

THESIS

LEACHING OF SALT FROM CONTAINER MEDIA

Submitted by

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ABSTRACT OF THESIS  
LEACHING OF SALT FROM CONTAINER MEDIA

The leaching of salt from container media was investigated by means of miscible displacement theory for a series of six peat-perlite-glass bead mixes and four other mixes. Columns were salinized with a 30 meq  $l^{-1}$  solution of  $CaCl_2$  and NaCl, and allowed to equilibrate. Electrical conductivity of the effluent was monitored as columns were leached using 1 cm constant head with 2, 8 and 14 meq  $l^{-1}$  solutions of  $CaCl_2$  and NaCl. A continuous series of physical properties were seen in the glass bead mixes, with efficiency of replacement of the soil solution by leaching solution increasing as glass bead content increased. Replacement efficiency had good correlations to physical properties of mixes, but insufficient data was available to relate this to particle size distribution. Leaching solution concentration did not influence replacement efficiency and, generally, after 1 to 1.5 container capacities of effluent, removal of original soil solution decreased substantially. A method is presented

to determine the leaching requirement for potting  
mixes.

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## INTRODUCTION

Water quality and supply problems for greenhouse agriculture have necessitated the investigation of salinity control in potting mixes. To date, little work has been done to characterize the leaching process as it occurs in these mixtures, or to relate properties of mixes and leaching solution concentration to leaching efficiency. In addition, recommendations for the leaching requirement of potting mixes are wholly inadequate and guidelines are needed in order for growers to control salinity with minimal water usage.

The objectives of this study were to define the characteristics of salt removal from container media as related to percolation rate, moisture holding capacity, pore space, particle size distribution, and leaching solution concentration and to develop recommendations for salinity control. This study approached the leaching phenomenon in potting mixes in terms of miscible displacement theory, which has been described thoroughly for the leaching of field soils (3,4,12,20,28,29,39,43,44,46,57,58).

Since potting mixes vary widely in their components and physical properties, and it is known that these properties change the leaching process in field soils (39) and potting

mixes (26), it was necessary that leaching be reviewed throughout a range of physical properties. This was accomplished by starting with a basic, highly porous mix, peat-perlite, and adding progressive amounts of glass beads (.10 - .11 mm d). These glass beads filled large pores in the peat-perlite and allowed investigation of a range of physical properties with minimal changes in chemical properties. Several other mixes were also tested to see if the relationships developed for these glass bead mixes were consistent for other mixes as well.

## LITERATURE REVIEW

Salinity in field soils has been studied for many years and there are many publications (e.g. 1,2,10,14,16,22,23,33,36,45,47,50,52,59,66,68) which deal with leaching and salinity control. Greenhouse agriculture, however, employs different growing media, irrigation systems, and cultural practices which change the nature of the salt problem. Although much of the literature available pertains to field soils and therefore is of limited value in this work, the general concepts are valuable in understanding salinity control under greenhouse conditions. These general concepts, and specific literature from greenhouse studies, where available, are discussed.

### Salt Balance

Salt balance refers to a quantified summary of all salt inputs and outputs for a defined volume of soil during a specific period of time (10,15,29). In greenhouse production, the significant salt inputs include the salt in the irrigation water and the salt applied as fertilizer. Salt output is mainly via the drainage water and leaching is required to maintain a favorable salt balance (15). An unfavorable salt balance occurs when more salts are brought

into the soil than are removed in the drainage water, resulting in salt accumulation (15).

### Leaching Process

The central process in salinity control is leaching. Leaching, as defined by Richards (50), is the process of dissolving and transporting salts by the downward movement of water through the soil. Hill (27) defined leaching as simply the passage of water through soil to control salinity. Salt removal by leaching, therefore, is obviously associated with the flow of water through soils.

In field soils, the replacement of the saline soil solution with irrigation water is explained in terms of miscible displacement. In other words, one solution is displaced by another solution with which it is completely miscible. A brief summary of this phenomenon, taken from several sources (3,4,12,20,28,29,39,43,44,46,57,58) is presented here.

Mixing between the leaching solution and the soil solution takes place at the boundary between the two solutions. This mixing is caused by several factors: (1) variations in pore velocities, called hydrodynamic dispersion, which arise from the distribution of pore sizes and shapes, (2) diffusion of ions and molecules from regions of high to low concentration, (3) ion adsorption and exchange reactions, and (4) differing densities and viscosities of the two solutions.

Hypothetically, the most efficient removal of a saline soil solution occurs when these forces which cause mixing are absent. This hypothetical phenomenon is called piston flow or piston displacement. In leaching curves of concentration versus volume of effluent, the boundary between the two solutions would remain sharp and would appear at one pore volume (one container capacity) of effluent if piston flow occurred. Piston flow, however, never actually occurs and the mixing forces cause the leaching curves to become sigmoidal, indicating less efficient leaching.

The relative extent to which the mixing factors come into play during leaching from greenhouse mixes is unknown. It is known that large pores, with their corresponding large flow rates, channel water through soils, decreasing leaching efficiency. Hanan et al. (26) supported this by showing salt removal to be more efficient in potting substrates with lower percolation rates. Since percolation rates are so large in greenhouse mixes (26), one might surmise that diffusion, ion adsorption and exchange reactions are not significant contributors to mixing because of a radically decreased opportunity time.

The amount of original soil water that is not easily displaced during leaching generally increases as complexity of the porous media increases, thereby decreasing leaching efficiency. Data from several studies (13,21,31,51) indicate that potting mixes contain a wide range of pore sizes, suggesting that the soil solution is probably not easily

displaced from these substrates. Juncker and Madison (31) presented data which showed that the pore size distribution range (as reflected by soil moisture characteristic curves) decreased in peat-sand mixes as sand content increased.

#### Irrigation Method

The leaching efficiency of various irrigation systems can be understood in terms of miscible displacement and water flow through pores. At fast rates of application, the large pores conduct water rapidly through soil, leaving salty soil solution in the small pores. Slower rates of application result in more water flowing through small pores and also allow more time for diffusion of salts from pores which do not conduct water to pores which do. Slow application rates, such as occur with sprinkling, are therefore more efficient than the faster application rates associated with ponding or flooding. In greenhouse mixes, ponding may not only be less efficient, but it also may not be practical. As Hanan et al. (26) pointed out, it is doubtful that any irrigation system now in use could supply sufficient water to flood highly porous greenhouse mixes.

Intermittent leaching is more efficient than continuous leaching. This is because diffusion occurs between leachings, redistributing salts to the main flow paths, through which they can be readily leached from the soil.

Also important in leaching efficiency is the distribution of water over the soil surface. Limited distribution of the leaching water, as occurs in drip and trickle

irrigation, results in leached zones below the emitter. This problem may be worse in porous container media (26) because of the low hydraulic conductivity of these mixes. Further, Furuta (17) found that increasing the amount of water applied by drip irrigation will not satisfactorily control salt buildup in container crops because of this limited distribution of the leaching water.

#### Leaching Requirement for Salinity Control

The leaching requirement, as used in greenhouse terminology, is the amount of water that must be leached through the container to control soil salinity at a specified level. The leaching requirement for salinity control is dependent upon: 1) initial soil salt level, 2) the distribution of salt in the soil, 3) the quality of the leaching water, 4) the depth of the soil to be leached, 5) the maximum concentration permissible in the soil solution, 6) the types of salts present in the soil and water, 7) the method of applying the leaching solution, 8) the soil moisture content, and 9) the physical and chemical characteristics of the soil (16,27,32,50).

In field soils, the fraction of irrigation water which must be leached through the root zone has been expressed in relation to the volume of water applied or the consumptive use (27,55). As the depth of the irrigation water applied exceeds the consumptive use, then some leaching will occur, with the lower limit of the soil solution's concentration being the concentration of the irrigation water. Some

workers (4,20) based their calculations for leaching of field soils on pore volumes of water, where one pore volume is the amount of water held by the soil at field capacity.

Greenhouse authorities (5,37,38,40,42) have suggested a common rule of thumb of 10% more water than the medium can hold to control salinity. However no data was presented by these authors. Other recommendations for leaching greenhouse potting mixtures are less specific. Several authors (17,53,63) advised that when there are problems of salinity, the medium should be leached with large quantities of water. Smith (56) stated that salt buildup can be prevented in pots to a great extent by applying enough water at each irrigation so that some water runs out of the drainage holes. One researcher (48) stated that good quality foliage plants could be grown without leaching, but methods and data presented were not convincing. The need for specific, research-based recommendations for salinity control in container culture seems apparent, particularly in arid and semi-arid regions where water quality and quantity may be limiting.

The causes of insufficient leaching in greenhouse soils have been cited as the absence of rainfall, insufficient quantity of irrigation water, partial wetting of the soil volume (as with drip irrigation), and, sometimes, impeded drainage (5,6). Meiri et al. (41) stated that water uptake by plants during leaching will also reduce the amount of water available for leaching, and that this problem will tend to be accentuated under conditions of restricted root

volume, high transpiration, and frequent irrigation, as is the case in pot culture.

#### Leaching Equations

The equations which have been proposed to describe leaching of salts from greenhouse mixes contain logarithmic relationships. Bunt (7), using mixes of 3:1 (volume:volume) of peat:sand and 1:1 of peat:vermiculite, found the loss of nutrient salts to be a function of the volume of leachate. His data fit the equation:  $K(\text{volume of leachate}) = \log_e [(1 - \text{salt eluted}) / (\text{total salt added})]$ . Hanan et al. (26), working with a number of potting media, fit the formula  $EC = EC_s - b \log t$  to curves of electrical conductivity versus time. EC was the electrical conductivity of the effluent at time t and  $EC_s$  was the starting conductivity at time 0. These workers stated that the "leaching rate" (b) was predictable from a knowledge of the starting EC of the effluent. Use of the term "leaching rate" may be misleading as this is simply the rate of change of salinity of the effluent. Their data showed that when the starting EC was high, the EC of the leachate decreased faster than if the EC was low, and as the fraction of the EC at time t to starting EC approached zero, the water required for removal increased exponentially. Waters (60) observed that the concentration of soluble salts in the leachate from pots ". . . decreased in a quadratic fashion when measured against the increasing increments of leaching water on a log scale." Schoonover and Sciaroni (53), examining curves of electrical

conductivity versus volume of leachate, noted that much of the salt from potting mixtures was removed in the "first portion" of the leachate.

#### Growing Medium

With the exception of the study by Hanan et al. (26), greenhouse workers have not investigated the properties of mixes which influence leaching. They have, however, made note of differences in salt retention by various potting mixtures. Since potting mixes typically have a high organic matter content, the salt removal characteristics of the medium should be significantly influenced by the organic matter present. Schoonover and Sciaroni (53) noted that fir bark caused greater salt retention than peat, and peat-sand mixes retarded salt removal when compared to sand alone. Data from Waters et al. (61) showed some differences in salt retention by German peat, Florida peat, and wood shavings.

Other media components modify the amount of salt held against leaching. Studies (8,53) have shown a high loss of nutrient salts by leaching in peat-sand mixes as opposed to peat-loam mixes. Vermiculite, when mixed with peat, reduced the rate of loss of nutrient salts compared to peat-sand substrates (7). In one investigation (61), increasing the perlite:peat ratio from 1:2 to 2:1 caused a decrease in salt retained after leaching.

In general, potting mixes having higher cation exchange capacities are commonly assumed to have higher salt accumulation (13,30) and greater difficulty in leaching salts

(13). However, the data are not adequate to determine the extent to which cation exchange, as compared to media physical properties, is important in leaching potting mixes.

#### Water Quality

Irrigation water quality has been discussed by many workers (e.g. 14, 15, 25, 42, 50, 62, 65, 67) and is pivotal to salinity control in soils. The higher the concentration of salts in the irrigation water, the greater the salt hazard, and the greater the amount of water that will be needed to leach (25). The classifications developed for water quality are arbitrary, but the characteristics of the water that are important to consider in the context of salinity can be isolated. Properties such as the total concentration of soluble salts, the relative proportion of sodium to other cations, the concentration of toxic elements, and the bicarbonate concentration as related to the concentration of calcium and magnesium have been cited (50, 65, 67) as most important in determining water quality. However, data (9) suggest that high sodium levels will not adversely affect physical properties of peat and therefore may not be as important for water quality determinations for container media as it is for mineral field soils.

Beyond this chemical analysis of the water, the soil properties, irrigation management, climate, crops, and economics must be evaluated before determining a water's suitability for irrigation (15, 18, 50, 67). The addition of fertilizer to irrigation water, as is practiced in

greenhouses, should also be considered in conjunction with water quality (24,25,35). Studies (48,53,61) have shown that the addition of fertilizer to irrigation water increased salinity problems and decreased water use efficiency.

#### Summary

The study of leaching of field soils is based on miscible displacement theory. An understanding of leaching from greenhouse mixes can be based on the same principles if one recognizes the differences in physical properties of the two substrates. Little reliable data was found on the leaching of container media and to our knowledge, only one study to date (26) has approached leaching in greenhouse mixes from the standpoint of physical properties.

## MATERIALS AND METHODS

### Media

The components of the 10 mixes (Table 1) were horticultural perlite (P), Canadian sphagnum peat moss (PM), grade 3 vermiculite (V), rockwool blowing wool (RW), 0.10-0.11 mm d glass beads (GB) and Ft. Collins clay loam (S). The peat and perlite used for the glass bead mixes were sieved to increase the reproducibility of the mixes. Peat was passed through a 7.925 mm sieve, and perlite through a 4.75 mm sieve screen and retained on a 2.0 mm sieve. The field soil was dried at 105 C for 24 hr, broken up with mortar and pestle, and passed through a 2.0 mm sieve. The rockwool was shredded with a Lindig shredder. All peat was air dried for at least 24 hr prior to use.

### Column Preparation

Three columns of each treatment were prepared, using 5.08 cm ID PVC plastic pipe. A 1.5 mm screen was glued to the bottom of the column to retain the medium. Each medium was moistened by adding 106 ml salt solution (15 meq l<sup>-1</sup> each CaCl<sub>2</sub> and NaCl) per liter medium (34). The columns were filled to 15 cm depth and then dropped 2.54 cm 5 times (34) for compaction. Medium was added after each drop to re-establish the 15 cm depth. A thin layer of glass wool

Table 1: Potting mixes used in experiments.

Components <sup>Z</sup>	Ratio (V-V-V)
<b>Glass Bead Mixes</b>	
PM-P-GB	10-10-0
	10-10-1
	10-10-2
	10-10-4
	10-10-6
	10-10-8
<b>Standard Mixes</b>	
PM-P	1-1
RW-P	1-1
PM-V	1-1
PM-P-S	2-2-1

<sup>Z</sup> PM = peat moss, P = perlite, GB = glass beads, RW = rock wool, V = vermiculite, S = field soil

was then placed on the surface of the mix to keep particles from being disturbed during salinization and leaching.

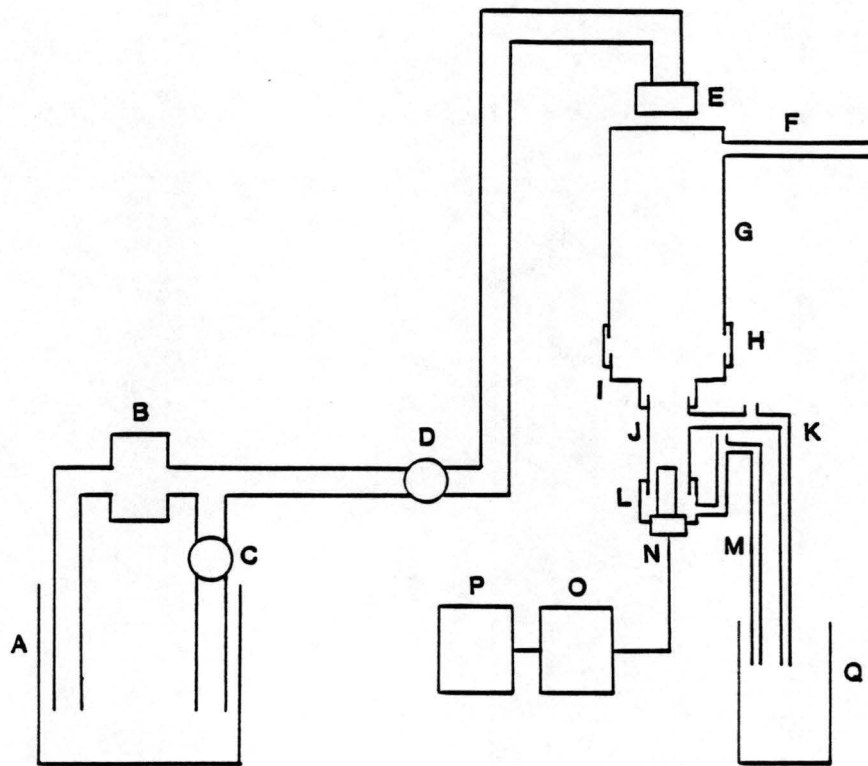
The mix in the column was then salinized by pouring 1 l of salinization solution ( $15 \text{ meq l}^{-1}$  each of  $\text{CaCl}_2$  and  $\text{NaCl}$ ) through the column. After 500 ml of solution had been applied, the medium was brought back to the 15 cm depth and the second 500 ml of solution applied. The ends of the columns were sealed with plastic film held in place by rubber bands and the columns allowed to equilibrate 24 hr. At this point, the mix was brought to the 15 cm depth and 500 ml more of the salinizing solution applied before a final 24 hr equilibration period.

#### Leaching

The 10 mixes were leached with three concentrations of leaching solution. The three leaching solutions had 1, 4, and  $7 \text{ meq l}^{-1}$  each of  $\text{CaCl}_2$  and  $\text{NaCl}$ . Irrigation waters of similar concentration are used by greenhouse operators in Colorado. Solutions were used at 20 to 23 C.

Prepared columns were placed on the leaching apparatus (Fig. 1). Leaching solution was pumped from a reservoir and applied to the column using a fogging nozzle as a breaker. The solution was applied at a rate high enough to establish a 1 cm head on the surface of the column. An overflow tube (D in Fig. 1) was placed 16 cm from bottom of column to carry away excess leaching solution. The electrical conductivity of the effluent from the column was measured by a

Figure 1: Diagram of column leaching apparatus.



- |                                |  |
|--------------------------------|--|
| A: Leaching solution reservoir | J: PVC pipe (1.908 cm d)               |
| B: Pump                        | K: Overflow tube                       |
| C: Valve                       | L: Coupler                             |
| D: Valve                       | M: Drain tube                          |
| E: Fogging nozzle              | N: Beckman model 414 conductivity cell |
| F: Overflow tube               | O: Conductivity bridge                 |
| G: Column (5.08 cm d PVC pipe) | P: Strip chart recorder                |
| H: PVC coupler                 | Q: Graduated cylinder                  |
| I: PVC plug reducer            |  |

conductivity bridge as it passed through a Beckman model 414 conductivity cell. A strip chart recorder was used to continuously monitor electrical conductivity. When the volume of effluent reached 500ml, the point was noted on the chart, and the pump turned off.

#### Media Properties

After leaching, the columns were allowed to drain. The medium in each was weighed, dried at 50 C (19) for 48 hr, and weighed again for bulk density and moisture content determinations. Percent total pore space was calculated from the equation: (percent total porosity) =  $98 - 36.2 \text{ Bulk density (26)}$ . The percent of pores filled with air at container capacity (air porosity) was determined as the difference of total porosity and moisture content. Percolation rate was determined by the time required for 500 ml to drain from the column. Cation exchange capacity of several mixes were determined by the Colorado State University Soil Testing Laboratory.

#### Particle Size Analysis

Three 250 ml samples of each media component, except glass beads, were used for particle size analysis. The sieve screens (7.925, 4.75, 2.0, .850, .425, .150, .075 mm, and the receiver pan) were shaken horizontally for 3 min. The fraction retained by each screen and the receiver pan was weighed and measured by volume to the nearest 5 ml in a 250 ml graduated cylinder.

Standard Curve of Electrical Conductivity Versus Concentration

All salt solutions used in these experiments contained equal parts (equal meq) of  $\text{CaCl}_2$  and  $\text{NaCl}$  so that salt concentration could be more accurately determined from electrical conductivity and to minimize precipitation of salts. Four solutions (1,4,7,15 meq  $\text{l}^{-1}$  each  $\text{CaCl}_2$  and  $\text{NaCl}$ ) were prepared for a standard curve of electrical conductivity versus concentration. This standard curve was used to determine the quantity of salt removed during leaching.

Definition of Terms

Total Porosity = the total amount of pore space in the medium ( $\text{cm}^3 \text{ cm}^{-3}$ ). Calculated from the equation

$$\text{Total Porosity} = .98 - .362 \text{ Bulk Density (26)}.$$

Container Capacity (64) = the volume of water held by the medium after drainage ( $\text{cm}^3$ )

Water Porosity = container capacity divided by bulk volume of medium ( $\text{cm}^3 \text{ cm}^{-3}$ ).

Air Porosity = total porosity minus water porosity ( $\text{cm}^3 \text{ cm}^{-3}$ ).

Actual Salt Removed = meq of salt in leachate minus the salt in the leaching solution.

Total Salt = total meq of salt in column.

% Total Salt = meq of salt leached from column expressed as % of the Total Salt.

Removable Salt = meq salt that can be removed from the column given complete replacement of the soil solution by the leaching solution. When leaching

solution is distilled water, Removable Salt equals  
Total Salt.

% Removable Salt = meq of salt leached from column  
expressed as a % of the Removable Salt.

Piston Flow Index = % Removable Salt at one container  
capacity of effluent.

## RESULTS AND DISCUSSION

### Media Properties

The physical properties of the glass bead mixes varied with glass bead content as expected (Table 2). Bulk density and water filled pore space (water porosity) increased, while total pore space, air filled pore space (air porosity), and percolation rate decreased with increasing proportion of glass beads.

These physical properties were interrelated, and total pore space was calculated directly from bulk density (26). The correlation matrix of these properties for the glass bead mixes (Table 3) showed close relationships. The correlation matrix for all 10 mixes (Table 4) reflected the more variable nature of the standard mixes.

As glass beads were added to the peat and perlite, the larger pores were filled with glass beads, thereby creating smaller pores. Since these smaller pores were responsible for retaining water against gravity, this increased proportion of smaller pores resulted in a greater amount of water filled pore space. The increase in water content, along with the decreased total pore space caused by adding glass beads, resulted in decreased air filled pore space. Air porosity was a good predictor of percolation rate for both the glass bead mixes alone ( $r^2=.95$ ) and all mixes together

Table 2: Physical properties and piston flow index of potting mixes. Nine observations (columns) per medium.

	PM-P-GB						PM-P	RW-P	PM-V	PM-P-S	HSD (.05)
	10-10-0	10-10-1	10-10-2	10-10-4	10-10-6	10-10-8	1-1	1-1	1-1	2-2-1	
Bulk Density (g cm <sup>-3</sup> )	.08	.17	.26	.44	.61	.74	.08	.11	.09	.33	.04
Container Capacity (ml)	98	107	121	128	128	127	94	107	155	115	7
Water Porosity <sup>W</sup> (cm <sup>3</sup> cm <sup>-3</sup> )	.32	.35	.40	.42	.42	.42	.31	.35	.51	.38	.02
Total Porosity <sup>X</sup> (cm <sup>3</sup> cm <sup>-3</sup> )	.95	.92	.88	.82	.76	.71	.95	.94	.95	.86	.01
Air Porosity <sup>Y</sup> (cm <sup>3</sup> cm <sup>-3</sup> )	.63	.57	.48	.40	.34	.30	.64	.59	.44	.48	.03
Percolation Rate (st. dev.) (cm hr <sup>-1</sup> )	4256 (318)	2922 (515)	986 (333)	243 (97)	57 (23)	41 (13)	4519 (690)	5436 (274)	1761 (367)	171 (77)	
Piston Flow Index <sup>Z</sup>	42	55	61	64	70	74	43	40	54	59	10

<sup>W</sup> Water porosity = (container capacity) / (bulk volume of media).

<sup>X</sup> Total porosity = .98 - .362 Bulk density (26).

<sup>Y</sup> Air porosity = Total porosity - water porosity.

<sup>Z</sup> Piston Flow Index is a measure of the efficiency of the replacement of the soil solution by leaching solution, where PFI = 100 for piston flow.

Table 3: Correlation matrix for the physical properties and  
Piston Flow Index (PFI) of the glass bead mixes.

	BD <sup>V</sup>	PR <sup>W</sup>	Log(PR)	TP <sup>X</sup>	WP <sup>Y</sup>	AP <sup>Z</sup>
PR	-.86					
Log(PR)	-.98	.89				
TP	-1.00	.86	.98			
WP	.79	-.92	-.82	-.78		
AP	-.98	.92	.98	.98	-.90	
PFI	.85	-.85	.86	-.85	.82	-.88

<sup>V</sup>BD=Bulk density  
<sup>W</sup>PR=Percolation rate  
<sup>X</sup>TP=Total porosity  
<sup>Y</sup>WP=Water porosity  
<sup>Z</sup>AP=Air porosity

Table 4: Correlation matrix for the physical properties and  
Piston Flow Index (PFI) of all 10 mixes.

	BD <sup>V</sup>	PR <sup>W</sup>	Log(PR)	TP <sup>X</sup>	WP <sup>Y</sup>	AP <sup>Z</sup>
PR	-.78					
Log(PR)	-.95	.89				
TP	-1.00	.78	.95			
WP	.35	-.62	-.46	-.35		
AP	-.89	.86	.90	.89	-.75	
PFI	.81	-.82	-.84	-.81	.53	-.84

<sup>V</sup>BD=Bulk density  
<sup>W</sup>PR=Percolation rate  
<sup>X</sup>TP=Total porosity  
<sup>Y</sup>WP=Water porosity  
<sup>Z</sup>AP=Air porosity

( $r^2=.81$ ) (Fig. 2). The air porosity was a measure of the relative amount of large pores, which determine percolation rate. Bulk density was also found to be a good predictor of percolation rate (Fig. 3).

Particle size analysis of the various media components (Appendix II) showed that they were quite different. Since greenhouse mixes are formulated on a volume basis, the particle size distribution was expressed on a volume basis, as well as on the conventional weight basis. Expressing the particle size analysis on a weight basis may be misleading for some ingredients. For example, rockwool had a measurable percentage by weight in the .425, .150, and .075 mm fractions but no appreciable volume.

The particle size analysis of the individual components were used to construct representative particle size distribution curves for the glass bead mixes (Fig. 4) and the standard mixes (Fig. 5). Particle size distribution alone did not provide any information concerning the pore structure of the media components themselves, which can be significant in container media. Because of this, further work is needed to relate particle size distribution curves to pore geometry and leaching. Field soil studies have used particle size analysis in conjunction with other physical properties, to predict pore structure (29). However, the porous nature of the components used in greenhouse mixes invalidates the assumptions made in such studies.

Figure 2: Plot of log(percolation rate) versus air porosity. Regression lines for both the glass bead mixes alone and all mixes together are shown. (All mixes:  $\log(\text{PR}) = -.125 + 6.12\text{AP}$ ,  $r^2=.81$ ; Glass bead mixes:  $\log(\text{PR}) = -.286 + 6.43\text{AP}$ ,  $r^2=.95$ ). Confidence bands (95%) are for glass bead mixes.

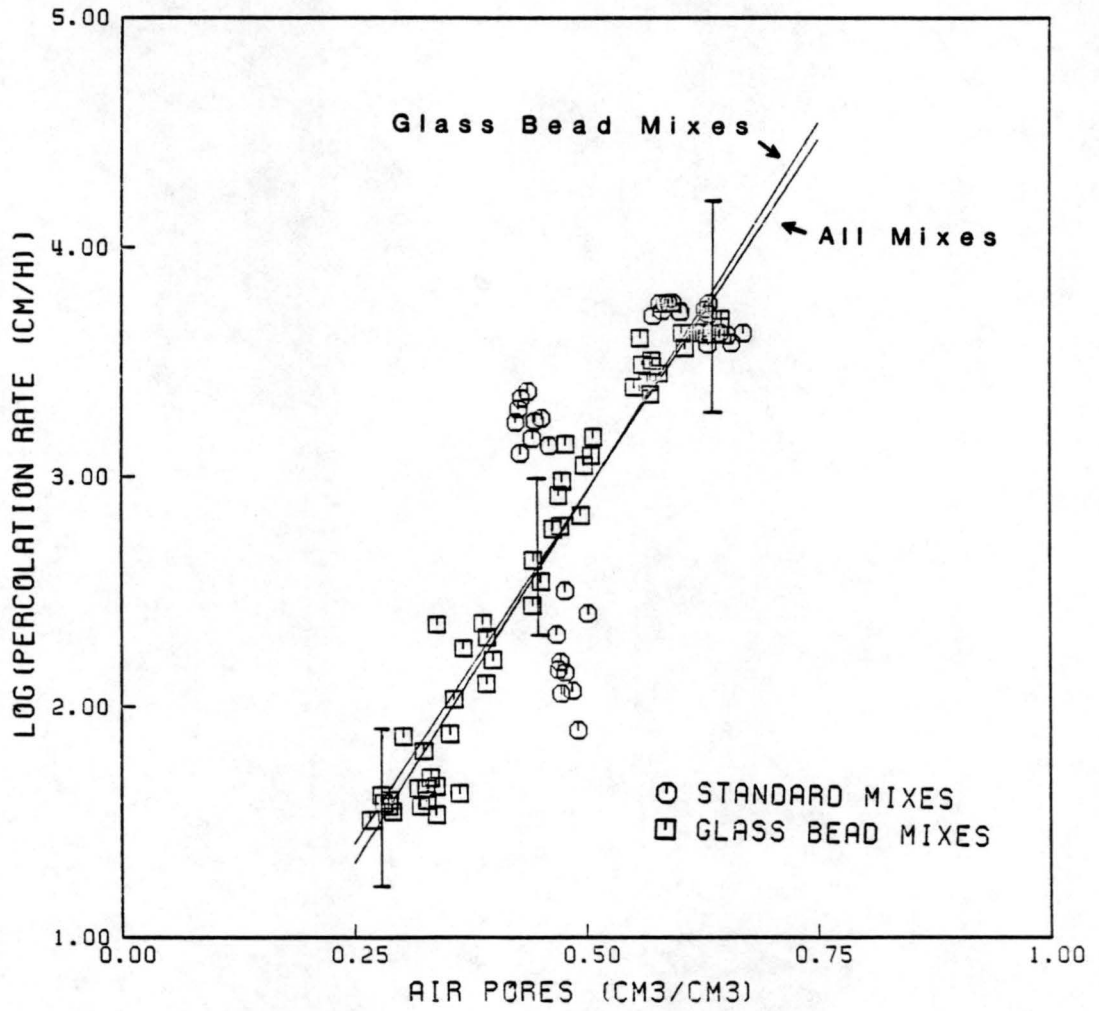


Figure 3: Plot of log(percolation rate) to bulk density. Regression lines are shown for both the glass bead mixes alone and all mixes together. (All mixes:  $\log(\text{PR}) = 3.81 - 3.29\text{BD}$ ,  $r^2 = .90$ ; Glass bead mixes:  $\log(\text{PR}) = 3.88 - 3.28\text{BD}$ ,  $r^2 = .96$ ). Confidence bands (95%) are for glass bead mixes.

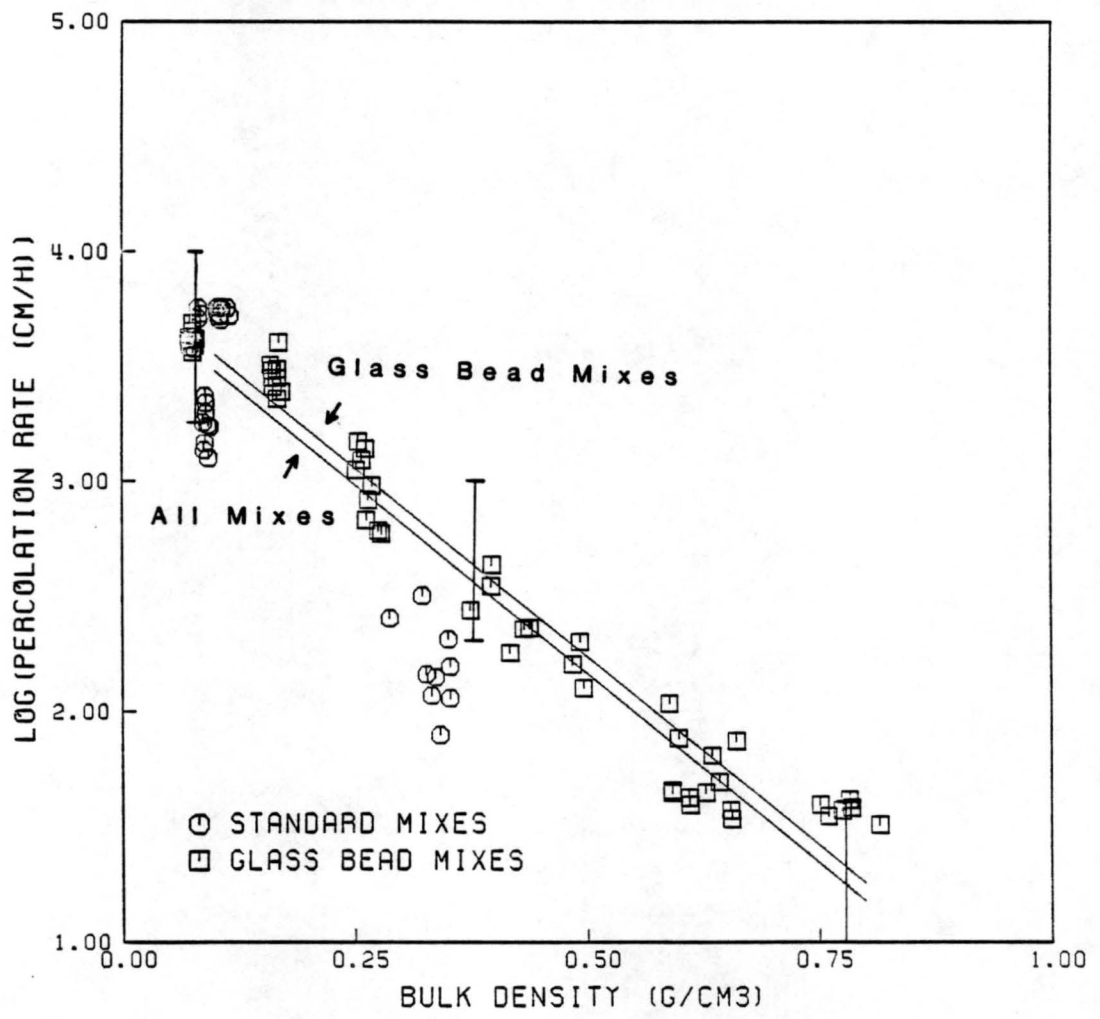


Figure 4: Cumulative particle size distribution curves for glass bead mixes. Constructed from analysis of media components.

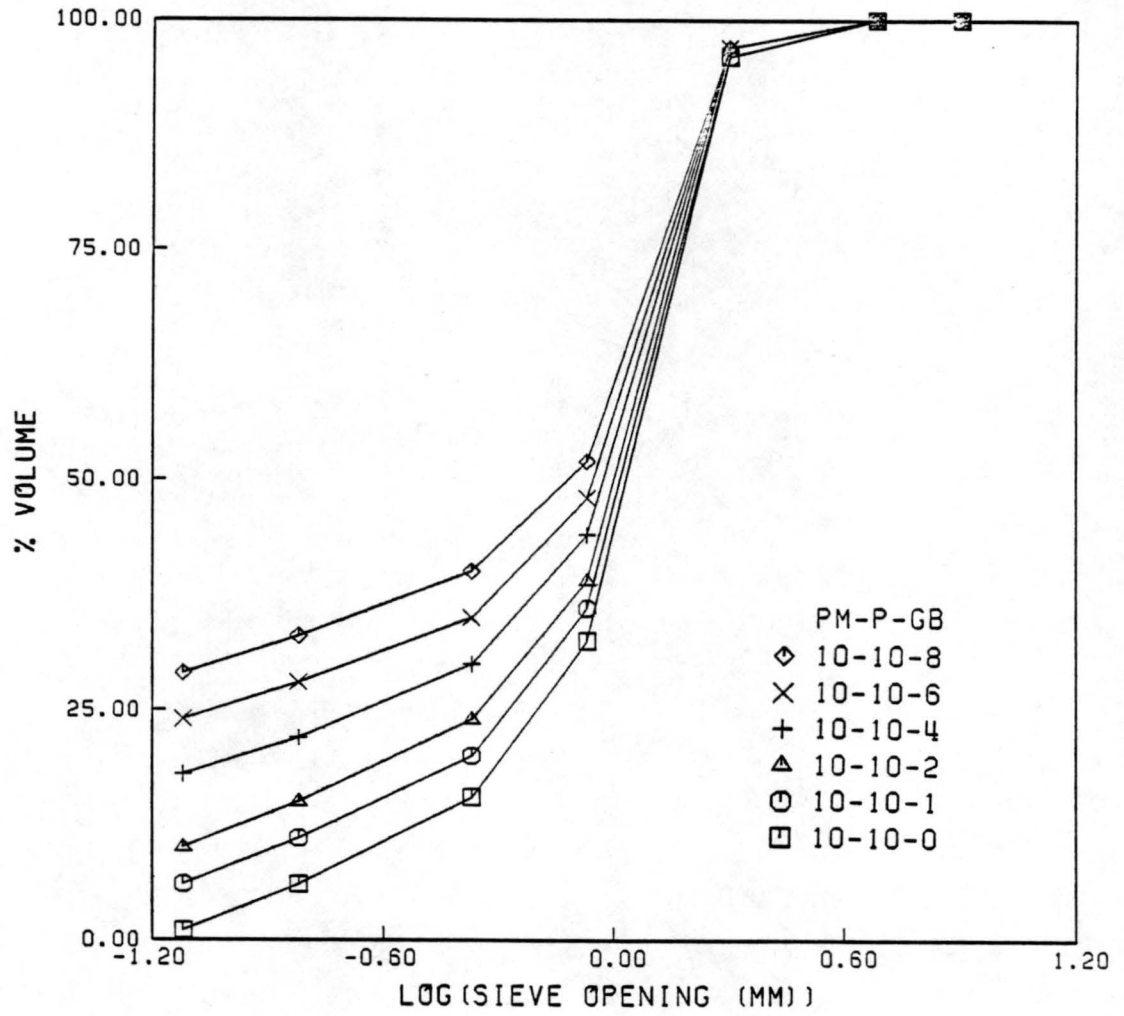
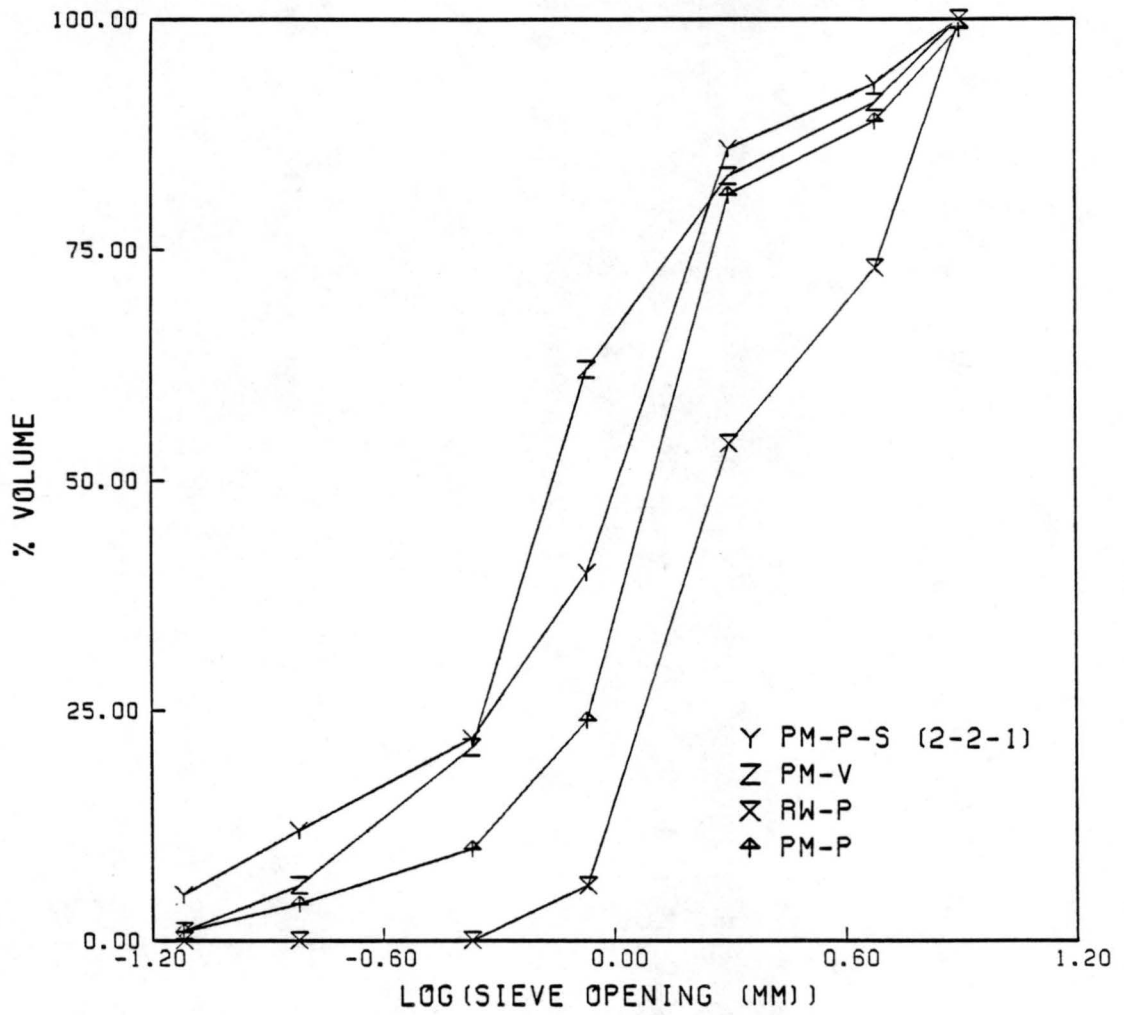


Figure 5: Cumulative particle size distribution curves for standard mixes. Constructed from analysis of media components.



It is of interest to note that the vermiculite used was the only component predominantly in the .850 mm fraction. This may account for the high moisture holding capacity of the PM-V. However, the lattice structure of vermiculite may have been a significant contributor to increased moisture holding capacity.

Except for percolation rate, the properties of the standard mixes (Table 2) were similar to those reported elsewhere (7,8,21,26,51,64). Percolation rates measured in this study ranged from 41 to 5436 cm hr<sup>-1</sup>, as compared to a previous high in the literature of 987 cm hr<sup>-1</sup> for a 1-1-1 mix of soil-almond hulls-bark (26). A mix with a percolation rate of 41 cm hr<sup>-1</sup> required 36 min for 500 ml of effluent to accumulate, whereas a mix with a percolation rate of 5436 cm hr<sup>-1</sup> required only 0.3 min.

The cation exchange capacities of the standard mixes (Table 5) were similar for PM-P and PM-V, with PM-P-S (2-2-1) being higher on a volume basis. On the other hand, RW-P had practically no exchange capacity. This demonstrated that mixes with a range of cation exchange capacities were tested in this study.

#### Leaching Curves

The average leaching curves for glass bead mixes (Fig. 6 - 8) showed a trend toward increased efficiency of replacement of the soil solution by the leaching solution with increased glass bead content for all three leaching solution concentrations. Of the standard mixes

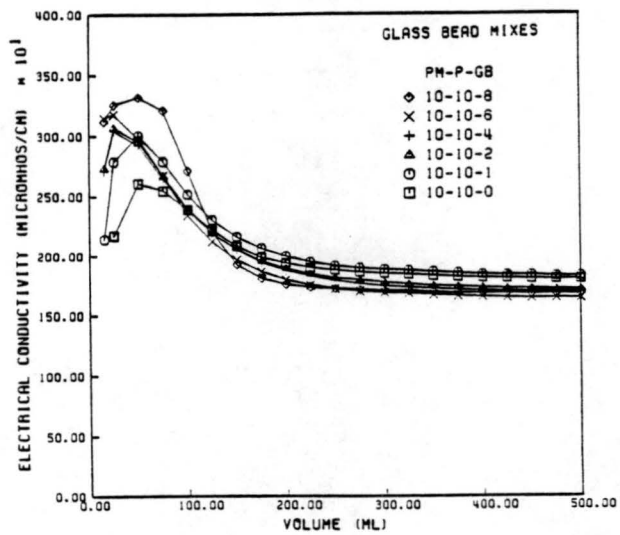
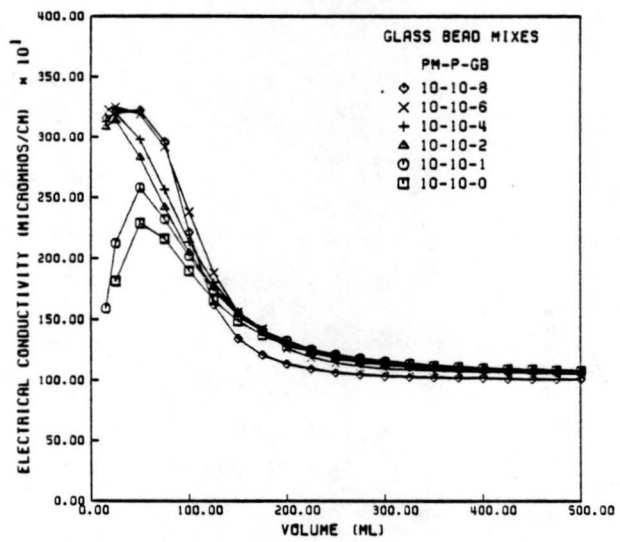
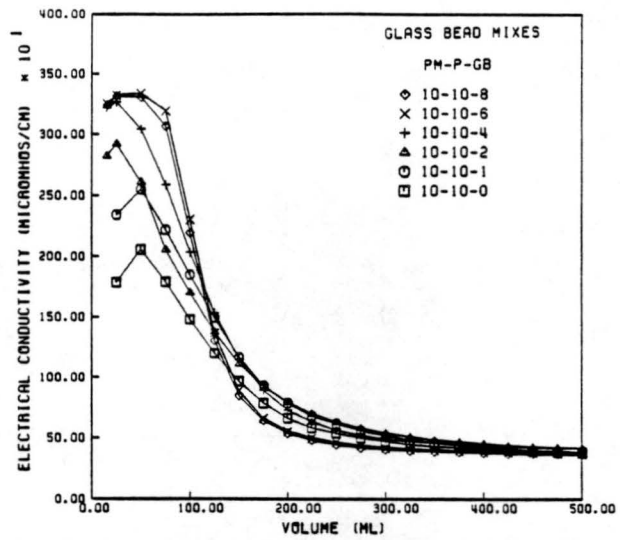
Table 5: Cation exchange capacity of standard potting mixes. PM-P should be a good estimate of PM-P-GB (10-10-0).

Mix	meq 100g <sup>-1</sup>	meq 100ml <sup>-1</sup>
PM-P	70	5.6
RW-P	2	0.2
PM-V	61	5.5
PM-P-S(2-2-1)	22	7.3

Figure 6: Leaching curves of glass bead mixes leached with 2 meq l<sup>-1</sup> solution. Leaching efficiency, maximum electrical conductivity, and slope after this maximum, all increased as glass bead content increased. Points shown are averages of three values.

Figure 7: Leaching curves of glass bead mixes leached with 8 meq l<sup>-1</sup> solution. Points shown are average of three values.

Figure 8: Leaching curves of glass bead mixes leached with 14 meq l<sup>-1</sup> solution. Points shown are average of three values.



(Fig. 9 - 11), the PM-P-S (2-2-1) and PM-V had more efficient replacement than RW-P or PM-P. (Data given in Appendix I.) This efficiency was reflected by the higher and broader peaks of the curves and also by a steeper leaching curve (an increased slope at the inflection point). For example, as percolation rate decreased, the maximum electrical conductivity of the leachate increased and the slope after the peak increased.

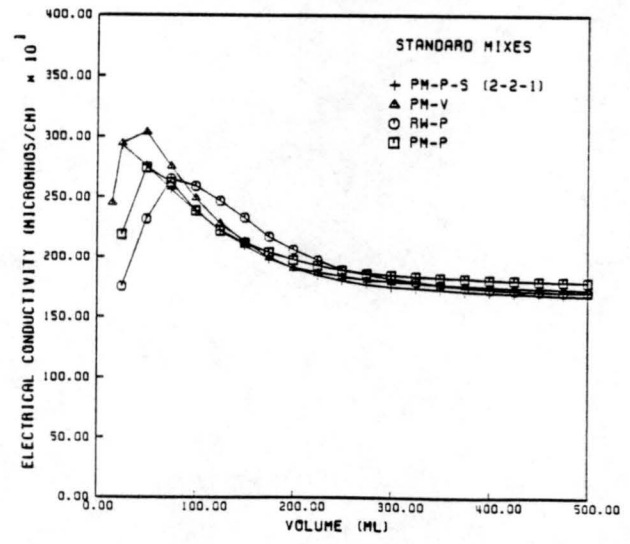
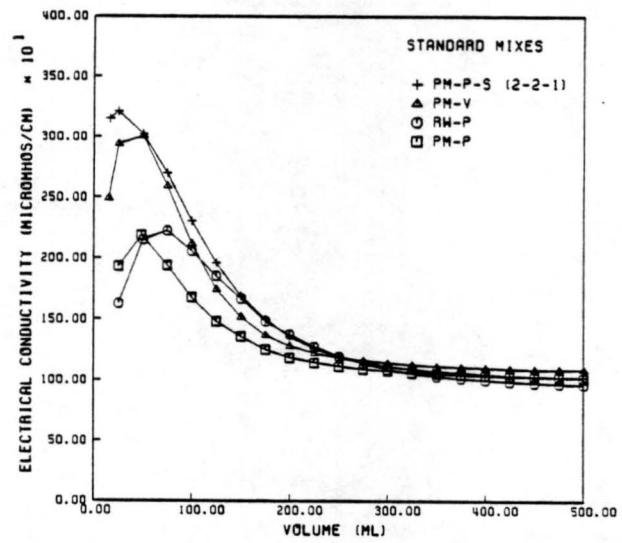
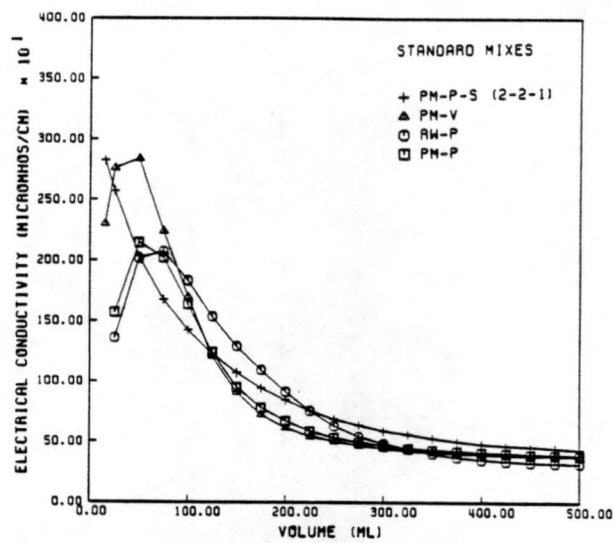
The initial increase in electrical conductivity of the leachate was also seen in the data of Schoonover and Sciaroni (53) and may have been due to large pores conducting leaching solution through the column with minimal displacement of the soil solution. Presumably, as leaching proceeded and the large pores were filled, increased conduction of water through the smaller pores resulted, increasing salt removal (increased electrical conductivity). The fact that this phenomenon was greater for more porous mixes substantiates this view. Also, Schoonover and Sciaroni (53) recorded this initial increase in electrical conductivity while using 4.5 cm deep columns, which discounted the possibility of the flow of leaching solution between the medium and the column wall as being the cause of this characteristic of the leaching curve.

The leaching curves presented also indicated that the electrical conductivity of the leachate cannot be used directly as a measure of the salinity of the potting mix. As these data show, the conductivity of the leachate only

Figure 9: Leaching curves of standard mixes leached with 2 meq l<sup>-1</sup> solution. Points shown are average of three values.

Figure 10: Leaching curves of standard mixes leached with 8 meq l<sup>-1</sup> solution. Points shown are average of three values.

Figure 11: Leaching curves of standard mixes leached with 14 meq l<sup>-1</sup> solution. Points shown are average of three values



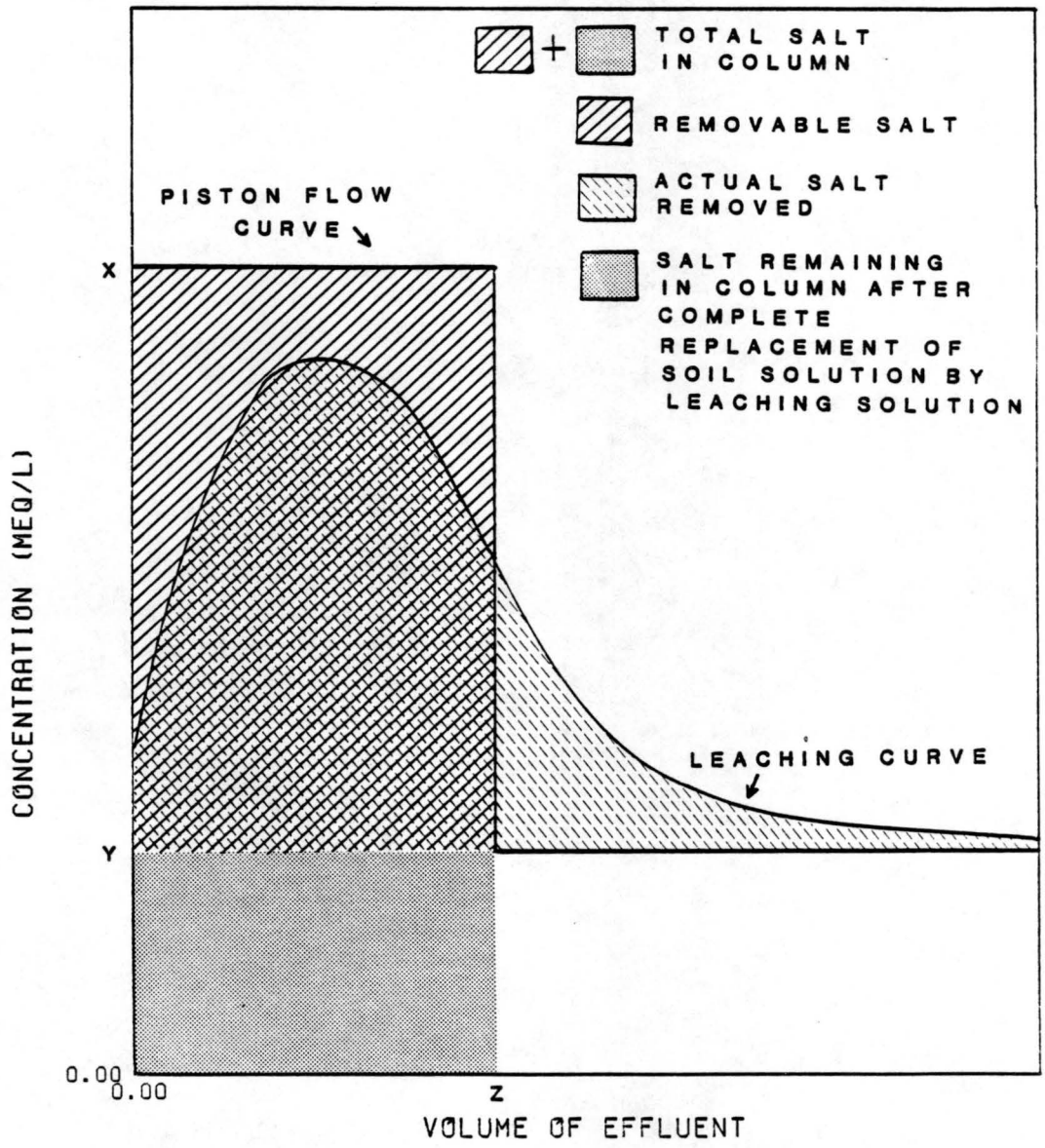
briefly reached the conductivity of the soil solution, and then only in the mixes with low percolation rates. The conductivity of the leachate from the more porous mixes never reached that of the soil solution. The physical properties of the mix (e.g. percolation rate, air porosity, water holding capacity) significantly influenced the salinity of the effluent. It is expected that several other factors including the leaching solution application rate and distribution, soil moisture content, container shape, crop, and leachate sample size will also affect the salinity of the effluent. The use of the electrical conductivity of the leachate as a measure of the soil solution concentration was developed (50) for large areas of field soils which would have relatively slow percolation rates (greater piston flow) and uniform distribution of the leaching water. Container culture is a shallow system with high percolation rates and a much less uniform distribution of the leaching water, even when flooded.

#### Replacement Efficiency

In order to quantify replacement efficiency, the data for each case were compared to the most efficient case i.e. piston flow. Piston flow would occur when one container capacity of leaching solution completely replaces the soil solution. The leaching curve for piston flow (Fig. 12) would be a straight horizontal line at the soil solution concentration, dropping instantaneously to the concentration of the leaching solution at one container capacity of

Figure 12: Theoretical Replacement curve for piston flow.

Where:  $X$  = soil solution concentration,  $Y$  =  
leaching solution concentration and  $Z = 1$  con-  
tainer capacity of effluent.



effluent. (The equation (electrical conductivity (micromhos  $\text{cm}^{-1}$ ) =  $78.34 - 109.0(\text{concentration (meq l}^{-1}\text{)})$ ), derived from standard solutions, was used to determine concentration. The concentration of the soil solution at the start of leaching was assumed to be equal to that of the salinization solution ( $30 \text{ meq l}^{-1}$ ) and the presence of extraneous salt in each medium was determined to be insignificant by preparing several soil columns with deionized water, instead of salt solution, and then leaching.) Since concentration times volume represents a quantity of salt leached (i.e.  $\text{meq l}^{-1} * \text{l} = \text{meq}$ ), the area under the piston flow curve, to one container capacity, would represent the total amount of salt in the column (Total Salt). The amount of salt actually removed from the column (Actual Salt Removed) is the area under the leaching curve corrected for the salt in the leaching solution (see Fig. 12). Since leaching cannot lower the soil solution concentration below that of the leaching solution, the actual amount of salt that can possibly be removed from the column (Removable Salt) is the total salt in the column minus the salt which would remain in the column after complete replacement of the soil solution by the leaching solution (i.e. Total Salt - salt remaining in column = Removable Salt).

The ratio of the amount of salt removed from the soil column after one container capacity of effluent to the Removable Salt (RS) was used as a measure of the efficiency of the replacement of the soil solution by the leaching

solution. A value of 1.0 would represent piston flow. This ratio, expressed as a percent, was the Piston Flow Index (PFI). Replacement efficiency (PFI) increased with increased glass bead content of the mixes (Table 2). Good correlations ( $r > .80$ ) existed between the physical properties of the glass bead mixes and PFI (Table 3). PFI increased as percolation rate, air porosity, and total pore space decreased, and as bulk density and water porosity increased. When all 10 mixes were included in the analysis (Table 4), the correlation between water porosity and PFI dropped substantially, possibly do to the high water porosity for PM-V. This information suggests that growers could manipulate their media components to create mixes which have more efficient leaching.

Regression of PFI on percolation rate (Fig. 13) found the equation  $PFI = 95.1 - 13.6 \log(\text{percolation rate})$  to have  $r^2 = .71$  for all mixes. The equation  $PFI = 101.0 - 92.3(\text{air porosity})$  had  $r^2 = .70$  for all mixes (Fig. 14). Both percolation rate and air porosity are relative measures of the amount of large pores in the mix.

#### Leaching Solution Concentration

A two way analysis of variance with medium and leaching solution concentration as treatments, showed that leaching solution concentration was not a significant factor in determining PFI. Replacement efficiency was not significantly influenced by leaching solution concentration. This did not mean that the soil solution was brought to the same

Figure 13: Relationship of Piston Flow Index (PFI) to log(percolation rate). Regression lines for glass bead mixes alone and all mixes together are shown. (All mixes:  $PFI = 95.1 - 13.6\log(PR)$ ,  $r^2 = .71$ ; Glass bead mixes:  $PFI = 94.3 - 12.6\log(PR)$ ,  $r^2 = .74$ ). Confidence bands (95%) are for all mixes.

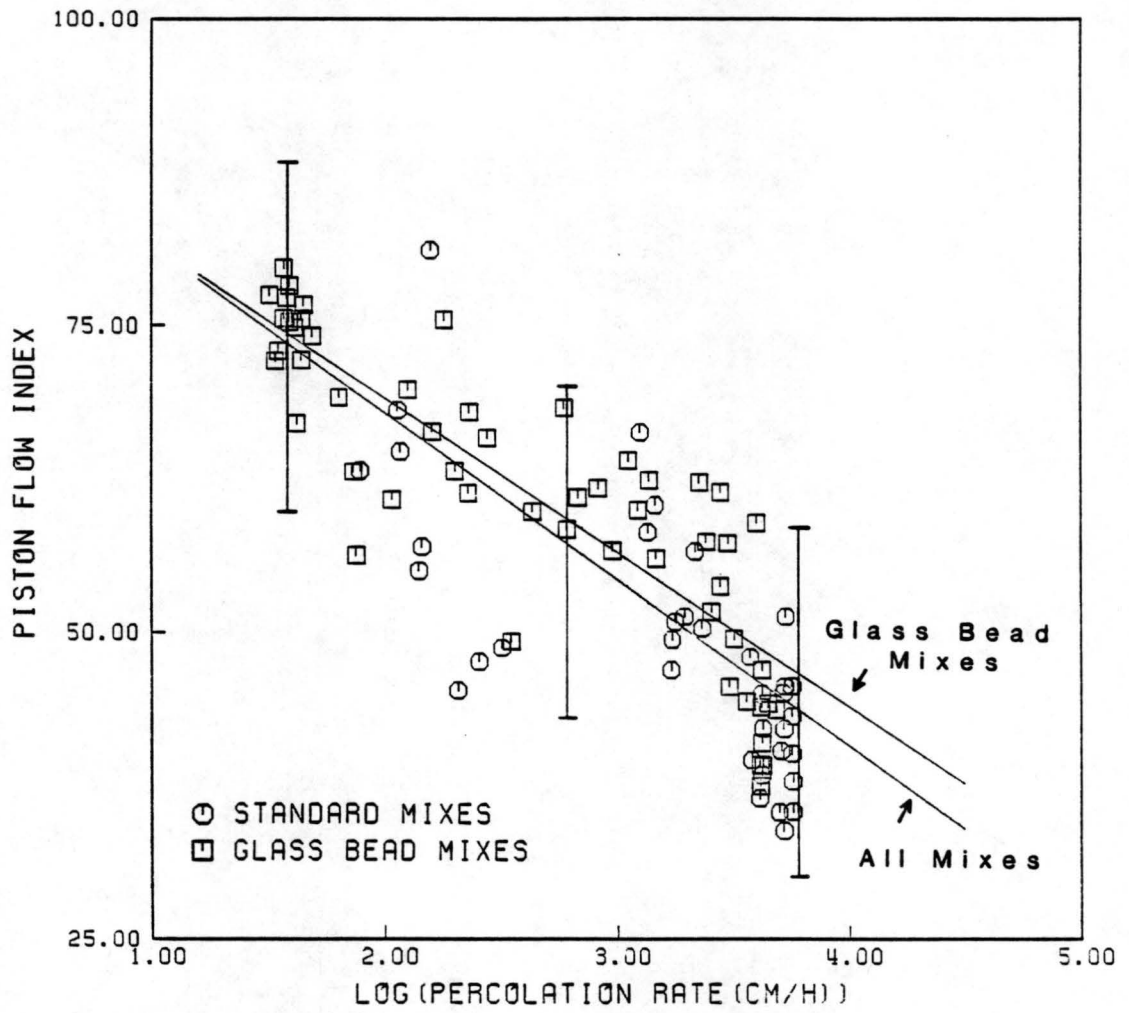
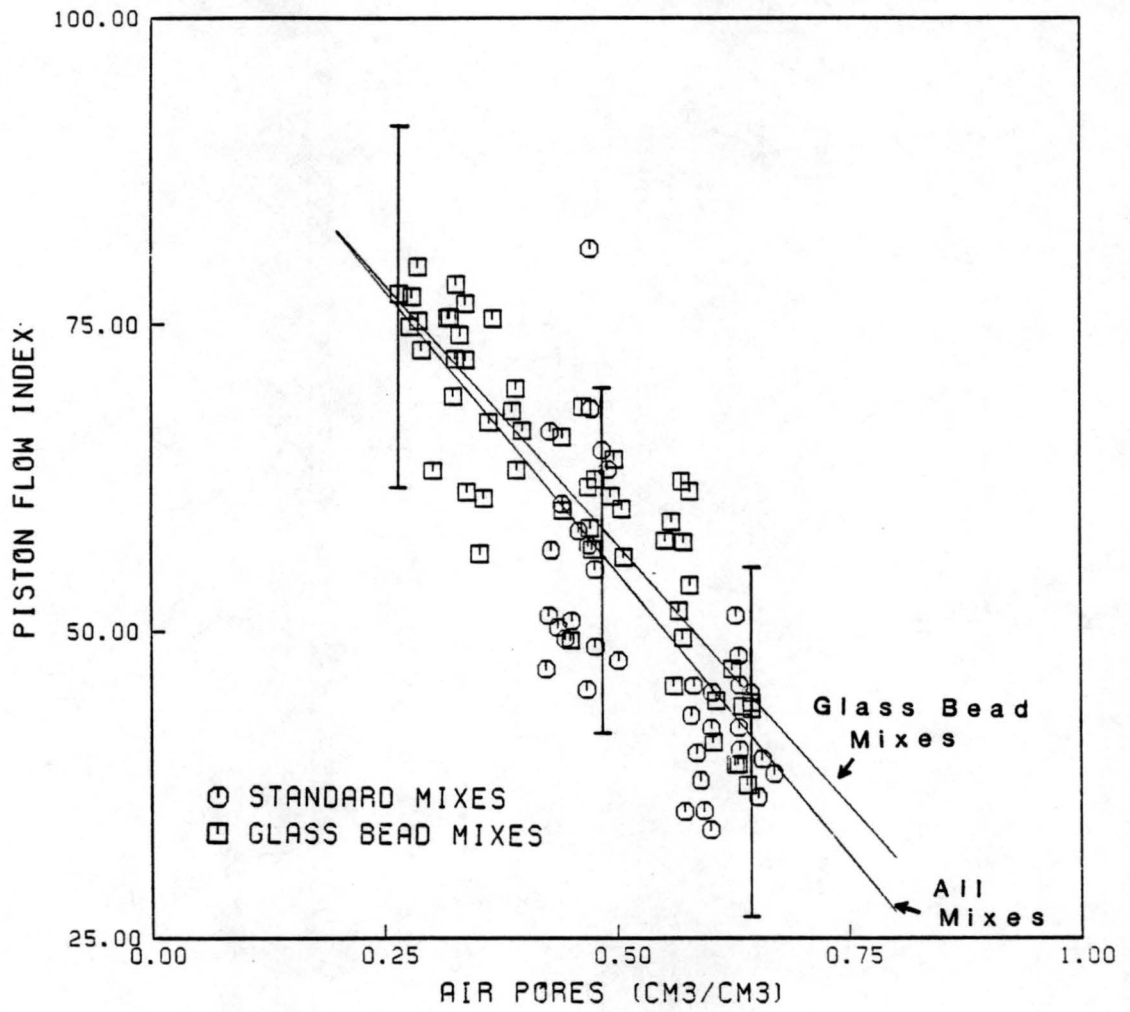


Figure 14: Plot of Piston Flow Index (PFI) versus air porosity. Regression lines for glass bead mixes alone and all mixes together are shown. (All mixes:  $PFI = 101.0 - 92.3AP$ ,  $r^2 = .70$ ; glass bead mixes:  $PFI = 99.7 - 85.2AP$ ,  $r^2 = .78$ ). Confidence bands (95%) are for all mixes.



concentration regardless of leaching solution concentration. It did show that several aspects of the leaching phenomenon were not of significant magnitude in potting mixes, or that their effects cancelled out. First, diffusion of ions from pores which do not conduct water into pores which do conduct water would increase where the concentration gradient is greater between the soil solution and the leaching solution, thereby increasing the PFI for leaching with low concentration solutions. Conversely, diffusion of ions at the interface of the soil solution and leaching solution would decrease PFI for the low concentration solutions. Second, variations in leaching solution concentration result in changes in the density and viscosity of the solution, which influence the mixing between the soil solution and the leaching solution (39). This difference in mixing would be reflected by a higher PFI for higher concentration leaching solutions. Third, leaching solution concentration may also influence the hydraulic conductivity of the soil (39), changing replacement efficiency.

Since no difference in PFI was noted as the result of leaching solution concentration, one may conclude that the effects outlined above were insignificant or that they cancelled one another. The large percolation rates of potting mixes would dictate a minimal opportunity time for diffusion, possibly negating the effect of diffusion on PFI. Together, this suggests that these factors discussed in the previous paragraph were not influential in regulating

leaching from potting mixes. It also indicated that the concentration of the soil solution should not influence the efficiency of replacement of the soil solution by leaching solution. Therefore, the mass flow of water through the medium is the only principle factor in leaching container media by continuous flooding. However, factors such as diffusion may come into play during intermittent leaching.

#### Salt Removal Equations

Plots of salt leached (Actual Salt Removed), expressed as a percent of the Total Salt in the column (% TS), versus volume of effluent, expressed in container capacities, for the glass bead mixes (Fig. 15 - 17) and the standard mixes (Fig. 18 - 20) showed the increase in salt removal brought about by leaching with solutions of lower concentration. The curves also changed with the medium's physical properties. Regression analysis was performed using the physical properties of the mix, leaching solution concentration, and volume of leachate (measured in container capacities) as predictors. Interaction terms were included as variables. Calculations were made with the intercept set to zero. Although the curves are theoretically sigmoidal, logarithmic relations were used to simplify interpretation. Many of the regression equations had adjusted  $R^2 > .90$ , showing that the physical properties of the mixes were somewhat interchangeable in the regression. This would be expected due to the correlations among physical properties. The equations chosen (Table 6) utilized water porosity (WP), leaching

Figure 15: Curves of salt leached from column expressed as % of Total Salt originally in column for glass bead mixes leached with 2 meq l<sup>-1</sup> solution. Data shown to 500 ml. Since the container capacity of the mixes vary, these curves do not end at the same X value. Each point is an average of three values.

Figure 16: Curves of salt leached expressed as % Total Salt for glass bead mixes leached with 8 meq l<sup>-1</sup> solution. Each point is an average of three values.

Figure 17: Curves of salt leached expressed as % Total Salt for glass bead mixes leached with 14 meq l<sup>-1</sup> solution. Each point is an average of three values.

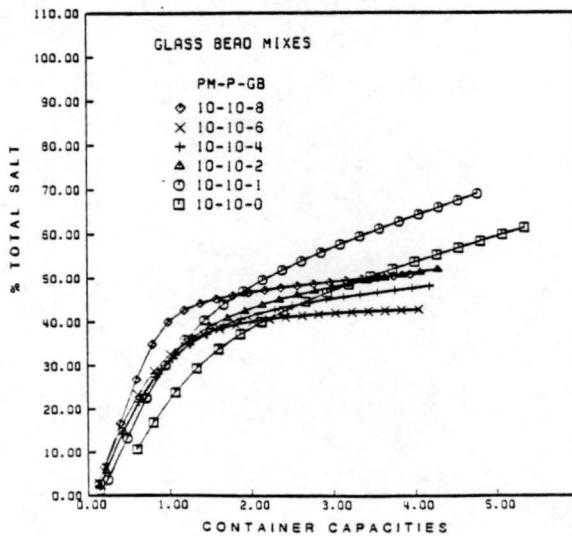
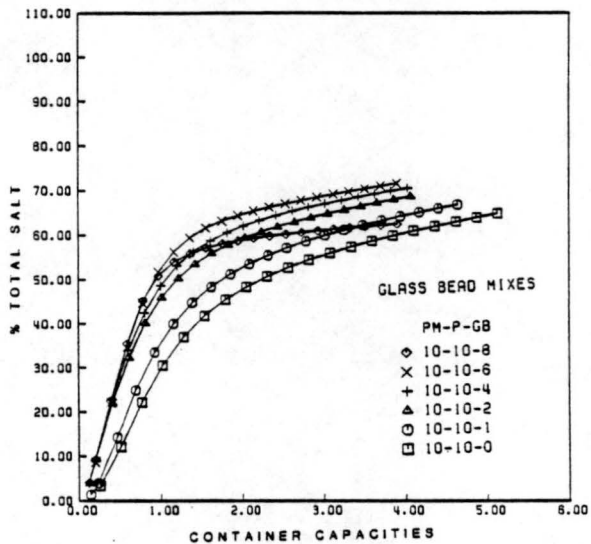
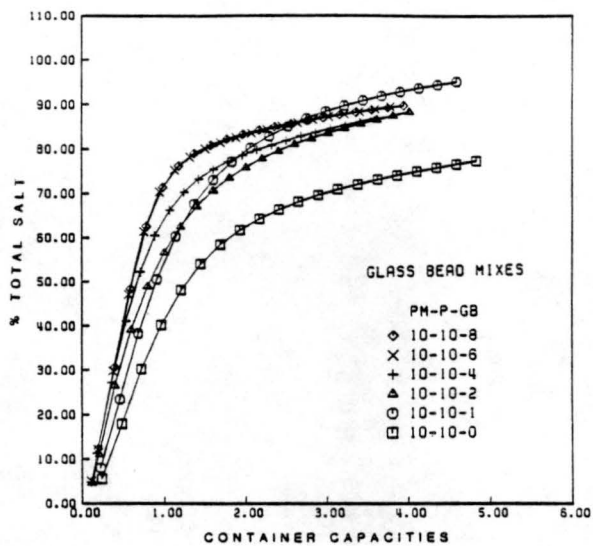


Figure 18: Curves of salt leached expressed as % of Total Salt for standard mixes leached with 2 meq l<sup>-1</sup> solution. Each point is an average of three values.)

Figure 19: Curves of salt leached expressed as % of Total Salt for standard mixes leached with 8 meq l<sup>-1</sup> solution.

Figure 20: Curves of salt leached expressed as % of Total Salt for standard mixes leached with 14 meq l<sup>-1</sup> solution. Each point is an average of three values.

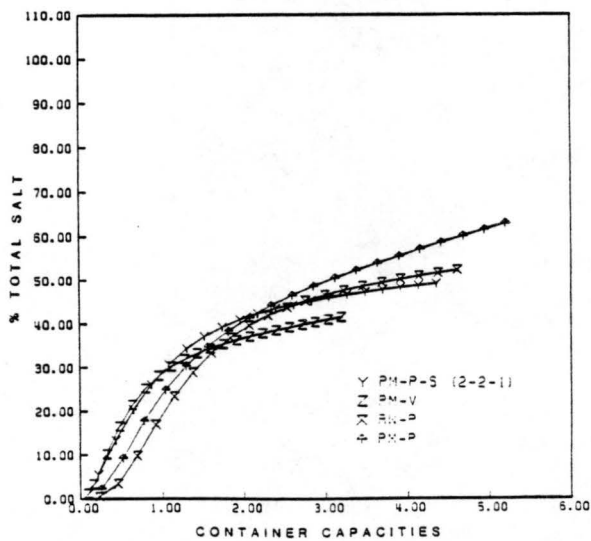
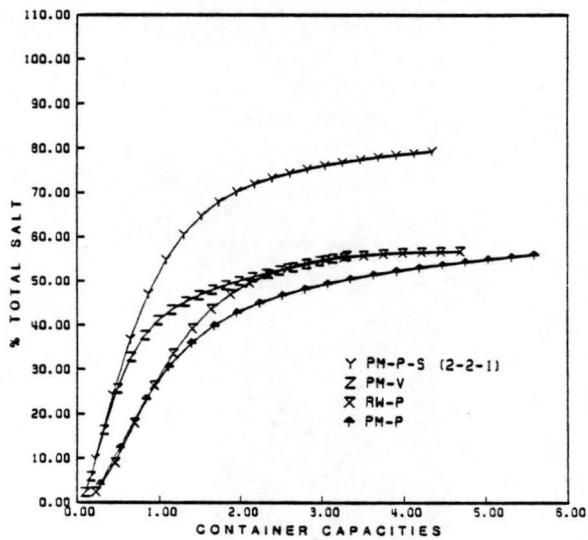
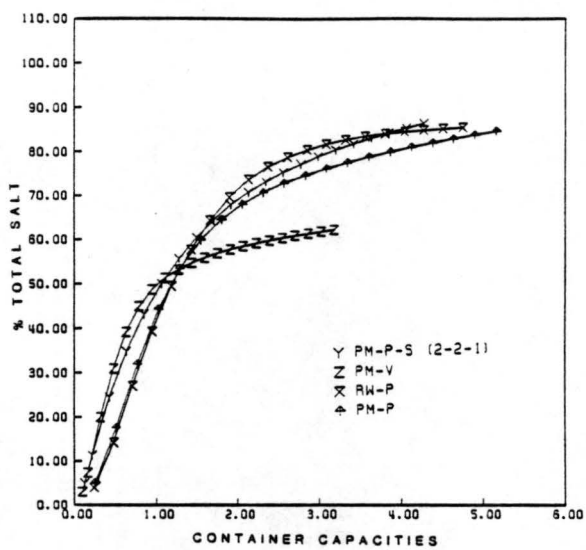


Table 6: Regression equations for salt removed during leaching expressed as % Total Salt (% TS), computed with intercept equal to zero.

Mixes tested	Equation	adj. R <sup>2</sup>
Glass bead mixes		
	% TS = 148.08 WP <sup>x</sup> - 1.94 LS <sup>y</sup> + 49.31 log(VL <sup>z</sup> )	.98
	% TS = 132.61 WP + 65.62 log(VL) - 0.72 (LS * VL)	.98
All mixes		
	% TS = 135.78 WP - 1.73 LS + 51.05 log(VL)	.96
	% TS = 121.52 WP + 65.59 log(VL) - 0.63 (LS * VL)	.96

<sup>x</sup>WP=Water porosity (cm<sup>3</sup> cm<sup>-3</sup>)

<sup>y</sup>LS=Leaching solution concentration (meq l<sup>-1</sup>)

<sup>z</sup>VL=Volume of leachate (container capacities)

solution concentration (LS), and volume of leachate (VL) (as container capacities) as predictors. The equation  $\% \text{ TS} = 135.78 \text{ WP} - 1.73 \text{ LS} + 51.05 \log(\text{VL})$  had adjusted  $R^2 = .96$  and can be used to determine how much leachate is required to bring the soil solution to a specified level as follows.

- Given:
1. Container capacity in  $\text{cm}^3$  (C)
  2. Water porosity in  $\text{cm}^3 \text{ cm}^{-3}$   
( $\text{WP} = \text{C} / \text{Bulk volume of soil}$ )
  3. Initial soil solution concentration in  $\text{meq l}^{-1}$  ( $\text{SS}_0$ )
  4. Desired soil solution concentration in  $\text{meq l}^{-1}$  ( $\text{SS}_1$ ) (cannot be lower than leaching solution concentration)
  5. Leaching solution concentration in  $\text{meq l}^{-1}$  (LS)

Calculate:

$$\text{TS} = \text{SS}_0 * (\text{C}/1000)$$

$$\text{SR} = \text{SS}_1 * (\text{C}/1000)$$

$$\% \text{ TS} = [(\text{TS} - \text{SR}) / \text{TS}] * 100$$

Where:

TS = Total meq of salt in container

SR = Meq salt remaining in column after leaching to desired level

$\% \text{ TS}$  =  $\%$  of TS to be leached

However, since C is constant for a given container of media, the calculations simplify to:

$$\% \text{ TS} = (\text{SS}_0 - \text{SS}_1) / \text{SS}_0$$

Then solve:

$$\% \text{ TS} = 135.78 \text{ WP} - 1.73 \text{ LS} + 51.05 \log(\text{VL})$$

Rearranging:

$$\text{VL} = \text{antilog}[(\% \text{ TS} - 135.78 \text{ WP} + 1.73 \text{ LS}) / 51.05]$$

For example, given:

$$C = 105 \text{ ml}$$

$$\text{WP} = .35 \text{ cm}^3/\text{cm}^3$$

$$\text{SS}_0 = 30 \text{ meq l}^{-1}$$

$$\text{SS}_1 = 15 \text{ meq l}^{-1}$$

$$\text{LS} = 10 \text{ meq l}^{-1}$$

Then:

$$\% \text{ TS} = [(30 - 15) / 30] * 100$$

$$\% \text{ TS} = 50$$

And:

$$\text{VL} = \text{antilog}[(50 - (135.78 * .35) + (1.73 * 10)) / 51.05]$$

$$\text{VL} = 2.44 \text{ container capacities}$$

Thus, given these conditions, 2.44 container capacities of drainage would be required to lower the soil solution concentration from 30 meq l<sup>-1</sup> to 15 meq l<sup>-1</sup>.

The above method deals with replacement efficiency and leaching solution concentration simultaneously. However, an alternate method was possible when salt leached was expressed as % Removable Salt (% RS). This can be interpreted directly as % replacement of the soil solution by the leaching solution and, as shown above for PFI, was not influenced by leaching solution concentration or initial salt level of the soil. Figures 21 and 22 show % RS versus container capacities of effluent for the glass bead mixes

Figure 21: Curves of salt leached from column expressed as  
% Removable Salt for glass bead mixes. Data for  
all three leaching solutions were combined.  
Points shown are average of nine values.

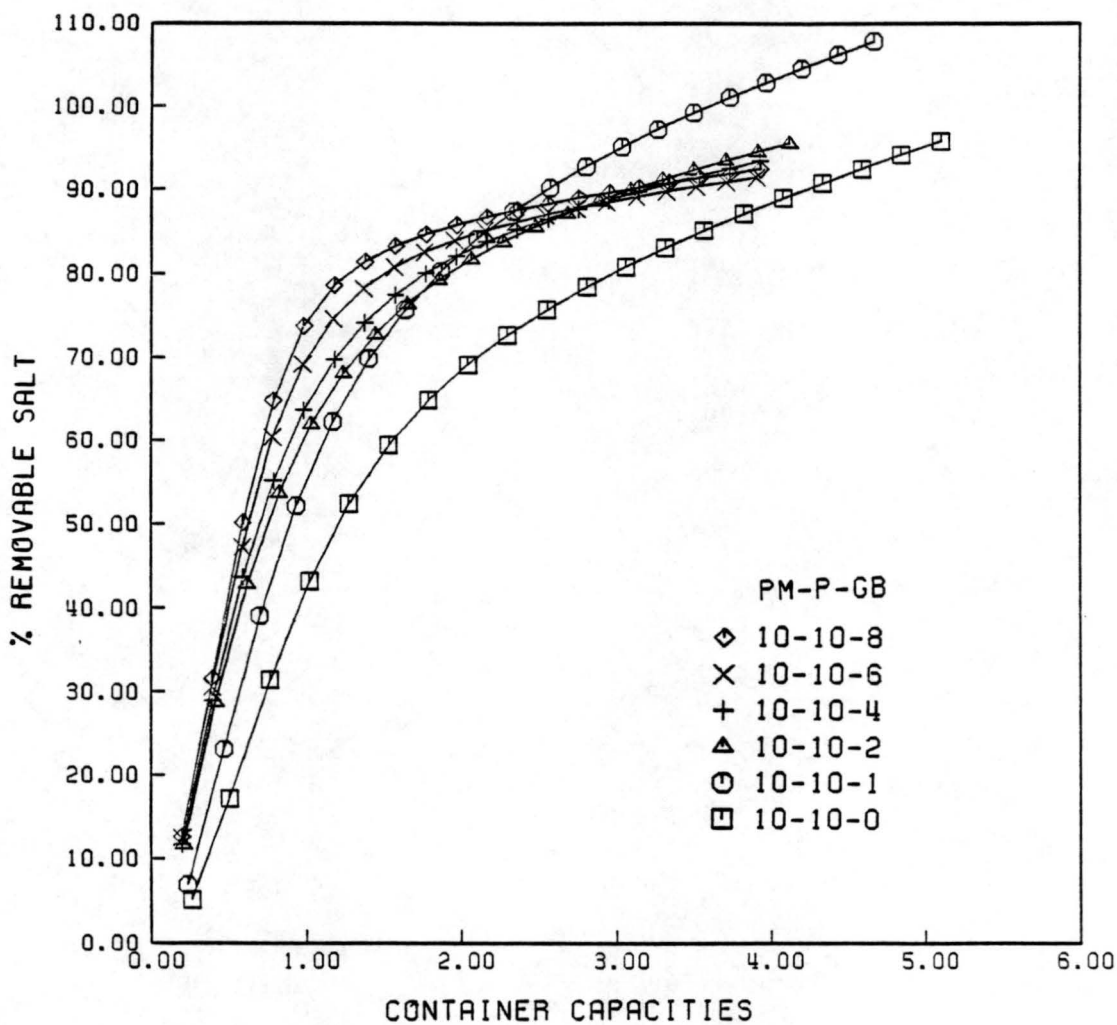
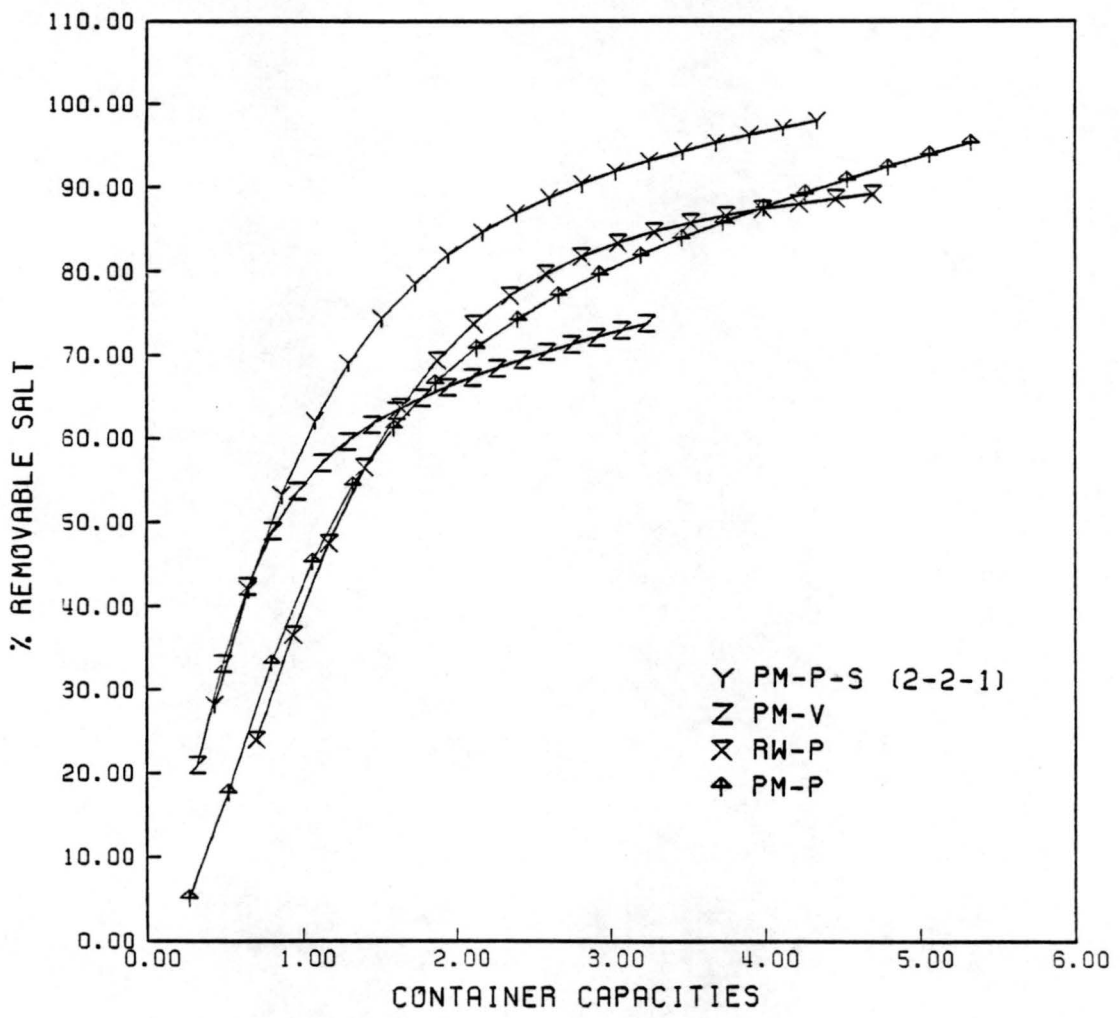


Figure 22: Curves of salt leached from column expressed as  
% Removable Salt for standard mixes. Data for  
all three leaching solutions were combined.  
Points shown are average of nine values.



and the standard mixes, respectively. Data from all leaching solutions were combined because % RS compensates for leaching solution concentration. The fact that the rate of salt removal decreased dramatically between 1 and 1.5 container capacities of effluent suggested that one could use these values as a general rule of thumb for leaching. Regression analysis of % RS on the same predictors used above for % TS, revealed that the equation  $\% \text{ RS} = 138.34 \text{ WP} + 69.07 \log(\text{VL})$  had  $\text{adj. } R^2 = .97$  (Table 7). Note that this equation did not contain leaching solution as a predictor and, as above, other physical properties gave reasonable multiple correlation coefficients.

Since this equation predicts % replacement of the soil solution by the leaching solution, one need only calculate the % of the original soil solution which would require replacement (% RS) in order to determine the leaching requirement. Calculations, given the same example as for % TS, would be:

$$\% \text{ RS} = [(SS_0 - SS_1) / (SS_0 - LS)] * 100$$

Substituting:

$$\% \text{ RS} = [(30-15)/(30-10)] * 100$$

$$\% \text{ RS} = 75$$

Solving the regression equation:

$$\text{VL} = \text{antilog} [(\% \text{ RS} - 138.34 \text{ WP}) / 69.07]$$

$$\text{VL} = \text{antilog} [(75 - (138.34 * .35)) / 69.07]$$

$$\text{VL} = 2.43 \text{ container capacities}$$

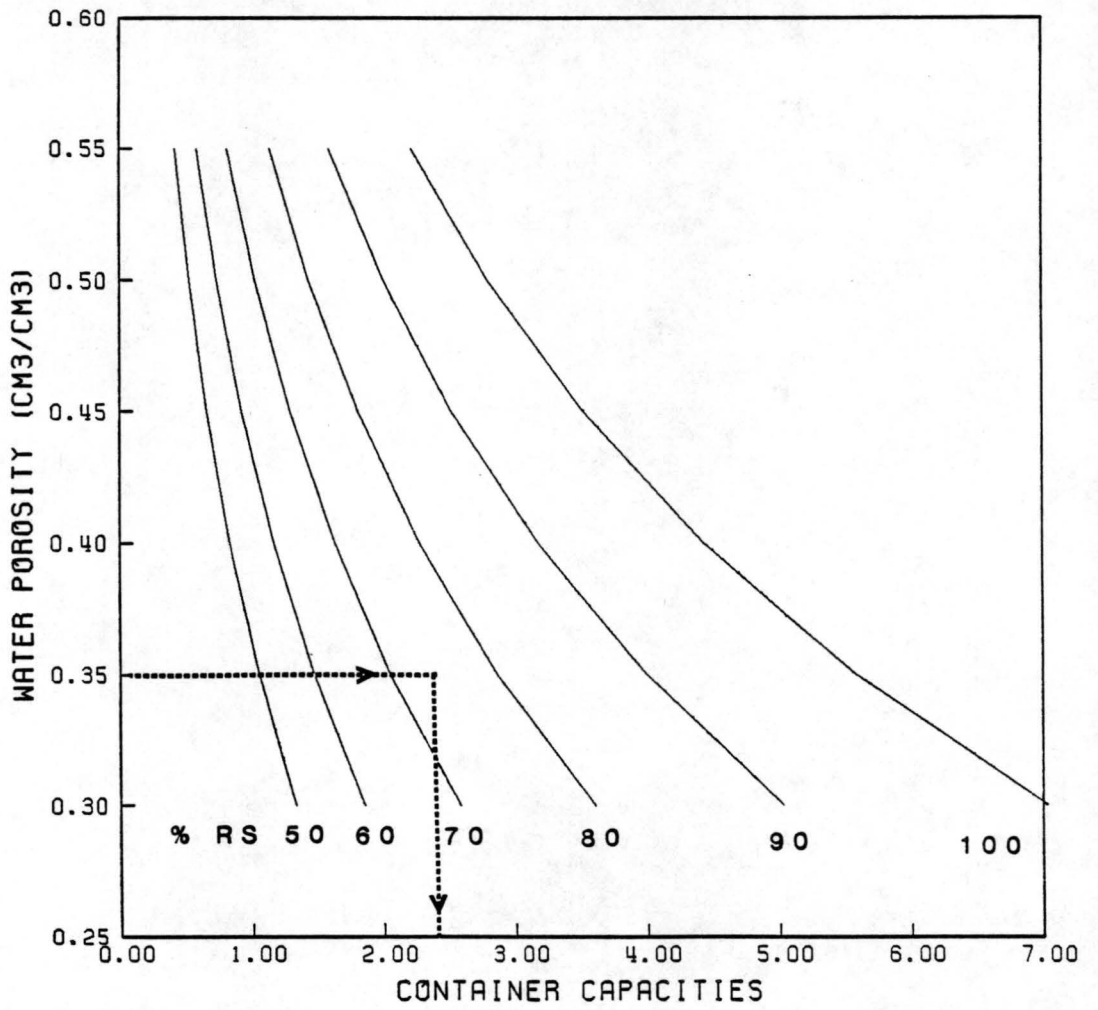
Table 7: Regression equations for salt removed during leaching expressed as % Removable Salt (% RS) and calculated with intercept equal to zero.

Mixes tested	Equation	adj. R <sup>2</sup>
Glass bead mixes	$\% \text{ RS} = 148.41 \text{ WP}^Y + 67.39 \log(\text{VL}^Z)$	.98
All mixes	$\% \text{ RS} = 138.34 \text{ WP} + 69.07 \log(\text{VL})$	.97

<sup>Y</sup>WP=Water porosity (cm<sup>3</sup> cm<sup>-3</sup>)

<sup>Z</sup>VL=Volume of leachate (container capacities)

Figure 23: Contour plot of the regression equation for % Removable Salt. After calculation of % RS =  $[(SS_0 - SS_1) / (SS_0 - LS)] * 100$ , one could determine the volume of leachate required by following horizontally from the water porosity of the given mix to the appropriate % RS, then reading volume. For the example given in the text (Water porosity = .35 and % RS = 75), the volume of leachate required is 2.44 container capacities (dashed line).



After finding % RS, one could use a contour plot of the regression equation (Fig. 23) to find the volume of leachate required by simply following horizontally from WP of the vertical axis to the desired % RS contour line and then reading VL. In this example, VL = 2.4 container capacities.

It was intended that this plot (Fig. 23) could be used as a first step toward developing recommendations for leaching of salt from potting media. It should be kept in mind that these equations were developed for leaching chloride salts by continuous flooding when the mixes were initially at container capacity. Further investigations are required to determine and quantify the changes in leaching caused by different initial soil moisture levels, different application rates, limited distribution of the leaching solution, distribution of salts in the soil profile, and different salt types. The effect of salt type would be expected mainly in the presence of significant quantities of calcium and magnesium carbonates and calcium sulfate, which precipitate at very low concentrations.

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APPENDICES

APPENDIX I

Table 8: Data from leaching curves for mixes leached  
with 2 meq l<sup>-1</sup> solution.

Mix	Vol. <sup>y</sup>	EC <sup>z</sup>	Vol.	EC	Vol.	EC
PM-P-GB 10-10-0						
	25.	1640.	25.	1840.	25.	1880.
	45.	1960.	50.	2110.	37.	2100.
	50.	1960.	61.	2110.	50.	2100.
	75.	1680.	75.	1930.	75.	1760.
	100.	1440.	100.	1630.	100.	1360.
	125.	1130.	125.	1380.	125.	1080.
	150.	900.	150.	1100.	150.	900.
	175.	760.	175.	870.	175.	730.
	200.	650.	200.	690.	200.	650.
	225.	580.	225.	600.	225.	570.
	250.	540.	250.	550.	250.	530.
	275.	500.	275.	510.	275.	490.
	300.	470.	300.	470.	300.	470.
	325.	450.	325.	440.	325.	440.
	350.	430.	350.	430.	350.	420.
	375.	420.	375.	420.	375.	410.
	400.	410.	400.	410.	400.	400.
	425.	400.	425.	400.	425.	390.
	450.	400.	450.	400.	450.	380.
	475.	390.	475.	390.	475.	370.
	500.	380.	500.	380.	500.	370.
PM-P-GB 10-10-1						
	25.	2000.	15.	1600.	15.	2340.
	50.	2590.	25.	2340.	25.	2680.
	58.	2610.	45.	2550.	35.	2690.
	75.	2470.	50.	2560.	50.	2500.
	100.	2200.	75.	2210.	75.	1970.
	125.	1790.	100.	1800.	100.	1540.
	150.	1350.	125.	1450.	125.	1230.
	175.	1000.	150.	1140.	150.	1000.
	200.	840.	175.	940.	175.	840.
	225.	710.	200.	830.	200.	690.
	250.	640.	225.	730.	225.	600.
	275.	570.	250.	670.	250.	540.
	300.	530.	275.	610.	275.	500.
	325.	480.	300.	560.	300.	460.
	350.	460.	325.	520.	325.	440.
	375.	440.	350.	490.	350.	420.
	400.	420.	375.	460.	375.	410.
	425.	410.	400.	440.	400.	400.
	450.	400.	425.	420.	425.	390.
	475.	390.	450.	400.	450.	380.
	500.	380.	475.	390.	475.	380.
			500.	380.	500.	370.

Table 8 (continued)

Mix	Vol.	EC	Vol.	EC	Vol.	EC
PM-P-GB 10-10-2	15.	2670.	15.	2980.	15.	2820.
	25.	2890.	20.	3070.	21.	2840.
	33.	2890.	25.	3070.	25.	2810.
	50.	2640.	31.	3070.	50.	2420.
	75.	2210.	50.	2770.	75.	1960.
	100.	1820.	75.	1990.	100.	1570.
	125.	1540.	100.	1710.	125.	1280.
	150.	1260.	125.	1300.	150.	1040.
	175.	1070.	150.	1030.	175.	880.
	200.	930.	175.	830.	200.	750.
	225.	810.	200.	700.	225.	670.
	250.	720.	225.	610.	250.	610.
	275.	660.	250.	560.	275.	560.
	300.	610.	275.	510.	300.	530.
	325.	570.	300.	480.	325.	490.
	350.	530.	325.	460.	350.	470.
	375.	510.	350.	440.	375.	460.
	400.	490.	375.	430.	400.	450.
	425.	470.	400.	420.	425.	430.
	450.	460.	425.	410.	450.	410.
	475.	450.	450.	410.	475.	400.
	500.	440.	475.	410.	500.	400.
			500.	410.		
PM-P-GB 10-10-4	15.	3130.	15.	3320.	15.	3210.
	19.	3190.	25.	3330.	21.	3270.
	25.	3190.	43.	3340.	25.	3280.
	50.	2810.	50.	3320.	28.	3280.
	75.	2290.	75.	3020.	50.	3000.
	100.	1840.	100.	2370.	75.	2450.
	125.	1450.	125.	1690.	100.	1890.
	150.	1140.	150.	1180.	125.	1450.
	175.	910.	175.	870.	150.	1120.
	200.	740.	200.	700.	175.	900.
	225.	650.	225.	600.	200.	750.
	250.	570.	250.	540.	225.	650.
	275.	530.	275.	500.	250.	580.
	300.	490.	300.	470.	275.	530.
	325.	470.	325.	460.	300.	500.
	350.	450.	350.	450.	325.	480.
	375.	440.	375.	440.	350.	470.
	400.	430.	400.	430.	375.	460.
	425.	430.	425.	420.	400.	440.
	450.	420.	450.	420.	425.	440.
	475.	420.	475.	410.	450.	430.
	500.	410.	500.	410.	475.	430.
					500.	430.

Table 8 (continued)

Mix	Vol.	EC	Vol.	EC	Vol.	EC
PM-P-GB 10-10-6						
	15.	3250.	15.	3270.	15.	3240.
	25.	3330.	25.	3330.	25.	3310.
	50.	3330.	50.	3340.	50.	3340.
	64.	3330.	54.	3340.	60.	3340.
	75.	3260.	75.	3120.	75.	3200.
	100.	2420.	100.	2210.	100.	2280.
	125.	1340.	125.	1380.	125.	1370.
	150.	850.	150.	910.	150.	910.
	175.	640.	175.	670.	175.	670.
	200.	530.	200.	560.	200.	570.
	225.	480.	225.	490.	225.	520.
	250.	450.	250.	460.	250.	480.
	275.	430.	275.	430.	275.	450.
	300.	410.	300.	420.	300.	420.
	325.	400.	325.	410.	325.	410.
	350.	390.	350.	400.	350.	400.
	375.	380.	375.	400.	375.	400.
	400.	380.	400.	390.	400.	390.
	425.	380.	425.	380.	425.	390.
	450.	380.	450.	380.	450.	380.
	475.	370.	475.	380.	475.	380.
	500.	370.	500.	370.	500.	370.
PM-P-GB 10-10-8						
	15.	3200.	15.	3270.	17.	3250.
	25.	3310.	25.	3320.	25.	3320.
	50.	3320.	43.	3320.	50.	3320.
	63.	3320.	50.	3280.	63.	3320.
	75.	3180.	75.	2850.	75.	3170.
	100.	2270.	100.	2100.	100.	2210.
	125.	1210.	125.	1380.	125.	1320.
	150.	730.	150.	960.	150.	850.
	175.	570.	175.	720.	175.	640.
	200.	490.	200.	580.	200.	540.
	225.	450.	225.	510.	225.	480.
	250.	420.	250.	460.	250.	450.
	275.	400.	275.	430.	275.	420.
	300.	390.	300.	410.	300.	410.
	325.	380.	325.	400.	325.	400.
	350.	370.	350.	400.	350.	390.
	375.	370.	375.	390.	375.	390.
	400.	370.	400.	380.	400.	380.
	425.	360.	425.	370.	425.	380.
	450.	360.	450.	370.	450.	370.
	475.	360.	475.	370.	475.	370.
	500.	360.	500.	360.	500.	370.
PM-P						
	25.	1100.	25.	1640.	25.	1980.

Table 8 (continued)

Mix	Vol.	EC	Vol.	EC	Vol.	EC
	50.	2060.	50.	2100.	50.	2280.
	67.	2060.	60.	2080.	60.	2270.
	75.	1930.	75.	2000.	75.	2140.
	100.	1610.	100.	1640.	100.	1660.
	125.	1190.	125.	1240.	125.	1280.
	150.	840.	150.	1000.	150.	1010.
	175.	700.	175.	820.	175.	820.
	200.	610.	200.	700.	200.	700.
	225.	540.	225.	610.	225.	600.
	250.	500.	250.	550.	250.	540.
	275.	460.	275.	510.	275.	510.
	300.	440.	300.	480.	300.	480.
	325.	420.	325.	460.	325.	450.
	350.	410.	350.	440.	350.	440.
	375.	400.	375.	430.	375.	430.
	400.	390.	400.	420.	400.	420.
	425.	390.	425.	410.	425.	410.
	450.	380.	450.	400.	450.	400.
	475.	370.	475.	400.	475.	400.
	500.	370.	500.	390.	500.	390.
RW-P						
	25.	1320.	25.	1560.	25.	1200.
	50.	2090.	50.	2000.	50.	1960.
	68.	2130.	75.	2020.	75.	2080.
	75.	2120.	100.	1810.	100.	1760.
	100.	1930.	125.	1570.	125.	1490.
	125.	1540.	150.	1350.	150.	1240.
	150.	1270.	175.	1140.	175.	1100.
	175.	1040.	200.	950.	200.	920.
	200.	870.	225.	790.	225.	750.
	225.	720.	250.	650.	250.	620.
	250.	610.	275.	550.	275.	550.
	275.	520.	300.	490.	300.	490.
	300.	470.	325.	440.	325.	440.
	325.	430.	350.	400.	350.	400.
	350.	400.	375.	370.	375.	360.
	375.	380.	400.	350.	400.	340.
	400.	360.	425.	340.	425.	330.
	425.	340.	450.	330.	450.	320.
	450.	330.	475.	320.	475.	320.
	475.	320.	500.	320.	500.	310.
	500.	320.				
PM-V						
	15.	2560.	15.	2300.	15.	2040.
	25.	2940.	25.	2700.	25.	2640.
	30.	3010.	38.	2910.	35.	2800.
	37.	3010.	50.	2910.	45.	2800.
	50.	2840.	75.	2490.	50.	2760.
	75.	1990.	100.	1920.	75.	2240.
	100.	1580.	125.	1370.	100.	1600.

Table 8 (continued)

Mix	Vol.	EC	Vol.	EC	Vol.	EC
	125.	1130.	150.	1040.	125.	1110.
	150.	840.	175.	790.	150.	840.
	175.	700.	200.	650.	175.	680.
	200.	600.	225.	560.	200.	590.
	225.	540.	250.	510.	225.	520.
	250.	510.	275.	470.	250.	480.
	275.	480.	300.	440.	275.	450.
	300.	460.	325.	420.	300.	430.
	325.	440.	350.	410.	325.	410.
	350.	430.	375.	400.	350.	400.
	375.	420.	400.	400.	375.	390.
	400.	410.	425.	380.	400.	380.
	425.	400.	450.	380.	425.	380.
	450.	400.	475.	380.	450.	370.
	475.	400.	500.	380.	475.	370.
	500.	390.			500.	360.
PM-P-S						
2-2-1						
	15.	2920.	15.	2760.	15.	2790.
	25.	2720.	25.	2510.	25.	2480.
	50.	2270.	50.	1950.	50.	1880.
	75.	1920.	75.	1590.	75.	1520.
	100.	1650.	100.	1350.	100.	1270.
	125.	1410.	125.	1170.	125.	1090.
	150.	1240.	150.	1010.	150.	960.
	175.	1080.	175.	890.	175.	850.
	200.	950.	200.	810.	200.	770.
	225.	840.	225.	730.	225.	690.
	250.	720.	250.	680.	250.	650.
	275.	660.	275.	630.	275.	610.
	300.	600.	300.	590.	300.	570.
	325.	560.	325.	570.	325.	550.
	350.	520.	350.	540.	350.	520.
	375.	480.	375.	520.	375.	500.
	400.	470.	400.	490.	400.	480.
	425.	450.	425.	480.	425.	470.
	450.	440.	450.	470.	450.	460.
	475.	430.	475.	460.	475.	450.
	500.	410.	500.	450.	500.	440.

<sup>y</sup> Vol. = volume of leachate (ml)

<sup>z</sup> EC = electrical conductivity (micromhos  $\text{cm}^{-1}$ )

Table 9: Data from leaching curves for mixes leached  
with 8 meq l<sup>-1</sup> solution.

Mix	Vol. <sup>y</sup>	EC <sup>z</sup>	Vol.	EC	Vol.	EC
PM-P-GB 10-10-0	25.	1800.	25.	1880.	25.	1760.
	50.	2230.	43.	2260.	50.	2370.
	58.	2230.	50.	2260.	65.	2410.
	75.	2090.	55.	2260.	75.	2390.
	100.	1900.	75.	2000.	100.	2060.
	125.	1690.	100.	1730.	125.	1770.
	150.	1530.	125.	1520.	150.	1560.
	175.	1440.	150.	1370.	175.	1400.
	200.	1350.	175.	1280.	200.	1290.
	225.	1290.	200.	1210.	225.	1240.
	250.	1240.	225.	1180.	250.	1200.
	275.	1200.	250.	1150.	275.	1170.
	300.	1180.	275.	1130.	300.	1140.
	325.	1160.	300.	1110.	325.	1130.
	350.	1140.	325.	1100.	350.	1120.
	375.	1120.	350.	1090.	375.	1110.
	400.	1110.	375.	1090.	400.	1100.
	425.	1100.	400.	1080.	425.	1090.
	450.	1100.	425.	1080.	450.	1080.
	475.	1090.	450.	1080.	475.	1080.
	500.	1090.	475.	1070.	500.	1070.
			500.	1070.		
PM-P-GB 10-10-1	15.	1680.	15.	1090.	15.	2000.
	25.	2300.	25.	2030.	25.	2040.
	39.	2530.	50.	2570.	38.	2660.
	50.	2530.	53.	2570.	43.	2660.
	75.	2320.	75.	2330.	50.	2640.
	100.	1960.	100.	2070.	75.	2310.
	125.	1750.	125.	1750.	100.	2030.
	150.	1530.	150.	1530.	125.	1720.
	175.	1410.	175.	1400.	150.	1530.
	200.	1320.	200.	1330.	175.	1400.
	225.	1240.	225.	1270.	200.	1320.
	250.	1200.	250.	1230.	225.	1240.
	275.	1160.	275.	1200.	250.	1200.
	300.	1140.	300.	1170.	275.	1180.
	325.	1120.	325.	1150.	300.	1160.
	350.	1110.	350.	1130.	325.	1140.
	375.	1100.	375.	1120.	350.	1120.
	400.	1090.	400.	1110.	375.	1110.
	425.	1080.	425.	1100.	400.	1100.
	450.	1080.	450.	1090.	425.	1090.
	475.	1080.	475.	1090.	450.	1090.

Table 9 (continued)

Mix	Vol.	EC	Vol.	EC	Vol.	EC
	500.	1070.	500.	1080.	475.	1080.
					500.	1080.
PM-P-GB 10-10-2						
	15.	3010.	15.	2970.	15.	3270.
	23.	3030.	22.	3080.	22.	3300.
	25.	3020.	25.	3090.	25.	3300.
	50.	2690.	28.	3080.	50.	3010.
	75.	2280.	50.	2790.	75.	2600.
	100.	1990.	75.	2370.	100.	2200.
	125.	1750.	100.	1950.	125.	1870.
	150.	1570.	125.	1670.	150.	1610.
	175.	1430.	150.	1460.	175.	1440.
	200.	1330.	175.	1330.	200.	1330.
	225.	1260.	200.	1260.	225.	1240.
	250.	1210.	225.	1200.	250.	1200.
	275.	1170.	250.	1160.	275.	1160.
	300.	1150.	275.	1140.	300.	1140.
	325.	1130.	300.	1120.	325.	1120.
	350.	1120.	325.	1110.	350.	1110.
	375.	1110.	350.	1100.	375.	1100.
	400.	1100.	375.	1090.	400.	1090.
	425.	1090.	400.	1080.	425.	1090.
	450.	1090.	425.	1080.	450.	1080.
	475.	1080.	450.	1080.	475.	1080.
	500.	1080.	475.	1070.	500.	1080.
			500.	1070.		
PM-P-GB 10-10-4						
	15.	3120.	15.	3170.	15.	3090.
	21.	3200.	21.	3190.	25.	3260.
	25.	3200.	25.	3140.	27.	3280.
	31.	3200.	50.	2780.	42.	3280.
	50.	2960.	75.	2410.	50.	3200.
	75.	2550.	100.	2110.	75.	2730.
	100.	2130.	125.	1870.	100.	2160.
	125.	1820.	150.	1660.	125.	1720.
	150.	1560.	175.	1480.	150.	1460.
	175.	1400.	200.	1380.	175.	1310.
	200.	1290.	225.	1300.	200.	1220.
	225.	1220.	250.	1230.	225.	1170.
	250.	1170.	275.	1180.	250.	1130.
	275.	1140.	300.	1150.	275.	1120.
	300.	1120.	325.	1130.	300.	1110.
	325.	1100.	350.	1110.	325.	1090.
	350.	1090.	375.	1100.	350.	1080.
	375.	1080.	400.	1090.	375.	1070.
	400.	1080.	425.	1080.	400.	1070.
	425.	1080.	450.	1080.	425.	1070.
	450.	1070.	475.	1070.	450.	1060.

Table 9 (continued)

Mix	Vol.	EC	Vol.	EC	Vol.	EC
	475.	1060.	500.	1060.	475.	1060.
	500.	1060.			500.	1050.
PM-P-GB 10-10-6	16.	3230.	21.	3260.	17.	3170.
	17.	3250.	25.	3290.	25.	3240.
	20.	3250.	50.	3320.	50.	3270.
	25.	3210.	58.	3320.	53.	3270.
	50.	2970.	75.	3080.	75.	2980.
	75.	2690.	100.	2400.	100.	2350.
	100.	2390.	125.	1830.	125.	1820.
	125.	2000.	150.	1530.	150.	1490.
	150.	1650.	175.	1470.	175.	1330.
	175.	1450.	200.	1260.	200.	1210.
	200.	1300.	225.	1180.	225.	1160.
	225.	1220.	250.	1140.	250.	1130.
	250.	1160.	275.	1110.	275.	1100.
	275.	1130.	300.	1090.	300.	1080.
	300.	1110.	325.	1080.	325.	1080.
	325.	1100.	350.	1080.	350.	1070.
	350.	1090.	375.	1070.	375.	1070.
	375.	1080.	400.	1070.	400.	1060.
	400.	1080.	425.	1060.	425.	1060.
	425.	1080.	450.	1060.	450.	1050.
	450.	1070.	475.	1060.	475.	1050.
	475.	1070.	500.	1050.	500.	1040.
	500.	1060.				
PM-P-GB 10-10-8	15.	3160.	16.	3210.	16.	3090.
	25.	3200.	25.	3280.	25.	3120.
	50.	3260.	50.	3290.	50.	3120.
	63.	3260.	56.	3280.	52.	3120.
	75.	3140.	75.	2940.	75.	2800.
	100.	2500.	100.	2130.	100.	2010.
	125.	1830.	125.	1560.	125.	1470.
	150.	1450.	150.	1310.	150.	1270.
	175.	1280.	175.	1190.	175.	1150.
	200.	1190.	200.	1120.	200.	1090.
	225.	1120.	225.	1090.	225.	1070.
	250.	1080.	250.	1070.	250.	1040.
	275.	1060.	275.	1050.	275.	1030.
	300.	1040.	300.	1040.	300.	1020.
	325.	1030.	325.	1030.	325.	1020.
	350.	1030.	350.	1020.	350.	1020.
	375.	1020.	375.	1020.	375.	1020.
	400.	1010.	400.	1020.	400.	1020.
	425.	1010.	425.	1010.	425.	1010.
	450.	1000.	450.	1010.	450.	1010.
	475.	1000.	475.	1010.	475.	1010.

Table 9 (continued)

Mix	Vol.	EC	Vol.	EC	Vol.	EC
	500.	1000.	500.	1010.	500.	1010.
PM-P						
	25.	1840.	25.	1960.	25.	2000.
	45.	2240.	39.	2150.	45.	2170.
	60.	2230.	50.	2150.	50.	2170.
	75.	2070.	75.	1830.	75.	1920.
	100.	1780.	100.	1560.	100.	1690.
	125.	1530.	125.	1390.	125.	1520.
	150.	1380.	150.	1280.	150.	1410.
	175.	1280.	175.	1190.	175.	1280.
	200.	1200.	200.	1140.	200.	1210.
	225.	1160.	225.	1120.	225.	1150.
	250.	1120.	250.	1100.	250.	1120.
	275.	1100.	275.	1080.	275.	1090.
	300.	1080.	300.	1070.	300.	1080.
	325.	1060.	325.	1060.	325.	1070.
	350.	1050.	350.	1050.	350.	1060.
	375.	1040.	375.	1040.	375.	1050.
	400.	1030.	400.	1040.	400.	1040.
	425.	1020.	425.	1040.	425.	1040.
	450.	1020.	450.	1030.	450.	1030.
	475.	1010.	475.	1030.	475.	1030.
	500.	1010.	500.	1020.	500.	1020.
RW-P						
	25.	1440.	25.	1630.	25.	1810.
	50.	2000.	50.	2170.	50.	2280.
	62.	2130.	68.	2240.	67.	2320.
	75.	2130.	75.	2240.	75.	2300.
	100.	1930.	100.	2140.	100.	2100.
	125.	1710.	125.	1960.	125.	1890.
	150.	1520.	150.	1740.	150.	1740.
	175.	1370.	175.	1530.	175.	1540.
	200.	1270.	200.	1410.	200.	1440.
	225.	1180.	225.	1300.	225.	1340.
	250.	1120.	250.	1200.	250.	1260.
	275.	1080.	275.	1140.	275.	1190.
	300.	1040.	300.	1090.	300.	1130.
	325.	1020.	325.	1060.	325.	1080.
	350.	1000.	350.	1030.	350.	1060.
	375.	990.	375.	1010.	375.	1040.
	400.	980.	400.	1000.	400.	1020.
	425.	970.	425.	990.	425.	1000.
	450.	960.	450.	980.	450.	990.
	475.	960.	475.	970.	475.	980.
	500.	960.	500.	960.	500.	970.
PM-V						
	15.	2400.	15.	2440.	15.	2630.
	25.	2880.	25.	2960.	25.	2980.
	38.	3120.	32.	3040.	37.	3120.
	50.	3110.	38.	3040.	45.	3120.

Table 9 (continued)

Mix	Vol.	EC	Vol.	EC	Vol.	EC
	75.	2740.	50.	2840.	50.	3070.
	100.	2340.	75.	2400.	75.	2640.
	125.	1930.	100.	1900.	100.	2110.
	150.	1660.	125.	1580.	125.	1720.
	175.	1480.	150.	1390.	150.	1500.
	200.	1360.	175.	1280.	175.	1340.
	225.	1270.	200.	1210.	200.	1270.
	250.	1200.	225.	1170.	225.	1220.
	275.	1170.	250.	1150.	250.	1190.
	300.	1140.	275.	1140.	275.	1170.
	325.	1120.	300.	1130.	300.	1150.
	350.	1100.	325.	1120.	325.	1140.
	375.	1100.	350.	1110.	350.	1130.
	400.	1090.	375.	1100.	375.	1120.
	425.	1090.	400.	1100.	400.	1110.
	450.	1080.	425.	1090.	425.	1100.
	475.	1080.	450.	1090.	450.	1090.
	500.	1080.	475.	1090.	475.	1090.
			500.	1090.	500.	1090.
PM-P-S						
2-2-1						
	15.	3010.	16.	3180.	18.	3260.
	25.	3140.	22.	3190.	25.	3340.
	28.	3140.	25.	3150.	50.	3310.
	50.	2910.	50.	2840.	75.	3060.
	75.	2610.	75.	2420.	100.	2670.
	100.	2210.	100.	2030.	125.	2240.
	125.	1890.	125.	1750.	150.	1890.
	150.	1680.	150.	1500.	175.	1630.
	175.	1500.	175.	1360.	200.	1430.
	200.	1380.	200.	1250.	225.	1310.
	225.	1280.	225.	1180.	250.	1220.
	250.	1220.	250.	1130.	275.	1170.
	275.	1170.	275.	1100.	300.	1120.
	300.	1130.	300.	1080.	325.	1090.
	325.	1110.	325.	1070.	350.	1080.
	350.	1080.	350.	1050.	375.	1070.
	375.	1070.	375.	1040.	400.	1060.
	400.	1050.	400.	1030.	425.	1050.
	425.	1030.	425.	1020.	450.	1040.
	450.	1030.	450.	1020.	475.	1030.
	475.	1020.	475.	1020.	500.	1030.
	500.	1020.	500.	1020.		

<sup>y</sup>Vol. = volume of leachate (ml)

<sup>z</sup>EC = electrical conductivity (micromhos cm<sup>-1</sup>)

Table 10: Data from leaching curves for mixes leached  
with 14 meq l<sup>-1</sup> solution.

Mix	Vol. <sup>y</sup>	EC <sup>z</sup>	Vol.	EC	Vol.	EC
PM-P-GB						
10-10-0						
	25.	2300.	48.	2320.	25.	2040.
	46.	2630.	50.	2610.	50.	2580.
	54.	2630.	56.	2640.	56.	2580.
	75.	2560.	65.	2640.	75.	2480.
	100.	2430.	75.	2600.	100.	2320.
	125.	2240.	100.	2420.	125.	2160.
	150.	2090.	125.	2260.	150.	2050.
	175.	1960.	150.	2110.	175.	1980.
	200.	1920.	175.	2020.	200.	1940.
	225.	1880.	200.	1960.	225.	1900.
	250.	1860.	225.	1910.	250.	1880.
	275.	1840.	250.	1890.	275.	1870.
	300.	1830.	275.	1870.	300.	1860.
	325.	1820.	300.	1850.	325.	1850.
	350.	1810.	325.	1840.	350.	1840.
	375.	1810.	350.	1830.	375.	1830.
	400.	1800.	375.	1820.	400.	1820.
	425.	1800.	400.	1820.	425.	1820.
	450.	1800.	425.	1810.	450.	1810.
	475.	1790.	450.	1810.	475.	1810.
	500.	1790.	475.	1810.	500.	1810.
			500.	1810.		
PM-P-GB						
10-10-1						
	15.	2410.	15.	1800.	15.	2210.
	25.	2810.	25.	2680.	25.	2870.
	45.	3060.	45.	2960.	37.	3010.
	50.	3050.	50.	2950.	50.	3010.
	75.	2820.	75.	2730.	75.	2820.
	100.	2530.	100.	2470.	100.	2550.
	125.	2320.	125.	2260.	125.	2330.
	150.	2160.	150.	2130.	150.	2190.
	175.	2060.	175.	2060.	175.	2070.
	200.	1980.	200.	2000.	200.	2010.
	225.	1920.	225.	1960.	225.	1960.
	250.	1900.	250.	1920.	250.	1920.
	275.	1890.	275.	1890.	275.	1900.
	300.	1880.	300.	1880.	300.	1880.
	325.	1870.	325.	1870.	325.	1870.
	350.	1860.	350.	1860.	350.	1860.
	375.	1850.	375.	1850.	375.	1850.
	400.	1840.	400.	1840.	400.	1840.
	425.	1840.	425.	1840.	425.	1830.
	450.	1840.	450.	1840.	450.	1830.

Table 10 (continued)

Mix	Vol.	EC	Vol.	EC	Vol.	EC
	475.	1830.	475.	1830.	475.	1820.
	500.	1830.	500.	1830.	500.	1820.
PM-P-GB 10-10-2						
	15.	2470.	15.	3080.	15.	2640.
	25.	2940.	25.	3210.	25.	3050.
	31.	2960.	31.	3200.	36.	3080.
	38.	2960.	50.	3000.	50.	2970.
	50.	2880.	75.	2690.	75.	2660.
	75.	2660.	100.	2410.	100.	2420.
	100.	2360.	125.	2210.	125.	2190.
	125.	2170.	150.	2060.	150.	2070.
	150.	2060.	175.	1930.	175.	1970.
	175.	1960.	200.	1870.	200.	1900.
	200.	1900.	225.	1810.	225.	1860.
	225.	1860.	250.	1780.	250.	1830.
	250.	1820.	275.	1770.	275.	1810.
	275.	1800.	300.	1760.	300.	1790.
	300.	1760.	325.	1750.	325.	1770.
	325.	1740.	350.	1740.	350.	1760.
	350.	1730.	375.	1730.	375.	1760.
	375.	1720.	400.	1720.	400.	1750.
	400.	1720.	425.	1710.	425.	1750.
	425.	1710.	450.	1710.	450.	1750.
	450.	1710.	475.	1700.	475.	1740.
	475.	1710.	500.	1700.	500.	1740.
	500.	1700.				
PM-P-GB 10-10-4						
	15.	2510.	15.	3120.	15.	2500.
	25.	2820.	25.	3240.	25.	3070.
	34.	2830.	31.	3240.	36.	3090.
	50.	2690.	50.	3080.	50.	3000.
	75.	2470.	75.	2750.	75.	2720.
	100.	2280.	100.	2460.	100.	2430.
	125.	2150.	125.	2190.	125.	2230.
	150.	2060.	150.	2030.	150.	2070.
	175.	1960.	175.	1910.	175.	1960.
	200.	1890.	200.	1840.	200.	1890.
	225.	1840.	225.	1810.	225.	1830.
	250.	1800.	250.	1770.	250.	1790.
	275.	1760.	275.	1750.	275.	1770.
	300.	1730.	300.	1740.	300.	1750.
	325.	1720.	325.	1730.	325.	1730.
	350.	1710.	350.	1720.	350.	1720.
	375.	1700.	375.	1720.	375.	1710.
	400.	1690.	400.	1710.	400.	1710.
	425.	1680.	425.	1710.	425.	1710.
	450.	1680.	450.	1710.	450.	1710.
	475.	1680.	475.	1710.	475.	1700.

Table 10 (continued)

Mix	Vol.	EC	Vol.	EC	Vol.	EC
	500.	1670.	500.	1710.	500.	1700.
PM-P-GB 10-10-6						
	15.	3040.	15.	3200.	15.	3200.
	19.	3080.	25.	3290.	20.	3220.
	25.	3040.	44.	3310.	25.	3200.
	50.	2770.	50.	3250.	50.	2920.
	75.	2590.	75.	2790.	75.	2640.
	100.	2370.	100.	2290.	100.	2370.
	125.	2170.	125.	2030.	125.	2170.
	150.	2000.	150.	1890.	150.	2010.
	175.	1900.	175.	1810.	175.	1890.
	200.	1820.	200.	1760.	200.	1810.
	225.	1770.	225.	1720.	225.	1760.
	250.	1730.	250.	1700.	250.	1730.
	275.	1710.	275.	1680.	275.	1700.
	300.	1700.	300.	1670.	300.	1680.
	325.	1690.	325.	1660.	325.	1680.
	350.	1680.	350.	1650.	350.	1670.
	375.	1670.	375.	1640.	375.	1660.
	400.	1660.	400.	1640.	400.	1660.
	425.	1650.	425.	1640.	425.	1650.
	450.	1650.	450.	1640.	450.	1640.
	475.	1650.	475.	1640.	475.	1640.
	500.	1650.	500.	1630.	500.	1640.
PM-P-GB 10-10-8						
	15.	3170.	15.	3100.	15.	3090.
	25.	3300.	25.	3230.	25.	3240.
	50.	3340.	50.	3310.	50.	3310.
	64.	3340.	66.	3310.	62.	3310.
	75.	3270.	75.	3230.	75.	3130.
	100.	2850.	100.	2730.	100.	2560.
	125.	2270.	125.	2200.	125.	2160.
	150.	1940.	150.	1920.	150.	1920.
	175.	1820.	175.	1800.	175.	1810.
	200.	1770.	200.	1750.	200.	1750.
	225.	1750.	225.	1720.	225.	1730.
	250.	1740.	250.	1710.	250.	1710.
	275.	1730.	275.	1700.	275.	1700.
	300.	1720.	300.	1690.	300.	1690.
	325.	1710.	325.	1690.	325.	1690.
	350.	1700.	350.	1680.	350.	1680.
	375.	1690.	375.	1680.	375.	1680.
	400.	1690.	400.	1680.	400.	1680.
	425.	1690.	425.	1680.	425.	1680.
	450.	1680.	450.	1680.	450.	1680.
	475.	1680.	475.	1680.	475.	1680.
	500.	1680.	500.	1670.	500.	1680.

Table 10 (continued)

Mix	Vol.	EC	Vol.	EC	Vol.	EC
PM-P						
	25.	2040.	25.	2190.	25.	2340.
	50.	2720.	50.	2720.	43.	2790.
	58.	2720.	61.	2720.	50.	2800.
	75.	2610.	75.	2650.	75.	2610.
	100.	2400.	100.	2440.	100.	2330.
	125.	2240.	125.	2280.	125.	2150.
	150.	2150.	150.	2170.	150.	2040.
	175.	2070.	175.	2080.	175.	1980.
	200.	2000.	200.	2000.	200.	1940.
	225.	1950.	225.	1950.	225.	1900.
	250.	1910.	250.	1900.	250.	1870.
	275.	1880.	275.	1870.	275.	1850.
	300.	1860.	300.	1850.	300.	1840.
	325.	1840.	325.	1840.	325.	1830.
	350.	1830.	350.	1830.	350.	1820.
	375.	1820.	375.	1820.	375.	1820.
	400.	1810.	400.	1810.	400.	1810.
	425.	1800.	425.	1810.	425.	1810.
	450.	1800.	450.	1800.	450.	1800.
	475.	1790.	475.	1800.	475.	1800.
	500.	1790.	500.	1800.	500.	1790.
RW-P						
	25.	1780.	25.	1680.	25.	1800.
	50.	2410.	50.	2500.	50.	2040.
	75.	2570.	75.	2670.	68.	2730.
	85.	2570.	86.	2670.	75.	2720.
	100.	2540.	100.	2650.	100.	2590.
	125.	2450.	125.	2560.	125.	2400.
	150.	2330.	150.	2460.	150.	2200.
	175.	2180.	175.	2250.	175.	2090.
	200.	2070.	200.	2130.	200.	2000.
	225.	1960.	225.	2040.	225.	1930.
	250.	1880.	250.	1930.	250.	1880.
	275.	1840.	275.	1880.	275.	1850.
	300.	1800.	300.	1830.	300.	1820.
	325.	1780.	325.	1800.	325.	1790.
	350.	1760.	350.	1780.	350.	1760.
	375.	1740.	375.	1760.	375.	1740.
	400.	1720.	400.	1750.	400.	1730.
	425.	1710.	425.	1740.	425.	1720.
	450.	1710.	450.	1730.	450.	1710.
	475.	1710.	475.	1720.	475.	1710.
	500.	1710.	500.	1720.	500.	1710.
PM-V						
	15.	2400.	15.	2530.	15.	2420.
	25.	2860.	25.	2960.	25.	3020.
	50.	3000.	50.	3130.	32.	3090.
	75.	2640.	66.	3130.	40.	3090.
	100.	2400.	75.	3050.	50.	2990.

Table 10 (continued)

Mix	Vol.	EC	Vol.	EC	Vol.	EC
	125.	2160.	100.	2810.	75.	2580.
	150.	2000.	125.	2620.	100.	2270.
	175.	1910.	150.	2460.	125.	2070.
	200.	1880.	175.	2200.	150.	1950.
	225.	1860.	200.	2020.	175.	1880.
	250.	1830.	225.	1970.	200.	1830.
	275.	1800.	250.	1910.	225.	1800.
	300.	1780.	275.	1860.	250.	1790.
	325.	1770.	300.	1840.	275.	1780.
	350.	1760.	325.	1810.	300.	1770.
	375.	1760.	350.	1790.	325.	1760.
	400.	1750.	375.	1770.	350.	1750.
	425.	1740.	400.	1760.	375.	1750.
	450.	1740.	425.	1750.	400.	1740.
	475.	1740.	450.	1740.	425.	1740.
	500.	1730.	475.	1740.	450.	1740.
			500.	1730.	475.	1730.
					500.	1730.
PM-P-S						
2-2-1						
	15.	2880.	25.	3080.	25.	2960.
	25.	2760.	34.	3080.	29.	2980.
	50.	2510.	50.	2980.	50.	2800.
	75.	2320.	75.	2770.	75.	2610.
	100.	2180.	100.	2550.	100.	2420.
	125.	2080.	125.	2350.	125.	2240.
	150.	2000.	150.	2170.	150.	2120.
	175.	1930.	175.	2020.	175.	2010.
	200.	1880.	200.	1920.	200.	1930.
	225.	1840.	225.	1840.	225.	1870.
	250.	1810.	250.	1790.	250.	1820.
	275.	1780.	275.	1760.	275.	1780.
	300.	1760.	300.	1730.	300.	1760.
	325.	1750.	325.	1720.	325.	1740.
	350.	1740.	350.	1710.	350.	1730.
	375.	1720.	375.	1700.	375.	1720.
	400.	1710.	400.	1690.	400.	1710.
	425.	1710.	425.	1680.	425.	1710.
	450.	1700.	450.	1680.	450.	1700.
	475.	1690.	475.	1670.	475.	1690.
	500.	1680.	500.	1670.	500.	1690.

<sup>y</sup>Vol. = volume of leachate (ml)

<sup>z</sup>EC = electrical conductivity (micromhos cm<sup>-1</sup>)

APPENDIX II

Figure 24: Particle size analysis of peat used in glass bead mixes. Fractions expressed as both % volume and % weight. Peat for glass bead mixes was passed through 7.925 mm sieve to improve uniformity.

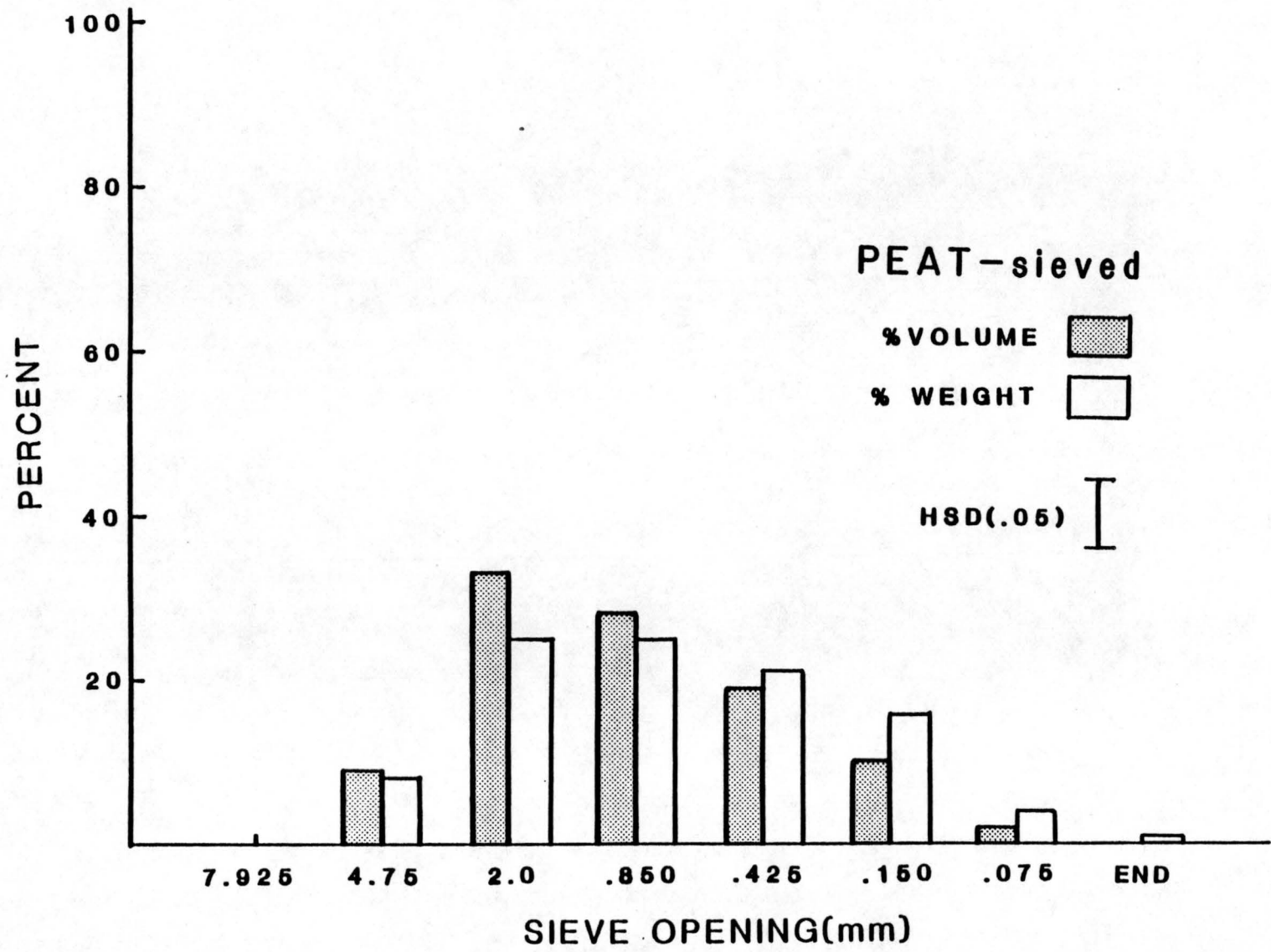


Figure 25: Particle size analysis of peat used in standard mixes. Fractions expressed as both % volume and % weight.

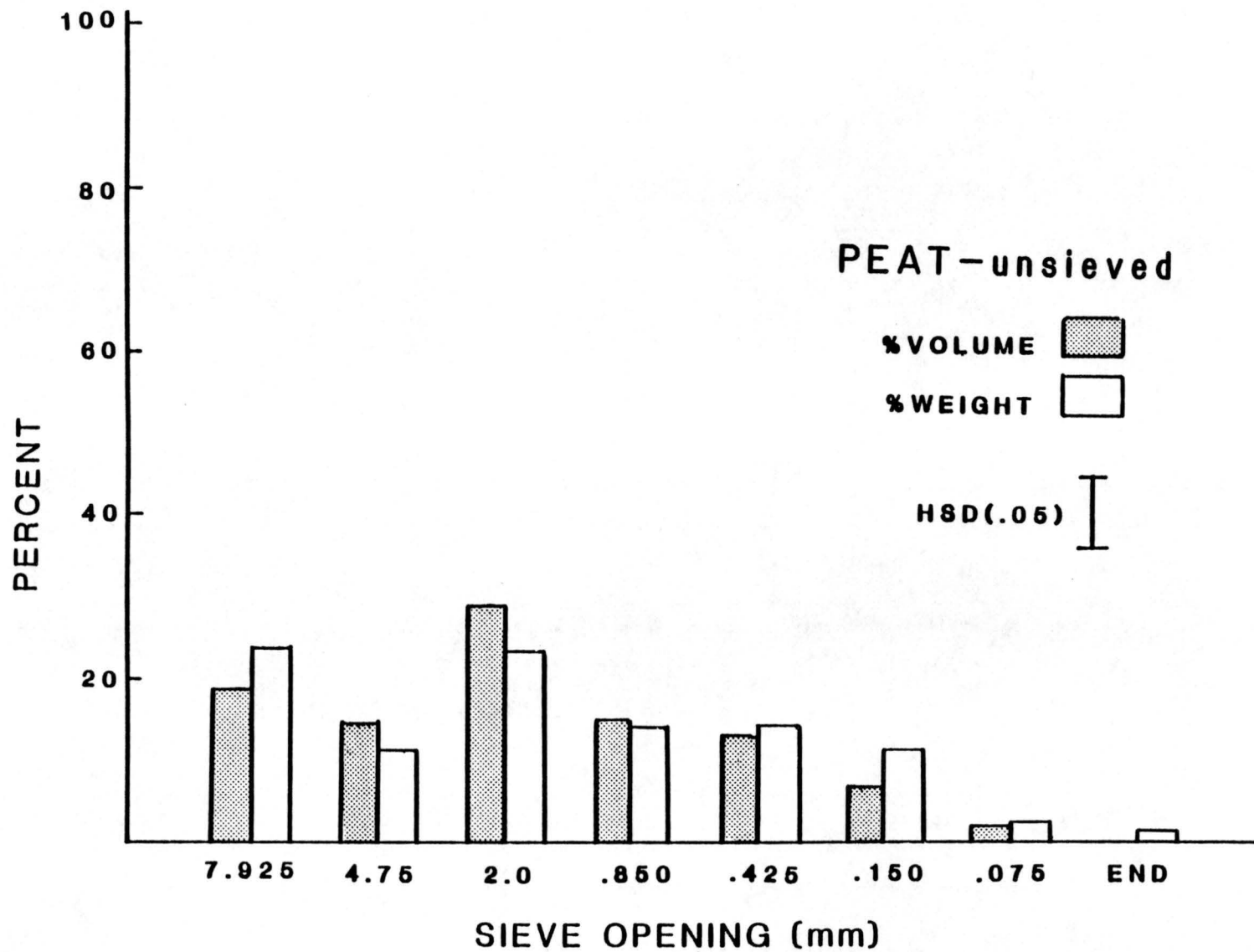


Figure 26: Particle size analysis of perlite used in glass bead mixes. Fractions expressed as both % volume and % weight. Perlite for glass bead mixes was passed through a 4.75 mm sieve but but retained by a 2.0 mm sieve. The 0.85 mm fraction shown was probably created during handling.

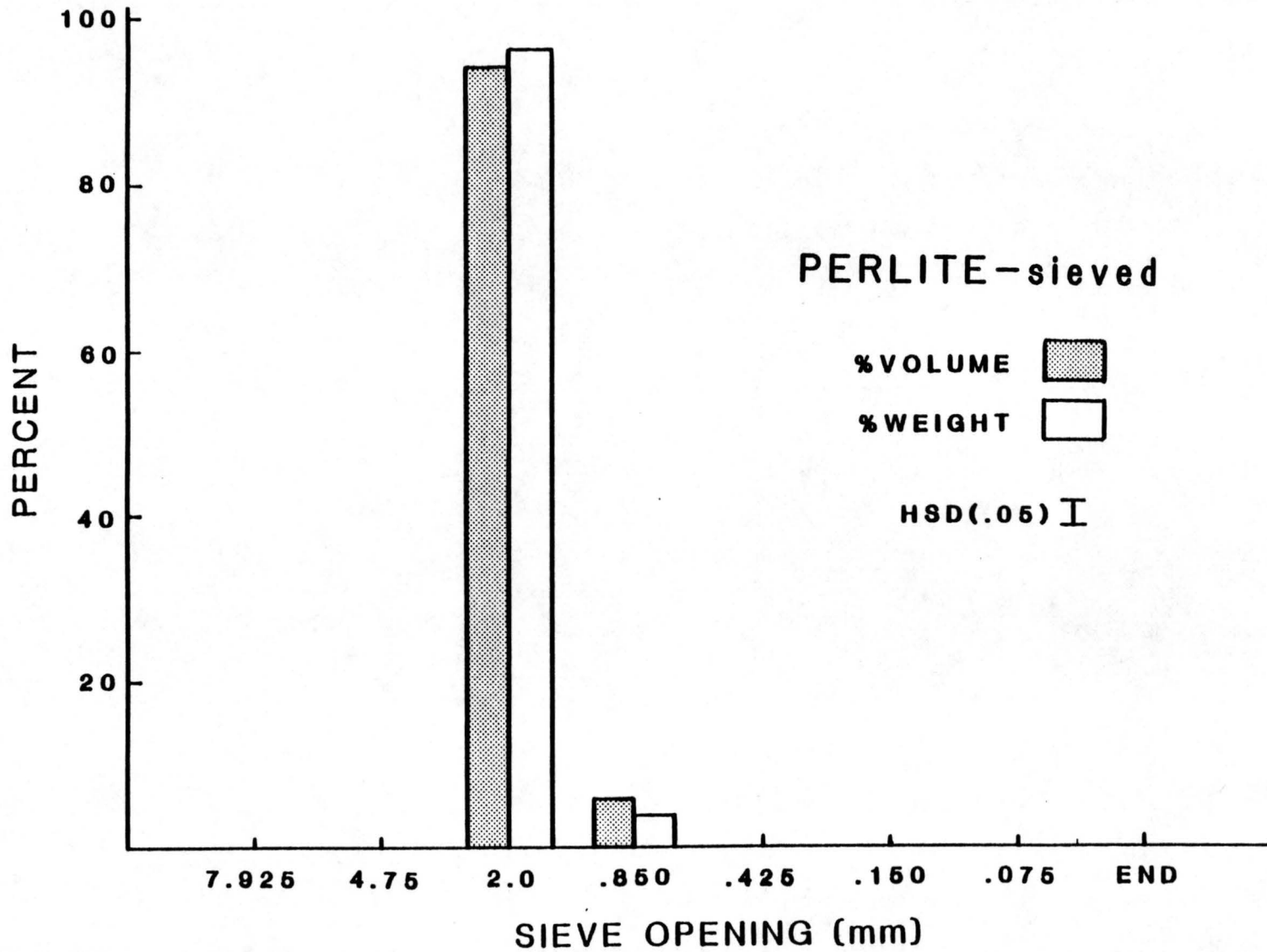


Figure 27: Particle size analysis of perlite used in standard mixes. Fractions expressed as both % volume and % weight.

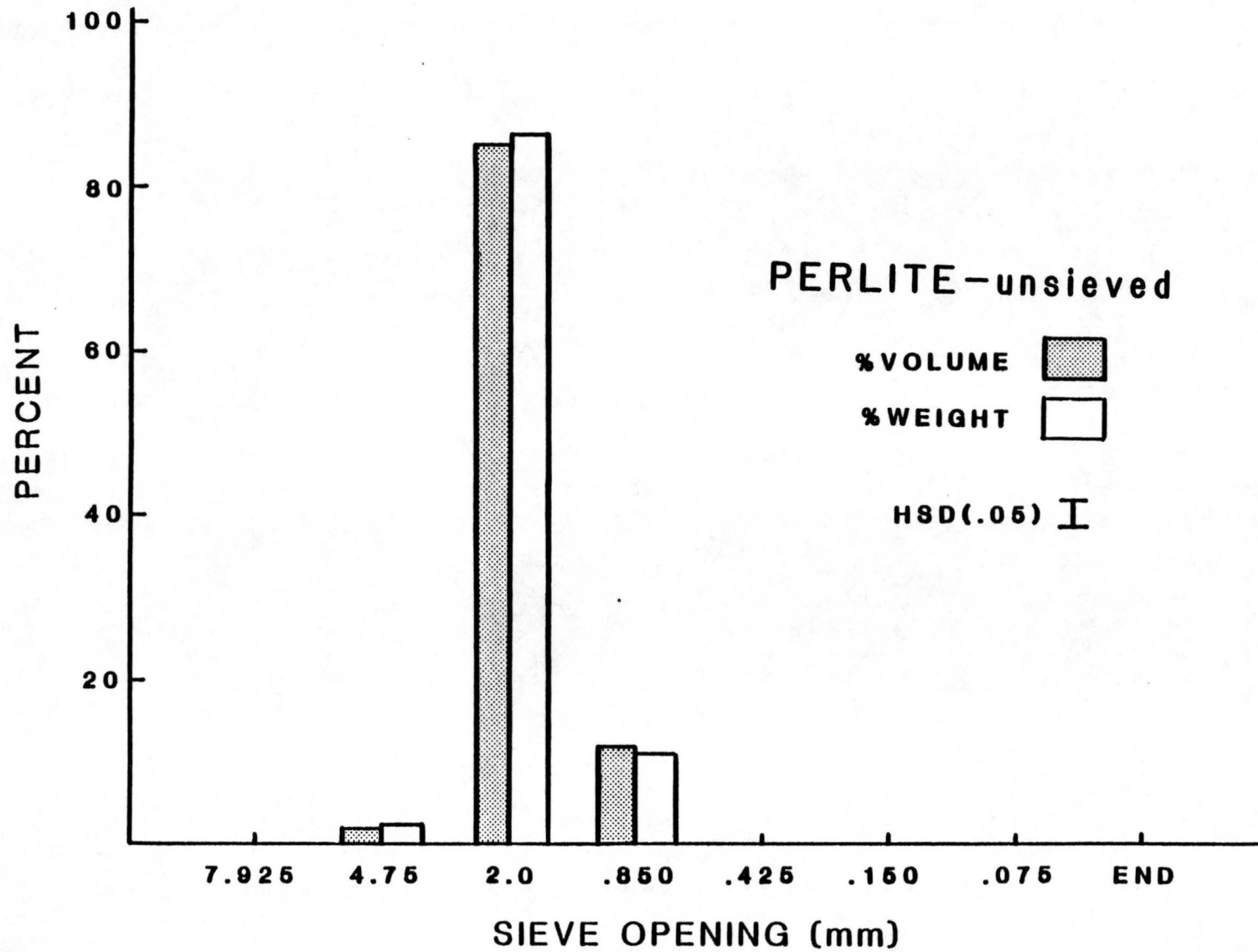


Figure 28: Particle size analysis of shredded rockwool. Note that the small size fractions did not have significant volume. The fractions were composed of small, dense pellets, whereas the large size fractions were fluff.

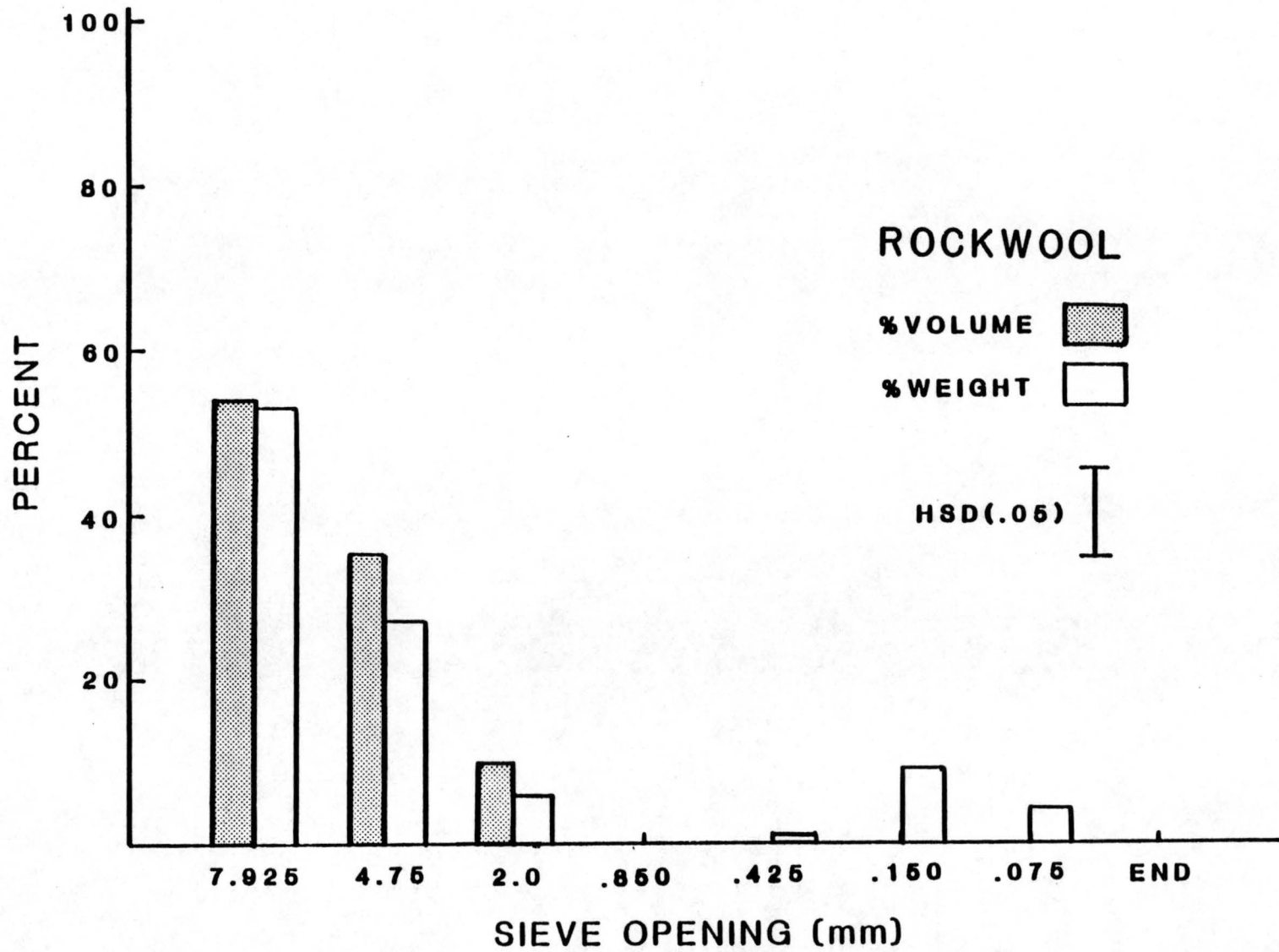


Figure 29: Particle size analysis of vermiculite. Fractions expressed as both % volume and % weight.

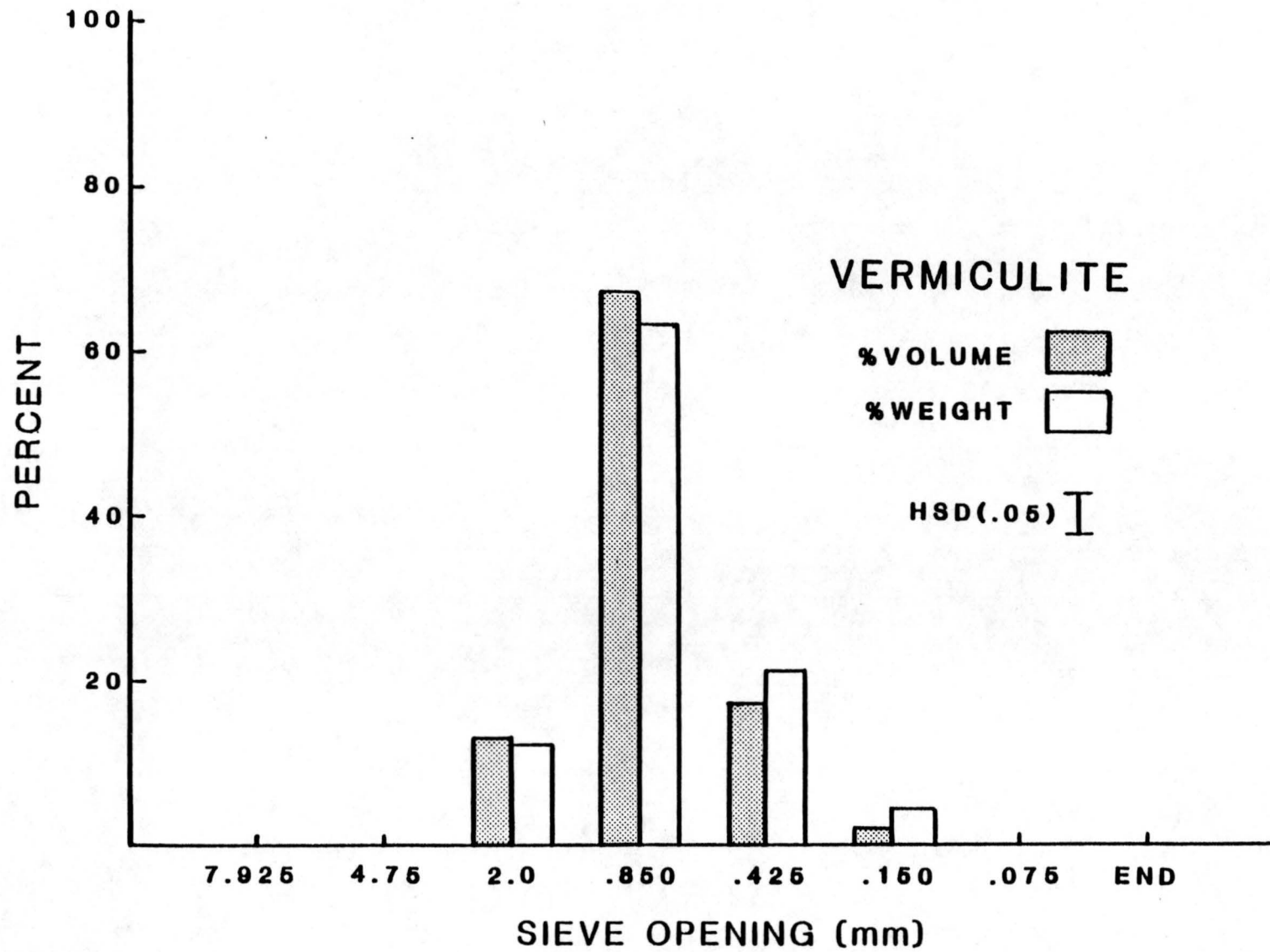


Figure 30: Particle size analysis of Ft. Collins clay loam. Fractions expressed as both % volume and % weight.

