Evaluation of New Technologies in Construction and Maintenance of Golf Greens

Summary Report (1997-1998) to the United States Golf Association Research Committee

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I. Laboratory Evaluations

Objectives:

- Determine physical properties of inorganic amendments alone and when mixed with three sand sizes for use in putting green rootzones.
- Characterize the physical properties of inorganically amended sands for use in sand-based rootzones.
- Determine nutrient retention of inorganic and organically amended sand rootzone mixtures.

A. Physical Properties of Three Sands and Inorganic Amendments

Sand sizes used (Fine, Medium, Coarse)
Amendments used (Ecolite, Greenschoice, Isolite, Profile, Sphagnum Peat Moss)

Rootzone mixtures:

- 10, 20 % amendment (v:v) through rootzone
- 10, 20% amendment (v:v) only in top 15 cm

Physical Properties measured:

- Hydraulic conductivity
- Bulk Density
- Moisture retention with depth
- Pore size distributions/water retention 0 to 200 cm tensions

Inorganic amendment evaluation:

Physical Properties measured:

- Particle size analysis
- Pore size distributions/water retention 0 to 15000 cm tensions

B. Nutrient Retention of Inorganic and Organically amended sand rootzones

- Used 30 cm deep sand rootzone mixtures over 10 cm suitable gravel
- Applied 50 kg ha^{-1} ammonium nitrate in liquid solution and leached with 2.5 pore volumes distilled water and analyzed for ammonium and nitrate by rapid diffusion method.

4 experiments

1. Tested all amendments at 20 % (v:v) material
2. Tested Ecolite and Profile at 1,5,10,20 %
3. Tested Ecolite and Profile 10% at 2.5, 15, 30 cm incorporation depths
4. Incubation study at 0,12 ,24 hrs in pure sand, 10% Ecolite and Profile

LABORATORY EVALUATIONS RESULTS / SUMMARY

A. Physical properties of three sand sizes amended with inorganic and organic amendments

- Porosity / water retention

Compared to pure sand, amendment addition increased total porosity, macroporosity, and water retained at 20 kPa tension. While, plant available water (water released from 4 kPa to 20 kPa) decreased with amendment addition (Table 6b). Only fine sand and amended fine sands met USGA guidelines for total porosity, macroporosity, and capillary water retention. Medium and coarse sands and sand amendment mixtures resulted in rootzone mixtures that had excess macroporosity and lacked adequate water retention. Of the amendments tested sphagnum peat (SP) resulted in the most water retained and SP effect was most dramatic in the medium and coarse sands.

Evaluations of the amendments alone resulted in the observation that indeed these materials have a high degree of internal porosity > 55% and retain significant > 20% water even at high tensions. One observation is that there are two clusters that appeared regarding the amendments indicating similar amendment performance. Ecolite was similar to Greenschoice for water retention and release, both measured less than Isolite and Profile which were similar (Figure 1).

- Hydraulic conductivity (Ksat)

Hydraulic conductivity effect was rather variable between the three sand sizes and was somewhat related to sand and amendment sizes (Table 1). Sphagnum peat with its wide variety of particle sizes had the most consistent effect on Ksat and decreased this parameter for all three sands. At no point was a Ksat recorded that was less than 6 inches per hour.

- Bulk Density (Db)

Amendment addition decreased bulk density of all rootzone mixtures compared to pure sand (Table 3).

B. Nitrogen retention of inorganic and organically amended sands

- Ammonium leaching

Ammonium leached rapidly from all mixtures with peak concentrations occurring at approximately 0.5 pore volumes. Significantly more NH_4^+-N leached from pure sand than for 20% (v:v) amended mixtures (Figure 2). Leaching losses ranked in decreasing order Pure sand > Greenschoice=Isolite>Peat>Profile>Ecolite. The most effective amendments, Profile and Ecolite reduced NH_4^+-N leaching of compared to pure sand by 74.9 and 88.4 % for Profile and Ecolite respectively. Further studies with Ecolite and Profile had the following results. Increasing Profile® and Ecolite® rates from 1 to 20 % resulted in stepwise decreases in NH_4^+-N loss (Table 8). Although 20% amendment may be the most effective rate for retaining NH_4^+ it may not be economically feasible. Amendment at 10% significantly reduced NH_4^+-N leaching, by 63.1 and 78.7 % compared to pure sand for Profile and Ecolite respectively.

Results of the 10% Ecolite and Profile at three incorporation depths indicate that when 10% amended sand is incorporated even to a shallow depth of 2.5 cm NH_4^+-N losses are significantly decreased by approximately 25 %, compared to pure sand (Table 9). Again, there was a step-wise reduction of NH_4^+-N leaching reduction with increasing amendment depth (Figure 6). Incorporation of 10% amendment through the entire 30 cm rootzone resulted in the least NH_4^+-N leaching loss, with a significant difference noted between Profile and Ecolite. Losses were decreased by 65.4 and 80 % for Profile and Ecolite respectively.

- Nitrate leaching

Large quantities of NO_3^--N, >90%, were recovered in leachate from all treatments under all experimental conditions. Peak NO_3^--N concentrations of over 70 mg L^{-1} in pure sand leachate were observed (Figure 4).

II. Field Evaluations

- **Objective:** To study the changes in soil physical properties and plant responses to sub-surface water evacuation and air-injection in five sand-based rootzones.

Construction:

- 12 sand-based rootzones (3 x 16 m) with 5 sub-plots (3 x 3.2 m) containing one of each of the following five sand amendment mixtures (pure sand, 10% Profile, 10% Greenschoice, 10% Ecolite, 10 % Sphagnum peat moss). * No choker layer
- Creeping bent 'L-93' seeded 6 October 1997.

Drainage Treatments:

1. Gravity (no mechanical drainage)
2. Vacuum (water evacuation for 20 minutes)
3. Vacuum plus air injection (water evacuation followed by 5min air-injection).

Measurements:

Plant Response Data

- Turfgrass Quality
- Seasonal Rootmass (Spring/End of Summer)
  3 depths (2.5-10, 10-20, 20-30 cm)

Soil Response Data

- Volumetric water content with depth (Time Domain Reflectometry)
  (0- to 15, 15- to 21, 21-to 27 cm)
- Soil gas composition (Infrared Gas analyzer)
  (Oxygen, Carbon Dioxide, Methane, Hydrogen Sulfide)
- Soil temperature (10% peat plots)
  (10 and 20 cm below the surface)
- Survey of seasonal microbial populations in the top 10 cm
  (Total bacteria, Gram- bacteria, Fluorescent *pseudomonas*, Actinomycetes, Fungi, Aerobic spore formers(*Bacillus* spp.), and Nitrogen oxidizers/reducers)

FIELD EVALUATIONS RESULTS / SUMMARY

A. Soil Responses

- Mechanically induced drainage significantly decreased water contents of treated rootzones (Table 11).
- The most significant change in water content was in the top 15 cm of the rootzone.
- Rootzones under all drainage treatments had high (>18%) oxygen levels and low (< 1.5 %) carbon dioxide levels.
- Water evacuation and/or air-injection had little effect on soil temperature while soil temperatures at bot 10 and 20 cm below the surface were very high (>30 °C) (Figure 9).

B. Plant Responses

- Drainage treatment had no significant effect on rootmass in 1998 (Table 14).
- Total rootmass for all treatments decreased (≈ 40%) from June to Sept.
- Pure sand consistently resulted in the lowest rootmass of the five sand-based rootzone mixtures tested (Table 14).
- Drainage treatment had no significant effect on turfgrass quality in 1998
- Pure sand quality was consistently lower than acceptable throughout 1998 due to a lack of turfgrass cover.
- Soil microbial populations reached relatively large numbers quickly in 1997 and followed a somewhat seasonal trend in 1998 with lower values in July perhaps due to rootmass decline (Figure 8).

Table 1. Particle size analysis and particle densities of inorganic amendments.

Amendment	Particle size (mm) > 2	2-1	1.0-0.5	0.5-0.25	0.25-0.10	0.1-0.05	< 0.05	Particle density
	g kg^{-1}							Mg m^{-3}
Greenschoice	0	3	871	108	11	7	< 1	2.15
Profile	0	< 1	00	714	272	14	< 1	2.50
Isolite	0	5	446	534	10	5	< 1	2.27
Zeolite	0	< 1	242	615	139	1	3	2.32

Table 2. Saturated hydraulic conductivity and water content of three sand sizes and sands amended with organic and inorganic amendments.

		Water Content	
	Ksat	2-6 cm depth	Average
	--cm h-1--	---------------cm3/cm3---------------	
Sand Size (S)			
Fine	81.5 c	38.3 a	42.6 a
Medium	184.5 b	17.5 b	34.1 b
Coarse	494.4 a	7.9 c	19.3 c
Amendment (A)			
None	268.5 ab	18.9 e	31.4 d
Isolite	248.4 bc	21.6 b	32.4 b
Greenschoice	281.3 a	20.1 d	30.9 e
Profile	236.6 c	20.9 c	31.7 c
Peat	206.6 d	27.0 a	35.7 a
Zeolite	275.9 a	18.9 e	29.8 f
Rate (R)			
0	268.5 a	18.9 c	31.4 c
10	266.9 a	21.2 b	31.9 b
20	232.4 b	22.3 a	32.3 a
Level (L)			
None	268.5 a	18.9 c	31.4 b
All	233.7 b	22.0 a	32.1 a
Top	265.7 a	21.4 b	32.1 a
Contrasts			
Peat vs. Other Amendments	***	***	***
Source of variation			
S	***	***	***
A	***	***	***
S*A	***	***	***
R	***	***	***
S*R	***	***	***
A*R	***	***	***
S*A*R	**	**	NS
L	***	***	NS
S*L	**	***	***
A*L	**	***	***
S*A*L	**	***	***
R*L	NS	NS	**
S*R*L	NS	**	***
A*R*L	NS	***	***
S*A*R*L	NS	**	**

Means in the same column followed by the same letter within the same sub-heading are not significantly different under Fisher's protected LSD (p=0.05).
NS,*,**,*** represents nonsignificant, or significant, at 0.05, 0.01, 0.001 levels respectively.

Table 3. Bulk density and saturated hydraulic conductivity of three sands and sand amendment mixtures.

Amendment	0	10	20	0	10	20	10 top 15 cm	20 top 15 cm
				Amendment Content (% vol)				
	Bulk density ---------- Mg m-3 ----------			Saturated conductivity ---------- cm h-1 ----------				
Fine Sand (0.1 - 0.25 mm)								
None	1.42			89.0				
Ecolite		1.41	1.42		88.1	58.7 ***	72.4 *	69.3 ***
Greenschoice		1.42	1.41		84.8	77.4	92.7	94.3
Isolite		1.39	1.37		86.9	73.6 *	101.6	93.0
Profile		1.39	1.34		80.3	65.7 ***	81.6	81.0
Sphagnum Peat		1.36	1.22		77.4	60.2 ***	83.6	70.3 **
Medium Sand (0.25 - 0.50 mm)								
None	1.47			211.4				
Ecolite		1.44	1.39		199.7	169.8 ***	213.5	202.9
Greenschoice		1.41	1.44		192.1 *	183.2 ***	207.0	187.9 **
Isolite		1.43	1.36		162.0 ***	146.4 ***	189.2 **	179.4 ***
Profile		1.43	1.35		172.4 ***	148.7 ***	198.9	201.1
Sphagnum Peat		1.38	1.23		188.8 **	104.0 ***	175.0 ***	132.7 ***
Coarse Sand (0.50 - 1.0 mm)								
None	1.59			505.2				
Ecolite		1.45	1.41		578.3	480.6	621.6	556.4
Greenschoice		1.47	1.43		614.5	580.4	493.3	568.5
Isolite		1.46	1.36		470.5	427.8	550.4	499.4
Profile		1.47	1.39		382.0	364.4	545.1	514.2
Sphagnum Peat		1.40	1.26		447.9	243.1 ***	556.9	339.0 *

*,**,*** represents significant at 0.05, 0.01, 0.001 levels respectively compared to unamended sand.

Table 4. Average water content of three sands amended with organic and inorganic amendments.

Amendment	Amendment Content (% vol) 0	10	20	10 top 15 cm	20 top 15 cm
	Water content ---- cm3 / cm3 ----				
	---- Fine Sand (0.1 - 0.25 mm) ----				
None	43.4				
Ecolite		40.1 ***	36.6 ***	39.9 ***	40.6 ***
Greenschoice		41.6 **	39.6 ***	43.6	42.6
Isolite		42.4	40.5 ***	43.1	42.7
Profile		42.6	41.6 **	43.4	42.9
Sphagnum Peat		45.2 ***	48.1 ***	44.8 *	47.2 ***
	---- Medium Sand (0.25 - 0.50 mm) ----				
None	34.1				
Ecolite		32.7	31.6 *	31.8 ***	32.5 *
Greenschoice		34.3	30.8	33.9	34.0
Isolite		35.5	34.0 ***	34.4	34.6
Profile		34.4	34.8 ***	32.0 ***	30.8 ***
Sphagnum Peat		36.3 ***	38.9 ***	36.3 ***	37.9 ***
	---- Coarse Sand (0.50 - 1.0 mm) ----				
None	16.7				
Ecolite		17.3	18.3 *	17.4	19.2 ***
Greenschoice		17.0	17.5	17.3	19.0 ***
Isolite		19.2 ***	21.0 ***	19.3 ***	21.7 ***
Profile		19.9 ***	22.2 ***	17.6	17.9
Sphagnum Peat		22.1 ***	27.0 ***	20.0 ***	24.1 ***

*,**,*** represents significant, at 0.05, 0.01, 0.001 levels respectively compared to unamended sand.

Table 5. Water content in top 2-6 cm of three sands and sands amended with organic and inorganic amendments.

Amendment	Amendment Content (% vol)				
	0	10	20	10 top 15 cm	20 top 15 cm
	Water content cm3 / cm3				
	Fine Sand (0.1 - 0.25 mm)				
None	37.6				
Ecolite		35.8	32.8 ***	33.6 ***	35.2 *
Greenschoice		36.6	35.2 *	38.9	37.0
Isolite		38.9	37.5	38.4	38.1
Profile		38.4	37.7	39.5	37.6
Sphagnum Peat		42.6 ***	44.8 ***	43.2 ***	46.7 ***
	Medium Sand (0.25 - 0.50 mm)				
None	14.5				
Ecolite		16.0	16.8	14.6	15.1
Greenschoice		17.9 **	15.5	16.1	17.3 *
Isolite		21.6 ***	20.2 ***	16.6	15.9
Profile		18.5 ***	19.0 ***	15.1	14.4
Sphagnum Peat		19.8 ***	26.0 ***	21.1 ***	25.0 ***
	Coarse Sand (0.50 - 1.0 mm)				
None	4.4				
Ecolite		6.2 *	7.4 ***	6.3 **	7.2 ***
Greenschoice		6.0 *	7.2 ***	6.2 **	7.7 ***
Isolite		6.9 ***	9.1 ***	6.6 ***	8.7 ***
Profile		7.6 ***	10.9 ***	5.7	6.6 ***
Sphagnum Peat		9.7 ***	18.6 ***	10.0 ***	16.9 ***

*,**,*** represents nonsignificant, or significant, at 0.05, 0.01, 0.001 levels respectively compared to unamended sand.

Table 6a. Porosity and water retention of three sands and inorganic amendments.

	Pore Space		Water Retention				
Amendment	Total	Macro	Capillary	0.002 MPa	Wilt†	$\Theta_{20\text{-}40}$	PAW‡
	----------Volumetric content cm^3 / cm^3----------						
Fine sand	45.0 c	18.2 c	26.8 b	44.6 a	4.6 e	17.8 a	22.2 a
Medium sand	42.9 cd	37.8 a	5.1 d	14.8 e	3.0 f	9.7 b	2.1 bc
Coarse sand	38.4 d	34.7 ab	3.7 e	4.7 f	2.5 f	1.0 de	1.2 d
Ecolite	60.6 b	37.2 a	23.4 c	24.7 d	20.8 d	1.3 de	2.6 b
Greenschoice	56.7 b	32.1 b	24.6 c	25.0 d	23.3 c	0.4 e	1.3 d
Isolite	72.2 a	36.4 ab	35.8 a	36.1 c	34.7 a	0.3 e	1.1 d
Profile	73.4 a	38.0 a	35.4 a	39.6 b	33.2 b	4.2 c	2.2 bc

†Wilt equals water retained at 0.02 MPa tension.
‡Plant available water (PAW)
Means followed by the same letter in the same column are not significantly different (p=0.05).

Table 6b. Pore size distributions and water retention of three sand sizes and sands amended with organic and inorganic amendments.

	Pore Space		Water Retention		
	Total	Macro	Θ_{40}	Θ_{200}†	PAW‡
	---------------------------- Volumetric content cm^3 / cm^3 ----------------------------				
Sand Size (S)					
Fine	45.1 a	19.4 b	25.7 a	7.2 a	18.5 a
Medium	44.3 b	35.4 a	8.9 b	6.2 b	2.7 b
Coarse	42.8 c	35.8 a	7.0 c	5.5 c	1.5 c
Amendment (A)					
None	42.1 c	30.2 b	11.9 c	3.4 e	8.5 a
Ecolite	43.5 b	31.5 a	12.0 c	5.2 d	6.8 b
Greenschoice	43.0 b	30.9 a	12.1 c	5.5 d	6.6 b
Isolite	44.9 a	30.9 a	14.0 b	7.0 b	7.0 b
Profile	45.1 a	31.2 a	13.9 b	6.4 c	7.5 b
Peat	44.9 a	27.0 c	17.9 a	8.8 a	9.1 a
Rate (R)					
0	42.1 c	30.2 ab	11.9 b	3.4 c	8.5 a
10	43.6 b	31.0 a	12.6 b	5.5 b	7.1 b
20	45.0 a	29.7 b	15.3 a	7.6 a	7.7 b
Contrast					
Peat vs. Amendments	**	***	***	***	***
Source of variation					
S	***	***	***	***	***
A	***	***	***	***	***
S*A	**	***	**	NS	***
R	***	**	***	***	NS
S*R	*	NS	NS	**	NS
A*R	**	NS	***	***	*
S*A*R	NS	NS	NS	*	NS

†Θ_{200} water retained at 0.02 MPa.
‡Plant available water (PAW) calculated from Θ_{40} - Θ_{200}.
Means in the same column followed by the same letter within the same sub-heading are not significantly different (p=0.05).
NS,*,**,*** represents nonsignificant, or significant, at 0.05,0.01 and 0.001 levels respectively.

Table 6c. Porosity and water retention of three sands and amended sand mixtures

Sand size	Amendment	Rate	Pore Space		Water Retention		
			Total	Macro	Θ_{40}	Θ_{200}†	PAW‡
			-------- Volumetric content cm^3 / cm^3 --------				
Fine	None	0	45.0	18.2	26.8	4.6	22.2
	Ecolite	10	44.7	22.5	22.2	5.3	16.9 **
		20	44.4	20.8	23.6	6.8 ***	16.8 **
	Greenschoice	10	44.2	21.1	23.1	5.6	17.5 *
		20	43.0	19.6	23.4	7.3 ***	16.1 **
	Isolite	10	45.8	22.8	23.0	5.9 *	17.1 *
		20	45.5	19.1	26.4	9.3 ***	17.1 *
	Profile	10	45.2	20.3	24.9	6.1 **	18.8
		20	46.4	19.8	26.6	8.8 ***	17.8 *
	Sphagnum Peat	10	44.5	17.6	26.9	8.1 ***	18.8
		20	47.2	15.3	31.9 *	11.4 ***	20.5
Medium	None	0	42.9	37.8	5.1	3.0	2.1
	Ecolite	10	43.5	37.2	6.3	4.2 ***	2.1
		20	44.5	36.5	8.0 **	5.6 ***	2.4
	Greenschoice	10	43.2	37.0	6.2	4.5 ***	1.7
		20	43.3	34.8	8.5 ***	6.1 ***	2.4
	Isolite	10	43.2	35.7	7.5 **	5.8 ***	1.7
		20	46.2 *	34.1 **	12.1 ***	8.3 ***	3.8
	Profile	10	44.5	36.9	7.6 **	5.2 ***	2.4
		20	46.7 **	37.2	9.5 ***	7.5 ***	2.0
	Sphagnum Peat	10	43.9	34.6 *	9.3 ***	7.2 ***	2.1
		20	46.1 *	27.7 ***	18.4 ***	10.2 ***	8.2 *
Coarse	None	0	38.4	34.7	3.7	2.5	1.2
	Ecolite	10	41.4	36.1	5.3	4.0	1.3
		20	42.8 **	36.0	6.8 ***	5.2 ***	1.6
	Greenschoice	10	42.0 *	36.9	5.1	4.0	1.1
		20	42.4**	35.8	6.6 **	5.6 ***	1.0
	Isolite	10	43.8 ***	36.5	7.3 ***	6.2 ***	1.1
		20	45.0 ***	37.4	7.6 ***	6.5 ***	1.1
	Profile	10	41.8 *	36.0	5.8 *	4.3 *	1.5
		20	45.7 ***	37.1	8.6 ***	6.4 ***	2.2
	Sphagnum Peat	10	42.5 **	34.2	8.3 ***	6.2 ***	2.1
		20	45.4 ***	32.9	12.5 ***	9.5 ***	3.0 ***

†Θ_{200} equals water retained at 0.02 MPa.
‡Plant available water (PAW)
*,**,*** represents significant, at 0.05, 0.01, 0.001 levels respectively compared to unamended sand.

Table 7. Effect of amendments on nitrogen (N) leaching in sand amended with organic and inorganic materials at 20% (v:v).

Soil Amendment	N present in leachate		
	NH_4-N	NO_3-N	Total N
	------------% of added NH_4NO_3-N ------------		
None	96.2 a*	98.1 a	96.1 a
Greenschoice	69.4 b	95.4 b	82.4 b
Profile	21.3 d	96.1 ab	58.7 d
Isolite	63.9 b	97.8 ab	80.8 b
Ecolite	7.8 e	99.2 a	53.5 e
Sphagnum Peat	37.7 c	95.1 b	66.4 c

Means in the same column followed by the same letter are not significantly different ($P < 0.05$).

Table 8. Nitrogen (N) leached in pure sand and sand amended with zeolite and a profile at four rates.

Soil Amendment	Rate (v:v)	N present in leachate			
		NH_4-N	NO_3-N	Total N	
		---------- % of added NH_4NO_3-N----------			
None	0	95.7	96.6	96.9	
Profile	1	78.7 *a	95.9 a	87.3 *a	
	5	51.6 * b	95.3 a	73.5 * b	
	10	32.6 * c	96.0 a	64.3 * c	
	20	22.4 * d	96.3 a	59.4 * c	
Ecolite	1	75.0 *a	92.9 b	83.9 *a	
	5	52.3 *b	98.8 a	75.5 *b	
	10	17.0 * c	96.9 ab	56.9 * c	
	20	7.7 * d	96.7 ab	52.2 * c	
Contrast 'Ecolite vs. Profile 1%'			NS	NS	NS
Contrast 'Ecolite vs. Profile 5%'			NS	NS	NS
Contrast 'Ecolite vs. Profile 10%'		NS	NS	NS	
Contrast 'Ecolite vs. Profile 20%'		***	NS	***	

Means in the same column followed by * are significantly different from pure sand.
Means in the same column within each soil amendment followed by the same letter are not significantly different ($P<0.05$).
Contrasts followed by ***, NS indicates significant a the 0.001 level and non-significant respectively.

Table 9. Nitrogen leached in pure sand and sand amended with zeolite and a porous ceramic at 10% (v:v) at three incorporation levels.

Soil Amendment	Depth (cm)	N present in leachate NH_4-N	NO_3-N	Total N
		-------% of added NH_4NO_3-N-------		
None	0	97.6	97.9	96.6
Profile	2.5	76.6 *a	94.7 a	85.7 *a
	15.0	49.4 *b	91.6 a	70.5 *b
	30.0	32.2 *c	97.4 a	64.8 *b
Ecolite	2.5	68.2 *a	93.0 a	80.6 *a
	15.0	38.2 *b	96.8 a	67.5 *b
	30.0	17.6 *c	96.5 a	57.1 *c
Contrast 'Ecolite vs. Profile 2.5 cm'		NS	NS	*
Contrast 'Ecolite vs. Profile 15 cm'		NS	NS	NS
Contrast 'Ecolite vs. Profile 30 cm'		*	NS	NS

Means in the same column followed by * are significantly different from pure sand.
Means in the same column within each soil amendment followed by the same letter are not significantly different ($P<0.05$).
Contrasts followed by *, NS indicates significant at the 0.05 level and non-significant respectively.

Table 10. Nitrogen (N) leaching in pure sand and sand amended with selected inorganic materials at 20% (v:v) and three incubation times.

Soil Amendment	Time	N present in leachate		
		NH_4-N	NO_3-N	Total N
	- hours -	----------% of added NH_4NO_3-N -----------		
None	0	95.3 a	96.5 a	94.1 a
	12	93.7 a	99.3 a	96.5 a
	24	95.9 a	94.6 a	95.2 a
Profile	0	21.5 a	94.7 ab	58.1 a
	12	21.6 a	98.6 a	60.1 a
	24	23.9 a	92.7 b	58.3 a
Ecolite	0	7.8 a	99.2 a	53.5 a
	12	7.4 a	96.9 a	52.2 a
	24	9.5 a	95.4 a	52.5 a

Means in the same column within the same soil amendment followed by the same letter are not significantly different ($P < 0.05$).

Table 11. Vacuum duration influence on water content of rootzone at five times.

Depth	Time (minutes) 0	5	10	20	40
-- cm --	volumetric water content cm^3 / cm^3				
0- to 15	13.0 a*	10.6 b	9.7 b	8.3 c	7.7 c
15- to 21	17.4 a	15.8 ab	13.4 bc	11.8 c	11.3 c
21- to 27	34.5 a	26.2 b	23.1 bc	18.8 cd	14.8 d
0- to 27	18.7 a	15.2 b	13.5 b	11.4 c	10.1 c

* Means in the same row followed by the same letter are not significantly different p=0.05.

Table 12. The influence of three drainage regimes on the water content of putting green rootzones.

	Depth			
	---- cm ----			
Drainage	0-to 27	0-to 15	15-to 21	21-to 27
	------- volumetric water content cm^3 / cm^3 ------------			
Gravity	16.3 a	13.2 a	14.2 a	25.9 a
Vacuum	12.9 b	11.0 b	12.2 a	18.5 b
Vacuum + Air	13.4 b	11.4 b	12.2 a	19.7 b

* Means in the same column followed by the same letter are not significantly different p=0.05.

Table 13. Water content of five sand rootzones under three drainage regimes.

Amendment	Depth (cm) 0-to 27	0-to 15	15-to 21	21-to 27
	------- volumetric water content cm^3 / cm^3 ------------			
None	13.2 c	10.3 c	11.3 b	22.2 ab
Ecolite	13.2 c	11.5 b	12.1 ab	18.6 b
Greenschoice	14.1 bc	11.6 b	13.2 ab	21.2 ab
Profile	14.7 ab	12.6 a	13.1 ab	21.4 ab
Sphagnum Peat	15.8 a	13.3 a	14.6 a	23.3 a
Contrasts				
None vs. amended	**	***	NS	NS
Peat vs. inorganics	***	***	NS	NS
None vs. inorganics	NS	***	NS	NS

* Means in the same column followed by the same letter are not significantly different p=0.05.

Table 14. Seasonal rootmass of sand-based putting greens under three forms of drainage.

	Spring	Summer
Drainage Treatment	grams / cm^2	
Gravity	0.059	0.033
Vacuum	0.058	0.034
Vacuum + Air	0.060	0.035
Soil Amendment		
None	0.040 b	0.028 b
Ecolite®	0.057 a	0.043 a
Greenschoice®	0.071 a	0.033 ab
Profile®	0.070 a	0.039 a
Sphagnum Peat	0.058 a	0.027 b
Orthogonal contrasts		
Spring vs. Fall	***	

Means in the same column under the same sub-heading followed by the same letter are not significantly different (p=0.05).

Figure 1. Water release of three sands compared to pure inorganic amendments

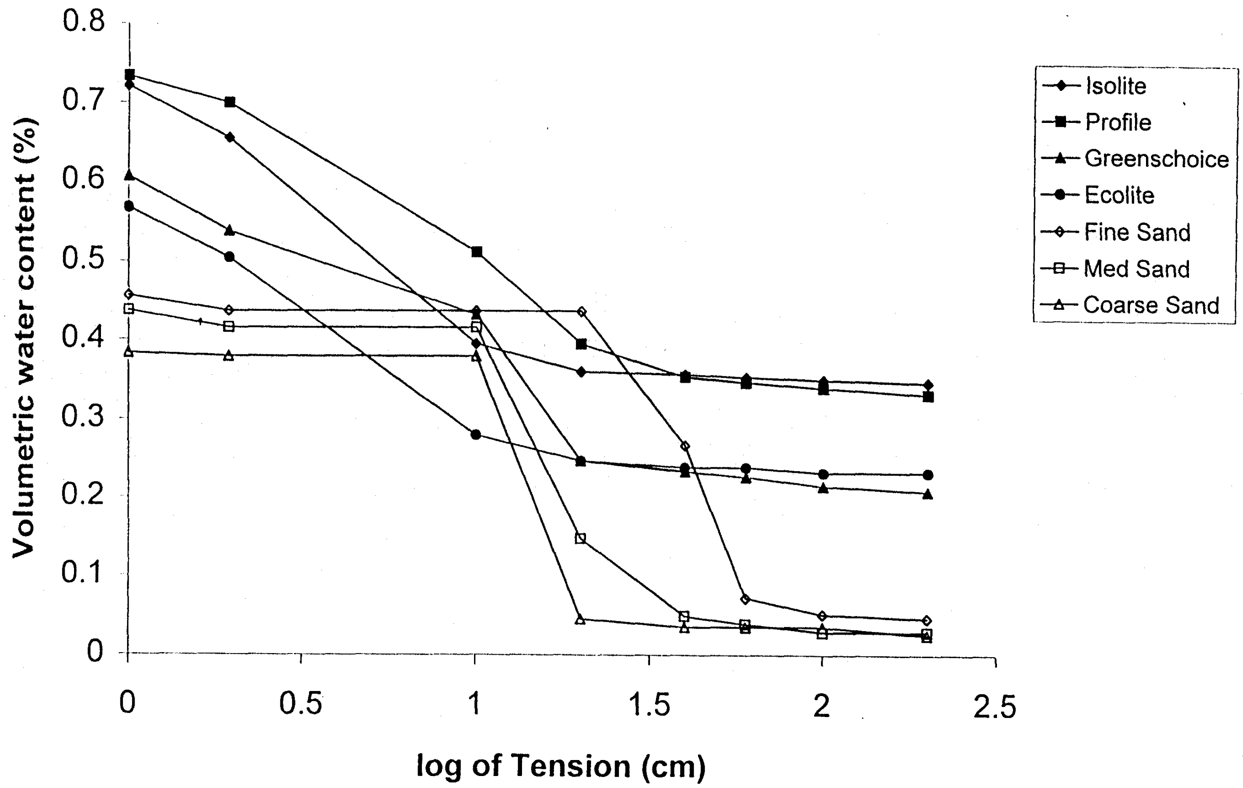

Figure 2. Concentrations of NH4- N in the leachate of pure sand and amended sand rootzone mixtures.

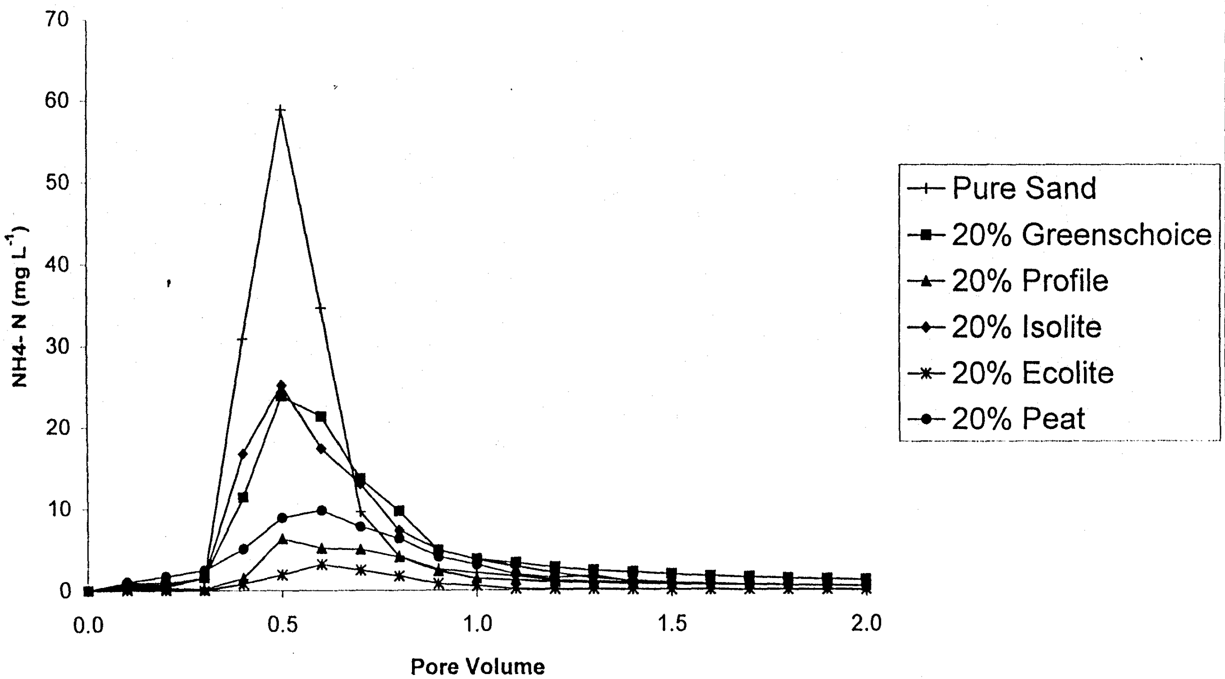

Figure 3. Cumulative NH4-N in the leachate of pure sand and amended sand rootzone mixtures

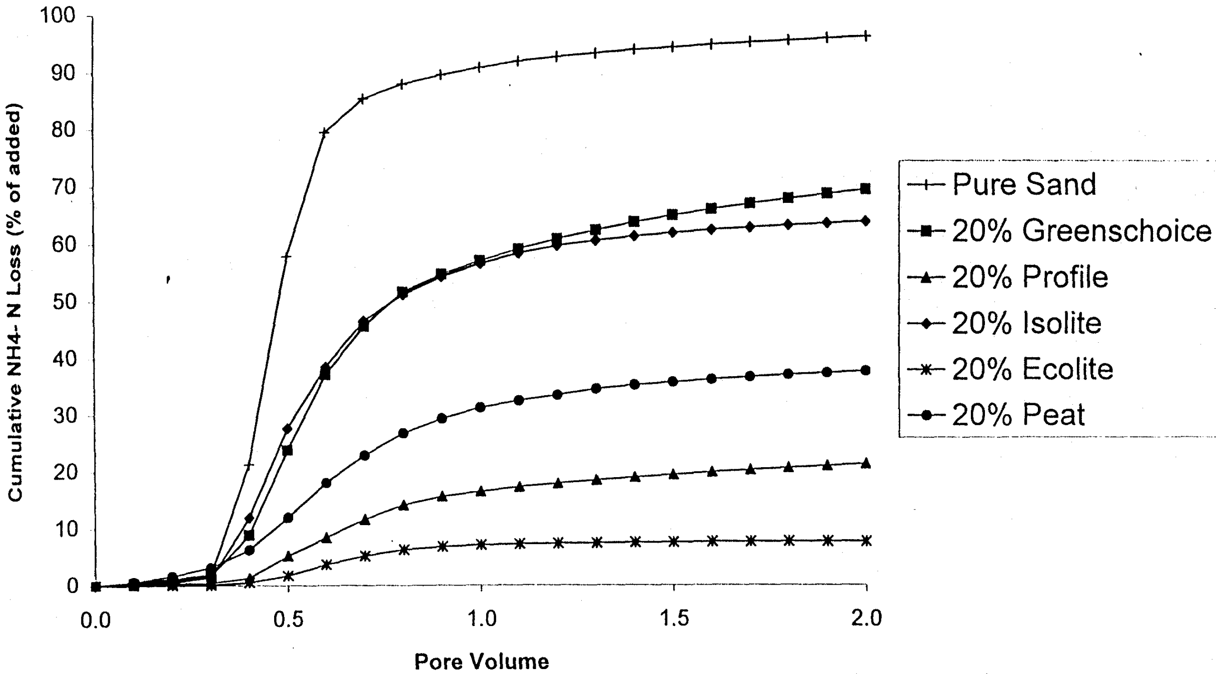

Figure 4. Concentrations of NO3- N in the leachate of pure sand and amended sand rootzone mixtures

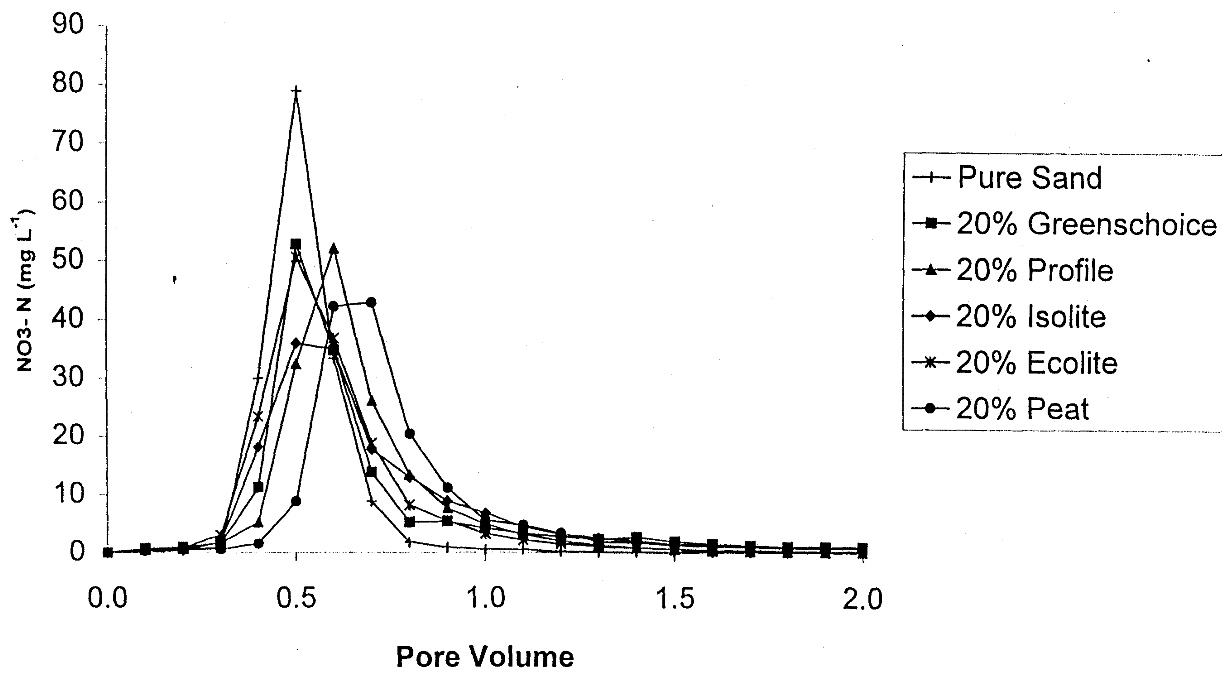

Figure 5. Cumulative NH4-N in the leachate of Ecolite and Profile amended sand at four incorporation rates.

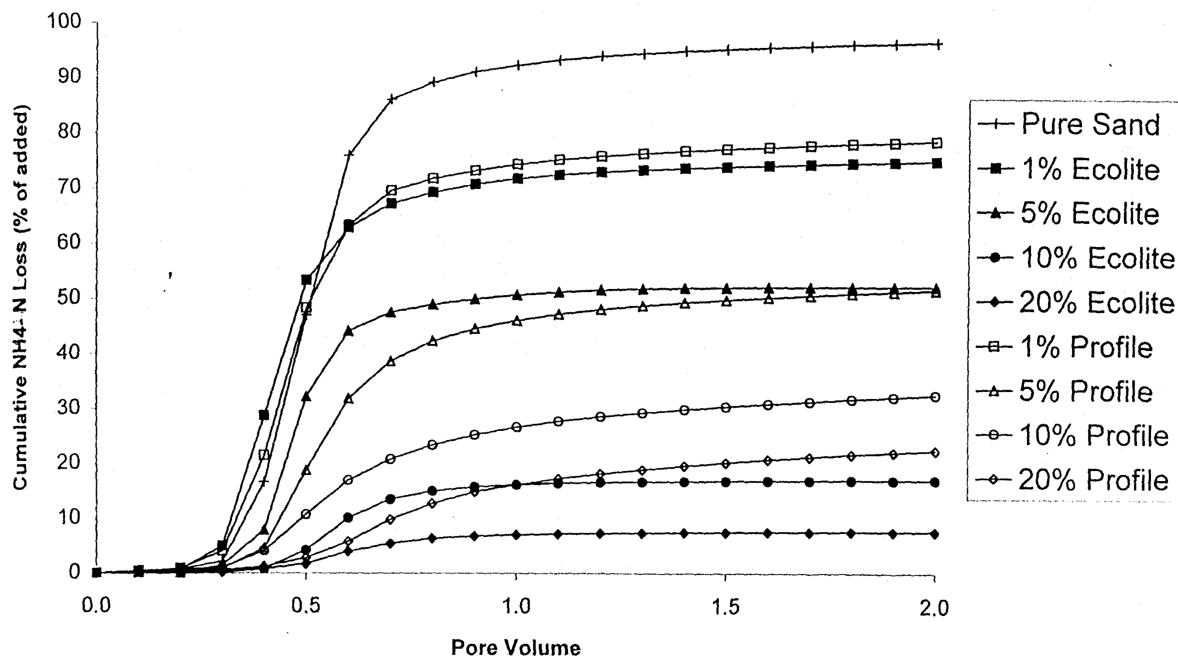

Figure 6. Cumulative NH4-N in the leachate of Ecolite and Profile amended sands at 10% (v:v) and three incorporation depths.

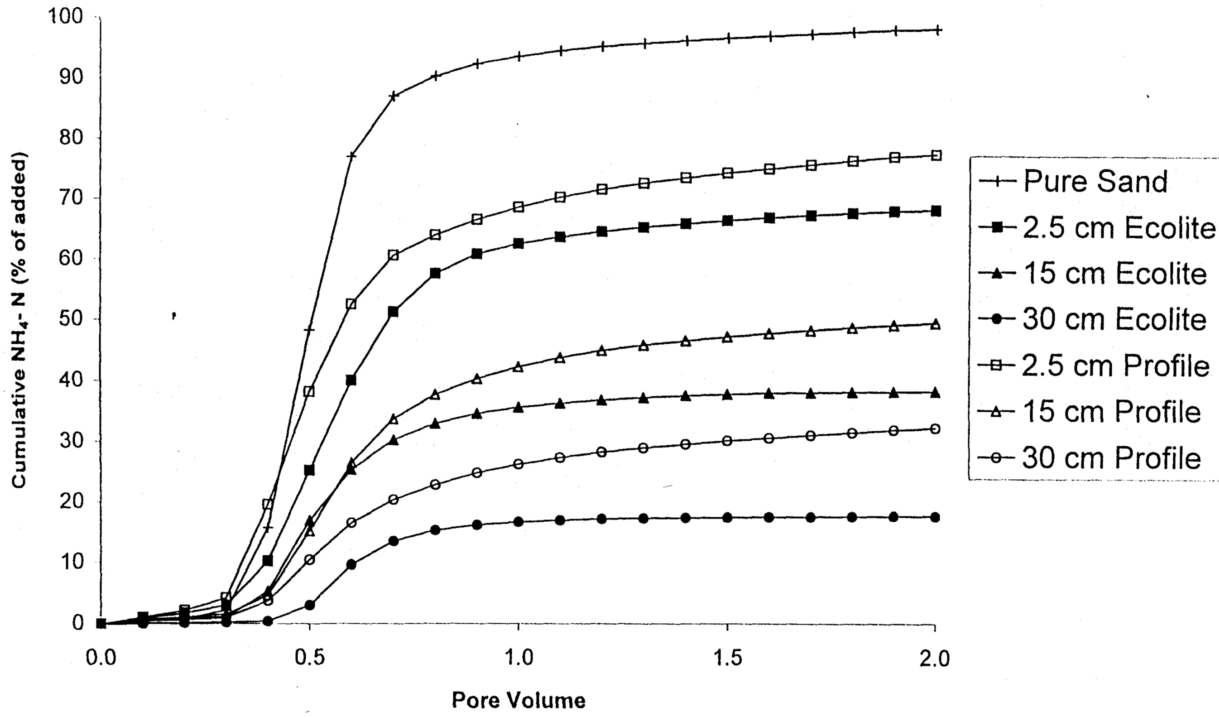

Figure 7. Cumulative NH4-N in the leachate of pure sand and amended rootzone sand at three incubation times.

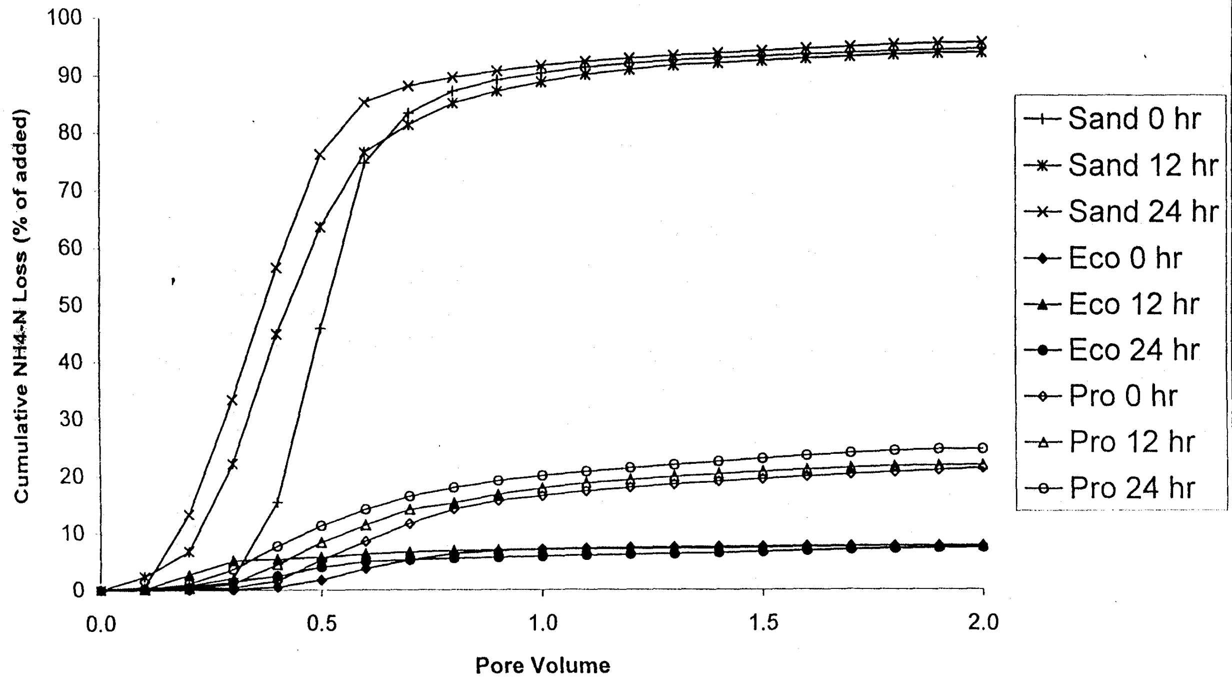

Figure 8. First year soil microbial populations (Top 10 cm) of five sand-based rootzones

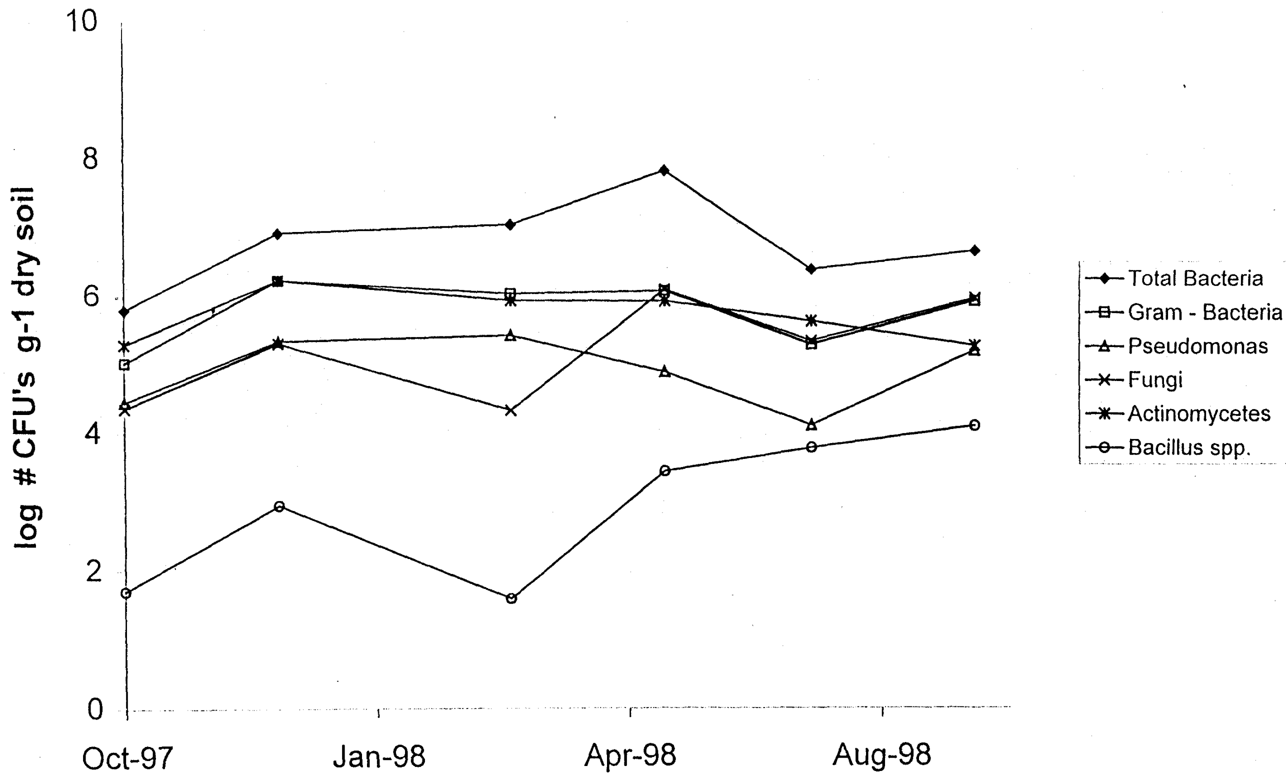

Figure 9. Air and rootzone temperatures for two weeks in August 1998 in a sand-based putting green rootzone located in Raleigh, NC