QUANTIFICATION OF PHYSICAL PROPERTIES OF SEVERAL PUTTING GREEN MEDIA

A Thesis
Presented to
the Graduate School of
Clemson University

In Partial Fulfillment
of the Requirements for the Degree
Master of Science
Horticulture

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by
Donald Jessie Wilson

December 1980

December 11, 1980

To the Graduate School:

Herewith is submitted a thesis written by Donald Jessie Wilson entitled "Quantification of Physical Properties of Several Putting Green Media." I recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Horticulture.

Thesis Advisor

We have reviewed this thesis and recommend its acceptance:

Accepted for the Graduate School:

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ABSTRACT

Compaction which is the result of increased play and the use of heavy maintenance equipment is a major problem in golf course putting green mixtures. Compaction inhibits water infiltration and percolation, root growth and the exchange of oxygen and carbon dioxide in the soil.

Studies were initiated to determine the physical properties of four mixtures, 70% sand and 30% bark (BS), 70% sand, 20% bark and 10% soil (BSS), 70% sand and 30% peat (PS), and 70% sand, 20% peat and 10% soil (PSS), typically used in golf course putting greens. The soil mixtures in laboratory columns with tensiometers placed at 5, 10, 15, 20 and 25 cm depths indicated field capacity was reached approximately 12 minutes after drainage began. At field capacity the BS, BSS and PSS mixtures were saturated at a depth of 15 cm while the PS mixture was saturated at a depth of 20 cm.

The addition of soil increased the bulk density and reduced the total porosity for all laboratory mixtures. When soil was added to the bark mixture, the water holding capacity was increased. However, the addition of soil to the peat mixture reduced the water content. Even though the soil reduced the total porosity and increased the bulk density, the flow rates remained very similar with the peat mixtures. The peat mixtures provided greater total porosity than the bark mixtures which allowed water to flow through the profile at a faster rate.

A value of -40 cm tension has generally been accepted as field capacity for putting green soil mixtures. However, tensiometer

readings indicated that high sand content mixtures reached field capacity at tensions of -5.92, -6.95, -9.94, and -9.47 cm for BS, BSS, PS and PSS, respectively.

The differences between the physical properties of the four soil mixtures were very small. However, the addition of soil to the BS mixture delayed wilting for 3 days. Wilting was not delayed with the addition of soil to the PS, but upward movement of water by capillarity was enhanced.

The major differences in the four soil mixutres were in establishment. The establishment of the peat mixtures was very acceptable, but very poor in the bark mixtures which was due primarily to phytotoxicity. The addition of soil to the bark mixture improved establishment to a certain degree, but establishment remained unacceptable.

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INTRODUCTION

Before the golf course boom of the 1960's, the majority of putting greens were constructed in essentially two ways (7). If the golf course was located in a river bottom area, the parent soil was generally of a sandy texture. To construct the greens, a nearby loamy soil was incorporated with the top 6 to 12 inches of naturally occurring sandy soil. If the golf course was located on a heavier soil, such as a clay or clay loam, a coarse sand and occasionally some organic matter, was mixed with the top 6 to 12 inches of soil. These methods were further modified by off-site mixing of the soil components and placing them on a bed of gravel containing tile drain lines (7). The objectives of both types of construction were to improve aeration and drainage which would result in a soil medium more conducive to plant growth. Some of these greens were very successful. However, many became very compacted and exhibited poor drainage, decreased aeration and restricted rooting which resulted in greens that were difficult or impossible to maintain (2,7).

Heavy maintenance equipment and traffic subjected putting greens to severe compaction (1,23,27). Although the effects of compaction can be minimized on large putting greens, foot traffic from golfers is especially deleterious to small greens (7,17). For the average golfer, over half of the playing time is on the green which comprises about 5% of the total area of the golf course (7). Golf greens and tees are in fixed locations. The majority of golfers walk onto the green and depart for the next tee along a similar path (17). Golf is often played during or shortly after rain or irrigation, and regardless of the weather, golfers expect very meticulous, high quality greens. In order to meet the high standard of quality expected by the golfer, putting greens are often mowed while the moisture content of the soil is near field capacity. In general, as moisture levels approach field capacity, compaction is increased.

Many methods of construction were evaluated that were designed to limit compaction and produce conditions suitable to the production of high quality putting greens. The U.S.G.A. Greens Section Staff developed a practical and successful method (32). Their plan specified high sand content soils amended with various portions of soil and organic matter. Using soil samples taken from greens that had proven successful with time, a criterion was established for permeability and porosity of the soil mixture. Specific steps to insure a suitable subgrade, proper drainage and uniform mixing were outlined. Greens built according to the U.S.G.A. specifications minimized compaction and provided internal drainage and aeration. However, these greens presented new problems for the turf manager primarily associated with establishment, nutrient retention and water management. High sand-low soil content mixtures tend to be draughty and extremely susceptible to leaching (7,10,22). Localized dry spots often develop (32) due to improper measuring and/or mixing of the materials comprising the putting green mixture. To prevent serious damage or complete loss of the turf in these areas, frequent irrigation was necessary. When high sand content mixtures are over-irrigated, leaching becomes a problem, and more fertilizer, specifically nitrogen, was needed to maintain a desirable putting surface (22). To minimize these problems the U.S.G.A.

Greens Section (32) suggested off-site mixing which tends to reduce errors in measuring and mixing.

Since 1960, golf has been an increasingly important industry in the U.S. Golfers are willing to financially support the game, but they are finical. An extremely high level of excellence is expected on the golf course. In order to provide the best playing conditions possible, many studies have been conducted to improve putting green predictability and quality.

This study was initiated to determine the moisture content, matrix potential, saturated hydraulic conductivity, pore space distribution, and bulk density of four high sand content golf course putting green mixtures under laboratory and actual putting green maintenance conditions.

LITERATURE REVIEW

Sand is the largest component (75-95%) of any highly amended golf course putting green (7). However, all sands are different and can be broken down into five distinct textural classes. These classes (28) are separated by the following particle sizes: (1) very coarse sand, 1-2 mm; (2) coarse sand, 0.5-1 mm; (3) medium sand, 0.25-0.5 mm; (4) fine sand, 0.1-0.25 mm; (5) very fine sand, 0.05-0.1 mm. Since sands contain a broad range of particle sizes, they perform differently when used with other components (soil and organic matter) of putting green mixes. Kunze (15,16) found highest yields of bermudagrass on compacted mixtures of 85% sand, 5% clay, and 10% peat with a mixed sand particle size distribution. However, a mixture with 80% sand, 10% soil and 10% peat drastically reduced yields. Using a sand with the particle size ranging from 0.5 to 1 mm, grass yields were greatest with a mixture of 80% sand, 10% soil, and 10% peat. Howard (13) found that a mixture of 85% sand, 5% soil and 10% peat was best using a brick and a Lakeland sand with 50% of the sand particles between 0.25 and 0.5 mm. When used in a mixture of 80% sand, 10% soil and 10% peat, a concrete sand with 40% of the particles between 0.25 and 0.5 mm produced the best grass. Bingaman and Kohnke (4) conducted similar experiments omitting the soil and organic matter components and found that sand of particle size 0.1 to 0.5 mm produced high quality bentgrass.

With proper particle size distribution, sand reduces compaction while increasing the noncapillary pore space of a soil. The result is improved aeration, drainage, percolation, oxygen diffusion and root penetration throughout the soil profile (3,4,11,17,18,20,21,29,31). Lutz and Leamer (21) determined that permeability increased exponentially as particle size increased within the coarser fractions of soil. Drainage was found to be rapid (20) in coarse textured soils containing a large portion of noncapillary pore space. Swartz and Kardos (31) amended eight Pennsylvania soils with 12% peat and three levels (30, 50 and 70%) of medium quartz sand. Results showed compaction to be more severe on mixtures containing 30 and 50% sand. Six of the compacted mixtures containing 70% sand were able to maintain a percolation rate of 3.8 cm/hr., but none of the 30 and 50% sand mixtures could do so. In order to achieve a percolation rate that would exceed all but the heaviest rainfalls for a duration of 30 minutes, Bingaman (4) suggested a hydraulic conductivity of 5 cm/hr. However with compacted mixes without established turf, the U.S.G.A. (11) considers a hydraulic conductivity of 6.5 cm/hr. to be ideal.

Previous studies (1,3,31) have proven that hydraulic conductivity, and total pore space are reduced by compaction. Baver (3) compacted a Cecil soil until 13% more solids were contained in a unit volume and found the percolation rate had been slowed and total pore space decreased. Swartz and Kardos (31) found hydraulic conductivity values ranging from 4.6 to 151.4 cm/hr. in lightly compacted soils. When severely compacted, the flow rate ranged from 0.0 to 52.3 cm/hr. with a significant decrease in noncapillary pore space. With soils heavily compacted by foot traffic, Alderfer (1) found infiltration rates and noncapillary porosity within the first inch of the soil surface reduced from 1.7 to 0.889 cm/hr. and 19.2 to 8.6%, respectively.

For grasses to grow and develop properly, respiration in the root system is essential. Foot traffic over wet putting greens enhances compaction and reduces aeration. Bingaman (4) found a minimum of 10% noncapillary pores at a depth of 5 cm was needed to grow healthy bentgrass and allow root penetration to reach 15 cm. The U.S.G.A. (32) suggests 12-18% noncapillary pores, and a minimum of 33% total pore space. As oxygen levels in the soil increased, Letey (18) found improved root and shoot growth coupled with increased potassium and phosphorus uptake. The concentration of sodium in the soil was found to increase with decreasing oxygen which suggests problems with salinity may arise in poorly aerated soils.

Although sand can add many beneficial properties to soil mix, it has significant problems that cannot be ignored. If sands are not used in correct proportions, little or no benefit will be seen. Generally, high sand content greens are low in available water and nutrient holding capacity (10,25,29). Various peats (29,30,31,38) and sawdusts (34,37), lignified redwood (33), well-rotted manure (29,30), pine and redwood shavings (25), and bark (38) are some of the materials which have been used to improve the water holding and nutrient holding capacity of sands. Richards (25) obtained adequate hydraulic conductivities and high water values when soils for container grown plants were amended with 60% peat. However with mixtures containing 60% sand, hydraulic conductivity increased at the expense of available water. With a set irrigation tension of 30 centibars, peat mixtures could double the time interval between irrigations. When used as a soil conditioner, peat (36) improved water holding and nutrient supplying capacities. On an oven-dry basis, Lucas (19) found sphagnum peat moss had a water absorbing capacity of 1500 to 3000%. Using three sources of peat, a well-rotted manure and a mushroom soil to amend three loamy soil types, Sprague (29,30) increased grass yields and improved water holding capacities. Due to slow release properties, Valoras (33) found highest concentrations of nitrogen in common bermudagrass clippings from soils amended with lignified redwood. Unamended soils and soils amended with peat and calcined clay were not able to produce similar nitrogen levels. Bermudagrass clippings grown on soils amended with peat, calcined clay and lignified redwood were found to contain higher levels of potassium than clippings from unamended soils.

Soil amendments are derived from organic and inorganic sources. Some of the materials have been shown to be detrimental to plant growth. Symptoms of phytotoxicity have been reported with ground rubber from automobile tires (35,39). Root growth is poor, and plants are found to be weak, spindly and chlorotic. Due to excessive aeration and reduced available water, fired clay (27) reduced the yield and quality of Tifgreen bermudagrass. However, vermiculite and colloidal phosphate improved soil properties and resulted in better growth and quality of bermudagrass. Richer (26) investigated various organic matter sources and found peat to be the best for golf course putting greens. When peat and calcined clay were used with 65% sand and 10% clay, germination of bentgrass was hastened, and excellent topgrowth was seen (39). However, root growth and development were reduced. Sawdust resulted in good root and shoot development, but topgrowth was weakened. While working with four turfgrass species, Waddington (34) found sawdust reduced shoot growth and inhibited germination. Sawdusts from pitch pine, white pine, ash, red oak, white oak, elm, white birch and hemlock significantly reduced stands of Pennlawn red fescue. Stands of Merion Kentucky bluegrass were reduced by sawdusts from twelve tree species. Penncross and Seaside creeping bentgrass were least affected. Pitch pine, white pine, ash and spruce were the sawdusts found to reduce bentgrass germination.

Management practices on amended soils may have an effect on plant growth. When properly irrigated, soils amended with peat produced good top growth and dense root systems (33). However, over-irrigation reduced aeration, and growth was limited. When irrigated with large volumes of water, lignified redwood produced excellent topgrowth of common bermudagrass. When the soil was not properly leached, salinity problems resulted, and plant growth was reduced.

Several laboratory and field methods have been used to determine the relationship between available water and soil moisture tension in golf course putting greens. The classical method is described by Ferguson (9). Noncapillary and capillary pore space is determined by subjecting soil cores to a tension of 40 cm. All pores drained by 40 cm tension are considered to be noncapillary, and the remainder are assumed to be capillary. Field capacity is determined by subjecting soil cores to a pressure of one-third atmospheres on a pressure plate apparatus. The water released at this tension is considered to be gravitational water, or the water pulled from a soil by the force of gravity. The permanent wilting point is determined by exposing the cores to 15 atmospheres (15 bars) tension on a pressure membrane extraction apparatus (24).

Using this procedure to determine the wilting point of tomatoes, White (37) found water values of 9.83% at 2 inches, 10.18% at 6 inches and 11.33% at 12 inches in an unamended Cecil soil. Swartz (31) used a pressure plate apparatus to determine field capacity (one-third atmosphere) and the wilt point (15 atmospheres) of several putting green mixtures. The wilt points ranged from 4.74% to 12.88% water by weight for mixtures consisting of 70% sand, 12% peat and 18% soil. The water content at the wilt point for each mixture was dependent upon the type of soil used.

Although one-third atmosphere and 15 atmospheres are highly accepted values for soils, Bingaman (4) found that sands and soils differ. Even though a soil can hold available water from 0 to 15 atmospheres pressure, sands hold very little water at tensions as low as 100 cm (0.1 bars). Juncher and Madison (14) have reported similar results using sand and peat mixtures. Most of the available water was lost at low tensions, and tensiometers showed that wilt points were reached far below the accepted value of 15 atmospheres. Howard (13) determined the water content by volume for several high sand content soils and found the loss of water from 0.25 bars to 15 bars to be very small. It appears that the water loss from approximately 0.2 to 15 bars is insignificant.

Due to inherent characteristics of high sand content mixtures, several conclusions concerning their behavior can be drawn. If a sand is expected to provide sufficient air and water for plant growth and development, a soil profile 30 cm thick is needed, and downward flow of water must be checked (4). Due to low gravitational tensions, the mixtures will be near saturation after drainage, and moisture content will increase as depth increases (14).

MATERIALS AND METHODS

The physical properties of four golf course putting green mixtures were determined. The mixtures consisted of 70% sand, 30% bark (BS); 70% sand, 20% bark and 10% soil (BSS); 70% sand, 30% peat (PS); 70% sand, 20% peat, and 10% soil (PSS).

The sand and bark (Table 1) fractions were sieved to determine their particle size distribution; screen size ranging from 12.5 mm to 0.05 mm. The soil (39.7% sand, 30.68% silt, and 29.62% clay) was a Cecil series clay loam (clayey, kaolinitic, thermic typic Hapludult), and the peat was a good quality Canadian sphagnum moss (36). The bark amendment was a fine chipped pine. Particle density (Table 2) measurements were made on each of the soil mixes using the procedure outlined by Blake (5).

Laboratory Experiments

To guarantee complete saturation of the organic matter fractions, the bark and peat were soaked 5 days in water with an added wetting agent. Each soil was mixed for 5 minutes using an electrically powered cement mixer. To insure uniformity of mix and prevent the separation of soil components, small amounts of water were periodically added during agitation.

Drains of 3.181 cm diameter were installed in plastic containers (35.56 cm high and 27.94 cm in diameter) which served to hold each mix. A small piece of shade cloth material was laid over each drain and approximately 2.54 cm of gravel was added. A circular tamping tool was

TABLE 1. Particle size distribution of the sand and bark used in the putting green mixtures determined by the sieve method

Screen size (mm)	Sand (% by weight)	Bark (% by weight)
Greater than 12.50	0.00	0.00
6.30 - 12.50	0.00	0.16
4.75 - 6.30	0.00	1.37
2.00 - 4.75	2.60	16.26
1.00 - 2.00	14.82	21.72
0.50 - 1.00	55.05	27.86
0.25 - 0.50	23.42	21.08
0.10 - 0.25	3.82	9.94
0.05 - 0.10	0.27	1.37
Less than 0.05	0.06	0.23

TABLE 2. Particle density measurements of the sand and bark components and the four soil mixtures determined by the method outlined by Blake (5)

	Reps						
	A	B	C	D	E	F	Mean
Sand	2.64	2.64	2.64				2.64
Bark	1.50	1.49	1.52				1.50
Bark plus sand	2.52	2.52	2.63	2.53	2.53	2.54	2.55
Bark, sand and soil	2.60	2.52	2.48	2.53	2.53	2.54	2.55
Peat plus sand	2.66	2.64	2.57	2.62	2.62	2.61	2.62
Peat, sand and soil	2.62	2.62	2.56	2.61	2.61	2.60	2.60

cut from 1.905 cm thick pine shelving board and a 0.762 m handle attached. Each mix was placed in its container in 2 L increments, tamped gently to insure proper firming and slightly scarified to prevent layering. This procedure was repeated until the containers were completely filled. Since the mixture level in each container was critical to insure proper tension calculations, additional settling was done by slowly filling each container from the bottom with water until flooded. The excess water was allowed to drain and the procedure repeated. The soil surface was again scarified, and additional mix added to fill each container. Settling was completed by gently adding water to the top of each mix until flooding occurred. After the drainage of excess soil water, the mix was removed from each container until a soil depth of 27 cm above the gravel was reached.

To determine the matrix potential of the soil mixes, tensiometers were constructed using rigid PVC-Excelon tubing (8 mm I.D.), one bar porous ceramic cups (6 mm I.D. x 3 cm), and nylon tubing (1.27 mm I.D.). The rigid tubing was cut into 7, 12, 17, 22, and 27 cm sections, and a hole (1.58 mm diam) was drilled at a slight angle 5 cm from one end. The porous cup was glued to the opposite end of each rod using epoxy glue. The nylon tubing was cut into 1.52 m sections and glued into the predrilled holes. A short piece of tygon tubing was slipped over the open end of the tensiometers, and a 00 rubber stopper was used as a seal. A flushing tool was made by forcing the end of a 50 cc hyperdermic needle through a 00 stopper. The mercury reservoir used with the tensiometers was placed 15.24 cm above the soil surface. To prevent breakage of the porous cup when the tensiometers were placed in the soil mixes, a piece of rigid plastic tubing was used to pull soil cores from each sample. Tensiometers were placed in the center of each container at 5, 10, 15, 20, and 25 cm depths. Boiled deionized water was used to fill and flush the tensiometers. After the tensiometers were properly flushed, the containers holding the soil mixes were again flooded until good pressure potentials were achieved with each tensiometer. Water was drained to the soil surface and tensiometer readings taken. To minimize water loss from evaporation, a piece of plastic was laid over each container. After the plastic was secured, the containers were allowed to drain to equilibrium with tensiometer readings taken at 4 minute intervals for the first 16 minutes. After 16 minutes the tensiometer readings were taken at 30, 45, and 60 minutes after the initiation of drainage. From this point tensiometers were read at various intervals until the downward flow of water ceased.

To determine bulk density and water content by weight and volume, soil cores were taken from each container approximately halfway through the experiment and again at the conclusion of drainage. Each mixture was sampled at 2.54 cm intervals to a depth of 25 cm. A modified soil probe was used to prevent the crushing of each sample. The end of the soil probe was cut off just below the taper and sharpened. This reduced the resistance of the probe moving through the soil and allowed for a more precise measurement of each core. A rubber retainer was made to fit inside the probe and prevent spillage of excess soil onto each core which helped minimize errors in bulk density measurements.

In order to compare actual field measurements with predicted values from established laboratory methods, capillary and noncapillary pore space determinations were made on compacted and noncompacted soil samples. The laboratory technique used is outlined by Ferguson, Howard and Bloodworth (9).

Hydraulic conductivity (K=Q/AT x dL/dH) was determined for each laboratory sample (12) where

K = hydraulic conductivity (cm/sec),

Q = quantity of water (cm^3) passing through the soil core,

A = cross sectional area (cm^2) of the soil core,

T = time (sec) required for the water to pass through the core,

dL = length (cm) of the soil core,

dH = head (cm) of the water imposed on the core.

A modified section of gutter (1.79 m long and 9 cm deep) with a down spout served as a water reservoir. To provide a stable, continuous water level inside the reservoir, an oval shaped overflow tube (7.5 cm long, 5 cm wide, and 7.5 cm deep) was cut from a flexible plastic bottle. The tube was inserted 2.5 cm into the down spout and sealed with a silicon rubber sealer. The water was supplied through a piece of tygon tubing (1 cm I.D.) and regulated so the spillage of water through the overflow tube would be as slow as possible.

The soil cores were placed on a metal screen (1.25 cm mesh) inside a circular wash tub (28.5 cm deep and 55 cm diam) and allowed to soak in boiled deionized water for 24 hours before measurements were made. To insure complete saturation, small amounts of water were added at various intervals until the water level inside the wash tub was equal to the height of the cores.

To establish a 8.39 cm head of water on the cores, it was necessary to modify a funnel rack. A vertical slot was cut in two pieces of pine shelving board (29 x 28.5 x 1.905 cm), and four holes were drilled in the funnel rack supports. The pieces of shelving board were attached to each end of the funnel rack with four bolts. Wing nuts were used which allowed easy height adjustment. A 60 degree pyrex funnel (10 cm mouth diam and 24 cm long) was used to hold each soil core while determinations were made. The funnel rack was adjusted so the top of each core was 1.25 cm below the water level inside the reservoir.

A 2.54 cm retainer ring was placed on each core using a small section of bicycle innertube. This prevented leaking of water at the core-retainer ring interface and allowed water to pond 1.25 cm above the soil surface. Glass tubing (6 mm I.D.) was bent at approximately a 90 degree angle and used as a siphon to establish water flow from the reservoir to the top of each core. To allow the flow of water through the soil core to reach equilibrium, siphons were established 10 minutes before measurements were made. The time necessary for 45 ml of water to pass through each core was recorded, and two determinations were made on each core.

Field Experiments

The mixes were prepared and placed in lysimeters as previously described by White (38). At initiation and after 12 months, hydraulic conductivity (K) measurements were determined for each mix. To facilitate this measurement, it was necessary to modify a drum (90 cm deep and 60 cm diam) which would serve as a water reservoir. The top of the drum was cut off, leaving the bottom section approximately 20 cm high. A drainage hole of 3.175 cm diameter was cut 10.16 cm from the bottom of this section, and a piece of polypipe was inserted. A 2 cm diameter hose was used to supply the water to the reservoir, and the water supply was adjusted so the flow of water through the drainage hole was as slow as possible. This allowed a constant water level to be maintained in the reservoir. Three pieces of hose (2 cm diam) were used as siphons to establish water flow from the reservoir to the top of each soil mix. A retainer ring was made by removing the bottom of a No. 3 wash tub, and it was pushed into each soil mix. The mixes were flooded from the bottom to insure complete saturation. When water was seen at the top of the soil surface, the siphons were started, and water ponded at a height of 10.16 cm above the soil surface which produced a head of 35.56 cm on each soil mix. When the water level in the retainer reached the same height as the water level in the reservoir, the mixes were allowed to drain. The water flowed through each mix for about five minutes before readings were taken. This allowed the water level in the reservoir and the retainer ring to reach equilibrium. Each mix was timed until 10 L of water had been collected, and two determinations were made for each mix.

Each mix was seeded May 5, 1978 with Penncross creeping bentgrass, (Agrostis palustris, Huds.) at a rate of 2 pounds per 1000 square feet. Visual ratings for cover were taken until satisfactory establishment had been obtained. Due to very poor establishment of the bark and sand treatment reseeding was necessary in the fall and preceding spring.

After final hydraulic conductivity measurements were made, April 21, 1979, tensiometers were placed in the field plots and readings were taken as previously outlined. When gravitational drainage ended, the plastic covers were removed and the mixes allowed to dry until the wilt point was reached. Soil cores and tensiometer readings were taken approximately halfway through drainage, at the conclusion of drainage, and again when the bentgrass wilted.

A randomized complete block design was used for laboratory experiments while the field experiment was a completely randomized design. Each experiment had three replications. The equations used to calculate the physical properties of the soil mixtures are shown in Table 3.

TABLE 3. The equations used to calculate the physical properties of the soil mixtures

1. Water content by weight (%) = $\frac{\text{wet core - dry core}}{\text{dry core}}$ x 100.

2. Bulk density (gm/cm^3) = $\frac{\text{dry weight of core}}{\text{apparent volume}}$.

3. Water content by volume (%) = water content by weight x bulk density.

4. Particle density (gm/cm^3) = $\frac{dw(Ws-Wa)}{(Ws-Wa) - (Wsw-Ww)}$, where

   dw = density of water in gm/cm^3 at room temperature,

   Ws = weight of pycnometer plus soil sample corrected to oven dry condition, gm,

   Wa = weight of pycnometer in air, gm,

   Wsw = weight of pycnometer, soil and water, gm,

   Ww = weight of pycnometer and water at room temperature, gm.

5. Matrix potential (cm) = -12.55(x) -y -z, where

   x = rise of mercury above reservoir, cm,

   y = height of mercury above soil surface, cm,

   z = depth of tensiometer below soil surface, cm.

6. Total potential (cm) = matrix potential + depth of tensiometer below soil surface.

7. Saturated hydraulic conductivity (cm/min) = $\frac{Q}{AT}$ x $\frac{dL}{dH}$, where

   Q = quantity of water passing through the soil core, cm^3,

   A = cross sectional area of the soil core, cm^2,

   T = time required for the water to pass through the core, sec,

   dL = length of soil core, cm,

   dH = head of the water imposed on core, cm.

TABLE 3--Continued

8. Cumulative drainage (cm) = $\int_{\partial}^{t} \frac{\partial\theta}{\partial Z}\, dt$

θ = water content.

9. Flux (cm/min) = $\frac{y2 - y1}{t}$, where

y2 = water drained (cm/min) at time 1,

y1 = water drained (cm/min) at time 0,

t = time (min) when the water drained.

10. Available water (cm) equals water content by volume at field capacity minus water content by volume at wilt point times depth of soil core.

11. The general soil water flow equation may be written

$$\partial\theta/\partial t = \partial/\partial Z(K \frac{\partial H}{\partial Z}) \qquad (1)$$

where θ = water content, cm^3/cm^3,

t = time,

Z = depth, cm,

K = hyd. cond. cm/day,

H = total water potential, cm.

If we integrate both sides with respect to Z, we obtain

$$\int_{Z1}^{Z2} \frac{\partial\theta}{\partial t}\, dZ = \int_{Z1}^{Z2} \frac{\partial}{\partial Z} \left(K(\theta)\ \frac{\partial H}{\partial Z}\right) dZ, \qquad (2)$$

TABLE 3--Continued

$$\left.\frac{\partial\theta}{\partial t}\right|_{Z_1}^{Z_2} = K(\theta)\left.\frac{\partial H}{\partial Z}\right|_{Z_1}^{Z_2} , \qquad (3)$$

$$K(\theta) = \frac{\frac{\partial\theta}{\partial t}(Z_2-Z_1)}{\left[\left.\frac{\partial H}{\partial Z}\right|_{Z_2} - \left.\frac{\partial H}{\partial Z}\right|_{Z_1}\right]} . \qquad (4)$$

If we assume that zero flux moves across one boundary, say the soil surface which is covered, equation (4) becomes

$$K(\theta) = \frac{\partial\theta/\partial t(Z_2-Z_1)}{\partial H/\partial Z} .$$

Thus K can be evaluated as a function of θ by dividing the flux of water $\left[\partial\theta/\partial t(Z_2-Z_1)\right]$ moving across an interval (Z_2-Z_1) in a unit time by the gradient which exists during that time interval at the depth of interest.

12. Total Porosity (PD) = $1 - \frac{P.D.}{B.D.} \times 100$, where

P.D. = particle density,

B.D. = bulk density.

RESULTS AND DISCUSSION

Laboratory Studies

The physical properties of each of the soil mixtures under laboratory conditions are summarized in Table 4.

The bulk densities of the PS and the BS mixtures were very similar and ranged from 0.7 gm/cm^3 near the soil surface to 0.9 gm/cm^3 at the lower depths. Due to the weight and the packing of each of the mixtures, bulk density increased with depth.

The addition of soil to the mixtures increased bulk densities. Near the soil surface the PSS was found to have a bulk density of 0.85 gm/cm^3 while the BSS was found to have a bulk density of 0.92 gm/cm^3. In the lower depths bulk density was found to be slightly greater than 1 for each of the mixtures containing soil. The unit weight of the soil is much greater than that of the sand or organic amendments, and an increase in bulk density would be expected. Bulk densities of these soils are much lower than those normally found in field soils. Brady (6) states that bulk densities may range from 1.00 to 1.60 gm/cm^3 for clay, silt loam and clay loam top soils, and sands or sandy loams may be as high as 1.2 to 1.8 gm/cm^3. Depending on the texture and compactness of the soil, bulk densities may be as high as 2.0 gm/cm^3 for subsoils.

Particle density measurements (Table 4) were determined for each mixture. Both bark mixtures were found to have particle densities of 2.55 gm/cm^3, while the PS and the PSS had particle densities of 2.62 and 2.60 gm/cm^3, respectively. Due to its physical structure and the

TABLE 4. Physical properties with depth for the soil mixtures contained in laboratory columns

	Depth (cm)	Bulk Density (gm/cm^3)	Particle Density (gm/cm^3)	Total Porosity using PD (%)	Total Porosity measured (%)	Water Content at Field Capacity (%)	Matrix Potential at Field Capacity (cm)
Bark and sand	5	.71	2.55	72.0	----	31	-5.18
	10	.77		69.8	----	32	-3.52
	15	.82		67.9	----	45	0.23
	20	.87		66.0	50.0	50	3.55
	25	.92		64.0	50.0	50	8.55
Bark, sand and soil	5	.92	2.55	64.0	----	35	-3.05
	10	.96		62.5	----	38	-0.98
	15	.99		61.1	----	41	1.10
	20	1.03		59.6	41.5	42	5.68
	25	1.06		58.4	41.5	42	9.84
Peat and sand	5	.75	2.62	71.4	----	41	-7.46
	10	.78		70.3	----	44	-4.17
	15	.81		69.0	----	50	-0.81
	20	.85		67.7	55.0	55	3.77
	25	.88		66.4	55.0	55	8.36
Peat, sand and soil	5	.85	2.60	67.2	----	34	-4.79
	10	.90		65.3	----	37	-3.56
	15	.95		63.4	----	46	0.57
	20	1.00		61.5	50.5	50	5.19
	25	1.05		59.6	50.5	50	9.77

extensive inner network of pores, peat can absorb a great quantity of water (36) which consequently causes swelling. As the swelling occurs, water is displaced which results in higher particle density measurements for the mixtures containing peat.

The total porosity of a soil mixture is very important since it is directly related to drainage and available oxygen in the root zone. Total porosity was calculated for each of the soil mixtures using the particle densities. The calculated porosity near the soil surface (Table 4) was found to be 72% for the BS and 71% for the PS. The mixtures with soil were found to have lower total porosities; 64% and 67% for the BSS and PSS mixtures, respectively. As reflected by the bulk densities of the mixtures, total porosity decreased with depth in all cases.

Total porosity was also estimated from volumetric water samples. If the soil is saturated, air space is absent and the water content should be an excellent estimate of the total porosity. From Table 4, the matrix potential measurements indicate that the BS, BSS, and PSS were saturated at a depth of 15 cm while the PS mixture was saturated at a depth of 20 cm. The total porosity of the BS and the PSS mixture was approximately 50%. The porosity of the BSS mixture was found to be about 42% while the PS mixture was 55%. The discrepancies between the total porosity actually measured and the total porosity calculated suggests problems in particle density measurements. Since the organic fractions (peat and bark) of these mixtures can absorb water in quantities many times greater than their weight, particle density measurements were probably too large. Since

$$\text{total porosity} = 1 - \frac{\text{bulk density}}{\text{particle density}}, \qquad (2)$$

large particle density measurements would result in greater total porosity measurements.

Cumulative Drainage

Figure 1 shows cumulative drainage with time for each of the soil mixtures. Even though the bulk of the downward flow of water stopped within twelve minutes, different amounts of water drained through each soil.

After 12 minutes of drainage, the BS mixture allowed 1.06 cm of water to pass through the soil column which was 25 cm deep. The BSS mixture allowed 0.9 cm while the PS and the PSS mixtures permitted the passage of 0.7 and 0.86 cm of water, respectively. However after 52 minutes, only 1.2 cm of water passed through the BS mixture which was an increase of 0.14 cm during the last 40 minutes. The BSS mixture passed an additional 0.3 cm of water, and the PS and PSS mixture passed an additional 0.4 cm. For all soil mixes, the difference in the amount of water that drained between 12 and 52 minutes was very small.

If the total porosity measurements (Table 4) are examined, the BS mixture is found to have 5% less total porosity than the PS mixture. However, more water drained through the bark mixture, and at all depths, the PS mixture held more water than the BS mixture (Fig. 2) which suggests that the peat mixture contains a greater percentage of small pores (capillary pores). The mixtures with soil were found to have essentially the same water contents to a depth of 10 cm (Fig. 2). However, the water content was greater for the PSS mixture in the remaining 15 cm. Since both mixtures containing soil are saturated between the 10 and 15 cm depth, and the total porosity is greater in the peat mixture (Table 4), higher water content values would be expected in the lower depths.

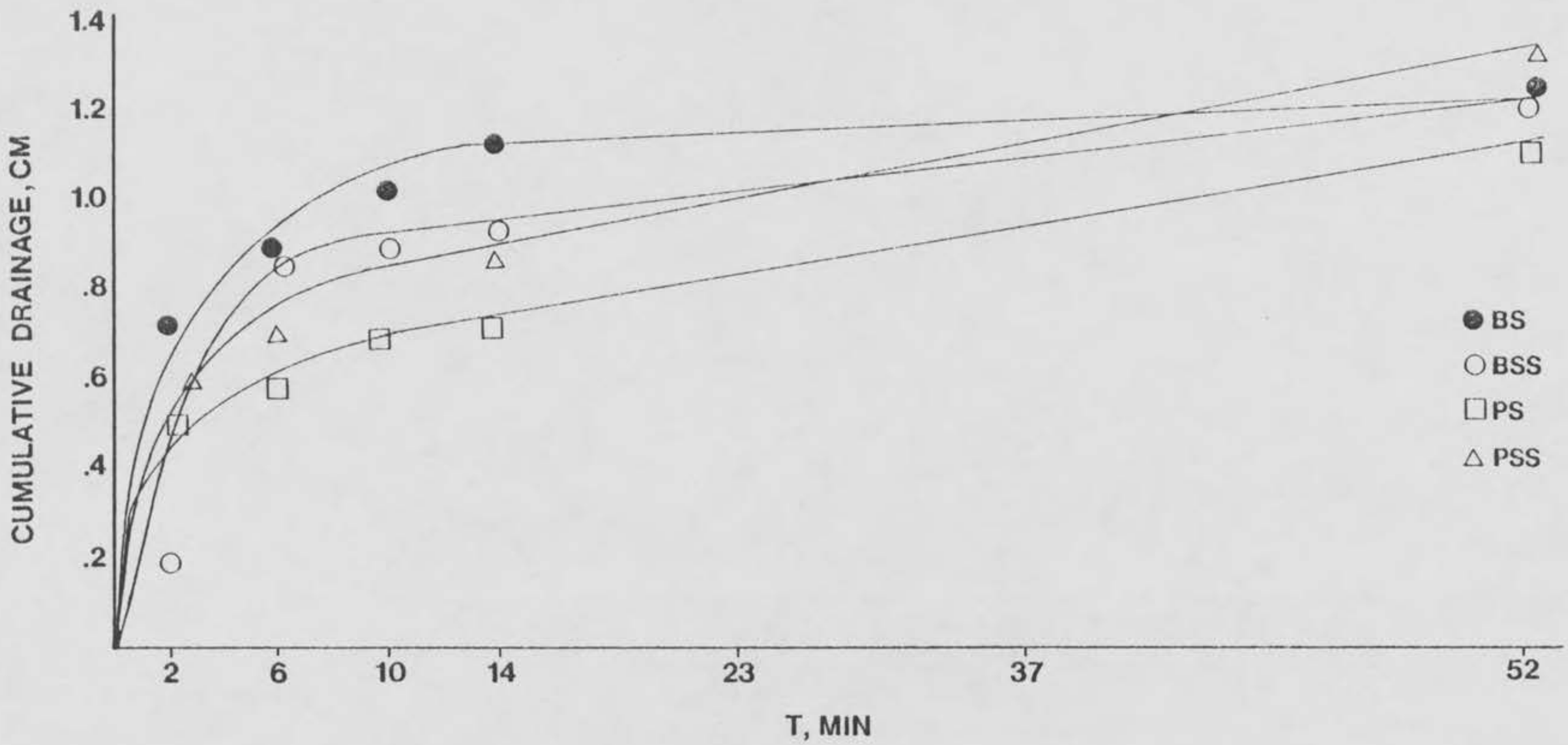


Figure 1. Cumulative drainage with time for the soil mixtures under laboratory conditions

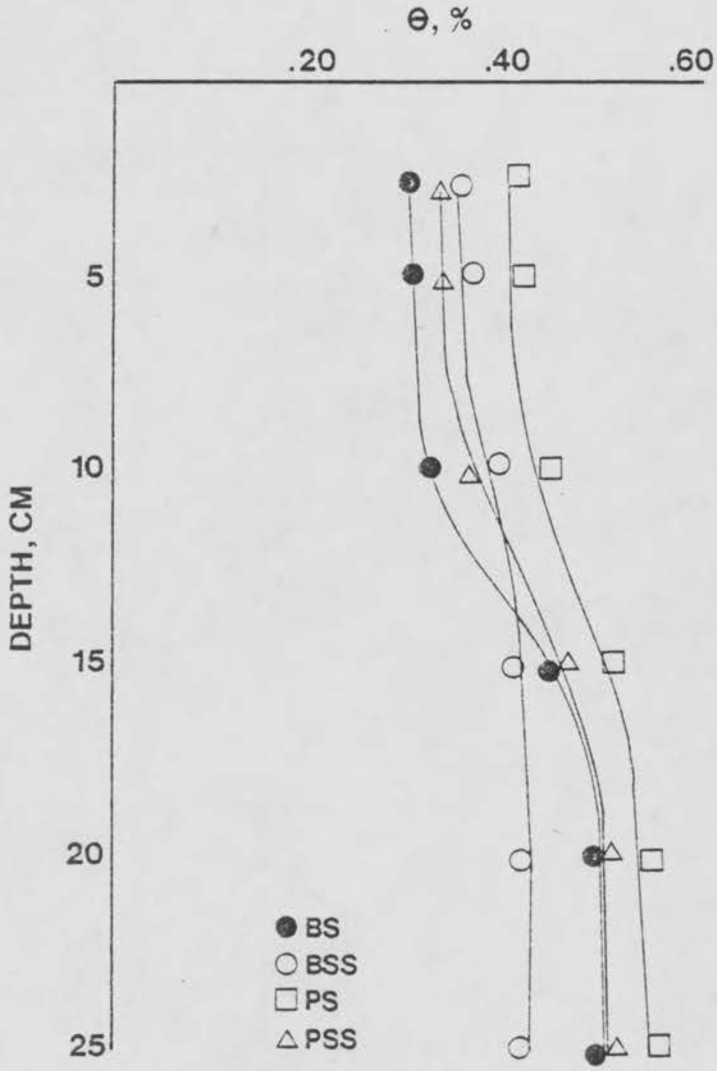


Figure 2. Water content with depth at field capacity for each of the soil mixtures under laboratory conditions

Field Capacity

Due to the U.S.G.A. method of putting green construction, water is perched above a gravel layer. The very large pore spaces found in the gravel layer allows the water to drain rapidly. However, the smaller pores of the putting green mixture create matrix tensions much greater than the gravel which enables the mixtures to hold water at positive pressures, and the lower depths of the soils remain saturated.

For each soil mixture, all significant downward flow of water (field capacity) stopped approximately 12 minutes after drainage began (Fig. 1). The relationship of water content with depth at field capacity for each soil mixture is seen in Figure 2. At any depth the peat mixtures contained higher water content values than the bark mixtures which indicates that the peat provides a greater water holding capacity than the bark.

Comparison of the bark mixtures (Fig. 2) shows that the addition of soil increases the water content to a depth of approximately 15 cm. However, from 15 to 25 cm the water content was greater (8%) in the soiless mixture. Positive matrix potential readings (Table 4) indicate that the bark mixtures approach saturation near the 15 cm depth. Since the mixtures are saturated below 15 cm, it follows that the addition of soil reduced the total porosity of the bark mixture. However, it improves the ability of the mixture to hold water.

By comparing the PS and the PSS mixtures (Fig. 2), it is evident that the PS mixture has higher water content values throughout the soil profile. In this case, the addition of soil reduced the water content (Fig. 2) and the total porosity (Table 4) of the PS mixture. Obviously, the peat can hold more water than the soil while maintaining greater total porosity.

Flux

Flux (Fig. 3) with time was plotted to determine the velocity of water movement through the soils. After 12 minutes, the downward flow of water for both peat mixtures was 0.01 cm/min while the flow of water for the BS and the BSS mixtures was 0.016 and 0.004 cm/min, respectively. Water velocity measurements of these magnitudes are a good indication that the soil mixtures have reached field capacity.

The movement of water through the PS was faster than the movement of water through the BS. The flow of water measured at 2 minutes was 0.10 cm/min for the BS, and 0.07 cm/min for the PS mixture. After 2 minutes, the flow of water in the PS mixture was slower than that of the BS; therefore, the PS appeared to have reached equilibrium at a slightly faster rate than the BS. The flow rate for the PS mixture was 0.04 cm/min after 4 minutes, while the flow rate of the BS mixture reached a flow rate of 0.04 cm/min after 6 minutes. However, after 12 minutes (field capacity) the differences in the flow rate of each mixture were very small (0.01 cm/min for the PS and 0.016 cm/min for the BS). Although these differences are very small, it appears that the additional 5% porosity of the PS mixture (Table 4) allowed the bulk of the free water to drain more rapidly. The same relationship exists with the mixtures containing soil. After 2 minutes the flow rate for the BSS mixture was 0.18 cm/min while the flow rate of the PSS mixture was 0.09 cm/min. The total porosity (Table 4) was greater in the PSS mixture (9%) which should allow the water to drain more rapidly and reach field capacity sooner. The slope of the curves for the BSS and PSS mixtures (Fig. 3) from 8 to 10 minutes verified this. The PSS curve is more horizontal indicating the mixture reached equilibrium faster.

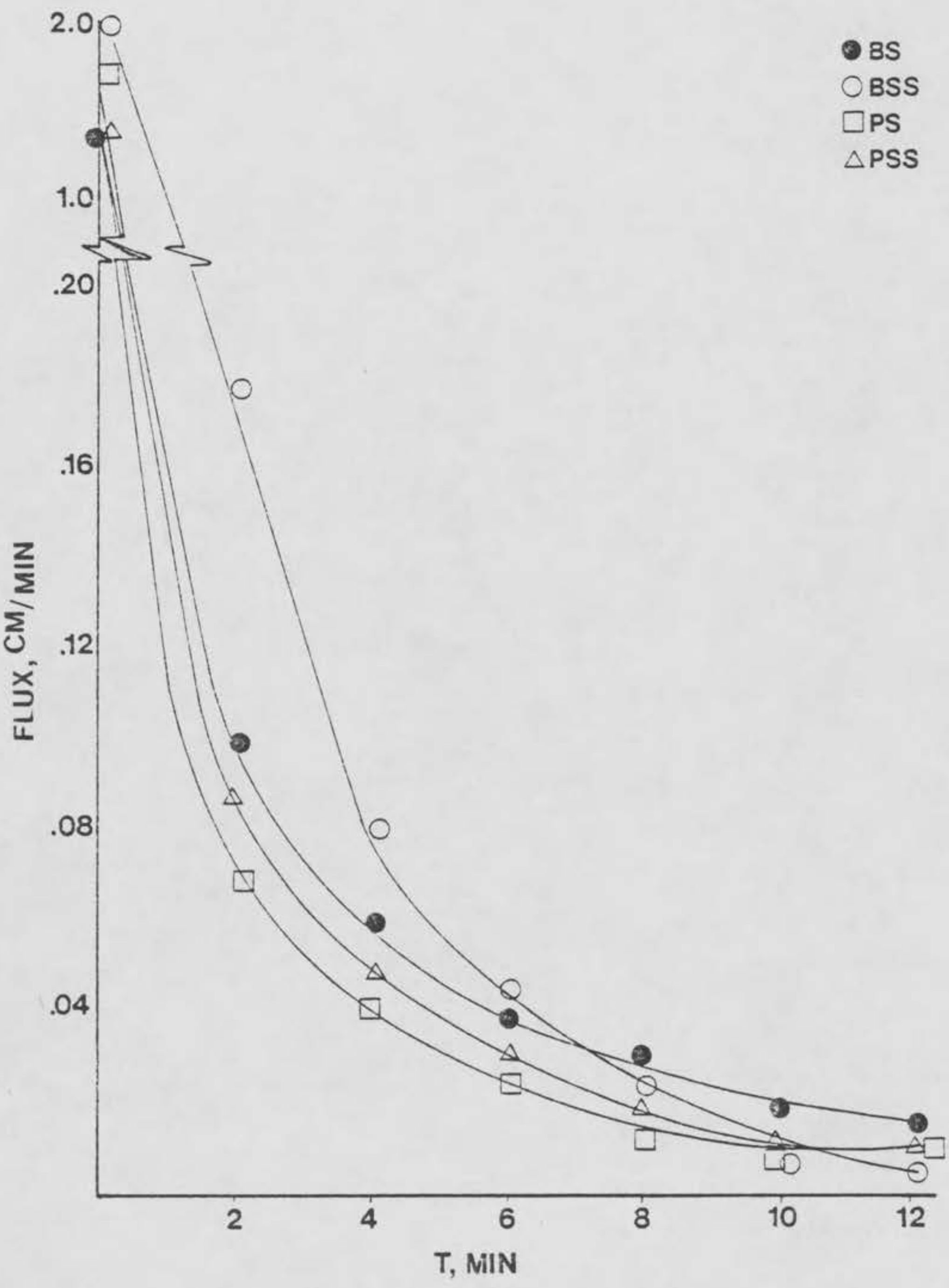


Figure 3. Flux with time for the soil mixtures under laboratory conditions

Comparison of the BS and BSS mixtures shows the addition of soil slows the rate of water movement. The difference in the flow rate after 2 minutes is very large, but after 6 minutes the flow of water is equal for each mixture (0.026 cm/min). The addition of soil to the bark decreases the noncapillary porosity and hinders the drainage of water. Bulk density and total porosity measurements shown in Table 4 verify this. Bulk density was increased which resulted in reduced porosity with the addition of soil.

Comparison of the PS and the PSS mixtures shows similar results. However, the differences in flow rates are not as pronounced as with the bark mixtures. Even though bulk density measurements (Table 4) are greater with the addition of soil to the peat, the rate of water movement through the profile remains very constant. Therefore, peat must contain a percentage of small pores (capillary pores) very similar to that of soil, and the addition of soil in this amount is not detrimental to the PS mixture.

Hydraulic Conductivity

As drainage occurred, hydraulic conductivity measurements were determined for each soil mixture (Fig. 4). For all mixtures, a decrease in water content reduced the hydraulic conductivity. With decreased water content, the soil pores contain more air space and less water which increased the surface tension (adhesive forces) between the water and soil particles. As the surface tension is increased, the flow of water is slowed.

From Table 4, it can be seen that the saturated water content is 50% for the BS mixture and 42% for the BSS mixture. Comparison of the

Figure 4.

A. Unsaturated hydraulic conductivity with water content for the bark and sand mixture under laboratory conditions

B. Unsaturated hydraulic conductivity with water content for the bark, sand and soil mixture under laboratory conditions

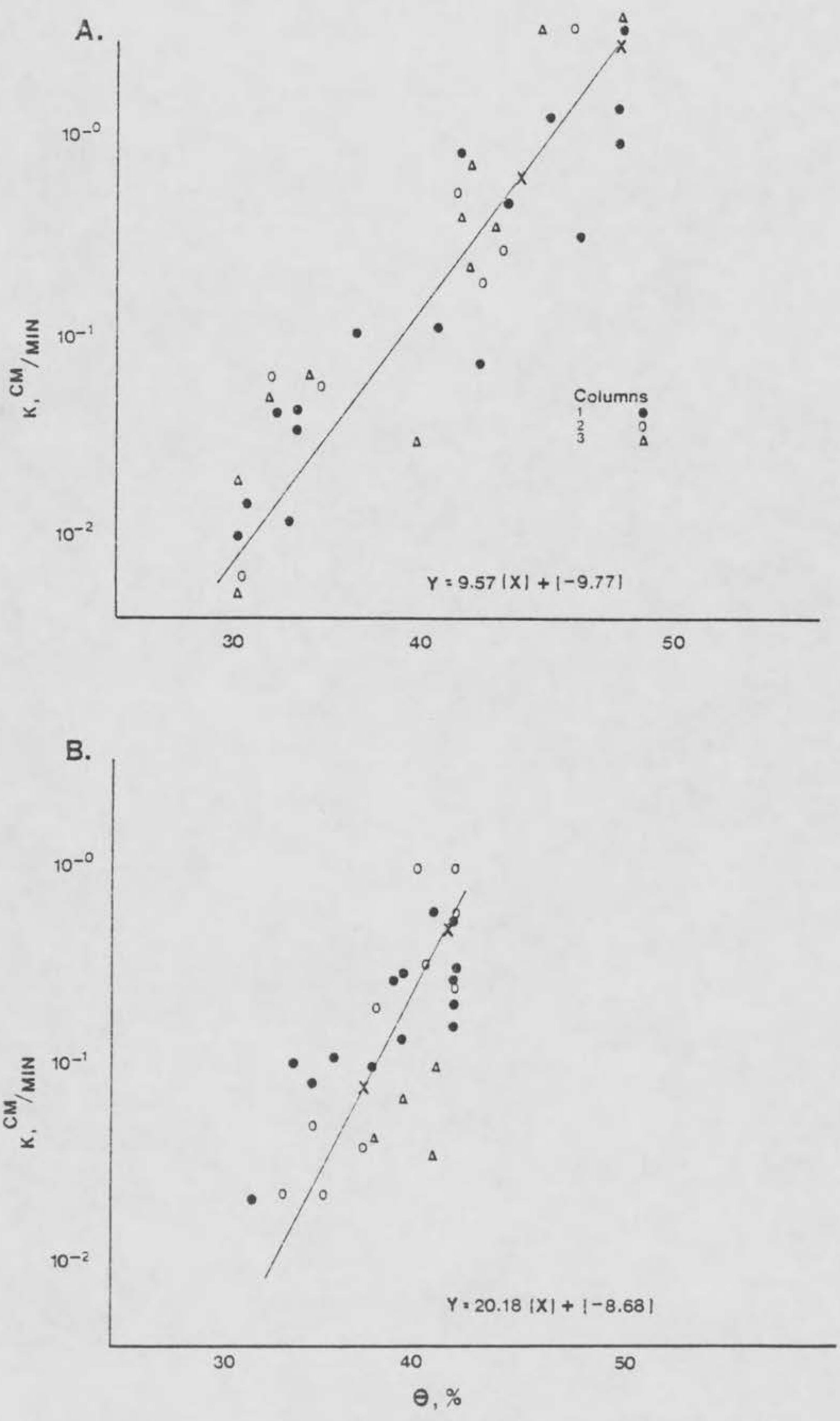
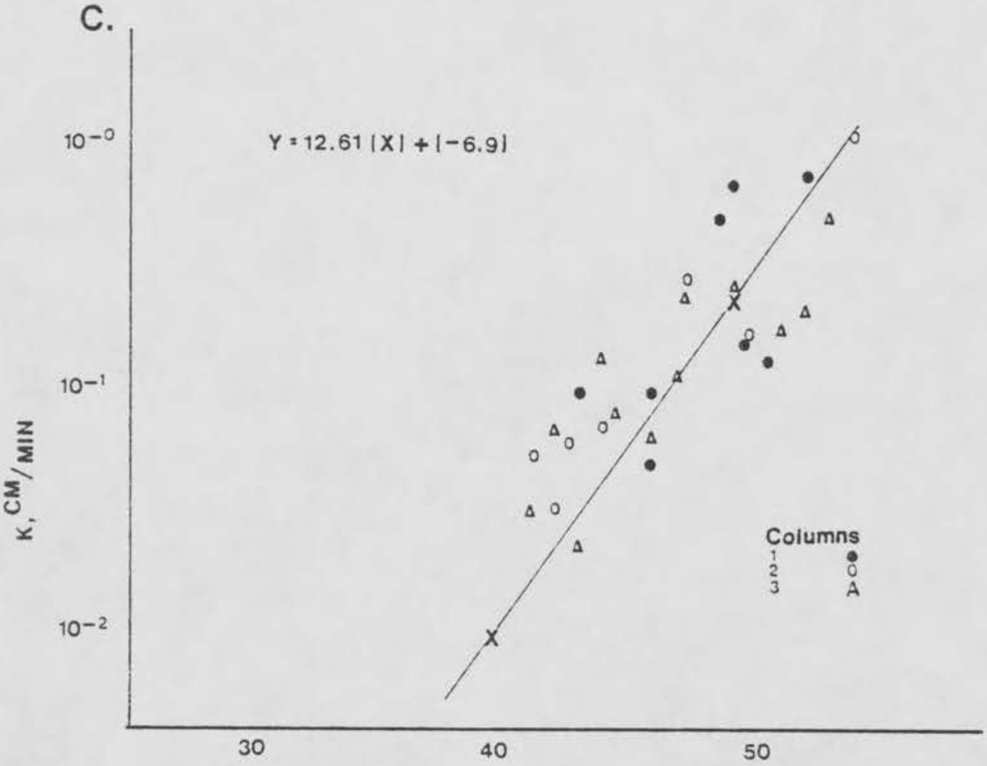
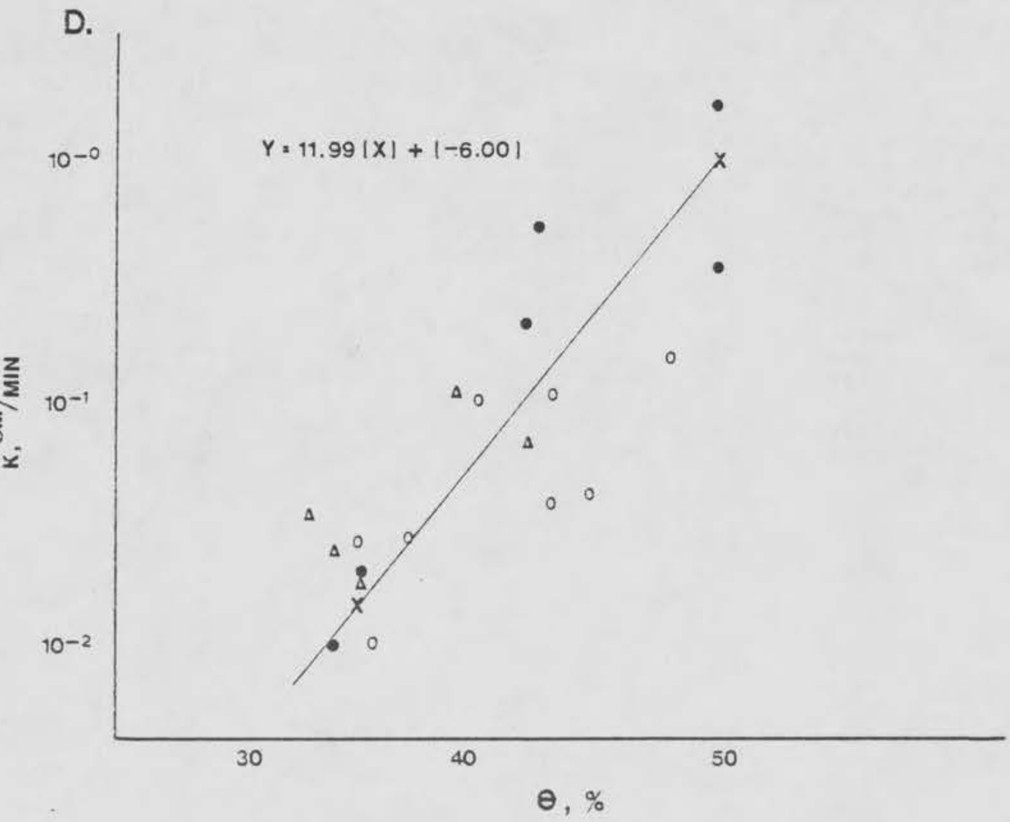

A.
10^-0
10^-1
10^-2
K, CM/MIN
Columns
1 ●
2 o
3 Δ
Y = 9.57 (X) + (-9.77)
30
40
50
B.
10^-0
10^-1
10^-2
K, CM/MIN
Y = 20.18 (X) + (-8.68)
30
40
50
Θ, %

Figure 4--Continued

C. Unsaturated hydraulic conductivity with water content for the peat and sand mixture under laboratory conditions

D. Unsaturated hydraulic conductivity with water content for the peat, sand and soil mixture under laboratory conditions


C.
Y = 12.61 (X) + (−6.9)
10−0
10−1
10−2
K, CM/MIN
Columns
1 ●
2 O
3 Δ
30
40
50


D.
Y = 11.99 (X) + (−6.00)
10−0
10−1
10−2
K, CM/MIN
30
40
50
Θ, %

BS and BSS mixtures shows the hydraulic conductivity at saturation (50% for BS and 42% for BSS) to be 3 cm/min and 0.7 cm/min, respectively. The addition of soil reduced hydraulic conductivity at all water contents. At a water content of 36%, hydraulic conductivity for each mixture was 0.04 cm/min which indicates the mixtures are very close to field capacity.

Figure 4 shows the saturated hydraulic conductivity to be 1.2 cm/min for the PS and 1.0 cm/min for the PSS. Field capacity for the peat mixtures was found to occur at a hydraulic conductivity of 0.01 cm/min. However, the water content was 6% greater for the PS mixture which indicates that the peat has a higher capillary porosity than soil.

Laboratory Cores Versus Columns

One of the objectives of this study was to compare accepted laboratory analysis determinations (9) with results from larger more representative laboratory columns. The results of the physical analysis of the smaller laboratory cores (7.62 cm high and 5.08 cm diam) and the larger laboratory columns are shown in Table 5. The determinations of the physical measurements for the larger laboratory columns were averages from the five depths measured in Table 4. From Table 5 the bulk density and total porosity measurements were greater for all soil mixtures when analyzed by accepted laboratory procedures (9). However, water content values were found to be much lower. It is believed that a tension of -40 cm approaches field capacity for these high sand content mixtures (9). The small laboratory cores were subjected to this tension for analysis. However, the larger laboratory columns were flooded and allowed to drain until field capacity was reached. Tensiometers placed at 5, 10, 15, 20, and 25 cm were used to determine

TABLE 5. Comparison of physical properties for the laboratory cores and the laboratory columns

	Bulk Density (gm/cm^3)	Capillary Porosity (%)	Noncapillary Porosity (%)	Total Porosity (%)	Water Content by Volume (%)
Laboratory Cores (7.62 x 5.08 cm)					
Bark and sand	1.11	16.63 b*	40.82	57.45	16.61
Bark, sand and soil	1.24	18.36a	38.02 d	56.38	18.31
Peat and sand	1.02	17.05ab	48.17a	65.23	17.03
Peat, sand and soil	1.17	14.47 c	44.71 b	58.98	14.43
Laboratory Columns (35.56 x 27.94 cm)					
Bark and sand	0.82			50.0	41.6
Bark, sand and soil	0.99			41.5	39.6
Peat and sand	0.81			55.0	49.0
Peat, sand and soil	0.95			50.5	43.4

*Significant at the 5% level using Duncan's Multiple Range Test. Means not followed by same letter are significantly different from each other.

the tension of the soil mixtures at field capacity. Figure 5 shows the relationship of water content and tension for each of the soil mixtures in the larger laboratory columns. At 5 cm the water content for the BS mixture is 31% (Table 4), and the tension is -5 cm (Fig. 5). Similar tensions are seen with the other soil mixtures which indicates that -40 cm is not an acceptable approximation of tension at field capacity. These results are similar to those of Bingaman (4) and Juncher (14). To achieve greater accuracy of measurement, it may be necessary to reduce the tension before making porosity and water content determinations. With the smaller cores the water does not perch, and this creates additional problems with analysis.

Field Studies

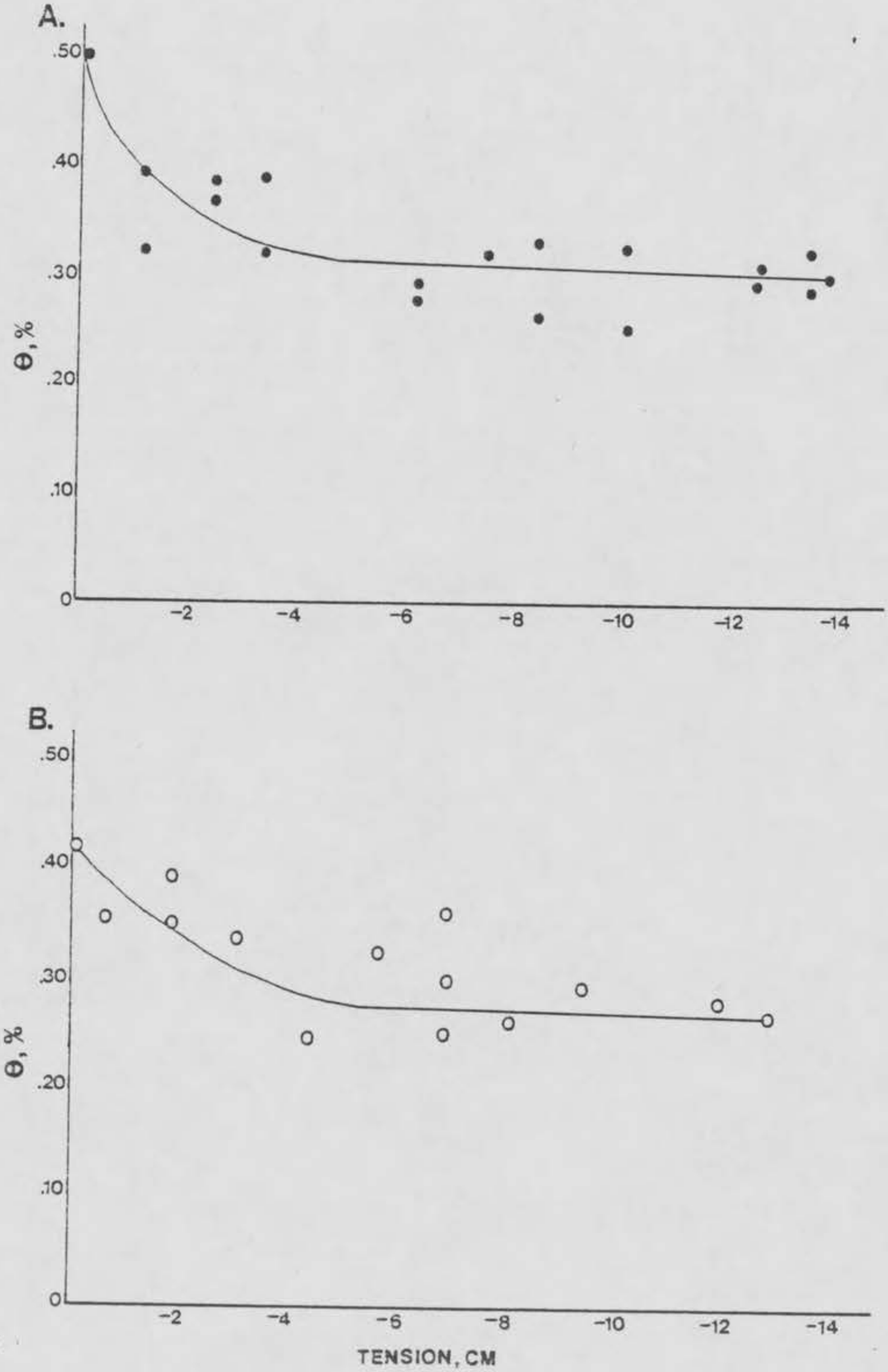
The physical properties of the soil mixtures under field conditions after one year are shown in Table 6.

The bulk densities of the BS and the PS mixtures are very similar to a depth of 15 cm and ranged from 1.12 to 1.20 gm/cm^3. The bulk density of the BS remained constant at 1.18 gm/cm^3 from 15 to 25 cm, but the bulk density of the PS was increased to 1.23 gm/cm^3 at the 20 cm depth and 1.27 gm/cm^3 at 25 cm. The bulk density was greater with the PS at 15 to 25 cm which suggests the peat mixture is more subject to compaction than the bark. The change in bulk density for a one year period (Table 7) does not reflect this trend. The change in bulk density was greater for the BS (0.05 gm/cm^3 at 5 cm and 0.03 gm/cm^3 at 10 cm) which indicates that the upper 10 cm of the BS is more compacted than the upper 10 cm of the PS. However, in the lower 15 cm, the change in bulk density was greater for the PS mixture (Table 7). The change in bulk density increased from 0.03 gm/cm^3 at 15 cm to 0.15 gm/cm^3 at 25 cm.

Figure 5.

A. Moisture release curve for the bark and sand mixture under laboratory conditions

B. Moisture release curve for the bark, sand and soil mixture under laboratory conditions



A.
.50
.40
.30
.20
.10
0
Θ, %
-2
-4
-6
-8
-10
-12
-14
B.
.50
.40
.30
.20
.10
0
Θ, %
-2
-4
-6
-8
-10
-12
-14
TENSION, CM

Figure 5--<u>Continued</u>

C. Moisture release curve for the peat and sand mixture under laboratory conditions

D. Moisture release curve for the peat, sand and soil mixture under laboratory conditions

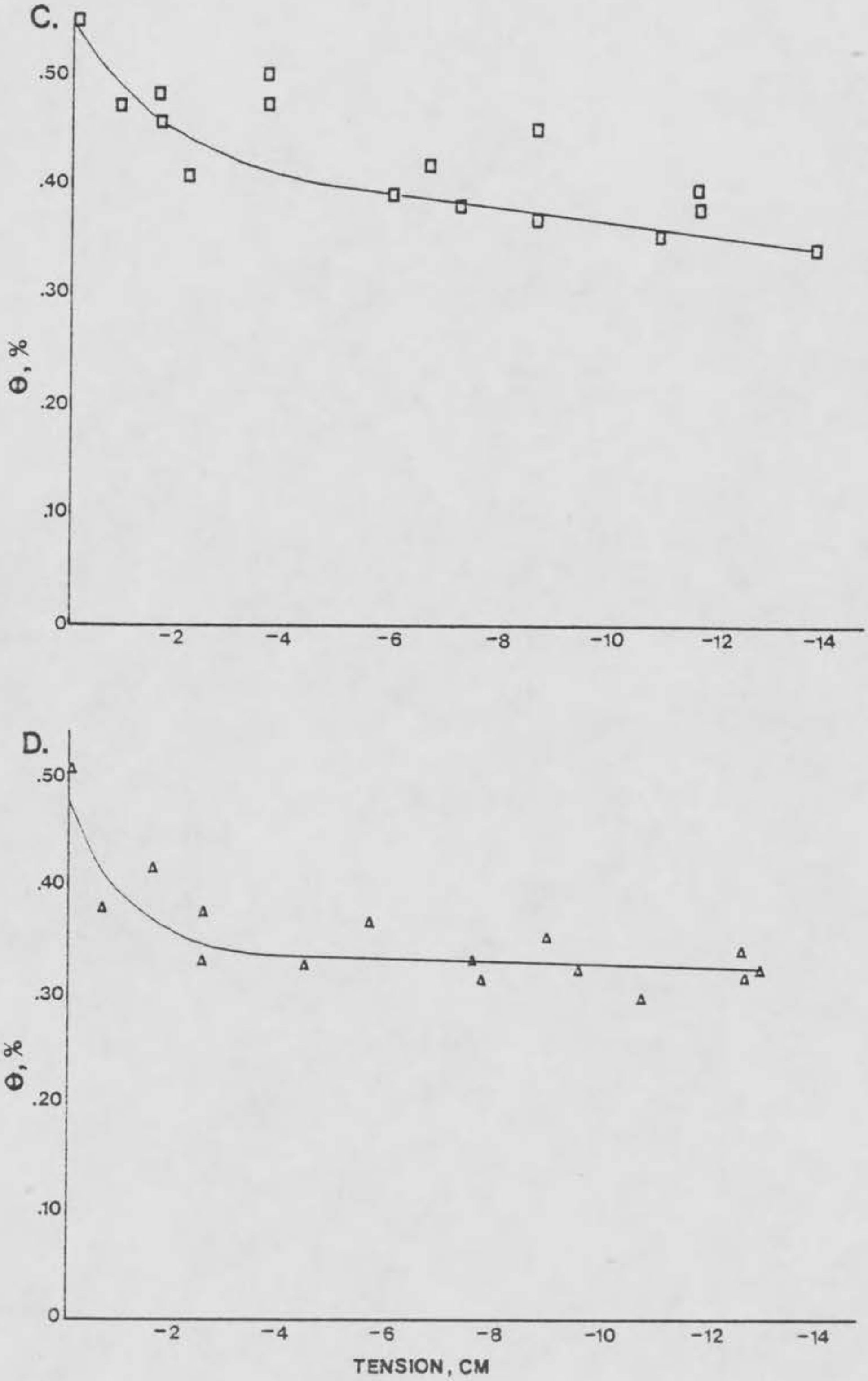

C.
.50
.40
.30
.20
.10
0
Θ, %
−2
−4
−6
−8
−10
−12
−14
D.
.50
.40
.30
.20
.10
0
Θ, %
−2
−4
−6
−8
−10
−12
−14
TENSION, CM

TABLE 6. Physical properties with depth for the field plots

	Depth (cm)	Bulk Density (gm/cm^3)	Particle Density (gm/cm^3)	Porosity using PD (%)	Porosity measured (%)	Water Content at Field Capacity (%)	Matrix Potential at Field Capacity (cm)
Bark and sand	5	1.13	2.55	56	----	25	-5.92
	10	1.18		54	----	26	-5.11
	15	1.18		54	----	31	-1.78
	20	1.17		54	36	36	2.80
	25	1.16		55	36	36	8.22
Bark, sand and soil	5	1.19	2.55	53	----	24	-6.95
	10	1.25		51	----	30	-3.41
	15	1.31		49	----	36	-0.92
	20	1.37		46	40	40	3.87
	25	1.43		44	40	40	8.45
Peat and sand	5	1.12	2.62	57	----	25	-9.94
	10	1.16		56	----	29	-6.62
	15	1.20		54	----	37	-2.45
	20	1.23		53	50	50	2.75
	25	1.27		53	50	50	6.71
Peat, sand and soil	5	1.23	2.60	53	----	24	-9.47
	10	1.33		49	----	27	-6.14
	15	1.29		50	----	34	-1.77
	20	1.36		48	38	38	2.39
	25	1.40		50	38	38	6.35

TABLE 7. The change in bulk density and total porosity for the soil mixtures under field conditions for one year

	Depth (cm)	Initial Bulk Density (gm/cm^3)	Final Bulk Density (gm/cm^3)	Change in Bulk Density (gm/cm^3)	Initial Porosity (%)	Final Porosity (%)	Change in Porosity (%)
Bark and sand	5	.71	1.13	.42			
	10	.77	1.18	.41			
	15	.82	1.18	.36			
	20	.87	1.17	.30	50	36	14
	25	.92	1.16	.24	50	36	14
Bark, sand and soil	5	.92	1.19	.27			
	10	.96	1.25	.29			
	15	.99	1.31	.32			
	20	1.03	1.37	.34	41.5	40	1.5
	25	1.06	1.43	.37	41.5	40	1.5
Peat and sand	5	.75	1.12	.37			
	10	.78	1.16	.38			
	15	.81	1.20	.39			
	20	.85	1.23	.38	55	50	5
	25	.88	1.27	.39	55	50	5
Peat, sand and soil	5	.85	1.23	.38			
	10	.90	1.33	.43			
	15	.95	1.29	.34			
	20	1.00	1.36	.36	50.5	38	12.5
	25	1.05	1.40	.35	50.5	38	12.5

If the change in bulk density was greater for the PS, a reduction in total porosity should be seen. The BS mixture had a reduction of 14% total porosity in the lower 10 cm while the PS had only a 5% reduction (Table 7). Even though the PS mixture was found to have higher bulk density measurements in the lower depths (Table 6), its total porosity was greater than the bark mixture. This unusual relationship may be due to the ability of the peat to expand when wet. The total porosity measurement was based on the water content at field capacity. The matrix potential readings (Table 6) indicate the lower 10 cm are saturated at field capacity. The additional water in the lower depths could cause the peat to expand and provide more total pore space. The laboratory data (Table 4) has shown that the peat is able to absorb and hold more water than the bark fraction. Since the peat can hold more water, it is logical to assume that the PS mixture contains a larger percentage of small (capillary) pores, and these pores are responsible for some of the additional total porosity.

The bulk density measurements for the mixtures with soil were found to be very similar with depth and ranged from 1.19 to 1.43 gm/cm^3 (Table 6). The addition of the soil increased the bulk density at each depth for both mixtures. Since the bulk density measurements were very similar, the total porosity and water content values should be very close. The total porosity and water content at field capacity (Table 6) are almost identical for the mixtures with soil. The BSS was 40%, while the PSS was 38%.

The bulk densities of all mixtures were greater after 1 year under field conditions (Table 7). The change in bulk density was much greater in the BS mixture than in the BSS mixture which suggests that the addition of soil actually reduced the degree of compaction with the bark mixtures. The change in total porosity indicates this much more dramatically. Over the 1 year period, a reduction of 14% total porosity was observed with the BS, but the total porosity of the BSS mixture was reduced by only 1.5%. It appears that the addition of soil to the BS mixture improves the soil structure and enables the sand and bark fractions to achieve greater homogeneity of pore space distribution which results in a soil mixture less subject to compaction.

The addition of soil to the peat mixture produced the opposite effect. Although the change in bulk density was less evident, the porosity of the PS mixture was reduced by only 5%; whereas, the PSS mixture was reduced by 12.5%. The addition of soil filled the capillary pores of the PS mixture which reduced the total porosity and increased the severity of compaction.

Cumulative Drainage

Cumulative drainage with time is shown in Figure 6. At field capacity, the BS and PSS mixture allowed approximately 0.7 cm of water to drain while the BSS and the PS mixture allowed 0.8 cm and 0.85 cm, respectively. Although more water drained through the PS mixture, the differences were very small.

Previous bulk density and total porosity data (Table 6) have indicated that the PS mixture contains a greater percentage of small (capillary) pores. However, the cumulative drainage curve (Fig. 6) and the water content measurements at field capacity (Table 6) indicate this is not true. Cumulative drainage was somewhat greater in the PS mixture, but the water content values at field capacity are essentially the same

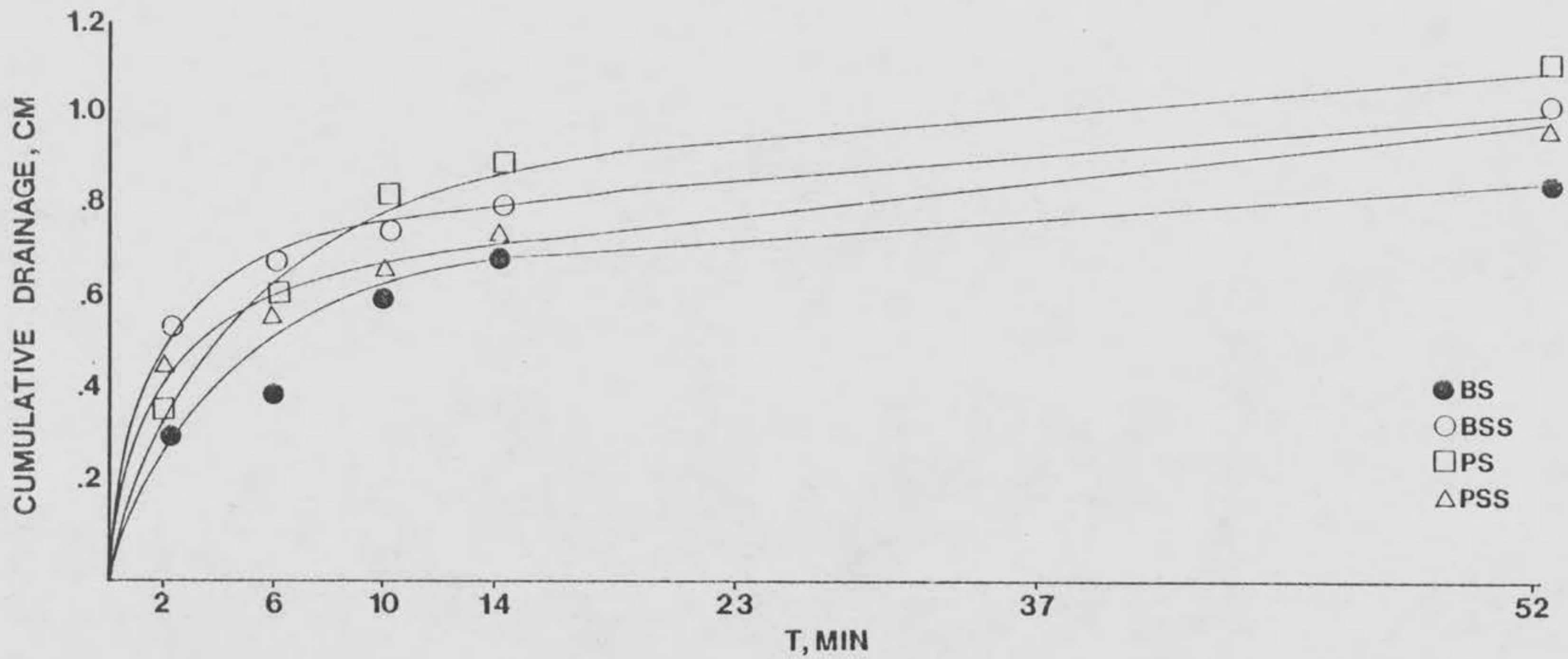


Figure 6. Cumulative drainage with time for the soil mixtures under field conditions

for all mixtures. The increased water contents are found in the lower depths where the mixtures were saturated or approached saturation. Therefore, it would appear that the capillary porosity is approximately the same for each of the mixtures and the differences in total porosity, approximately 10%, are due to the larger noncapillary pores. Therefore, cumulative drainage was greater in the PS mixture.

Field Capacity

From Figure 6 the PSS, BSS and the PS reached field capacity approximately 10 minutes after drainage began. However, 12 minutes was needed for the BS mixture to reach field capacity. The addition of soil to the BS mixture increased the amount of water found in the mixture (Table 6). At 5 cm the water content for both bark mixtures was essentially the same (25%), but at each subsequent sampling depth (10, 15, 20, and 25 cm), the addition of soil increased the water content by approximately 4%.

When soil was added to the PS mixture, water content decreased throughout the mixture (Table 7). In the upper 15 cm the water content was essentially the same for both peat mixtures. However, in the lower 10 cm the water content was decreased from 50 to 38% with the addition of soil. The soil increased bulk density measurements and lowered water content. It appears that the addition of soil to the peat and sand mixture filled the noncapillary pores which resulted in reduced pore space and lowered the water content with depth.

Flux

Flux with time is shown in Figure 7. The movement of water through the PS is faster than the movement through the BS. Two minutes after drainage began, the movement of water through the PS was slowed to 0.06 cm/min, but the movement of water through the BS was 0.09 cm/min. The BS mixture achieved a flow rate of 0.06 cm/min four minutes after drainage began. The velocity of water movement was faster for the PS mixtures until field capacity was reached (12 min) and the flow rates of the two mixtures became equal (0.01 cm/min).

The porosity of the bark and peat mixtures containing soil was very similar (Table 6) which suggests the flow rates should be very similar, and the flux curves are essentially the same. The BSS had a flow rate of 0.08 cm/min after 2 minutes, and the PSS was 0.07 cm/min. However, 4 minutes after drainage began both mixtures with soil were found to have flow rates of 0.05 cm/min.

The flux curves (Fig. 7) indicate that the PS, PSS, and BSS reached field capacity 10 minutes after drainage began. Once again, the total porosity was less with the BS mixture, and more time was needed for the water to move through the mixture.

Hydraulic Conductivity

Hydraulic conductivity determinations with water content are shown in Figure 8. From Table 6 it can be seen that the saturated water content is 36% for the BS mixture and 40% for the BSS. The hydraulic conductivity at the saturated water contents is 0.7 cm/min for the BS and 1.2 cm/min for the BSS (Fig. 8). The total porosity was greatest in the BSS mixture (Table 6) which explains the increased hydraulic conductivity. Since the BSS mixture maintained a higher total porosity which resulted in a greater hydraulic conductivity, it appears that the BS mixture is more subject to compaction. An indication of this is the

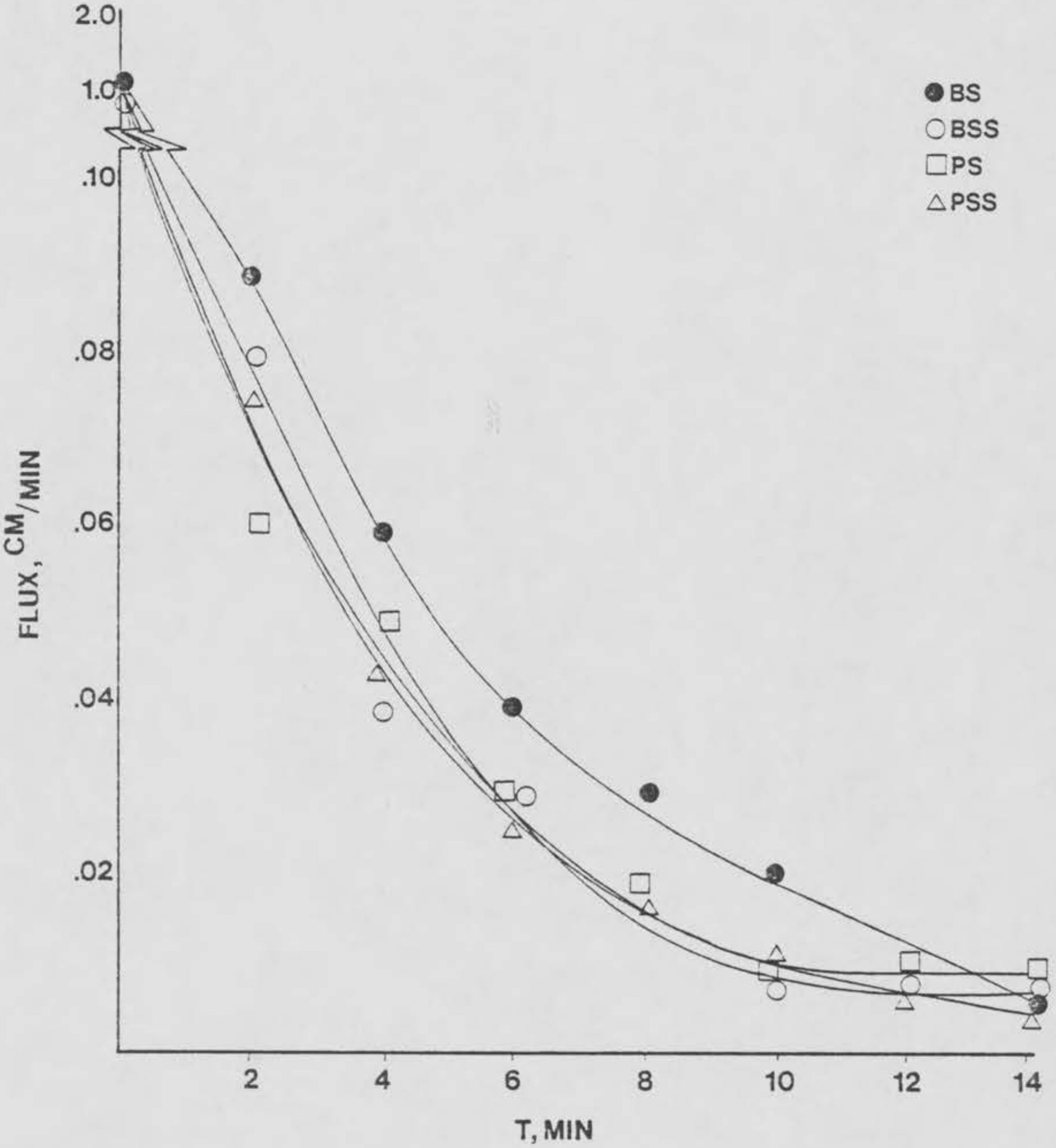


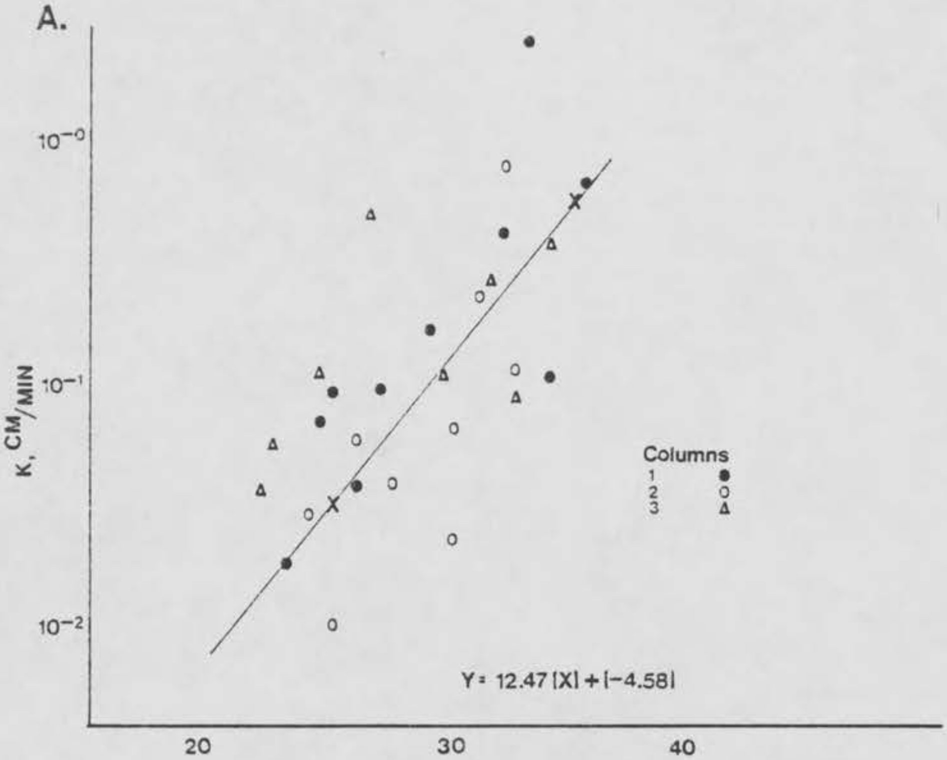
Figure 7. Flux with time for the soil mixtures under field conditions

Figure 8.

A. Unsaturated hydraulic conductivity with water content for the bark and sand mixture under field conditions

B. Unsaturated hydraulic conductivity with water content for the bark, sand and soil mixture under field conditions

A.


10⁻⁰
10⁻¹
10⁻²
K, CM/MIN
Columns
1 ●
2 o
3 Δ
Y = 12.47 [X] + [-4.58]
20
30
40

B.

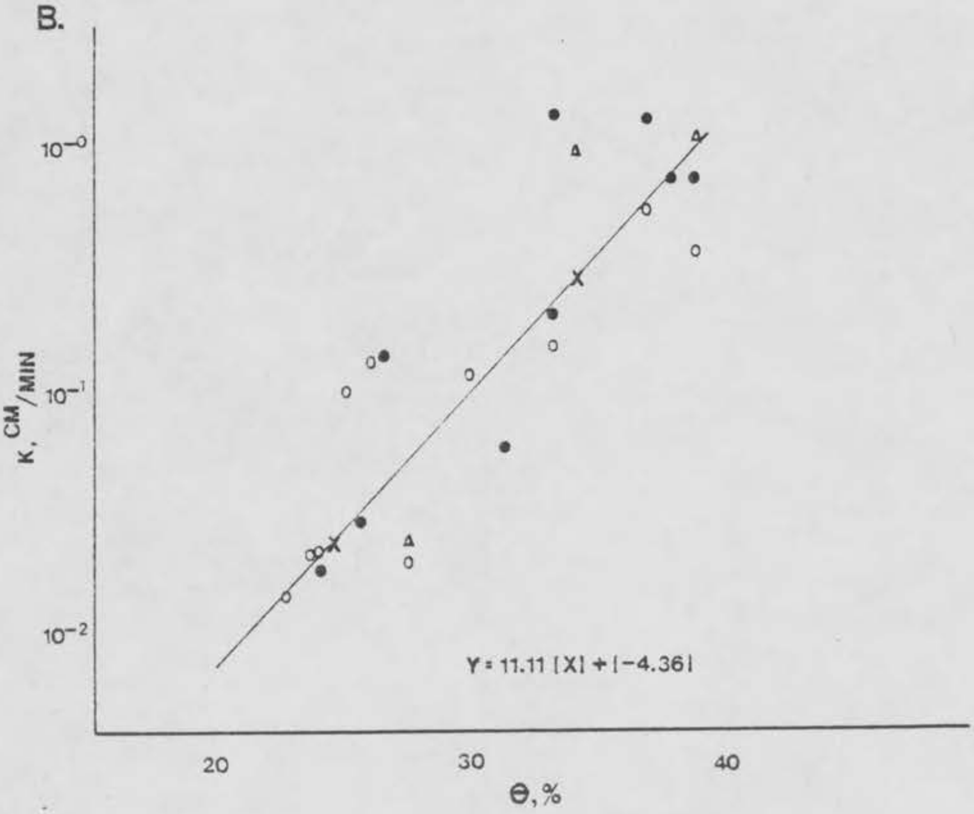
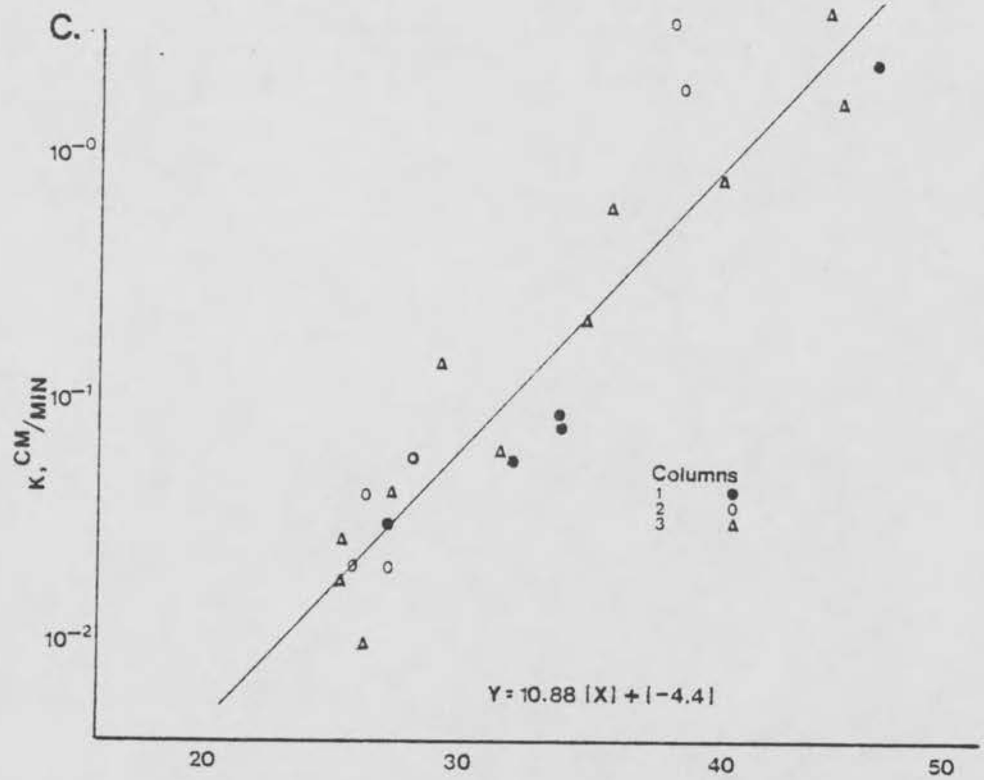
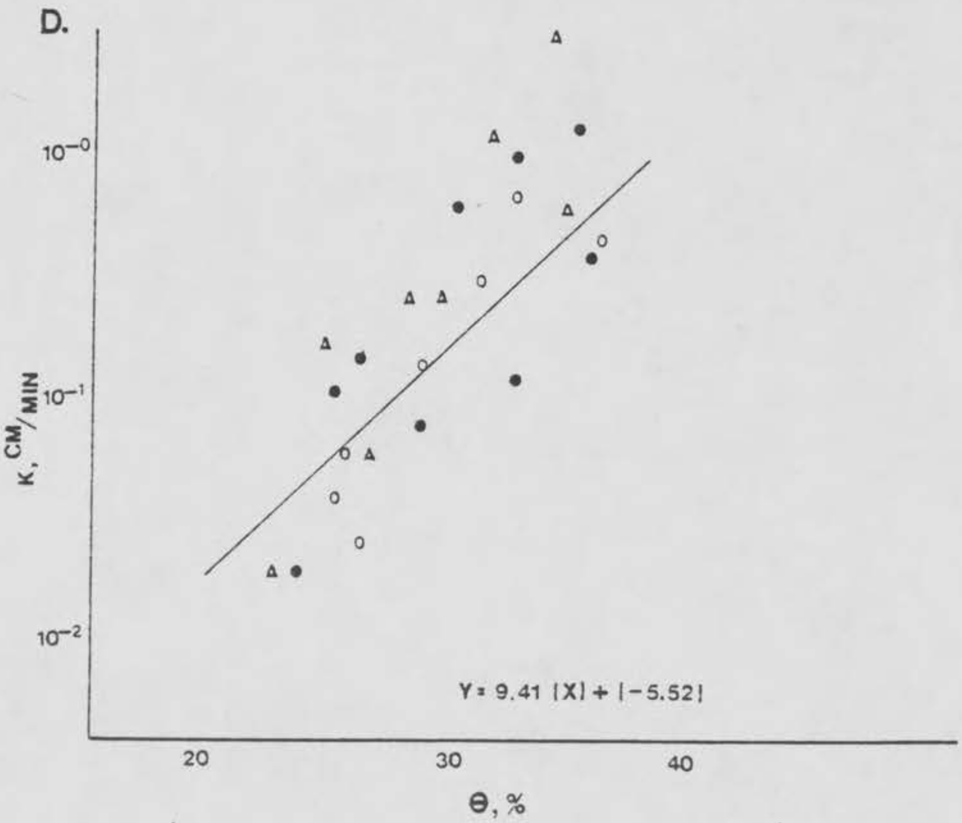

10⁻⁰
10⁻¹
10⁻²
K, CM/MIN
Y = 11.11 [X] + [-4.36]
20
30
40
Θ, %

Figure 8--Continued

C. Unsaturated hydraulic conductivity with water content for the peat and sand mixture under field conditions

D. Unsaturated hydraulic conductivity with water content for the peat, sand and soil mixture under field conditions


C.
10^-0
10^-1
10^-2
K, CM/MIN
Columns
1 ●
2 O
3 Δ
Y = 10.88 [X] + [-4.4]
20
30
40
50


D.
10^-0
10^-1
10^-2
K, CM/MIN
Y = 9.41 [X] + [-5.52]
20
30
40
Θ, %

change in total porosity and change in bulk density measurements (Table 7). It appears that the addition of soil to the BS mixture provided a more uniform pore space distribution; and subsequently, the BSS mixture maintained a greater porosity. From the available data, regardless of the cause, the BS mixture appears to have less total porosity and compacts more readily than the BSS.

Table 6 shows the saturated water content is 50% for the PS mixture and 38% for the PSS. The saturated hydraulic conductivity was greater than 10 cm/min for the PS mixture and 0.9 cm/min for the PSS (Fig. 8). The addition of soil reduced the total porosity which resulted in a 10-fold reduction of the saturated hydraulic conductivity. Reduced hydraulic conductivity coupled with the reduced total porosity measurements of Table 7 indicate that the PSS mixture is more subject to compaction than the PS.

Since the BSS and PSS mixtures have very similar porosities, bulk densities and water contents (Table 6), the hydraulic conductivity for each mixture should be very similar. The saturated hydraulic conductivity was 1.2 cm/min for the BSS and 0.9 cm/min for the PSS (Fig. 8). Due to slightly higher porosity measurements, the BSS mixture provided higher conductivities throughout the profile.

Compacted Laboratory Cores Versus One Year Old Field Plots

Table 8 compares the physical characteristics of the smaller compacted laboratory cores and the one year old field plots. The determinations of the physical measurements for the field plots are averages from the five depths shown in Table 6.

TABLE 8. Comparison of physical properties for the compacted laboratory cores and the one year old field plots

	Bulk Density (gm/cm^3)	Capillary Porosity (%)	Noncapillary Porosity (%)	Total Porosity (%)	Water Content at Field Capacity (%)
Laboratory Cores (7.62 x 5.08 cm)					
Bark and sand	1.18	14.7 b*	34.3a	49.0	14.74
Bark, sand and soil	1.39	17.3a	23.3 c	40.6	17.32
Peat and sand	1.27	16.8a	34.9a	51.7	16.88
Peat, sand and soil	1.36	16.6a	31.1 b	47.7	16.88
Field Plots After 12 Months					
Bark and sand	1.16			36	30.8
Bark, sand and soil	1.31			40	34.0
Peat and sand	1.20			50	38.2
Peat, sand and soil	1.32			38	32.2

*Duncan's Multiple Range Test. Means in the same column followed by same letter are not significantly different.

Table 8 shows that bulk density measurements are slightly higher for the compacted laboratory cores, but the measurements are very close. The smallest difference was 0.02 gm/cm^3 with the BS, and the largest difference 0.08 gm/cm^3 with the BSS. The difference in bulk density was 0.07 gm/cm^3 for the PS and 0.04 gm/cm^3 for the PSS mixture. Since the bulk density measurements are very similar, it appears that soil samples compacted with 45 foot pounds of energy at -40 cm tension is a very good estimate of the degree of compaction that occurs in the field on putting green mixtures. If the laboratory and field bulk density measurements are similar, the total porosity measurements should be very comparable. The data (Table 8) did not reflect this assumption. Under compacted laboratory conditions the BSS (40.6%) and the PS (51.7%) mixtures were found to have essentially the same total porosity as they did under field conditions. However, the BS and the PSS measurements were very different. It is interesting to note that the mixtures with the greatest difference in bulk density were found to have essentially the same total porosity, but the mixtures with the smallest differences in bulk density were found to have the greatest difference in total porosity. Conflicting results of this kind should not occur. However, it is important to remember that the laboratory cores are much smaller than the field plots. Perhaps the laboratory cores were not large enough to provide a representative sample of the soil mixture.

Comparison of the water content measurements at field capacity are very different (Table 8). The water content of the laboratory cores was found to be much lower than the field mixtures. The laboratory cores were analysed at a tension of -40 cm, but the field mixtures were allowed to reach field capacity as previously described. Table 6 and

Figure 9 show that field capacity (-5.92 cm for BS, -6.95 for the BSS, -9.94 cm for the PS and -9.47 for the PSS) for these mixtures is far above the traditional tension of -40 cm. The lowered water contents of the laboratory cores are due to the excessive tension applied before determinations were made. Therefore, it is impossible to compare water content at field capacity.

Establishment

Establishment rates of Penncross creeping bentgrass on the various mixtures are given in Table 9. The peat mixture with soil showed an earlier increase in cover. The PS mixture did not show the same degree of cover until July 15. On August 12 the PS and PSS mixtures had essentially complete coverage. The establishment of the BSS mixture was very similar to that of the PS. However, by August 12 the PS (91.7%) was far superior to the BSS (53.3%). The BS mixture proved very difficult to establish, and it was necessary to reseed and mulch this mixture during the experiment.

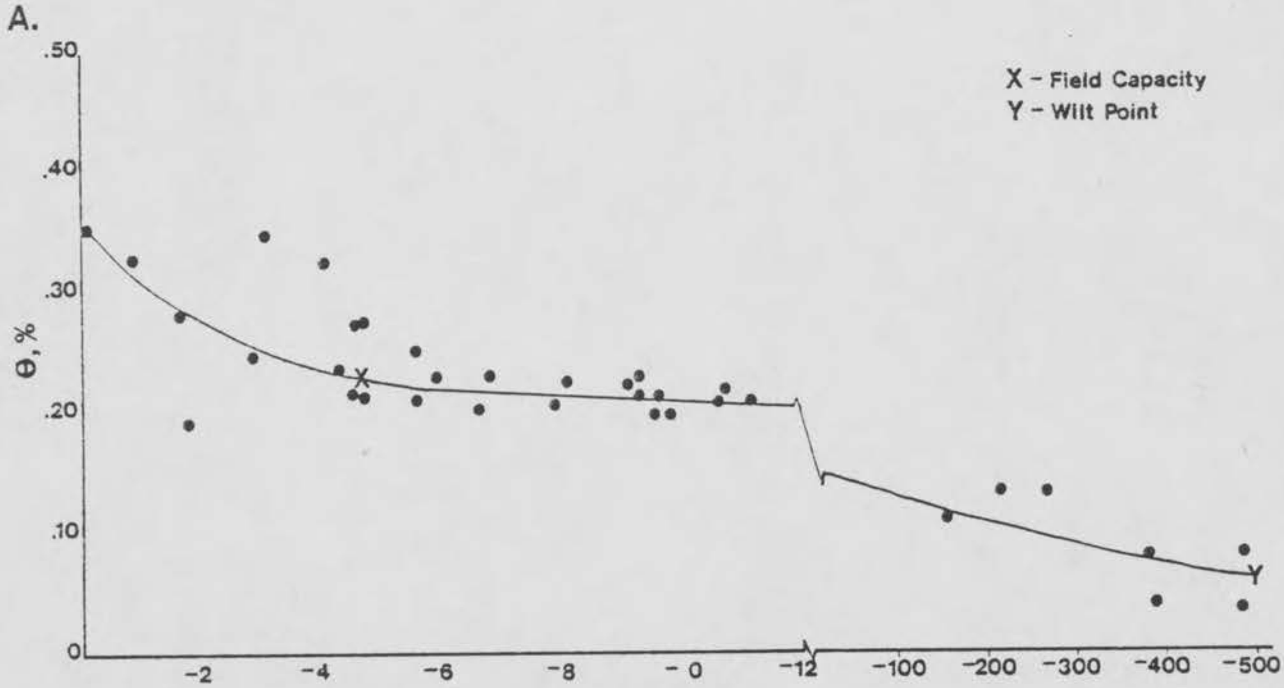
When seeded, the field mixtures had not been subjected to compaction or environmental changes. Therefore, it is necessary to compare the cover ratings (Table 9) with the physical properties determined under laboratory conditions.

The ability of the mixtures to establish suitable cover is primarily dependent upon the water content at or near the soil surface. Table 9 indicated that the PSS mixture provided far superior cover ratings at both 30 and 60 days after establishment. However, at 5 cm the water content (Table 4) was 7% greater for the PS mixture. Although very important, it appears that the water content is not the primary factor determining cover for these mixtures. The flux data (Fig. 3) previously

Figure 9.

A. Moisture release curve for the bark and sand mixture under field conditions

B. Moisture release curve for the bark, sand and soil mixture under field conditions


A.
X - Field Capacity
Y - Wilt Point
.50
.40
.30
.20
.10
0
Θ,%
-2
-4
-6
-8
- 0
-12
-100
-200
-300
-400
-500

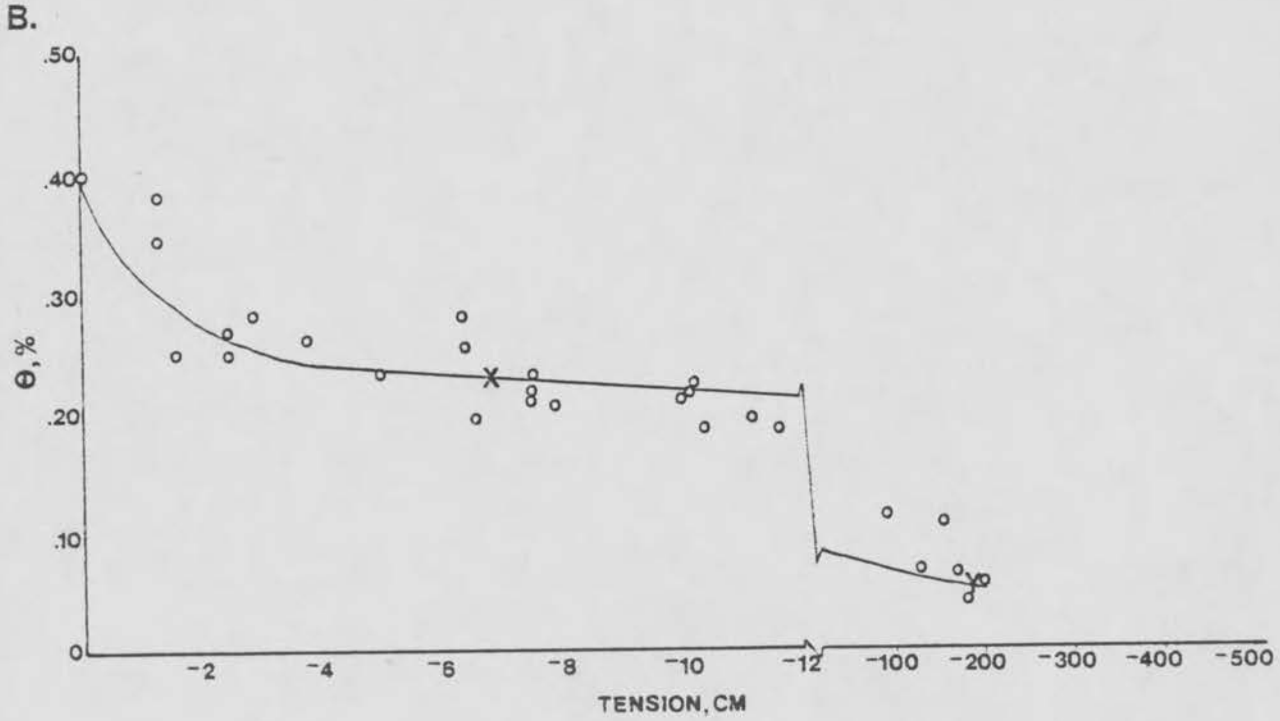
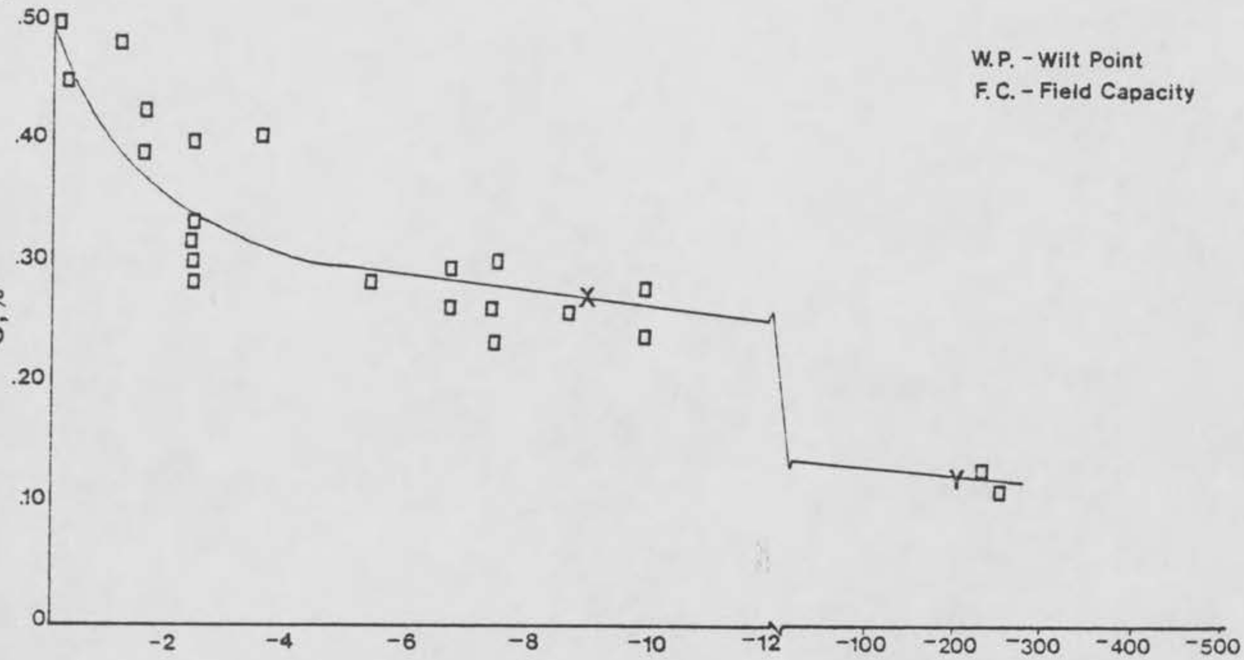

B.
.50
.40
.30
.20
.10
0
Θ,%
-2
-4
-6
-8
-10
-12
-100
-200
-300
-400
-500
TENSION, CM

Figure 9--Continued

C. Moisture release curve for the peat and sand mixture under field conditions

D. Moisture release curve for the peat, sand and soil mixture under field conditions

C.


.50
.40
.30
.20
.10
0
Θ, %
W.P. - Wilt Point
F.C. - Field Capacity
-2
-4
-6
-8
-10
-12
-100
-200
-300
-400
-500

D.

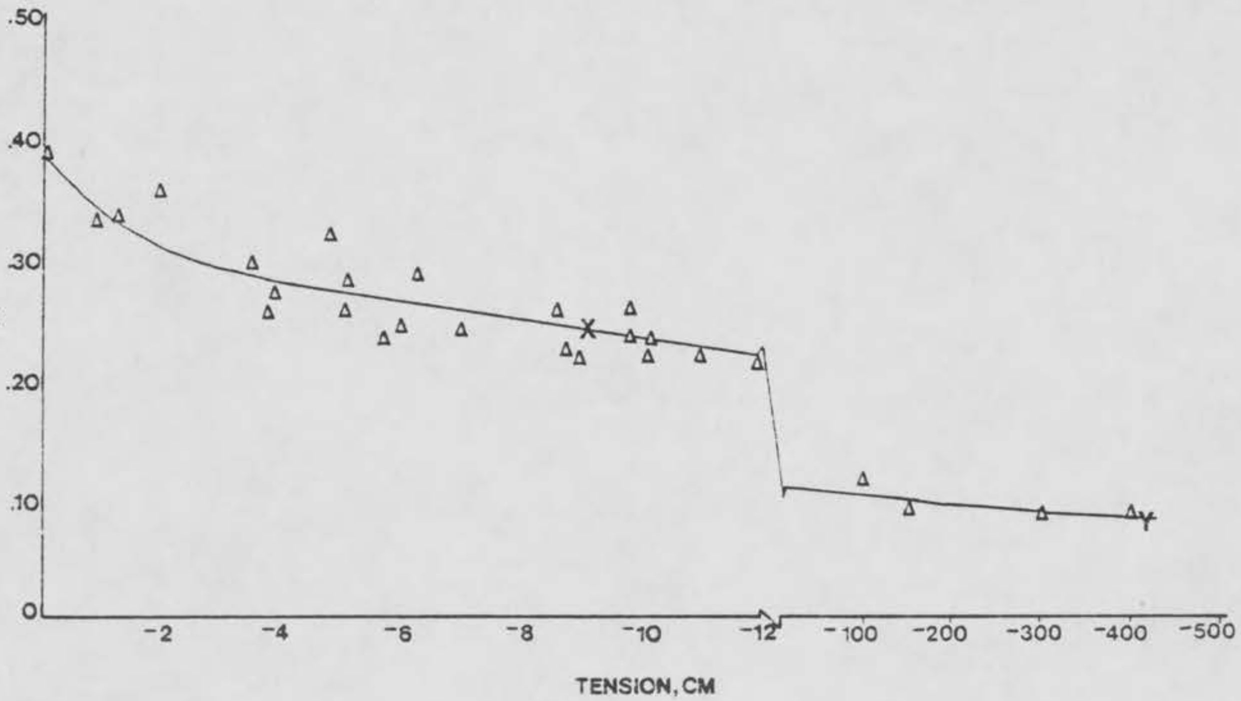

.50
.40
.30
.20
.10
0
Θ, %
-2
-4
-6
-8
-10
-12
-100
-200
-300
-400
-500
TENSION, CM

TABLE 9. Cover ratings† for the four soil mixtures

	Dates						
	6-09-78	6-27-78	7-15-78	7-24-78	8-12-78	8-29-78	9-08-78
Bark and sand	0.7 c*	0.7 c	1.0 c	1.0 c	4.3 c	6.3 c	5.3 c
Bark, sand and soil	9.4 bc	11.7 bc	40.0 b	46.7 b	53.5 b	60.0 b	61.7 b
Peat and sand	22.2 b	25.0 b	63.3ab	68.3ab	91.7a	94.7a	96.0a
Peat, sand and soil	50.0a	55.0a	83.3a	89.0a	93.3a	97.3a	98.7a

†Cover expressed as percent.

*Means within columns followed by same letter are not significantly different at the 5% level using the Duncan's Multiple Range Test.

presented, indicated that the addition of soil reduced the total porosity of the PS mixture which restricted the movement of water through the profile. In the case of establishment, the soil restricted the flow of water from the surface which explains the increased establishment rate of the PSS mixture. Each mixture provided a minimum of 30% water content at 5 cm (Table 4) which should be adequate for seed germination. However, the hydraulic properties of the PSS mixture held the water near the surface for a longer period of time which enhanced germination and cover.

Table 9 indicated that the PS and BSS mixture provided similar cover ratings through July 24, but by August 12, the PS was superior. The water content near the surface was 6% greater for the PS mixture (Table 4), and the increased cover (38%) seen in August with the PS mixture was probably due to the increased water content. In South Carolina, bentgrass is under extreme environmental stress, and the additional water found in the PS facilitated the spreading and survival of the grass.

When considering establishment and cover, the BS mixture was found to be very poor. The water content (31%) at 5 cm was found to be adequate for establishment and cover. Therefore, it could be assumed that the rapid flux of water in the BS mixture was responsible for the poor establishment rates. However, the flux data (Fig. 3) indicate the PSS mixture allowed water to move from the surface at a faster rate than the BS mixture. Previous research (34,35) has shown that various soil amendments can reduce establishment and inhibit the growth of certain turfgrass species. When 10% of the bark was replaced with soil, the establishment rate was enhanced (Table 9); however, 4 months after seeding the BSS was still inferior to the peat mixtures.

It would appear that the bark used in this study was somewhat phytotoxic to Penncross creeping bentgrass.

Available Water and Wilting

Since high sand content soil mixtures tend to be draughty and require frequent watering, the available water for plant use is very important. Figures 10-13 show the water content, and cumulative available water with depth for each of the soil mixtures.

Comparison of Figures 10 and 11 shows the water content at the wilt point was essentially the same for both bark mixtures. However, water content at field capacity was much greater for the BSS mixture. Starting at the 10 cm depth and proceeding to the bottom of the soil mixture, the water content was 4 to 5% greater for the BSS. Comparison of the cumulative available water curves (Fig. 10 and 11) show the BS mixture provided 4.2 cm of water for plant utilization while the BSS provided 5.2 cm of water. This should extend the time interval between irrigations, and Table 10 shows the BS mixture wilted June 20 while the BSS mixture wilted June 23.

Water content with depth (Fig. 10 and 11) indicate that the additional available water of the BSS mixture was found from 10 to 25 cm. Table 10 indicates that the matrix potential readings at the wilt point are much greater at 5 and 10 cm in the BS mixture. The tension at 5 and 10 cm for the BS mixture was -574.44 cm and -298.78 cm, respectively. The tension at 5 cm for the BSS was -184.13 cm and -148.60 cm tension at the 10 cm depth. However, the water content was less with the BSS. The pores of the bark are very fine and capable of holding water at very high tensions. Much greater tensions were required to pull the

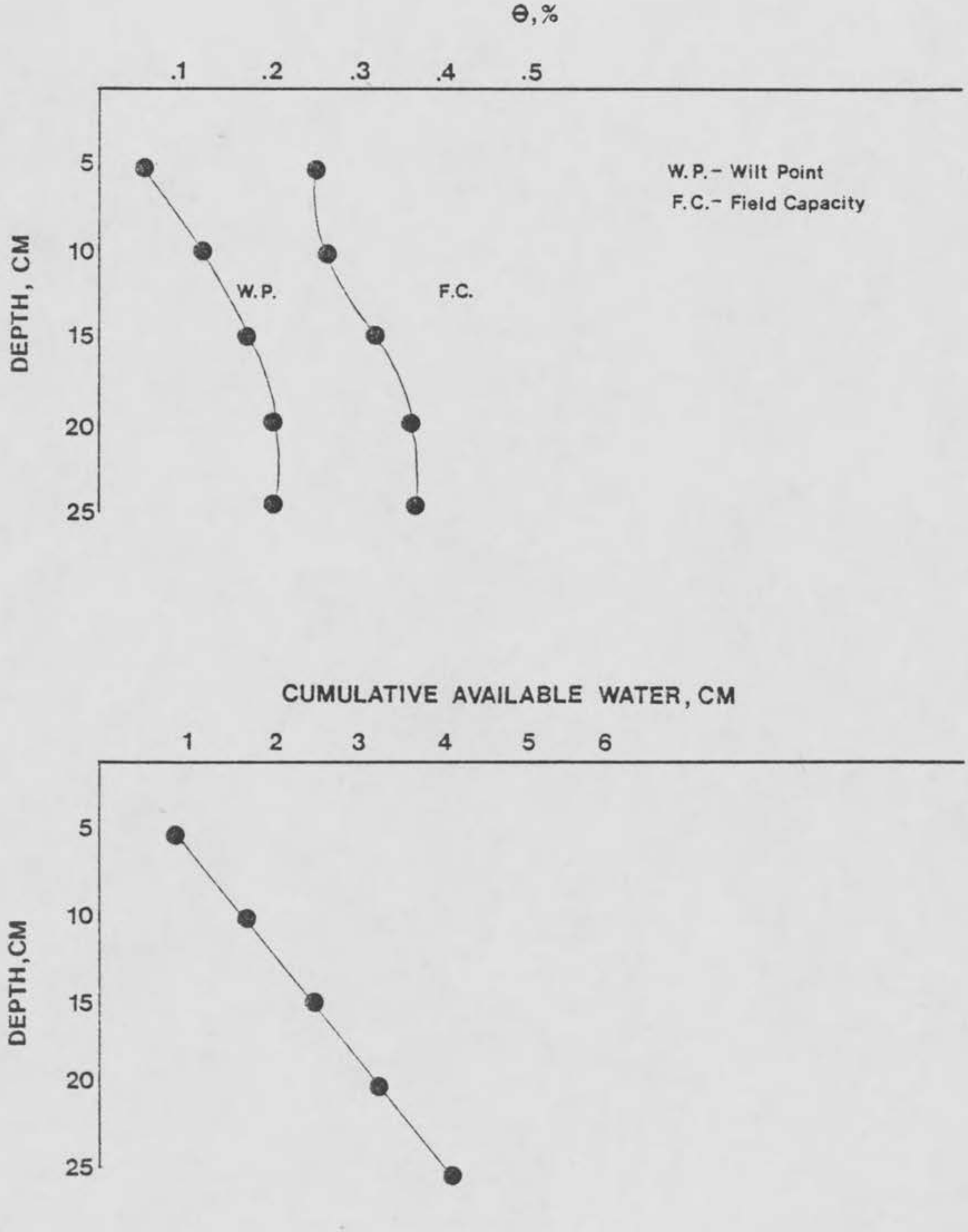


Figure 10. Water content and cumulative available water with depth for the bark and sand mixture under field conditions

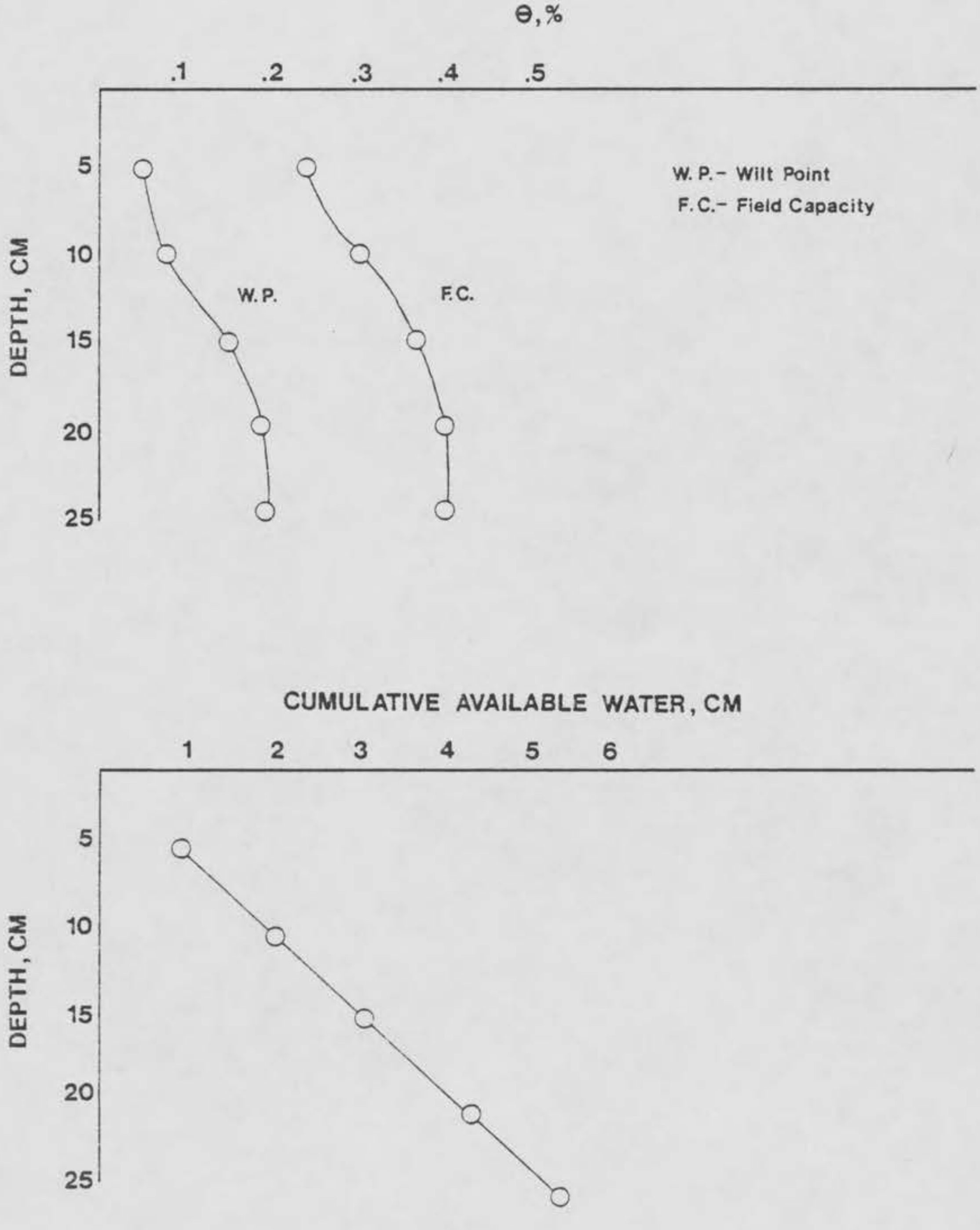


Figure 11. Water content and cumulative available water with depth for the bark, sand and soil mixture under field conditions

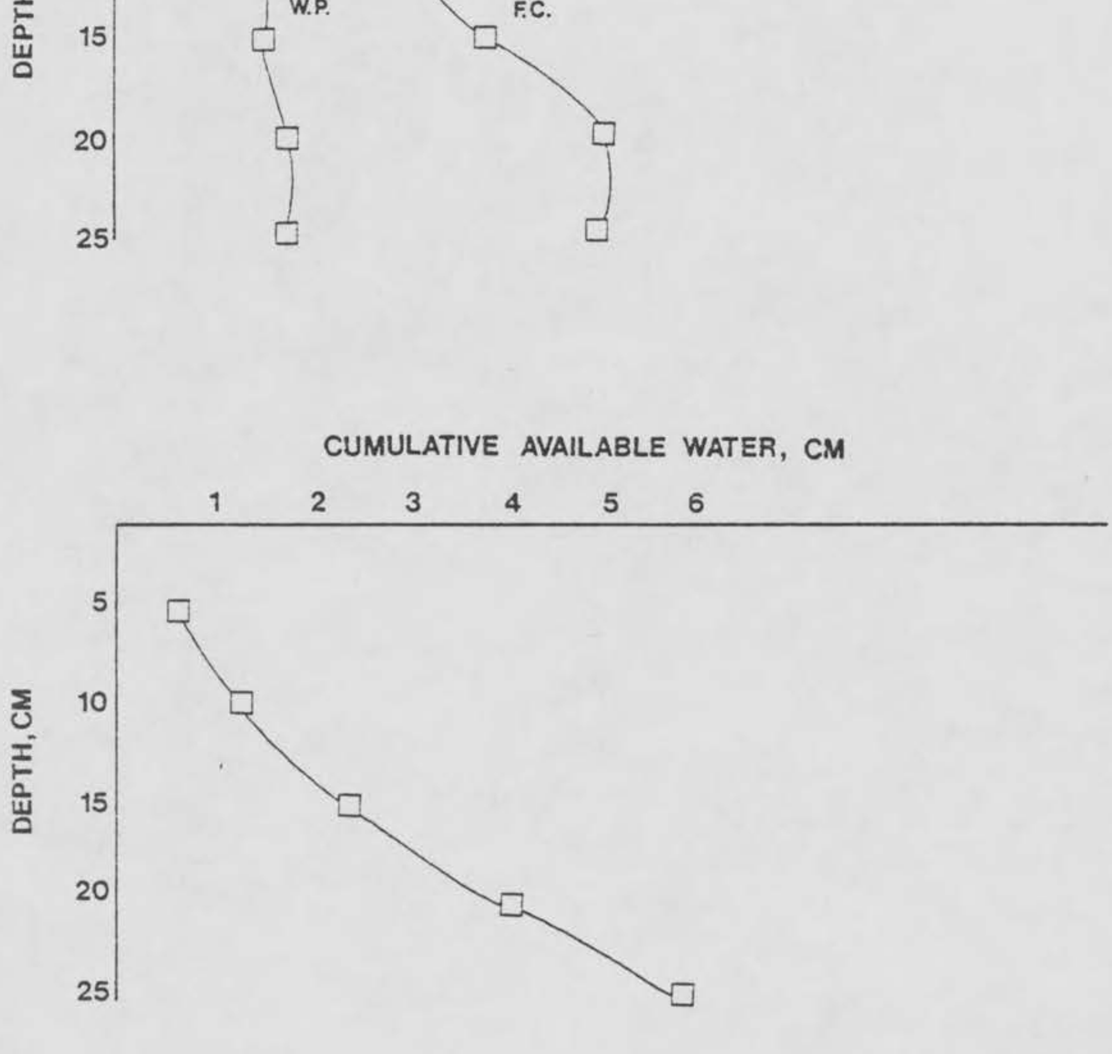


Figure 12. Water content and cumulative available water with depth for the peat and sand mixture under field conditions

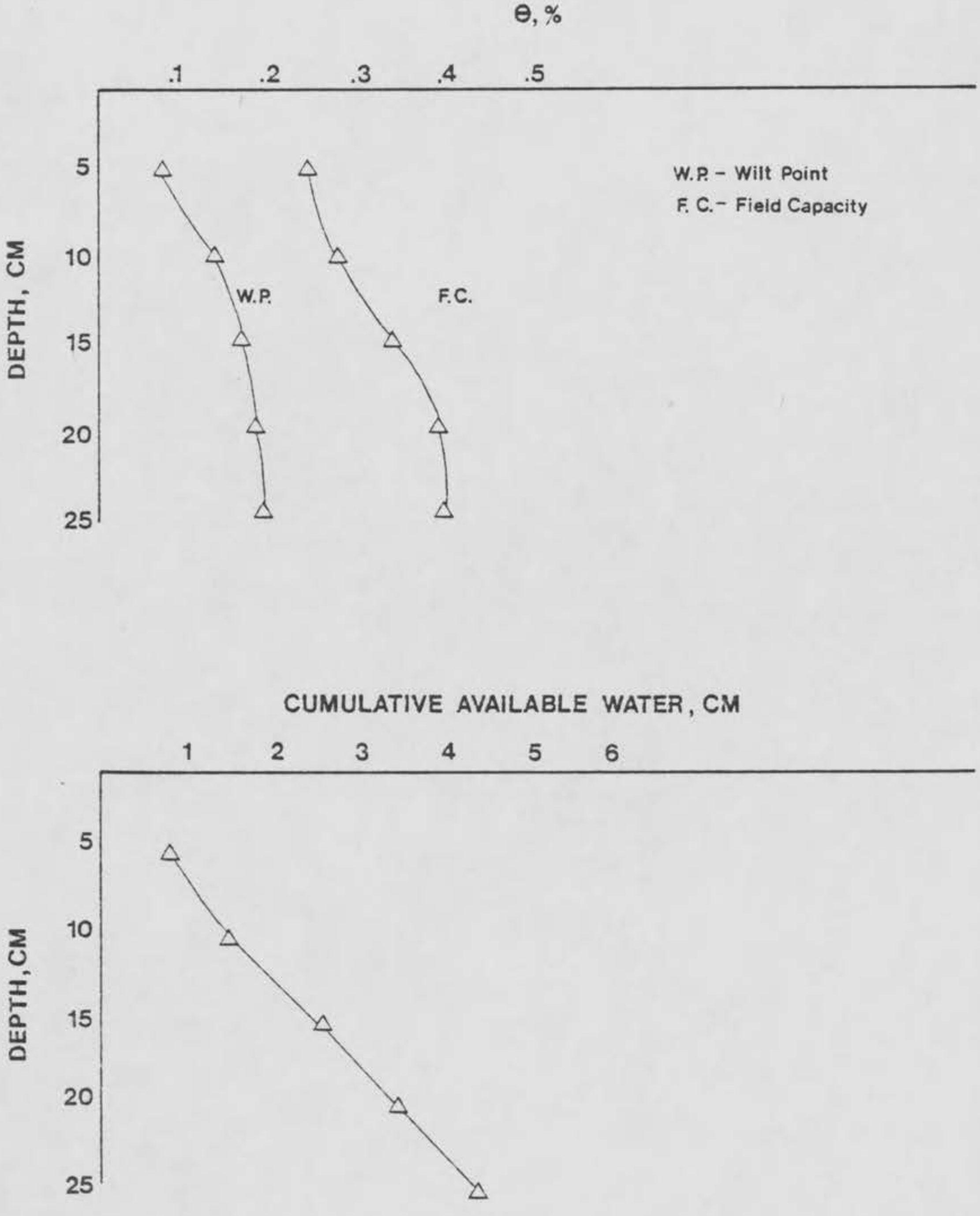


Figure 13. Water content and cumulative available water with depth for the peat, sand and soil mixture under field conditions

TABLE 10. Matrix potential and water content with depth at the wilt point, water content with depth at field capacity and the date of wilting for each soil mixture under field conditions.

	Depth (cm)	Water Content Field Capacity (%)	Water Content Wilt Point (%)	Matrix Potential Wilt Point (cm)	Wilt Date
Bark and sand	5	25	6	-574.44	June 20
	10	26	11	-298.78	
	15	31	16	-28.97	
	20	36	20	-17.28	
	25	36	20	-13.95	
Bark, sand and soil	5	24	5	-184.13	June 23
	10	30	8	-148.60	
	15	36	15	-84.61	
	20	40	19	-41.13	
	25	40	19	-26.08	
Peat and sand	5	25	13	-205.30	June 22
	10	29	15	-65.18	
	15	37	15	-50.14	
	20	50	17	-43.05	
	25	50	17	-39.31	
Peat, sand and soil	5	24	8	-417.97	June 22
	10	27	14	-126.41	
	15	34	16	-74.14	
	20	38	18	-46.55	
	25	38	17	-39.46	

water from the bark and sand mixture which is a good indication that the top 10 cm is extremely compacted. From 15 to 25 cm the matrix potential readings are greater in the BSS, but the differences are small compared to those seen in the upper 10 cm. Perhaps the addition of the soil to the bark and sand mixture improved the soil structure which provided better pore space continuity and enhanced the upward capillary movement of water from the lower 15 cm.

Table 10 indicates that the BS mixture wilted three days before the BSS which was due to less available water in the mixture. However, matrix potential readings (Table 6) indicate that both bark mixtures are saturated just below the 15 cm depth when field capacity was reached. Previous research (2) has shown that root growth and development is severely restricted in anaerobic conditions. Due to constant irrigation of putting greens, the lower 10 cm of the mixtures are frequently saturated which would inhibit rooting in the lower depths. However, comparison of water content measurements (Table 10) at field capacity and the wilt point indicate that some of the water in the lower depths is being utilized by the grass plants. In the BS mixture (Table 10), it appears that 16% of the water is being used, while the BSS mixture provides 21% water for utilization. If rooting is minimal in these depths (20-25 cm), the water must be moving into the root zone by capillary action. Due to the infrequency of tensiometer readings taken between field capacity and the wilt point, which was an oversight in experimental procedure, capillarity with depth could not be quantified. However from Figure 8 it can be seen that the upward movement of water for both bark mixtures at water contents as low as 20% was 0.008 cm/min. This upward movement is equivalent to 4.54 inches of water in a 24 hour period, and indicates that the capillary movement of water is not insignificant.

Comparison of Figures 12 and 13 indicates that the water content with depth at the wilt point is essentially the same for both peat mixtures from 10 to 25 cm. However, at 5 cm the water content was 13% in the PS mixture and 8% in the PSS. The water content with depth at field capacity (Fig. 12 and 13) was found to be much greater in the peat mixture without soil. Through the upper 15 cm of the mixtures, the water contents are relatively equal, but as depth increased to 20 and 25 cm, the water content was found to increase from 38 to 50% in the peat mixture without soil. The increased water content in the lower depths of the PS mixture is due to the increased total porosity at field capacity. The matrix potential readings at field capacity (Table 6) indicated that both peat mixtures were saturated at the 20 and 25 cm depth. Therefore, the increased porosity of the PS mixture provided much more water for plant utilization.

Comparison of the cumulative available water curves (Fig. 12 and 13) shows that the PS mixture provided 5.7 cm of water for bentgrass utilization while the PSS mixture provided 4.4 cm. However, the bentgrass wilted on the same day for each mixture which suggests that the water utilization was faster with the PS mixture. However, Table 10 indicates that at the wilt point the water content was 5% greater at the 5 cm depth. Considering the water contents at wilting for the other mixtures at the 5 cm depth, it appears that the soil samples may have been taken prematurely, and the PS mixture could have withstood an additional day of drying before sampling.

Comparison of the matrix potential readings with depth (Table 10) indicates that the PS mixture is more resistant to compaction than the PSS mixture. The tensions in the upper 15 cm are much greater for the PSS which suggests the soil fraction has filled the noncapillary pores of the mixture. However, the matrix potential readings were very similar in the lower 10 cm of both mixtures which suggests that compaction becomes less severe as depth increases. It appears that compaction from traffic is more severe in the upper 10 cm of putting greens.

Comparison of water content measurements (Table 10) at field capacity and the wilt point indicate that 33% of the water found in the lower depths was used by the bentgrass grown in the PS mixture, but only 20% is utilized in the PSS. Figure 8 shows the capillary movement of water in the peat mixtures. At water contents as low as 20%, the upward movement of water was found to be 0.006 cm/min in the PS (Fig. 8) and 0.019 cm/min in the PSS mixture. It appears the addition of soil increases capillarity but reduces the total water content and porosity of the peat mixtures.

SUMMARY AND CONCLUSIONS

A 70% sand, 30% peat mixture provided adequate establishment while maintaining excellent porosity and hydraulic properties. After 1 year under field conditions, the PS mixture proved to be the best of the four mixtures. The PS mixture was found to have excellent drainage while maintaining the highest available water content which indicates compaction was minimal.

The addition of soil to the PS mixture improved establishment, but total porosity and available water for plant utilization were sacrificed. The porosity and water holding capacity of the peat mixture was found to be equal to or greater than that with soil. The addition of soil to the PS reduced matrix potentials from 10-25 cm which enhanced the capillary movement of water. After 1 year the PS mixture was found to be more compacted when soil was added.

The addition of soil was beneficial to the BS mixture and detrimental to the PS. Soil enhanced establishment and increased the water content with depth in the BSS mixture while sustaining pore space uniformity. The BSS mixture which was found to have greater total porosity and more available water was less compacted than the BS mixture. Consequently, the uptake of water by the plant and the upward movement of water by capillarity to the root zone was enhanced. When added to the PS mixture, soil increased the bulk density, reduced the total porosity and decreased the water content with depth.

A 70% sand, 30% bark mixture was not as effective as the other putting green mixtures. After 1 year in the field the BS mixture was found to have higher bulk densities, less total pore space and less available water for plant use. Consequently, the BS mixture was more difficult to establish and wilted sooner than the other mixtures while showing indications of phytotoxicity.

The data from this study indicated that the differences between the physical properties of the 4 mixtures is very small. However, great differences were observed with respect to establishment, which was assumed to be due to the phytotoxicity of the bark. The addition of soil to the BS was helpful, but both bark mixtures proved to be undesirable due to poor establishment.

APPENDIX

TABLE A-1. Matrix potential (ψm), water content (θ) and total gradient (ψT) with depth and time for the bark and sand mixture under laboratory conditions

		Reps								
		A			B			C		
Time (min)	Depth (cm)	ψm (cm)	θ (%)	ψT (cm)	ψm (cm)	θ (%)	ψT (cm)	ψm (cm)	θ (%)	ψT (cm)
0	5	2.98	.50	-2.02	15.22	.50	10.72	3.93	.50	-1.07
	10	6.72	.50	-3.28	2.66	.50	-7.34	8.93	.50	-1.07
	15	10.46	.50	-4.54	7.66	.50	-7.34	13.93	.50	-1.07
	20	15.46	.50	-5.46	12.66	.50	-7.34	18.93	.50	-1.07
	25	20.46	.50	-4.54	18.91	.50	-6.09	23.93	.50	-1.07
4	5	-3.30	.32	-8.30	-3.60	.32	-8.60	-2.34	.35	-7.34
	10	-2.06	.36	-12.06	-1.11	.41	-11.11	-2.36	.35	-12.36
	15	0.42	.50	-14.58	2.64	.50	-12.36	1.38	.50	-13.62
	20	2.92	.50	-17.08	6.38	.50	-13.62	5.12	.50	-14.88
	25	7.92	.50	-17.08	11.38	.50	-13.62	8.87	.50	-16.13
8	5	-4.55	.31	-9.55	-3.60	.32	-8.60	-3.60	.32	-8.60
	10	-2.06	.36	-12.06	-2.36	.35	-12.36	-2.36	.35	-12.36
	15	-0.83	.42	-15.83	1.38	.50	-13.62	1.38	.50	-13.62
	20	2.92	.50	-17.08	5.12	.50	-14.88	5.12	.50	-14.88
	25	6.66	.50	-18.34	10.12	.50	-14.88	10.12	.50	-14.88
12	5	-5.81	.31	-10.81	-4.86	.31	-9.86	-4.86	.31	-9.86
	10	-3.32	.33	-13.32	-3.62	.32	-13.62	-3.62	.32	-13.62
	15	-2.08	.36	-17.08	1.38	.50	-13.62	1.38	.50	-13.62
	20	1.66	.50	-18.34	3.87	.50	-16.13	5.12	.50	-14.88
	25	6.66	.50	-18.34	8.87	.50	-16.13	10.12	.50	-14.88

TABLE A-1--Continued

		Reps								
		A			B			C		
Time (min)	Depth (cm)	ψm (cm)	θ (%)	ψT (cm)	ψm (cm)	θ (%)	ψT (cm)	ψm (cm)	θ (%)	ψT (cm)
16	5	-5.81	.31	-10.81	-4.86	.31	-9.86	-6.11	.31	-11.11
	10	-4.58	.31	-14.58	-3.62	.32	-13.62	-4.88	.31	-14.88
	15	-2.08	.36	-17.08	1.38	.50	-13.62	0.12	.50	-14.88
	20	1.66	.50	-18.34	3.87	.50	-15.13	3.87	.50	-15.13
	25	6.66	.50	-18.34	8.87	.50	-16.13	8.87	.50	-15.13
30	5	-7.06	.30	-12.06	-7.36	.31	-12.36	-6.11	.31	-11.11
	10	-4.58	.31	-14.58	-6.13	.31	-16.13	-3.62	.32	-13.62
	15	-2.08	.36	-17.08	-1.13	.49	-16.13	0.12	.50	-14.88
	20	2.92	.50	-17.08	2.62	.50	-17.38	5.12	.50	-14.88
	25	7.92	.50	-17.08	7.62	.50	-17.38	10.12	.50	-14.88
45	5	-8.32	.30	-13.32	-6.11	.31	-11.11	-7.36	.30	-12.36
	10	-5.83	.31	-15.83	-4.88	.31	-14.88	-4.88	.31	-14.88
	15	-2.08	.36	-17.08	0.12	.50	-14.88	-1.13	.48	-16.13
	20	2.92	.50	-17.08	3.87	.50	-16.13	3.87	.50	-16.13
	25	7.92	.50	-17.08	8.87	.50	-16.13	8.87	.50	-16.13
60	5	-9.58	.30	-14.58	-6.11	.31	-11.11	-8.62	.30	-11.62
	10	-5.83	.31	-15,83	-4.88	.31	-14.88	-4.88	.31	-14.88
	15	-2.08	.36	-17,08	0.12	.50	-14,88	-1.13	.48	-16.13
	20	2.92	.50	-17.08	3.87	.50	-16.13	3.87	.50	-16.13
	25	6.66	.50	-18.34	8.87	.50	-16.13	8.87	.50	-16.13
360	5				-9.88	.30	-14.88			
	10				-6,13	.31	-16.13			
	15				-1,13	.49	-16.13			
	20				3,87	.50	-16.13			
	25				8.87	.50	-16.13			

TABLE A-1--Continued

		Reps								
		A			B			C		
Time (min)	Depth (cm)	ψm (cm)	θ (%)	ψT (cm)	ψm (cm)	θ (%)	ψT (cm)	ψm (cm)	θ (%)	ψT (cm)
450	5				-9.88	.30	-14.88			
	10				-6.13	.31	-16.13			
	15				-1.13	.49	-16.13			
	20				3.87	.50	-16.13			
	25				8.87	.50	-16.13			
690	5							-9.88	.29	-13.88
	10							-6.13	.31	-16.13
	15							-1.13	.48	-16.13
	20							3.87	.50	-16.13
	25							8.87	.50	-16.13
750	5	-13.34	.29	-18.34						
	10	-8.34	.30	-18.34						
	15	-3.34	.32	-18.34						
	20	1.66	.50	-18.34						
	25	6.66	.50	-18.34						
990	5	-13.34	.29	-18.34						
	10	-8.34	.30	-18.34						
	15	-3.34	.32	-18.34						
	20	1.66	.50	-18.34						
	25	6.66	.50	-18.34						
1080	5				-11.13	.29	-16.13			
	10				-7.38	.30	-17.38			
	15				-2.38	.35	-17.38			
	20				2.62	.50	-17.38			
	25				7.62	.50	-17.38			

TABLE A-1--Continued

Time (min)	Depth (cm)	Reps A ψm (cm)	Reps A θ (%)	Reps A ψT (cm)	Reps B ψm (cm)	Reps B θ (%)	Reps B ψT (cm)	Reps C ψm (cm)	Reps C θ (%)	Reps C ψT (cm)
1110	5							-11.13	.29	-16.13
	10							-6.13	.31	-16.13
	15							-1.13	.48	-16.13
	20							3.87	.50	-16.13
	25							8.87	.50	-16.13
1440	5							-12.38	.29	-17.38
	10							-7.38	.30	-17.38
	15							-2.38	.35	-17.38
	20							2.62	.50	-17.38
	25							7.62	.50	-17.38
1500	5				-12.38	.29	-17.38			
	10				-7.38	.30	-17.38			
	15				-2.38	.35	-17.38			
	20				2.62	.50	-17.38			
	25				7.62	.50	-17.38			
1590	5				-12.38	.29	-17.38			
	10				-7,38	.30	-17.38			
	15				-2,38	.35	-17.38			
	20				2.62	.50	-17.38			
	25				7,62	.50	-17.38			

TABLE A-2. Matrix potential (ψm), water content (θ) and total gradient (ψT) with depth and time for the bark, sand and soil mixture under laboratory conditions

		Reps								
		A			B			C		
Time (min)	Depth (cm)	ψm (cm)	θ (%)	ψT (cm)	ψm (cm)	θ (%)	ψT (cm)	ψm (cm)	θ (%)	ψT (cm)
0	5	12.02	.42	7.02	2.02	.42	-2.98	6.94	.42	1.94
	10	11.99	.42	1.99	8.28	.42	-1.72	11.94	.42	1.94
	15	16.99	.42	1.99	10.76	.42	-4.24	16.94	.42	1.94
	20	20.74	.42	0.74	14.51	.42	-5.49	21.94	.42	1.94
	25	25.74	.42	0.74	20.76	.42	-4.24	26.94	.42	1.94
4	5	-1.79	.36	-6.79	-1.74	.36	-6.74	0.66	.42	-4.34
	10	-0.56	.38	-10.56	-1.76	.36	-11.76	3.16	.42	-6.84
	15	3.19	.42	-11.81	0.72	.42	-14.28	4.39	.42	-10.61
	20	5.68	.42	-14.32	4.47	.42	-15.53	8.14	.42	-11.86
	25	9.42	.42	-15.58	9.47	.42	-15.53	13.14	.42	-11.86
8	5	-4.30	.33	-9.30	-4.26	.33	-9.26	-0.59	.38	-5.59
	10	-1.81	.36	-11.81	-3.02	.35	-13.02	1.90	.42	-8.10
	15	1.94	.42	-13.06	-0.53	.39	-15.53	1.88	.42	-13.12
	20	5.68	.42	-14.32	4.47	.42	-15.53	6.88	.42	-13.12
	25	9.42	.42	-15.58	8.22	.42	-16.78	11.88	.42	-13.12
12	5	-4.30	.33	-9.30	-3.00	.35	-8.00	-1.84	.36	-6.84
	10	-1.81	.36	-11.81	-1.76	.36	-11.76	0.64	.42	-9.46
	15	1.94	.42	-13.06	-0.53	.39	-15.53	1.88	.42	-13.12
	20	5.68	.42	-14.32	4.47	.42	-15.53	6.88	.42	-13.12
	25	9.42	.42	-15.58	8.22	.42	-16.78	11.88	.42	-13.12

TABLE A-2--Continued

		Reps								
		A			B			C		
Time (min)	Depth (cm)	ψ_m (cm)	θ (%)	ψ_T (cm)	ψ_m (cm)	θ (%)	ψ_T (cm)	ψ_m (cm)	θ (%)	ψ_T (cm)
16	5	-5.56	.31	-10.56	-4.26	.33	-9.26	-0.59	.38	-5.59
	10	-3.06	.35	-13.06	-1.76	.36	-11.76	1.90	.42	-8.10
	15	0.68	.42	-14.32	-0.53	.39	-15.53	3.14	.42	-11.86
	20	5.68	.42	-14.32	4.47	.42	-15.53	8.14	.42	-11.86
	25	9.42	.42	-15.58	8.22	.42	-16.78	13.14	.42	-11.86
30	5	-5.56	.31	-10.56	-4.26	.33	-9.26	-0.59	.38	-5.59
	10	-3.06	.35	-13.06	-1.76	.36	-11.76	1.90	.42	-8.10
	15	0.68	.42	-14.32	-1.78	.36	-16.78	3.14	.42	-11.86
	20	5.68	.42	-14.32	3.22	.42	-16.78	8.14	.42	-11.86
	25	9.42	.42	-15.58	3.22	.42	-16.78	13.14	.42	-11.86
45	5	-6.81	.30	-11.81	-5.51	.31	-10.51	-3.10	.35	-8.10
	10	-4.32	.33	-14.32	-4.28	.33	-14.28	-0.61	.38	-10.61
	15	0.68	.42	-14.32	-1.78	.36	-16.78	0.62	.42	-14.38
	20	4.42	.42	-15.58	3.22	.42	-16.78	5.62	.42	-14.38
	25	9.42	.42	-15.58	8.22	.42	-16.78	11.88	.42	-13.12
60	5	-6.81	.30	-11.81	-5.51	.31	-10.51	-3.10	.35	-8.10
	10	-4.32	.33	-14.32	-4.28	.33	-14.28	-0.61	.38	-10.61
	15	0.68	.42	-14.32	-1.78	.36	-16.78	1.88	.42	-13.12
	20	4.42	.42	-15.58	3.22	.42	-16.78	5.62	.42	-14.38
	25	9.42	.42	-15.58	8.22	.42	-16.78	11.88	.42	-13.12
150	5	-8.06	.28	-13.06						
	10	-4.32	.33	-14.32						
	15	0.68	.42	-14.32						
	20	4.42	.42	-15.58						
	25	9.42	.42	-15.58						

TABLE A-2--Continued

		Reps								
		A			B			C		
Time (min)	Depth (cm)	ψm (cm)	θ (%)	ψT (cm)	ψm (cm)	θ (%)	ψT (cm)	ψm (cm)	θ (%)	ψT (cm)
360	5				-8.02	.28	-13.02			
	10				-5.53	.31	-15.53			
	15				-1.78	.36	-16.78			
	20				3.22	.42	-16.78			
	25				8.22	.42	-16.78			
450	5				-9.28	.26	-14.28			
	10				-6.78	.30	-16.78			
	15				-3.04	.35	-18.04			
	20				1.96	.42	-18.04			
	25				6.96	.42	-18.04			
690	5							-5.61	.31	-10.61
	10							-1.86	.36	-11.86
								1.88	.42	-13.12
								5.62	.42	-14.38
								10.62	.42	-14.38
1080	5				-10.53	.25	-15.53			
	10				-6.78	.30	-16.78			
	15				-3.04	.35	-18.04			
	20				1.96	.42	-18.04			
	25				6.96	.42	-18.04			
1110	5							-6.86	.30	-11,86
	10							-3,12	.35	-13.12
	15							-0,63	.38	-15.63
	20							4.37	.42	-15.63
	25							9.37	.42	-15,63

TABLE A-2--Continued

Time (min)	Depth (cm)	A ψm (cm)	A θ (%)	A ψT (cm)	B ψm (cm)	B θ (%)	B ψT (cm)	C ψm (cm)	C θ (%)	C ψT (cm)
1500	5				-11.78	.23	-16.78			
	10				-6.78	.30	-16.78			
	15				-1.78	.36	-16.78			
	20				1.96	.42	-18.04			
	25				6.96	.42	-18.04			
1650	5	-10.58	.24	-15.58						
	10	-6.83	.30	-16.83						
	15	-0.58	.35	-15.58						
	20	4.42	.42	-15.58						
	25	9.42	.42	-15.58						
2130	5							-8.12	.20	-13.12
	10							-4.38	.33	-14.38
	15							-0.62	.38	-15.62
	20							5.62	.42	-14.38
	25							10.62	.42	14.38
2550	5							-9.38	.26	-14.38
	10							-4.38	.33	-14.38
	15							-0.63	.38	-15.63
	20							4.37	.42	-15.63
	25							9.37	.42	-15.63

TABLE A-3. Matrix potential (ψm), water content (θ) and total gradient (ψT) with depth and time for the peat and sand mixture under laboratory conditions

		Reps								
		A			B			C		
Time (min)	Depth (cm)	ψm (cm)	θ (%)	ψT (cm)	ψm (cm)	θ (%)	ψT (cm)	ψm (cm)	θ (%)	ψT (cm)
0	5	0.16	.55	-4.84	2.88	.55	-2.12	-2.18	.47	-7.18
	10	3.91	.55	-6.09	7.88	.55	-2.12	2.82	.55	-7.18
	15	6.40	.55	-8.60	10.36	.55	-4.64	10.92	.55	-4.08
	20	11.40	.55	-8.60	16.62	.55	-3.38	15.92	.55	-4.08
	25	16.40	.55	-8.60	22.88	.55	-2.12	20.92	.55	-4.08
4	5	-4.86	.44	-9.86	-4.66	.44	-9.66	-4.10	.44	-9.10
	10	-3.62	.45	-13.62	-2.16	.47	-12.16	-2.86	.46	-12.86
	15	-1.13	.48	-16.13	1.58	.55	-13.42	0.88	.55	-14.12
	20	2.62	.55	-17.38	6.58	.55	-13.42	4.62	.55	-15.38
	25	7.62	.55	-17.38	10.32	.55	-14.68	9.62	.55	-15.38
8	5	-7.36	.41	-12.36	-5.91	.42	-10.91	-6.61	.42	-11.61
	10	-3.62	.45	-13.62	-3.42	.45	-13.42	-2.86	.46	-12.86
	15	-1.13	.48	-16.13	0.32	.55	-14.68	0.88	.55	-14.12
	20	1.36	.55	-18.64	6.58	.55	-13.42	4.62	.55	-15.38
	25	6.36	.55	-18.64	9.07	.55	-15.93	9.62	.55	-15.38
12	5	-8.62	.39	-13.62	-7.16	.41	-12.16	-6.61	.42	-11.61
	10	-3.62	.45	-13.62	-4.68	.44	-14.68	-4.20	.44	-14.20
	15	-1.13	.48	-16.13	-0.93	.49	-15.93	-0.38	.51	-15.38
	20	1.36	.55	-18.64	5.32	.55	-14.68	4.62	.55	-15.38
	25	6.38	.55	-18.62	9.07	.55	-15.93	9.62	.55	-15.38

TABLE A-3--Continued

Time (min)	Depth (cm)	A ψm (cm)	A θ (%)	A ψT (cm)	B ψm (cm)	B θ (%)	B ψT (cm)	C ψm (cm)	C θ ()	C ψT (cm)
16	5	-8.62	.40	-13.62	-7.16	.41	-12.16	-7.86	.40	-12.86
	10	-3.62	.45	-13.62	-3.42	.45	-13.42	-4.20	.44	-14.20
	15	-1.13	.48	-16.13	0.32	.55	-14.68	-0.38	.51	-15.38
	20	1.36	.55	-18.64	6.58	.55	-13.42	3.37	.55	-16.63
	25	6.36	.55	-18.64	10.32	.55	-14.68	8.37	.55	-16.63
30	5	-9.88	.38	-14.88	-7.16	.41	-12.16	-9.12	.39	-14.12
	10	-3.62	.45	-13.62	-3.42	.45	-13.42	-5.38	.43	-15.38
	15	-1.13	.48	-16.13	1.58	.55	-13.42	-1.63	.48	-16.63
	20	1.36	.55	-18.64	7.84	.55	-12.16	3.37	.55	-16.63
	25	6.36	.55	-18.64	11.58	.55	-13.42	8.37	.55	-16.63
45	5	-11.13	.37	-16.13	-8.42	.40	-13.42	-9.12	.39	-14.12
	10	-9.90	.38	-19.90	-4.68	.44	-14.68	-5.38	.43	-15.38
	15	-3.64	.45	-18.64	0.32	.55	-14.68	-1.63	.48	-16.63
	20	1.36	.55	-18.64	5.32	.55	-14.68	3.37	.55	-16.63
	25	6.36	.55	-18.64	10.32	.55	-14.68	8.37	.55	-16.63
60	5	-11.13	.37	-16.13	-9.68	.38	-14.68	-10.38	.38	-15.38
	10	-9.90	.38	-19.90	-4.68	.44	-14.68	-6.63	.42	-16.63
	15	-3.64	.45	-18.64	-0.93	.49	-15.93	-1.63	.48	-16.63
	20	1.36	.55	-18.64	4.07	.55	-15.93	2.12	.55	-17.88
	25	6.36	.55	-18.64	10.32	.55	-14.68	7.12	.55	-17.88
360	5				-9.68	.39	-14.68			
	10				-4.68	.44	-14.68			
	15				0.32	.55	-14.68			
	20				5.32	.55	-14.68			
	25				10.32	.55	-14.68			

TABLE A-3--Continued

		Reps								
		A			B			C		
Time (min)	Depth (cm)	ψm (cm)	θ (%)	ψT (cm)	ψm (cm)	θ (%)	ψT (cm)	ψm (cm)	θ (%)	ψT (cm)
450	5				-10.93	.37	-15.93			
	10				-5.93	.42	-15.93			
	15				-0.93	.49	-15.93			
	20				4.07	.55	-15.93			
	25				9.07	.55	-15.93			
630	5	-13.64	.34	-18.64				-11.63	.36	-16.63
	10	-8.64	.40	-18.64				-6.63	.42	-16.63
	15	-3.64	.45	-18.64				-1.63	.48	-16.63
	20	1.36	.55	-18.64				3.37	.55	-16.63
	25	6.36	.55	-18.64				8.37	.55	-16.63
930	5	-13.64	.34	-18.64						
	10	-8.64	.40	-18.64						
	15	-3.64	.45	-18.64						
	20	1.36	.55	-18.64						
	25	6.38	.55	-18.64						
1050	5				-10.93	.37	-15.93	-11.63	.36	-16.63
	10				-5.93	.42	-15.93	-6.63	.42	-16.63
	15				-0.93	.49	-15.93	-1.63	.48	-16.63
	20				4.07	.55	-15.93	3.37	.55	-16.63
	25				9.07	.55	-15.93	8.37	.55	-16.63
1500	5				-12.18	.36	-17.18			
	10				-7.18	.41	-17.18			
	15				-2.18	.46	-17.18			
	20				2.82	.55	-17.18			
	25				7.82	.55	-17.18			

TABLE A-4. Matrix potential (ψm), water content (θ) and total gradient (ψT) with depth and time for the peat, sand and soil mixture under laboratory conditions

		Reps								
		A			B			C		
Time (min)	Depth (cm)	ψm (cm)	θ (%)	ψT (cm)	ψm (cm)	θ (%)	ψT (cm)	ψm (cm)	θ (%)	ψT (cm)
0	5	2.58	.50	-2.42	6.94	.50	1.94	2.48	.50	-2.52
	10	6.32	.50	-3.68	10.68	.50	0.68	7.48	.50	-2.52
	15	11.32	.50	-3.68	14.43	.50	-0.57	12.48	.50	-2.52
	20	16.32	.50	-3.68	16.92	.50	-3.08	16.22	.50	-3.78
	25	21.32	.50	-3.68	21.92	.50	-3.08	21.22	.50	-3.78
4	5	-2.44	.36	-7.44	-1.84	.37	-6.84	-3.80	.35	-5.80
	10	-2.46	.35	-12.46	1.90	.50	-8.10	-2.56	.36	-12.56
	15	1.28	.50	-13.72	3.14	.50	-11.86	-0.08	.48	-15.08
	20	6.28	.50	-13.72	6.88	.50	-13.12	3.67	.50	-16.33
	25	8.77	.50	-16.23	11.88	.50	-13.12	8.67	.50	-16.33
8	5	-3.70	.35	-8.70	-3.10	.35	-8.10	-5.06	.34	-10.06
	10	-4.98	.34	-14.98	0.64	.50	-9.36	-3.82	.35	-13.82
	15	0.02	.50	-14.98	1.88	.50	-13.12	-0.08	.48	-15.08
	20	5.02	.50	-14.98	6.88	.50	-13.12	4.92	.50	-15.08
	25	8.77	.50	-16.23	11.88	.50	-13.12	9.92	.50	-15.08
12	5	-4.96	.34	-9.96	-3.10	.35	-8.10	-6.31	.34	-11.31
	10	-4.98	.34	-14.98	-0.61	.42	-10.61	-5.08	.34	-15.08
	15	0.02	.50	-14.98	1.88	.50	-13.12	-1.33	.38	-16.33
	20	5.02	.50	-14.98	6.88	.50	-13.12	3.67	.50	-16.33
	25	8.77	.50	-16.23	11.88	.50	-13.12	8.67	.50	-16.33

TABLE A-4--Continued

Time (min)	Depth (cm)	A ψm (cm)	A θ (%)	A ψT (cm)	B ψm (cm)	B θ (%)	B ψT (cm)	C ψm (cm)	C θ (%)	C ψT (cm)
16	5	-6.21	.34	-11.21	-3.10	.35	-8.10	-6.31	.34	-11.31
	10	-4.98	.34	-14.98	-0.61	.42	-10.61	-5.08	.34	-15.08
	15	0.02	.50	-14.98	1.88	.50	-13.12	-1.33	.38	-16.33
	20	5.02	.50	-14.98	6.88	.50	-13.12	3.67	.50	-16.33
	25	8.77	.50	-16.23	11.88	.50	-13.12	8.67	.50	-16.33
30	5	-7.46	.33	-12.46	-4.36	.35	-9.36	-7.56	.33	-12.56
	10	-6.23	.33	-16.23	-1.86	.37	-10.86	-5.08	.34	-15.08
	15	-1.23	.38	-16.23	1.88	.50	-13.12	-2.58	.36	-17.58
	20	3.77	.50	-16.23	6.88	.50	-13.12	2.42	.50	-17.58
	25	8.77	.50	-16.23	11.88	.50	-13.12	8.67	.50	-16.33
45	5	-7.46	.33	-12.46	-5.61	.34	-10.61	-8.82	.32	-13.82
	10	-7.48	.33	-17.48	-1.86	.37	-11.86	-5.08	.34	-15.08
	15	-2.48	.36	-17.48	1.88	.50	-13.12	-2.58	.36	-17.58
	20	2.52	.50	-17.48	6.88	.50	-13.12	2.42	.50	-17.58
	25	8.77	.50	-16.23	11.88	.50	-13.12	8.67	.50	-16.33
60	5	-9.98	.31	-14.98	-6.86	.33	-11.86	-8.82	.32	-13.82
	10	-7.48	.33	-17.48	-3.12	.35	-13.12	-5.08	.34	-15.08
	15	-2.48	.36	-17.48	0.62	.50	-14.38	-2.58	.36	-17.58
	20	2.52	.50	-17.48	5.62	.50	-14.38	2.42	.50	-17.58
	25	8.77	.50	-16.23	10.62	.50	-14.38	8.67	.50	-16.33
360	5				-8.12	.32	-13.12			
	10				-3.12	.35	-13.12			
	15				0.62	.50	-14.38			
	20				5.62	.50	-14.38			
	25				10.62	.50	-14.38			

TABLE A-4--Continued

Time (min)	Depth (cm)	Reps A ψm (cm)	A θ (%)	A ψT (cm)	B ψm (cm)	B θ (%)	B ψT (cm)	C ψm (cm)	C θ (%)	C ψT (cm)
450	5				-9.38	.32	-14.38			
	10				-4.38	.35	-14.38			
	15				-0.63	.42	-15.63			
	20				4.37	.50	-15.63			
	25				9.37	.50	-15.63			
690	5	-12.48	.30	-17.48				-12.58	.30	-17.58
	10	-7.48	.33	-17.48				-7.58	.33	-17.58
	15	-2.48	.36	-17.48				-2.58	.36	-17.58
	20	2.52	.50	-17.48				2.42	.50	-17.58
	25	8.77	.50	-16.23				7.42	.50	-17.58
1050	5				-10.63	.31	-15.63			
	10				-5.63	.34	-15.63			
	15				1.63	.37	-16.63			
	20				4.37	.50	-15.63			
	25				9.37	.50	-15.63			
1110	5							-12.58	.30	-17.58
	10							-8.84	.32	-18.84
	15							-2.58	.36	-17.58
	20							2.42	.50	-17.58
	25							7.42	.50	-17.58

TABLE A-5. Matrix potential (ψm), water content (θ) and total gradient (ψT) with depth and time for the bark and sand mixture under field conditions

		Reps								
		A			B			C		
Time (min)	Depth (cm)	ψm (cm)	θ (%)	ψT (cm)	ψm (cm)	θ (%)	ψT (cm)	ψm (cm)	θ (%)	ψT (cm)
0	5	14.62	.36	9.62	12.28	.36	7.28	5.52	.36	0.52
	10	18.37	.36	8.37	18.54	.36	8.54	11.78	.36	1.78
	15	24.62	.36	9.62	22.28	.36	7.28	11.76	.36	-3.24
	20	29.62	.36	9.62	27.28	.36	7.28	16.76	.36	-3.24
	25	33.37	.36	8.37	32.28	.36	7.28	38.07	.36	13.07
4	5	-7.96	.22	-12.96	-5.29	.25	-10.29	-2.01	.30	-7.01
	10	-4.22	.26	-14.22	-1.54	.31	-11.54	1.74	.36	-8.26
	15	0.78	.36	-14.22	2.20	.36	-12.80	6.74	.36	-8.26
	20	0.76	.36	-19.24	8.46	.36	-11.54	11.74	.36	-8.26
	25	8.27	.36	-16.73	13.46	.36	-11.54	16.74	.36	-8.26
8	5	-6.71	.24	-11.71	-5.29	.25	-10.29	-2.01	.30	-7.01
	10	-4.22	.26	-14.22	-2.80	.28	-12.80	1.74	.36	-8.26
	15	-1.73	.29	-16.73	0.94	.36	-14.06	0.80	.36	-14.20
	20	0.76	.36	-19.24	5.94	.36	-14.06	5.80	.36	-14.20
	25	7.02	.36	-17.98	12.20	.36	-12.80	5.80	.36	-14.20
12	5	-7.96	.22	-12.96	-6.54	.24	-11.54	-3.26	.28	-8.26
	10	-5.48	.25	-15.48	-4.06	.27	-14.06	-5.80	.25	-15.80
	15	-2.98	.28	-17.98	-0.31	.34	-15.31	-2.05	.30	-17.05
	20	0.76	.36	-19.24	4.69	.36	-15.31	2.95	.36	-17.05
	25	7.02	.36	-17.98	9.69	.36	-15.31	7.95	.36	-17.05

TABLE A-5--Continued

		Reps								
		A			B			C		
Time (min)	Depth (cm)	ψm (cm)	θ (%)	ψT (cm)	ψm (cm)	θ (%)	ψT (cm)	ψm (cm)	θ (%)	ψT (cm)
16	5	-7.96	.22	-12.96	-6.54	.24	-11.54	-9.54	.22	-14.54
	10	-5.48	.25	-15.48	-4.06	.27	-14.06	-7.05	.24	-17.05
	15	-2.98	.28	-17.98	-0.31	.34	-15.31	-3.30	.28	-18.30
	20	2.02	.36	-17.98	4.69	.36	-15.31	1.70	.36	-18.30
	25	7.02	.36	-17.98	9.69	.36	-15.31	6.70	.36	-18.30
30	5	-10.48	.21	-15.48	-7.80	.23	-12.80	-10.80	.21	-15.80
	10	-7.98	.23	-17.98	-4.06	.27	-14.06	-7.05	.24	-17.05
	15	-4.24	.27	-19.24	-0.31	.34	-15.31	-2.05	.30	-17.05
	20	0.76	.36	-19.24	4.69	.36	-15.31	1.70	.36	-18.30
	25	5.76	.36	-19.24	9.69	.36	-15.31	6.70	.36	-18.30
45	5	-10.48	.21	-15.48	-7.80	.23	-12.80	-12.05	.20	-17.05
	10	-6.73	.24	-16.73	-4.06	.27	-14.06	-7.05	.24	-17.05
	15	-4.24	.27	-19.24	-0.31	.34	-15.31	-3.30	.28	-18.30
	20	0.76	.36	-19.24	4.69	.36	-15.31	1.70	.36	-18.30
	25	5.76	.36	-19.24	9.69	.36	-15.31	6.70	.36	-18.30
60	5	-11.73	.21	-16.73	-9.06	.22	-14.06	-12.05	.20	-17.05
	10	-7.98	.23	-17.98	-5.31	.25	-15.31	-8.30	.22	-18.30
	15	-4.24	.27	-19.24	-1.56	.30	-16.56	-3.30	.28	-18.30
	20	0.76	.36	-19.24	4.69	.36	-15.31	1.70	.36	-18.30
	25	5.76	.36	-19.24	9.69	.36	-15.31	6.70	.36	-18.30

TABLE A-6. Matrix potential (ψm), water content (θ) and total gradient (ψT) with depth and time for the bark, sand and soil mixture under field conditions

		Reps								
		A			B			C		
Time (min)	Depth (cm)	ψm (cm)	θ (%)	ψT (cm)	ψm (cm)	θ (%)	ψT (cm)	ψm (cm)	θ (%)	ψT (cm)
0	5	13.94	.40	8.94	13.77	.40	8.77	17.34	.40	12.34
	10	17.68	.40	7.68	15.00	.40	5.00	23.59	.40	13.59
	15	23.94	.40	8.94	25.02	.40	10.02	27.34	.40	12.34
	20	27.68	.40	7.68	23.75	.40	8.75	32.34	.40	12.34
	25	31.42	.40	6.42	40.04	.40	15.04	38.59	.40	13.59
4	5	-6.14	.25	-11.14	-7.56	.24	-12.56	-5.26	.26	-10.26
	10	-2.40	.32	-12.40	-2.56	.32	-12.56	-1.51	.35	-11.51
	15	-1.34	.40	-13.66	1.18	.40	-13.82	2.24	.40	-12.76
	20	5.09	.40	-14.91	6.18	.40	-13.82	5.98	.40	-14.02
	25	10.09	.40	-14.91	7.42	.40	-17.58	9.72	.40	-15.28
8	5	-7.40	.24	-12.40	-7.56	.24	-12.56	-5.26	.26	-10.26
	10	-3.65	.29	-13.65	-3.82	.28	-13.82	-1.51	.35	-11.51
	15	-1.16	.36	-16.16	-1.33	.36	-16.33	-0.28	.39	-15.28
	20	3.84	.40	-16.16	3.67	.40	-16.33	4.72	.40	-15.28
	25	7.58	.40	-17.42	8.67	.40	-16.33	8.47	.40	-16.53
12	5	-7.40	.24	-12.40	-8.82	.22	-13.82	-5.26	.26	-10.26
	10	-4.91	.27	-14.91	-5.08	.27	-15.08	-1.51	.35	-11.51
	15	-1.16	.36	-16.16	-2.58	.32	-17.58	0.98	.40	-14.02
	20	3.84	.40	-16.16	2.42	.40	-17.58	4.72	.40	-15.28
	25	8.84	.40	-16.16	7.42	.40	-17.58	9.72	.40	-15.28

TABLE A-6--Continued

		Reps								
		A			B			C		
Time (min)	Depth (cm)	ψm (cm)	θ (%)	ψT (cm)	ψm (cm)	θ (%)	ψT (cm)	ψm (cm)	θ (%)	ψT (cm)
16	5	-7.40	.24	-12.40	-8.82	.23	-13.82	-5.26	.27	-10.26
	10	-4.91	.27	-14.91	-5.08	.27	-15.08	-1.51	.35	-11.51
	15	-1.16	.36	-16.16	-2.58	.32	-17.58	0.98	.40	-14.02
	20	2.58	.40	-17.42	2.42	.40	-17.58	4.72	.40	-15.28
	25	7.58	.40	-17.42	7.42	.40	-17.58	9.72	.40	-15.28
30	5	-7.40	.24	-12.40	-10.08	.22	-15.08	-5.26	.26	-10.26
	10	-4.91	.27	-14.91	-5.08	.27	-15.08	-2.76	.31	-12.76
	15	-1.16	.36	-16.16	-2.58	.32	-17.58	-0.28	.39	-15.28
	20	3.84	.40	-16.16	2.42	.40	-17.58	4.72	.40	-15.28
	25	8.84	.40	-16.16	6.16	.40	-18.84	9.72	.40	-15.28
45	5	-8.66	.22	-13.66	-10.08	.22	-15.08	-6.51	.24	-11.51
	10	-6.16	.26	-16.16	-6.33	.25	-16.33	-2.76	.31	-12.76
	15	-2.42	.32	-17.42	-3.84	.28	-18.84	-0.28	.39	-15.28
	20	3.84	.40	-16.16	1.16	.40	-18.84	4.72	.40	-15.28
	25	8.84	.40	-16.16	6.16	.40	-18.84	9.72	.40	-15.28
60	5	-8.66	.22	-13.66	-11.33	.22	-16.33	-6.51	.24	-11.51
	10	-6.16	.26	-16.16	-6.33	.25	-16.33	-2.76	.31	-12.76
	15	-2.42	.32	-17.42	-3.84	.28	-18.84	-0.28	.39	-15.28
	20	3.84	.40	-16.16	1.16	.40	-18.84	4.72	.40	-15.28
	25	8.84	.40	-16.16	6.16	.40	-18.84	8.47	.40	-16.53

TABLE A-7. Matrix potential (ψm), water content (θ) and total gradient (ψT) with depth and time for the peat and sand mixture under field conditions

		Reps								
		A			B			C		
Time (min)	Depth (cm)	ψm (cm)	θ (%)	ψT (cm)	ψm (cm)	θ (%)	ψT (cm)	ψ (cm)	θ (%)	ψT (cm)
0	5	15.28	.50	10.28	16.57	.50	11.57	12.37	.50	7.37
	10	20.28	.50	10.28	21.57	.50	11.57	19.88	.50	9.88
	15	26.54	.50	11.54	27.82	.50	12.82	23.62	.50	8.62
	20	31.54	.50	11.54	32.82	.50	12.82	29.88	.50	9.88
	25	36.54	.50	11.54	39.08	.50	14.08	33.62	.50	8.62
4	5	-8.56	.26	-13.56	-9.78	.25	-14.78	-6.46	.29	-11.46
	10	-6.08	.30	-16.08	-6.04	.30	-16.04	-3.96	.33	-13.96
	15	-2.33	.38	-17.33	-1.04	.42	-16.04	-0.22	.48	-15.22
	20	5.18	.50	-14.82	3.96	.50	-16.04	4.78	.50	-15.22
	25	6.42	.50	-18.58	8.96	.50	-16.04	8.52	.50	-16.48
8	5	-9.82	.25	-14.82	-9.78	.25	-14.78	-8.96	.26	-13.96
	10	-6.08	.30	-16.08	-7.30	.28	-17.30	-6.48	.29	-16.48
	15	-2.33	.38	-17.33	-2.30	.38	-17.30	-2.73	.36	-17.73
	20	5.18	.50	-14.82	2.70	.50	-17.30	1.02	.50	-18.98
	25	6.42	.50	-18.58	7.70	.50	-17.30	6.02	.50	-18.98
12	5	-9.82	.25	-14.82	-11.04	.24	-16.04	-10.22	.25	-15.22
	10	-6.08	.30	-16.08	-7.30	.28	-17.30	-6.48	.29	-16.48
	15	-2.33	.38	-17.33	-2.30	.38	-17.30	-2.73	.36	-17.73
	20	3.92	.50	-16.08	2.70	.50	-17.30	1.02	.50	-18.98
	25	6.42	.50	-18.58	7.70	.50	-17.30	6.02	.50	-18.98

TABLE A-7--Continued

		Reps								
		A			B			C		
Time (min)	Depth (cm)	ψm (cm)	θ (%)	ψT (cm)	ψm (cm)	θ (%)	ψT (cm)	ψm (cm)	θ (%)	ψT (cm)
16	5	-9.82	.25	-14.82	-11.04	.24	-16.04	-10.22	.25	-15.22
	10	-6.08	.30	-16.08	-7.30	.28	-17.30	-7.73	.28	-17.73
	15	-2.33	.38	-17.33	-2.30	.38	-17.30	-2.73	.36	-17.73
	20	3.92	.50	-16.08	1.45	.50	-18.45	2.27	.50	-17.73
	25	6.42	.50	-18.58	6.45	.50	-18.45	7.27	.50	-17.73
30	5	-11.08	.24	-16.08	-12.30	.23	-17.30	-11.48	.24	-16.48
	10	-7.33	.28	-17.33	-8.55	.26	-18.55	-7.73	.28	-17.73
	15	-2.33	.38	-17.33	-3.55	.34	-18.55	-2.73	.36	-17.73
	20	3.92	.50	-16.08	1.45	.50	-18.55	2.27	.50	-17.73
	25	6.42	.50	-18.58	6.45	.50	-18.55	7.27	.50	-17.73
45	5	-11.08	.24	-16.08	-12.30	.23	-17.30	-12.73	.23	-17.73
	10	-7.33	.28	-17.33	-8.55	.26	-18.55	-8.98	.26	-18.98
	15	-3.58	.34	-18.58	-3.55	.34	-18.55	-3.98	.33	-18.98
	20	3.92	.50	-16.08	1.45	.50	-18.55	1.02	.50	-18.98
	25	6.42	.50	-18.58	6.45	.50	-18.55	4.76	.50	-20.24
60	5	-11.08	.24	-16.08	-12.30	.23	-17.30	-12.73	.23	-17.73
	10	-7.33	.28	-17.33	-8.55	.26	-18.55	-8.98	.26	-18.98
	15	-3.58	.34	-18.58	-3.55	.34	-18.55	-3.98	.33	-18.98
	20	2.67	.50	-17.33	1.45	.50	-18.55	1.02	.50	-18.98
	25	6.42	.50	-18.58	6.45	.50	-18.55	6.02	.50	-18.98

TABLE A-8. Matrix potential (ψm), water content (θ) and total gradient (ψT) with depth and time for the peat, sand and soil mixture under field conditons

		Reps								
		A			B			C		
Time (min)	Depth (cm)	ψm (cm)	θ (%)	ψT (cm)	ψm (cm)	θ (%)	ψT (cm)	ψm (cm)	θ (%)	ψT (cm)
0	5	13.86	.38	8.86	14.17	.38	9.17	14.47	.38	9.47
	10	20.12	.38	10.12	21.68	.38	11.68	20.72	.38	10.72
	15	25.12	.38	10.12	26.68	.38	11.68	25.72	.38	10.72
	20	30.12	.38	10.12	30.42	.38	10.42	31.98	.38	6.98
	25	33.86	.38	8.86	34.17	.38	9.17	33.22	.38	8.22
4	5	-7.48	.26	-12.48	-7.16	.26	-12.16	-9.38	.24	-14.38
	10	-3.73	.31	-13.73	-3.42	.31	-13.42	-5.63	.28	-15.63
	15	-1.24	.36	-16.24	1.58	.38	-13.42	-1.88	.34	-16.88
	20	3.76	.38	-16.24	5.32	.38	-14.68	1.86	.38	-18.14
	25	8.76	.38	-16.24	6.56	.38	-18.44	4.35	.38	-20.65
8	5	-8.73	.24	-13.73	-8.42	.25	-13.42	-10.63	.22	-15.63
	10	-4.98	.29	-14.98	-4.68	.29	-14.68	-6.88	.26	-16.88
	15	-1.24	.36	-16.24	0.32	.38	-14.68	-3.14	.32	-18.14
	20	2.50	.38	-17.50	4.07	.38	-15.93	1.86	.38	-18.14
	25	7.50	.38	-17.50	7.82	.38	-17.18	4.35	.38	-20.65
12	5	-9.98	.23	-14.98	-8.42	.25	-13.42	-10.63	.22	-15.63
	10	-7.50	.26	-17.50	-5.93	.28	-15.93	-6.88	.26	-16.88
	15	-2.50	.33	-17.50	-0.93	.36	-15.93	-3.14	.32	-18.14
	20	1.25	.38	-18.75	2.82	.38	-17.18	1.86	.38	-18.14
	25	7.50	.38	-17.50	6.56	.38	-18.44	4.35	.38	-20.65

TABLE A-8--Continued

Time (min)	Depth (cm)	Reps A ψm (cm)	A θ (%)	A ψT (cm)	B ψm (cm)	B θ (%)	B ψT (cm)	C ψm (cm)	C θ (%)	C ψT (cm)
16	5	-9.98	.23	-14.98	-9.68	.24	-14.68	-11.88	.22	-16.88
	10	-6.24	.27	-16.24	-5.93	.28	-15.93	-8.14	.25	-18.14
	15	-2.50	.33	-17.50	-2.18	.34	-17.18	-4.40	.30	-19.40
	20	2.50	.38	-17.50	2.82	.38	-17.18	0.60	.38	-19.40
	25	7.50	.38	-17.50	6.56	.38	-18.44	4.35	.38	-20.65
30	5	-9.98	.23	-14.98	-9.68	.24	-14.68	-13.14	.21	-18.14
	10	-7.50	.26	-17.50	-5.93	.28	-15.93	-9.40	.24	-19.40
	15	-3.75	.30	-18.75	-2.18	.34	-17.18	-4.40	.30	-19.40
	20	1.25	.38	-18.75	2.82	.38	-17.18	0.60	.38	-19.40
	25	7.50	.38	-17.50	6.56	.38	-18.44	4.35	.38	-20.65
45	5	-11.24	.22	-16.24	10.93	.22	-15.93	-11.88	.22	-16.88
	10	-7.50	.26	-17.50	-5.93	.28	-15.93	-8.14	.25	-18.14
	15	-3.75	.30	-18.75	-2.18	.34	-17.18	-4.40	.30	-19.40
	20	1.25	.38	-18.75	2.82	.38	-17.18	0.60	.38	-19.40
	25	7.50	.38	-17.50	7.82	.38	-17.18	4.40	.38	-20.60
60	5	-11.24	.22	-16.24	-10.93	.22	-15.93	-13.14	.21	-18.14
	10	-7.50	.26	-17.50	-7.18	.26	-17.18	-9.40	.24	-19.40
	15	-3.75	.30	-18.75	-2.18	.34	-17.18	-4.40	.30	-19.40
	20	1.25	.38	-18.75	1.56	.38	-18.44	0.60	.38	-19.40
	25	7.50	.38	-17.50	6.56	.38	-18.44	4.40	.38	-20.60

TABLE A-9. Water content (θ) by weight and volume, bulk density (B.D.) and matrix potential (ψm) with depth and time for the bark and sand mixture under laboratory conditions

Rep	Depth (cm)	θ (%) Weight	B.D. (gm/cm^3)	θ (%) Volume	ψm (cm)	θ (%) Weight	B.D. (gm/cm^3)	θ (%) Volume	ψm (cm)
		4-19-79		8:10 A.M.		4-19-79		11:15 P.M.	
A	5	.41	.70	.29	-13.30	.48	.72	.32	-13.30
	10	.36	.72	.26	-8.30	.47	.81	.34	-8.30
	15	.43	.75	.32	-3.30	.51	.86	.39	-3.30
	20	.49	.78	.38	1.70	.52	.91	.42	1.70
	25	.61	.80	.49	6.70	.62	.96	.54	6.70
		4-19-79		9:35 P.M.		4-20-79		4:30 P.M.	
B	5	.46	.70	.32	-9.88	.47	.67	.31	-12.38
	10	.38	.77	.29	-6.13	.60	.72	.43	-7.38
	15	.47	.83	.39	-1.13	.50	.77	.38	-2.38
	20	.55	.90	.49	3.87	.57	.83	.47	2.62
	25	.65	.96	.63	8.87	.62	.88	.55	7.62
		4-20-79		8:05 A.M.		4-21-79		3:30 P.M.	
C	5	.35	.73	.25	-9.88	.41	.72	.30	-12.38
	10	.36	.78	.28	-6.13	.40	.81	.32	-7.38
	15	.39	.83	.32	-1.13	.43	.86	.37	-2.38
	20	.51	.88	.45	3.87	.54	.91	.49	2.62
	25	.55	.94	.52	8.87	.61	.96	.59	7.62

TABLE A-10. Water content (θ) by weight and volume, bulk density (B.D.) and matrix potential (ψm) with depth and time for the bark, sand and soil mixture under laboratory conditions

Rep	Depth (cm)	θ (%) Weight	B.D. (gm/cm^3)	θ (%) Volume	ψm (cm)	θ (%) Weight	B.D. (gm/cm^3)	θ (%) Volume	ψm (cm)
		4-19-79		8:10 A.M.		4-19-79		11:15 P.M.	
A	5	.27	.96	.26	-8.06	.18	.93	.16	-10.58
	10	.25	.98	.25	-4.32	.37	.98	.36	-6.83
	15	.24	.99	.23	0.68	.24	1.02	.25	-0.58
	20	.33	1.00	.33	4.42	.33	1.07	.35	4.42
	25	.39	1.02	.40	9.42	.38	1.12	.43	9.42
		4-19-79		9:35 P.M.		4-20-79		4:30 P.M.	
B	5	.34	.89	.30	-9.28	.30	.93	.28	-11.78
	10	.33	.92	.30	-6.78	.26	.97	.25	-6.78
	15	.34	.98	.34	-3.04	.35	1.00	.35	-1.78
	20	.44	1.03	.46	1.96	.36	1.04	.37	1.96
	25	.47	1.08	.51	6.96	.54	1.07	.58	6.96
		4-20-79		8:05 A.M.		4-21-79		3:30 P.M.	
C	5	.34	.96	.33	-5.61	.35	.86	.30	-9.38
	10	.41	.96	.39	-1.86	.38	.93	.35	-4.38
	15	.38	.96	.36	1.88	.35	1.00	.35	-0.63
	20	.44	.96	.43	5.62	.40	1.07	.43	4.37
	25	.42	.97	.41	10.62	.48	1.14	.55	9.37

TABLE A-11. Water content (θ) by weight and volume, bulk density (B.D.) and matrix potential (ψm) with depth and time for the peat plus sand mixture under laboratory conditions

		4-19-79		8:10 A.M.		4-19-79		11:15 P.M.	
Rep	Depth (cm)	θ (%) Weight	B.D. (gm/cm^3)	θ (%) Volume	ψm (cm)	θ (%) Weight	B.D. (gm/cm^3)	θ (%) Volume	ψm (cm)
A	5	.39	.77	.30	-13.64	.44	.72	.32	-13.64
	10	.46	.80	.37	-8.64	.64	.73	.46	-8.64
	15	.61	.83	.51	-3.64	.66	.73	.48	-3.64
	20	.55	.87	.47	1.36	.64	.73	.47	1.36
	25	.69	.90	.62	6.36	.70	.73	.51	6.36
		4-19-79		9:30 P.M.		4-20-79		4:30 P.M.	
B	5	.47	.76	.36	-10.93	.50	.69	.34	-12.18
	10	.49	.81	.39	-5.93	.51	.74	.38	-7.18
	15	.56	.85	.47	-0.93	.51	.81	.41	-2.18
	20	.60	.90	.53	4.07	.57	.88	.50	2.82
	25	.63	.94	.60	9.07	.63	.95	.59	7.82
		4-20-79		8:05 A.M.		4-21-79		3:30 P.M.	
C	5	.49	.79	.38	-11.63	.53	.77	.41	-11.63
	10	.65	.82	.53	-6.63	.54	.78	.42	-6.63
	15	.54	.86	.46	-1.63	.60	.80	.48	-1.63
	20	.65	.89	.58	3.37	.65	.81	.53	3.37
	25	.67	.93	.62	8.37	.81	.83	.67	8.37

TABLE A-12. Water content (θ) by weight and volume, bulk density (B.D.) and matrix potential (ψm) with depth and time for the peat, sand and soil mixture under laboratory conditions

		4-19-79		8:10 A.M.		4-19-79		11:15 P.M.	
Rep	Depth (cm)	θ (%) Weight	B.D. (gm/cm^3)	θ (%) Volume	ψm (cm)	θ (%) Weight	B.D. (gm/cm^3)	θ (%) Volume	ψm (cm)
A	5	.37	.87	.32	-12.48	.42	.81	.34	-12.48
	10	.37	.90	.33	-7.48	.27	.89	.24	-7.48
	15	.36	.93	.33	-2.48	.39	.97	.38	-2.48
	20	.45	.96	.43	2.52	.44	1.05	.47	2.52
	25	.50	.99	.50	8.77	.43	1.13	.48	8.77
		4-19-79		9:30 P.M.		4-20-79		4:30 P.M.	
	5	.38	.85	.33	-9.38	.36	.84	.30	-10.63
	10	.36	.92	.33	-4.38	.42	.88	.37	-5.63
	15	.38	.99	.38	-0.63	.45	.93	.42	-1.63
	20	.45	1.06	.47	4.37	.55	.97	.54	4.37
	25	.50	1.13	.56	9.37	.58	1.02	.59	9.37
		4-20-79		8:05 A.M.		4-21-79		3:30 P.M.	
C	5	.29	.88	.25	-12.58	.36	.87	.31	-12.58
	10	.35	.91	.32	-7.58	.39	.91	.36	-8.84
	15	.55	.94	.52	-2.58	.54	.95	.51	-2.58
	20	.45	.97	.43	2.42	.52	.99	.51	2.42
	25	.52	1.00	.52	7.42	.53	1.03	.54	7.42

TABLE A-13. Water content (θ) by weight and volume, bulk density (B.D.) and matrix potential (ψm) with depth and time for the bark plus sand mixture under field conditions

		5-02-79		10:00 P.M.		5-03-79		9:15 A.M.	
Rep	Depth (cm)	θ (%) Weight	B.D. (gm/cm^3)	θ (%) Volume	ψm (cm)	θ (%) Weight	B.D. (gm/cm^3)	θ (%) Volume	ψm (cm)
A	5	.18	1.10	.20	-14.24	.17	0.99	.17	-14.24
	10	.19	1.13	.21	-9.24	.18	1.29	.23	-9.24
	15	.20	1.16	.24	-4.24	.21	1.18	.25	-5.50
	20	.27	1.20	.33	0.50	.26	1.27	.32	0.50
	25	.36	1.24	.45	5.50	.40	0.93	.37	5.50
		5-04-79		10:00 A.M.		5-05-79		3:00 P.M.	
	5	.15	1.18	.18	-14.24	.14	1.07	.15	-18.00
	10	.17	1.19	.21	-10.50	.17	1.26	.21	-11.00
	15	.18	1.20	.21	-5.50	.19	1.22	.23	-6.75
	20	.17	1.22	.21	0.50	.21	0.90	.19	-1.75
	25	.18	1.24	.22	5.50	.34	0.95	.32	3.25
		5-17-79		12:00 A.M.		5-20-79		wilt point	
	5	.12	1.22	.15	-31.81	.04	1.08	.04	-489.88
	10	.15	1.29	.20	-20.54	.07	1.11	.08	-486.14
	15	.16	1.29	.20	-14.28	.11	1.14	.13	-21.81
	20	.21	1.07	.22	-8.02	.16	1.18	.19	-15.56
	25	.29	1.18	.35	-3.02	.18	1.22	.22	-10.56

TABLE A-13--Continued

Rep	Depth (cm)	5/05/79 θ (%) Weight	B.D. (gm/cm^3)	10:00 A.M. θ (%) Volume	ψm (cm)	5-05-79 θ (%) Weight	B.D. (gm/cm^3)	1:30 P.M. θ (%) Volume	ψm (cm)
B	5	.18	1.12	.20	-14.08	.17	1.10	.19	-16.58
	10	.18	1.14	.21	-7.82	.20	1.11	.22	-9.08
	15	.21	1.17	.25	-2.82	.29	1.12	.32	-4.08
	20	.31	1.19	.37	2.18	.39	1.13	.44	0.92
	25	.36	1.22	.44	5.92	.42	1.14	.48	4.67
		5-17-79		12:00 A.M.		6-20-79		wilt point	
	5	.09	1.18	.11	-35.41	.04	1.16	.05	-618.98
	10	.14	1.18	.17	-12.84	.10	1.18	.11	-147.12
	15	.17	1.19	.20	-6.58	.15	1.20	.18	-36.70
	20	.24	1.19	.28	-1.58	.17	1.23	.21	-22.92
	25	.25	1.20	.30	3.42	.13	1.26	.16	-16.66
		5/06/79		10:00 A.M.		5-06-79		1:45 P.M.	
C	5	.20	1.10	.22	-13.30	.20	1.07	.21	-13.30
	10	.18	1.12	.20	-9.56	.21	1.03	.21	-9.56
	15	.19	1.14	.21	-4.56	.25	1.11	.27	-4.56
	20	.34	1.16	.39	0.44	.34	1.10	.38	0.44
	25	.28	1.18	.33	5.44	.14	0.98	.14	5.44
		5-17-79		12:00 A.M.		6-20-79		wilt point	
	5	.14	1.22	.17	-25.86	.06	1.22	.08	-614.45
	10	.16	1.23	.19	-13.32	.11	1.23	.13	-263.07
	15	.18	1.24	.23	-5.82	.13	1.24	.16	-28.40
	20	.26	1.26	.32	-0.82	.17	1.26	.22	-13.36
	25	.23	1.28	.29	4.18	.16	1.28	.21	-14.64

TABLE A-14. Water content (θ) by weight and volume, bulk density (B.D.) and matrix potential (ψm) with depth and time for the bark, sand and soil mixture under field conditions

		5-02-79		10:00 P.M.		5/03/79		9:15 A.M.	
Rep	Depth (cm)	θ (%) Weight	B.D. (gm/cm^3)	θ (%) Volume	ψm (cm)	θ (%) Weight	B.D. (gm/cm^3)	θ (%) Volume	ψm (cm)
A	5	.17	1.13	.19	-11.16	.19	1.11	.21	-12.42
	10	.20	1.18	.23	-7.42	.18	1.17	.21	-7.42
	15	.22	1.23	.27	-2.42	.20	1.23	.25	-2.42
	20	.27	1.28	.35	1.32	.30	1.29	.39	3.84
	25	.33	1.33	.44	6.32	.34	1.35	.45	8.84
		5-04-79		10:00 A.M.		5-05-79		3:00 P.M.	
	5	.19	1.20	.22	-12.42	.15	1.21	.18	-17.44
	10	.17	1.24	.22	-7.42	.17	1.25	.21	-9.93
	15	.21	1.28	.26	-3.68	.18	1.29	.24	-4.93
	20	.29	1.31	.38	1.32	.24	1.33	.32	0.07
	25	.36	1.34	.48	6.32	.24	1.37	.32	5.07
		6/23/79		wilt point					
	5	.04	1.23	.05	-198.72				
	10	.08	1.32	.11	-149.80				
	15	.14	1.41	.20	-72.01				
	20	.14	1.50	.21	-49.44				
	25	.11	1.59	.17	-48.20				

TABLE A-14--Continued

Rep	Depth (cm)	θ (%) Weight	B.D. (gm/cm^3)	θ (%) Volume	ψm (cm)	θ (%) Weight	B.D. (gm/cm^3)	θ (%) Volume	ψm (cm)
		5-05-79		10:00 A.M.		5-05-79		1:30 P.M.	
B	5	.17	1.18	.20	-15.10	.17	1.22	.21	-15.10
	10	.18	1.27	.22	-10.10	.17	1.26	.21	-10.10
	15	.21	1.36	.28	-6.35	.20	1.30	.26	-6.35
	20	.24	1.44	.35	-1.35	.28	1.35	.38	-1.35
	25	.33	1.52	.50	4.90	.36	1.40	.51	3.65
		6-23-79		wilt point					
	5	.03	1.27	.04	-169.70				
	10	.05	1.32	.06	-129.56				
	15	.08	1.37	.11	-118.28				
	20	.11	1.42	.15	-58.06				
	25	.12	1.47	.18	-31.72				
		5-06-79		10:00 A.M.		5-06-79		1:45 P.M.	
C	5	.17	1.09	.19	-10.28	.16	1.16	.19	-11.53
	10	.16	1.19	.19	-6.53	.16	1.26	.20	-7.78
	15	.19	1.29	.25	-1.53	.21	1.36	.28	-2.78
	20	.26	1.39	.36	3.47	.26	1.46	.38	2.22
	25	.27	1.49	.40	8.47	.30	1.56	.47	7.22
		6-23-79		wilt point					
	5	.03	1.31	.04	-183.98				
	10	.05	1.32	.06	-166.44				
	15	.11	1.33	.14	-63.54				
	20	.16	1.34	.21	-15.88				
	25	.19	1.35	.25	1.68				

TABLE A-15. Water content (θ) by weight and volume, bulk density (B.D.) and matrix potential (ψm) with depth and time for the peat plus sand mixture under field conditions

		5-02-79		10:30 P.M.		5-03-79		9:15 A.M.	
Rep	Depth (cm)	θ (%) Weight	B.D. (gm/cm^3)	θ (%) Volume	ψm (cm)	θ (%) Weight	B.D. (gm/cm^3)	θ (%) Volume	ψm (cm)
A	5	.24	1.14	.27	-12.33	.21	1.10	.23	-13.58
	10	.21	1.16	.24	-7.33	.24	1.17	.28	-9.84
	15	.25	1.18	.29	-2.33	.30	1.25	.37	-4.84
	20	.36	1.19	.43	3.92	.37	1.32	.48	-1.10
	25	.39	1.20	.46	6.42	.38	1.40	.53	3.90
		5-04-79		10:00 A.M.		5-05-79		3:00 P.M.	
	5	.21	1.13	.24	-14.84	.19	1.15	.21	-17.35
	10	.21	1.14	.24	-9.84	.19	1.17	.22	-16.10
	15	.26	1.14	.30	-7.35	.22	1.19	.26	-7.35
	20	.35	1.14	.40	-2.35	.26	1.21	.32	-2.35
	25	.42	1.14	.48	3.90	.32	1.23	.39	2.65
		5-17-79		12:00 A.M.		6-22-79		wilt point	
	5	.16	1.17	.19	-23.62	.12	1.14	.13	-240.74
	10	.15	1.22	.19	-17.37	.12	1.16	.14	-62.55
	15	.16	1.27	.21	-12.37	.13	1.18	.15	-43.74
	20	.20	1.32	.27	-7.37	.16	1.20	.19	-37.49
	25	.22	1.37	.30	-2.37	.14	1.22	.18	-32.49

TABLE A-15--Continued

Rep	Depth (cm)	5-05-79 θ (%) Weight	B.D. (gm/cm^3)	10:00 A.M. θ (%) Volume	ψm (cm)	5-05-79 θ (%) Weight	B.D. (gm/cm^3)	1:30 P.M. θ (%) Volume	ψm (cm)
B	5	.35	1.08	.38	-17.32	.22	1.15	.25	-18.57
	10	.19	1.14	.22	-12.32	.18	1.21	.22	-13.57
	15	.22	1.20	.26	-7.32	.21	1.27	.26	-8.57
	20	.26	1.26	.33	-2.32	.31	1.33	.41	-3.57
	25	.44	1.32	.58	2.68	.44	1.39	.62	1.43
		5-17-79		12:00 A.M.		6-22-79		wilt point	
	5	.19	1.01	.19	-37.40	.09	1.20	.11	-250.74
	10	.14	1.10	.16	-28.63	.13	1.23	.16	-61.26
	15	.15	1.20	.18	-21.12	.15	1.26	.18	-48.73
	20	.18	1.30	.23	-16.12	.13	1.29	.17	-42.48
	25	.26	1.40	.37	-11.12	.13	1.32	.18	-37.48
		5-06-79		10:00 A.M.		5-06-79		1:45 P.M.	
C	5	.21	1.14	.24	-15.24	.26	1.05	.27	-16.50
	10	.21	1.18	.25	-10.24	.21	1.08	.23	-11.50
	15	.24	1.22	.29	-5.24	.27	1.11	.29	-6.50
	20	.36	1.26	.45	-0.24	.37	1.14	.43	-1.50
	25	.38	1.30	.49	4.76	.44	1.17	.52	3.50
		5-17-79		12:00 A.M.		6-22-79		wilt point	
	5	.17	1.08	.19	-24.02	.12	1.14	.14	-124.42
	10	.20	1.09	.22	-17.77	.12	1.16	.14	-71.74
	15	.20	1.10	.22	-11.52	.10	1.19	.12	-57.95
	20	.24	1.11	.27	-6.52	.14	1.21	.17	-49.18
	25	.35	1.12	.39	-1.52	.13	1.24	.16	-47.95

TABLE A-16. Water content (θ) by weight and volume, bulk density (B.D.) and matrix potential (ψm) with depth and time for the peat, sand and soil mixture under field conditions

		5-02-79		10:00 P.M.		5-03-79		9:15 A.M.	
Rep	Depth (cm)	θ (%) Weight	B.D. (gm/cm^3)	θ (%) Volume	ψm (cm)	θ (%) Weight	B.D. (gm/cm^3)	θ (%) Volume	ψm (cm)
A	5	.15	1.19	.18	-13.75	.17	1.20	.20	-15.00
	10	.17	1.29	.22	-8.75	.18	1.24	.22	-10.00
	15	.19	1.39	.26	-3.75	.23	1.28	.29	-6.26
	20	.21	1.49	.31	1.25	.25	1.33	.33	-1.26
	25	.31	1.59	.49	8.76	.32	1.38	.44	3.74
		5-04-79		10:00 A.M.		5-05-79		3:00 P.M.	
	5	.14	1.24	.17	-15.00	.13	1.25	.16	-23.79
	10	.18	1.29	.24	-10.00	.14	1.31	.18	-16.28
	15	.19	1.34	.26	-5.00	.18	1.09	.19	-10.02
	20	.23	1.40	.33	0.00	.22	1.28	.28	-5.02
	25	.32	1.46	.47	5.00	.31	1.34	.42	-0.02
		5-17-79		12:00 A.M.		6-22-79		wilt point	
	5	.12	1.27	.16	-51.40	.04	1.18	.04	-341.30
	10	.13	1.31	.17	-22.56	.08	1.23	.09	-155.58
	15	.15	1.35	.20	-15.04	.09	1.28	.11	-99.13
	20	.16	1.39	.22	-8.79	.12	1.32	.16	-56.48
	25	.19	1.43	.27	-3.79	.11	1.36	.14	-51.48

TABLE A-16--Continued

Rep	Depth (cm)	θ (%) Weight	B.D. (gm/cm^3)	θ (%) Volume	ψm (cm)	θ (%) Weight	B.D. (gm/cm^3)	θ (%) Volume	ψm (cm)
		5-05-79		10:00 A.M.		5-05-79		1:30 P.M.	
B	5	.18	1.26	.23	-13.44	.18	1.27	.23	-13.44
	10	.18	1.35	.24	-9.70	.21	1.28	.26	-9.70
	15	.25	1.17	.29	-3.44	.25	1.29	.32	-4.70
	20	.31	1.43	.45	1.56	.32	1.30	.42	0.30
	25	.30	1.02	.31	6.56	.27	1.31	.36	5.30
		5-17-79		12:00 A.M.		6-22-79		wilt point	
	5	.14	1.22	.17	-31.01	.08	1.24	.10	-628.39
	10	.18	1.53	.28	-22.24	.13	1.34	.17	-112.60
	15	.18	1.22	.23	-13.48	.14	1.44	.20	-69.96
	20	.21	1.21	.26	-8.48	.14	1.54	.21	-47.38
	25	.17	1.11	.19	-3.48	.13	1.64	.21	-37.36
		5-06-79		10:00 A.M.		5-06-79		1:45 P.M.	
C	5	.15	1.24	.18	-15.65	.08	1.24	.11	-16.90
	10	.18	1.26	.22	-10.90	.17	1.26	.21	-11.90
	15	.19	1.28	.25	-5.90	.19	1.28	.24	-6.90
	20	.25	1.31	.33	-0.90	.27	1.30	.35	-1.90
	25	.17	1.34	.23	3.10	.27	1.32	.36	1.84
		5-17-79		12:00 A.M.		6-20-79		wilt point	
	5	.16	1.20	.20	-40.75	.08	1.25	.09	-284.22
	10	.12	1.51	.17	-24.46	.12	1.42	.16	-111.05
	15	.19	1.38	.26	-16.94	.15	1.22	.18	-53.34
	20	.05	1.44	.08	-10.69	.14	1.33	.18	-35.79
	25	.27	0.89	.24	-5.69	.15	1.06	.16	-29.54

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