Understanding the Hydrology of Modern Putting Green Construction Methods
Progress Report
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Dr. Ed McCoy, Dr. Mike Boehm, Mr. Guy Prettyman
Ohio State University

The two most prevalent, modern putting green construction methods are the United States Golf Association (USGA) and the California (CA) green construction techniques. The principal differences between these construction methods are the presence of a gravel drainage blanket in the USGA design and a higher recommended root zone permeability in the CA design. Our earlier reported (10 December, 1997) research on these systems examined water drainage and redistribution as influenced by root zone composition and green slope. The results of this study showed that putting green profile design, root zone permeability and green slope all yielded distinct hydrologic behaviors.

Regarding root zone drainage, the key understanding we demonstrated was that both profile design and root zone mix permeability contribute to drainage rate. Given equal root zone permeability, the experimental USGA greens yielded a more rapid drainage. Indeed, even a rainfall rate of about 4.5 in hr^{-1} failed to overwhelm drainage of the USGA profiles as evidenced by equivalent drainage rates for both the low and high permeability root zones. Further, this same rainfall rate exceeded the drainage capacity of the CA green containing a root zone mix initially tested to have a permeability of 20 in hr^{-1}. For equivalent drainage performance, therefore, it seems that a CA style green would need a root zone mix permeability at least 20 in hr^{-1} greater than a USGA green.

Drainage rate represents an intensity factor. The capacity factor of the drainage process is the completeness of excess water removal from the root zone. Here, it is commonly thought that a USGA green would be less completely drained than a CA green. Our results showed that for equivalent root zone mix permeability the USGA green was drier after 48 hr (interpreted as more completely drained) than a CA green. This appears to be principally due to the need for water to move laterally through the root zone in a CA green before reaching a drain line. Again, for more complete drainage, a CA green would appear to need a higher root zone permeability as evidenced by nearly equal soil moistures after 48 hr drainage in the CA high permeability profile and the USGA low permeability profile.

Finally, all greens are sloped to some degree. This contouring clearly has an effect on water redistribution following rainfall. Prior to this study we believed that the perched water table in a sloped, USGA green would lead to strong lateral movement of water to more downslope locations. We did not believe this would occur to a great extent in a CA green. Again, our results showed our prior beliefs to be somewhat incorrect. While lateral water movement was observed in sloped USGA greens, it was also observed in CA greens. Thus, for equal root zone permeability, there was a much greater lateral difference in water contents after 48 hr drainage in the CA greens than the USGA greens.

Rationale for Reported and Future Research

The overall program co-funded by the USGA and GCSAA investigates the influence of green construction method on hydrologic processes including: water infiltration, redistribution within the rootzone, drainage, and uptake by the turf. The study is subdivided into Phases I and II. Our previously reported research was conducted on the Phase I experimental greens. Future research on turf water use as influenced by green construction method and irrigation management will be conducted on the Phase II greens. In addition, root zone microbial population dynamics are being investigated on the Phase I greens.

The current findings of our Phase I research (as summarized above) are incomplete without a physical characterization of the root zones of the respective experimental greens. Thus, we have conducted lab and field measurements of root zone physical properties from 'fresh' mixes and from the Phase I root zones on a yearly basis. Completed analyses of these physical property measurements are included in the present report. We will continue these measurements for the 5-year duration of the overall project.

Also, our Phase I research showed lateral patterns of root zone moisture after 48 hr drainage. These patterns were influenced by drain line spacing in CA greens and slope in both CA and USGA greens. The question, therefore, arose whether turf drought symptoms would be observed with lateral position across these greens if further irrigation was withheld. Consequently, we conducted an initial replication of a dry-down study on the Phase I experimental units to help address this concern. Preliminary results of this study are included in the present report.

Finally, one caveat of our Phase I results to date is that these greens were just 1 year old and had not experienced foot traffic. During this past year, we have applied simulated foot traffic to the greens by using a weighted roller. The roller is 4 ft in length, 8 inches in diameter and has a weight of about 325 lbs. The 'rolling factor' for this roller is about 1.2 which we estimate to simulate the heel pressure of a average human. Consequently, the water drainage and redistribution study we conducted in the fall of 1997 will be repeated in the spring of 1999.

Phase I Physical Property and Microbiology Investigations

Methods: The Phase I experiment employed 4 greens designs consisting of 1) a CA system soil profile containing a 9:1 sand:sphagnum root zone, 2) a CA profile containing a 6:2:2 sand:compost:topsoil mix, 3) a USGA design soil profile containing the 9:1 sand:sphagnum, and 4) a USGA profile containing the 6:2:2 sand:compost:topsoil mix. The sand:sphagnum blend had a lab permeability of 20.8 in hr^{-1} and is referred to as the high permeability mix while the sand:compost:topsoil blend had a lab permeability of 12.6 in hr^{-1} and is referred to as the low permeability mix. These 4 profile design/root zone mix treatments were replicated three times for a total of 12 experimental greens. The greens contained a Penncross creeping bentgrass turf maintained at a mowing height of 3/16th inch.

Water retention measurements were conducted on root zone mixes prior to construction (fresh mixes) and on undisturbed soil cores collected from the greens 3 and 20 months after seeding. The data was fit to the equation of McCoy, 1992 (Agron. J., 84:375-381) and relevant water retention indices were calculated. Additionally, ponded, single ring infiltration measurements were conducted on the units 20 months after seeding. Soil moistures at 3, 6 and 9 inch depth were collected in association with the ponded infiltration measurements.

Biological properties of the fresh mixes and the putting green root zones was determined by isolation and enumeration of bacteria an fungi. Samples of the fresh mixes were collected, serially diluted and plated on either 0.1 trypticase soy agar (0.1 TSA), King's media B (KB), and acidified potato dextrose (APDA). The number of colony forming units (CFUs) after 4 days incubation at room temperature were calculated and reported as the $\log_{10}$ (CFU) g^{-1} dry weight root zone mix. Next, 100 bacterial colonies were systematically isolated from a representative 0.1 TSA plate harboring 50-300 colonies, and transferred to fresh 0.1 TSA. All fungal colonies growing on APDA dilution plates 10^{-2} or 10^{-3} were transferred to fresh APDA plates for purification and identification.

At 3 and 15 months after turf establishment, enumeration of bacteria and fungi were performed as described above. Also, enumeration of chitinolytic bacteria were performed by plating dilution samples on chitin agar. Plates were incubated at room temperature for seven days before counts were taken. Approximately 50-100 bacterial colonies were systematically isolated from a representative chitin plate containing 50-200 colonies to fresh chitin media.

<u>Results</u>: The water retention curve coefficients for either the fresh root zone mixes or from undisturbed soil cores collected 3 months after turf establishment are shown in Table 1. Differences in the coefficients for the fresh mixes principally reflect the addition of soil material to the low permeability mixes resulting in increased water retention at higher soil water suctions. Statistical analysis of the curve coefficients from cores collected 3 months after turf establishment show no statistical differences due to profile design (either USGA or California). There was, however, differences due to root zone with the low permeability mix exhibiting higher water retention than the high permeability mix.

Ponded infiltration rates measured 20 months after turf establishment (Table 2) yielded some surprising results but were consistent with our observations reported in November, 1997. While we expected and observed greater infiltration rates from the high permeability root zone, we also observed greater infiltration rates from the USGA profile than in the California profile. Apparently, the presence of the gravel drainage blanket below the root zone in the USGA profile allowed for more rapid water infiltration regardless of the root zone mix composition. This behavior was inferred in our previous study where a reduction in total drainage from the California profile was associated with visually observed runoff that was not apparent for the USGA profile. Thus, soil profile features at 12 inches depth have an influence of water entering the soil surface in modern putting green designs.

Table 1. Mean water retention curve coefficients from fresh root zone mixes (not included in statistical analysis) and undisturbed soil cores as influenced by putting green soil profile and root zone mix composition.

Profile	Root Zone	Θ_1	α_1	n_1	Θ_2	α_2	n_2
		$m^3\ m^{-3}$	m^{-1}		$m^3\ m^{-3}$	m^{-1}	
Fresh Mix	High Perm.	0.75*	6.7	4.16	0.25	0.11	1.81
	Low Perm.	0.70	6.3	4.29	0.30	0.11	1.63
USGA	High Perm.	0.80	9.7	2.34	0.20	0.11	1.79
	Low Perm.	0.67	7.4	2.35	0.33	0.096	1.59
California	High Perm.	0.80	10.3	2.21	0.20	0.11	1.80
	Low Perm.	0.67	6.5	2.44	0.33	0.096	1.57
Analysis of Variance							
Profile		NS	NS	NS	NS	NS	NS
Root Zone		***	NS	NS	***	*	*
Profile x Root Zone		NS	NS	NS	NS	NS	NS
LSD (0.05)		0.03	4.7	0.52	0.03	0.012	0.22

The high permeability mix is a 9:1 (vol.) Van Wey sand:sphagnum peat blend.
The low permeability mix is a 6:2:2 (vol.) Malvern sand:compost:topsoil blend.
*, **, *** indicates significance at $p < 0.05$, 0.01 and 0.001 respectively.
LSD (0.05) given for the highest order interaction.

Table 2. Mean ponded infiltration rates and soil water contents with depth as influenced by putting green soil profile and root zone mix composition.

Profile	Root Zone	Infiltration Rate (40 mm head)	Water Content 3 in depth	Water Content 6 in depth	Water Content 9 in depth
		$cm\ min^{-1}$	$m^3\ m^{-3}$	$m^3\ m^{-3}$	$m^3\ m^{-3}$
USGA	High Perm.	1.91	0.47	0.46	0.44
	Low Perm.	1.20	0.43	0.43	0.41
California	High Perm.	1.31	0.44	0.40	0.44
	Low Perm.	0.96	0.45	0.41	0.41
Analysis of Variance					
Profile		*	NS	**	NS
Root Zone		**	**	*	NS
Profile x Root Zone		NS	**	*	NS
LSD (0.05)		0.41	0.013	0.013	0.06

*, **, *** indicates significance at $p < 0.05$, 0.01 and 0.001 respectively.
LSD (0.05) given for the highest order interaction.

This project also includes research on the microbiology of the experimental putting green root zones. Briefly, this research has noted that prior to greens construction, the low permeability mix harbored approximately 100-fold greater bacterial and fungal populations than the high permeability mix. Recall that the low permeability mix was a 6:2:2 sand:compost:topsoil blend and the high permeability mix contained 9:1 sand:sphagnum. Three months after seeding, however, the bacterial and fungal population differences began to decrease with only slightly higher populations in the low permeability mix (Table 3). Further, there were small and inconsistent differences due to profile design.

Table 3. Bacterial, fungal and chitinolytic actinomycete populations at 3 months after green establishment.

		Population Density ($\log_{10}$ CFU/g dry wt.)			
Profile	Root Zone	TSA[1]	KB[2]	APDA[3]	Chitin[4]
USGA	High Perm.	8.1	7.8	5.2	6.2
	Low Perm.	9.0	8.9	5.3	6.9
California	High Perm.	8.5	8.4	4.9	6.3
	Low Perm.	9.0	8.8	5.2	6.9
LSD (0.05)		0.1	0.2	0.2	0.1

[1] 0.1 Trypticase soy (TSA) is used to enumerate soil bacteria
[2] King's media B (KB) is used to enumerate fluorescent pseudomonades.
[3] Acidified potato dextrose (APDA) is used to enumerate fungi.
[4] Chitin agar is uses to enumerate chitinolytic actinomycetes.

At 15 months after greens establishment, there were again, slightly higher populations in the low permeability mix with no apparent differences due to profile design (Table 4). Further, there was about an order of magnitude less bacterial CFUs at 15 months than at 3 months. Fungal and actinomycete populations were similar for these two sampling dates. Approximately 3600 bacteria, 1200 actinomycetes and 1000 fungi have been isolated from these samplings and stored for species identification.

Table 4. Bacterial, fungal and chitinolytic actinomycete populations at 15 months after green establishment.

Profile	Root Zone	Population Density ($\log_{10}$ CFU/g dry wt.) TSA[1]	KB[2]	APDA[3]	Chitin[4]
USGA	High Perm.	7.1	7.0	4.2	5.7
	Low Perm.	7.4	7.1	5.1	6.3
California	High Perm.	6.9	6.7	4.1	5.8
	Low Perm.	7.5	7.2	5.7	6.3
LSD (0.05)		0.3	0.3	0.3	0.2

[1] 0.1 Trypticase soy (TSA) is used to enumerate soil bacteria

[2] King's media B (KB) is used to enumerate fluorescent pseudomonades.

[3] Acidified potato dextrose (APDA) is used to enumerate fungi.

[4] Chitin agar is uses to enumerate chitinolytic actinomycetes.

Phase I 'Dry Down' Study

Methods: The Phase I experimental greens were randomly configured to slopes of 0 or 4% and were uniformly set to a drain line spacing of 15 feet. Subsequently, the greens were mowed to 3/16 inch and heavily irrigated with a dilute, 20-20-20 fertilizer solution. No further irrigation was applied for the dry down period and when rain threatened, the greens were loosely covered with plastic sheeting. Following a 24 hr drainage period, drainage outflow from the furthest downslope drain line, soil moistures within the root zone, and indicators of turf drought stress were recorded daily for a 2-week period. The soil moistures were recorded using TDR probes that existed within these experimental greens. Moistures were collected at 3 depths (3, 6 and 9 inches) and 5 locations (2, 7, 12, 17, and 22 feet) for a total of 15 measurements within each experimental green. Drought stress was assessed visually and by differential (air-canopy) temperature measurements at 2, 7, 12, 17 and 22 feet along the length of the green. Since early visual indications showed a patchy distribution of stress for the different locations, digital photographic images were occasionally collected for improved estimation of the area extent of drought stress. At the end of the stress period, clipping yields were collected as a function of distance along the experimental units. The study was initiated on 3 August, 1998.

Results: Since not all data has been analyzed, only preliminary findings from this study are reported here. The reported results are drainage outflow and soil moistures from representative high permeability CA and USGA greens at 0 and 4% slope. Comments on observed patterns of drought stress and clipping yields will also be given.

Cumulative drainage outflow with time after an initial 24 hrs drainage is shown for these treatments in Fig. 1. At equivalent green slopes, the CA greens showed higher cumulative outflows than the USGA greens. Further, for both construction methods, a 4% sloped green yielded higher outflow than a 0% sloped green. This result was expected since, from our previous study, USGA greens have higher drainage rates than CA greens containing the same root zone mix. Consequently, most of the excess, irrigated water has drained from the USGA profile prior to our first outflow collection. The CA greens, having shower drainage rates, retained more water within the profile that was subsequently drained during our measurement period. The effect of slope on both green systems was also expected since, again, our previous research showed lateral migration of root zone moisture at 4% slope. Both systems required from 4 to 5 days for nearly complete root zone drainage.

Soil moistures as a function of distance and depth in the root zone and for days 2, 4, 8 and 10 are shown in Figs. 2 to 5. Early in the stress period, the CA green at 0% slope (Fig. 2) exhibited a pattern of lower soil moistures over the drain lines and higher moistures between the drains. This pattern diminished with time so that by day 8, the root zone uniformly contained soil moistures of about 16% by volume. This same profile when sloped at 4% (Fig. 3) showed a downslope accumulation of moisture throughout the 10 day period but with a progressive drying over the drought stress period. Compared with the CA green at 0% slope, the 4% sloped system exhibited soil moistures of about 7% within the upslope half of the green.

With the exception of some edge effects, the USGA green at 0% slope did not show a strong lateral pattern in soil moistures (Fig. 4). Progressive drying of the green was, however, observed; so that after 10 days, the upper portions of this green were at 7% soil moisture increasing to about 11% at depth. This increasing moisture with depth is evidence of the perched water table that was seemingly not as pronounced in the comparative CA green. Establishing a 4% slope on the USGA green yielded a downslope accumulation of soil moisture that, again, persisted throughout the 10 day period (Fig. 5). Near-surface soil moistures after 10 days were about 6% within the upslope half of the green.

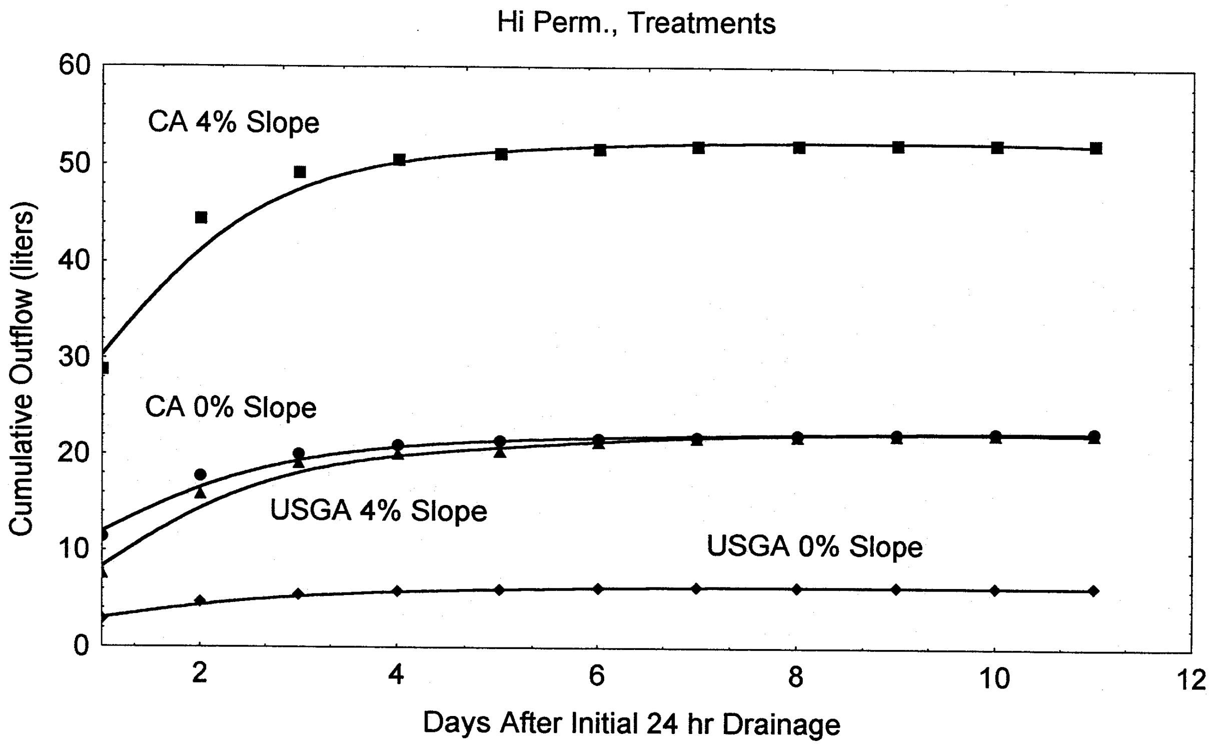
We anticipated an earlier onset of drought stress in the high permeability root zones than in the low permeability root zones. We also anticipated earlier drought over drain lines in the CA green at 0% slope, and at further distances upslope for both green systems at 4% slope. The strongest realization of these expectations was the response to slope in the high permeability CA and USGA greens. These greens at 10 days contained from 6 to 7% surface soil moisture at uplsope locations and from 15 to 16% moisture at extreme downslope locations. This gradient in soil moisture yielded progressively increased stress symptoms from the downslope to the upslope locations. This was confirmed by our clipping yield measurements where fewer clippings were collected at upslope locations than downslope locations. Some of the more subtle turf responses to stress during this dry down study (if they exist) will require further data analysis before they are revealed.

Phase II Progress

We have recently completed construction and established turf on an additional experiment to assess turf water use as influenced by root zone depth, root zone composition and water perching in a USGA profile. The study employs 6 root zone mixes and 2 root zone depths constructed as a 2-tier USGA soil profile. Two of the root zones are 100% sand where the sands are relatively coarse and fine as based on USGA specifications. Two root zones are sand:sphagnum peat blends using the coarse and fine sand materials, and the final 2 root zones are sand:soil:peat blends again using the coarse and fine sands. Each root zone is placed in a 2-tier USGA profile with root zone depths of 9 or 12 inches. Each root zone mix and profile depth treatment combination is replicated 3 times for a total of 36 experimental greens.

To study turf water use, a complete accounting must be made of all water inputs and outputs from the root zone. For this reason, the greens soil profile is constructed within 6 ft diameter non-weighing lysimeters where drainage from individual greens is collected in an adjacent service pit. Additionally, TDR probes for soil moisture measurement are located at 3 and 6 inches depth for the 9 inch root zone and 3, 6 and 9 inches depth for the 12 inch profile. Use of the TDR probes will allow measurement of water loss from the turf by evapotranspiration. Water for the entire area is provided by an overhead irrigation system. The greens were seeded to Penncross creeping bentgrass in the spring of 1998.

Fig. 1


Hi Perm., Treatments
CA 4% Slope
CA 0% Slope
USGA 4% Slope
USGA 0% Slope
Cumulative Outflow (liters)
Days After Initial 24 hr Drainage
0
10
20
30
40
50
60
2
4
6
8
10
12

398

Fig 2

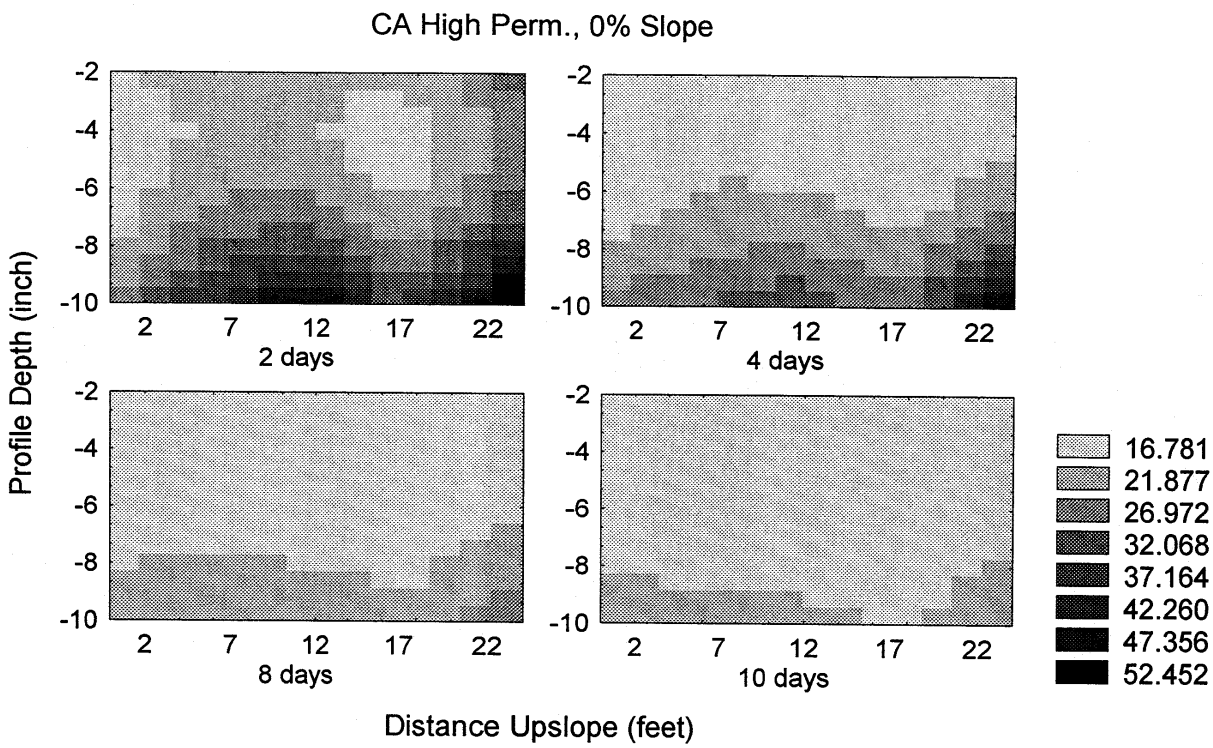
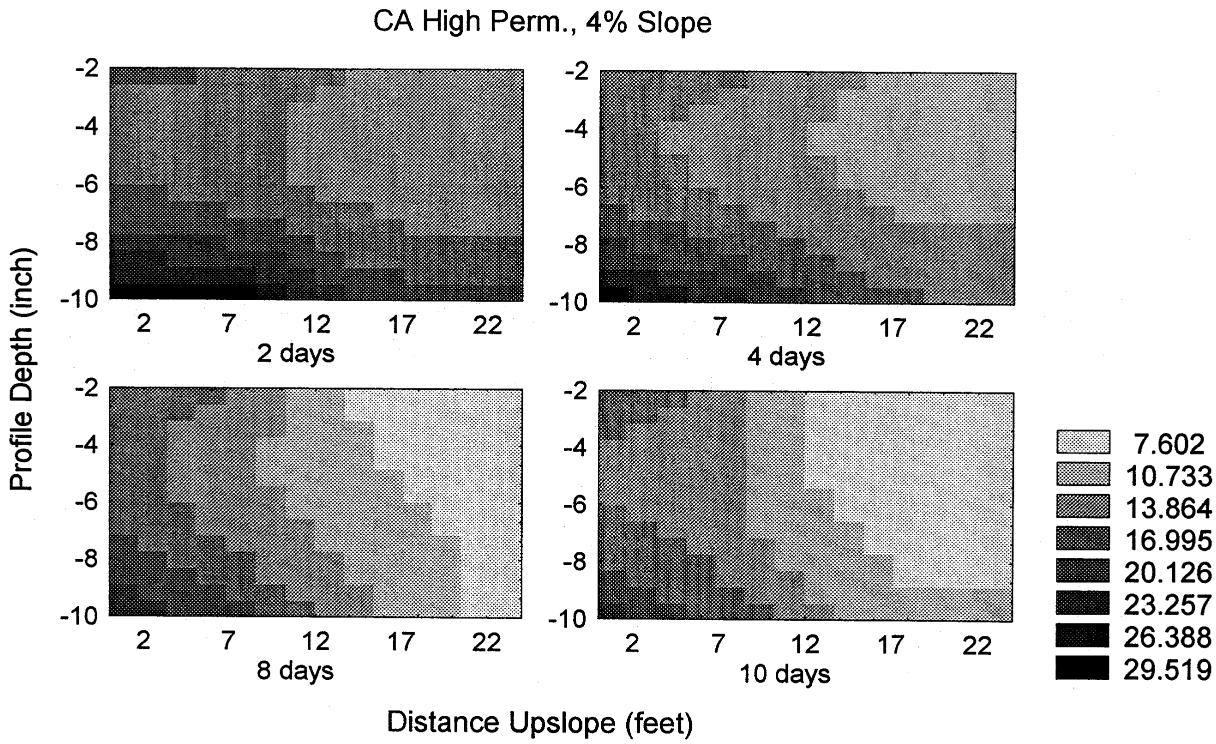

CA High Perm., 0% Slope
Profile Depth (inch)
-2
-4
-6
-8
-10
2
7
12
17
22
2 days
4 days
8 days
10 days
Distance Upslope (feet)
16.781
21.877
26.972
32.068
37.164
42.260
47.356
52.452

Fig 3



CA High Perm., 4% Slope
Profile Depth (inch)
-2
-4
-6
-8
-10
2
7
12
17
22
2 days
4 days
8 days
10 days
Distance Upslope (feet)
7.602
10.733
13.864
16.995
20.126
23.257
26.388
29.519

Fig 4

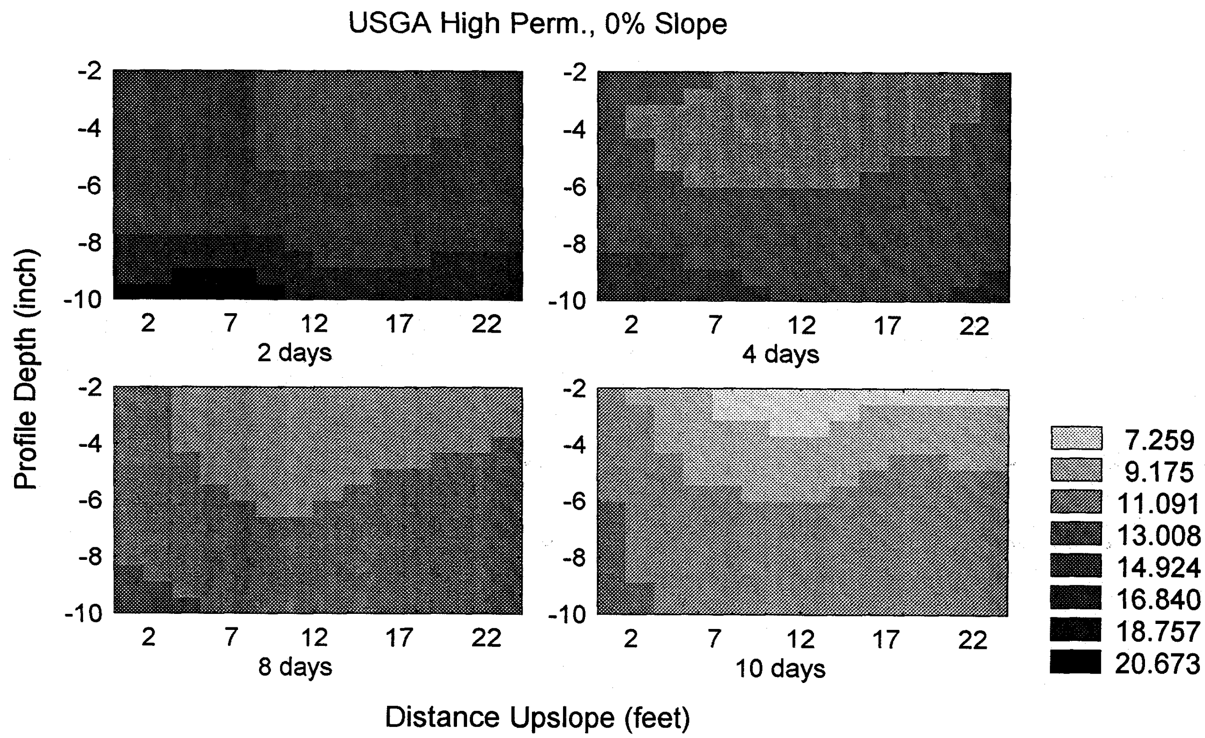
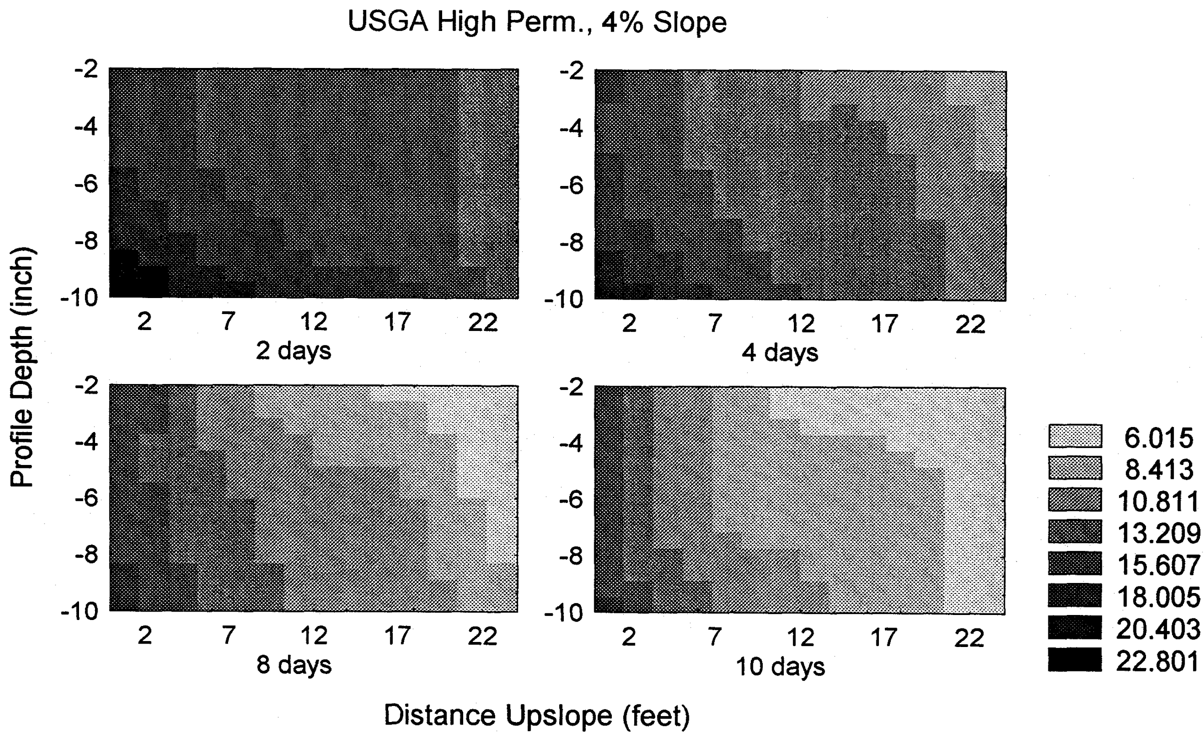

USGA High Perm., 0% Slope
Profile Depth (inch)
-2
-4
-6
-8
-10
2
7
12
17
22
2 days
4 days
8 days
10 days
Distance Upslope (feet)
7.259
9.175
11.091
13.008
14.924
16.840
18.757
20.673

Fig 5



USGA High Perm., 4% Slope
Profile Depth (inch)
-2
-4
-6
-8
-10
2
7
12
17
22
2 days
4 days
8 days
10 days
Distance Upslope (feet)
6.015
8.413
10.811
13.209
15.607
18.005
20.403
22.801