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Results of Soil Sampling Along the Middle Rio Grande, 2006 Report

U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Environmental Services Division
Fisheries and Wildlife Resources Group
Denver, Colorado

December 2007

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Results of Soil Sampling Along the Middle Rio Grande, 2006 Report

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Introduction

Soils were sampled along the Middle Rio Grande upstream from and within the Elephant Butte Reservoir Conservation Pool (Figure 1) in September of 2006. Sampling was conducted in order to test the assumption that the concentration of salts has increased within the rooting zone of woody plant species as reservoir levels and flushing flows have decreased. Over the past several years, Elephant Butte Reservoir has been receding (Moore 2005). As reservoir levels have receded, native and exotic riparian plant species have occupied areas exposed at the reservoir's headwaters, providing some areas of optimum habitat for the endangered Southwestern willow flycatcher (SWFL). Over time, flushing flows from overbank flooding or fluctuating reservoir levels have decreased in frequency, due not only to the receding reservoir but also to reduced flows and degraded channel in the Rio Grande. As the reservoir continued to recede, soils in some areas dried out and the native willow species (*Salix* spp.) important to SWFL habitat were replaced by exotic species, particularly saltcedar (*Tamarix* spp.). We hypothesized that along with these changes in hydrology, salt accumulation in the soils was also a factor in the mortality of willow species. This hypothesis was based on the theory that the lack of flows to flush salts from the system would lead to an accumulation of salts in the soils, which would in turn be detrimental to the health of the native plant population.

Figure 1. Location map of study site.

Methods

Samples were collected from two paired plots within 10 sites, for a total of 20 plots (Figure 2). Within each of the plots, three samples were gathered from the soil profile at 0- to 6-inch (in), 6- to12-in, and 12- to 36-in depths using a 2 inch diameter auger. The samples were tested for a suite of parameters, including electrical conductivity (EC), which provides an indication of salt levels, and sodium adsorption ratio (SAR), which provides information on the comparative concentrations of sodium, calcium, and magnesium in the soil solution. Other parameters tested were pH, percent organic matter (OM), nitrate nitrogen (NO_3-N), phosphorous (P), potassium (K), zinc (Zn), iron (Fe), manganese (Mn), copper (Cu), calcium (Ca), magnesium (Mg), and sodium (Na), as well as an estimate of texture.

Within each site, one plot was located in a healthy willow population, and the other plot was located in a dying willow population. The two plots appeared to have similar hydrologic conditions and samples were generally collected within the same type of plant community in areas adjacent to each other. Table 1 provides qualitative descriptions of the vegetation and hydrology in each of the plots. In the plots with dying willow, saltcedar was typically encroaching. Sampling directly under saltcedar was avoided to prevent elevated salt levels caused by input from saltcedar foliage and roots. This sampling plan allowed for a paired comparison of areas where healthy stands of willow currently or recently stood and where soil characteristics were presumably once similar.

The paired t-test was used for normally distributed data and the signed rank test was used for data that was not normally distributed to statistically compare the healthy and dying sites. Statistically significant differences between the two areas would lend support to the conclusion that altered soils may have been a reason for the change in the condition of the vegetation, independent from effects of altered soil moisture availability alone.

Photos were taken at each of the sites to document the condition of the plant communities at the time of sampling.

Results and Discussion

The laboratory results of the soil analyses are shown in Appendix A. Note that three of the values are highlighted; two in the NO_3–N test results and one in the P test results. These values were outliers that were removed from statistical analysis. A series of graphs in Appendix B shows comparisons between plots with healthy and dying vegetation by sample for each parameter.

In statistical comparisons of soil parameters tested between the two types of plots, only NO_3-N and P showed significant differences, with values being higher in the plots with dying native vegetation (Table 2). There was not a statistically significant difference in

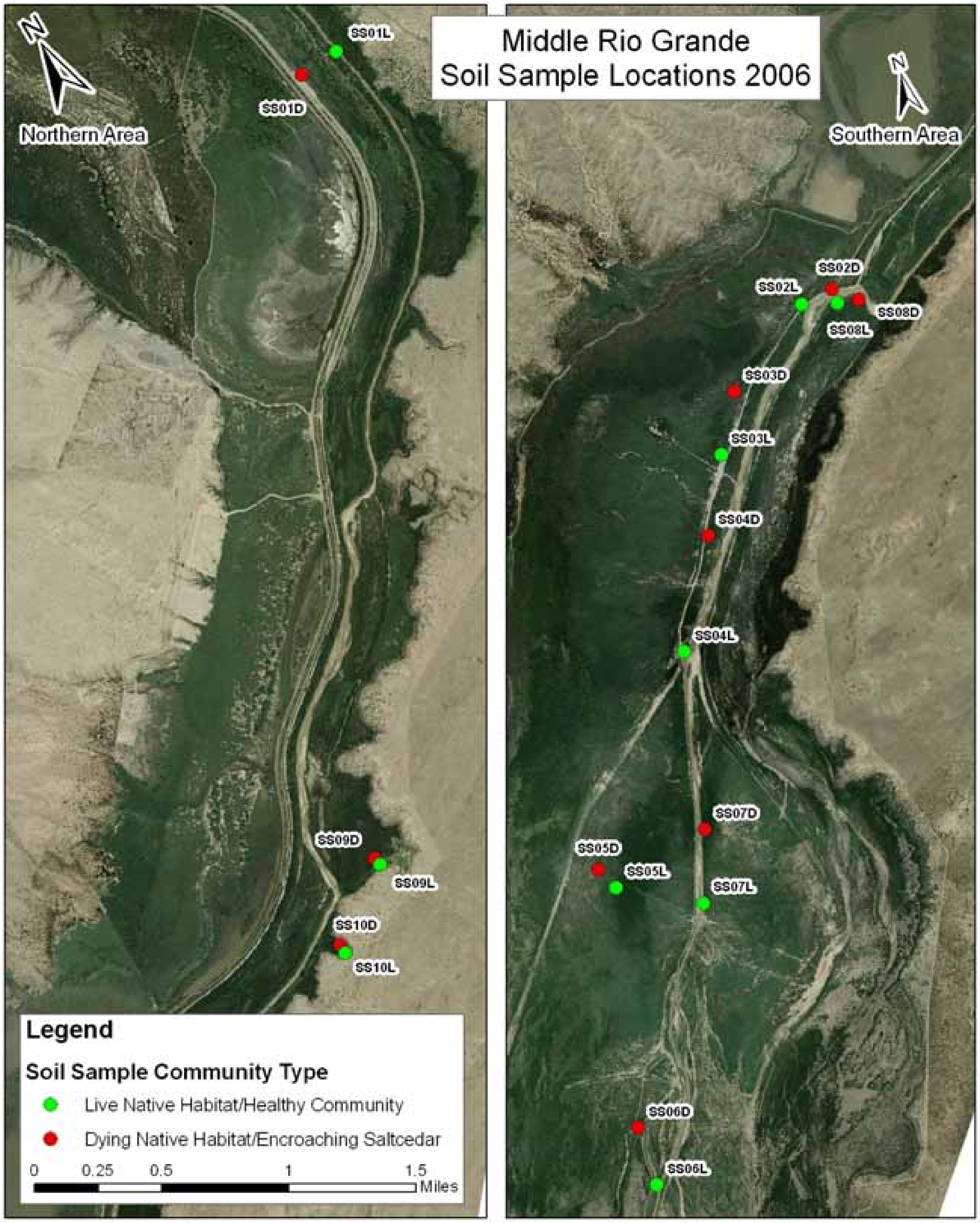

Figure 2. Soil sample locations along the Middle Rio Grande, New Mexico.

Table 1. Descriptions of the vegetation and hydrology of the plots where soil samples were collected, Middle Rio Grande, New Mexico

Site No.	Vegetation*		Hydrology	
	Healthy	**Dying**	**Healthy**	**Dying**
1	Large Goodding's willow w/ scattered cottonwood overstory; sparse saltcedar and Goodding's willow understory	Dead standing and downed Goodding's willow; scattered cottonwood and saltcedar along edge; some willow regeneration	On terrace adjacent to river	> 164 ft (50 m) from river along road
2	10- to 15-ft tall stand of coyote willow, alkali muhly understory; good willow regeneration	Dead coyote willow in strip adjacent to live willow and cottonwood	Adjacent to road, which is adjacent to river on opposite side; < 164 ft from river; soil saturated between 12-18"	Adjacent to road, which is adjacent to river on opposite side; < 164 ft from river
3	25- to 30-ft tall closed stand of Goodding's willow, scattered young cottonwood throughout; dead willow in understory	Dying Goodding's willow, some coyote willow regeneration, sparse to moderate understory of saltcedar; entire site surrounded by saltcedar	> 164 ft from river; adjacent to road	> 164 ft from river
4	Patches of Goodding's willow w/ cottonwood and coyote willow between patches	Dying mid-age stand of Goodding's and coyote willows, large Goodding's willow still appears healthy; thick understory of saltcedar, seep willow, and dying coyote willow	< 164 ft from river; rock layer at 33" in soil profile	> 164 ft from river
5	25-ft tall closed stand of Goodding's willow, tops healthy and bottom branches dying out; salt cedar beginning to encroach; seep willow in understory, no willow regeneration	10- to 15-ft tall open stand of dead and dying Goodding's willow, sparse saltcedar and coyote willow; heavy grazing impact	> 0.25 mi from river	> 0.25 mi from river
6	Open canopy of Goodding's willow w/ understory of sparse saltcedar and sparse coyote willow and Russian olive	20-ft tall open stand of dead and dying Goodding's willow, large seepwillow and unhealthy coyote willow; salt cedar encroaching; very weedy herbaceous layer	Between river and road; < 164 ft from river	> 164 ft from river on road
7	Narrow strip of healthy Goodding's willow, saltcedar encroaching; stand of unhealthy Goodding's willow just behind on side away from river	Approximately 45 percent canopy cover of dead and dying Goodding's willow; no shrub understory or regeneration of any species	In narrow strip on terrace immediately adjacent to river	< 164 ft from river in stand on terrace
8	Large Goodding's willow in strip between dead coyote willow that is adjacent to river and stand of dying Goodding's willow and cottonwood located behind	Dying Goodding's willow at interface w/ dead coyote willow that is adjacent to river; thick stand of saltcedar behind	On terrace adjacent to river	On terrace adjacent to river
9	Strip of Goodding's willow along perimeter of river inlet/canyon	20-ft tall stand of dead and dying Goodding's willow in interior of river inlet/canyon	At base of canyon wall in large river inlet	In interior of large river inlet
10	35- to 40-ft tall Goodding's willow in strip at back of river inlet/canyon; dead salt cedar just outside of willow stand against mesa	25- to 30-ft tall dead and dying Goodding's willow inside of river inlet/canyon; no understory	At back of small river inlet	In interior of small river inlet

* Goodding's willow - *Salix gooddingii*; coyote willow -*Salix exigua*; – Rio Grande cottonwood - *Populus deltoides*; seep willow - *Baccharis salicifolia*; alkali muhly - *Muhlenburgia asperifolia*; barnyard grass - *Echinochloa crus-galli;* Russian olive – *Elaeagnus angustifolia.*

Table 2. Results of statistical comparisons of soil parameters between samples collected in plots with healthy and dying native vegetation on the Middle Rio Grande, New Mexico. Alpha = 0.05

Parameter	Statistical comparison	Parameter	Statistical comparison
EC	Healthy = Dying P = 0.360[2]	**Mn**	Healthy = Dying P = 0.992[2]
SAR	Healthy = Dying P = 0.666[2]	**NO_3 - N**	Healthy < Dying P = 0.009[2 *]
Ca	Healthy = Dying P = 0.871[1]	**Na**	Healthy = Dying P = 0.841[1]
Cu	Healthy = Dying P = 0.249[2]	**% OM**	Healthy = Dying P = 0.914[2]
Fe	Healthy = Dying P = 0.420[1]	**P**	Healthy < Dying P = 0.006[2 **]
K (meq/L)	Healthy = Dying P = 0.946[2]	**pH**	Healthy = Dying P = 0.487[1]
K (ppm)	Healthy = Dying P = 0.100[2]	**Zn**	Healthy = Dying P = 0.350[2]
Mg	Healthy = Dying P = 0.778[1]	**Texture**	Healthy = Dying P = 0.462[1]

[1] = paired t-test
[2] = signed rank test
* = two outliers removed from analysis; with outliers included P=0.003
** = one outlier removed from analysis; with outlier included P=0.003

either EC or SAR between plot types, suggesting that salts in the soil were not a component in the mortality of willow at these sites. This is also demonstrated in EC and SAR levels. Saline soils are defined as those having an EC > 4, and sodic soils are those with an SAR > 13-15, which are levels considered to be toxic to plants (Brady 1990). The average EC values for the healthy stands and the dying stands were 1.71 and 1.27, respectively (Table 3). The average SAR values for the plots with healthy vegetation and with dying vegetation were 2.22 and 2.34, respectively. None of these values were at levels considered to seriously interfere with the growth of plants.

Native willows and cottonwoods planted in revegetation efforts on the Bosque del Apache NWR generally performed best in sandy soils with low salinity and moderate water tables (Taylor, no date; Table 4). The average EC's found in this study fell within the recommended range for Goodding's willow (<1.0-2.9), further suggesting that salts were not a factor in willow mortality. Because soils were only sampled to 36 inches, it is unknown if water table depths were within the acceptable levels of 3.9-10.2 ft.

Although the levels of NO_3–N and P were significantly higher in the plots with dying vegetation, willow mortality is likely not attributable to toxic levels of either of these nutrients. Anderson (2002) tested soils in flood plains along the Yampa and Green rivers in Colorado where vegetation was robust. Concentrations of NO_3–N and P were comparable to those found in the dying vegetation plots in this study, which would indicate that these levels are not detrimental to riparian plant health.

Table 3. Average value of each parameter tested by plot type and depth

	0-6 inch depth		6-12 inch depth		12-36 inch depth		Total depth	
	Healthy	**Dying**	**Healthy**	**Dying**	**Healthy**	**Dying**	**Healthy**	**Dying**
pH	7.79	7.70	7.81	7.79	7.74	7.50	7.78	7.74
EC (mmhos/cm)	1.80	1.25	1.49	1.16	1.85	1.00	1.71	1.27
% OM	1.03	1.08	0.89	1.12	1.33	5.40	1.08	1.25
NO_3-N (ppm)*	4.53	10.90	4.45	10.10	6.21	19.40	5.06	20.43
P (ppm)**	5.17	6.64	4.03	5.36	4.14	8.40	4.45	8.39
K (ppm)	166.74	274.59	145.48	189.48	153.12	353.70	155.11	209.19
Zn (ppm)	1.06	1.64	0.88	1.14	1.15	2.51	1.03	1.30
Fe (ppm)	39.05	36.41	43.46	41.95	54.86	95.81	45.79	41.92
Mn (ppm)	2.80	3.73	2.89	3.14	3.22	5.70	2.97	3.24
Cu (ppm)	2.89	3.23	2.65	3.35	3.71	6.93	3.08	3.44
Ca (meq/L)	4.99	5.39	4.70	5.33	6.74	5.83	5.48	5.67
Mg (meq/L)	1.89	2.29	1.81	2.09	2.89	2.18	2.20	2.33
Na (meq/L)	3.24	3.74	3.97	4.24	6.26	3.74	4.49	4.66
K (meq/L)	0.47	0.59	0.28	0.33	0.33	0.28	0.36	0.40
SAR	1.66	1.71	2.15	2.46	2.86	1.90	2.22	2.34

Table 4. Salinity, soil and water table planting requirements for selected riparian species at Bosque del Apache National Wildlife Refuge, New Mexico

Species	E.C. Level (dS/m)	Soil Type	H2O Table Depth (ft)
Cottonwood	< 1.0-2.5	Sandy loam	4.9-12.8
Goodding's willow	<1.0-2.9	Sandy – clay loam	3.9-10.2

It is uncertain why NO_3–N and P levels were higher in the plots with dying native vegetation. One possibility could be that N and P were added to the soil profile through decomposition of dead leaves falling from the dying broadleaf plants to form litter. Under this scenario, die-off of willows within these plots would have been very recent since N and P do not remain available in the system for long durations. NO_3–N is very mobile and quickly flushed, and P becomes readily fixed.

Based on the soil sampling results, mortality of willows is unlikely to be linked to salt accumulation in the soils. There are a number of other factors that could be affecting the condition of the native species that were not measured, including shading and competition (i.e., density) as well as hydrologic variables such as depth to water table, chronology (length of time since last inundation, etc.), and flooding. Hydrology is the most probable reason for differences in the health of the two stands. Although the goal in choosing the location of the paired plots was to position them where hydrologic conditions were similar, this wasn't always necessarily the case due to limited options in finding plots with desired attributes in proximity to one another. Plots were always adjacent to each other, but some plots with dying vegetation were further from the river (e.g., SS01D, SS04D, SS06D, SS07D), and some plots with healthy vegetation were located nearer to canyon walls where springs or landscape depressions may have been a factor (e.g., SS09L, SS10L). The paired plots probably have a history of similar hydrology since vegetation is comparable, but may have recently incurred changes in the hydrologic regime, perhaps because of decreases in flow and reservoir levels.

Although hydrology is believed to be the factor having the strongest influence on the state of willow stands, there was no indication that hydrology was different between the two plot types based on observation of soil samples. Only one sample was collected from a site with saturated soils (SS02L), which would seemingly be the reason for the healthy willow stand at that site. No redoximorphic features were noted in any of the samples, the presence of which would indicate prolonged flooding at some time during the year. It was impossible to know how long, if at all, and to what depth any of the soils remained saturated since samples were collected at one point in time. Another consideration is how rapidly the water table decreased. Amlin and Rood (2002) found that water level declines of > 2 cm/d reduced the growth and survival of willow species, whereas declines of 1-2 cm/d promoted root elongation. Differences in the water table decline rates between plots could potentially affect the condition of the willows as well.

Photos of the sample sites are provided in Appendix B. A few of the plots are not included because photos at these sites were not produced due to camera malfunction or operator error.

Conclusions and Recommendations

More soil sampling should be conducted to further determine factors affecting the health of willow stands in the Middle Rio Grande near the Elephant Butte Reservoir delta. The following revisions to the sampling method are recommended to address issues discovered through this initial sampling effort.

- **Use a smaller diameter auger and collect more samples to form a composite sample at each plot site.** Sample SS05D had outlier values within the $NO\text{-}N_3$ and P test results. It was noted that this site showed signs of heavy cattle grazing (Table 1). It is possible that there was a concentration of urine in the sample, causing a huge spike in the amount of N and P collected. To avoid this spot variability, more samples (e.g., 5 to 10) could be collected using an auger with a 1 inch diameter. These samples could then be combined to a) make one composite sample per plot or b) analyzed separately to determine and isolate within-plot variability.

- **Document the depth and decomposition level of litter at each sample plot.** To determine if there is a difference in the amount of plant litter between the plots, which could be affecting the levels of N and P, the depth of litter and the level of decomposition should be recorded at each sampling point. The level of decomposition in the O (Organic) horizon (i.e., the litter horizon) is typically described using the following terminology (Brady 1990):

  Oi: Original plant and animal residues, only slightly decomposed
  Oe: Residues intermediately decomposed
  Oa: Residues highly decomposed

- **Establish shallow groundwater monitoring wells at each of the collection plots**. Although the addition of this feature in the sampling plan would increase time and money needed, it would be a valuable tool in determining potential causes of willow mortality in the area. Hydrology is the factor that is most likely affecting the condition of the vegetation. Groundwater monitoring wells would provide information not only on the duration of flooding and soil saturation (and if either occurs), but would also give an idea of the rate of water table decline and influence of water quality parameters.

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Appendix A

Laboratory Results of Soil Analyses

	----------paste-----------				-----AB-DTPA-----							Texture
Sample	pH	EC	Lime	%	-----ppm-----							Estimate
ID #		mmhos/cm	Estimate	OM	NO_3-N	P	K	Zn	Fe	Mn	Cu	
SS01L 0-6	7.5	0.8	High	1.5	1.0	3.7	185	1.89	81.8	4.00	2.42	Sandy Loam
SS01L 6-12	7.7	1.5	High	1.2	4.4	4.0	97.2	0.69	55.7	5.18	1.56	Sandy Loam
SS01 L 12-36	8.1	1.0	High	2.5	3.2	2.5	90.7	0.72	43.9	3.20	3.79	Loamy Sand
SS02 L 0-6	7.6	1.6	High	0.9	1.5	2.5	63.4	0.74	66.6	3.98	2.29	Loamy Sand
SS02 L 6-12	7.8	1.0	Low	0.9	0.9	1.8	43.1	0.54	37.9	2.03	1.21	Loamy Sand
SS02 L 12-36	8.1	1.9	High	0.7	1.6	2.5	85.8	0.59	34.3	2.22	2.91	Sandy Loam
SS03 L 0-6	8.3	0.3	High	0.2	2.6	7.4	109	0.41	13.6	1.53	1.03	Loamy Sand
SS03 L 6-12	8.2	0.5	High	0.4	6.8	2.8	111	0.43	33.1	1.28	1.29	Loamy Sand
SS03 L 12-36	7.7	2.3	High	0.7	4.2	3.1	68.3	0.60	42.3	1.79	2.68	Loamy Sand
SS04 L 0-6	7.6	1.3	High	2.0	10.2	6.2	225	1.95	47.2	3.14	4.68	Clay
SS04 L 6-12	7.7	0.8	High	1.2	2.9	4.9	93.5	0.95	41.8	2.21	2.64	Clay Loam
SS04 L 12-33	7.6	3.1	High	1.3	3.6	4.3	134	1.18	65.8	2.40	3.18	Clay Loam
SS05 L 0-6	8.0	0.4	High	0.3	5.3	8.1	103	0.39	14.6	1.37	1.41	Loamy Sand
SS05 L 6-12	7.8	0.5	High	0.3	6.1	4.6	80.7	0.35	24.2	1.12	1.24	Loamy Sand
SS05 L 12-36	7.8	0.7	High	1.9	14.1	4.9	105	1.09	58.4	2.13	4.93	Clay Loam
SS06 L 0-6	7.9	1.7	High	0.7	2.7	3.7	168	0.47	14.5	1.45	2.51	Loamy Sand
SS06 L 6-12	8.2	0.8	High	0.4	3.6	4.3	62.8	0.40	20.7	1.58	1.62	Loamy Sand
SS06 L 12-36	8.0	1.5	High	0.7	5.3	4.6	105	0.88	61.4	2.66	2.70	Sandy Loam
SS07 L 0-6	8.3	0.3	High	0.3	2.1	3.7	57.8	0.37	14.6	1.23	2.17	Loamy Sand
SS07 L 6-12	7.9	5.3	High	0.5	3.7	3.4	59.5	0.37	19.5	1.39	2.26	Loamy Sand
SS07 L 12-36	7.7	1.3	High	1.1	7.7	5.6	149	1.34	67.1	2.63	2.74	Sandy Loam
SS08 L 0-6	7.8	0.9	High	1.3	9.0	8.4	202	1.43	31.0	3.13	2.14	Sandy Loam
SS08 L 6-12	7.7	2.5	High	1.0	3.4	4.0	150	0.76	34.0	2.39	2.69	Sandy Loam
SS08 L 12-36	7.6	5.3	High	0.4	0.7	3.1	44.3	0.43	31.4	1.69	1.58	Loamy Sand
SS09 L 0-6	7.4	5.4	High	2.0	6.9	4.3	352	2.01	64.9	5.18	6.05	Clay
SS09 L 6-12	7.5	0.9	High	2.0	8.6	4.9	369	2.13	78.1	6.45	6.41	Clay
SS09 L 12-36	7.4	1.0	High	2.0	3.9	3.4	322	2.13	87.4	6.34	6.23	Clay
SS10 L 0-6	7.5	5.3	High	1.1	4.0	3.7	201	0.96	41.5	3.01	4.16	Clay Loam

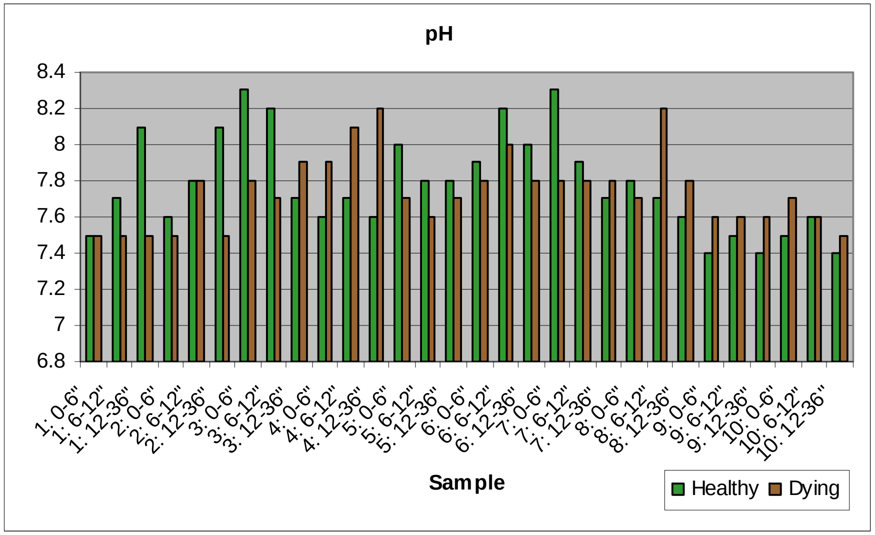
Sample ID #	pH	EC mmhos/cm	Lime Estimate	% OM	NO_3-N	P	K	Zn	Fe	Mn	Cu	Texture Estimate
	----------paste----------				----AB-DTPA---- ppm							
SS10 L 6-12	7.6	1.1	High	1.0	4.1	5.6	388	2.15	89.7	5.31	5.56	Clay
SS10 L 12-36	7.4	0.4	High	2.0	17.8	7.4	428	2.51	56.6	7.14	6.32	Clay
SS01 D 0-6	7.5	1.5	High	1.6	2.8	6.2	179	1.20	51.7	5.04	3.23	Clay Loam
SS01 D 6-12	7.5	1.1	High	1.7	4.3	5.6	205	1.24	45.8	3.81	3.44	Clay Loam
SS01 D 12-36	7.5	1.7	High	1.6	2.3	4.3	160	1.08	47.6	4.24	4.40	Clay Loam
SS02 D 0-6	7.5	1.2	High	1.1	3.4	4.1	125	0.92	5.2	3.40	2.80	Clay Loam
SS02 D 6-12	7.8	1.0	High	0.8	5.2	5.6	96.9	0.77	38.9	2.43	1.89	Sandy Loam
SS02 D 12-36	7.5	0.8	High	0.1	3.2	4.9	40.9	0.25	17.2	1.09	1.26	Loamy Sand
SS03 D 0-6	7.8	0.3	High	0.2	6.0	7.4	63.6	0.75	5.52	1.67	0.81	Loamy Sand
SS03 D 6-12	7.7	0.5	High	0.2	5.7	6.8	56.4	0.60	4.76	1.82	1.56	Loamy Sand
SS03 D 12-36 ??	7.9	0.3	High	0.1	1.5	2.5	39.0	0.20	6.30	1.41	2.08	Loamy Sand
SS04 D 0-6 ??	7.9	0.4	High	0.2	3.3	6.2	131	0.32	8.49	1.20	0.61	Loamy Sand
SS04 D 6-12	8.1	1.1	High	0.3	2.4	2.8	49.5	0.25	12.0	1.21	1.14	Loamy Sand
SS04 D 12-36	8.2	2.4	High	0.4	1.6	3.1	50.0	0.25	17.3	1.77	1.10	Loamy Sand
SS05 D 0-6	7.7	2.7	High	2.1	151	89.8	679	4.40	50.6	6.21	5.70	Clay Loam
SS05 D 6-12	7.6	3.0	High	1.2	165	8.4	417	2.73	61.2	6.79	7.37	Clay Loam
SS05 D 12-36	7.7	1.8	High	0.5	34.2	6.8	239	2.34	77.4	2.18	4.23	Clay
SS06 D 0-6	7.8	1.1	High	0.8	1.3	4.9	124	0.49	15.8	2.07	2.92	Loamy Sand
SS06 D 6-12	8.0	0.8	High	0.5	9.6	3.7	63.3	0.75	40.2	1.44	2.69	Loamy Sand
SS06 D 12-36	7.8	1.1	High	1.1	17.8	4.0	110	0.90	41.1	1.20	3.72	Loamy Sand
SS07 D 0-6	7.8	0.8	High	0.5	32.7	16.8	305	2.51	33.8	3.39	2.20	Sandy Loam
SS07 D 6-12	7.8	1.2	High	0.8	18.6	4.9	86.6	0.48	19.4	1.38	1.91	Loamy Sand
SS07 D 12-36	7.8	2.5	High	1.6	16.3	5.6	143	0.80	39.3	1.70	2.50	Loamy Sand
SS08 D 0-6	7.7	2.2	High	0.3	2.0	3.1	263	1.09	42.4	2.58	2.99	Loam
SS08 D 6-12	8.2	1.2	High	0.7	0.8	3.4	89.2	0.42	23.2	1.99	1.24	Loamy Sand
SS08 D 12-36	7.8	1.9	High	3.0	2.3	4.3	100	0.64	43.8	2.32	2.49	Loamy Sand
SS09 D 0-6	7.6	1.9	High	1.6	22.6	6.5	431	3.08	90.7	6.08	5.47	Clay
SS09 D 6-12	7.6	0.8	High	1.6	17.5	4.6	401	1.90	83.8	5.44	5.74	Clay
SS09 D 12-36	7.6	0.6	High	1.6	9.8	4.6	400	2.13	88.2	6.99	8.81	Clay

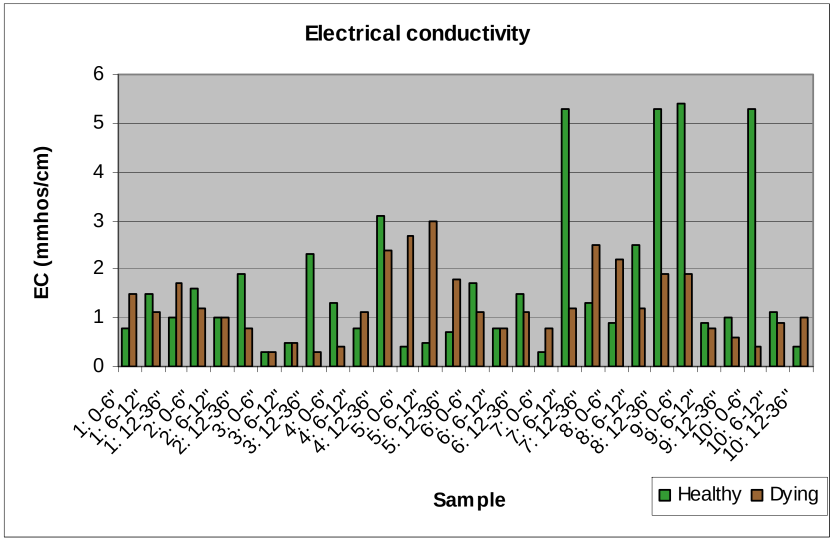
	----------paste-----------				----------AB-DTPA----------							Texture
Sample	**pH**	**EC**	**Lime**	**%**	----------ppm----------							**Estimate**
ID #		**mmhos/cm**	**Estimate**	**OM**	**NO_3-N**	**P**	**K**	**Zn**	**Fe**	**Mn**	**Cu**	
SS10 D 0-6	7.7	0.4	High	2.4	23.8	4.6	446	1.66	59.8	5.65	5.54	Clay
SS10 D 6-12	7.6	0.9	High	3.4	27.1	7.8	431	2.27	90.3	5.07	6.49	Clay
SS10 D 12-36	7.5	1.0	High	5.4	19.4	8.4	354	2.51	95.8	5.70	6.93	Clay

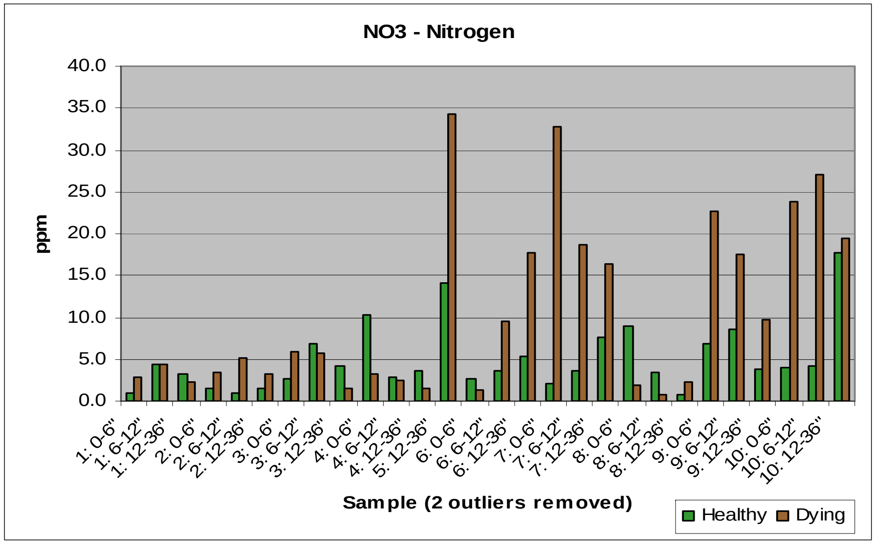
Sample ID #	Ca	Mg	Na	K	SAR	Sample ID #	Ca	Mg	Na	K	SAR
	---meq/L---						---meq/L---				
SS01 L 0-6	3.4	1.4	3.2	0.5	2.1	SS01 D 0-6	7.5	2.7	6.0	0.4	2.6
SS01 L 6-12	4.6	2.0	8.4	0.3	4.6	SS01 D 6-12	5.2	2.0	3.9	0.3	2.1
SS01 L 12-36	2.4	0.8	5.4	0.2	4.2	SS01 D 12-36	8.9	3.9	6.0	0.3	2.4
SS02 L 0-6	10.3	3.4	4.3	0.5	1.6	SS02 D 0-6	0.0	0.0	0.0	0.0	0.1
SS02 L 6-12	4.7	1.7	3.7	0.3	2.1	SS02 D 6-12	3.3	0.9	5.7	0.3	3.9
SS02 L 12-36	6.6	4.0	9.8	0.6	4.2	SS02 D 12-36	3.3	0.8	3.6	0.2	2.6
SS03 L 0-6	1.1	0.4	0.5	0.5	0.6	SS03 D 0-6	1.3	0.8	0.5	0.4	0.5
SS03 L 6-12	1.6	1.0	1.7	0.4	1.5	SS03 D 6-12	2.2	1.2	0.6	0.5	0.5
SS03 L 12-36	7.0	3.6	13.7	0.3	6.0	SS03 D 12-36	1.3	0.5	0.5	0.3	0.5
SS04 L 0-6	6.2	2.4	4.4	0.4	2.1	SS04 D 0-6	1.5	0.6	1.2	0.9	1.2
SS04 L 6-12	3.1	1.1	3.2	0.1	2.2	SS04 D 6-12	3.6	1.9	4.9	0.2	2.9
SS04 L 12-36	15.8	6.7	11.4	0.5	3.4	SS04 D 12-36	4.4	3.2	15.4	0.3	8.0
SS05 L 0-6	1.6	0.6	0.5	0.6	0.5	SS05 D 0-6	19.0	7.7	7.8	1.8	2.1
SS05 L 6-12	2.7	0.9	0.7	0.3	0.6	SS05 D 6-12	18.5	6.4	5.7	0.8	1.6
SS05 L 12-36	4.4	1.8	1.8	0.2	1.0	SS05 D 12-36	11.1	4.2	5.1	0.4	1.8
SS06 L 0-6	9.3	3.6	5.1	0.9	2.0	SS06 D 0-6	3.8	1.8	2.4	0.6	1.4
SS06 L 6-12	2.8	1.0	3.8	0.2	2.7	SS06 D 6-12	5.4	2.2	4.0	0.1	2.0
SS06 L 12-36	7.9	3.1	5.3	0.3	2.2	SS06 D 12-36	6.2	2.5	3.3	0.2	1.6
SS07 L 0-6	1.1	0.3	0.6	0.1	0.7	SS07 D 0-6	4.4	1.9	1.9	0.7	1.1
SS07 L 6-12	1.7	0.6	1.4	0.1	1.3	SS07 D 6-12	4.8	2.0	4.5	0.3	2.4
SS07 L 12-36	7.2	2.7	4.4	0.3	2.0	SS07 D 12-36	13.0	5.4	9.3	0.5	3.1
SS08 L 0-6	3.0	1.2	4.1	0.5	2.8	SS08 D 0-6	7.3	4.1	12.6	0.6	5.3
SS08 L 6-12	15.0	5.7	10.6	0.3	3.3	SS08 D 6-12	2.5	1.2	8.1	0.2	6.0
SS08 L 12-36	5.3	2.0	4.4	0.3	2.3	SS08 D 12-36	6.6	2.7	10.5	0.3	4.9
SS09 L 0-6	6.4	2.1	2.5	0.4	1.2	SS09 D 0-6	4.4	1.5	2.2	0.3	1.3
SS09 L 6-12	5.3	2.0	2.2	0.3	1.1	SS09 D 6-12	3.1	1.2	2.5	0.2	1.7
SS09 L 12-36	5.2	2.1	3.7	0.3	1.9	SS09 D 12-36	2.5	0.9	2.3	0.2	1.8
SS10 L 0-6	7.5	3.5	7.1	0.4	3.0	SS10 D 0-6	4.6	1.8	2.7	0.3	1.5
SS10 L 6-12	5.4	2.1	4.0	0.3	2.1	SS10 D 6-12	4.7	1.9	2.7	0.3	1.5
SS10 L 12-36	5.7	2.2	2.8	0.5	1.4	SS10 D 12-36	5.8	2.2	3.7	0.3	1.9

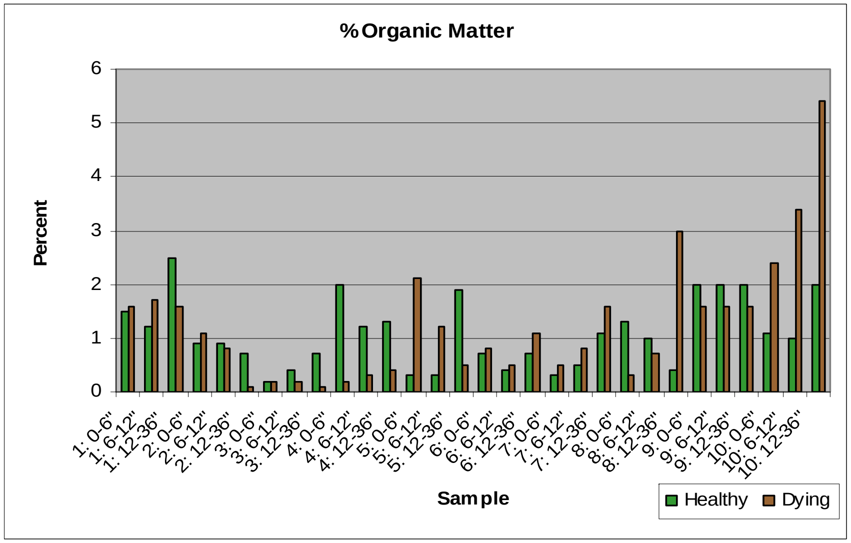
Appendix B

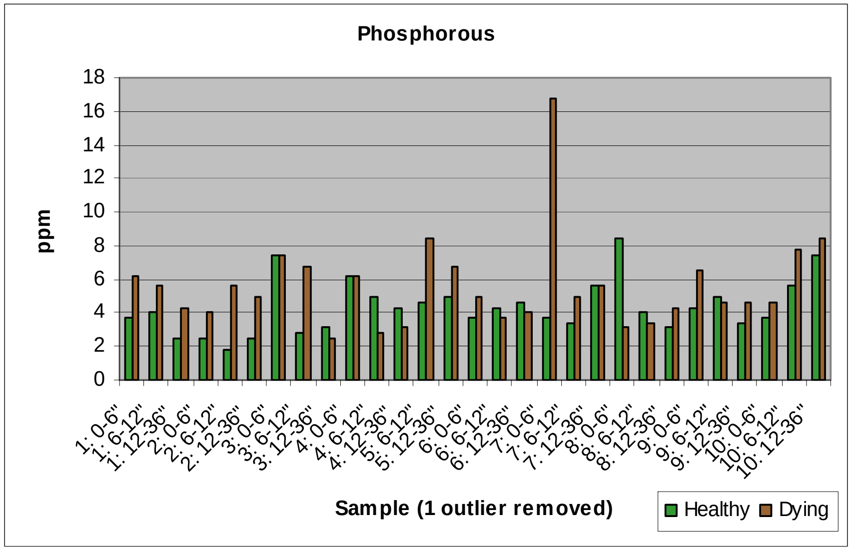
Sample Comparisons of Each Parameter

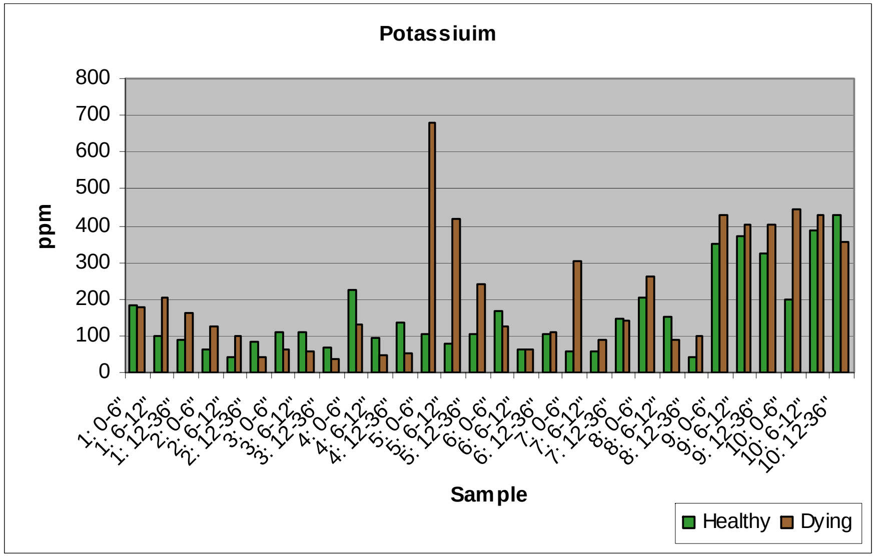

pH
8.4
8.2
8
7.8
7.6
7.4
7.2
7
6.8
1: 0-6"
1: 6-12"
1: 12-36"
2: 0-6"
2: 6-12"
2: 12-36"
3: 0-6"
3: 6-12"
3: 12-36"
4: 0-6"
4: 6-12"
4: 12-36"
5: 0-6"
5: 6-12"
5: 12-36"
6: 0-6"
6: 6-12"
6: 12-36"
7: 0-6"
7: 6-12"
7: 12-36"
8: 0-6"
8: 6-12"
8: 12-36"
9: 0-6"
9: 6-12"
9: 12-36"
10: 0-6"
10: 6-12"
10: 12-36"
Sample
Healthy
Dying

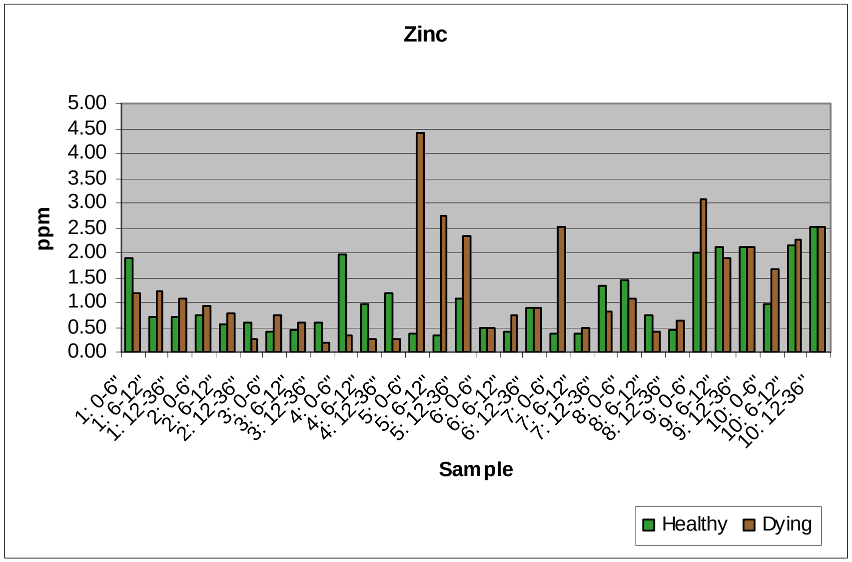

Electrical conductivity
EC (mmhos/cm)
6
5
4
3
2
1
0
Sample
Healthy
Dying

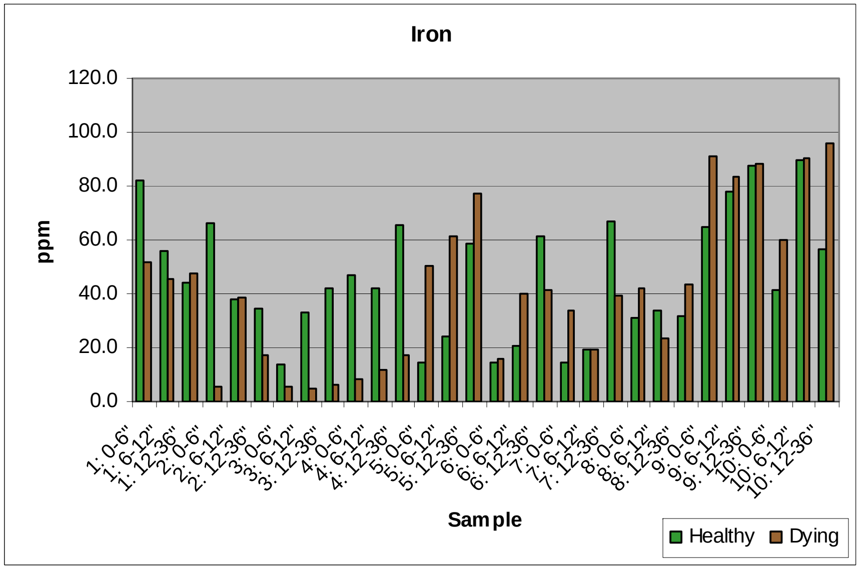

NO3 - Nitrogen
ppm
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
Sample (2 outliers removed)
Healthy
Dying

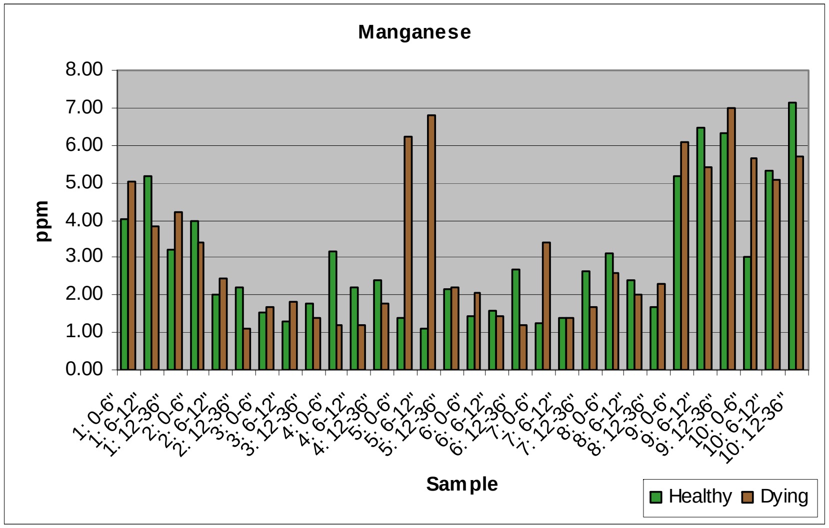

% Organic Matter
Percent
6
5
4
3
2
1
0
Sample
Healthy
Dying

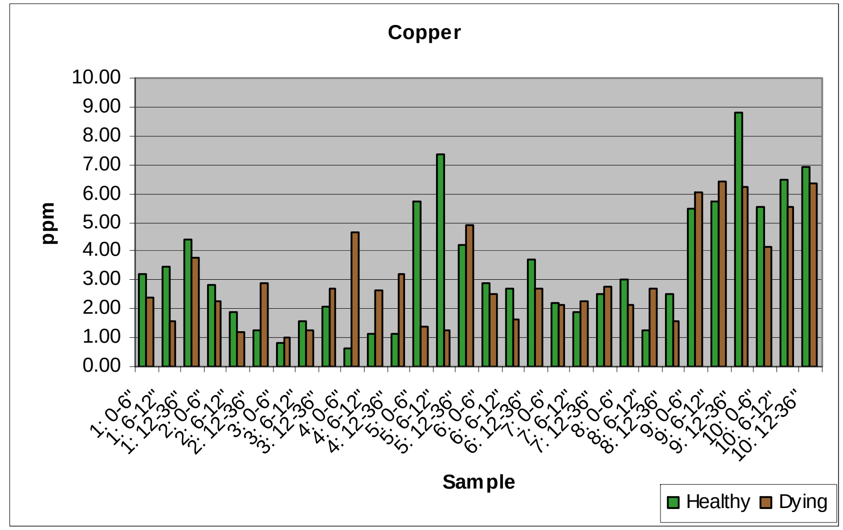

Phosphorous
ppm
Sample (1 outlier removed)
Healthy
Dying

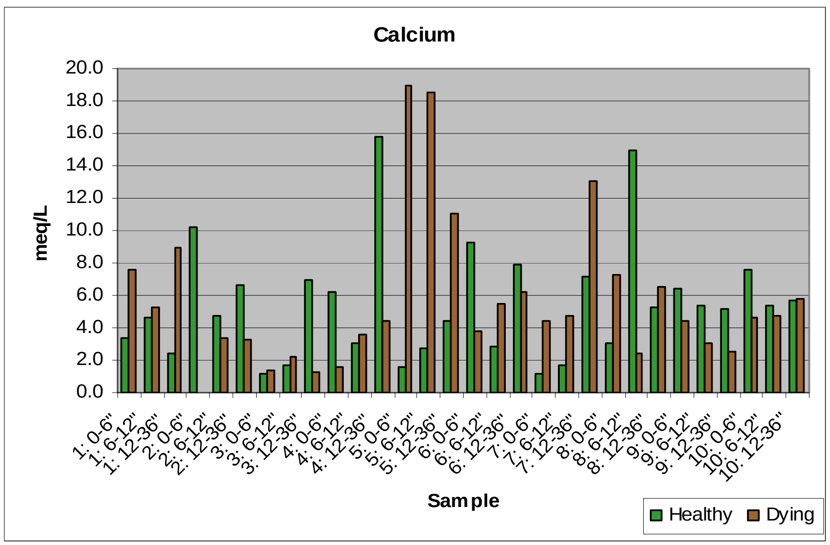

Potassiuim
ppm
Sample
Healthy
Dying

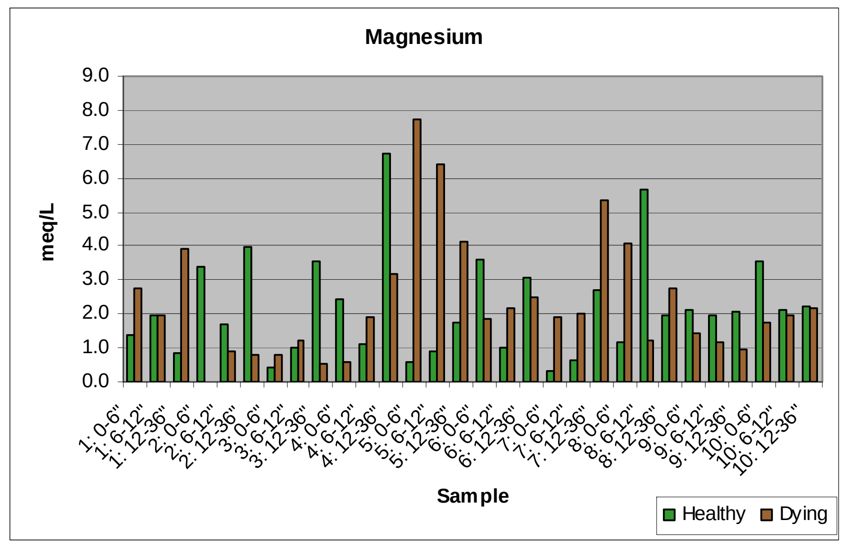

Zinc
ppm
Sample
Healthy
Dying

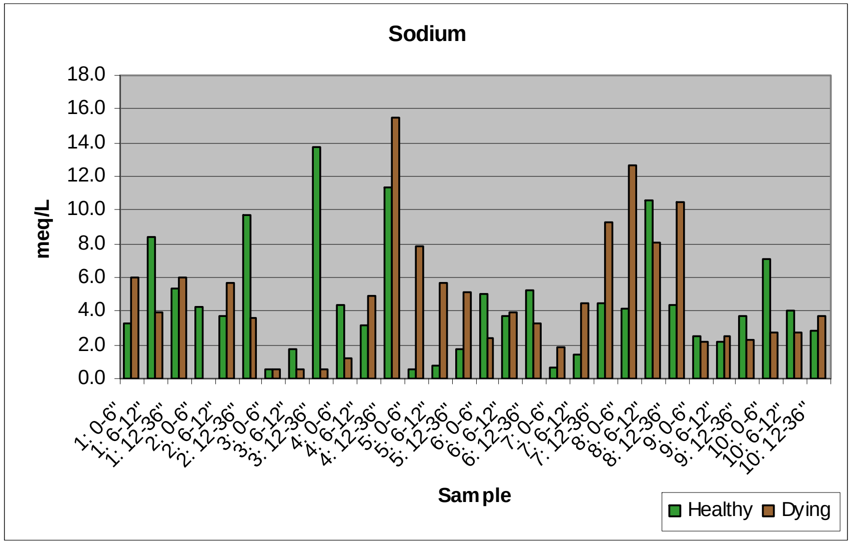

Iron
ppm
Sample
Healthy
Dying

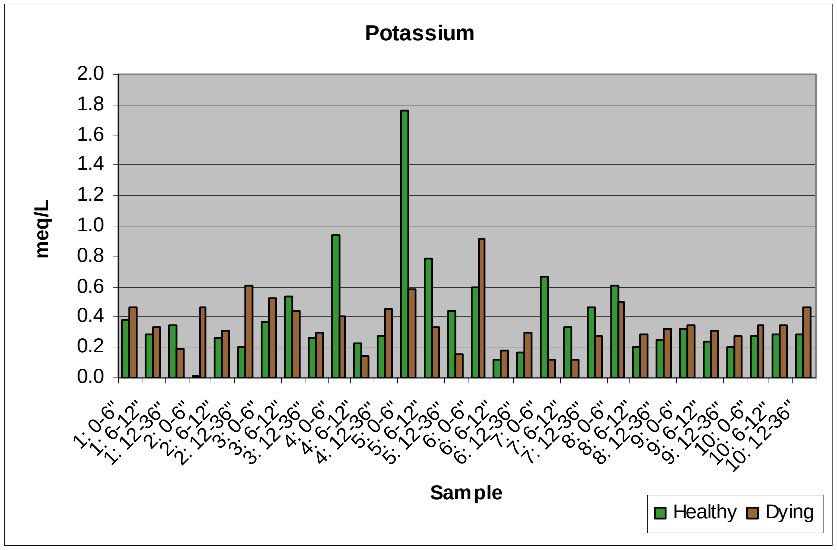

Manganese
ppm
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
1: 0-6"
1: 6-12"
1: 12-36"
2: 0-6"
2: 6-12"
2: 12-36"
3: 0-6"
3: 6-12"
3: 12-36"
4: 0-6"
4: 6-12"
4: 12-36"
5: 0-6"
5: 6-12"
5: 12-36"
6: 0-6"
6: 6-12"
6: 12-36"
7: 0-6"
7: 6-12"
7: 12-36"
8: 0-6"
8: 6-12"
8: 12-36"
9: 0-6"
9: 6-12"
9: 12-36"
10: 0-6"
10: 6-12"
10: 12-36"
Sample
Healthy
Dying

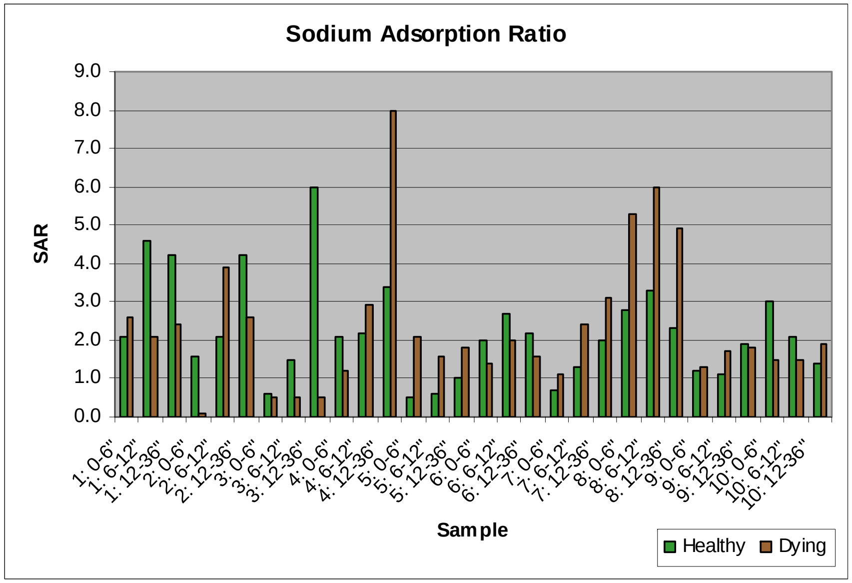

Copper
ppm
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
1: 0-6"
1: 6-12"
1: 12-36"
2: 0-6"
2: 6-12"
2: 12-36"
3: 0-6"
3: 6-12"
3: 12-36"
4: 0-6"
4: 6-12"
4: 12-36"
5: 0-6"
5: 6-12"
5: 12-36"
6: 0-6"
6: 6-12"
6: 12-36"
7: 0-6"
7: 6-12"
7: 12-36"
8: 0-6"
8: 6-12"
8: 12-36"
9: 0-6"
9: 6-12"
9: 12-36"
10: 0-6"
10: 6-12"
10: 12-36"
Sample
Healthy
Dying


Calcium
meq/L
20.0
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
1: 0-6"
1: 6-12"
1: 12-36"
2: 0-6"
2: 6-12"
2: 12-36"
3: 0-6"
3: 6-12"
3: 12-36"
4: 0-6"
4: 6-12"
4: 12-36"
5: 0-6"
5: 6-12"
5: 12-36"
6: 0-6"
6: 6-12"
6: 12-36"
7: 0-6"
7: 6-12"
7: 12-36"
8: 0-6"
8: 6-12"
8: 12-36"
9: 0-6"
9: 6-12"
9: 12-36"
10: 0-6"
10: 6-12"
10: 12-36"
Sample
Healthy
Dying


Magnesium
meq/L
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
1: 0-6"
1: 6-12"
1: 12-36"
2: 0-6"
2: 6-12"
2: 12-36"
3: 0-6"
3: 6-12"
3: 12-36"
4: 0-6"
4: 6-12"
4: 12-36"
5: 0-6"
5: 6-12"
5: 12-36"
6: 0-6"
6: 6-12"
6: 12-36"
7: 0-6"
7: 6-12"
7: 12-36"
8: 0-6"
8: 6-12"
8: 12-36"
9: 0-6"
9: 6-12"
9: 12-36"
10: 0-6"
10: 6-12"
10: 12-36"
Sample
Healthy
Dying


Sodium
meq/L
Sample
Healthy
Dying


Potassium
meq/L
Sample
Healthy
Dying


Sodium Adsorption Ratio
SAR
Sample
Healthy
Dying

Appendix C

Photos of Sample Plots

SS01L-Healthy

SS01D–Dying

SS02L–Healthy

No Photo

SS02D-Dying

SS03L–Healthy, from inside

SS03L-from outside

SS03D - Dying

No Photo

SS04L–Healthy, from inside

SS04L-from outside

SS04D-Dying, from outside

SS05L-Healthy

SS05D-Dying

SS06L-Healthy

SS06D-Dying

SS07L-Healthy, from inside

SS07L-from across river

SS07D-Dying

SS07D-into canopy

SS08L-Healthy

SS08D-Dying

SS09L-Healthy,from outside

SS09D-Dying

SS10L-Healthy, from inside

SS10L-from outside

SS10D-Dying, from inside

SS10D-from outside