Understanding the Hydrology of Modern Putting Green Construction Methods
Progress Report
17 November, 1999

Dr. Ed McCoy and 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. 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. Phase I focuses on water redistribution and drainage as influenced by soil profile design, root zone composition and green slope. Phase II focuses on turf water use in a USGA profile as influenced by root zone composition and depth.

The Phase I results included in this report are essentially a repetition of our project conducted in the fall of 1997. In the earlier study, the greens were just 1 year old and had not received any compaction treatments to simulate foot traffic. Prior to our spring 1999, Phase I work, we applied a compaction treatment 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 that we estimate to simulate the heel pressure of an average human. In addition, the greens of the 1999, Phase I research had aged an additional 20 months.

The Phase II results of this report examine turf water use as influenced by green construction method. This was conducted as a 'dry down' study wherein water was withheld for a period of 10 days during which soil moisture status and turf response were monitored. The Phase II results should, however, be viewed as preliminary in that only 1 dry down cycle was completed. Additional cycles will be conducted in the summer months of 2000.

Phase I Methods

The study of water infiltration, drainage and redistribution employed 4 greens designs consisting of 1) a CA style 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.

The greens were built above ground in 4 by 24-ft wooden boxes supported by a legged, metal framework. Six inch wide by 8 inch deep simulated drainline trenches were fabricated from sheet metal extending below the profiles with each containing an outlet in the center. For experimental units containing a USGA 2-tier profile, the sides of the wooden box was 16 inches whereas units containing a CA style profile were 12 inches. The drainline trenches (perpendicular to long axis) were constructed into each unit at 2, 12, 17 and 22 ft from the downslope end. Nominal 2 inch PVC drainpipes were connected to the outlet of each drainline trench with each fitted with a valve for selective closure. The present study was conducted with only the 2 and 17-ft drainlines open effectively yielding a drain spacing of 15 ft.

The 12 experimental units were placed, in a randomized complete block design, on an 80 by 28-foot concrete pad. This allowed for adjustment of the green slope by jacking and blocking the metal legs. Green slopes used in this study were 0, 2, and 4%.

The root zone of each experimental green was instrumented with TDR soil moisture probes at 3 depths (3, 6 and 9 inches) and 5 locations (2, 7, 12, 17 and 22 ft from the downslope end of the green) for a total of 15 positions per green. The probes were connected to a multiplexed recording unit for continuous monitoring of soil moistures. Additionally, tipping bucket rain gauges were connected to the drainage outflow pipe of the furthest downslope drainline to monitor drainage outflow rate.

This experimental set-up was used to monitor water drainage and redistribution within the root zone as influenced by green construction method, green slope and rainfall rate. The overall study was conducted as a series of 18 individual experimental runs. During an experimental run, one green from each replication was configured to a predetermined slope of 0, 2, or 4%. Additionally each green received rainfall from a rain simulation device set to deliver either a high or low rainfall rate. Continuous measurements of drainage outflow rates and soil water contents were started at the beginning of the rainfall period. Rainfall was then applied for 3 hr to ensure we had achieved a constant drainage rate. Rainfall measurements were also collected during this 3-hr period. At the end of the rainfall period, the rain simulation device was turned off but drainage outflow and soil moisture measurements continued for an additional 48 hr. Subsequently, the next replication was configured for an experimental run.

Drainage outflow was measured every 5 min for the 51 hr duration of an experimental run. Soil water contents were measured every 30 min for the first 27 hr and hourly for the remaining 24 hours.

Phase I Results

Drainage of the experimental greens was expressed as cumulative outflow vs. time after rain application was stopped (Figs. 1 and 2). The curves begin at 1.5 hr prior to rain ending and continue for the 48 hr drainage period. Data is shown for the 0% and 4% slope treatments under the high rainfall rate conditions. Error bars shown on the curves are the standard errors for 3 replications.

At 0% slope under the high rainfall rate conditions (Fig. 1), the CA low permeability green had very low drainage rates compared to all other experimental greens. This is shown by the rather flat slope of the cumulative outflow curve prior to rain cessation. During this same period, both USGA greens and the CA high permeability green exhibited relatively higher drainage rates. Drainage rate differences between these greens will require further statistical analysis to determine if differences exist. After rainfall stopped, drainage from the USGA greens slowed substantially since the cumulative outflow curve quickly became almost flat. The CA greens, on the other hand, showed continued drainage although at a slower rate than during rain application. The much lower cumulative outflow after 48 hr from the CA low permeability system was the result of the infiltration rate being less than the rainfall rate such that excess rainfall occurred as runoff and did not enter the soil profile.

At 4% slope under the high rainfall rate conditions (Fig. 1), both USGA greens exhibited high and nearly equivalent drainage rates. Again, the CA low permeability green had a very low drainage rate with the CA high permeability green intermediate. After rainfall stopped, drainage from the USGA greens, slowed substantially, similar to that observed for 0% slope. The CA greens, on the other hand, showed continued drainage although at a slower rate than during rain application. Indeed, the CA greens continued to drain at a reasonable rate for the full 48 hr. The overall reduced cumulative drainage from these greens was due to excess runoff that was not apparent in the USGA profiles.

The remaining figures depict the progress of root zone drainage over 45 hr for each of the experimental greens. This is shown using contour graphs of soil water content (% by vol.) as a function of profile depth (inch) distance upslope (feet), and for times of 0, 1, 3, 9, 27, and 45 hours after rainfall stopped. Results for the low rainfall rate treatment were quite similar to that for the high rainfall rate and thus only the high rainfall rate treatments at 0 and 4% slope are shown here. Although each graph is roughly square, it is important to remember that the lateral distance is about 1/10th of the true scale. Also, an open drainline is located in each graph at 2 and 17 ft. upslope for a drain spacing of 15 ft.

The CA high permeability greens at 0% slope showed virtually a textbook example of soil drainage after rainfall (Fig. 3). As rainfall ended (0 hr) there was a lateral pattern of higher water contents between the drainlines and lower water contents above the drainlines and near the soil surface. As the soil drained, this pattern was maintained as overall water contents declined. An equilibrium condition developed at 27 hr with a vertical gradient of increasing moisture with depth and a lateral gradient of decreasing water contents over the drainlines. Little change in this situation was observed after 45-hr drainage. A very similar response was observed early in the drainage period when the CA high permeability greens was sloped at 4% (Fig. 4). At 27 hr, however, there was a trend of increasing soil water contents at the downslope locations. Further, additional drainage occurred from 27 to 45 hr. This led to an overall drier root zone at 45 hr and an accumulation of soil moisture at the furthest downslope location for the 4% slope as compared to the 0% slope condition.

The CA low permeability greens at 0% slope maintained very high soil moisture contents virtually throughout the period of this study (Fig 5). Additionally, there was little evidence that an open drainline was present at 17 feet upslope. This was not expected, and reasons for this seemingly ineffective drainline will require further research for an explanation. Equilibrium conditions again appeared after 27 hr with little further drainage after 45 hr. Again, a very similar response was observed early in the drainage period when the CA low permeability greens were sloped at 4% (Fig. 6). At 9 hr a trend began to develop with increasing water contents at the downslope locations. This trend strengthened after 27 hr resulting in about a 15% difference in water content from the downslope to the furthest upslope location. Unlike the CA high permeability greens at 4% slope, equilibrium conditions appeared to be established after 27 hr for the CA low permeability system.

Except for some edge effects, the USGA high permeability greens at 0% slope exhibited quite uniform root zone moistures early in the drainage period (Fig. 7). Additionally, since all figures are shown using the same scale, it is easy to note the drier soil conditions of this system than the CA high permeability greens. As drainage progressed a slight trend of higher water contents with depth developed. Perhaps due to antecedent conditions, there was also a slight trend of higher water contents at the downslope locations even for this 0% slope configuration. Regardless, the major portion of the root zone from 9 to 45 hours averaged 20% volumetric water content. A similar behavior was observed for the USGA high permeability greens at 4% slope (Fig. 8). There was, however, a more pronounced tendency for water accumulation at the downslope locations resulting in an 8% difference from the extreme downslope location to the extreme upslope location.

Results for the USGA low permeability greens at 0% slope (Fig. 9) were similar to that of the USGA high permeability greens except for the expected high water contents throughout the drainage period. Consequently, water contents throughout were about 4% greater for this treatment than the USGA high permeability system. This system did not, however, exhibit the very high water contents of the CA low permeability greens. When positioned at a 4% slope (Fig. 10), the USGA low permeability system was again similar to the USGA high permeability greens with again about 4% greater water content.

One apparent difference between the 1997 and the 1999 data from our Phase I research was generally higher water content for most treatments in 1999. A second difference was the very low drainage rates and absence of drainline effects on soil moisture for the CA low permeability greens. More subtle differences will likely appear after complete statistical analysis.

Phase II Methods

This 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. The treatments were arranged in a randomized complete block design.

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 and maintained at a mowing height of 3/16th inch.

To conduct an individual dry down cycle, the experimental were heavily irrigated using both the overhead irrigation system and by hand to uniformly charge the perched water table. During the subsequent days of no rainfall and seasonally high evapotranspiration demand, daily measurements of 1) soil moisture with root zone depth, 2) average soil moisture over the entire root zone depth, 3) volume of drained water over the previous 24 hours, and 4) visual indications of turf drought stress were collected. This initial study lasted 10 days.

As an additional index of turf water status, spectral reflectance measurements of the turf surface were conducted daily throughout the dry down period. The measurements were taken with a Li-Cor, LI-1800 spectral radiometer spanning the range of 350-1100 nm wavelength. The radiometer was enclosed in a 4-ft tall and 42-inch diameter PVC drain tile containing a lid. Illumination was provided using two 1000-watt tungsten light sources. In this manner, the measurements were collected independent from daylight illumination conditions.

Phase II Results

As mentioned previously, only one dry down period was completed during the summer of 1999. While we had hoped to complete several dry down cycles during this period, weather conditions, and our efforts on the Phase I work precluded more extensive experimentation. Additional cycles will be conducted in the summer of 2000.

Measurements of soil water content at 3, 6 and 9 inches depth for the 12-inch root zone, and 3 and 6 inches for the 9-inch root zone showed a consistent patter of water use with time (Figs. 11 to 14). For the 12-inch root zone containing coarse sand, water contents at the 3 inch depth were lowest throughout the stress period for the pure sand, intermediate for the sand/peat mix and highest for the sand/peat/soil blend (Fig. 11). The same general pattern was observed for measurements at the 6 and 9-inch depths although water contents throughout the period were expectedly higher at the deeper depths (data not shown). Additionally water contents declined in a similar manner at all depths. Further, a similar behavior was observed at the 3-inch depth of the 9-inch root zone (Fig. 12). The exception here was that water contents were higher for the 9-inch root zone at day 3, and about the same after 10 days, both as compared with results from the 12-inch root zone. Consequently, water depletion rates throughout the stress period were greater for the 9 than the 12-inch root zone.

For the 12-inch root zone containing fine sand, water contents at the 3-inch depth were also lowest throughout the stress period for the pure sand, but the sand/peat mix and sand/peat/soil mixes showed similar water contents throughout the stress period (Fig. 13). Again, the same general pattern was observed for measurements at the 6 and 9-inch depths although water contents throughout the period were expectedly higher at the deeper depths (data not shown). Additionally water contents declined in a similar manner at all depths. Further, a similar behavior was observed at the 3-inch depth of the 9-inch root zone (Fig. 14). Finally, water depletion rates throughout the stress period were again greater for the 9 than the 12-inch root zone.

Most of the water content results described above would be expected. Amending sands with peat and soil and using a shallower root zone depth would expectedly lead to higher water contents. A shallow root zone depth would also expectedly lead to greater water use rates assuming all soil depths contribute water for turf uptake. One surprising aspect of this data was the apparent insensitivity to soil addition in the fine sand as compared to the increased water contents from soil addition in the coarse sand. Adding to this confounding is the fact that the fine sand/peat/soil mix contained 90.3% sand whereas that coarse sand/peat/soil mix contained 92.1% sand. This and other, more subtle insights will require additional dry down cycles and data analysis to gain a further understanding of the processes involved.

Turf evapotranspiration (ET) was determined using average soil moisture over the root zone, drainage volume over the previous 24 hours, and a water balance calculation. This approach had not been tried for this system but appeared to work quite well. Results are shown for coarse and fine sand treatments using a 9 or 12 inch root zone for days 5 and 10 (Figs. 15 to 18).

ET for day 5 (actually for the 24 hour period from mid afternoon on day 4 to the same time on day 5) for the coarse sand treatments averaged about 0.43 cm day^{-1} irrespective of root zone composition or depth (Fig. 15). Essentially the same result was observed for the fine sand treatments (Fig. 16). After 10 days of withholding water, however, treatment differences became apparent for both the coarse and fine sand treatments. Use of a 12-inch root zone for the coarse sand treatments generally yielded higher ET rates than the corresponding 9-inch root zone (Fig. 17). Further addition of peat or peat and soil for both root zone depths generally yielded greater ET rates as well. Consequently, for the coarse sand treatments, increasing available water through using a deeper root zone and amendments generated higher ET rates at 10 days of stress. Similar results were observed for the fine sand treatments (Fig. 18) particularly regarding the benefit of a deeper root zone. Peat amendment also yielded higher ET rates for either depth whereas ET from peat and soil additions were slightly less than that due to peat addition alone.

The natural implication of comparatively reduced ET rates is that turf in this situation is under some drought stress. We are seeking to confirm this with spectral reflectance measurements. While a complete analysis of the data has not yet been performed, it appears that there was some correspondence between our measured near red and infrared reflectance and the ET data. The analysis of this (limited) data is ongoing.

Plans for 2000

Our plans for the 2000 season are to complete several dry down cycles of the Phase II study. All methodology has been established at this time so progress should go smoothly (weather permitting). We will also conduct a dry down study on the Phase I greens with individual treatments sloped at either 0 or 4%. This should flush out our previous experiment examining the effect of slope, profile design and root zone composition on soil water status and turf response to drought. Other more routine analysis is support of the Phase I and Phase II work will also continue.

Fig. 1

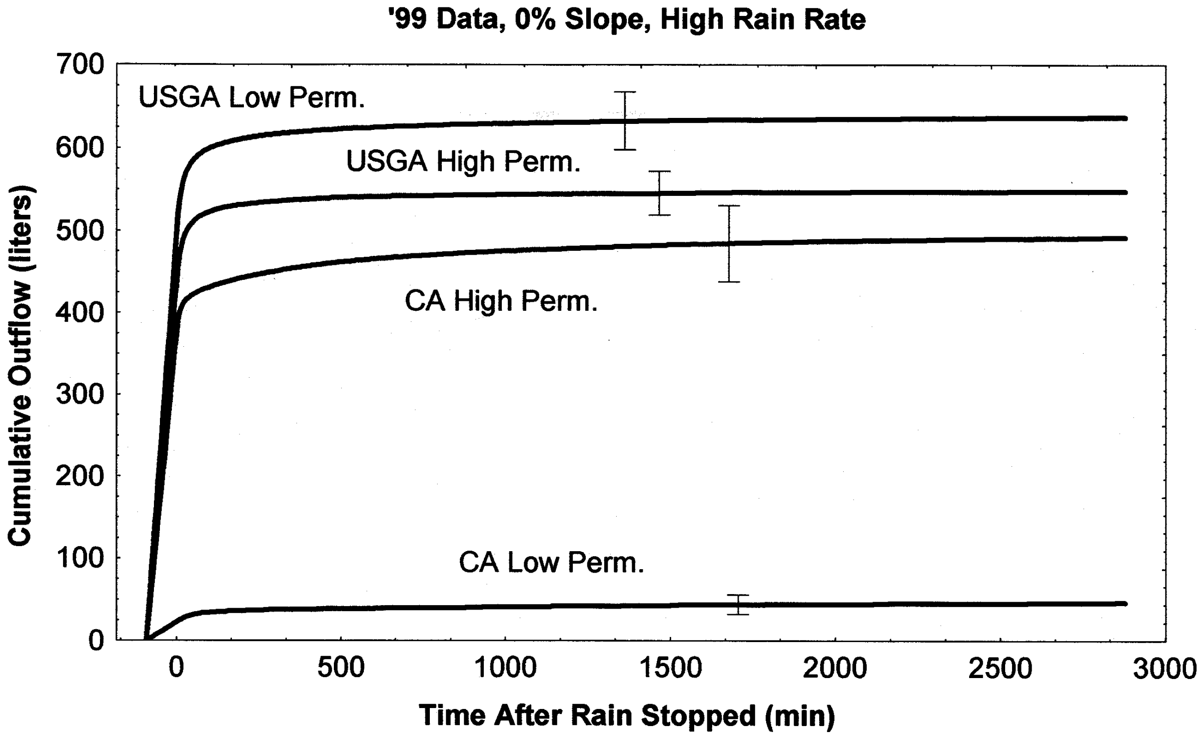

'99 Data, 0% Slope, High Rain Rate
USGA Low Perm.
USGA High Perm.
CA High Perm.
CA Low Perm.
Cumulative Outflow (liters)
0
100
200
300
400
500
600
700
0
500
1000
1500
2000
2500
3000
Time After Rain Stopped (min)

Fig. 2

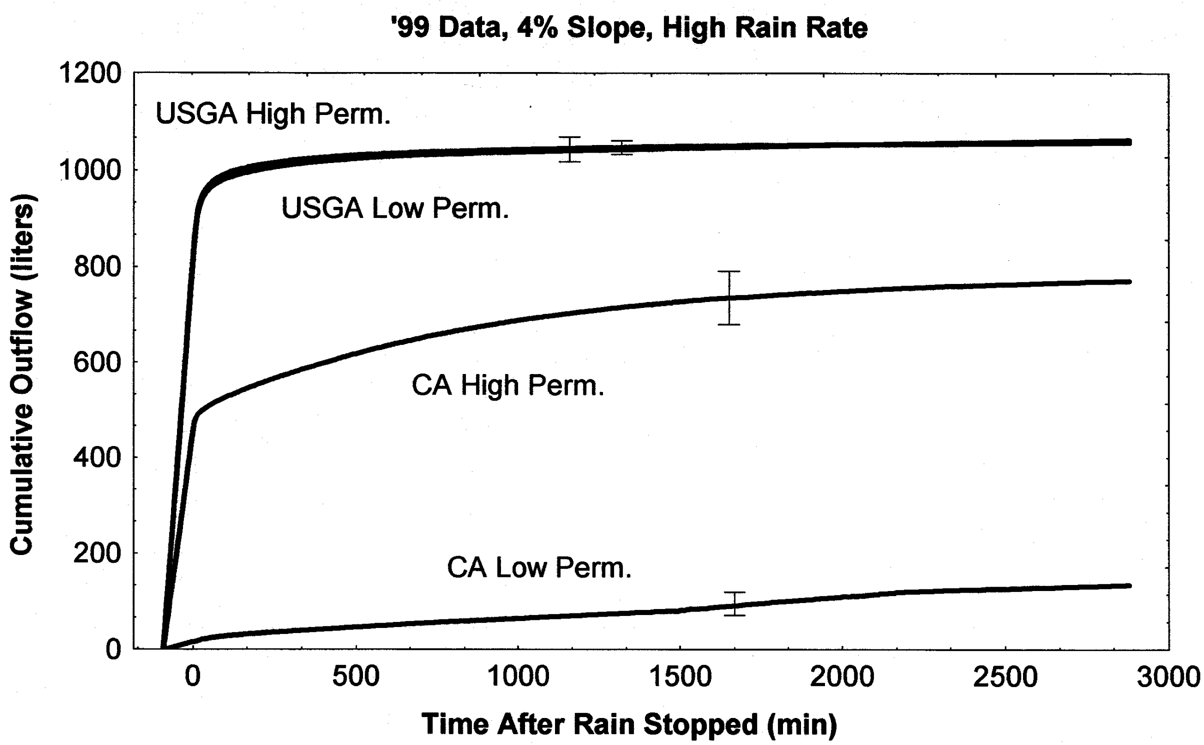
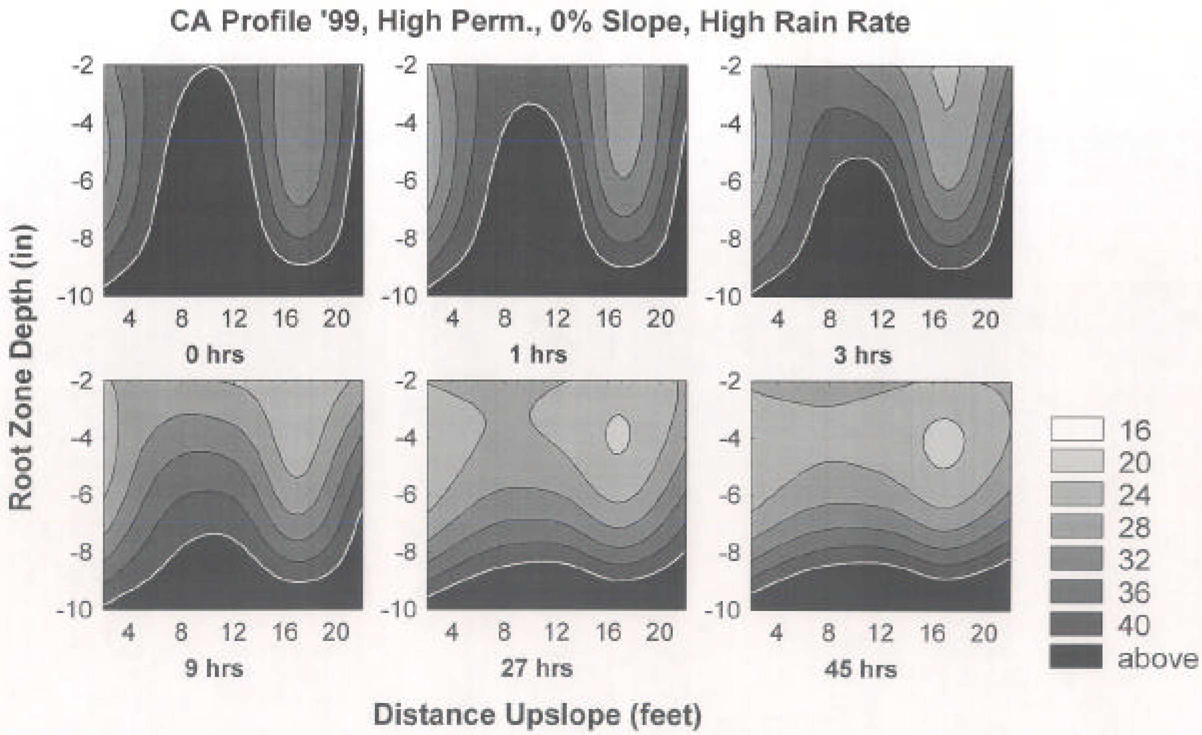
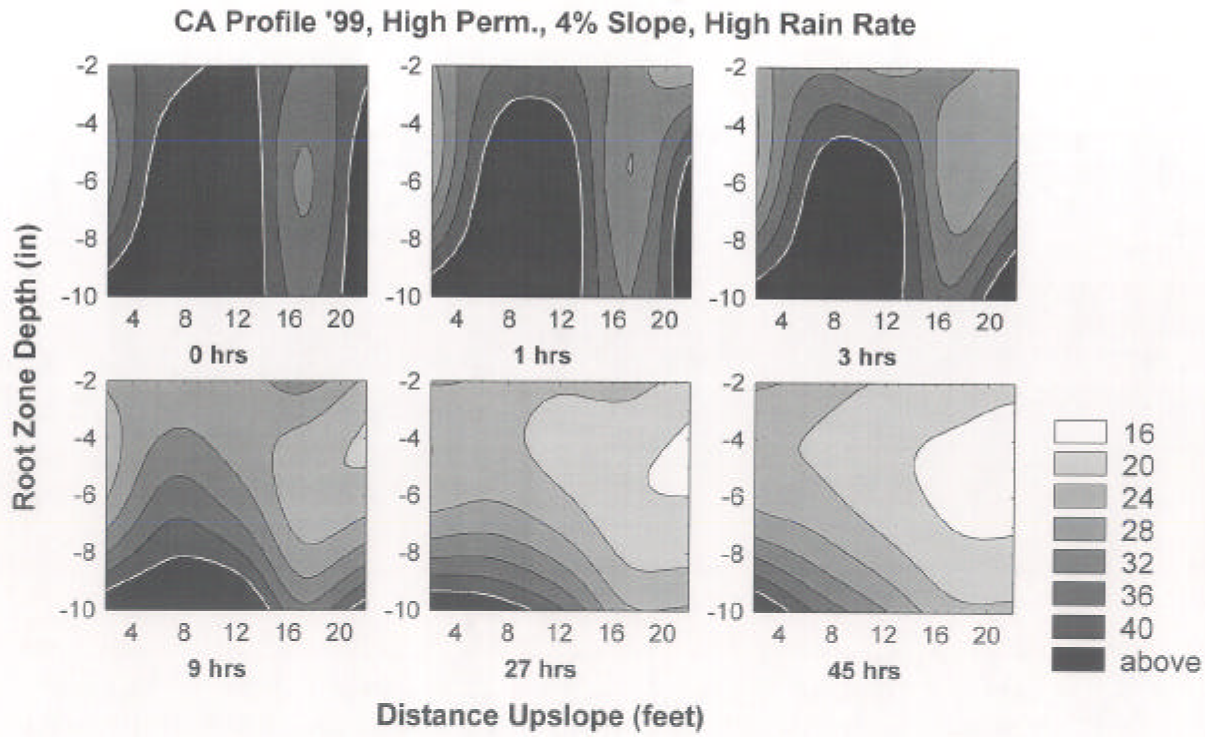

'99 Data, 4% Slope, High Rain Rate
USGA High Perm.
USGA Low Perm.
CA High Perm.
CA Low Perm.
Cumulative Outflow (liters)
Time After Rain Stopped (min)
0
200
400
600
800
1000
1200
0
500
1000
1500
2000
2500
3000

Fig. 3



CA Profile '99, High Perm., 0% Slope, High Rain Rate
Root Zone Depth (in)
-2
-4
-6
-8
-10
4
8
12
16
20
0 hrs
1 hrs
3 hrs
9 hrs
27 hrs
45 hrs
16
20
24
28
32
36
40
above
Distance Upslope (feet)

Fig. 4



CA Profile '99, High Perm., 4% Slope, High Rain Rate
Root Zone Depth (in)
-2
-4
-6
-8
-10
4
8
12
16
20
0 hrs
1 hrs
3 hrs
9 hrs
27 hrs
45 hrs
Distance Upslope (feet)
16
20
24
28
32
36
40
above

Fig. 5

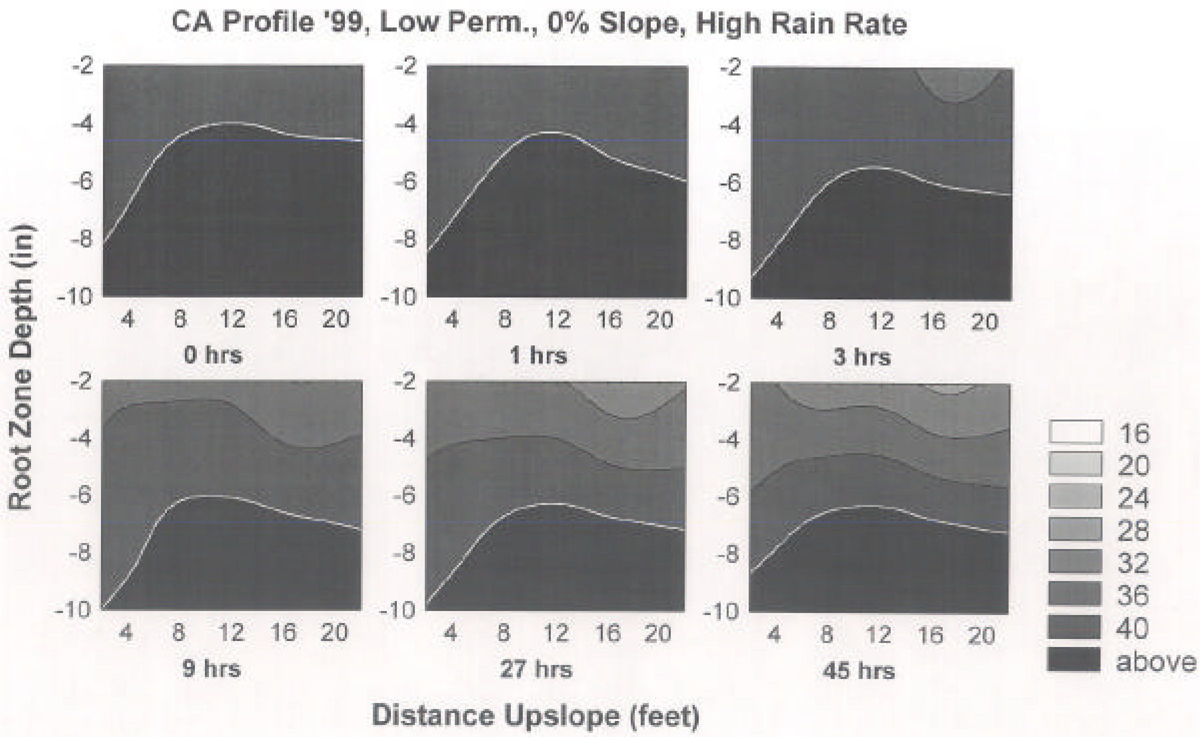

CA Profile '99, Low Perm., 0% Slope, High Rain Rate
Root Zone Depth (in)
-2
-4
-6
-8
-10
4
8
12
16
20
0 hrs
1 hrs
3 hrs
9 hrs
27 hrs
45 hrs
16
20
24
28
32
36
40
above
Distance Upslope (feet)

Fig. 6

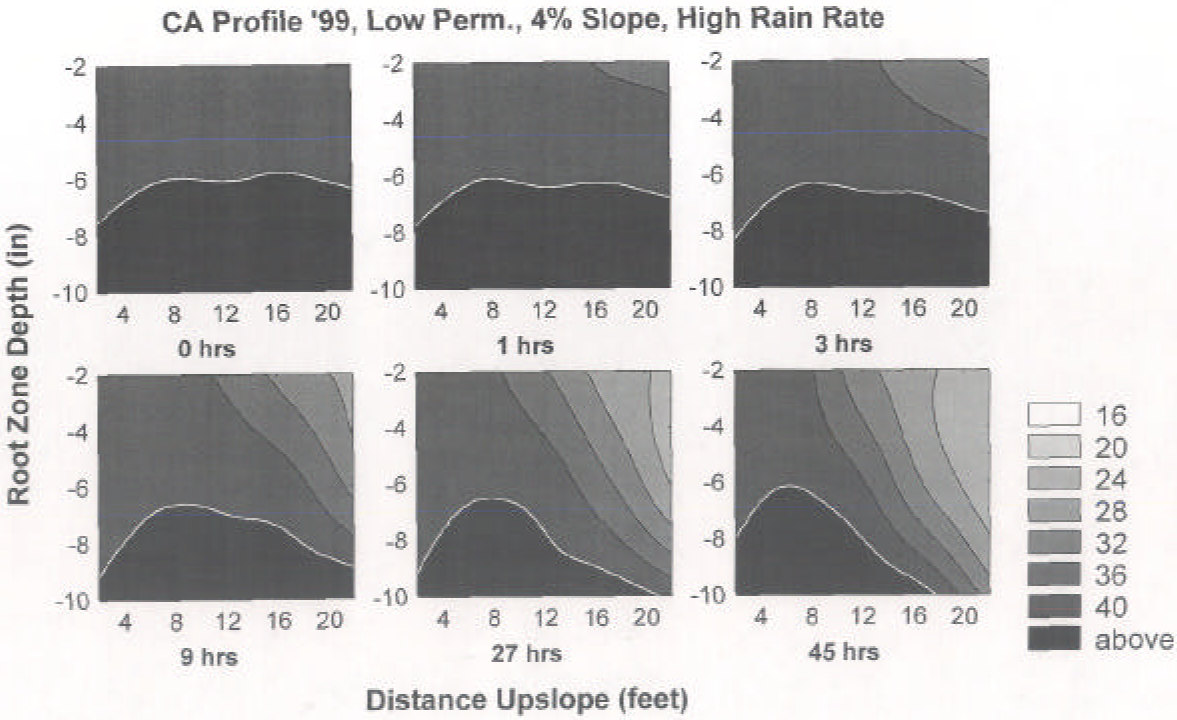
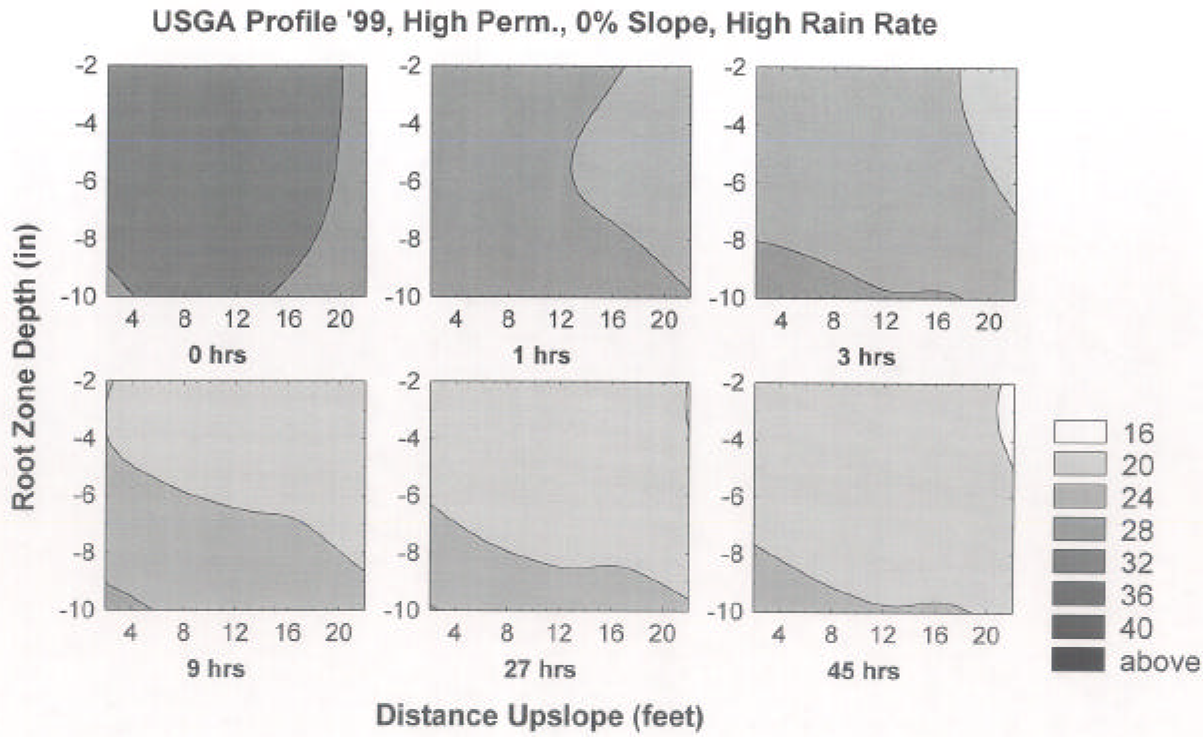
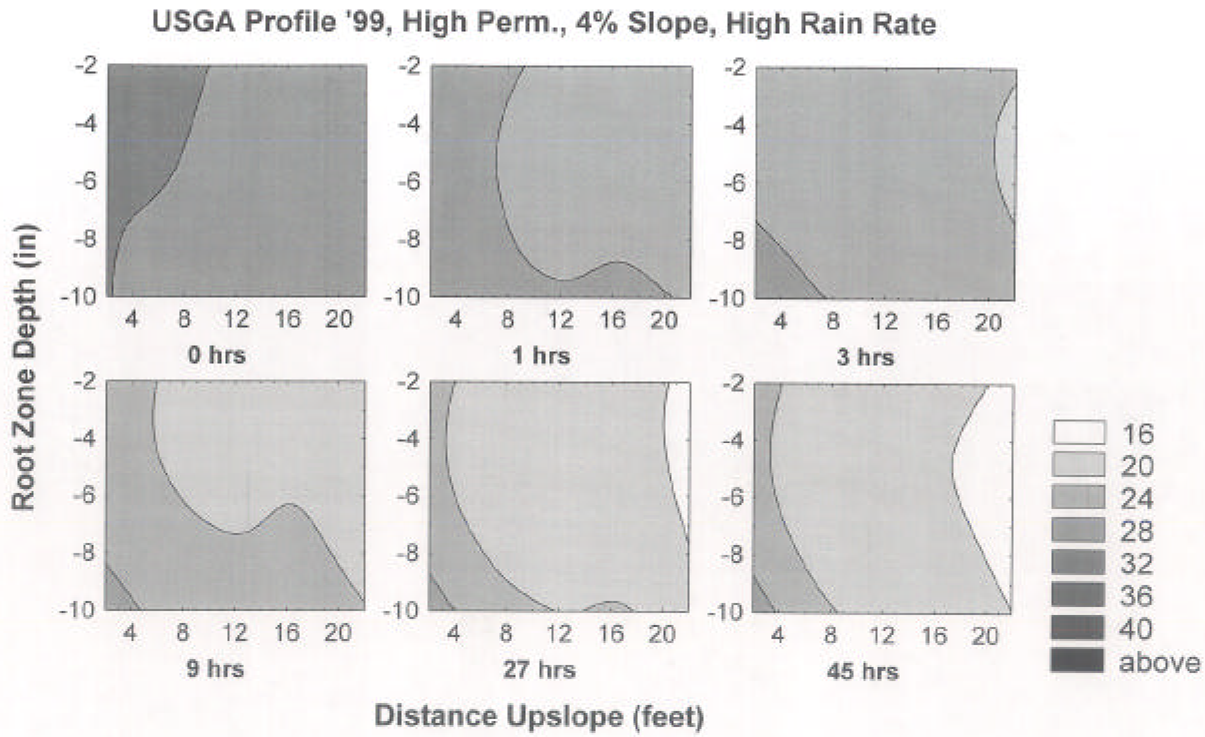

CA Profile '99, Low Perm., 4% Slope, High Rain Rate
Root Zone Depth (in)
-2
-4
-6
-8
-10
4
8
12
16
20
0 hrs
1 hrs
3 hrs
9 hrs
27 hrs
45 hrs
Distance Upslope (feet)
16
20
24
28
32
36
40
above

Fig. 7



USGA Profile '99, High Perm., 0% Slope, High Rain Rate
Root Zone Depth (in)
-2
-4
-6
-8
-10
4
8
12
16
20
0 hrs
1 hrs
3 hrs
9 hrs
27 hrs
45 hrs
16
20
24
28
32
36
40
above
Distance Upslope (feet)

Fig. 8


USGA Profile '99, High Perm., 4% Slope, High Rain Rate
Root Zone Depth (in)
-2
-4
-6
-8
-10
4
8
12
16
20
0 hrs
1 hrs
3 hrs
9 hrs
27 hrs
45 hrs
16
20
24
28
32
36
40
above
Distance Upslope (feet)

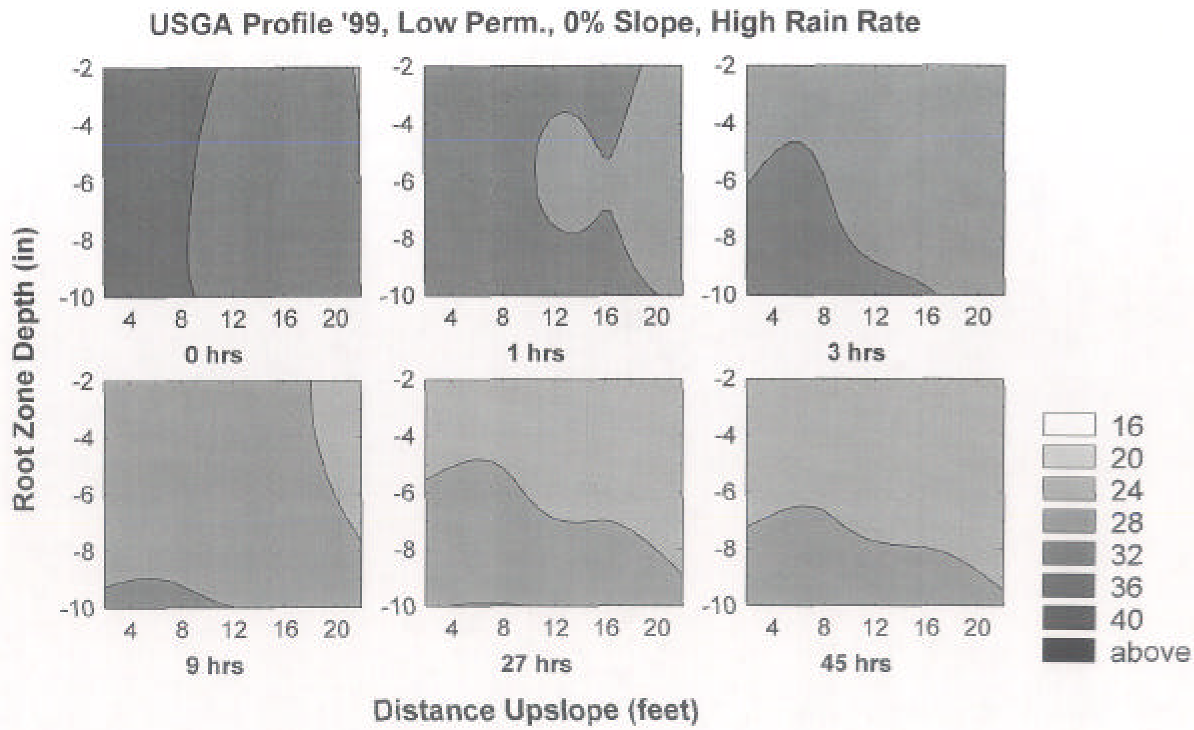
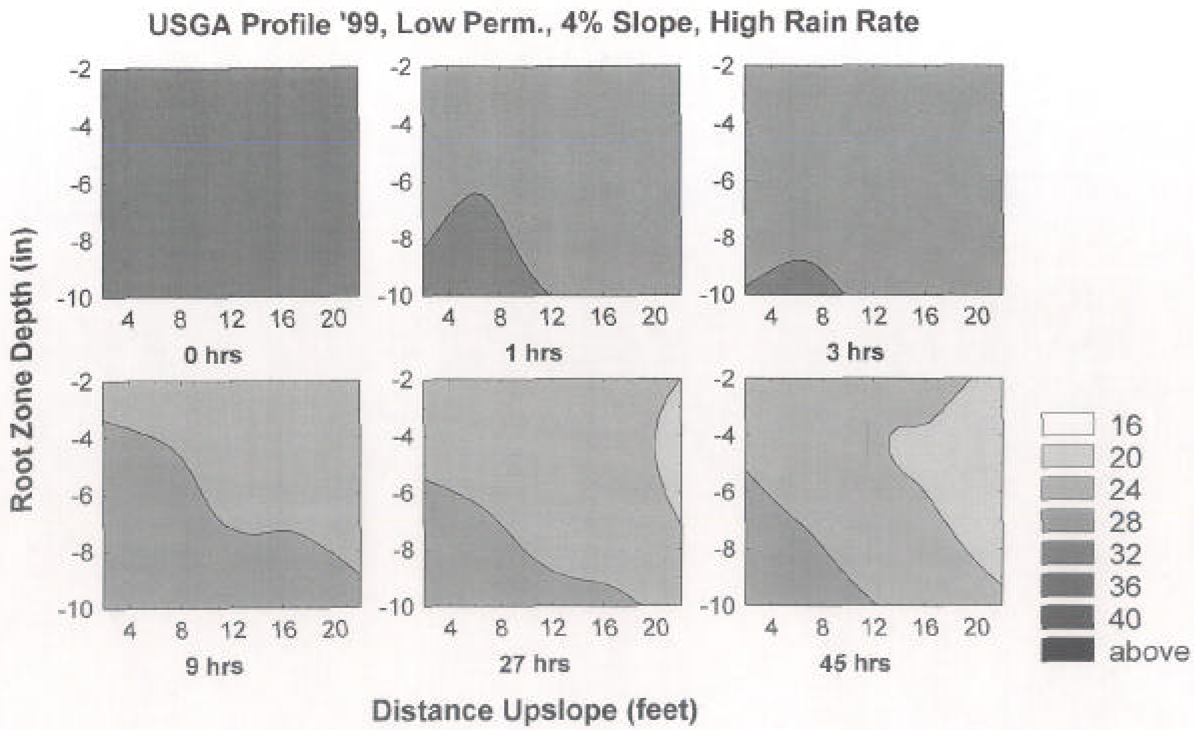
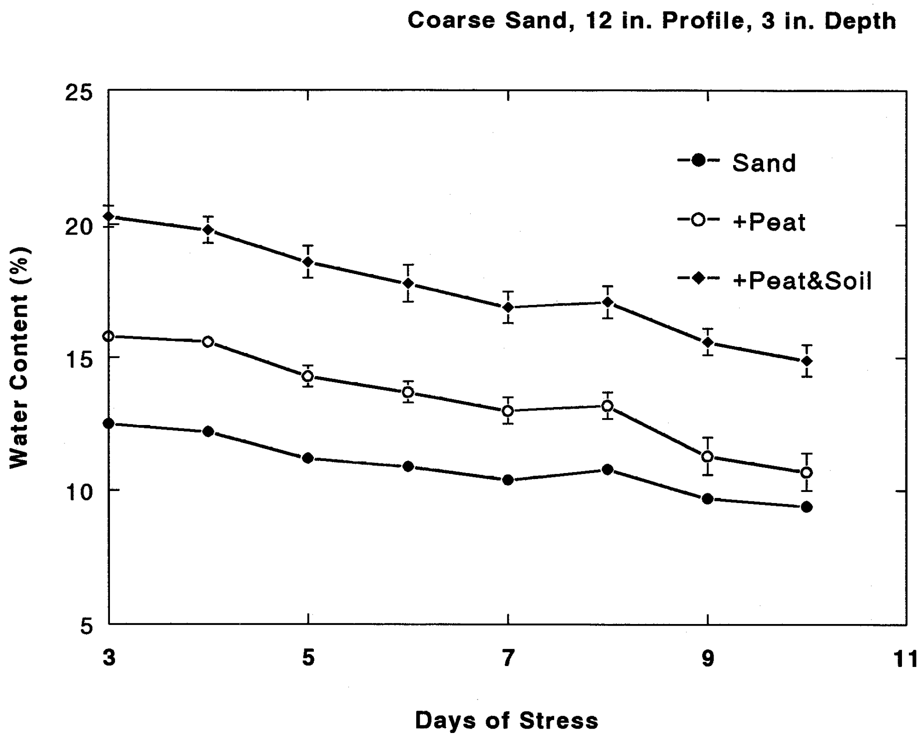
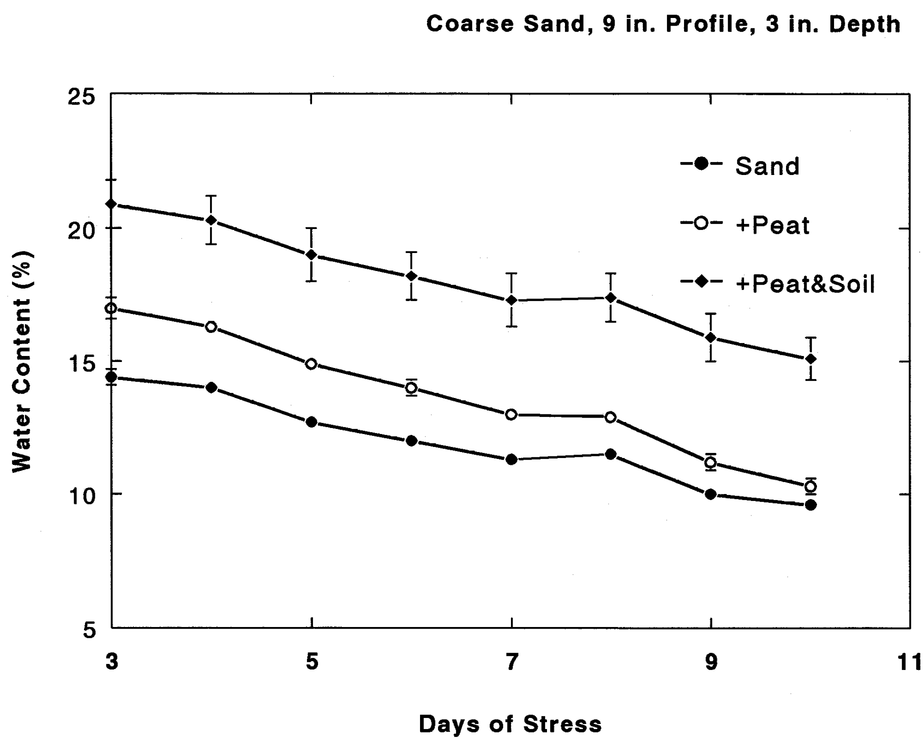
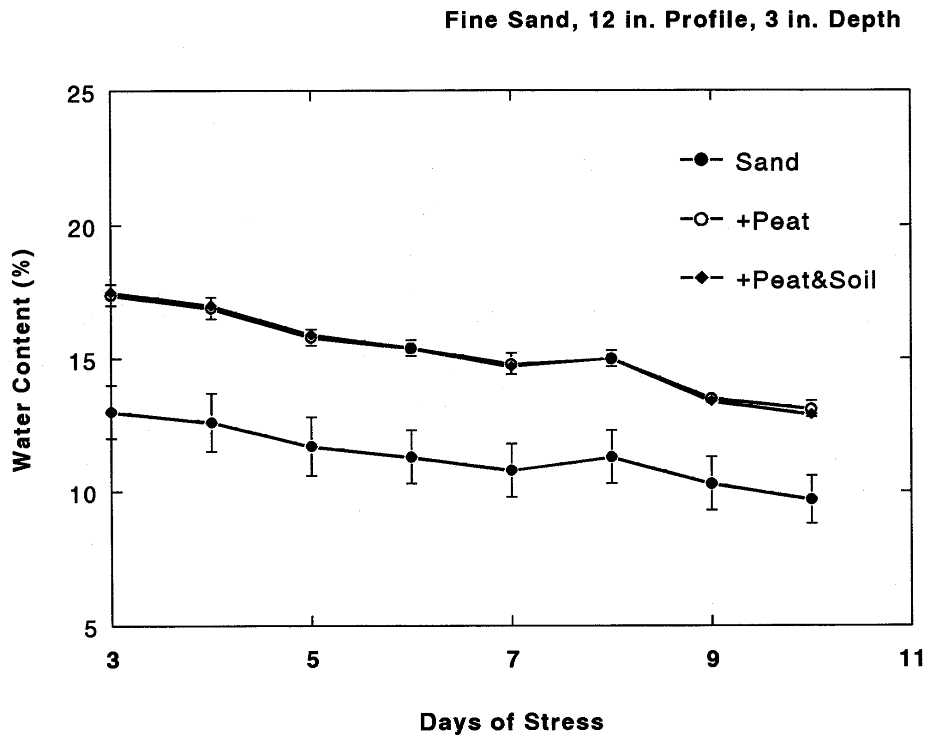

USGA Profile '99, Low Perm., 0% Slope, High Rain Rate
Root Zone Depth (in)
Distance Upslope (feet)
0 hrs
1 hrs
3 hrs
9 hrs
27 hrs
45 hrs
16
20
24
28
32
36
40
above

Fig. 9


USGA Profile '99, Low Perm., 4% Slope, High Rain Rate
Root Zone Depth (in)
Distance Upslope (feet)
0 hrs
1 hrs
3 hrs
9 hrs
27 hrs
45 hrs
16
20
24
28
32
36
40
above


Coarse Sand, 12 in. Profile, 3 in. Depth
Sand
+Peat
+Peat&Soil
Water Content (%)
25
20
15
10
5
3
5
7
9
11
Days of Stress


Coarse Sand, 9 in. Profile, 3 in. Depth
Water Content (%)
25
20
15
10
5
3
5
7
9
11
Days of Stress
Sand
+Peat
+Peat&Soil


Fine Sand, 12 in. Profile, 3 in. Depth
Water Content (%)
25
20
15
10
5
3
5
7
9
11
Days of Stress
Sand
+Peat
+Peat&Soil

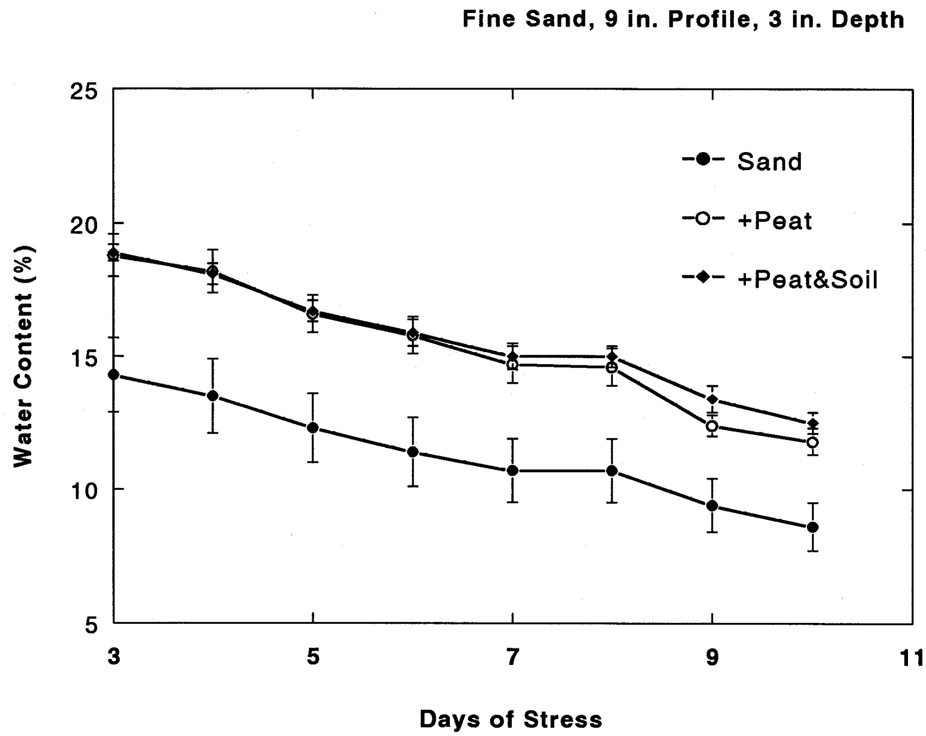

Fine Sand, 9 in. Profile, 3 in. Depth
Sand
+Peat
+Peat&Soil
Water Content (%)
Days of Stress
25
20
15
10
5
3
5
7
9
11

Fig. 15

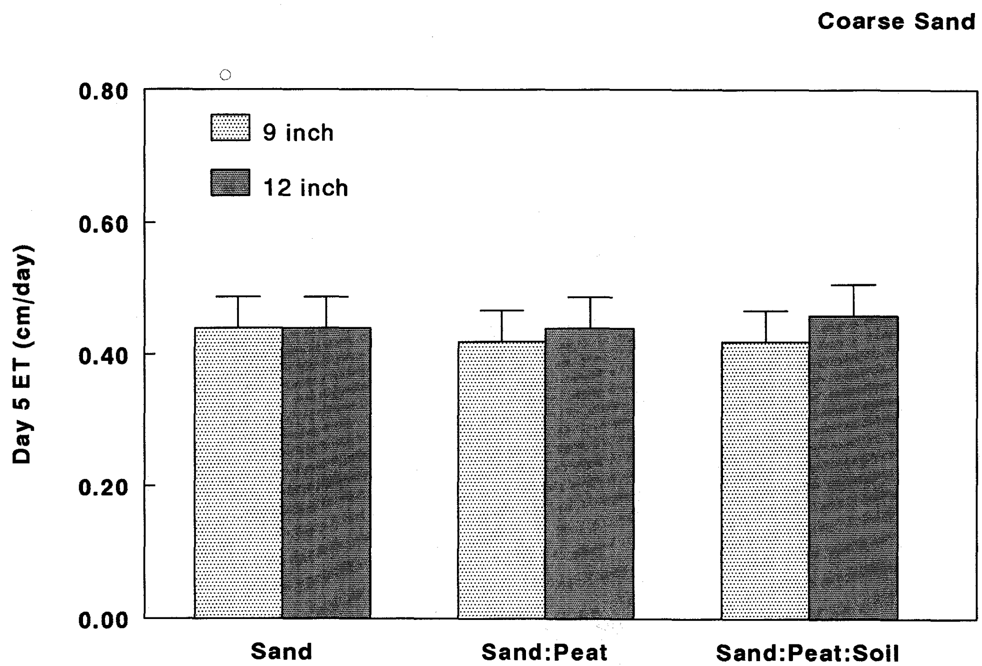

Coarse Sand
9 inch
12 inch
Day 5 ET (cm/day)
0.80
0.60
0.40
0.20
0.00
Sand
Sand:Peat
Sand:Peat:Soil

Fig. 16

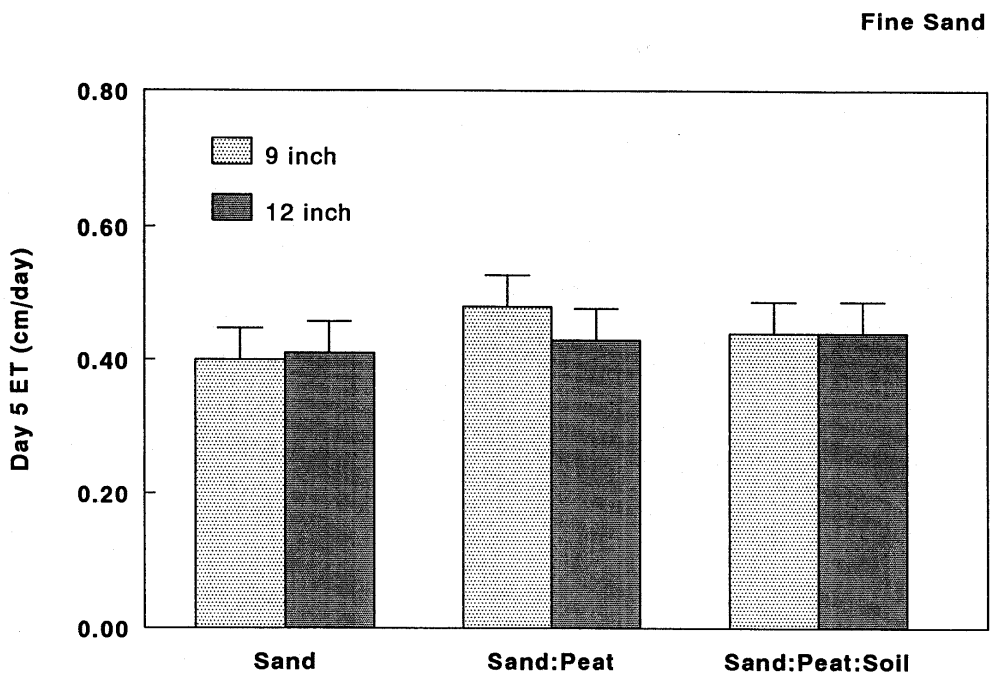

Fine Sand
9 inch
12 inch
Day 5 ET (cm/day)
0.80
0.60
0.40
0.20
0.00
Sand
Sand:Peat
Sand:Peat:Soil

Fig. 17

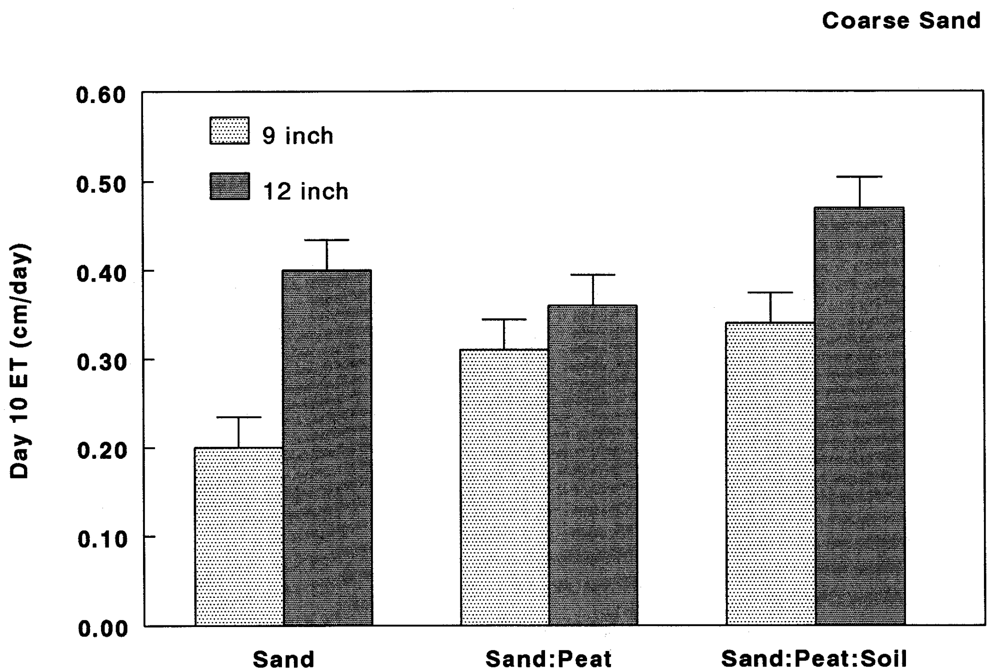
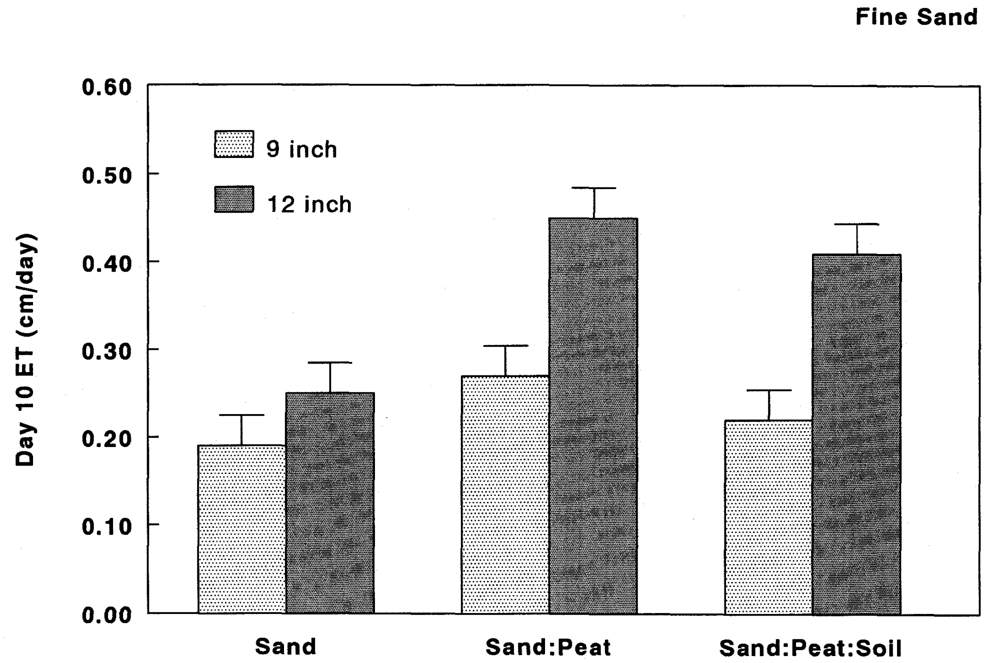

Coarse Sand
9 inch
12 inch
Day 10 ET (cm/day)
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Sand
Sand:Peat
Sand:Peat:Soil

Fig. 18


Fine Sand
9 inch
12 inch
Day 10 ET (cm/day)
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Sand
Sand:Peat
Sand:Peat:Soil