Project	Rainfall impact on sodium leaching at Denver Country Club
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Sponsor	Denver Country Club

Summary

This study evaluated the impact of 2.5 inches of rainfall over 36 hours on soil sodium and salinity. Following rainfall, sodium dropped from an average of 133 ppm to 77 ppm, a 41% reduction after rainfall. Soil salinity dropped from 0.95 dS/m to 0.77 dS/m, a 19% reduction following rainfall. Two major components of soil salinity, sulfur and chloride also dropped dramatically. Soil sulfur dropped from 63 ppm to 21 ppm, a 67% reduction following rainfall. Soil chloride dropped from 29 ppm to 6.6 ppm, a 77% reduction following rainfall.

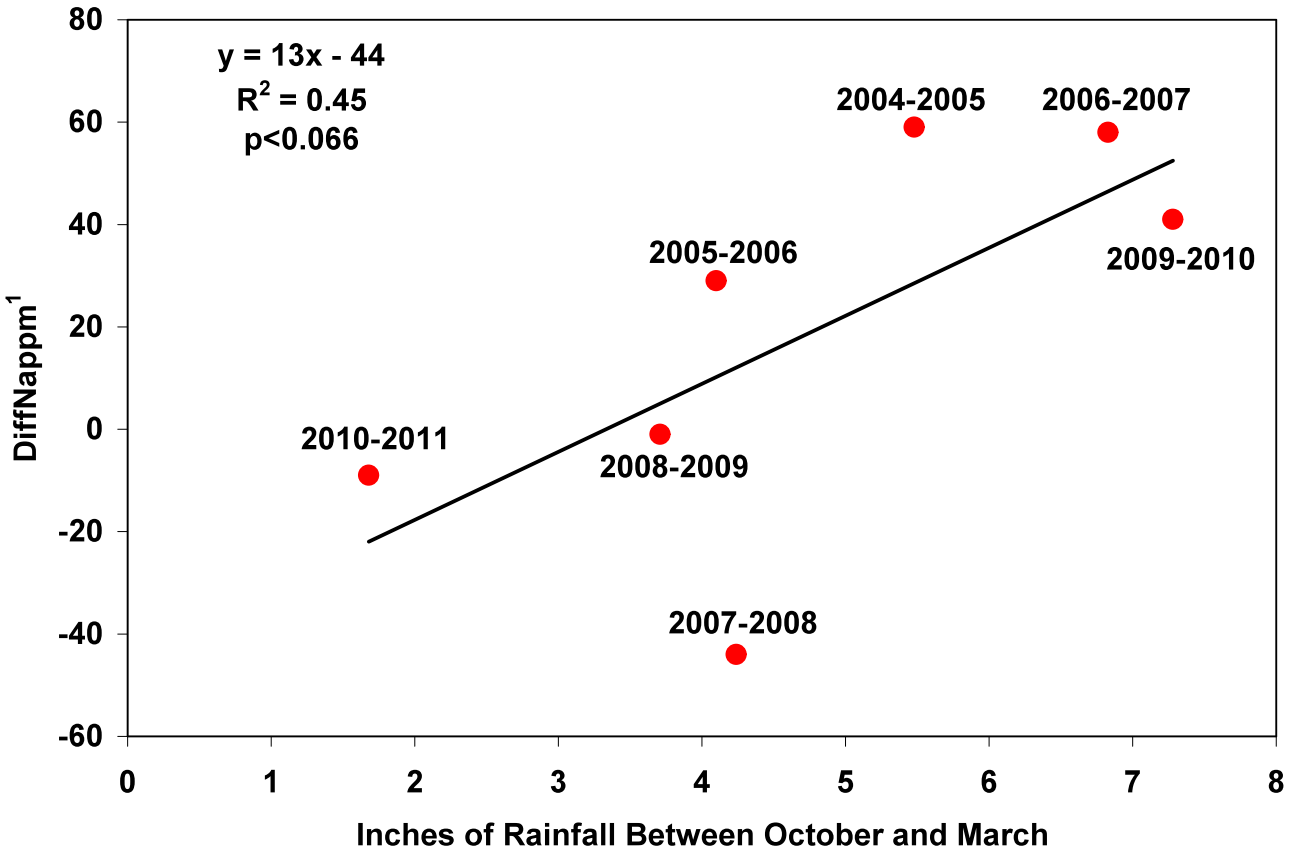
High soil sodium (more than 110 ppm) and high soil salts (more than 2 dS/m) have been associated with severe rapid blight caused by Labyrinthula terrestris on poa annua. To avoid this disease, low sodium and salt levels are targeted. Unfortunately, at Denver Country Club, a high sodium well water must be used periodically for irrigation during the winter months. The result is rapid accumulation of sodium in the soil to levels that may exceed 110 ppm. Depending upon the amount of winter rainfall and snow melt, the sodium deposited by periodic winter irrigation may be leached from the soil surface. During low rainfall winters, sodium can accumulate. Figure 1 illustrates the relationship between spring soil sodium and winter precipitation. During low rainfall years, sodium accumulates in the root zone. In heavy rainfall years, sodium is washed out of the soil profile.

This study provides further demonstration that rainfall quantity and timing can play a critical role in management of soil chemistry when high salt irrigation waters are used for irrigation.

Methods

Greens 5, 9 and 15 were selected for comparison of before and after rainfall soil quality factors. Before-rainfall analyses were conducted in March of 2011. Soil cores were collected to a depth of 4 inches and the thatch layer removed. After-rainfall soil samples were collected on May 19th, after 2.5 inches of rain fell over a period of 36 hours (See Figure 1 and personal communication, Ben Getman, Denver Country Club). Soils were analyzed by Brookside Laboratories, New Knoxville, OH. Analytical procedures are listed in Appendix A.

Figure 1. Accumulation of sodium following use of high-sodium and high-bicarbonate well water during the months of October through March (greens). Fall soil sodium ppm minus spring soil sodium ppm (DiffNappm) reflects leaching due to rainfall balanced against sodium applied when well water is used for irrigation during the months of October through March. Negative values for DiffNappm indicates that sodium levels accumulated during the months of October through March. Positive values indicate a reduction in sodium during this time period due to leaching rainfall. Use of low-sodium domestic water for irrigation during this period might help prevent accumulation of sodium. The p value of 0.066 indicates that there is roughly a 7% chance that the regression is due to chance.



[1]DifNappm = (fall soil Na ppm) – (spring Na ppm)

Figure 2. Average fall and spring soil sodium levels by year for greens. The target soil sodium guideline to suppress rapid blight is less than 110 ppm soil sodium. Some fall and spring samples exceed this maximum target. Since 2007, fall sodium levels have been increasing toward the 110 ppm maximum threshold target making winter sodium leaching more critical.

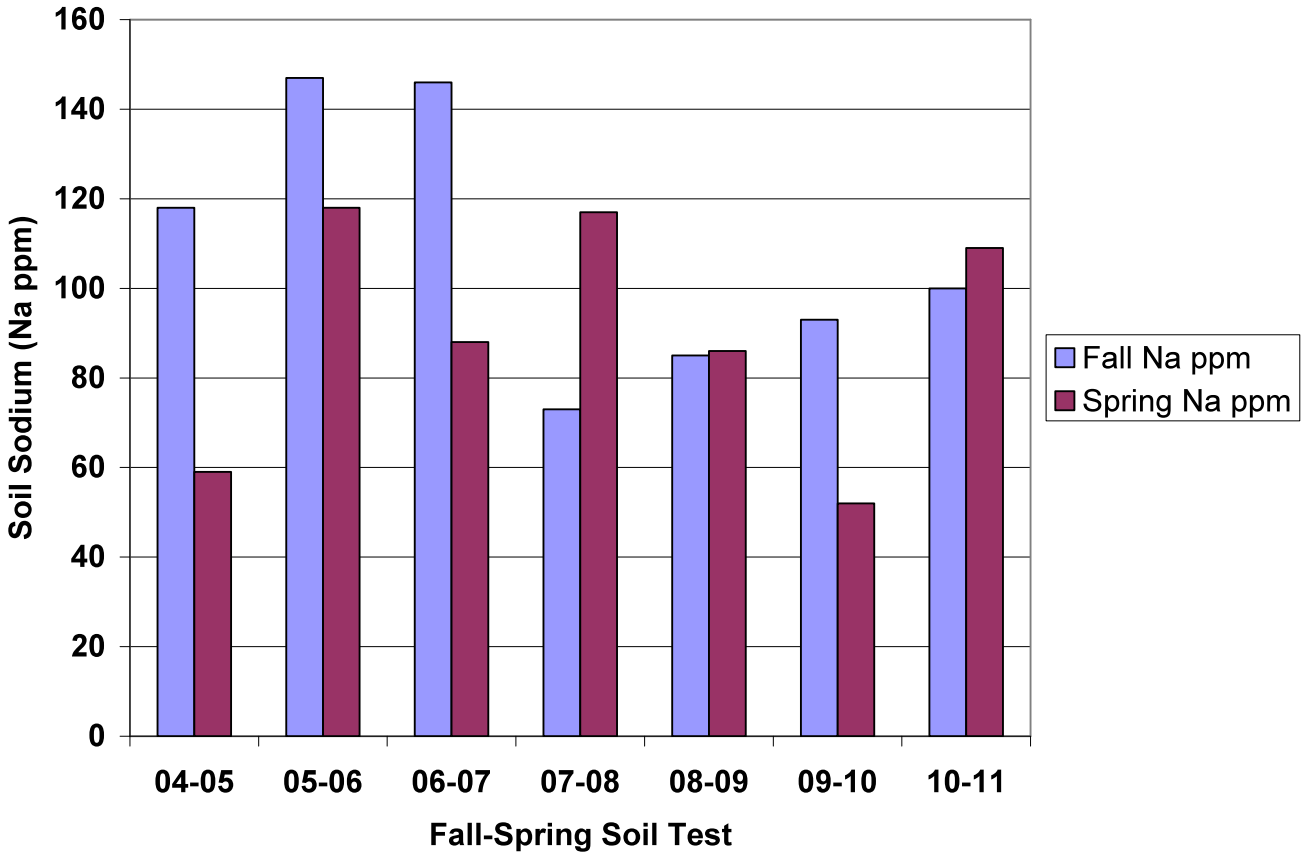


Figure 3. Summer season rainfall in inches (May, June, July, August, September, and October) by year for Denver. Summer season rainfall totals are a summation of precipitation for the months of May through September.

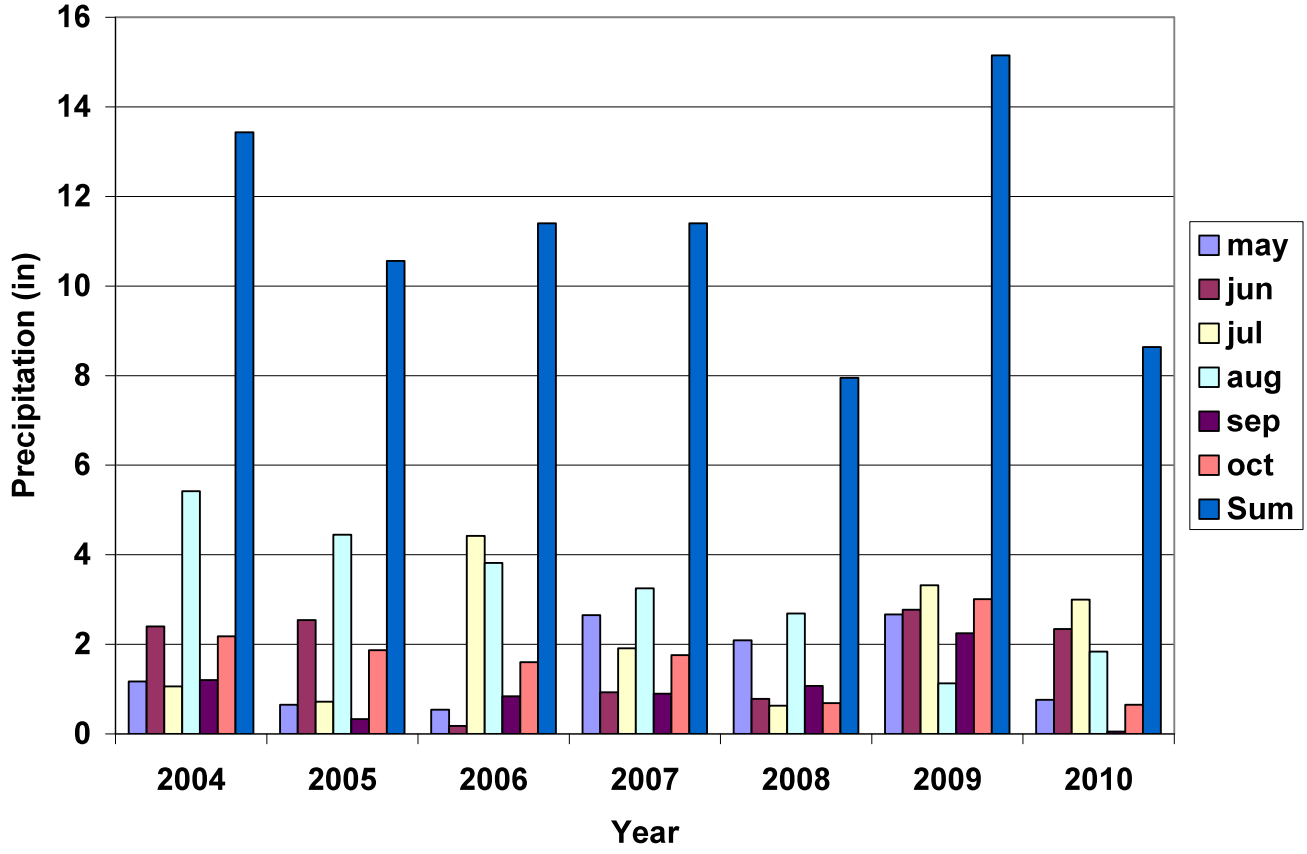


Figure 4. Winter season rainfall in inches (November, December, January, February, March, and April) by year for Denver. Winter rainfall totals are a summation of the precipitation for the months of October through March – prior to spring soil sample collection.

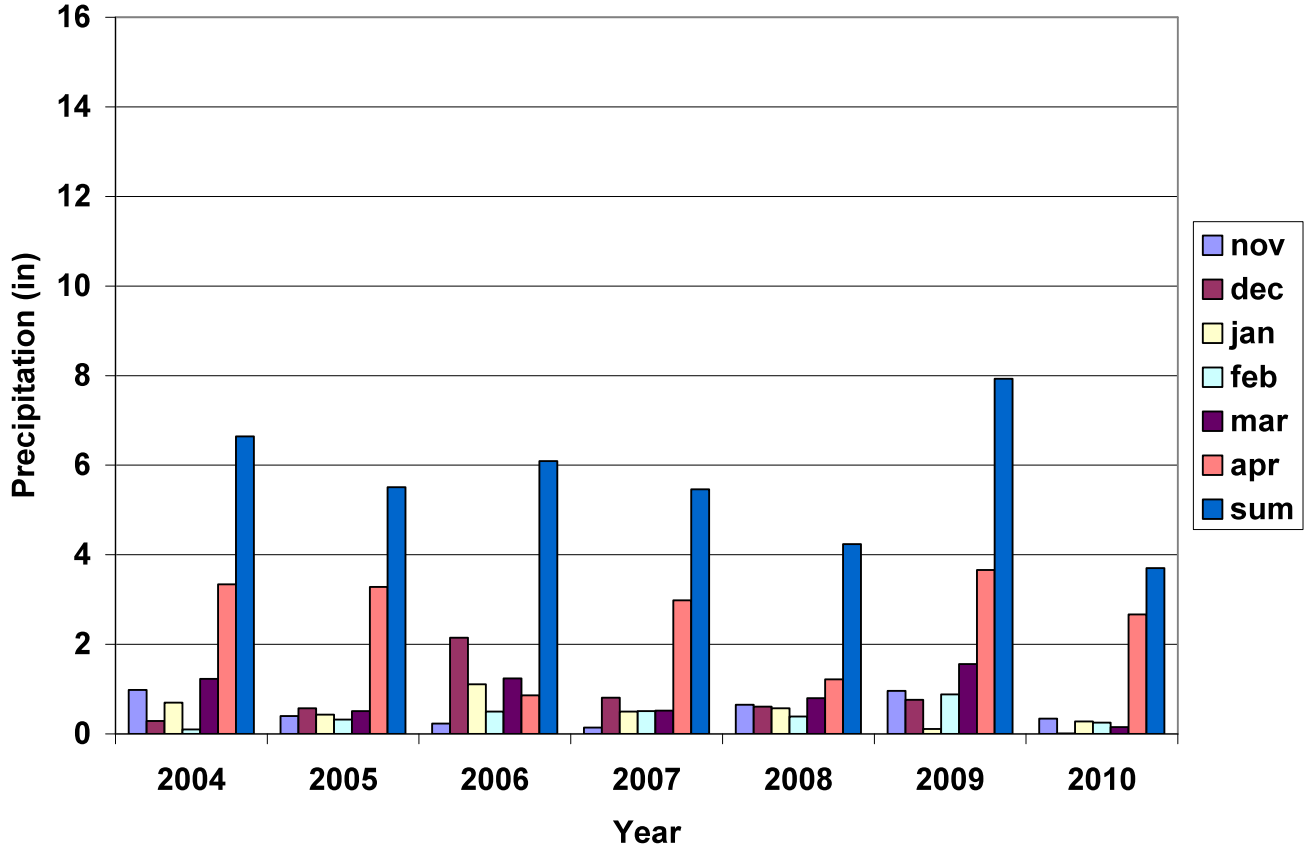


Table 1. Recycled, well water used during the winter months and domestic water comparison and City Ditch water that was used prior to acceptance of recycled water.

Parameter	7/12/2004 City Ditch	Well 5 pond	Well 14 pond	Domestic	Recycled Ditch	Proposed Recycled
Electrical Conductivity EC (dS/m)	0.4	**1.2**	**1.3**	0.33	**0.9**	<0.82
Total Dissolved Salts TDS (ppm)	224	**793**	**806**	208	**587**	<525
pH	6.5	7.8	7.8	7.3	7.5	6.5 - 7.8
Sodium Adsorption Ratio SAR	0.9	2.5	3.0	1.2	**4.0**	<3.1
Bicarbonate HCO_3 (ppm)	1.2	**377**	**391**	**98**	**108**	<50
Sodium Na (ppm)	22	**117**	**138**	28	**118**	<100
Boron B (ppm)	ND[1]	0.4	0.3	ND	0.2	<0.5
Chloride Cl (ppm)	22	**109**	**106**	25	**112**	<90
Nitrate-N NO_3 (ppm)	0.4	1.5	1.4	0.2	**17**	<8.0

ND[1]: None detected

Figure 5. Rainfall during May 2011, Denver Colorado (Source: The WeatherUnderground).

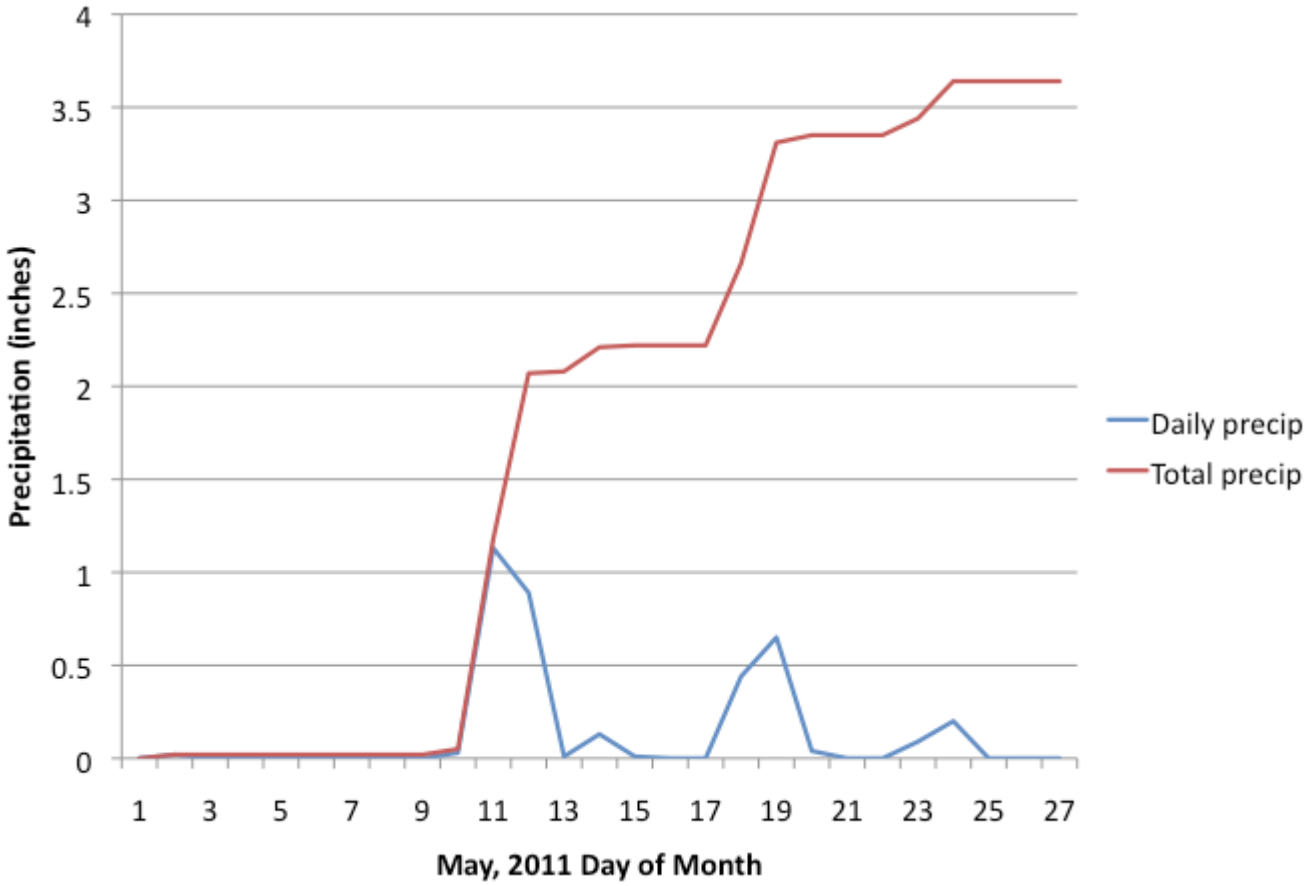
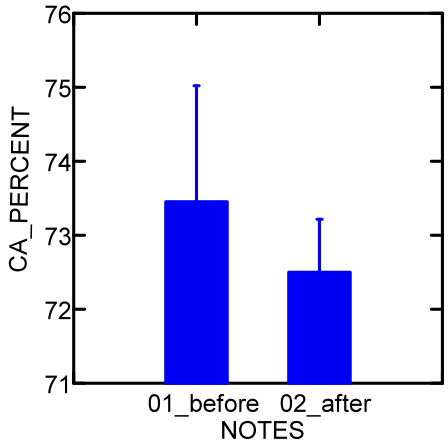


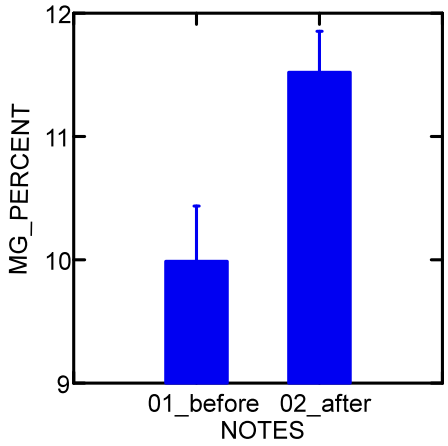
Table 2. Changes in key soil quality factors following 2.5 inches of rainfall.
Values highlighted in green are significantly different (P<0.05). Values represent the average of samples analyzed before and after rainfall.

Parameter	Before 2.5 inch rain	After 2.5 inch rain	P[1]
pH	7.5	7.7	0.124
Organic Matter (OM%)	2.5	2.1	0.053
Sulfur (SO4-S ppm)	63	21	0.001
Phosphorous (P Bray ppm)	316	224	0.348
Calcium (Ca ppm)	1269	941	0.166
Magnesium (Mg ppm)	105	91	0.474
Potassium (K ppm)	193	174	0.526
Sodium (Na ppm)	133	79	0.018
Calcium percentage	73	73	0.506
Magnesium percentage	10	12	0.022
Potassium percentage	5.8	6.9	0.030
Sodium percentage	6.9	5.4	0.216
Electrical Conductivity (EC dS/m)	0.95	0.77	0.013
Chloride (Cl ppm)	29	6.6	0.049
Boron (B ppm)	0.89	1.10	0.047
Iron (Fe ppm)	432	345	0.038
Manganese (Mn ppm)	19	34	0.061
Copper (Cu ppm)	5.9	8.9	0.271
Zinc (Zn ppm)	29	20	0.297
Ammonium nitrogen (NH4 ppm)	0.47	0.57	0.868
Nitrate nitrogen (NO3 ppm)	1.8	2.6	0.462
Total nitrogen (TOTN ppm)	2.3	36.2	0.545

[1]P = Fisher's Protected LSD probability that the values are the same

Figure 1. Greens soil cations reported in percentage of total extractable cations.
Desired values are: Calcium (Ca) 68%, Magnesium (Mg) 12 - 20%, sodium (Na) less than 3%.





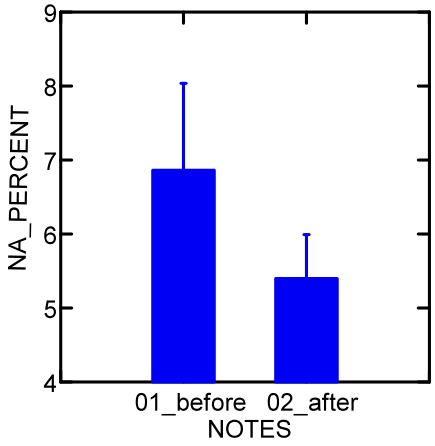
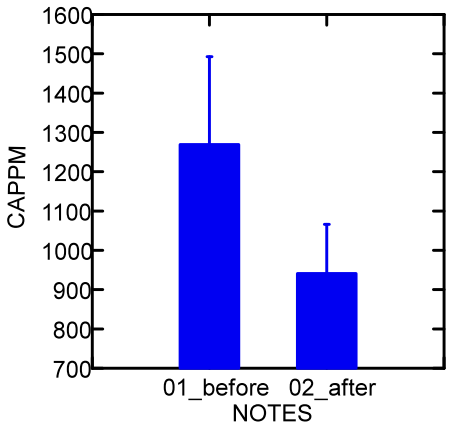
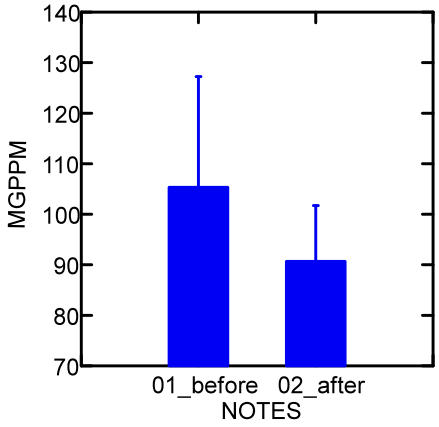


Figure 2. Greens soil cations reported in parts per million (ppm).
Desired values are calcium (Ca) greater than 750 ppm, magnesium (Mg) greater than 140 ppm, and sodium (Na) less than 110 ppm.





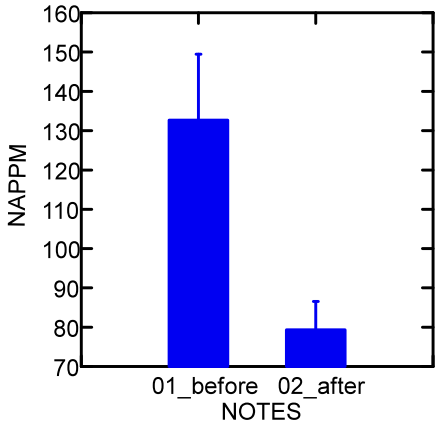
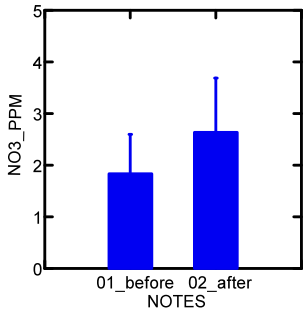


Figure 3. Greensand soil plant available nitrogen values reported in parts per million (ppm), potassium (K ppm and K%) and phosphorous (P2O5).
Desired values are: Nitrate (NO_3) between 3 and 20 ppm, ammonium (NH_4) less than 7 ppm, nitrate:ammonium (NO_3NH_4) ratio greater than 3:1, and total plant available nitrogen less than 20 ppm. Potassium levels above 110 ppm are desired and phosphorous (BrayIIP) above 50 ppm is optimal.


NO3_PPM
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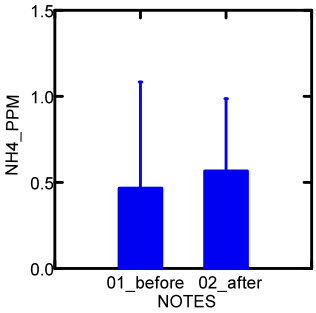
4
3
2
1
0
01_before
02_after
NOTES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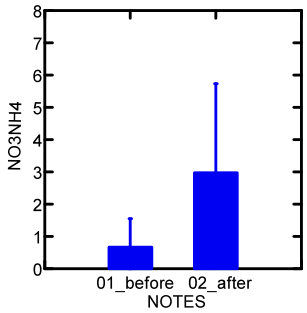
1.0
0.5
0.0
01_before
02_after
NOTES


NO3NH4
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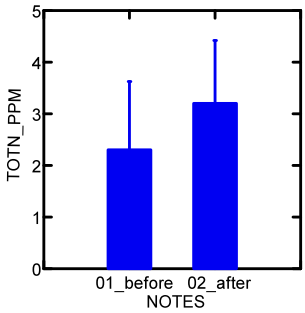
7
6
5
4
3
2
1
0
01_before
02_after
NOTES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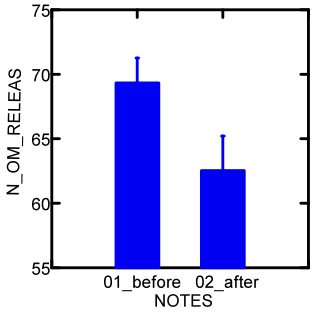
4
3
2
1
0
01_before
02_after
NOTES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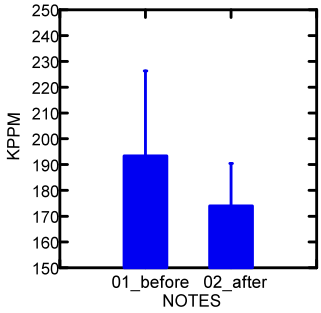
70
65
60
55
01_before
02_after
NOTES


KPPM
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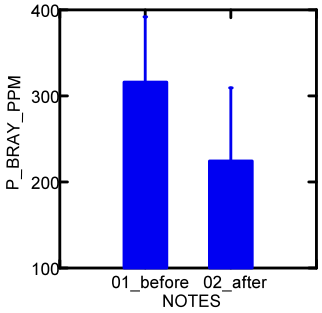
220
210
200
190
180
170
160
150
01_before
02_after
NOTES


P_BRAY_PPM
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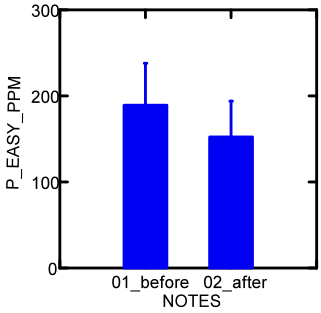
300
200
100
01_before
02_after
NOTES


P_EASY_PPM
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200
100
0
01_before
02_after
NOTES

Figure 4. Greens soil pH, sulfate (ppm), organic matter (percentage) and electrical conductivity (EC dS/m).

Desired values are: pH between 6.2 and 7.4, sulfate between 15 and 130 ppm, organic matter less than 2% for greens and less than 4% for fairways, electrical conductivity less than 3 dS/m for poa greens, less than 4 dS/m for bentgrass greens, less than 6 dS/m for ryegrass and tall fescue, less than 8 dS/m for bermuda and less than 12 dS/m for paspalum. Chloride less than 90 ppm for Poa, 400 ppm for bentgrass and ryegrass, and less than 1300 ppm for warm season grasses. The sum of Cl and S (CLPPM_SPPM) should not exceed 200 ppm for poa, 800 ppm for bentgrass and ryegrass, and 1300 ppm for warm season grasses.

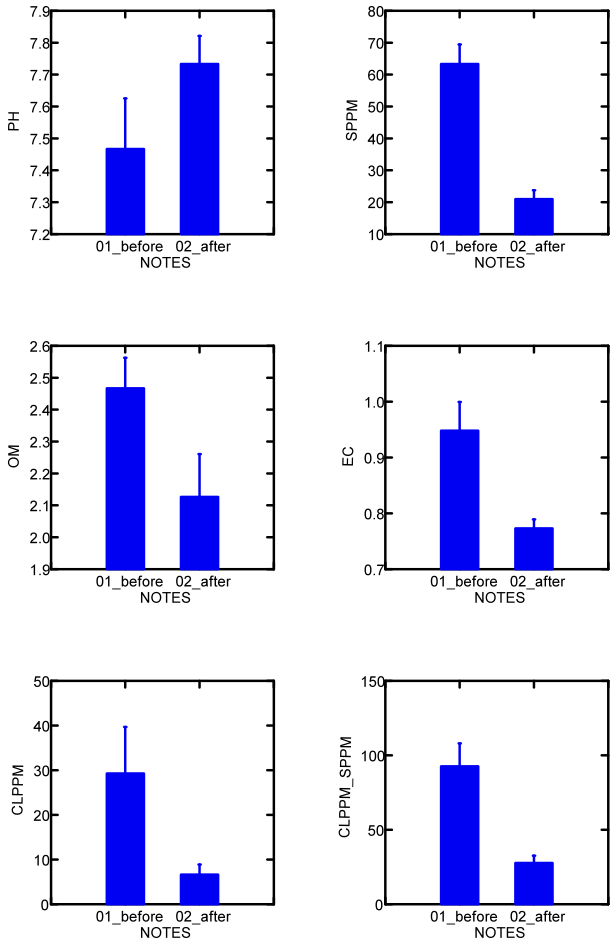
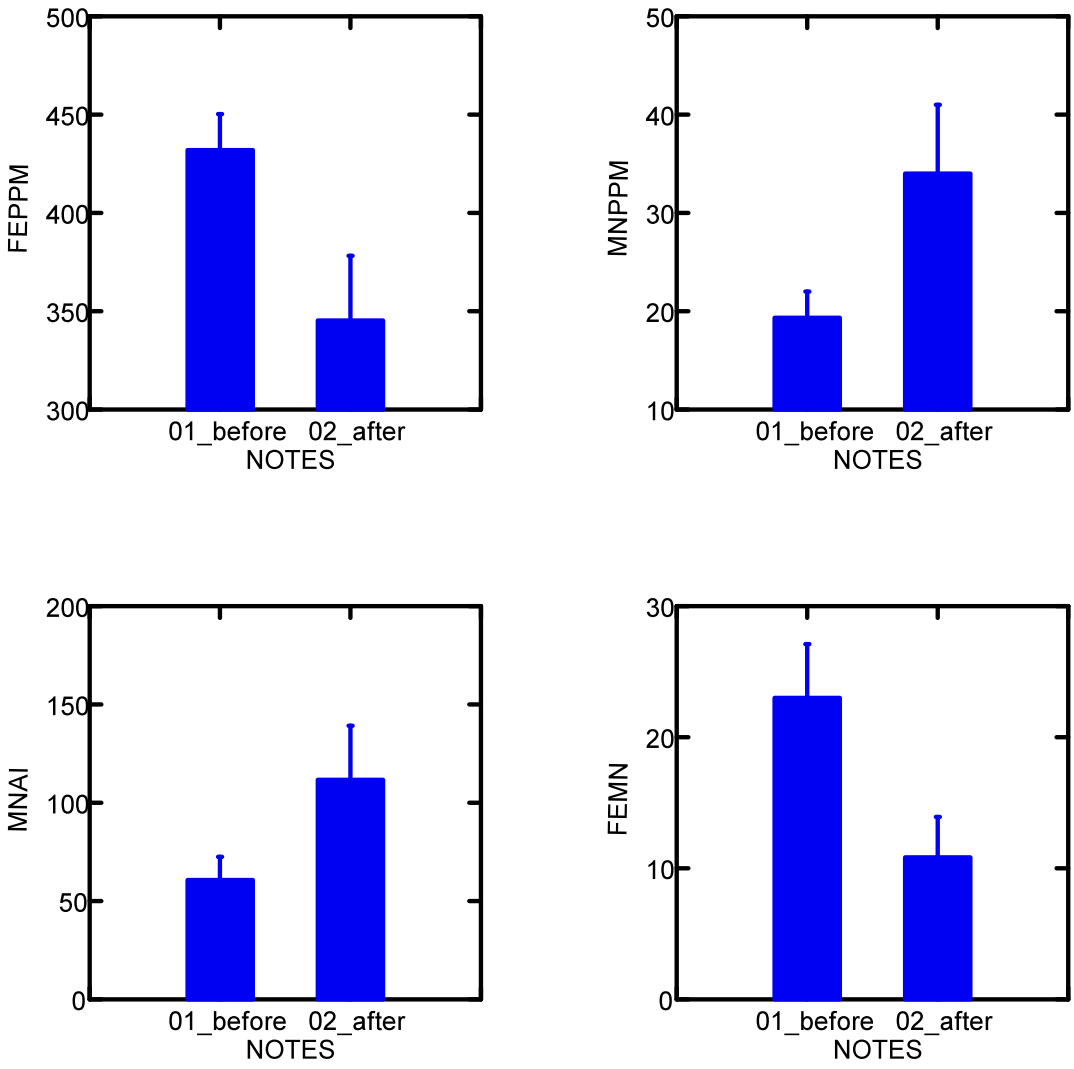


Figure 5. Greens soil iron and manganese relationships.
Desired values are currently based upon manganese availability and iron levels needed to balance the iron:manganese ratio. Manganese availability index should exceed 110. Iron should be present at three times the manganese level resulting in a iron:manganese ratio of 3:1.



Soil appraisals

Denver Country Club **g 05**
11033101 Standard Extraction Methods 01_before
3/31/2011 Brookside 0021-1

Major Elements and Sodium	Observed	Desired	Deficit Lb/Acre	Deficit Lb/1000 Sq Ft
Phosphorus (P) - Bray II (ppm):	201			
Phosphate P2O5 ppm:	461	118	0	0
Phosphorus (P) - Olsen (ppm):	29			
Phosphorus (P) - M3 (ppm)	118			
Phosphorus Saturation Index:	0.29	< 0.23		
Sulfur (S) ppm:	71	15-40		
Calcium (Ca) ppm:	970	922	0	0
Magnesium (Mg) ppm:	81	140	118	3
Potassium (K) ppm:	164			
Potash (K2O) ppm:	198	148	0	0
Sodium (Na) ppm:	134	< 67		
Aluminum (Al) ppm:	160			

Minor Elements	Observed	Desired		
Boron (B) ppm:	0.82	0.4 - 1.5		
Iron (Fe) ppm:	408.00	97		
Manganese (Mn) ppm:	23.00	32	Manganese Availability Index =	75.5
Copper (Cu) ppm:	4.38	0.6 - 2.0		
Zinc (Zn) ppm:	17.69	1.3 - 3.5		

Cations Expressed as Percent of Total Extractable Cations	Observed	Desired
Precent Calcium (% Ca)	71.32	60 - 70 (68 optimum)
Percent Magnesium (% Mg)	9.93	10 - 20 (12 optimum)
Percent Potassium (% K)	6.18	1.5 - 10
Percent Sodium (%Na)	8.57	0.5 - 3

		Plant available soil nitrogen ppm	
pH:	7.4		
Percent Organic Matter (% OM):	2.4	Nitrate (NO3)	0.8
Soluble Salts (SS) 1:2 (ppm):	160.0	Ammonium (NH4)	0.0
Electrical Conductivity (EC) 1:2 (dS/m)	0.3	Total available	0.8
SS estimated saturated paste (ppm)	656.0	NO3:NH4 ratio	0.0
EC estimated saturated paste (dS/m)	1.0	Organic N release	67.0
Total Extractable Cations (meq/100 g)	6.8		
Chloride Cl ppm	44.83		

Denver Country Club **g 05**
11052702res Standard Extraction Methods 02_after
5/27/2011 Brookside 0927-1

Major Elements and Sodium	Observed	Desired	Deficit Lb/Acre	Deficit Lb/1000 Sq Ft
Phosphorus (P) - Bray II (ppm):	137			
Phosphate P2O5 ppm:	314	117	0	0
Phosphorus (P) - Olsen (ppm):	25			
Phosphorus (P) - M3 (ppm)	96			
Phosphorus Saturation Index:	0.27	< 0.23		
Sulfur (S) ppm:	20	15-40		
Calcium (Ca) ppm:	761	723	0	0
Magnesium (Mg) ppm:	74	140	132	3
Potassium (K) ppm:	152			
Potash (K2O) ppm:	183	135	0	0
Sodium (Na) ppm:	76	< 67		
Aluminum (Al) ppm:	159			

Minor Elements	Observed	Desired		
Boron (B) ppm:	1.03	0.4 - 1.5		
Iron (Fe) ppm:	323.00	101		
Manganese (Mn) ppm:	32.00	34	Manganese Availability Index =	103.1
Copper (Cu) ppm:	3.50	0.6 - 2.0		
Zinc (Zn) ppm:	13.00	1.3 - 3.5		

Cations Expressed as Percent of Total Extractable Cations	Observed	Desired
Precent Calcium (% Ca)	71.39	60 - 70 (68 optimum)
Percent Magnesium (% Mg)	11.57	10 - 20 (12 optimum)
Percent Potassium (% K)	7.31	1.5 - 10
Percent Sodium (%Na)	6.2	0.5 - 3

pH:	7.8	Plant available soil nitrogen ppm	
Percent Organic Matter (% OM):	2.0	Nitrate (NO3)	1.6
Soluble Salts (SS) 1:2 (ppm):	83.2	Ammonium (NH4)	0.0
Electrical Conductivity (EC) 1:2 (dS/m)	0.1	Total available	1.6
SS estimated saturated paste (ppm)	494.7	NO3:NH4 ratio	0.0
EC estimated saturated paste (dS/m)	0.8	Organic N release	59.2
Total Extractable Cations (meq/100 g)	5.3		
Chloride Cl ppm	6.78		

Denver Country Club **g 09**
11033101 Standard Extraction Methods 01_before
3/31/2011 Brookside 0023-1

Major Elements and Sodium	Observed	Desired	Deficit Lb/Acre	Deficit Lb/1000 Sq Ft
Phosphorus (P) - Bray II (ppm):	377			
Phosphate P2O5 ppm:	864	120	0	0
Phosphorus (P) - Olsen (ppm):	39			
Phosphorus (P) - M3 (ppm)	241			
Phosphorus Saturation Index:	0.47	< 0.23		
Sulfur (S) ppm:	64	15-40		
Calcium (Ca) ppm:	1556	1438	0	0
Magnesium (Mg) ppm:	137	152	30	1
Potassium (K) ppm:	243			
Potash (K2O) ppm:	293	180	0	0
Sodium (Na) ppm:	154	< 67		
Aluminum (Al) ppm:	230			

Minor Elements	Observed	Desired		
Boron (B) ppm:	1.02	0.4 - 1.5		
Iron (Fe) ppm:	456.00	100		
Manganese (Mn) ppm:	16.00	33	Manganese Availability Index =	44.7
Copper (Cu) ppm:	7.28	0.6 - 2.0		
Zinc (Zn) ppm:	38.53	1.3 - 3.5		

Cations Expressed as Percent of Total Extractable Cations	Observed	Desired
Precent Calcium (% Ca)	73.33	60 - 70 (68 optimum)
Percent Magnesium (% Mg)	10.76	10 - 20 (12 optimum)
Percent Potassium (% K)	5.87	1.5 - 10
Percent Sodium (%Na)	6.31	0.5 - 3

pH:	7.7	Plant available soil nitrogen ppm	
Percent Organic Matter (% OM):	2.6	Nitrate (NO3)	1.9
Soluble Salts (SS) 1:2 (ppm):	128.0	Ammonium (NH4)	0.0
Electrical Conductivity (EC) 1:2 (dS/m)	0.2	Total available	1.9
SS estimated saturated paste (ppm)	588.8	NO3:NH4 ratio	0.0
EC estimated saturated paste (dS/m)	0.9	Organic N release	72.0
Total Extractable Cations (meq/100 g)	10.6		
Chloride Cl ppm	19.24		

Denver Country Club **g 09**
11052702res Standard Extraction Methods 02_after
5/27/2011 Brookside 0928-1

Major Elements and Sodium	Observed	Desired	Deficit Lb/Acre	Deficit Lb/1000 Sq Ft
Phosphorus (P) - Bray II (ppm):	350			
Phosphate P2O5 ppm:	802	118	0	0
Phosphorus (P) - Olsen (ppm):	33			
Phosphorus (P) - M3 (ppm)	205			
Phosphorus Saturation Index:	0.48	< 0.23		
Sulfur (S) ppm:	25	15-40		
Calcium (Ca) ppm:	1082	1003	0	0
Magnesium (Mg) ppm:	100	140	80	2
Potassium (K) ppm:	195			
Potash (K2O) ppm:	235	153	0	0
Sodium (Na) ppm:	90	< 67		
Aluminum (Al) ppm:	178			

Minor Elements	Observed	Desired		
Boron (B) ppm:	1.13	0.4 - 1.5		
Iron (Fe) ppm:	395.00	101		
Manganese (Mn) ppm:	26.00	34	Manganese Availability Index =	80.6
Copper (Cu) ppm:	6.14	0.6 - 2.0		
Zinc (Zn) ppm:	29.04	1.3 - 3.5		

Cations Expressed as Percent of Total Extractable Cations	Observed	Desired
Precent Calcium (% Ca)	73.11	60 - 70 (68 optimum)
Percent Magnesium (% Mg)	11.26	10 - 20 (12 optimum)
Percent Potassium (% K)	6.76	1.5 - 10
Percent Sodium (%Na)	5.29	0.5 - 3

pH:	7.8	Plant available soil nitrogen ppm	
Percent Organic Matter (% OM):	2.3	Nitrate (NO3)	4.2
Soluble Salts (SS) 1:2 (ppm):	89.6	Ammonium (NH4)	0.6
Electrical Conductivity (EC) 1:2 (dS/m)	0.1	Total available	4.8
SS estimated saturated paste (ppm)	508.2	NO3:NH4 ratio	7.0
EC estimated saturated paste (dS/m)	0.8	Organic N release	66.2
Total Extractable Cations (meq/100 g)	7.4		
Chloride Cl ppm	9.5		

Denver Country Club **g 15**
11033101 Standard Extraction Methods 01_before
3/31/2011 Brookside 0026-1

Major Elements and Sodium	Observed	Desired	Deficit Lb/Acre	Deficit Lb/1000 Sq Ft
Phosphorus (P) - Bray II (ppm):	370			
Phosphate P2O5 ppm:	848	119	0	0
Phosphorus (P) - Olsen (ppm):	38			
Phosphorus (P) - M3 (ppm)	209			
Phosphorus Saturation Index:	0.43	< 0.23		
Sulfur (S) ppm:	55	15-40		
Calcium (Ca) ppm:	1281	1151	0	0
Magnesium (Mg) ppm:	98	140	84	2
Potassium (K) ppm:	173			
Potash (K2O) ppm:	208	162	0	0
Sodium (Na) ppm:	110	< 67		
Aluminum (Al) ppm:	215			

Minor Elements	Observed	Desired		
Boron (B) ppm:	0.82	0.4 - 1.5		
Iron (Fe) ppm:	432.00	95		
Manganese (Mn) ppm:	19.00	32	Manganese Availability Index =	62.0
Copper (Cu) ppm:	6.14	0.6 - 2.0		
Zinc (Zn) ppm:	31.21	1.3 - 3.5		

Cations Expressed as Percent of Total Extractable Cations	Observed	Desired
Precent Calcium (% Ca)	75.44	60 - 70 (68 optimum)
Percent Magnesium (% Mg)	9.62	10 - 20 (12 optimum)
Percent Potassium (% K)	5.22	1.5 - 10
Percent Sodium (%Na)	5.63	0.5 - 3

		Plant available soil nitrogen ppm	
pH:	7.3		
Percent Organic Matter (% OM):	2.5	Nitrate (NO3)	2.8
Soluble Salts (SS) 1:2 (ppm):	121.6	Ammonium (NH4)	1.4
Electrical Conductivity (EC) 1:2 (dS/m)	0.2	Total available	4.2
SS estimated saturated paste (ppm)	575.4	NO3:NH4 ratio	2.0
EC estimated saturated paste (dS/m)	0.9	Organic N release	69.0
Total Extractable Cations (meq/100 g)	8.5		
Chloride Cl ppm	23.74		

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Major Elements and Sodium	Observed	Desired	Deficit Lb/Acre	Deficit Lb/1000 Sq Ft
Phosphorus (P) - Bray II (ppm):	186			
Phosphate P2O5 ppm:	426	118	0	0
Phosphorus (P) - Olsen (ppm):	31			
Phosphorus (P) - M3 (ppm)	156			
Phosphorus Saturation Index:	0.40	< 0.23		
Sulfur (S) ppm:	18	15-40		
Calcium (Ca) ppm:	980	913	0	0
Magnesium (Mg) ppm:	98	140	84	2
Potassium (K) ppm:	175			
Potash (K2O) ppm:	211	147	0	0
Sodium (Na) ppm:	72	< 67		
Aluminum (Al) ppm:	187			

Minor Elements	Observed	Desired		
Boron (B) ppm:	1.14	0.4 - 1.5		
Iron (Fe) ppm:	318.00	99		
Manganese (Mn) ppm:	44.00	33	Manganese Availability Index =	151.2
Copper (Cu) ppm:	3.49	0.6 - 2.0		
Zinc (Zn) ppm:	17.54	1.3 - 3.5		

Cations Expressed as Percent of Total Extractable Cations	Observed	Desired
Precent Calcium (% Ca)	72.81	60 - 70 (68 optimum)
Percent Magnesium (% Mg)	12.13	10 - 20 (12 optimum)
Percent Potassium (% K)	6.67	1.5 - 10
Percent Sodium (%Na)	4.65	0.5 - 3

		Plant available soil nitrogen ppm	
pH:	7.6		
Percent Organic Matter (% OM):	2.1	Nitrate (NO3)	2.1
Soluble Salts (SS) 1:2 (ppm):	76.8	Ammonium (NH4)	1.1
Electrical Conductivity (EC) 1:2 (dS/m)	0.1	Total available	3.2
SS estimated saturated paste (ppm)	481.3	NO3:NH4 ratio	1.9
EC estimated saturated paste (dS/m)	0.8	Organic N release	62.2
Total Extractable Cations (meq/100 g)	6.7		
Chloride Cl ppm	3.65		

Soil chemical guidelines - Melich III extraction

Table 1. Guidelines for iron and manganese, for soils at a range of different pHs. Note that the desired levels of micronutrients increases as soil pH increases. Maintaining higher levels of manganese and iron helps to overcome their tendency to become bound, and therefore unavailable, to the plant in more basic soils. We have paid special attention to these two micronutrients because plants are more likely to be deficient in iron than any other micronutrient. And higher levels of manganese appear to play a role in suppressing turf diseases caused by *Gaeumannomyces* such as bermudagrass decline, kikuyugrass decline, and take-all patch.

	Desired soil concentrations (ppm) for pH 6 - 8.5 soils						**Average range for greens, tees & fairways (across all pHs)**
	6	**6.5**	**7**	**7.5**	**8**	**8.5**	
Iron (Fe)	**80**	**86**	**92**	**98**	**104**	**110**	**157-185**
Manganese (Mn)	**27**	**29**	**31**	**33**	**35**	**37**	**30-43**

Table 2. Soil nutritional guidelines. Iron and manganese values are reported in Table 1 above.

	Greens		**Tees**		**Fairways**	
Nutrient concentration (ppm)	Average	Desired	Average	Desired	Average	Desired
Nitrate (NO_3)	6.7	3-20	17.1	3-20	24.2	3-20
Ammonium (NH_4)	2.5	<7	4.2	<7	4.4	<7
NO_3 + NH_4	9.4	<20	21.3	<20	28.6	<20
Phosphorous (P)	99	51	92	40	101	44
Potassium (K)	156	144	135	174	235	229
Calcium (Ca)	1346	1327	1857	1916	2640	3043
Magnesium (Mg)	174	140	332	203	611	322
Sodium (Na)	174	<67	260	<67	584	<67
Sulfate (SO_4)	139	15 - 40	135	15 - 40	490	15 - 40
Boron (B)	1.0	0.4 - 1.5	1.2	0.4 - 1.5	1.7	0.4 - 1.5
Copper (Cu)	4.7	0.6 - 2.0	3.1	0.6 - 2.0	2.4	0.6 - 2.0
Iron (Fe)	185	See Table 1	175	See Table 1	157	See Table 1
Manganese (Mn)	30	See Table 1	30	See Table 1	43	See Table 1
Zinc (Zn)	18.9	1.3 - 3.5	13.9	1.3 - 3.5	8.4	1.3 - 3.5

	Greens		**Tees**		**Fairways**	
Other soil measurements	Average	Desired	Average	Desired	Average	Desired
pH	7.1	6.5 - 7.5	7.4	6.5 - 7.5	7.2	6.5 - 7.5
EC (dS/m)	3.2	<3.0	3.0	<3.0	6.4	<3.0
TEC (meq/100 g)	9.9	NA	14.5	NA	24	NA
OM%	2.0	NA	3.0	NA	4.4	NA
% Ca	69	68	66	68	59	68
% Mg	15	12-20	20	12-20	23	12-20
% K	4	4	3	4	3	4
%Na	8	<3	8	<3	11	<3
% H	0	10 - 15	0	10 - 15	0	10 - 15

These guidelines are based upon PACE data collected from golf course greens, tees and fairways. Soil analysis using Melich III extraction by Brookside Laboratories, New Knoxville, OH. This data can be used as an aid in developing turf fertility programs, but should always be used in conjunction with specific soil test results from your golf course.

Irrigation water - guidelines

Parameter	Desired range	Average Domestic	Average Reclaimed	Good Water
pH	6.5 - 8.4	7.8	7.2	8.1
Electrical Conductivity EC (dS/m)	< 1.2	0.7	1.1	0.6
Sodium Absorption Ratio SAR	< 6.0	2.7	4.0	0.9
Total Dissolved Salts TDS (ppm)	<800	499	723	378
Carbonate CO_3^{-2} (ppm)	<50 (0.8 meq/l)	0.3	0	0
Bicarbonate HCO_3^{-1} (ppm)	<90 (1.5 meq/l)	134	201	267
Residual Sodium Carbonate (meq/l)	0	0.04	0.12	0
Calcium Ca (ppm)	<100 (5.0 meq/l)	56	66	72
Magnesium Mg (ppm)	<40 (3.0 meq/l)	20	24	13
Potassium K (ppm)	<160 (4.1 meq/l)	4	11	3
Sodium Na (ppm)	<160 (7 meq/l)	85	147	31
Boron B (ppm)	<0.50	0.22	0.42	0.06
Chloride Cl (ppm)	<100 (2.8 meq/l)	74	149	44.8
Copper Cu (ppm)	<0.05	0.35	0.02	0
Iron Fe (ppm)	<0.30	0.27	0.10	0
Manganese Mn (ppm)	<0.15	0.01	0.02	0
Sulfate SO_4^{-2} (ppm)	<200 (4.2 meq/l)	158	197	67
Zinc Zn (ppm)	<2.00	0.7	0.8	0
Nitrate NO_3 (ppm)	<8.0	0.9	7.3	3.6

Electrical Conductivity, Chloride and Sulfur Guidelines

Maintaining soil levels below the maximum guidelines below will improve plant health. The target is low salinity in addition to low levels of chloride and sulfate.

	EC dS/m	Cl ppm	SO4-S ppm	Cl + SO4-S ppm
Poa	**3**	**90**	**130**	**200**
Bentgrass	**6**	**400**	**460**	**800**
Bermuda	**8**	**700**	**800**	**1300**
Paspalum	**12**	**1600**	**1750**	**3000**

Climate Appraisal

DENVER STAPELTON CO Latitude 39.763 Longitude -104.86 Elevation (ft): 5286

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Normal Average Temperature (F)	29	33	40	48	57	68	73	72	62
Normal Average Temperature (C)	-1.6	0.7	4.2	8.7	14.0	19.8	23.0	22.1	16.9
Normal Precipitation (in)	0.5	0.5	1.3	1.9	2.3	1.6	2.2	1.8	1.1
Normal Precipitation (cm)	1.3	1.2	3.3	4.9	5.9	4.0	5.5	4.6	2.9
Cool season GP	0	0	2	12	56	100	86	93	85
Warm season GP	0	0	0	0	4	24	48	40	10
Cool season lb N/1000 sq ft	0.00	0.00	0.01	0.08	0.39	0.69	0.60	0.65	0.59
Cool season g N/100 sq m	0	0	5	39	191	337	293	318	288
Warm season lb N/1000 sq ft	0.00	0.00	0.00	0.00	0.02	0.16	0.33	0.27	0.07
Warm season g N/100 sq m	0	0	0	0	10	78	161	132	34

Appendix A.

Brookside Laboratories, Inc.

Soil Methodologies: (for standard packages)

All soils for standard packages are air-dried and ground to pass a 2-mm sieve.

Total Exchange Capacity (TEC by summation): Ross, D. 1995. Recommended soil tests for determining exchange capacity. p. 62-69 *In* J.T. Sims and A. Wolf (eds.) Recommended soil testing procedures for the northeastern United States. Northeastern Regional Bulletin #493. Ag Experiment Station, University of Delaware, Newark, DE.

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Total Carbon and Nitrogen (Combustion): Nelson, D.W., and L.E. Sommers. 1996. Total carbon, organic carbon and organic matter. p. 961- 1010. *In* J.M. Bartels et al. (ed.) Methods of soil analysis: Part 3 Chemical methods. (3rd ed.) ASA and SSSA Book Series 5, Madison, WI. McGeehan, S.L., and D.V. Naylor. 1988. Automated instrumental analysis of carbon and nitrogen in plant and soil samples. Commun. Soil Sci. Plant Anal. 19:493-505.

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Bray II P: Bray, H.R., and L.T. Kurtz. 1945. Determination of total, organic, and available forms of phosphorus in soils. Soil Science 59:39-45.

Olsen P: Olsen, S.R. and L.E. Sommers. 1982. Phosphorus. p. 403-430. *In* A.L. Page et al. (eds.) Methods of soil analysis, part 2. Agron. Monogr. 9. 2nd ed. ASA and SSSA, Madison, WI.

Electrical Conductivity-Soluble Salts (1:2): Soil, Plant, and Water Reference Methods for the Western Regions S – 2.10, 2003.

Saturated Paste Extract for pH, bicarbonate, nitrate, salts, chloride, cations, and minor nutrients: Soil, Plant, and Water Reference Methods for the Western Regions S – 1.10, 1.30, 1.80, 1.20, 1.40, 1.50, 1.60, 2003.

Mineralization Nitrogen: Dahnke, W.C. 1990. Testing soils for available nitrogen. p. 120-140. *In* R.L. Westerman (ed.) Soil testing and plant analysis. Soil Sci. Soc. Am. Book Series 3, ASA, Madison, WI.

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The majority of the above methods are also referenced in either: Soil, Plant, and Water Reference Methods for the Western Region. 2003. R.G. Gavlak, D.A. Horneck, R.O. Miller, and J. Kotuby-Amacher. 2nd edition. WREP-125. Brown, J. R. (ed.). 1998. Recommended Chemical Soil Test Procedures for the North Central Region. North Central Regional Research Publication No. 221. Missouri Agricultural Experiment Station SB 1001. Columbia, MO.