Project: Evaluation of Invigorate for Improved Infiltration on Sand Greens

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Summary

A study was conducted to evaluate the effect of aerification and application of the soil amendment, Invigorate, on infiltration, turf quality, root mass and length, soil chemistry, and soil gas levels. Key results include:

- Infiltration rate was consistently highest in plots that received a regime of monthly Invigorate treatments PLUS a hollow tine and verti-drain aerification in April, and a small tine aerification in June (treatment 2). In contrast, plots that received only Invigorate applications, but no verti-drain aerification (treatment 4), did not differ significantly from the non-treated check in infiltration rate on any of the dates tested. The positive effects of high infiltration rate were mirrored in the results on root length and soil nutrient levels, but were not correlated with turf quality, root mass or carbon dioxide ratings.

- The improved infiltration rate and increased root length observed in treatment 2 were not mirrored in results obtained for turf quality, root mass or carbon dioxide readings. The highest quality turf was observed for treatment 3, which received a combination of aerification treatments, but was not treated with Invigorate. Similarly, the highest root mass readings were taken from plots that were not treated with Invigorate; root length and root mass were in fact not significantly correlated with one another.

- Soil chemistry results indicate that higher infiltration rates resulted in lower levels of ions such as sodium, magnesium, sulfate, iron, manganese and aluminum. This resulted in lower soil electrical conductivity values, a potential benefit of increased infiltration rates.

- The overall lack of correlation between turf quality and any of the many measurements taken in this study indicates that there is no single tool or measurement that accurately reflects the complex interaction of variables that contribute to turf quality.

- When used in conjunction with aerification, monthly applications of Invigorate resulted in improved infiltration rates. However, aerification – particularly a springtime deep tine aerification – was critical to improved infiltration rates. When the deep tine aerification step was omitted, Invigorate applications did not result in any appreciable benefits. For this reason, Invigorate should be used only in conjunction with aerification, and not as a substitute for it.

Materials and Methods:

Location: Research plots were located on a bentgrass/poa practice putting green at Balboa Park Golf Course, San Diego, CA. This location was selected based on a history of heavy traffic (150,000 rounds per year), compaction and summer stress.

Experimental design and application: Plots measured 5 feet by 10 feet and treatments were replicated three times, in a randomized design. Invigorate treatments were applied with a CO_2 backpack sprayer equipped with 8004 VS flat fan nozzles and delivering 0.98 gallons of water per 1000 square feet, with 28 psi at the boom. Calibration of each nozzle was confirmed prior to application to be within 5% of the desired nozzle flow rate. Boom height was 17 inches above the ground. The spray swath was 5 feet. Speed was 3 mph. Spray bottles were agitated by shaking 5 times prior to charging with compressed CO_2.

Treatments and application dates are listed in Table 1.

Vertidrain treatments: On 4/7/99, treatments 1-3 were aerified with 5/8-inch hollow tines and cores were removed. Sand was applied to the green surface, and then the plots were vertidrained with ¾" tines, to a depth of approximately 6.5 inches. Sand was then swept into aerification holes to fill the holes.

Small tine aerification schedule: Prior to the start of the study, the golf course superintendent conducted frequent small tine (1/4" solid tines) aerifications on the entire green, which accounts for the initially rapid flow rates on the first sampling date. Small tine aerifications were then suspended on the green for two months -- from April 5 through June 14. On June 14, all treatments except treatment 3 received small tine aeration with ¼" tines, to a depth of approximately 3 inches. A second small tine aeration occurred on July 19, this time to treatment 3 only.

Evaluations:

Turf quality and hydraulic conductivity (infiltration) evaluations were carried out monthly in April through June and every two weeks subsequently. Quality was rated on a 0-9 scale, with 9 equal to the best quality turf, and 0 equal to the worst quality turf. Ratings apply to the entire test plot. Hydraulic conductivity (inches per hour) was determined using a Guelph infiltrometer (a ring infiltrometer, 20 cm in diameter, inserted into the soil to a depth of 5 cm, with a constant head pressure of 5 cm) to measure infiltration rates in two locations per plot, for a total of six readings, per date, per treatment. Infiltration rates were converted to field saturated hydraulic conductivity values using the computation in Figure 1 below (Reynolds, 1993)

Root mass and length measurements were taken at the completion of the trial (9/13/99). Three cores, two inches wide and at least 6 inches deep were removed from each plot. Each core was pressure washed in the laboratory to remove sand and other debris. Root length was then measured in millimeters by measuring the distance between the base of the thatch to the tip of the longest root. Roots were then excised from the thatch and verdure using a razor blade, and were dried in tared aluminum trays at 80ºC for 24hrs. Following drying, samples were weighed on a Mettler analytical balance to determine the dry weight of the root mass in grams.

Soil chemistry data was obtained by collecting 8 soil cores per plot (one-inch in diameter, 4 inches deep), using a soil probe. Cores were collected at the start of the trial (4/5/99) and at the conclusion of the trial (9/13/99). The soil cores were shipped to Brookside Laboratories in New Knoxville, OH for soil chemistry testing.

Data was subjected to analysis of variance, and treatment means separated using Fisher's LSD, where $P<0.05$. Samples collected at the start of the trial (4/5/99), did not demonstrate any significant differences, as was expected. The data for this initial reading appears in the data file that accompanies this report.

To determine the interaction between soil chemistry values at the completion of the trial (9/13/99) and infiltration rates, a linear regression was performed, using infiltration rate (grand mean across all post-treatment dates from 5/3 – 9/13/99) as the independent variable, and each soil factor as the dependent variable. The interaction was considered significant if the probability that the interaction was due to chance was less than 5% ($p<0.05$).

Soil carbon dioxide levels were sampled on 9/13/99 in two locations per plot to determine the effect of Invigorate applications and aerification practices on soil gas levels. A Dräger tube apparatus was used for this purpose.

Table 1. Treatments: Treatments and dates of application are listed below.

Product	**5/8" Hollow tine + vertidrain date**	**Small tine aerification date**	**Invigorate application**
1) no product	4/7/99	6/14/99	
2) Invigorate, 6 oz/1000	4/7/99	6/14/99	4/5, 5/3, 6/1, 6/28, 7/26, 8/30
3) no product	4/7/99	7/19/99	
4) Invigorate, 6 oz/1000	None	6/14/99*	4/5, 5/3, 6/1, 6/28, 7/26, 8/30
5) no product	None	6/14/99*	

Figure 1. Computation of field saturated hydraulic conductivity (infiltration) K_{fs} in cm/sec.

$$K_{fs} = \frac{\alpha^* G A R_1}{(a(\alpha^* H_1 + 1)) + G\alpha^* \pi a^2}$$

Where:

α^* = 0.36 Coarse and gravelly sands including highly structured soils with large cracks and macropores

G = shape factor

a = inside radius of the ring = 10 cm

d = depth of ring insertion = 5 cm

$$G = 0.316\left(\frac{d}{a}\right) + 0.184 = 0.342$$

A = cell constant for infiltrometer

R_1 = rate of water level drop in infiltrometer

H_1 = Head pressure on infiltration surface = 5 cm

To convert K_{fs} to inches per hour multiply by 1417.32

Results

Infiltration: Hydraulic conductivity (infiltration rate) was consistently highest in plots that received monthly Invigorate treatments PLUS a hollow tine and verti-drain aerification in April, and a small tine aerification in June (treatment 2). In contrast, plots that received only Invigorate applications, but no verti-drain aerification (treatment 4), did not differ significantly from the non-treated check in infiltration rate on any of the dates tested. (Table 2, Figures 2 and 3).

The positive effects of high infiltration rate were mirrored in the results on root length and on soil chemistry. Root length measurements (Table 4) show that treatment 2 had the highest root lengths, while plots that received Invigorate without deep tine aerification (treatment 4) did not differ significantly from the check. When soil chemistry data was evaluated at the completion of the study (Tables 6 and 7), cation and electrical conductivity values for Treatment 2 were lower than for other treatments, although in most cases the differences were not statistically significant. However, there was an overall significant negative correlation between infiltration rate and the level (in parts per million) of many soil nutrients, indicating that when infiltration rates are high, ions such as sodium, magnesium, sulfate, iron, manganese and aluminum are leached below the root zone, a potentially beneficial effect that can lead to reduced soil electrical conductivity (EC) readings.

In contrast, infiltration rates were not significantly correlated with root mass (Table 4), soil carbon dioxide levels (Table 5), and most importantly, turf quality ratings (Table 3). The lack of correlation was not necessarily expected, and can be explained from a variety of vantagepoints:

- *Variability:* There was a high degree of variability among readings taken, even within a single replicate. This indicates that compaction and infiltration can be very location-dependent parameters that are affected by varying traffic patterns, drainage efficiencies, irrigation distribution, etc. at different locations on the green. For this reason, although many numerical trends were observed among treatments, few were statistically significant, even by the most lenient standards (p<0.10).

- *Role of organic layer:* Although infiltration rates provide a good overall assessment of soil compaction in the top five centimeters of the root zone, they probably do not accurately reflect the strong influence that we believe may be exerted by the formation of an organic layer near the green surface, due to decomposition of foliage and thatch. This layer can result in a "sealing" of the green and concomitant decreased nutrient, water and gas movement. However, because it comprises only a fraction of the area that is evaluated using an infiltrometer, its contribution to turf quality, root mass, etc. was not accurately assessed by infiltration rates. It is likely that the small tine aerations that are typically conducted during the summer have their greatest benefit in breaking this organic "seal", and improving the physical, chemical and gas environment. The effect of these small tine aerations on overall compaction levels, however, may be negligible.

When used in conjunction with aerification, monthly applications of Invigorate resulted in improved infiltration rates. However, aerification – particularly a springtime deep tine aerification – was critical to improved infiltration rates. When the deep tine aerification step was omitted (treatment 4), Invigorate applications did not result in any appreciable benefits. For this reason, Invigorate should be used only in conjunction with aerification, and not as a substitute for it.

Table 2. Hydraulic conductivity (Infiltration rates). Values within the same column that are followed by the same letter are not significantly different (P<0.10). Treatments in green boxes were significantly better than the non-treated check (treatment 5), while treatments in red shaded boxes were significantly worse than the check. Note that the 4/5/99 readings, taken prior to the initiation of treatments, had extremely high infiltration rates. This was due to lower traffic, cooler temperatures, and frequent aerifications carried out by the superintendent prior to the start of the study. The grand mean represents an average of infiltration on all post-treatment dates (5/3/99 – 9/13/99).

	MEAN HYDRAULIC CONDUCTIVITY (inches per hour)									
TRT	**4/5**	**5/3**	**6/1**	**6/28**	**7/12**	**7/26**	**8/19**	**8/30**	**9/13**	**Grand mean**
1	18.55a	4.15a	3.13a	3.25b	2.82b	1.55ab	1.61ab	1.23a	1.39a	2.39b
2	22.87a	5.19a	4.18a	8.92a	5.61a	3.12a	3.42a	2.20a	2.06a	4.34a
3	18.74a	3.56a	3.26a	1.98b	1.42b	3.03a	3.04ab	1.63a	1.95a	2.48b
4	21.39a	4.13a	1.94a	2.03b	1.96b	1.64ab	1.40b	1.20a	1.39a	1.96b
5	20.09a	3.54a	1.78a	1.86b	2.32b	1.30b	1.80ab	1.57a	0.98a	1.89b

Figure 2. Mean infiltration rates, on all post-treatment evaluation dates (5/3/99 – 9/13/99).

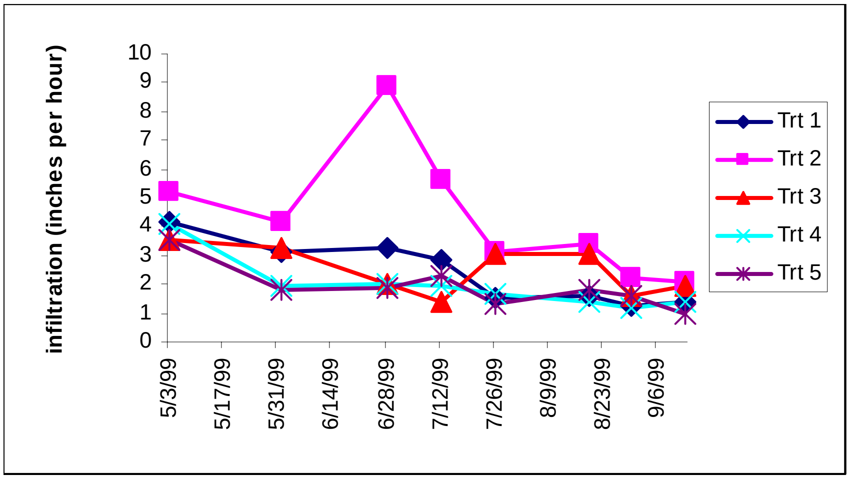


Table 3. Turf quality ratings. Quality was rated on a 0-9 scale, with 9 equal to the best quality turf, and 0 equal to the worst quality turf. Values within the same column that are followed by the same letter are not significantly different (P<0.10). Treatments in green boxes were significantly better than the non-treated check (treatment 5), while treatments in red shaded boxes were significantly worse than the check.

	TURF QUALITY RATINGS								
TRT	**5/3**	**6/1**	**6/28**	**7/12**	**7/26**	**8/19**	**8/30**	**9/13**	**Grand mean**
1	5.8bc	4.7ab	4.7b	5.7bc	5.7a	6.3a	6.5a	6.5ab	5.7a
2	6.2ab	4.7ab	4.8ab	5.7bc	4.8b	5.0c	6.5a	6.0ab	5.5a
3	5.7c	4.3b	5.0ab	6.0ab	5.7a	5.5bc	6.7a	6.7a	5.7a
4	5.7c	4.8ab	5.0ab	6.3a	5.5a	5.3c	6.5a	6.0ab	5.7a
5	6.3a	5.0a	5.2a	5.3c	5.2ab	6.0ab	6.5a	5.8b	5.7a

Table 4. Mean root mass and root length measurements made 9/13/99, at the completion of the trial. Values within the same column that are followed by the same letter are not significantly different (P<0.10). Treatments in green boxes were significantly better than the non-treated check (treatment 5), while treatments in red shaded boxes were significantly worse than the check. There was no correlation between root mass and root length.

Treatment	Mean Root mass (grams dry weight)	Mean Root length (mm)
1	0.168a	86.7c
2	0.120ab	122.2a
3	0.163a	116.7ab
4	0.079b	97.8abc
5	0.101b	94.7bc

Table 5. Mean carbon dioxide levels measured at a one-inch soil depth on 9/13/99. In general, CO_2 levels below 3% are an indicator of acceptable soil gas ratios, while CO_2 levels above 3% indicate a build-up of CO_2 that will negatively affect turf quality. There were no significant differences recorded due to high levels of variability among replicates.

Treatment	Mean carbon dioxide levels (percent).
1	5.83
2	3.33
3	3.25
4	5.79
5	5.42

Table 6. Soil chemistry test results from experimental plots (mean of three replicates). Samples were taken at the conclusion of the study on 9/13/99. Analysis conducted by Brookside Laboratories, New Knoxville, OH. Treatments followed by the same letter are not significantly different ($p<0.05$, Fisher's LSD). Treatments significantly different from the check (treatment 5) are highlighted in green type.

	Trt 1	**Trt 2**	**Trt 3**	**Trt 4**	**Trt 5**
pH	6.73a	6.90a	6.83a	6.87a	6.87a
Phosphorous (ppm)	54.67a	53.67a	57.67a	62.00a	61.67a
Calcium (ppm)	542.33a	448.67a	512.00a	550.33a	498.67a
Magnesium (ppm)	114.00a	104.00a	116.33a	121.33a	122.00a
Potassium (ppm)	101.0a	79.67a	87.33a	110.33a	118.67a
Sodium (ppm)	107.67a	91.00a	105.00a	122.33a	128.00a
Sulfate (ppm)	85.67a	48.67a	72.00a	84.67a	88.00a
Boron (ppm)	0.67a	0.66a	0.66a	0.64a	0.65a
Iron (ppm)	176.00a	126.33a	154.33a	167.33a	188.33a
Manganese (ppm)	**17.67b**	**13.67a**	**16.33ab**	**18.00b**	20.67c
Copper (ppm)	1.13a	0.98a	1.26a	1.05a	1.39a
Aluminum (ppm)	159.33a	146.33a	164.33a	175.00a	174.67a
Zinc (ppm)	6.47a	6.14a	6.89a	6.45a	11.38a
Electrical conductivity (dS/m)	1.54a	1.26a	1.40a	1.51a	1.56a
Total exchange capacity (meq/100g)	4.83a	3.97a	4.55a	4.97a	4.74a
Organic matter (%)	1.25a	1.35a	1.31a	1.09a	1.31a
% calcium	56.23a	56.80a	56.77a	55.69a	53.10a
% magnesium	19.95a	21.64a	21.49a	21.10a	21.65a
% potassium	5.37a	5.12a	4.89a	5.70a	6.31a
% sodium	9.79a	9.94a	9.79a	10.47a	11.40a
Nitrate (ppm)	5.00a	3.27a	6.57a	9.90a	6.10a
Ammonium (ppm)	7.60b	3.90a	5.20ab	4.67ab	5.07ab
Total nitrogen (ppm)	12.60a	7.17a	11.77a	14.57a	11.17a

Table 7. Interaction between infiltration rate (grand mean of infiltration rate, averaged over 8 post-treatment sampling dates: 5/3/99 – 9/13/99) and soil chemistry factors sampled on 9/13/99. The interaction was considered significant if the probability that the interaction was due to chance was less than 5% ($p<0.05$). The probability (p) and regression coefficient (r^2) values for significant interactions are listed below. The negative slopes indicate a negative correlation between infiltration and the listed variables.

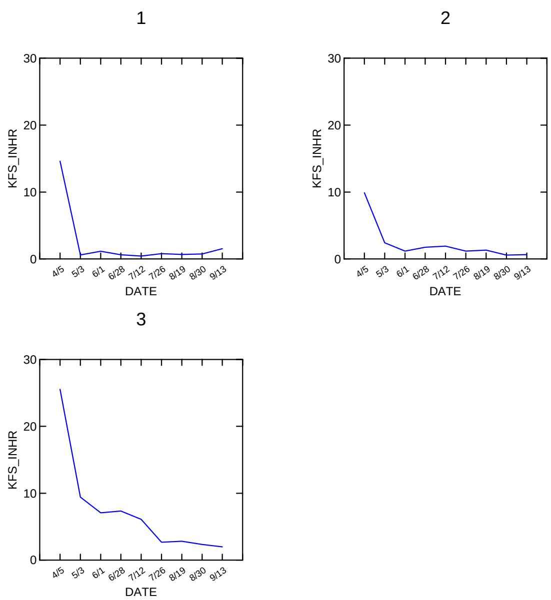
	Regression coefficient (r^2)	**Probability (p)**	**Slope**
Magnesium (ppm)	0.937	0.007	–7.037
Sodium (ppm)	0.803	0.039	–13.176
Sulfate (ppm)	0.928	0.008	–15.794
Iron (ppm)	0.827	0.032	–21.560
Manganese (ppm)	0.796	0.042	–2.280
Aluminum (ppm)	0.867	0.021	–11.107
Electrical conductivity (dS/m)	0.850	0.026	–0.115
Total exchange capacity (meq/100g)	0.895	0.015	–0.369

References:

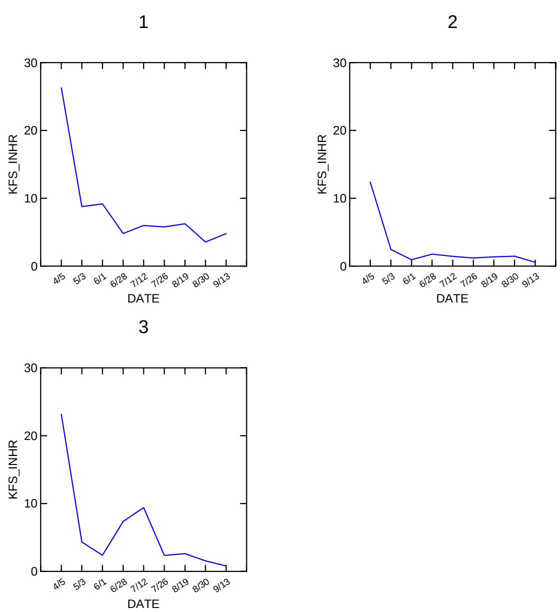
Reynolds, W.D. 1993. Saturated hydraulic conductivity: field measurement *in* M.R. Carter, ed. Soil Sampling and Methods of Analysis. Lewis Publishers. Boca Raton, FL.

Figure 3. Change in infiltration rates (KFS-in/hr) in each replicated plot during the course of the study. Replicates 1 – 3 are labeled at the top of each graph. Note the variability among replicates and the dramatic decrease in infiltration rates in almost all replicates after the April sampling date.

Treatment 1



Treatment 2



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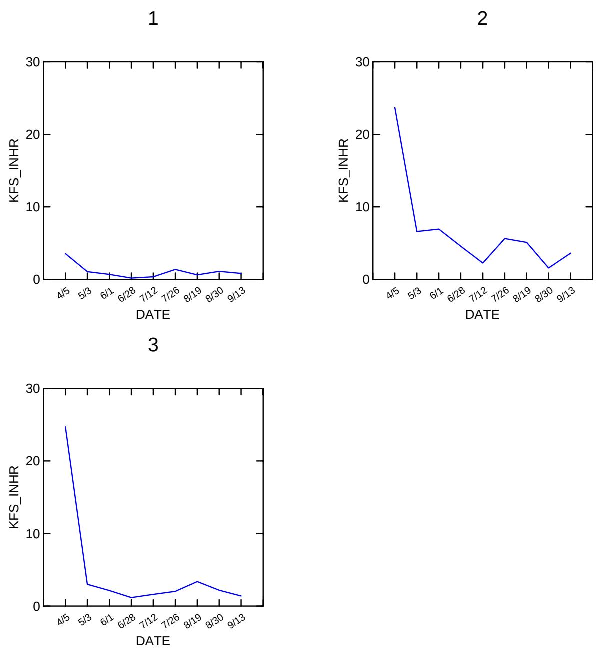

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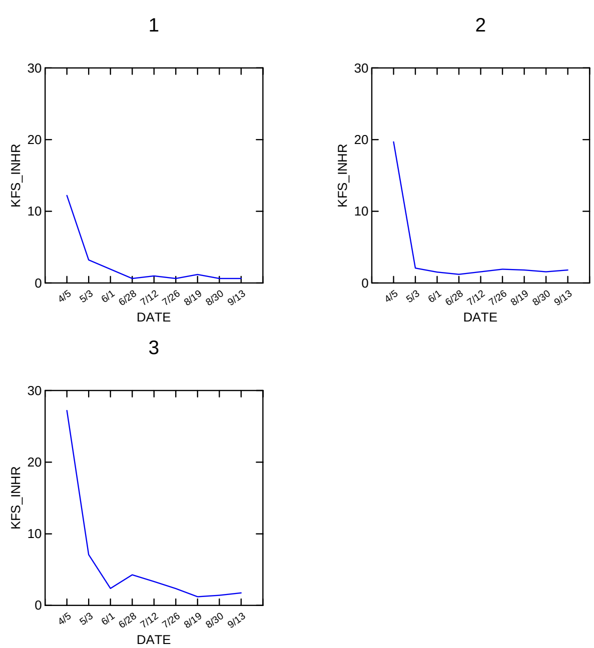
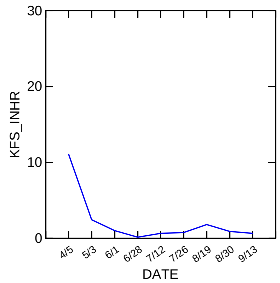


Treatment 5

1



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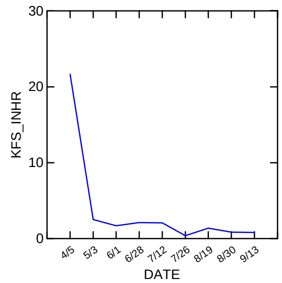

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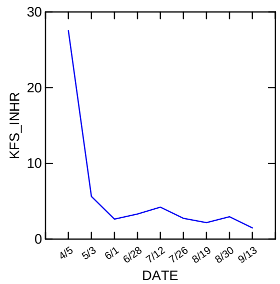

PHOTOGRAPHS

Operation of Guelph infiltrometer

April 7, 1999 aeration (vertidrain through sand)

June 14, 1999 small tine aerification