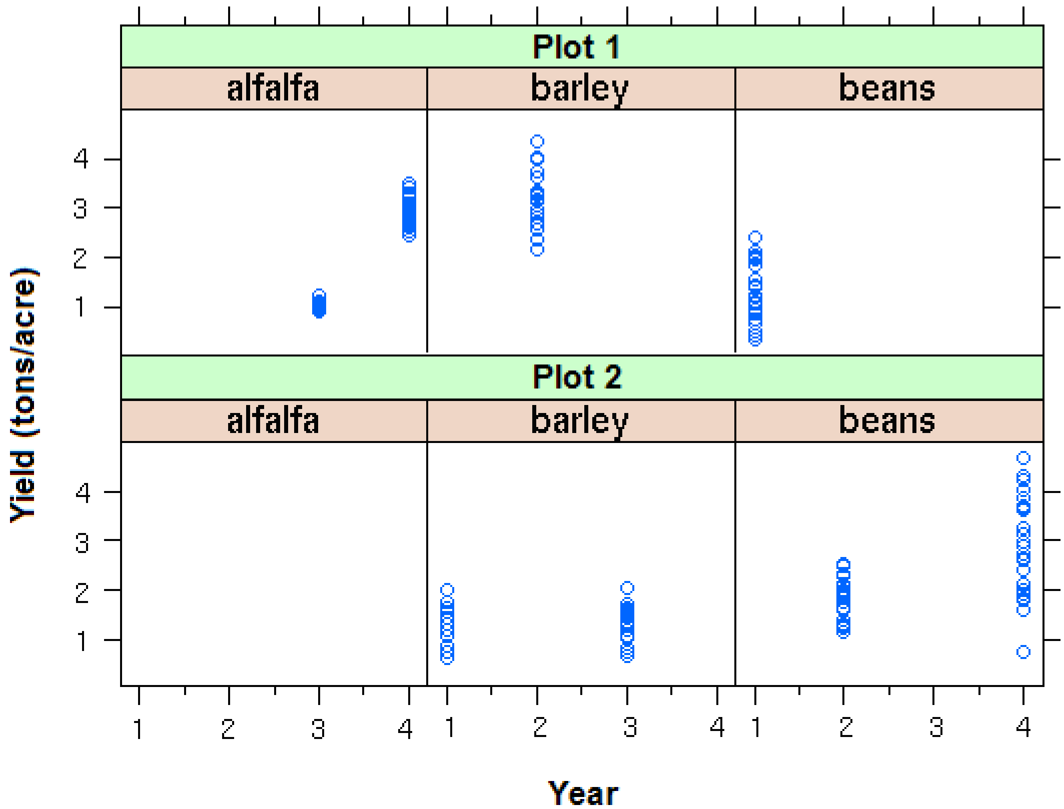

Figure 8. Crop yield by crop type and plot.

5.0 Summary

Separate statistical models were developed for pH, EC, and SAR, at each soil depth sampled, based on the amount of data variability observed and trends across years. Three models, "trend", "jump", and "null", were used in the analysis of the sampling data. A trend model was used to describe the data in cases where treatment effects accumulate over time. A jump model was used in cases where treatments affect a mean response during the first year, creating a "jump", or initial increase in the data; following the initial increase, means remain similar throughout years 1 through 4. The null model was used to describe the data when treatments have no effect on mean responses. Akaike Information Criteria were used to determine which model, trend, jump, or null, was most appropriate for a specific data set. The jump model was determined to best fit the pH and EC data sets at the upper sampling depths. For the SAR data set, the jump model fit the 0 to 6 inch sampling depth best, while the trend model best fit the 6 to 12 and 12 to 24 inch sampling depths. For all three parameters, at the 24 to 36 and 36 to 48 inch sampling depths, the null model provided the best fit to the data.

The effects of irrigating with blended CBNG produced water and Tongue River water on soil chemistry, specifically pH, EC, and SAR, were often statistically significant. Mean soil sample pH ranged from 7.42 to 7.87 for the 0 to 6 inch depth for all four irrigation water treatments; these pH values are considered normal for eastern Montana soils. Mean soil sample EC ranged from 0.94 to 1.31 dS/m for the 0 to 6 inch depth for all four irrigation water treatments; with these EC levels, salinity effects would be considered negligible. Mean soil sample SAR ranged from 0.81 to 6.60 for the 0 to 6 inch depth for all four irrigation water treatments; these SAR values are well below the sodic soil threshold of 13. Even though statistically significant, the effects of the treatments on the chemical properties of the soils, from a practical viewpoint, are within acceptable limits.

For the three seasons that hay barley was grown, average yields were 2.62, 2.49, 2.31, and 2.41 tons per acre, for water Treatments 1 through 4, respectively. For the three seasons that pinto beans were grown, average yields were 22.51, 23.18, 21.12, and 18.63 hundred weight (cwt) per acre, for water Treatments 1 through 4, respectively. For the two seasons that alfalfa has been planted, average yields have been 1.90, 1.95, 1.85, and 2.02 tons per acre for water Treatments 1 through 4, respectively. Even though a statistical evaluation of crop yield over time was not possible, there is no evidence of a drop in yield for any of the three crops regardless of water treatment.

The limited information presented in this Irrigated Crop and Forage Test Report represent four years of data collection and interpretations are preliminary. The variability in the data, especially in the deeper soil samples collected, indicates the need for continuation of the Irrigated Crop and Forage Test.

References

Agricultural Engineering Irrigation Group, University of Nebraska-Lincoln, 1980. Irrigation Scheduling Handbook, Third Edition. UNL Cooperative Extension Service, Lincoln, NE.

Bohn, H.L., McNeal, B.L., and O'Connor, G.A. 1985. Soil Chemistry. John Wiley and Sons. New York, NY.

Burnham, K.P. and D.R. Anderson. 2002. Model Selection and Multimodel Inference: A Practical Information-Theoretic Approach Second Edition. Springer

Dinkins, C.P. and C. Jones. 2007. Interpretation of soil test reports for agriculture. MontGuide MT200702AG. Montana State University Extension. Bozeman, MT.

R Development Core Team (RDCT) (2006). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org.

Soil Improvement Committee, California Plant Health Association. 2002. Western Fertilizer Handbook, ninth edition. Interstate Publishers, Inc. Danville, IL.

Soil Science Society of America. 2001. Glossary of Soil Science Terms. Madison, WI.

U.S. Salinity Laboratory Staff. 1954. Diagnosis and Improvement of Saline and Alkali Soils. U.S.D.A. Agriculture Handbook No. 60. U.S. Government Printing Office. Washington, DC.