STREET DIRT AS A PHOSPHORUS SOURCE IN URBAN STORMWATER

by

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Nutrient loads from stormwater runoff can cause eutrophication of receiving waters. Phosphorus is one of the nutrients that accelerates this process.

Streets, roadways, and so on accumulate dirt particles and other debris that are washed off by stormwater into receiving waters. Phosphorus is adsorbed onto the particles and may desorb into water bodies. This research was conducted to evaluate total phosphorus concentrations associated with the street dirt particles and leaves. The particles have been collected from four different streets in Madison, Wisconsin, over a two-year period and separated into different particle sizes (<25, 25-63, 63-250, >250 µm, plus leaves). These sites were Monroe Street, Glenway Avenue, Gammon Road and the Seneca, Spring, Huron Hill area.

The objective of this project was to indicate whether leaves contributed a significant portion of the phosphorus contained in the street dirt. Other sources of phosphorus were also investigated. Street cleaning is a control practice to prevent the street dirt particles from entering water bodies; however, only larger particles are usually removed, and the smaller particles remain and are washed off with rain. This poses a problem because the smaller particles (<25 microns) have higher phosphorus concentrations (mg/L) than the larger particles (>250 microns) due to their greater surface

area; however, leaves, if present, may also contribute significant phosphorus levels. Distinguishing the phosphorus content of the street dirt by size and by potential source aids in identifying effective stormwater control practices.

In addition to evaluating phosphorus concentrations, a thermal chromatography procedure was developed. This process involved heating individual street contaminants such as asphalt, paper, rubber, cigarettes, and leaves to determine at which temperature the highest mass percentage loss occurs. After choosing these temperatures, most of the 96 street dirt samples were heated in order to determine their composition. This information was used to determine the relative phosphorus contributions from the different potential sources, especially leaves. Leaf material made up 5.5 ± 5.5% (average ± standard deviation) of the street dirt mass but probably contributed 23.9 ± 20.2 of the street dirt phosphorus content (See Appendix C). More rigorous leaf control could therefore have an important benefit on reducing phosphorus in the street dirt, and in stormwater.

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CHAPTER 1

RESEARCH PROCEDURE

The purpose of this research was to determine if leaves contributed important amounts of phosphorus to stormwater. This experiment evaluated phosphorus concentrations in most of the 96 dirt samples and 21 leaf samples collected from four different sites in Madison, Wisconsin. Three dirt and four leaf samples were not evaluated due to insufficient sample mass or due to a particular site not being sampled. In addition, a thermal chromatography experiment was also conducted in order to estimate the street dirt sample compositions.

The first part of the research required determining specific analytical procedures using the HACH phosphorus Test 'n Tube™ procedure for these solid samples. The required replicate number for each dirt sample was chosen according to acceptable error levels (the goal was 25%). Blank and standards were also periodically analyzed to maintain quality control for the experiment.

After these procedures had been determined, an experimental design was established and phosphorus testing for the dirt and leaf samples began. The actual phosphorus test required using 1 N sulfuric acid, 1 N sodium hydroxide, Phosver3 for 5 mL powder pillow reagent, Phosver3 potassium persulfate powder pillow reagent, reverse osmosis water, reactor, weighing paper, analytical scale, pipette, 25 test vials, and an HACH DR/2000 spectrophotometer. The time necessary to conduct one test run of 25 vials consists of approximately 20 min for sample weighing, 15 min for pipetting 2 mL of sulfuric acid and pouring a powder pillow into each vial, 30 min reaction time, 1 to 1.5 hours for the vials to cool to room temperature, another 15 min for pipetting 2 mL of sodium hydroxide and pouring a powder pillow into each vial, 30 min. for the powder pillow reagents to react with the sample, and 10 min to read the phosphorus concentrations with the spectrophotometer. Therefore, the entire procedure takes approximately 3.5 hours for 25 analyses. Twenty of these vials are samples, while the remaining five are QA/QC samples. With five replicates, only four samples were analyzed for each 3.5-hour test run.

In addition to the phosphorus tests, a thermal chromatography method was also developed. Most of the 96 dirt samples were heated in a muffle furnace at increasing temperatures and weighed at specific temperatures to help determine the composition of the street dirt. The samples are not homogeneous and may be composed of many components. Different heating temperatures were determined by initially heating four different dirt samples, in addition to other substrates that could be present on the streets, such as paper, rubber, cigarettes, leaves, and asphalt. These samples were placed in a crucible that had been heated at 550°C for cleaning. An initial temperature of 105°C started the process to dry the samples. After 105°C, 150°C was the next temperature and 50°C increments were then used until 550°C was reached to complete the process. A heating time of 1 hour at each temperature was determined to ensure stable weights.

After each heating interval, the crucible (with sample) was cooled and weighed in order to determine the percent mass burned off for each material since the last temperature. Graphs and calculations were used to determine the appropriate temperatures to be used for all of the street dirt samples. These "burn-off" temperatures were 105°C, 240°C, 365°C, 470°C, and 550°C. In general, the mass lost at 105°C was associated with moisture, the mass lost between 105°C and 240°C was mostly associated with paper debris, the mass lost between 240°C and 365°C was mostly associated with leaves and grass, the mass lost between 365°C and 470°C was mostly associated with rubber, and the mass lost between 470°C and 550°C was mostly associated with asphalt. The remaining mass, after ignition at 550°C, was associated with inert (mostly soil) material.

CHAPTER 2

LITERATURE SEARCH

Street Dirt Characteristics

Debris, contaminants from open land areas, publicly used chemicals, air-deposited substances, and dirt and contaminants washed from vehicles, can be sources of water pollution from street runoff. Since streets and roadways are composed of impervious materials, these contaminants can be washed off during rains.

Street runoff is usually highly contaminated, especially considering its heavy metal content. Nutrient levels in street runoff may also periodically cause problems. Factors such as the area of surrounding land, rain characteristics, drainage area, atmospheric deposition, and auto traffic affect the runoff water quality. Because of these factors, different contaminants such as phosphorus are being tested from the streets in order to learn how to prevent contaminating the runoff (Barrett et al. 1995).

Runoff from streets contains contaminants which pollutes receiving waters. These contaminants, such as phosphorus, adsorb onto dust and dirt particles that are deposited on the streets from being blown, washed, or tracked in from surrounding land areas. Phosphorus causes water pollution problems because it serves as a nutrient which results in excessive plant and algal growth. This accelerated eutrophication of the waters can contribute undesirable conditions such as nuisance algae and anaerobic conditions. This in time can lead to taste and odor problems for drinking water supplies, aesthetic problems in recreation water, and highly variable dissolved oxygen levels that are lethal to most aquatic organisms. Some possible phosphorus sources in stormwater are fertilizers, decomposing vegetation, animal wastes, and naturally occurring phosphorus within soils. Litter such as paper, rubber, asphalt, and cigarettes can also contribute to the phosphorus levels in the street dirt particulates (Shaheen 1975).

A few management practices can be implemented, such as street cleaning, to reduce street dirt particulate washoff; however, street cleaning usually removes only the larger particulates and leaves behind most of the finer silt- and clay-like particulates. Several studies, starting with early work by Boyd and Sartor (1972), have found that it is these finer particulates that contain the highest contaminant concentrations because of their increased surface area; therefore, currently used street cleaning practices are generally not successful in combatting this problem. Repeated street cleaning cycles, at slower speeds, are needed to increase the dust and dirt particulate removal rates (Pitt 1979). Understanding the phosphorus sources and concentrations within the dirt particulates on the streets can assist with the prevention of pollutants entering surface waters (Jewell and Swan 1975).

Vehicles can contribute much of the pollution found in highway runoff. They are a source of the metals, chemical oxygen demand, oil and grease, and other materials deposited on roadways. Other major sources of contaminants in the runoff include dustfall and dissolved constituents in the rain itself. Rainfall can contribute the majority of ionic contaminants leaving the road surface in runoff and can also wash vehicle derived pollutants out of the atmosphere. Dustfall loadings can be a significant fraction of the loadings in runoff and an important source of roadway runoff pollution. The surrounding land use has a major impact on the amount of pollution in dustfall deposited on a roadway and the ensuing quality of stormwater runoff. A number of roadway maintenance practices also may adversely affect water quality.

The type and size of the receiving body, the potential for dispersion, the size of the catchment area, and the biological diversity of the receiving water ecosystem are just some of the factors which determine the extent and importance of roadway runoff effects. Roads increase the amount of impervious cover on a watershed and thus raise storm runoff volumes and peak discharges. Consequently, there is an increase in streambank erosion and greater loads of solids and other pollutants into receiving waters. More important than the total concentration of many pollutants are the form in which they occur and their bioavailability (Barrett et al. 1995). Many studies have concluded that the non-apatite inorganic portion of particulate phosphorus is considered the most bioavailable to algae and other aquatic life.

Increased solids loadings on streets have been attributed to not only environmental sources but roadway maintenance practices, as well (Barrett et al. 1995). A study performed in 1985 revealed that many current roadway maintenance practices may adversely affect water quality. The nearness of water bodies to the maintenance activity and the composition of the materials and methods implemented in the activity may also affect water quality. Some other factors that might contribute to the water quality deterioration due to roadway maintenance practices are

> exposing or moving soil or sediment, including activities that result in accidental or incidental removal of vegetative cover, the use or disposal of materials containing nutrients, the use or disposal of decomposable organic materials, and the use or disposal of materials that could change the suspended or dissolved solids content of the receiving body of water. (Barrett et al. 1995)

Street cleaning effectiveness is highly dependent on the street dirt loading. Street dirt loadings are the result of deposition and removal rates, plus "permanent storage." Street texture and condition affect the permanent storage, which is related to the amount of street dust and dirt maintained on roadways after natural and street cleaning processes have been implemented. Natural and vehicle induced wind turbulence is responsible for most of the particulate removals from roadways in arid and semi-arid areas (Pitt 1979).

A study in Toronto investigating street dirt accumulation revealed that land use was the most important factor affecting the street dirt deposition rate. Street texture and condition were found to influence the initial and maximum loading values. Whether a street was smooth or rough with the same land use also affected the loading rates; the smoother streets had less loadings because of the absence of cracks and pores that could trap the particulates (Pitt and McClean 1986).

Another study in Bellevue, Washington observed that street dirt loadings at the beginnings and endings of rains were affected by street dirt washoff and by erosion residues from non-street areas (Bissonette and Pitt 1984). This study revealed that large amounts of the finest particulates were washed off, while the largest particulate amounts actually increased on the streets for most rains. This increase in the large particulates could be the result of deposited erosion materials generated from surrounding areas that were not carried by the gutter flows. Bed armoring may have affected the washoff of the small particulates. These larger particulates, as well as street litter and leaves, can shield the finer particulates underneath. This shielding prevents the finer particulates from washing off with the stormwater runoff (Pitt 1996). Street cleaning can actually increase the washoff of fine particulates by removing these bed-armoring large particles (Bannerman et al. 1983).

Sources of Pollutants Affecting Street Dirt

Vehicles, dustfall, particulates, and precipitation are some of the major sources of pollutants on roadways. Barrett et al. (1995) state that factors such as traffic volume, local land use, and weather patterns can affect the composition and amount of these pollutants.

Vehicles produce pollutants from exhaust, metals lost from the body, and wear from frictional parts. Vehicles can serve as both a direct and an indirect pollutant source. Pollutants formed from operation and wear of frictional parts serve as a direct source of pollutants, while pollutants adsorbed onto solids that reside on vehicles are indirect pollutant sources. These solids are later deposited onto the streets and may be washed off during storms. Vehicles indirectly contribute to runoff pollution by increasing solids loadings onto parking lots, urban roadways, construction sites, farms, and dirt roads (Barrett et al. 1995).

A study performed by Shaheen (1975) revealed that over 95% of solids on roadways originate from sources other than vehicles. These solids can result from soil erosion which can be a major contributor of nutrients to surface waters in rural areas. Finer particulates erode more quickly than the coarser soil particulates (Jewell and Swan 1975). These finer eroding particulates pose a greater pollution problem because they contain higher concentrations of pollutants. A study conducted by Jewell and Swan (1975) found that a high percentage of the stormwater runoff pollution problem was associated with the fine particulates fraction of the street surface contaminants. They also found that these fine particulates contribute only a small portion of the total loading on street surfaces. "The very fine, siltlike material (<43 microns) accounts for only 5.9% of the total solids but about 1/4 of the total oxygen demand and perhaps 1/3 to 1/2 of the algal nutrients" (Jewell and Swan 1975).

These finest particulates have been found from previous studies to be discharged in roadway runoff during the early parts of storms (Pitt 1996). This early part of storms is referred to as the "first flush" effect, which is defined as the discharge of the higher pollutant concentrations at the beginning of an event (Barrett et al. 1995). Barrett et al. (1995) found that the "first flush" effect was most applicable during short storms with fairly constant rainfall intensities, while changes in traffic volume, rainfall intensity, and other parameters produced a magnitude reduction for the "first flush" during longer events.

Other contributors to highway pollution include atmospheric sources. Fuel burning, automobile exhaust, manufacturing processes, forest and other fires, volcanic eruptions, and wind erosion can generate constituents to the atmosphere. These constituents originating from one area can return to earth at other areas (Jewell and Swan 1975).

Atmospheric deposition can result in storms or as dustfall during dry periods. The rainfall can wash pollutants originating from vehicles out of the atmosphere and atmospheric dry fallout can contribute great amounts of roadway pollutants, depending on the surrounding land usage. A study performed in 1981 observed that highways in or near urban areas have higher levels of pollutant concentrations from dustfall as opposed to those in rural areas. This makes sense considering the vehicle traffic average is higher for urban areas (Barrett et al. 1995).

Phosphorus

The growth of macrophytes and phytoplankton is stimulated principally by nutrients such as phosphorus and nitrogen. Nutrient-stimulated primary production is of most concern in lakes and estuaries because primary production in flowing water is thought to be controlled by physical factors, such as light penetration, timing of flow, and type of substrate available, instead of by nutrients (Phosphorus 1996). The non-apatite inorganic particulate phosphorus portion is the most bioavailable to algae and aquatic species.

Most freshwater systems generally have phosphorus (as orthophosphate) as their limiting nutrient: if all phosphorus is used, plant growth will cease, no matter how much nitrogen is available. Similarly, if phosphorus is reduced, plant growth will also be reduced, as most freshwaters have an excess of nitrogen and other required nutrients. An interesting exception is the Cahaba River near Birmingham, Alabama, where nitrogen is the limiting nutrient because of large amounts of treated sewage (naturally high in P) and small amounts of stormwater discharged into the river. Natural background levels of total phosphorus are generally less than 0.03 mg/L. Natural levels of orthophosphate usually range from 0.005 to 0.05 mg/L (Phosphorus 1996).

Many bodies of freshwater are currently experiencing influxes of phosphorus and nitrogen from outside sources. The increasing concentration of available phosphorus allows plants to assimilate more nitrogen before the phosphorus is depleted. Thus, if sufficient phosphorus is available, elevated concentrations of nitrates will lead to algal blooms. Although levels of 0.08 to 0.10 mg/L orthophosphate may trigger periodic blooms, long-term eutrophication will usually be prevented if total phosphorus levels and orthophosphate levels are below 0.5 mg/L and 0.05 mg/L, respectively (Phosphorus 1996).

Nutrient-induced production of aquatic plants in both freshwater and estuaries has several detrimental consequences:

1. Algal mats, decaying algal clumps, odors, and discoloration of the water will interfere with recreational and aesthetic water uses.

2. Extensive growth of rooted aquatic macrophytes will interfere with navigation, aeration, and channel capacity.

3. Dead macrophytes and phytoplankton settle to the bottom of a water body, stimulating microbial breakdown processes that require oxygen. Eventually, oxygen will be depleted.

4. Aquatic life uses may be hampered when the entire water body experiences daily fluctuations in dissolved oxygen levels as a result of plant respiration at night. Extreme oxygen depletion can lead to death of desirable fish species.

5. Siliceous diatoms and filamentous algae may clog water treatment plant filters and result in reduced time between backwashing (process of reversing water flow through the water filter in order to remove debris).

6. Toxic algae (such as the occurrence of "red tide") have been associated with eutrophication in coastal regions and may result in paralytic shellfish poisoning (Phosphorus 1996).

7. Algal blooms shade submersed aquatic vegetation, reducing or eliminating photosynthesis and productivity (Phosphorus 1996).

To explain a wide range of values of contaminants in runoff, several factors must be considered, including the processes involved in the deposition and transport of the pollutants (Barrett et al. 1995).

To understand the transport of a pollutant such as the nutrient phosphorus, one must know the sources for the contaminant. A study performed on a 1-hectare residential area suggests that vegetation is the principal source of phosphorus and that explicit consideration of individual sources may be a useful approach to predict phosphorus loads from urban areas (Malmquist 1978).

Phosphorus is an essential nutrient for all life forms. Phosphorus is the 11^{th}-most abundant mineral in the earth's crust and does not exist in a gaseous state. Natural inorganic phosphorus deposits occur primarily as phosphate in the mineral apatite. Apatite is defined as a natural, variously colored calcium fluoride phosphate with chlorine, hydroxyl, and carbonate sometimes replacing the fluoride. Apatite is found in igneous, metamorphic, and sedimentary rocks. When released to the environment, phosphate will speciate as orthophosphate according to the pH of the surrounding soil (Phosphorus 1996).

Phosphorus is one of the key elements necessary for growth of plants and animals. Phosphorus in elemental form is very toxic and is subject to bioaccumulaton. Phosphates (PO_4) are formed from this element. Phosphates exist in three forms: orthophosphate, metaphosphate (or polyphosphate), and organically bound phosphate. Each compound contains phosphorus in a different chemical formula. Ortho forms are produced by natural processes and are found in sewage. Poly forms are used for treating boiler waters and are added to detergents. In water, they change into the ortho form, which is the most damaging form. Organic phosphates are important in nature. Their occurrence may result from the breakdown of organic pesticides which contain phosphates. They may exist in solution, as particles, as loose fragments, or in the bodies of aquatic organisms (Phosphorus 1996).

Phosphate is usually not readily available for uptake in soils. Phosphate is only freely soluble in acid solutions and under reducing conditions. In the soil it is rapidly immobilized as calcium or iron phosphates. Most of the phosphorus in soils is adsorbed to soil particles or incorporated into organic matter (Phosphorus 1996).

Phosphorus in freshwater and marine systems exists in either a particulate phase or a dissolved phase. Particulate matter includes living and dead plankton, precipitates of phosphorus, phosphorus adsorbed to particulates, and amorphous phosphorus. The dissolved phase includes inorganic phosphorus (generally in the soluble orthophosphate form), organic phosphorus excreted by organisms, and macromolecular colloidal phosphorus (Phosphorus 1996).

The organic and inorganic particulate and soluble forms of phosphorus undergo continuous transformations. The dissolved phosphorus (usually as orthophosphate) is assimilated by phytoplankton and altered to organic phosphorus. The phytoplankton are then ingested by detritivores or zooplankton. Over half of the organic phosphorus taken up by zooplankton is excreted as inorganic P. Continuing the cycle, the inorganic P is rapidly assimilated by phytoplankton (Phosphorus 1996).

Lakes and reservoir sediments serve as phosphorus sinks. Phosphorus-containing particles settle to the substrate and are rapidly covered by sediment. Continuous accumulation of sediment will leave some phosphorus too deep within the substrate to be reintroduced to the water column. Thus, some phosphorus is removed permanently from biocirculation (Phosphorus 1996).

A portion of the phosphorus in the substrate may be reintroduced to the water column. Phosphorus stored in the uppermost layers of the bottom sediments of lakes and reservoirs is subject to bioturbation by benthic invertebrates and to chemical transformations by water chemistry changes. For example, the hypolimnion layer in a lake often experiences reducing conditions during the summer months which may stimulate the release of phosphorus from the benthos. Recycling of phosphorus stimulates blooms of phytoplankton. Because of this phenomenon, a reduction in phosphorus loading may not be effective in reducing algal blooms for a number of years (Phosphorus 1996).

EPA Water Quality Standards for Phosphorus

The EPA water quality criteria listed in Table 1 state that phosphates should not exceed 0.05 mg/L if streams discharge into lakes or reservoirs, 0.025 mg/L within a lake or reservoir, and 0.1 mg/L in streams or flowing waters not discharging into lakes or reservoirs to control algal growth. Surface waters that are maintained at 0.01 to 0.03 mg/L of total phosphorus tend to remain uncontaminated by algal blooms (Phosphorus 1996).

Colorado and Minnesota State water quality criteria state that Total Phosphorus should not exceed 0.035 mg/L and 0.015 mg/L, respectively, within a reservoir. North Carolina and Vermont water quality criteria state that Total Phosphorus should not exceed 0.05 mg/L and 0.014 mg/L respectively, within a lake. It can be concluded from these water quality standards in Table 1 that state water quality standards for Total Phosphorus or phosphates can be stricter than the federal water quality criteria. Water quality criteria for Minnesota and Vermont are examples of stricter standards.

Table 1. EPA Water Quality Standards for Phosphorus

Type	Criteria	Water Body	Total P (mg/L)
Freshwater	Federal	Streams/rivers	0.1
Freshwater	Federal	Streams/entering lakes	0.05
Freshwater	Federal	Lakes/reservoirs	0.025

(Phosphorus 1996)

Type	Criteria	Water Body	Total P (mg/L)
Reservoirs	State	Reservoirs (CO)	0.035
Reservoirs	State	Reservoirs (MN)	0.015
Impoundments (EPA Region 4)	State	Water supply	0.015
Impoundments (EPA Region 4)	State	Aquatic life	0.025
Lakes (NC)	State	Lakes (NC)	0.05
Lakes (VT)	State	Mountain lakes (VT)	0.014

(Phosphorus 1996)

Type	Criteria	Phosphorus Concentrations
Estuaries	Aquatic life support	0.1µg/L elemental phosphorus
Estuaries	Maximum diversity	0.01* mg/L total phosphorus
Estuaries	Moderate diversity	0.1* mg/L

* These figures are recommended; eutrophication is also dependent on freshwater influx, nutrient cycling, dilution, and flushing of a pollutant load in a particular estuary. (Phosphorus 1996).

Environmental Effects

Nonpoint Sources

Natural: Phosphate deposits and phosphate-rich rocks release phosphorus during weathering, erosion, and leaching (Phosphorus 1996). Phosphorus may be released from lake and reservoir bottom sediments during seasonal overturns. This phosphorus release can cause accelerated algal growth within the water body.

Anthropogenic: The primary anthropogenic nonpoint sources of phosphorus include runoff from 1) land areas being mined for phosphate deposits, 2) agricultural areas, and 3) urban/residential areas. Because phosphorus has a strong affinity for soil, little dissolved phosphorus will be transported in runoff. Instead, the eroded sediments from mining and agricultural areas carry the adsorbed phosphorus to the water body. An additional source is the overboard discharge of phosphorus-containing sewage by boats (Phosphorus 1996).

Point Sources

Sewage treatment plants provide most of the available phosphorus to surface water bodies. A normal adult excretes 1.3-1.5 g of phosphorus per day. Additional phosphorus originates from the use of industrial products, such as toothpaste, detergents, pharmaceuticals, and food-treating compounds. Primary treatment removes only 10% of the phosphorus in the waste stream; secondary treatment removes only 30%. The remainder is discharged to the water body. Tertiary treatment is required to remove additional phosphorus from the water. Some available technologies include biological removal and chemical precipitation (Phosphorus 1996).

Mode of Transport

Phosphates are primarily discharged directly into the water body by sewage treatment plants. Phosphorus that is adsorbed to sediment particles may be transported in overland flow (Phosphorus 1996).

Phosphorus was discovered in 1660 by Hennig Brand, who prepared it from urine. Some of its industrial uses are

1. Used in the manufacture of safety matches, pyrotechnics, incendiary shells, smoke bombs, tracer bullets, etc.
2. Manufacture and use of fertilizers
3. Phosphates are used in the production of special glasses, such as those used for sodium lamps
4. Bone-ash, calcium phosphate, is used to produce fine chinaware and to produce monocalcium phosphate used in baking powder
5. Important in the production of steels, phosphor bronze, and many other products
6. Na_3PO_4 is important as a cleaning agent, as a water softener, and for preventing boiler scale and corrosion of pipes and most boiler tubes (Elemental Phosphorus 1996).

Environmental Impact

Rainfall can cause varying amounts of phosphates to wash from farm soils into nearby waterways. Phosphate will stimulate the growth of plankton and aquatic plants which provide food for fish. This increased growth may cause an increase in the fish population and improve the overall water quality. However, if an excess of phosphate enters the waterway, algae and aquatic plants will grow wildly, choke up the waterway, and use up large amounts of oxygen. This condition is known as eutrophication or over-fertilization of receiving waters. The rapid growth of aquatic vegetation can cause the death and decay of vegetation and aquatic life because of the decrease in dissolved oxygen levels (Environmental Impact 1996).

Phosphates are not toxic to people or animals unless they are present in very high levels. Digestive problems could occur from extremely high levels of phosphate (Environmental Impact 1996).

Summary of Observed Phosphorus Content of Urban Soils

Some typical street dirt and other urban soil phosphorus values are shown in Tables 2-4. These data are from various studies (which are further listed) in Appendix A of this text. Typical street dirt phosphorus concentrations range from about 500 to 1,000 mg TP/kg dirt. Small particles generally have the largest concentrations, but some large particles may also have large concentrations.

Table 2. Typical Street Dirt Phosphorus Concentration

Site	Street Dirt Phosphorus Concentration (mg TP/kg dirt)
Bellevue	560
Main Basin	580
108th Street	510
West Road	590
Lake Hills	640
148th Street	460
Castro Valley	462
Castro Valley	481
Milwaukee	
State Fair	670
Congress	1150
Rustler (Rough)	445
Rustler (Smooth)	505
Hastings	715

Table 3 shows some typical street dirt phosphorus concentrations by particle size for sites in Bellevue, Washington; Reno/Sparks, Nevada; and Winston-Salem, North Carolina. It is interesting to note that the street dirt phosphorus concentrations in the North Carolina sites are significantly less than the other sites. Some possible reasons for this phosphorus concentration difference are the geographical separation (North Carolina as compared to Washington and Nevada) and the season each sample was taken.

The geographical difference might indicate that the soils from each region differ. There could be more apatite within the western soils as compared to the southern. Also, the North Carolina samples could have been taken during the winter season, whereas the other region's samples could have been taken during the fall season.

Table 3. Typical Street Dirt Phosphorus Concentration by Particle Size

Site	Particle Size (µm)	Street Dirt Phosphorus Concentration
Bellevue	<63	880
	63-125	690
	125-250	630
	250-500	610
	>6350	760
Reno/Sparks Nevada	<63	900-1800
	63-125	590-1100
	125-250	500-960
	250-500	260-960
	500-1000	560-900
	1000-2000	610-1000
	2000-6370	640-1800
	>6370	490-1000
Winston-Salem, NC		
Central Business District	20-30	5.18
	30-45	19.22
	45-106	80.02
	106-212	49.65
	212-1000	62.14
	>1000	36.12
Residential	20-30	4.92
	30-45	16.69
	45-106	82.62
	106-212	69.76
	212-1000	126.18
	>1000	115.55

Table 4. Typical Phosphorus Concentrations in Urban Runoff

Site	Total Phosphorus (mg/L)
Bellevue	
Surrey Downs	
Baseflow	0.1
Stormwater	0.4
Bellevue (USGS)	
Maximum	9.2
Minimum	0.01
Median	0.15
Bellevue (City)	
Maximum	3.6
Minimum	0.002
Median	0.26
Castro Valley	
Seaview Station	
Maximum	1.9
Minimum	0.08
Average	0.6
Knox Station	
Maximum	0.85
Minimum	0.15
Average	0.42

CHAPTER 3

RESEARCH RESULTS AND CONCLUSIONS

Comparisons of Phosphorus Content by Particle Size for Different Locations

A "box and whiskers" plot was generated for each sample site comparing observed phosphorus concentration by particle size. The five replicate total phosphorus results for each of the six time periods were entered into a statistical software program and visually represented. These graphs revealed the time periods (April, June, July, August, September, and October) on the abscissa and the mg TP/kg dirt on the ordinate axis. Twenty graphs should have been generated, five for each sample site (Gammon, Glenway, Monroe, and Seneca Spring Huron Hill), representing different particle sizes (<25 µm, 25-63 µm, 63-250 µm, and >250 µm), as well as a leaf graph. However, only 19 graphs were created due to lack of sample for the <25 µm particle size sample for Glenway.

Table 5 is an analysis of the minimum and maximum phosphorus concentrations from these box and whiskers graphs (see Appendix B). From Table 5, the minimum and maximum total phosphorus (TP) concentrations range from 50 mg TP/kg sample to 1200 mg TP/kg sample and 210 mg TP/kg sample to 2600 mg TP/kg sample, respectively. The higher TP concentrations consist of the leaf samples and a majority of the smallest TP concentrations consist of the >250 µm street dirt samples. The exceptions to this trend could be due to sample matrix interference such as grass and other debris.

Table 5. Phosphorus Concentrations by Sample Site and Constituent

Site	Sample Content	Minimum Value (mg TP/kg dirt)	Maximum Value (mg TP/kg dirt)
Gammon	<25μm	350	650
Glenway	<25μm	NS*	NS*
Monroe	<25μm	210	350
Seneca	<25μm	260	480
Gammon	25-63μm	340	420
Glenway	25-63μm	250	500
Monroe	25-63μm	210	410
Seneca	25-63μm	NS	500
Gammon	63-250μm	300	430
Glenway	63-250μm	210	500
Monroe	63-250μm	110	350
Seneca	63-250μm	180	480
Gammon	>250μm	90	210
Glenway	>250μm	180	700
Monroe	>250μm	50	300
Seneca	>250μm	50	720
Gammon	Leaves	1200	1800
Glenway	Leaves	400	1600
Monroe	Leaves	800	2100
Seneca	Leaves	400	2600

* NS indicates that no sample was taken

Evaluation of Street Dirt Sources Through Thermal Chromatography

Part of the research involved "thermal chromatography." The development process for this procedure was explained previously in the laboratory section. Temperatures starting at 105°C, with additional 50°C increments up to 550°C, were used for heating known samples (standards) at 1-hour time periods. After each 1-hour heating period, the sample was weighed and noted. The purpose of this experiment was to determine at what temperature interval the highest percent mass loss for each known sample material was "burned off." These temperature intervals for each standard sample aid in the characterization of each street dirt sample. Knowing these standard samples' temperature intervals, each dirt sample can be analyzed, and, possibly, the constituents contained in each sample could be determined. This analysis, combined with the total P standard concentrations, was used to determine the major P sources for the street dirt samples.

Table 6 contains the mass loss percentages for different temperature intervals for each standard burned. Appendix C contains the detailed data.

Table 6. Mass Loss Percentages for Various Street Dirt Sources and Temperatures

Street Dirt Source	Temperature Interval (°C) (where most of the mass loss occurred)	Avg. Mass Loss (%)
Paper	300-350	49.2
Asphalt	350-450	4.3
Rubber	350-450	55.2
Cigarettes	150-250	76.3
UAB grass	250-350	18.0
UAB leaf	250-350	60.0
Seneca leaf	250-350	51.0
Glenway leaf (8/94)	200-300	63.2
Glenway leaf (9/94)	200-300	56.8

The largest mass loss percentage within a temperature interval was 76.3% for the cigarettes, with the two leaves and a rubber sample the next highest (63.2%, 56.8%, and 55.2%, respectively).

Four example street dirt composite samples were also heated at the 50°C intervals. The highest percent mass loss for the <25-µm street dirt sample occurred within the temperature interval of 100-150°C (14.5%). The highest percent mass loss for the 25- to 63-µm street dirt sample occurred within the temperature interval of 250-350°C (2.6%). The highest percent mass loss for the 63- to 250-µm street dirt sample occurred within temperature intervals of 350-400°C (1.0% loss) and 500-550°C (1.9% loss). The highest percent mass loss for the >250-μm street dirt sample occurred within the temperature interval of 300-350°C (0.5%).

A noticeable trend was indicated from these street dirt sample mass losses. The amount of sample loss for the critical temperature interval decreased as the particle size increased. The temperature range causing the greatest incremental mass loss also seems to increase for the larger particle sizes. The histograms (Appendix C) were generated by entering the % mass loss of the sample being heated between each temperature interval.

Table 7 lists the mass loss percentage observed for each leaf sample heated at the 240-365°C temperature interval.

Table 7. Leaf Percent Mass Loss

Site	Date	Temperature Interval (°C)	Max. Mass Loss (%)
Gammon	6/94	240-365	55.4
Gammon	7/94	240-365	50.5
Gammon	8/94	240-365	45.8
Gammon	9/94	240-365	52.0
Gammon	10/94	240-365	47.6
Glenway	4/94	240-365	40.7
Glenway	6/94	365-470	36.6
Glenway	7/94	365-470	41.0
Glenway	8/94	240-365	42.9
Glenway	9/94	240-365	38.6
Glenway	10/94	365-470	34.3
Monroe	6/94	365-470	40.0
Monroe	8/94	240-365	39.8
Monroe	9/94	240-365	50.9
Monroe	10/94	240-365	49.3
Seneca	4/94	240-365	59.7
Seneca	6/94	240-365	58.9
Seneca	7/94	240-365	46.7
Seneca	8/94	240-365	47.4
Seneca	9/94	240-365	50.5
Seneca	10/94	240-365	35.6

From Table 7, the highest percent mass loss for the leaf samples burned was most prevalent within the 240-365°C temperature interval. The mass loss within this temperature interval ranged from 34.3 to 59.7% and averaged 46%.

Accumulated Percent Mass Loss by Site

These plots (shown in Appendix D) were generated by entering the mass loss percentage data obtained from the "thermal chromatography" experiment into a statistical software and then creating graphs containing the heating temperatures on the abscissa and the accumulated mass loss (%) on the ordinate. The accumulated mass loss (shown in Table 8) was calculated by knowing the original mass of each sample and comparing that with the mass of the sample after each heating interval. This process was continued for each heating interval until 550°C was reached.

The >250-µm samples have the lowest percent mass loss compared to the other particle sizes, excluding the leaf fraction. This was to be expected considering a majority of the >250-µm samples were composed of rock, which is not highly combustible. The <25, 25- to 63-, and 63- to 250-µm samples were closely related in accumulated percent mass loss.

The leaf samples had the highest accumulated percent mass losses. The leaf samples had a total percent mass loss of as much as 96%. Since a majority of the leaf samples had these high total percent mass loss percentages, it can be concluded that there were probably not any rock or high concentrations of other debris within the samples.

From viewing Table 8, the four sample sites of Gammon, Glenway, Monroe, and Seneca Spring Huron Hill all have very high total percent leaf mass loss percentages.

Table 8. Accumulated Percent Mass Loss by Site

Site	Size	Accumulated % Mass Loss at 550°C (range of observations)
Gammon	<25 µm	5.8-7.9
Gammon	25-63 µm	5.0-6.7
Gammon	63-250 µm	2.4-4.8
Gammon	>250 µm	1.2-2.4
Gammon	Leaves	84.6-93.0
Glenway	<25 µm	4.9-15.9
Glenway	25-63 µm	4.7-12.1
Glenway	63-250 µm	3.0-13.1
Glenway	>250 µm	1.3-30.3
Glenway	Leaves	83.9-96.2
Monroe	<25 µm	4.0-7.3
Monroe	25-63 µm	2.8-6.1
Monroe	63-250 µm	2.6-5.2
Monroe	>250 µm	1.0-4.4
Monroe	Leaves	84.0-94.0
Seneca	<25 µm	6.3-13.0
Seneca	25-63µm	6.4-13.8
Seneca	63-250µm	4.1-12.0
Seneca	>250 µm	3.3-28.2
Seneca	Leaves	86.6-91.7

- NS indicates that no sample was taken.

Phosphorus Concentrations by Particle Size

All four of these plots (Appendix E), one for each sample site, showed the same results. The leaves had the highest concentration of total phosphorus per kg of sample, except for the October leaf sample for Glenway. This leaf sample could possibly have been composed of mostly twigs and rocks, which would have lowered the total phosphorus concentration. The <25-µm and 25- to 63-µm particle size samples were consistently close in concentration, which would be expected since the sizes are similar. However, the smallest size, <25 µm, came out higher in some samples. The smaller the particle size was, the higher the total phosphorus concentration to be expected since the smallest sizes have the most surface area to adsorb the phosphorus. The >250-µm particle size had the lowest total phosphorus concentrations, except for the October Glenway sample. This sample could have had more leaves and vegetation contained within it than other samples.

Conclusions

Contributions of the street dirt phosphorus originating from leaves was determined using several methods. The first step was to calculate the percentage mass losses for all of the leaf samples at 240-365°C, since this temperature interval caused the highest mass loss for the leaf samples during the initial tests. The average % mass loss for the individual leaf samples in this temperature interval was 50%. The percentage loss for the leaves was then compared to the mass lost from 240-360°C for each dirt sample for the four sample sites and six time periods. This was used to calculate the approximate leaf content for each dirt sample, which is shown in Table 9. As an example, if a street dirt sample lost 2% in this temperature interval, and the corresponding leaf sample for that site and time period had a mass loss of 50% for the same temperature interval, the calculated leaf fraction was 4%.

The total phosphorus (TP) concentration per kilogram of leaf sample was also calculated for each site and time period. The average leaf sample value was 1550 mg TP/kg leaf sample. This average TP concentration was multiplied by each dirt % of leaves value (determined above) to indicate the "Total Phosphorus" of leaves within each dirt sample. Then, this TP concentration was divided by the average TP/kg dirt concentration for the respective dirt sample in order to calculate the % of TP from leaves within each sample (Table 9).

"Total mass of each dirt sample" was denoted as well as the individual particle size masses after the sample had been sieved. From this data, the mass percentage of each particle size for each dirt sample was determined.

The characterization of the samples was aided by being capable of understanding the composition of the samples; for example, whether or not the >250 μm particle size composed the majority of each sample which it did. The >250 μm particle size did comprise a definite majority of each sample; however, the total phosphorus contribution was the smallest. Also, it was this size that was removed the most efficiently from streets by sweeping. Removal efficiencies of approximately 60% were calculated from several studies as shown in Appendix F.

The street dirt particle accumulation is affected by the average traffic density for the particular sample site. The land use of the sample site, as well as the land uses of the adjacent sites, can also affect street dirt particle accumulation. The four sample sites were Monroe Street, Glenway Avenue, Gammon Road, and Seneca, Spring, Huron Hill. The Monroe Street sample site has an average daily traffic count of 18,600 vehicles per day and has adjacent park and commercial land uses. Glenway Avenue has an average daily traffic count of 6,157 vehicles per day and has residential and golf course land uses adjacent to this site. Gammon Road has an average daily traffic count of 27,887 vehicles per day with mostly commercial and some open space as land uses adjacent to the site. The Seneca, Spring, Huron Hill area consists mainly of residential land uses. These factors, average daily traffic count and land uses, also serve as possible sources of phosphorus within the street dirt samples. More samples are needed to determine the correlations.

Table 9. % Total Phosphorus Ranges

<25 microns

% TP from leaves		mg TP/kg dirt (avg)	% TP(dirt) by particle size
Gammon	1.5%-46.7%	355-555	0.9%-3.6%
Glenway	17.2%-46.5%	153-525	0.0%-0.6%
Monroe	5.1%-86.4%	231-320	0.2%-1.6%
SSHH	6.8%-54.8%	250-506	0.2%-1.2%

25-63 microns

% TP from leaves		mg TP/kg dirt (avg)	% TP(dirt) by particle size
Gammon	13.2%-41.1%	198-391	3.0%-10.0%
Glenway	12.4%-32.0%	236-489	0.0%-3.8%
Monroe	7.6%-38.4%	189-367	2.4%-9.9%
SSHH	5.9%-61.8%	361-512	1.2%-10.4%

63-250 microns

% TP from leaves		mg TP/kg dirt (avg)	% TP(dirt) by particle size
Gammon	3.3%-24.1%	296-388	13.5%-39.2%
Glenway	4.0%-41.7%	194-484	10.3%-22.3%
Monroe	5.2%-37.0%	125-345	9.4%-24.9%
SSHH	3.2%-55.7%	204-403	8.3%-56.3%

>250 microns

% TP from leaves		mg TP/kg dirt (avg)	% TP(dirt) by particle size
Gammon	5.3%-85.1%	99-340	50.5%-81.0%
Glenway	4.7%-93.1%	137-874	73.4%-88.2%
Monroe	0.8%-28.8%	134-409	63.6%-87.6%
SSHH	10.0%-73.8%	70-722	39.2%-90.2%

Street Cleaning Efficiencies

Table 10 contains the removal efficiencies of various street dirt particle sizes by frequent sweeping practices. It is evident from this table that the larger particulates are removed more efficiently than the smaller particulates.

Table 10. Particle Removal Efficiencies by Sweeping (Boyd and Sartor 1972)

Particle Size (μm)	Removal Efficiency in Mass (%)
0-40	15
40-100	20
100-250	48
250-850	60
850-2000	66
>2000	79

It is evident from Appendix F and Table 10 that the smaller particulates had the highest total phosphorus unit weight concentrations; however, the larger particulates make up the highest mass percentage of all the samples. The large particulates, therefore, contributed the largest fraction of the total sample phosphorus. Although the smaller particle sizes do have the greatest surface area and tend to contain the highest phosphorus concentration, they do not comprise a very large fraction of the street dirt. This is important in terms of street cleaning, as cleaning efficiencies are greater for these larger particles. Boyd and Sartor (1972) reports that larger particles (>250 μm) are removed more efficiently (approximately 60%) than the smaller particle sizes (<25 μm; approximately 15%).

The leaf samples overall had the highest total phosphorus concentrations compared to the street dirt samples (average 1500 mg TP/kg leaf). Many of the >250 μm samples had high leaf percentages (maximum 36%); therefore, street cleaning could prove to be successful in removing phosphorus concentrations from streets. Removal of leaf material frequently from the streets can also prevent the leaf material from decomposing into smaller particle sizes that are more difficult to remove by street cleaning and are more efficiently washed from the streets during rains.

APPENDIX A

STREET DIRT AND URBAN RUNOFF PHOSPHORUS CONCENTRATIONS FROM PRIOR STUDIES

PHOSPHORUS CONCENTRATIONS FROM DIFFERENT AREAS AND SOURCES

The following tables show phosphorus values observed in Bellevue, Washington; Castro Valley, California; San Jose, California; Champaign-Urbana, Illinois; Milwaukee, Wisconsin; Reno Sparks, Nevada; and Winston-Salem, North Carolina. Various studies have been conducted in these areas that have generated data on phosphorus concentrations in solids from different sources. Some of these studies evaluate phosphorus in street dirt specifically.

BELLEVUE URBAN RUNOFF PROGRAM SUMMARY REPORT PREPARED BY PITT & BISSONNETTE; JUNE , 1984

TABLE A1. TYPICAL SOLIDS QUALITY

TYPICAL DRY-WEIGHT CONCENTRATIONS for TOTAL PHOSPHORUS
(mg constituent / kg total solids)

Constituent	Street Dirt	Catchbasin Sediment
TP	560	690

TABLE A2. SURREY DOWNS DEPOSITION, ACCUMULATION, AND WASHOFF OF TOTAL SOLIDS AND PHOSPHORUS

	Unit Area Value (kg/ha/yr)	
"Sources"	Total Solids	Total Phosphorus
Atmospheric deposition		
Rain	32	0.1
Particulate (dry)	88	0.2
Street dirt		
Accumulation	200	0.1
Washoff	30	0.02
Lost to air	20	0.01
Storm drainage inlet		
Accumulation	150	0.3
Urban runoff		
Baseflows	110	0.1
Stormwater	210	0.4
Kelsey Creek discharges	300(suspended solids only)	0.9
Bear Creek discharges	80 (suspended solids only)	0.3

TABLE A3. ANNUAL CREEK DISCHARGES FOR JUNE 1979 THROUGH MAY 1980 (kg/ha/yr)

Constituent	Kelsey Creek (Urbanized)	Bear Creek (Forested)	Ratio of Kelsey to Bear Creek Discharge
Total suspended solids	300	78	3.8
Soluble reactive P	0.56	0.17	3.3
Total phosphorus	0.87	0.33	2.6

TABLE A4. URBAN RUNOFF QUALITY REPORTED BY THE USGS (Many Discrete Samples for a Limited Number of Storms)

Constituent (mg/L)	Max.	Min.	Approx. Median	# of Discrete Samples
Suspended solids	2740	1	50	1180
Dissolved solids	788	8	35	240
Total phosphorus	9.2	0.01	0.15	686
Dissolved phosphorus	7.2	<0.01	0.06	686

Note: Data for all Bellevue urban sites combined (most of the median values are averages of the 3 site medians): Lake Hills, Surrey Downs, and 148th Avenue, S.E.

TABLE A5. URBAN RUNOFF QUALITY REPORTED BY THE CITY OF BELLEVUE (total storm, flow-weighted composite samples for most events)

Constituent	Max.	Min.	Average	# of Total Storm Samples
Total solids (mg/L)	620	24	109	208
Total P (mg/L)	3.6	0.002	0.26	208

Note: Data for Surrey Downs and Lake Hills combined, from 2/80 through 1/82

TABLE A6. SOURCE AREAS FOR TOTAL SOLIDS AND PHOSPHORUS (for 2.5 to 65 mm rains)

Percent Contributions from Source Areas		
Source Area	**Total Solids**	**Phosphates**
Streets	9%	32%
Driveways and parking lots	6	21
Rooftops	<1	5
Front yards	44	22
Back yards	39	20
Vacant lots and parks	2	<1

TABLE A7. STREET DIRT CHEMICAL CHARACTERISTICS FOR TOTAL PHOSPHORUS WHOLE SAMPLE STRENGTH (mg TP/kg total solids)

Constituent	**Surrey Downs**			**Lake Hills**	**148th Ave., SE**
	Main Basin	108th Street	Westwood Homes Road		
Total P	580	510	590	640	460

TABLE A8. MEDIAN PARTICLE SIZE (μm) (1)

Constituent	**Surrey Downs**			**Lake Hills**	**148th Ave. SE**
	Main Basin	108th Street	Westwood Homes Road		
Total solids	520	1400	840	420	610
Total P	670	1900	890	430	260

(1) Half of the constituents (by weight) are associated with particles greater than these sizes, while half are associated with particles smaller than these sizes.

TABLE A9. APPROXIMATE ANNUAL STREET DIRT ACCUMULATION AND WASHOFF (kg/ha/yr)

	Surrey Downs			**Lake Hills**		
Constituent	Accumul.	Washoff	Lost to Air	Accumulat.	Washoff	Lost to Air
Total solids	200	30	20	350	60	20
Total P	0.1	0.02	0.01	0.4	0.1	0.02

TABLE A10. CATCHBASIN SEDIMENT QUALITY

Average Concentrations (mg TP/kg total solids)	
Particle Size (microns)	**Total Phosphorus**
<63	880
63-125	690
125-250	630
250-500	610
500-1000	550
1000-2000	930
2000-6350	1100
>6350	760

Note: Surrey Downs samples collected from 1/13 to 6/17/81.

TABLE A11. ANNUAL ACCUMULATIONS OF SEDIMENTS AND TOTAL PHOSPHORUS IN STORM SEWER INLET STRUCTURES

	Total Solids		TP	Approx. % of Tot.
	L/ha/yr	kg/ha/yr[1]	kg/ha/yr	%
Surrey Downs				
Catchbasins	65	100	0.17	67
Inlets	24	36	0.06	25
Manholes	7	11	0.02	8
Total	**96**	**147**	**0.25**	**100**
Lake Hills				
Catchbasins	30	45	0.03	46
Inlets	19	28	0.02	28
Man-holes	17	27	0.02	26
Total	**66**	**100**	**0.07**	**100**

(1) assuming 1.5 g/cm^3 wet sediment density.

DATA FROM CASTRO VALLEY, CALIFORNIA
Prepared by Pitt and Shawley 1981

TABLE A12. STRENGTHS OF CASTRO VALLEY SOURCE AREA PARTICULATES
(mg constituent/kg total solids)

Source Area:	**Ortho-Phosphate**
Unpaved areas:	
Rural vacant lot-1	16

TABLE A12. STRENGTHS OF CASTRO VALLEY SOURCE AREA PARTICULATES (Continued)

Source Area:	**Ortho-Phosphate**
Rural vacant lot-2	19
Rural vacant lot-3	21
Rural vacant lot-4	5
Urban vacant lot-1	58
Urban vacant lot-2	18
Urban resid. const. site	19
Urban driveways	5
Urban parking lots	5
Residential lawns	30
School turf	393
Residential gardens	41
Landscaped park	10
Paved Areas:	
Driveways	11
Parking lots	8
School playground	6
Typical city streets	5
Rural road (1)	-
Highway (1)	-
Airport taxiway and runway (1)	-
Rooftops:	
Resid., wooden shingles, 20yr. old	2
Resid., asphalt shingles, 1yr. old	4
Resid., asphalt shingles, 1yr. old	80
Commercial composites of asphalt, wood, and tar & gravel	5
(1) Source: Pitt and Shawley 1981	**(San Francisco Bay Area values)**

TABLE A13. STREET DIRT CHEMICAL QUALITY (mg constituent/kg total solids)

	Phosphorus		**Ortho-Phosphate**	
	First Year	Second Year	First Year	Second Year
Minimum	169	432	18	18
Maximum	622	594	49	29
Mean	462	481	39	21
Standard dev.	80	48	6.6	2.7
St. Dev./Mean	0.17	0.10	0.17	0.13

TABLE A14. ESTIMATES OF INLET LOADINGS COMPARED TO ANNUAL STORM FLOW

	Total Load per Inlet (dry lbs.)	Total Load for 200 Inlets (dry lbs.)	Total Load for 200 Inlets as a % of Annual Runoff Yield	Relative Strength of Inlet Solids (mg constituent per kg tot. solids)	Median Inlet Particle Size Microns
Constituents					
Total P	0.08	16	2	1360	1750

TABLE A15. STRENGTHS OF CASTRO VALLEY CREEK SEDIMENTS (mg constituent/kg total solids)

Castro Valley Creek Sediments	Ortho-Phosphate
"Rural" station	
Above seaview	10
Seaview confluence	47
Seaview gaging station	<5
"Urban" stations	
Heyer St.	8
Berdina St.	5
Knox gaging station	13
Chabot confluence	10

TABLE A16. CASTRO VALLEY CREEK OBSERVED STORM FLOW CONCENTRATIONS (mg/L)

	Seaview Station (Rural)						Knox Station (Urban)					
Constituent	Min.	Max.	Avg.	Std. Dev.	Std. Dev./ Avg. Ratio	No. of Obser.	Min.	Max.	Avg.	Std. Dev.	Std. Dev./ Avg. Ratio	No. of Observat.
TP	0.08	1.9	0.6	0.5	0.9	16	0.15	0.85	0.42	0.19	0.5	21
Diss. Ortho-P	0.03	0.8	0.4	0.3	0.6	14	0.06	0.95	0.46	0.26	0.6	20

TABLE A17. CASTRO VALLEY CREEK AND URBAN AREA OBSERVED STORM PERIOD RELATIVE CONCENTRATIONS (mg constituent/kg total solids)

	Seaview Station (Rural)				Knox Station (Urban)					
Const.	Min.	Max.	Avg.	No. of Obs.	Min.	Max.	Avg.	Std. Dev.	Std. Dev./ Avg. Ratio	No. of Ob-serv.
TP	76	1600	590	16	220	2000	1200	540	0.4	21
Diss. Ortho-P	44	1100	460	14	570	4200	1500	-	-	20

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TABLE A18. AVERAGE NATIONWIDE POLLUTANT STRENGTHS ASSOCIATED WITH STREET SURFACE PARTICULATES
(From Boyd and Sartor 1972)
(mg pollutant / kg solids)

Parame-ter(ppm)	Mean Strength	Minimum Strength	Max Strength	STD	Ratio of STD /Mean
Ortho PO4	1300	14	6700	1400	1.1
Total P	2900	210	5400	<10 samples	-

The median particle size for the street surface contaminant PO_4 was 36 microns. The total solids median particle size was 220.

TABLE A19. RUNOFF POLLUTANT RELATIVE STRENGTHS (mg pollutant/kg total solids)

Study Area	Ortho PO_4
Keyes study area	
3/15 & 16/77 storm	22,600
3/23 & 24/77 storm	-------
4/30 & 5/1/77 storm	11,000
Tropicana study area	
3/15 & 16/77 storm	8000
3/23 & 24/77 storm	1800
4/30 & 5/1/77 storm	16,000

TABLE A20. CHEMICAL CONCENTRATIONS BY PARTICLE SIZE--DOWNTOWN TEST AREAS (mg consituent/kg solids)

Downtown--Poor Asphalt Street Surface Condition--Study Area								
	Particle Sizes (µm)							
Parameter	>6370	2000-	850-	600-	250-	106-	45-	<45
12/13/76 -1/23/77		6370	2000	850	600	250	106	
OrthoPO_4	104	74	129	61	159	184	221	221
Downtown--Good Asphalt Street Surface Condition--Study Area								
	Particle Sizes (µm)							
Parameter	>6370	2000-	850-	600-	250-	106-	45-	<45
12/13/76 -1/23/77		6370	2000	850	600	250	106	
OrthoPO_4	55	147	116	116	184	123	208	215

TABLE A21. CHEMICAL CONCENTRATIONS BY PARTICLE SIZE--TROPICANA GOOD ASPHALT TEST AREA

	Particle Sizes (µm)							
Parameter	>6370	2000-6370	850-2000	600-850	250-600	106-250	45-106	<45
1/13/76-1/23/77								
OrthoPO_4	178	282	184	233	178	202	257	276
1/24/-3/20/77								
OrthoPO_4	61	98	178	104	116	159	178	429
3/21-5/15/77								
OrthoPO_4	98	80	147	123	233	178	264	288
5/16-7/31/77								
OrthoPO_4	130	120	154	156	132	113	146	199
8/1-9/23/77								
OrthoPO_4	96	125	161	172	131	161	205	246

TABLE A22. CHEMICAL CONCENTRATIONS BY PARTICLE SIZE--KEYES GOOD ASPHALT TEST AREA
(mg constituent/kg solids)

	Particle Size (µm)							
Parameter	>6370	2000-6370	850-2000	600-850	250-600	106-250	45-106	<45
12/13/76 -1/23/77								
$OrthoPO_4$	86	202	129	159	129	141	227	233
1/24-3/20/77								
$OrthoPO_4$	86	178	129	153	141	172	239	300
3/21-5/15/77								
$OrthoPO_4$	116	184	54	141	165	172	245	233
5/16-7/31/77								
$OrthoPO_4$	108	108	131	113	107	114	153	178
8/1-9/23/77								
$OrthoPO_4$	47	90	334	99	21	123	165	189

TABLE A23. CHEMICAL CONCENTRATIONS BY PARTICLE SIZE KEYES--OIL AND SCREENS TEST AREA
(mg constituent/kg solids)

	Particle (microns)							
Parameter	>6370	2000-6370	850-2000	600-850	250-600	106-250	45-106	<45
12/13/76 -1/23/77								
$OrthoPO_4$	49	74	31	37	49	18	147	178
1/24-3/20/77								
$OrthoPO_4$	22	25	43	31	61	80	159	215
3/21-5/15/77								
$OrthoPO_4$	129	18	74	43	74	80	129	165
5/16-7/31/77								
$OrthoPO_4$	57	22	29	15	35	49	80	113
8/1-9/23/77								
$OrthoPO_4$	50	56	50	45	49	60	92	156

CHAMPAIGN-URBANA, ILLINOIS
NURP: EVALUATION OF THE EFFECTIVENESS OF MUNICIPAL STREET SWEEPING IN THE CONTROL OF URBAN STORM RUNOFF POLLUTION
MICHAEL L. TERSTRIEP
G. MICHAEL BENDER
H. DOUGLAS C. NOEL
DECEMBER, 1982

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TABLE A24. AVERAGE CONCENTRATIONS OF SEVEN CONSTITUENTS IN STREET DIRT BY PARTICLE SIZE GROUP FOR EACH BASIN
(data for no sweeping periods only)

Area and Particle Size (µm)	Phosphorus (mg/kg)
Mattis North	
500-1000	135
250-500	135
125-250	261
63-125	474
<63	421
Mattis South	
500-1000	219
250-500	101
125-250	150
63-125	529
<63	388
John South	
500-1000	853
250-500	629
125-250	606
63-125	926
<63	667
John North	
500-1000	273
250-500	148
125-250	225
63-125	596
<63	403

EVALUATION OF URBAN NONPOINT SOURCE POLLUTION MANAGEMENT IN MILWAUKEE COUNTY, WISCONSIN

VOLUME 1: URBAN STORMWATER CHARACTERISTICS, SOURCES AND POLLUTANT MANAGEMENT BY STREET SWEEPING

WISCONSIN DEPARTMENT OF NATURAL RESOURCES
MADISON, WISCONSIN
Bannerman et al. 1983

TABLE A25. MEAN CONCENTRATION OF TOTAL PHOSPHORUS IN STREET DIRT

Site	PARTICLE SIZE OF STREET DIRT (mm)							
	<0.031	0.031-0.063	0.063-0.125	0.125-0.25	0.25-0.50	0.50-1.0	1.0-2.0	2.0-4.0
	Total Phosphorus Concentration (mg/kg)							
State Fair	670	375	415	275	200	215	170	190
Congress	1150	550	800	575	475	525	425	275
Rustler Rough	445	205	250	215	115	145	120	150
Rustler Smooth	505	250	285	210	110	125	170	125
Hastings	715	395	495	415	345	360	330	275

RENO/SPARKS, NEVADA
WASHOE COUNTY URBAN STORMWATER MANAGEMENT PROGRAM
VOLUME II
STREET PARTICULATE DATA COLLECTION AND ANALYSES

PITT and SUTHERLAND
AUGUST 1982

TABLE A26. OBSERVED STREET DIRT CONSTITUENT CONCENTRATIONS, BY PARTICLE SIZE

TOTAL PHOSPHORUS (mg/kg)

Part. Size Range (microns)	Parkv.	Mill	Fifth	CBD	Tallman	Trainer	Lepori	Locust	Brookf.	Glend.
<63	1100	1100	1200	1800	900	1400	1000	1100	960	1200

TABLE A26. OBSERVED STREET DIRT CONSTITUENT CONCENTRATIONS BY PARTICLE SIZE (Continued)

63-125	860	900	900	1100	780	930	910	590	710	1000
125-250	670	630	740	930	590	930	620	500	540	960
250-500	690	740	720	960	620	790	670	260	780	920
500-1000	720	560	670	860	650	880	790	630	560	900
1000-2000	790	610	810	1000	840	970	800	620	840	1000
2000-6370	810	700	1000	1000	1000	1800	830	640	740	1100
>6370	830	870	580	960	860	2000	920	490	910	1000
Weight. avg.	720	800	770	900	710	1200	760	720	760	890

TABLE A27. OBSERVED STREET DIRT CONSTITUENT CONCENTRATIONS (mg constituent/kg total solids)

	Total Phosphorus
Parkview full street (1st series)	
x	703
σ	130
N	8
Full street (2nd series)	
x	670
σ	96
N	9
Driving lane only (2nd series)	
x	786
σ	112
N	9
Driving lane to full street ratio	1.2
Fifth Street	
Full street (1st series)	
x	910
σ	75
N	5

TABLE A27. OBSERVED STREET DIRT CONSTITUENT CONCENTRATIONS (Continued)

	Total Phosphorus
Glendale	
Full street (1st series)	
x	1100
σ	210
N	8
Full street (2nd series)	
x	850
σ	240
N	9
Driving lane only (2nd series)	
x	710
σ	140
N	9
Driving lane to full street ratio:	0.84
Mill Street	
Full street (1st series)	
x	800
σ	290
N	8
Tallman	
Full street (1st series)	
x	710
σ	67
N	9
Trainer	
Full street (1st series)	
x	1160
σ	190
N	8
Locust	
Full street (1st series)	
x	715
σ	190
N	10
Brookfield	
Full street (1st series)	
x	760
σ	50
N	7

APPENDIX B

VARIATIONS OF TOTAL PHOSPHORUS BY SITE, SAMPLING PERIOD, AND PARTICLE SIZE

FIGURE B2. GAMMON: 25-63 MICRONS

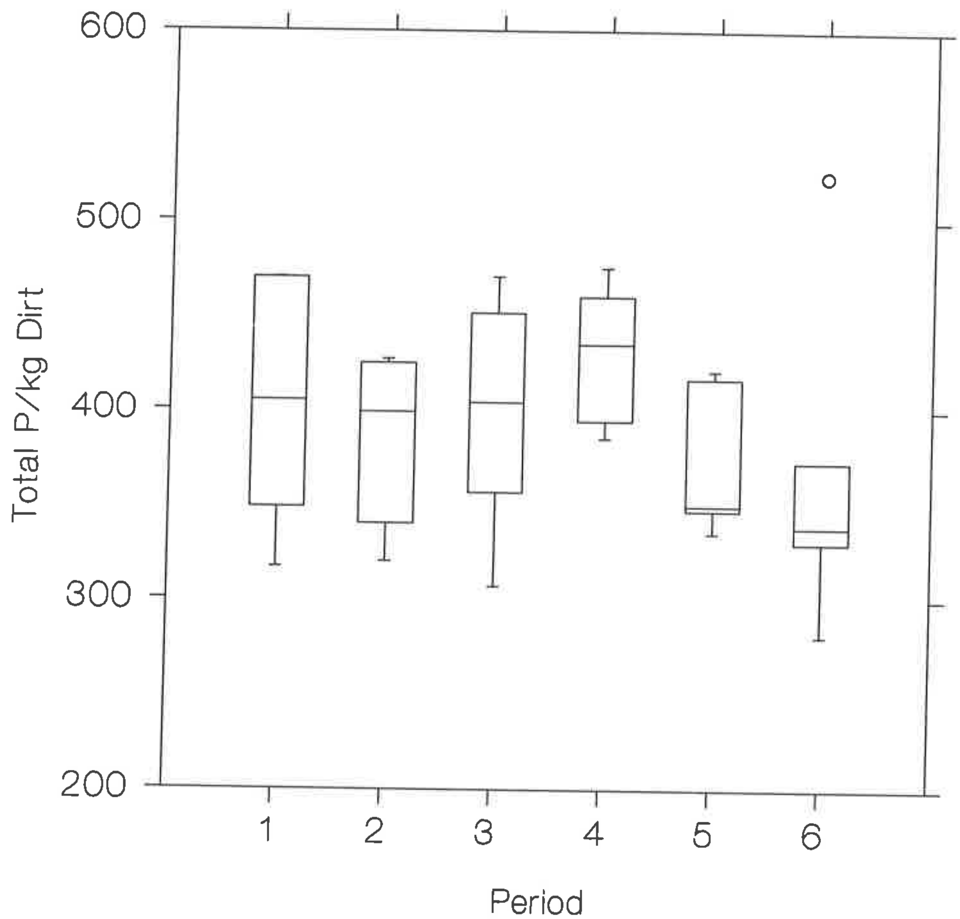


FIGURE B3. GAMMON: 63-250 MICRONS

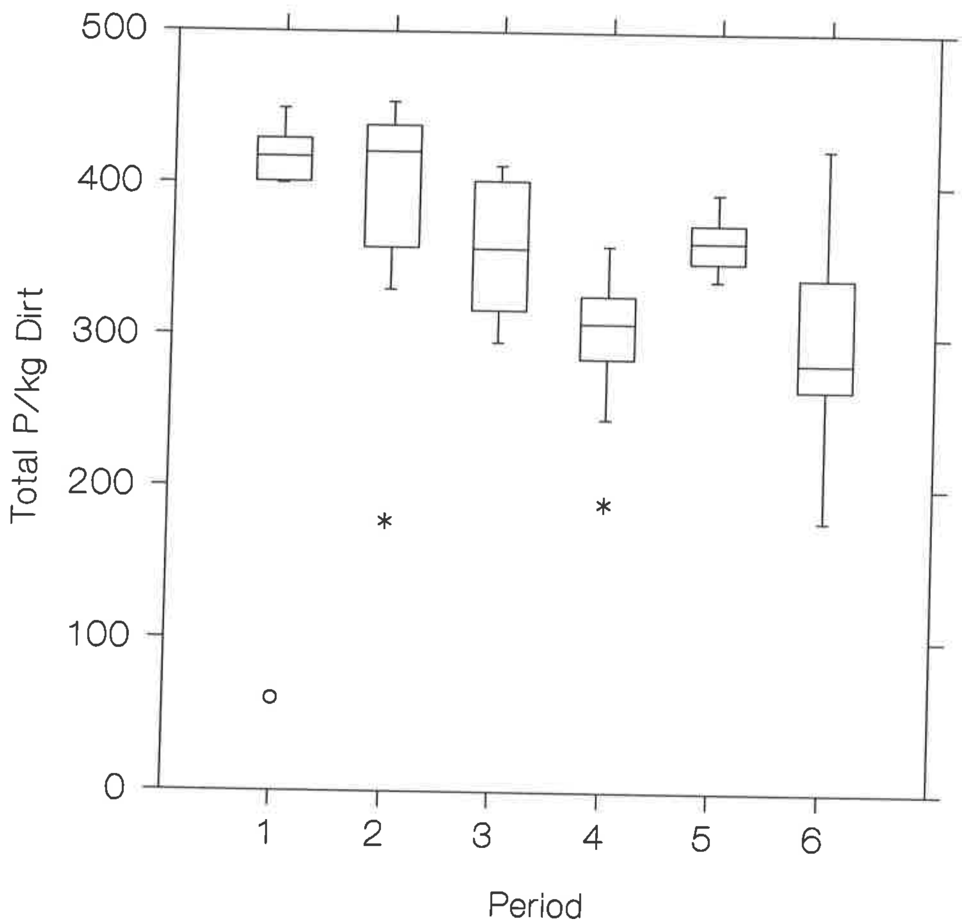


FIGURE B4. GAMMON: >250 MICRONS

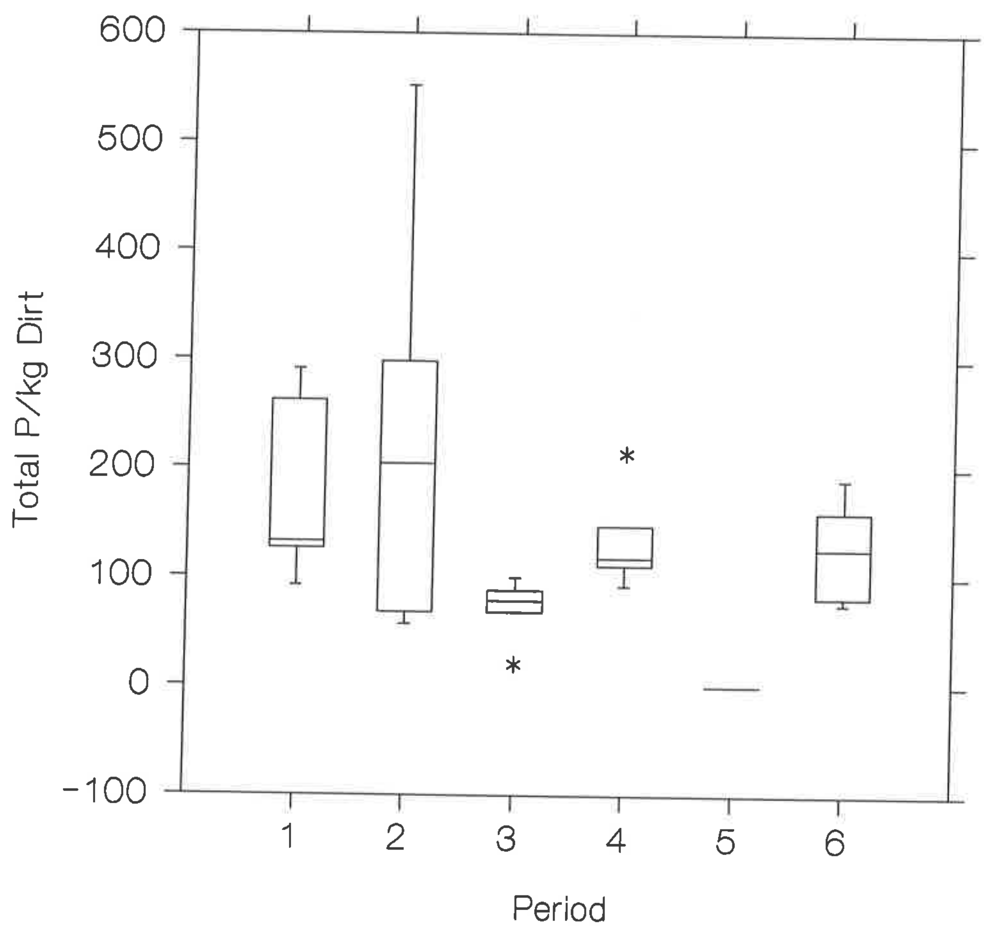


FIGURE B5. GAMMON: LEAVES

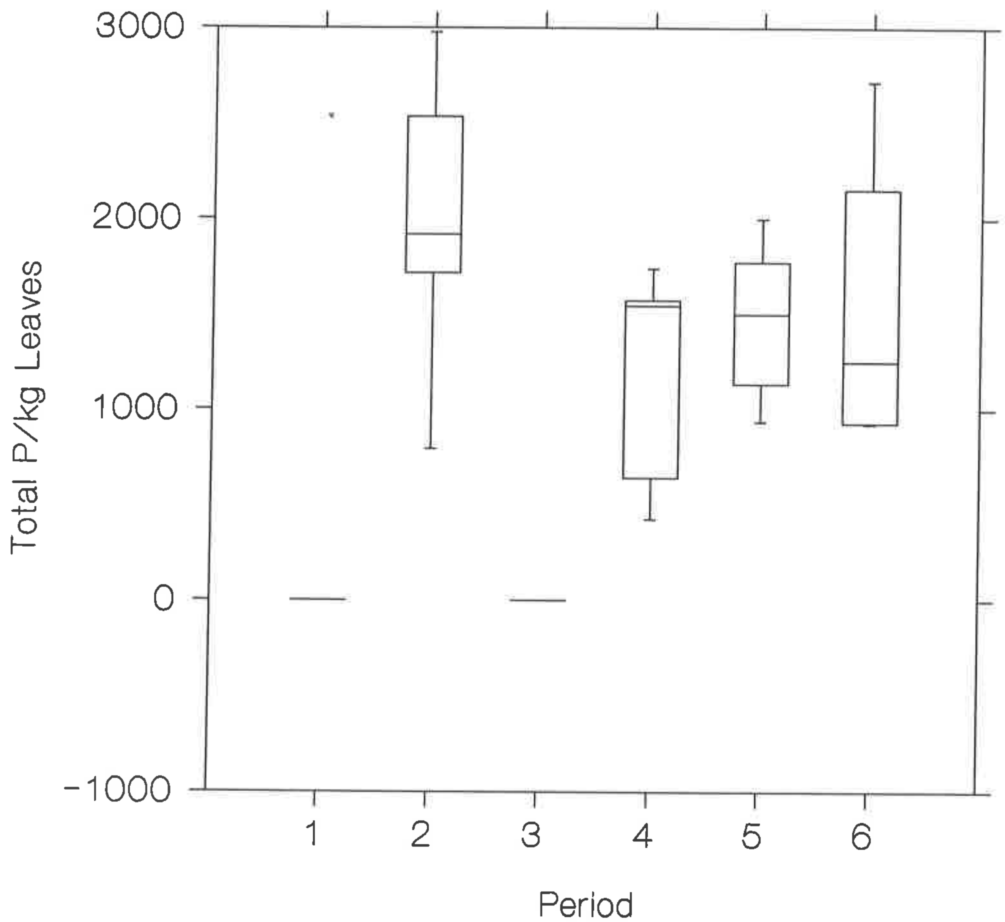


FIGURE B6. GLENWAY: 25-63 MICRONS

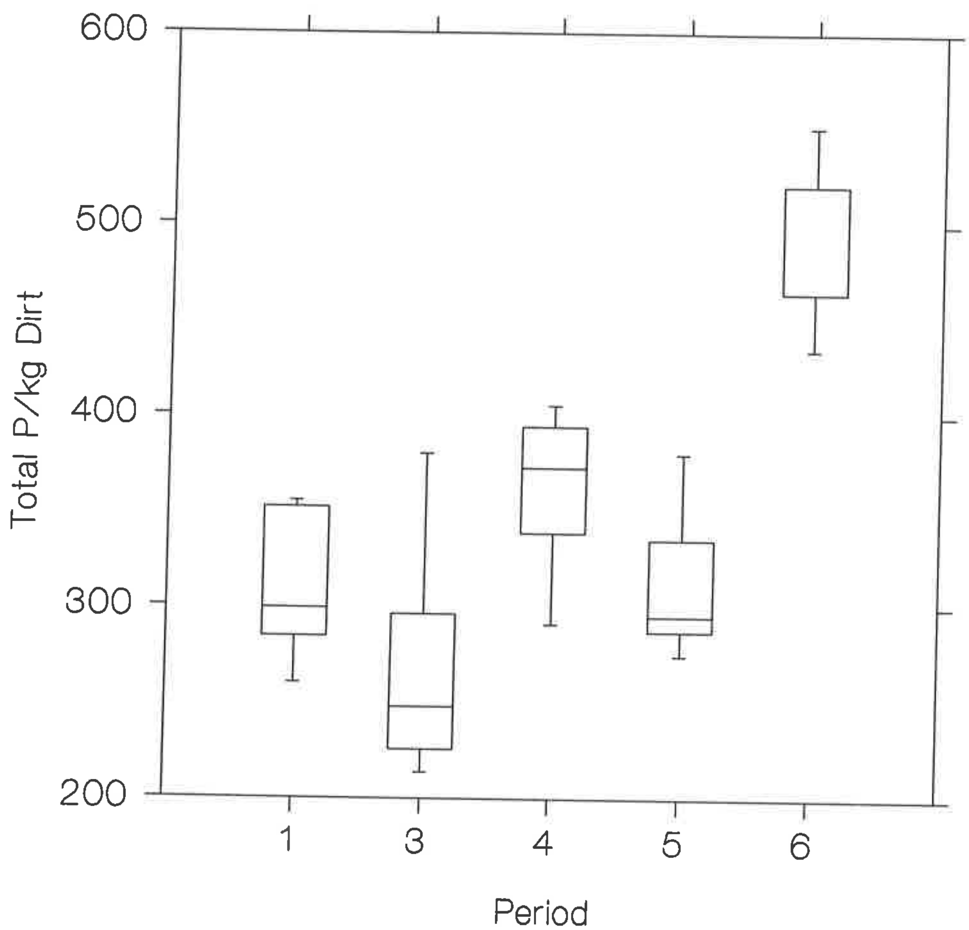


FIGURE B7. GLENWAY: 63-250 MICRONS

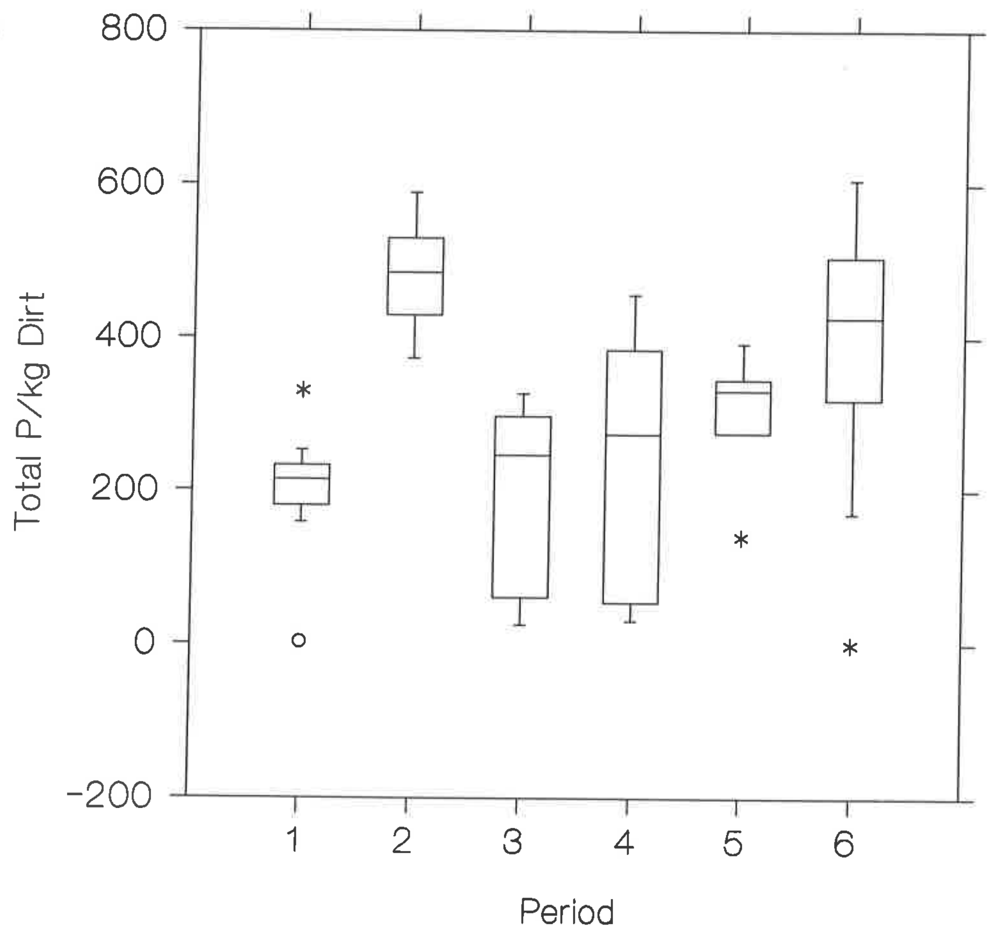


FIGURE B8. GLENWAY: >250 MICRONS

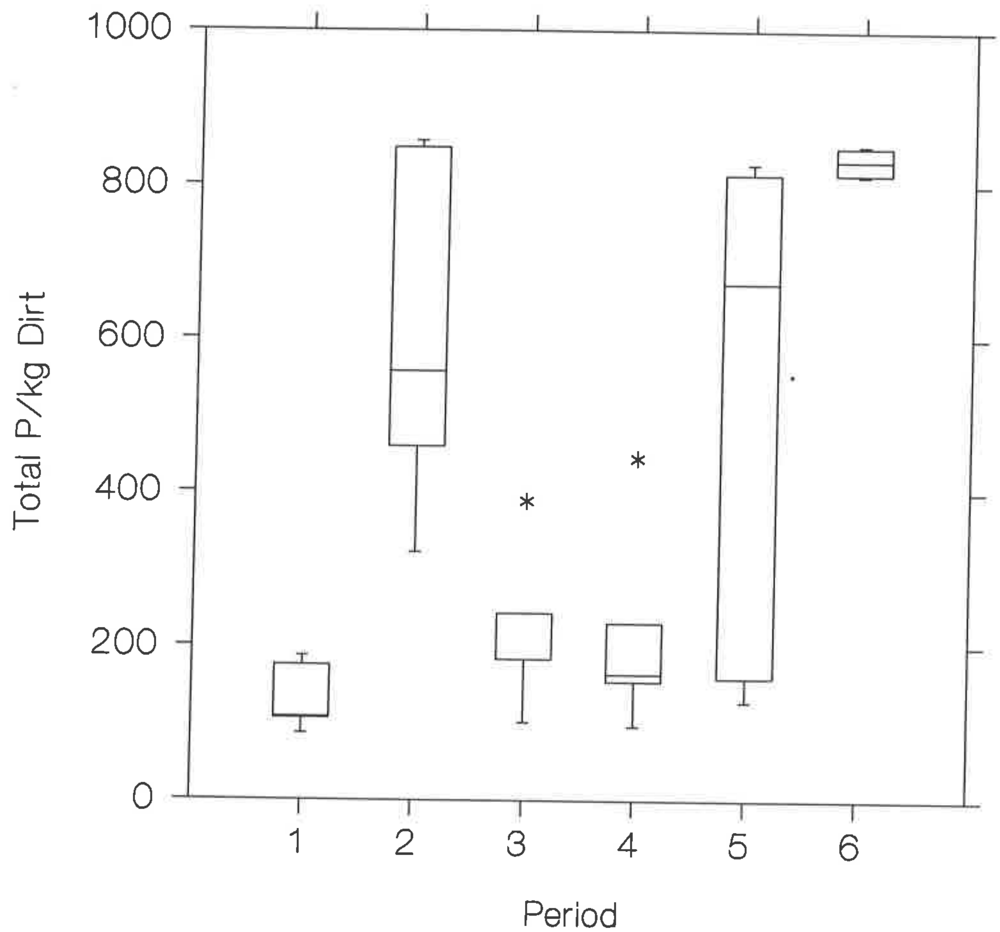


FIGURE B9. GLENWAY: LEAVES

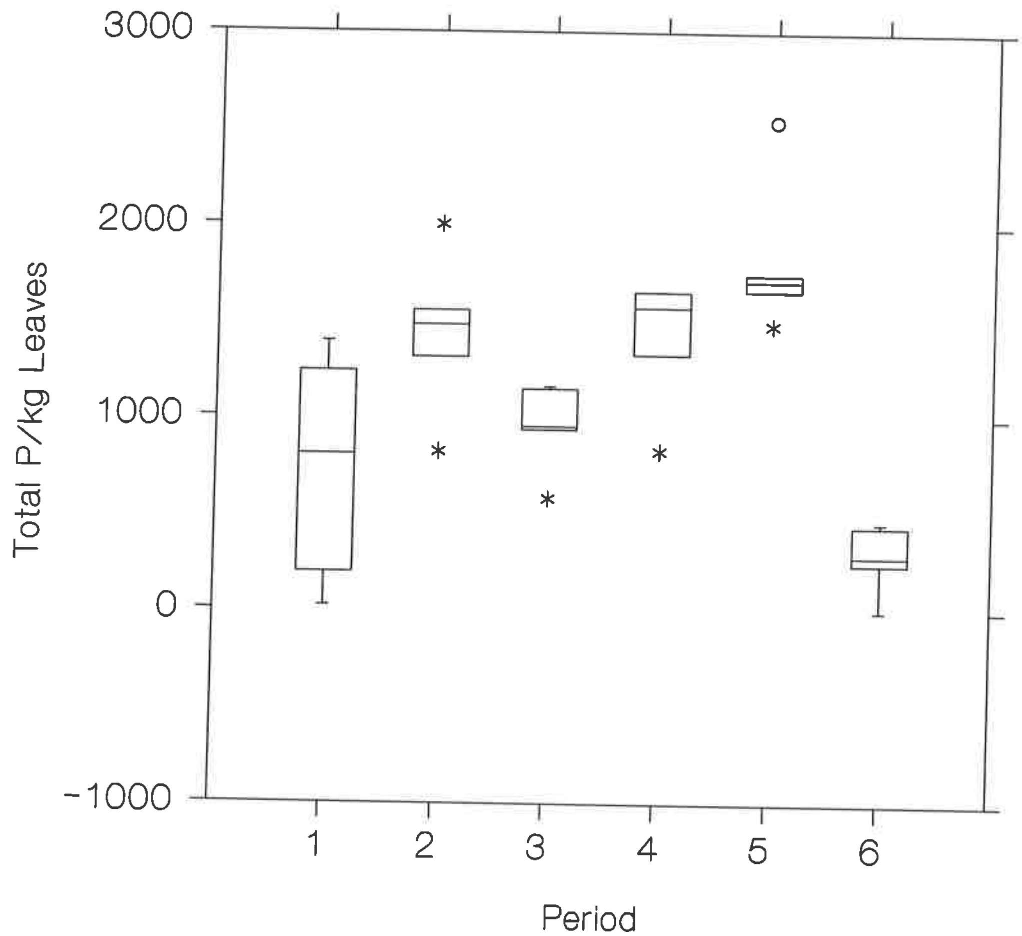


FIGURE B10. MONROE: <25 MICRONS

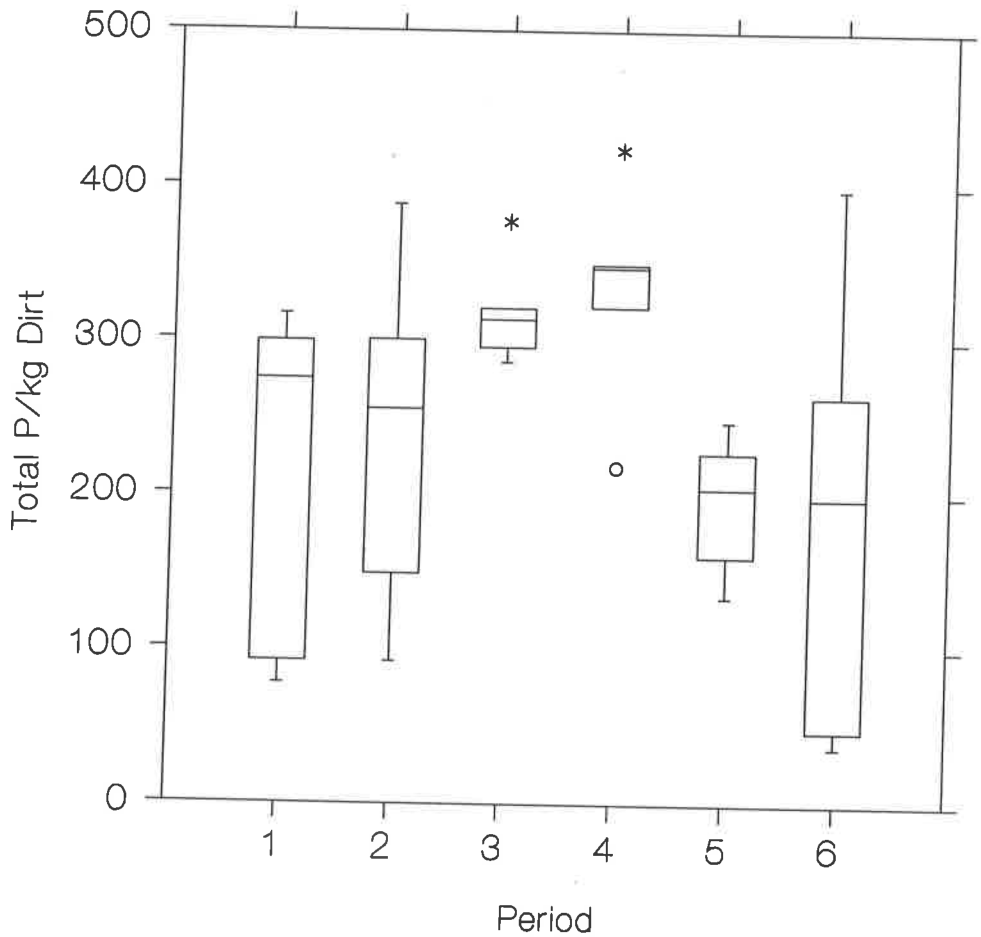


FIGURE B11. MONROE: 25-63 MICRONS

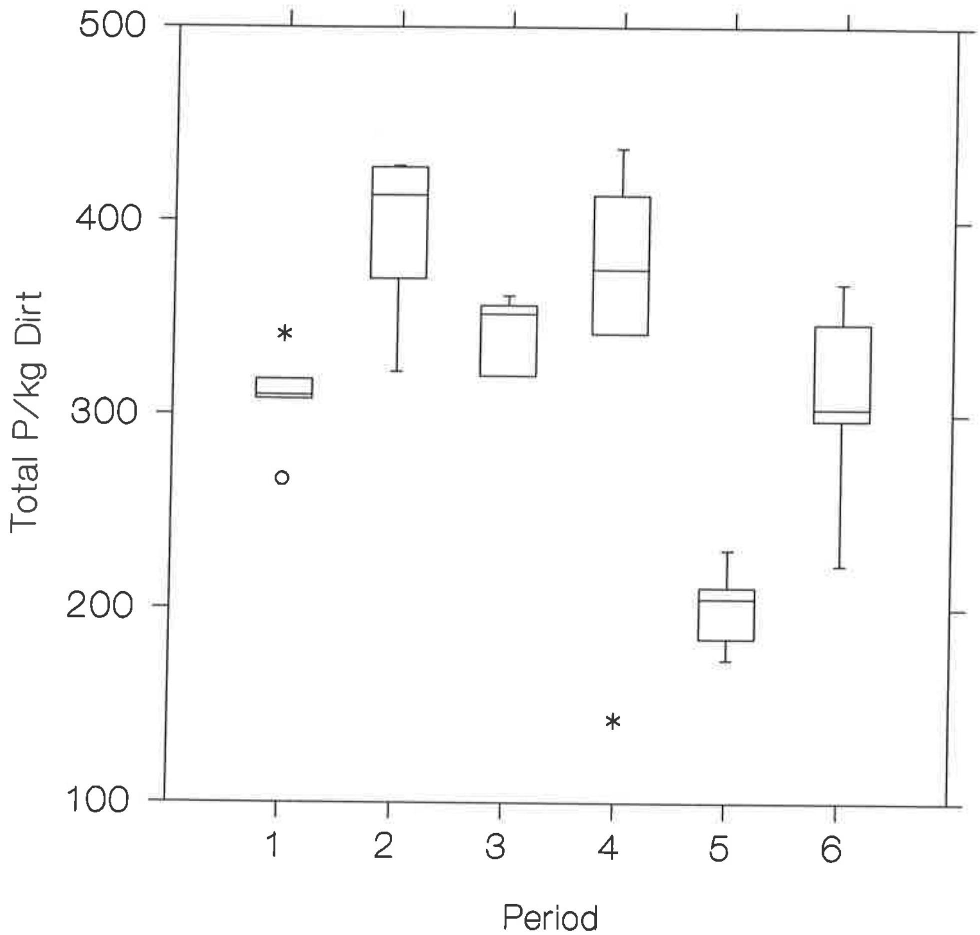


FIGURE B12. MONROE: 63-250 MICRONS

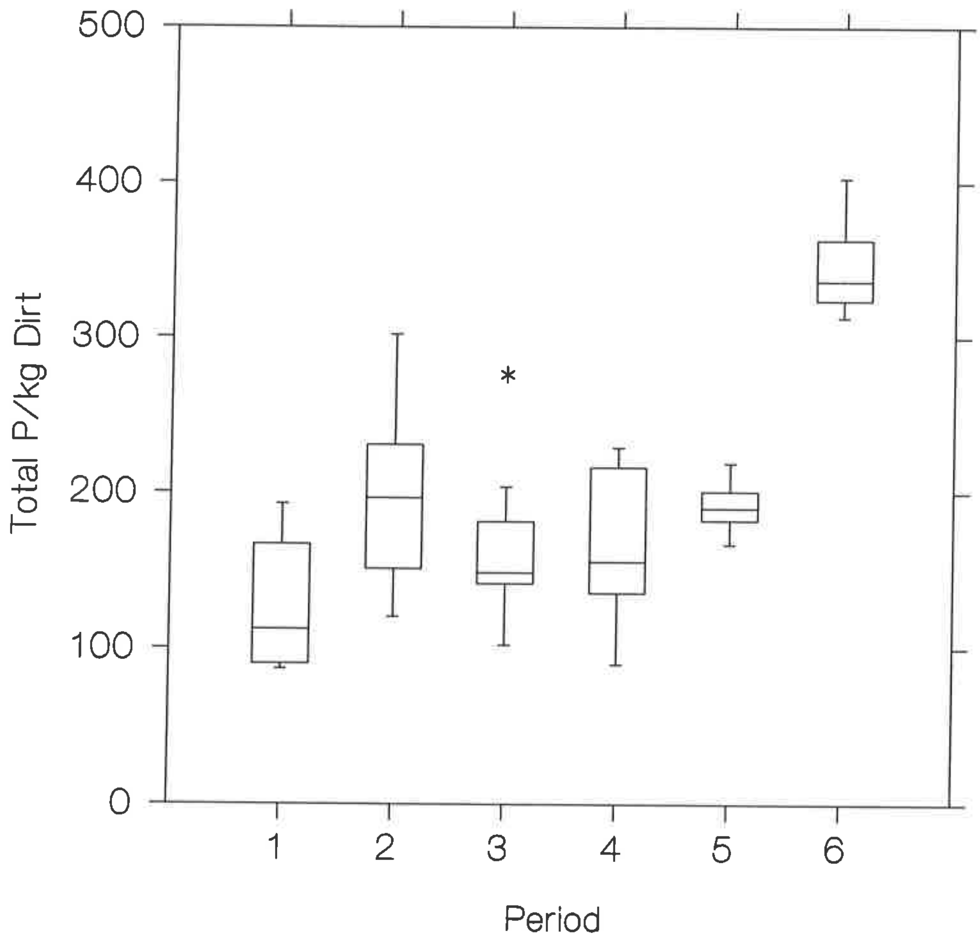


FIGURE B13. MONROE: >250 MICRONS

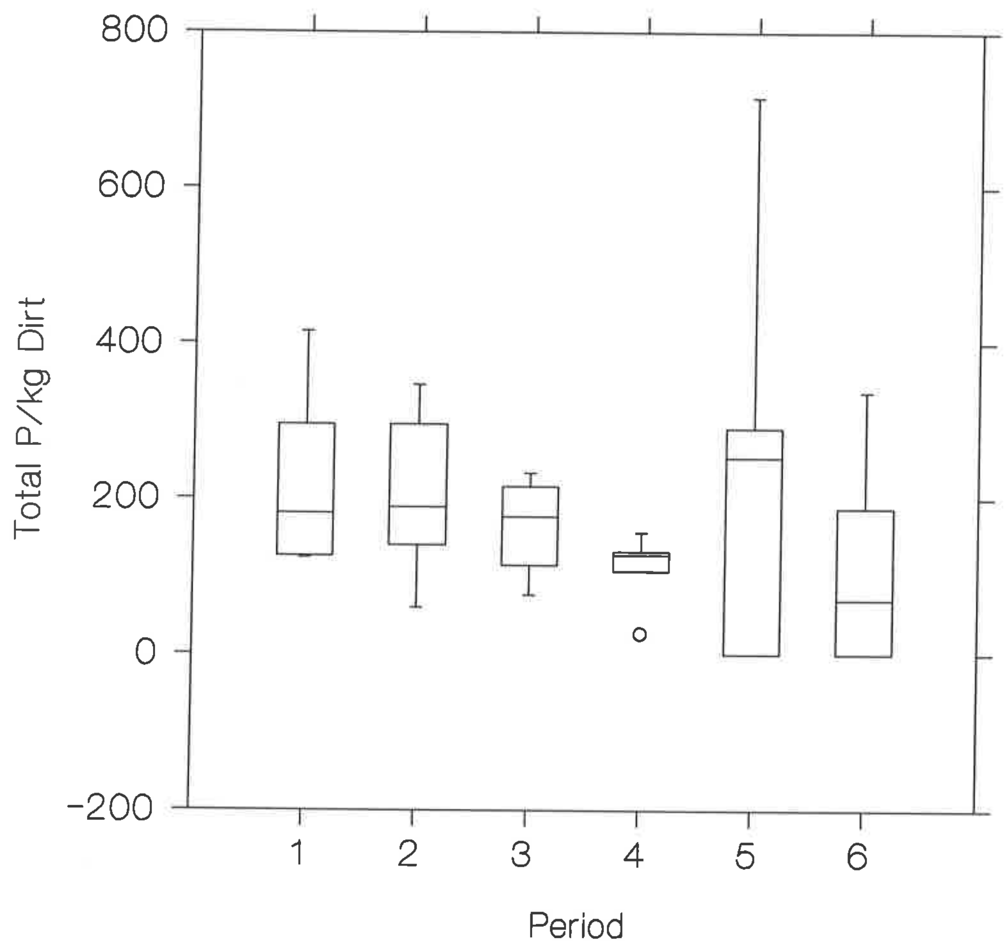


FIGURE B14. MONROE: LEAVES

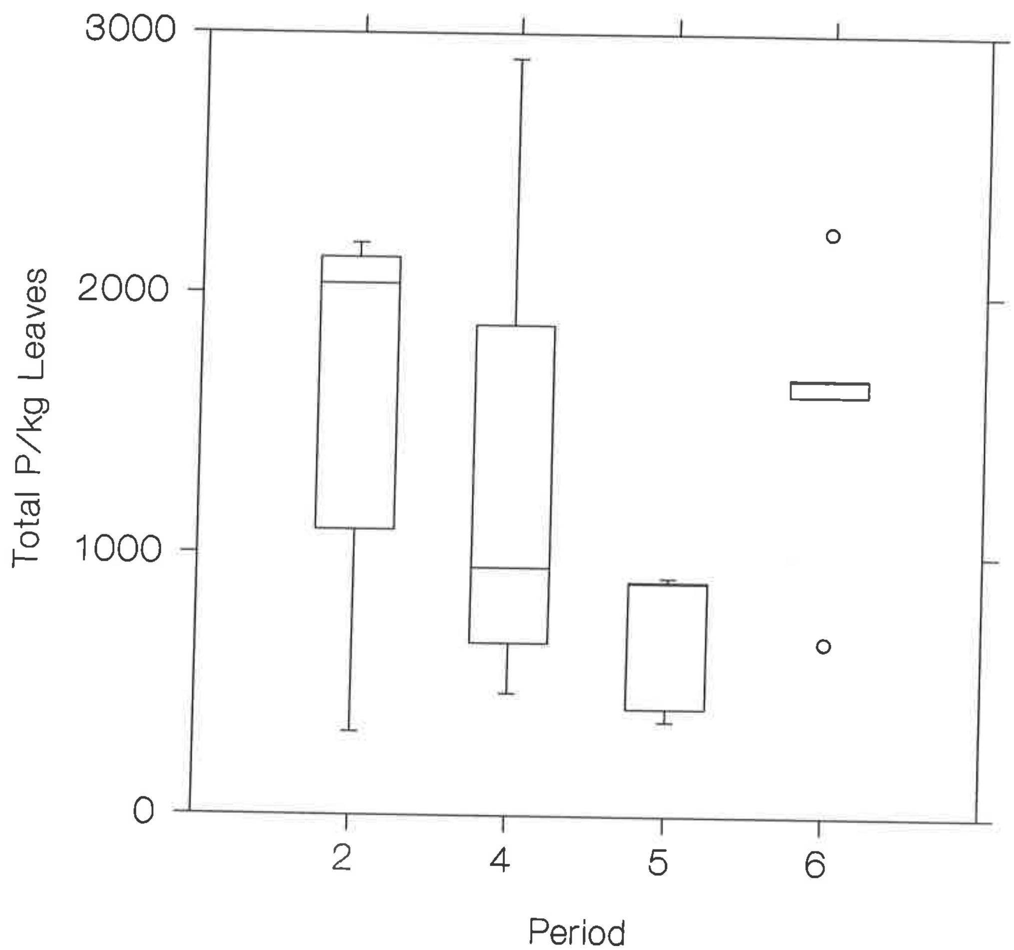


FIGURE B15. SSHH: <25 MICRONS

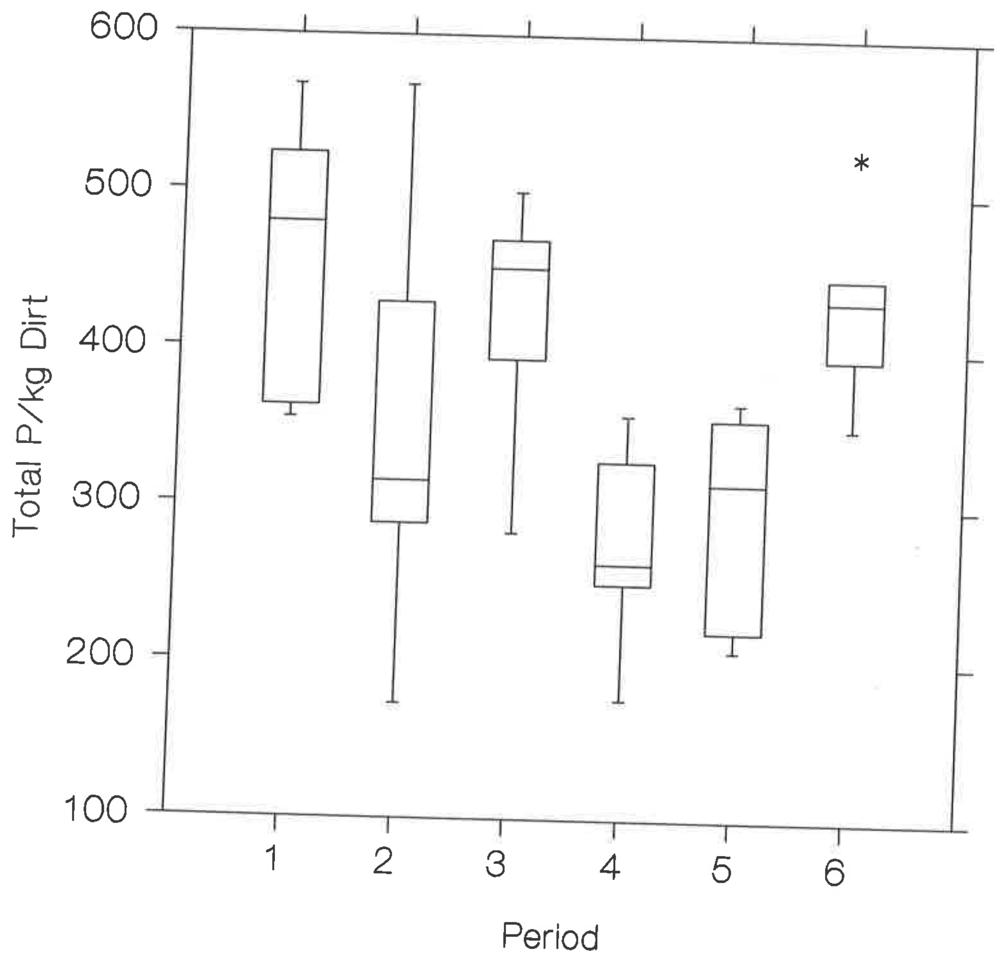


FIGURE B16. SSHH: 25-63 MICRONS

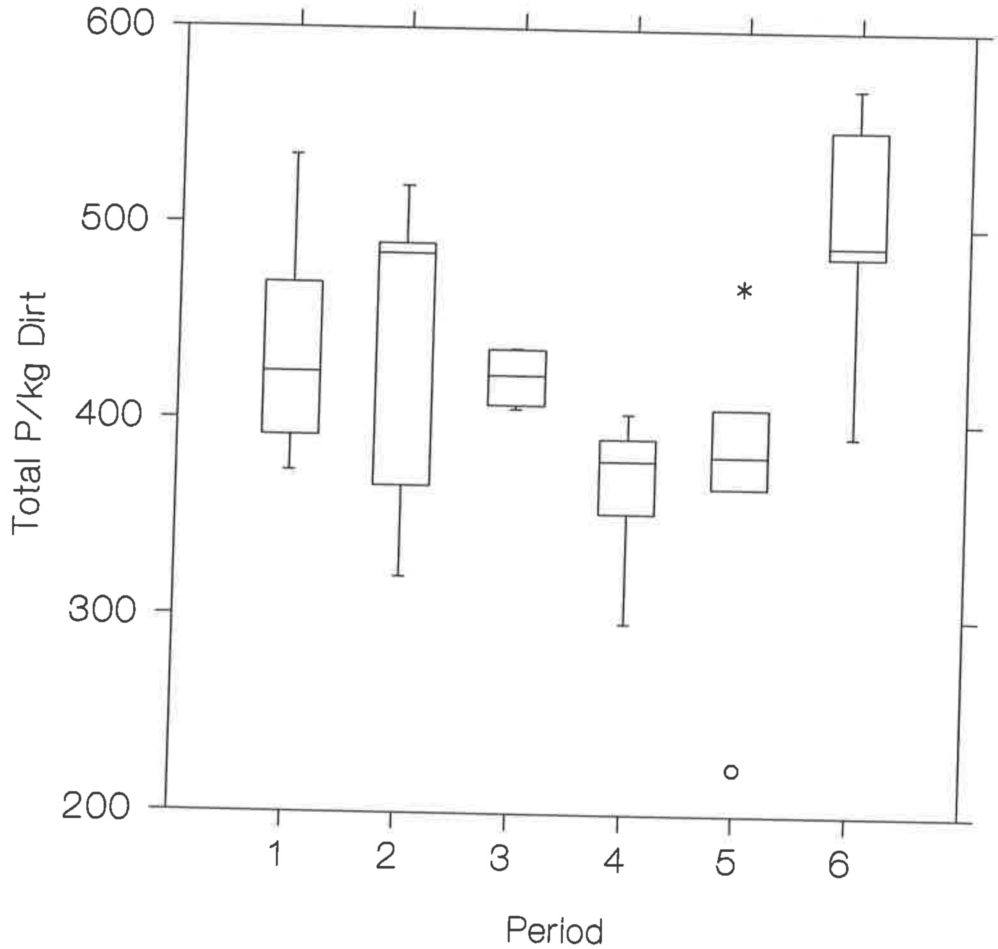


FIGURE B17. SSHH: 63-250 MICRONS

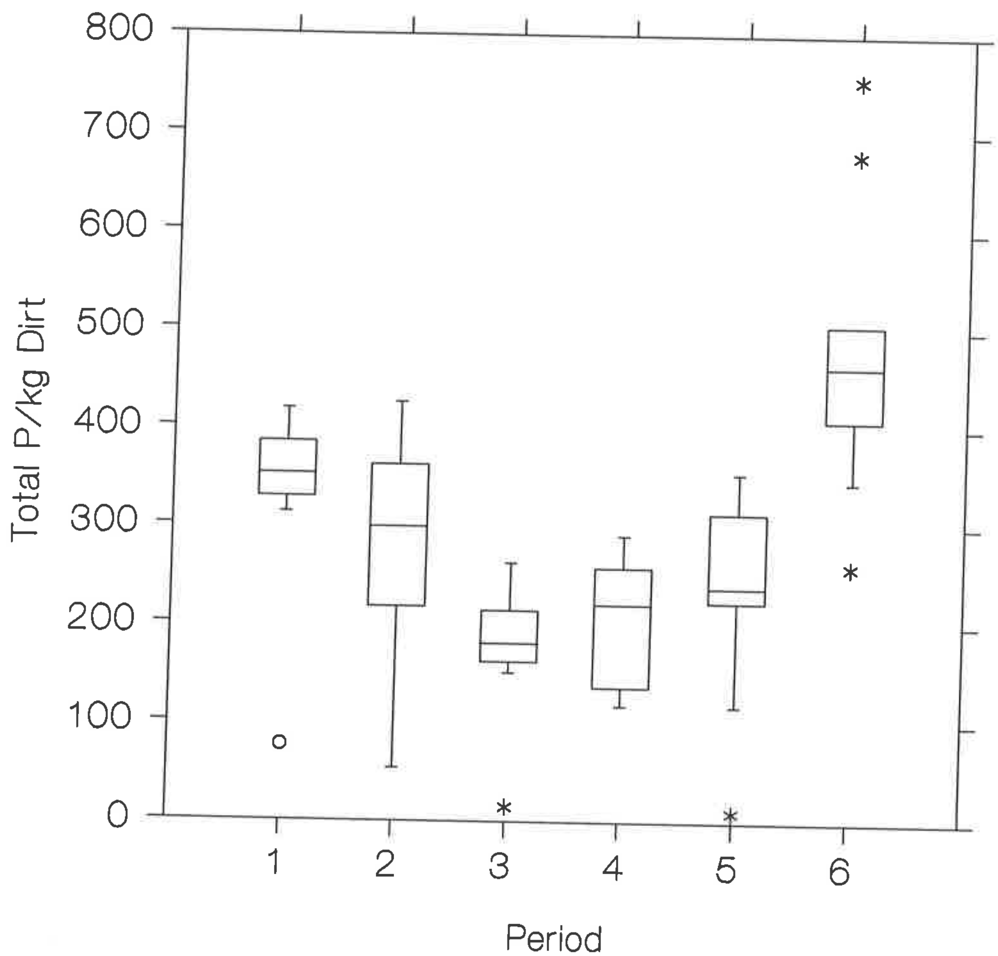


FIGURE B18. SSHH: >250 MICRONS

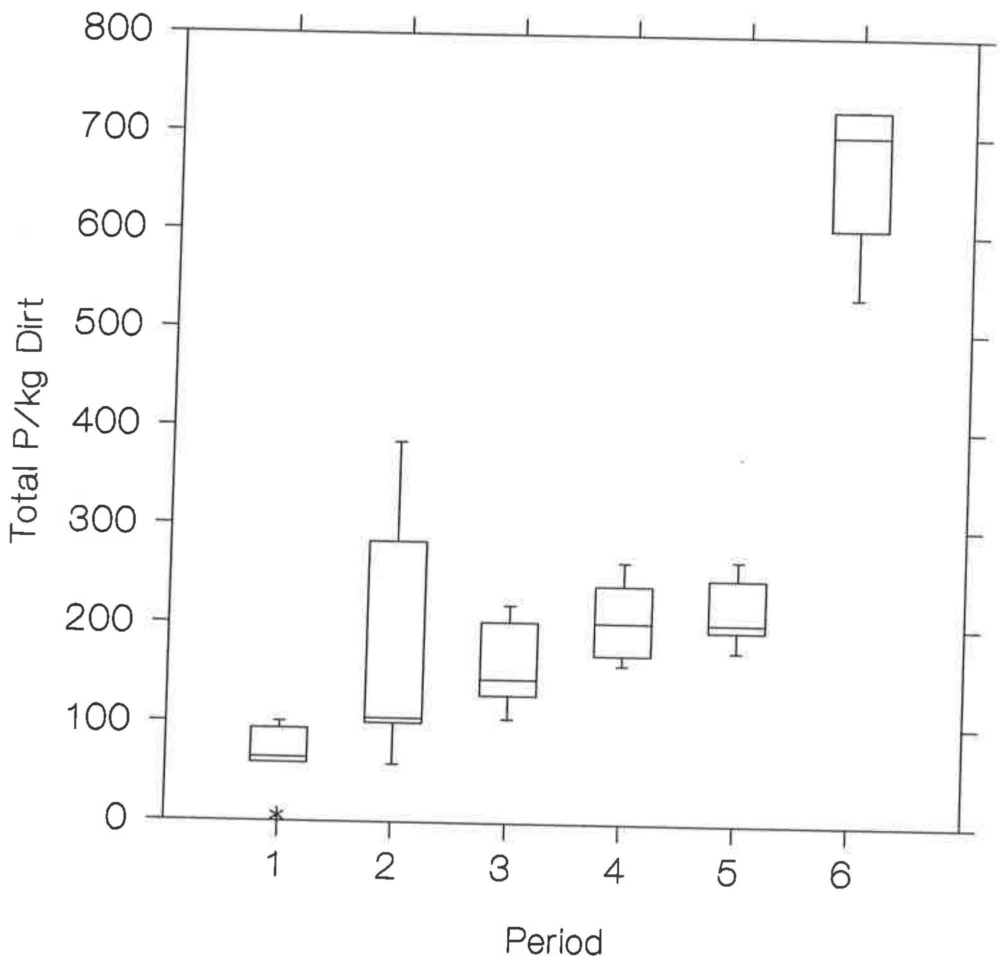
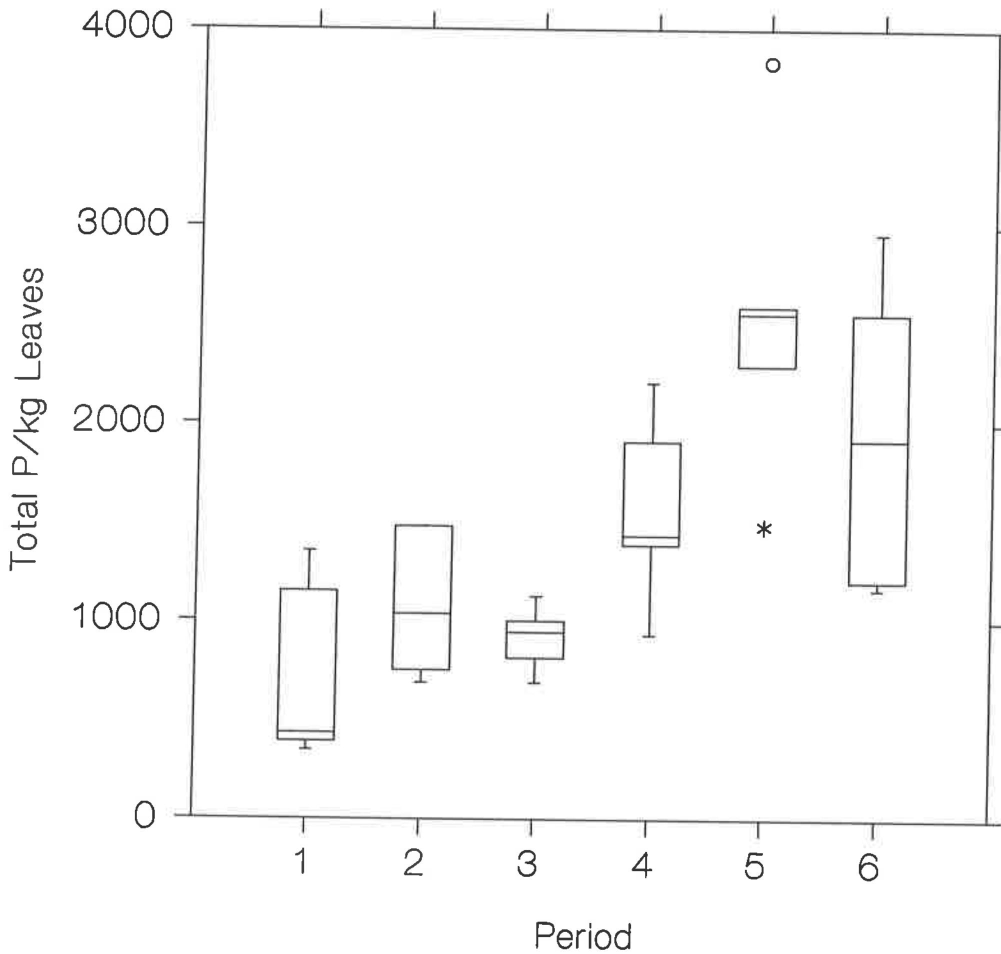


FIGURE B19. SSHH: LEAVES



APPENDIX C

MASS LOSS FOR DIFFERENT TEMPERATURE RANGES WITH KNOWN SAMPLES

FIGURE C1. DIRT COMPOSITE (<25 MICRONS)

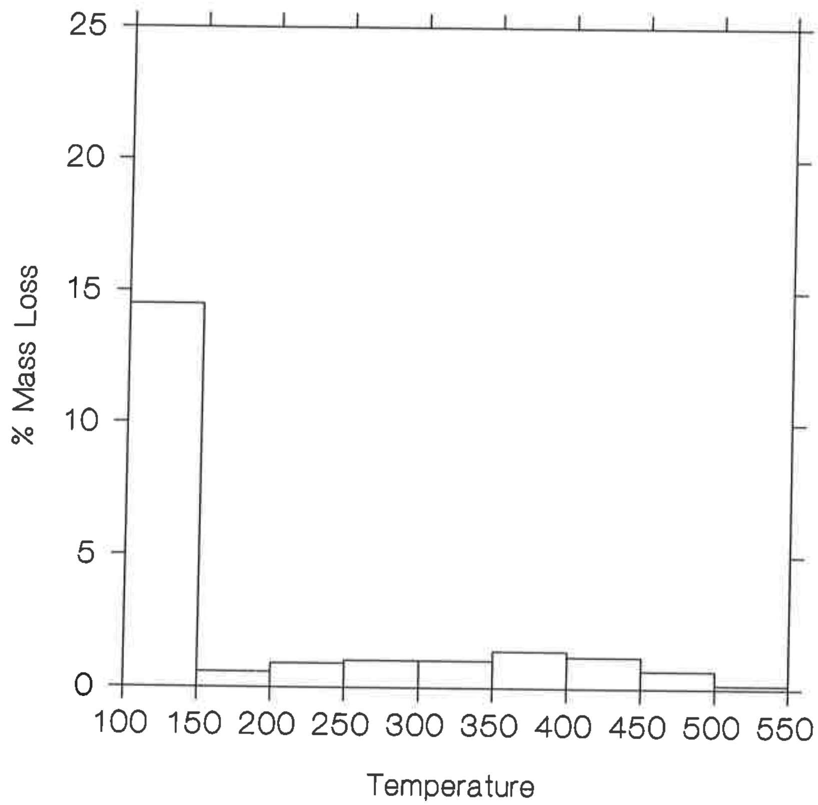


FIGURE C2. DIRT COMPOSITE (25-63 MICRONS)

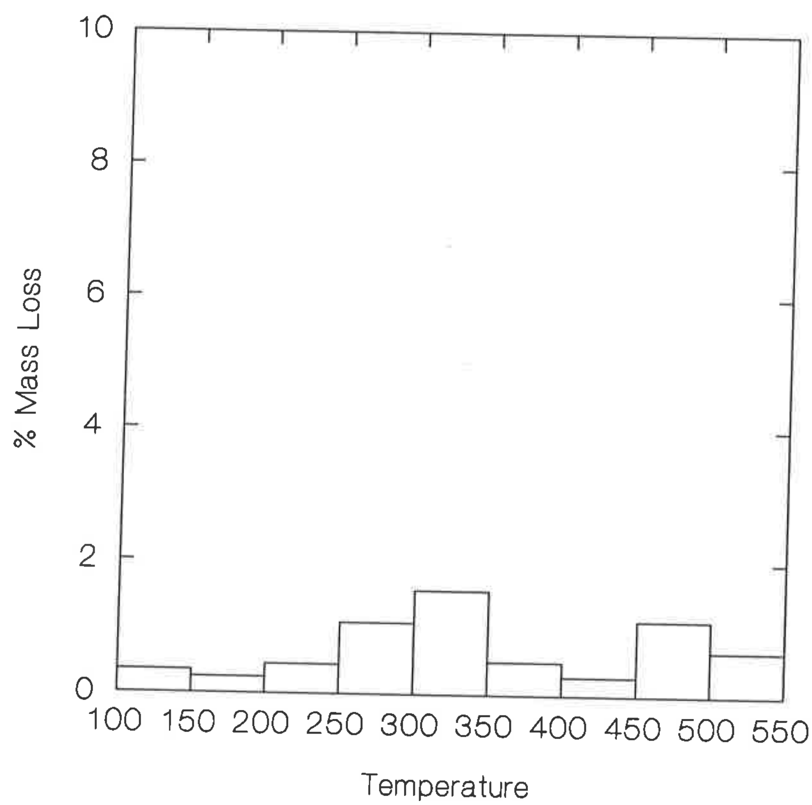


FIGURE C3. DIRT COMPOSITE (63-250 MICRONS)

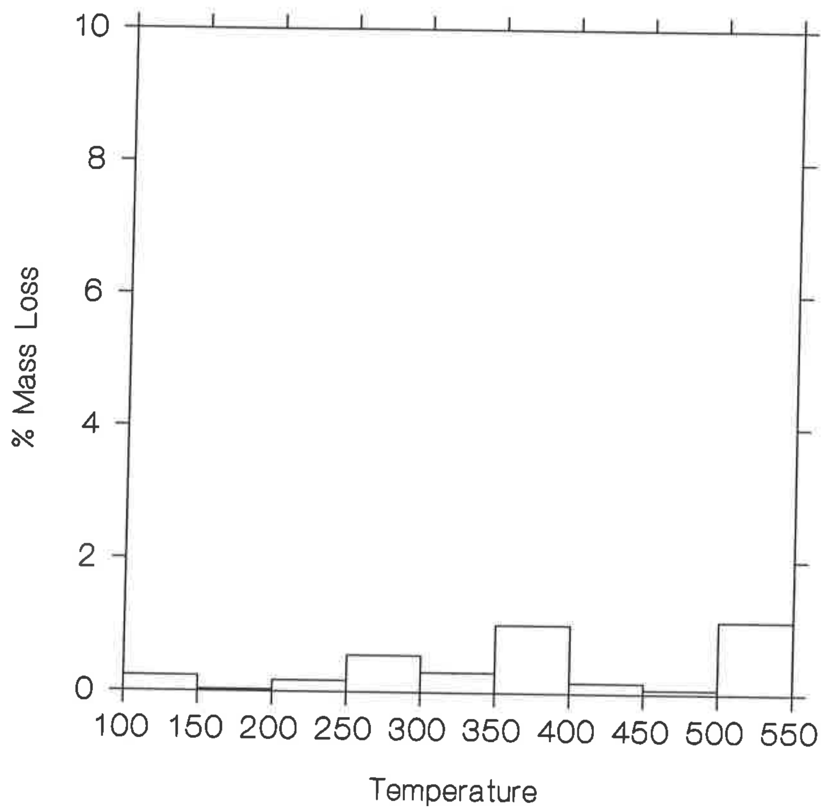


FIGURE C4. DIRT COMPOSITE (>250 MICRONS)

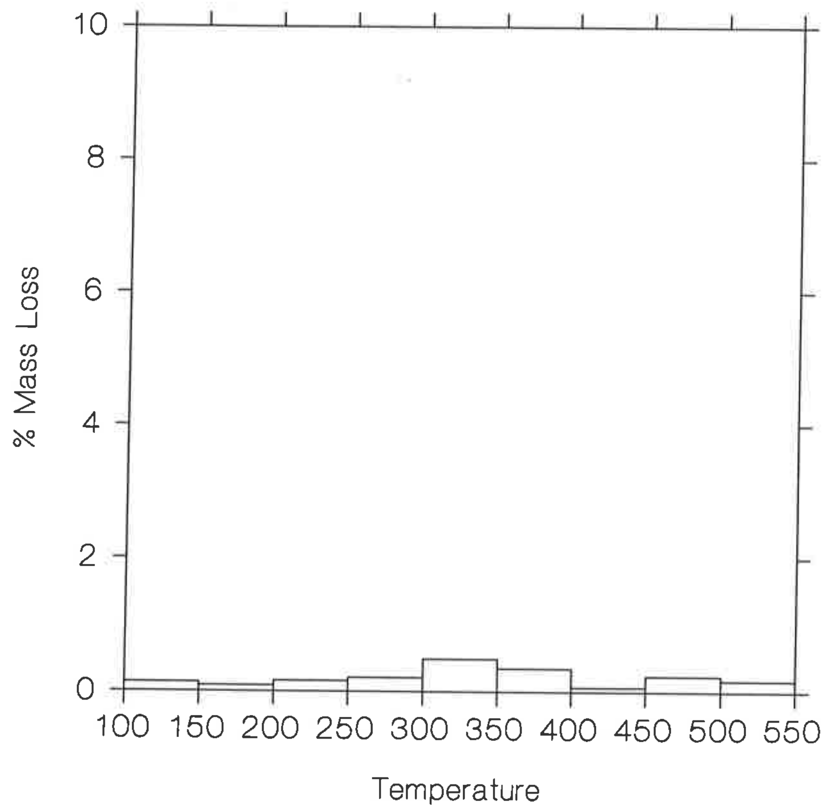


FIGURE C5. STANDARD: PAPER

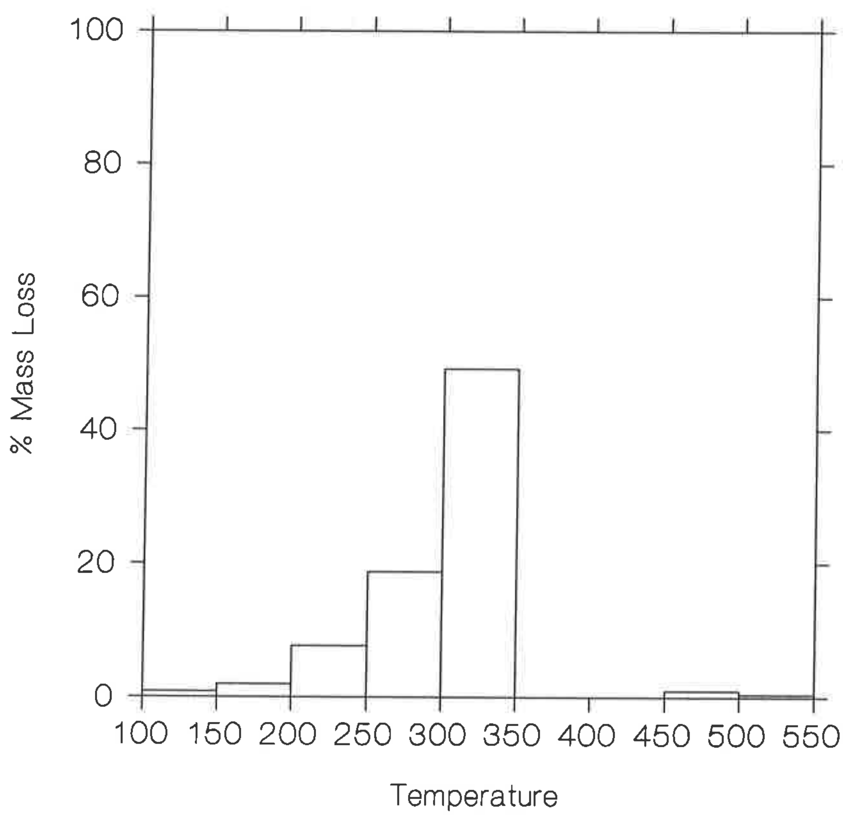


FIGURE C6. STANDARD: ASPHALT

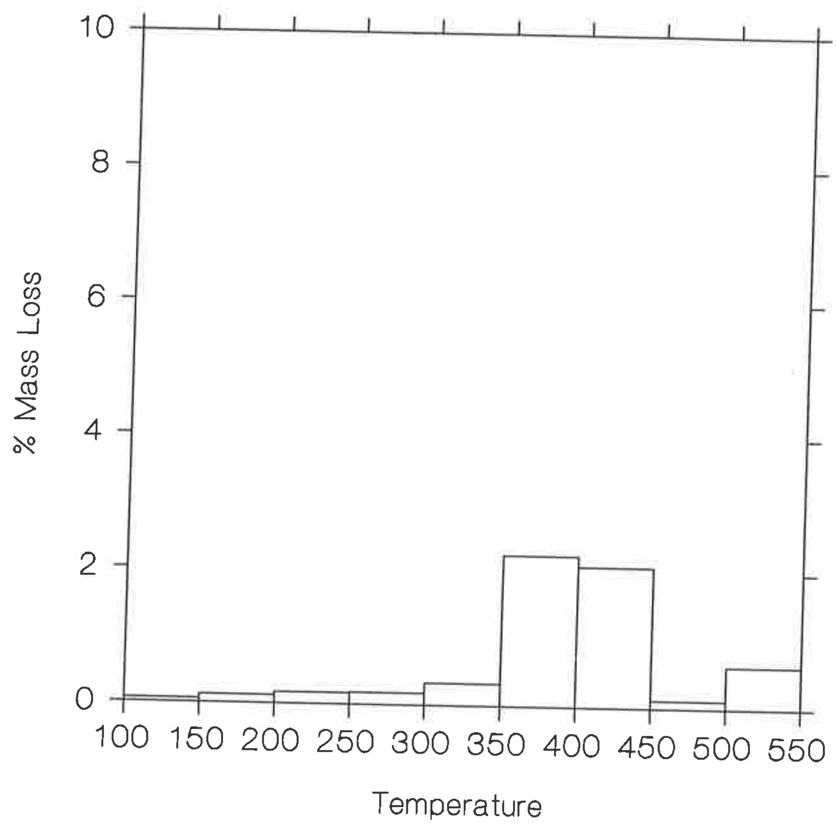


FIGURE C7. STANDARD: RUBBER

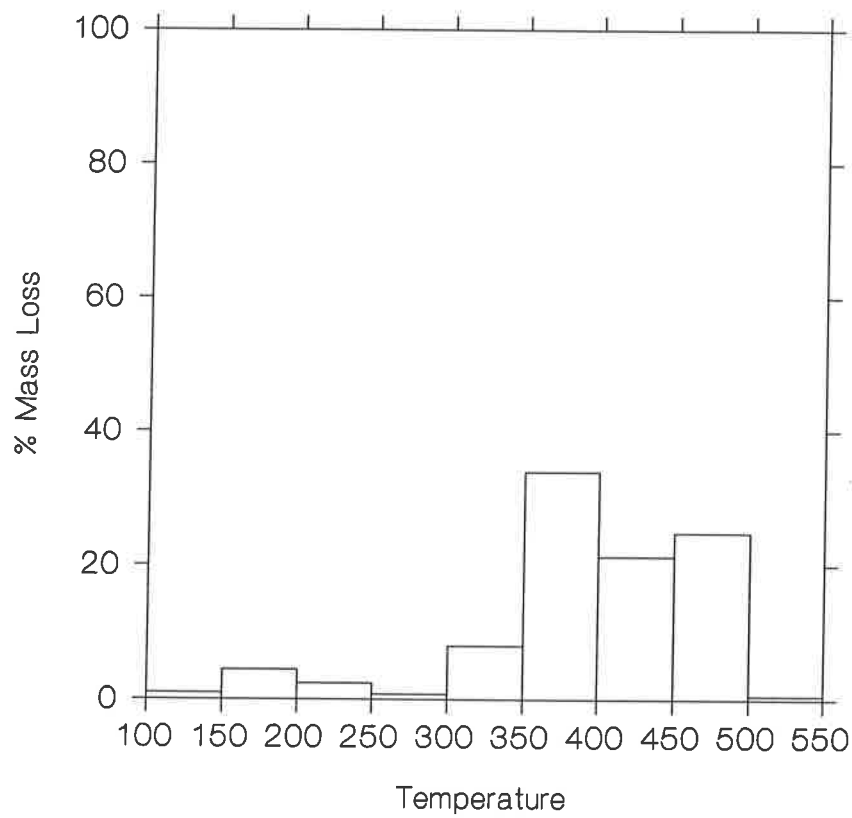


FIGURE C8. STANDARD: CIGARETTES

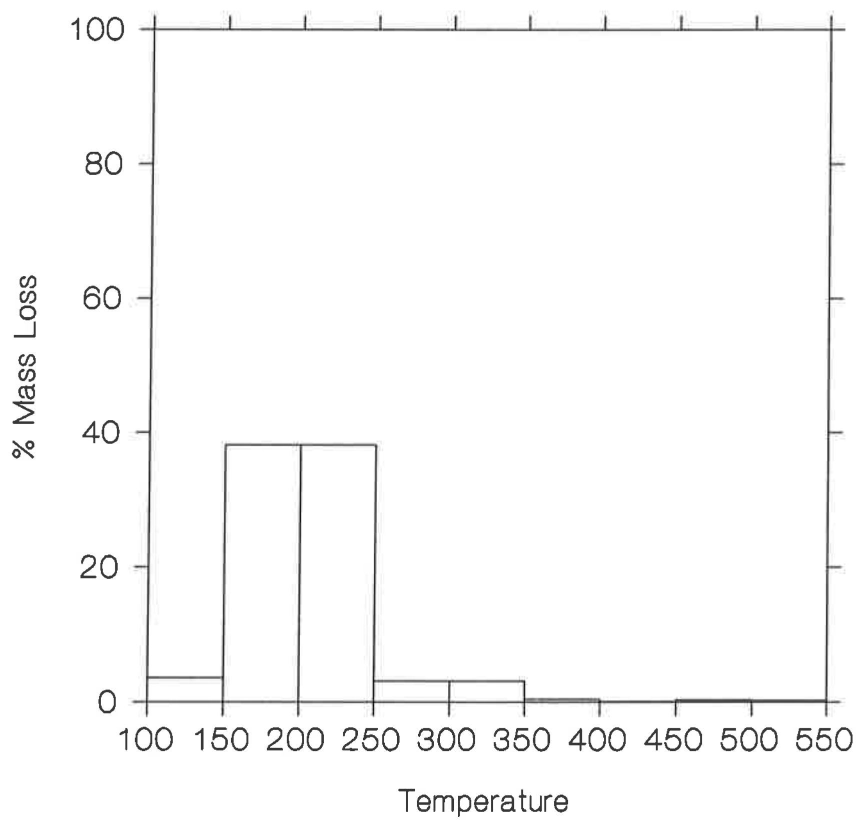


FIGURE C9. SSHH LEAVES

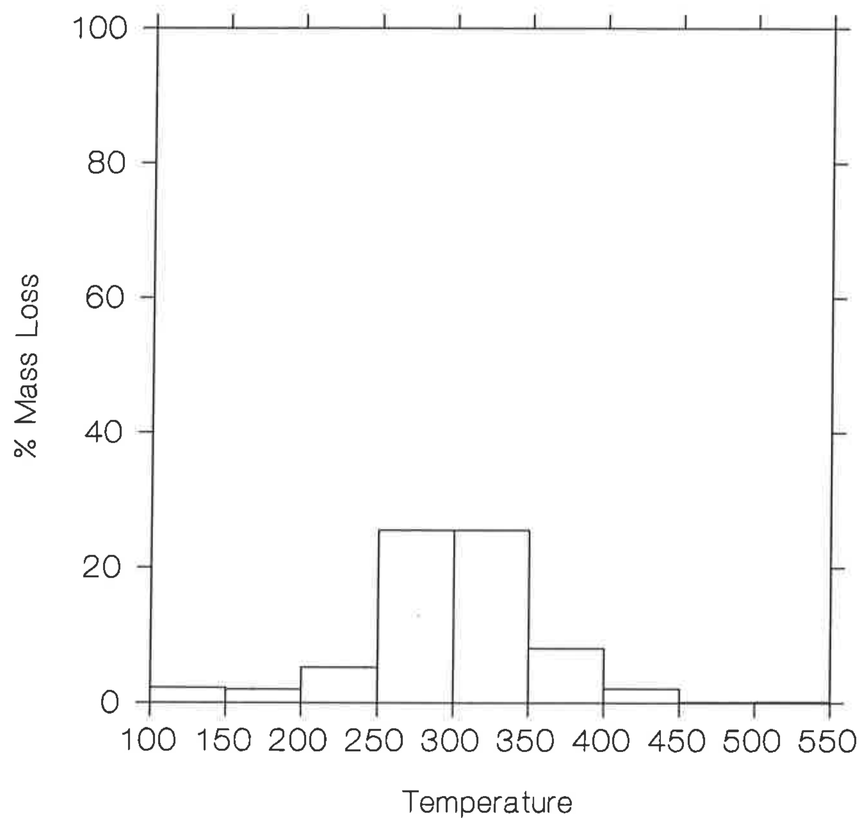


FIGURE C10. GLENWAY 8/94 LEAVES

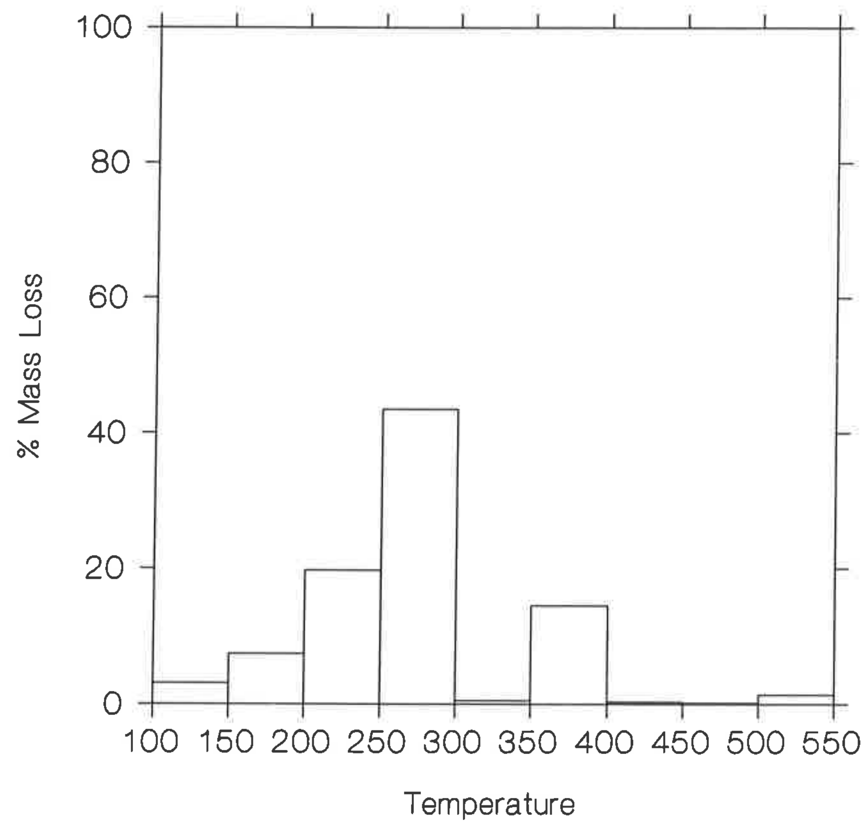
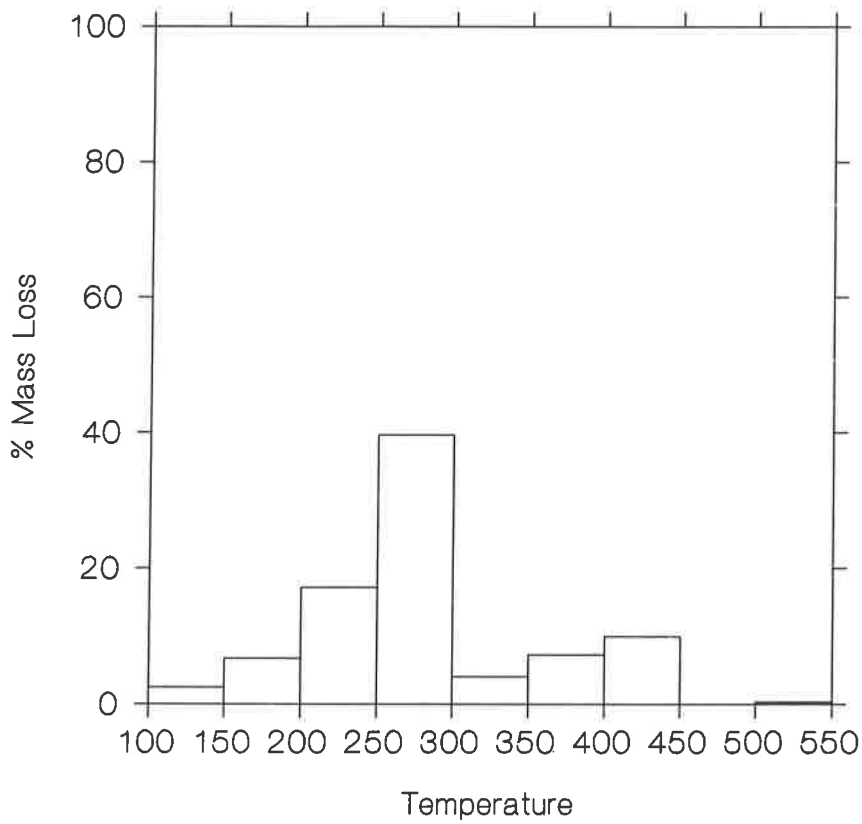


FIGURE C11. GLENWAY: 9/94 LEAVES



APPENDIX D

MASS LOSS FOR STREET DIRT SAMPLES FOR DIFFERENT TEMPERATURES

FIGURE D1. Gammon 4/94
Accumulated Mass Loss vs. Temperature

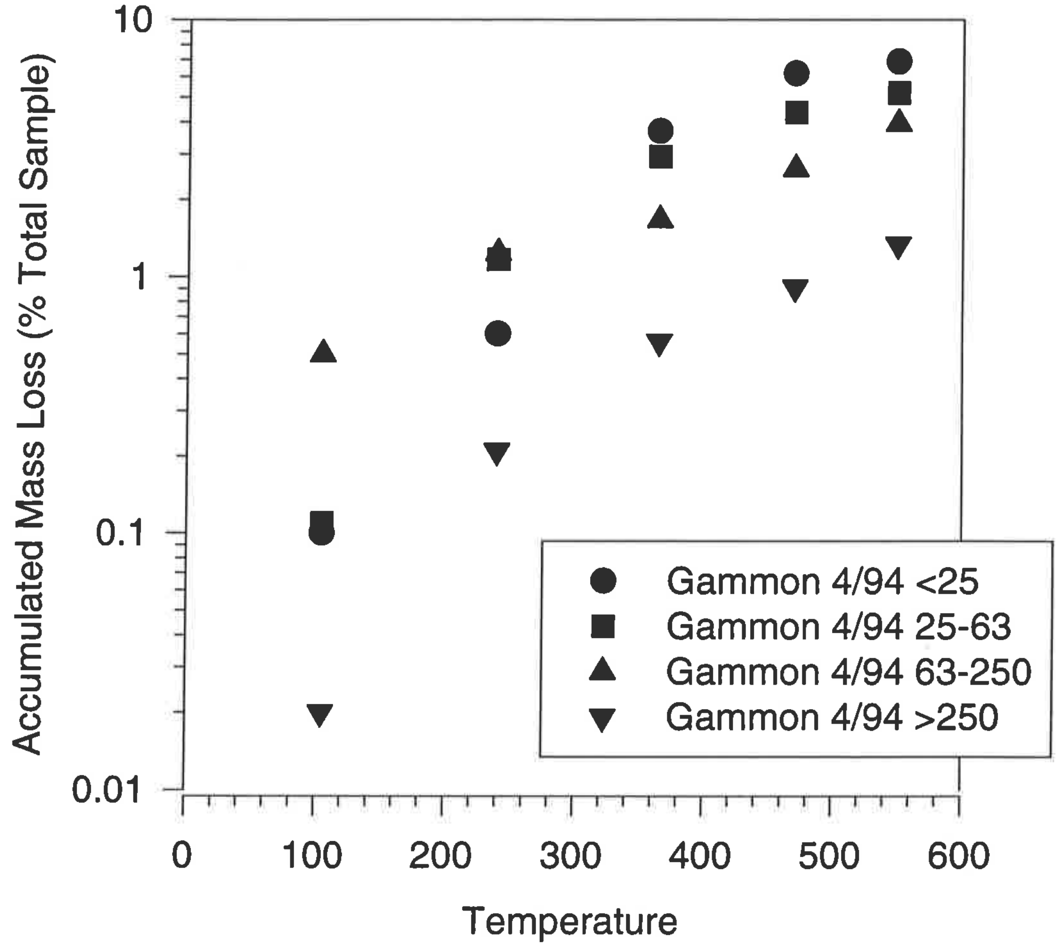


FIGURE D2. Gammon 6/94
Accumulated Mass Loss vs. Temperature

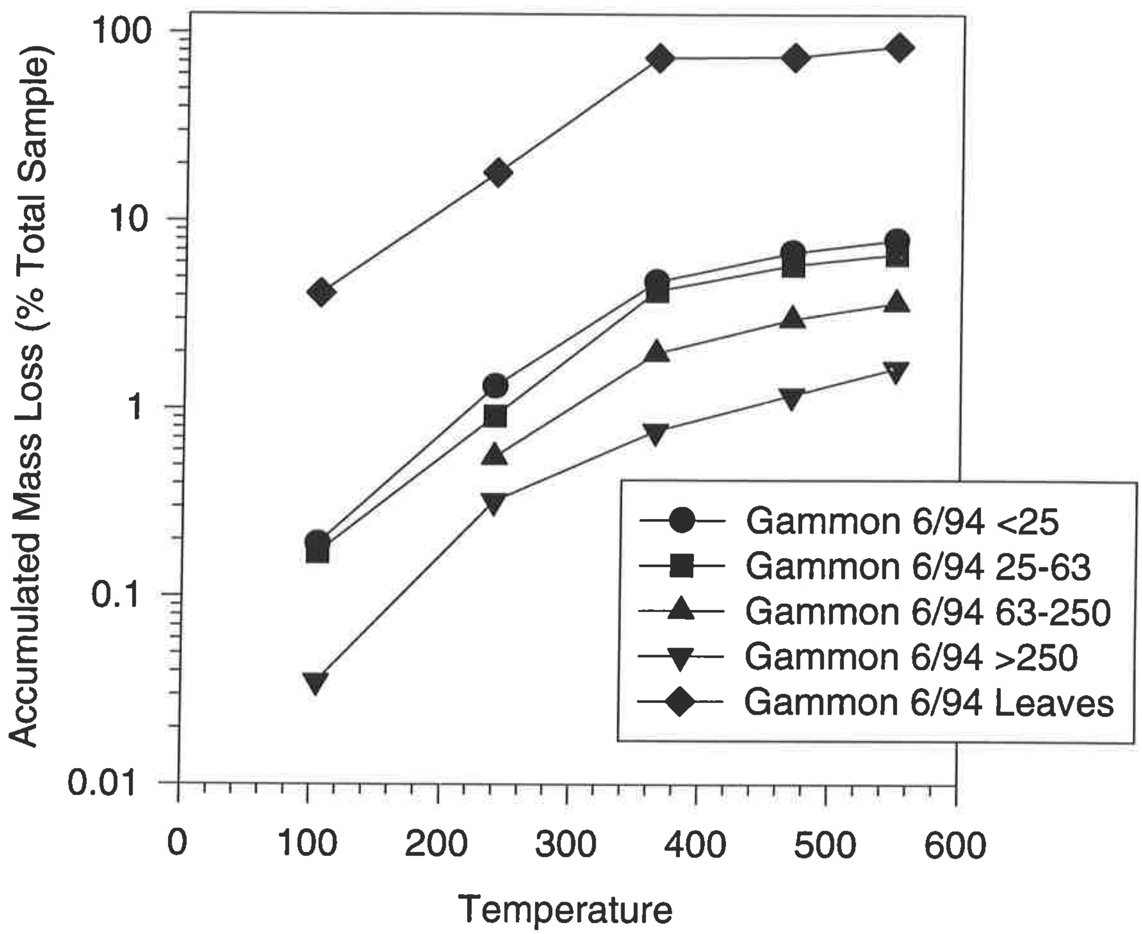


FIGURE D3. Gammon 7/94
Accumulated Mass Loss vs. Temperature

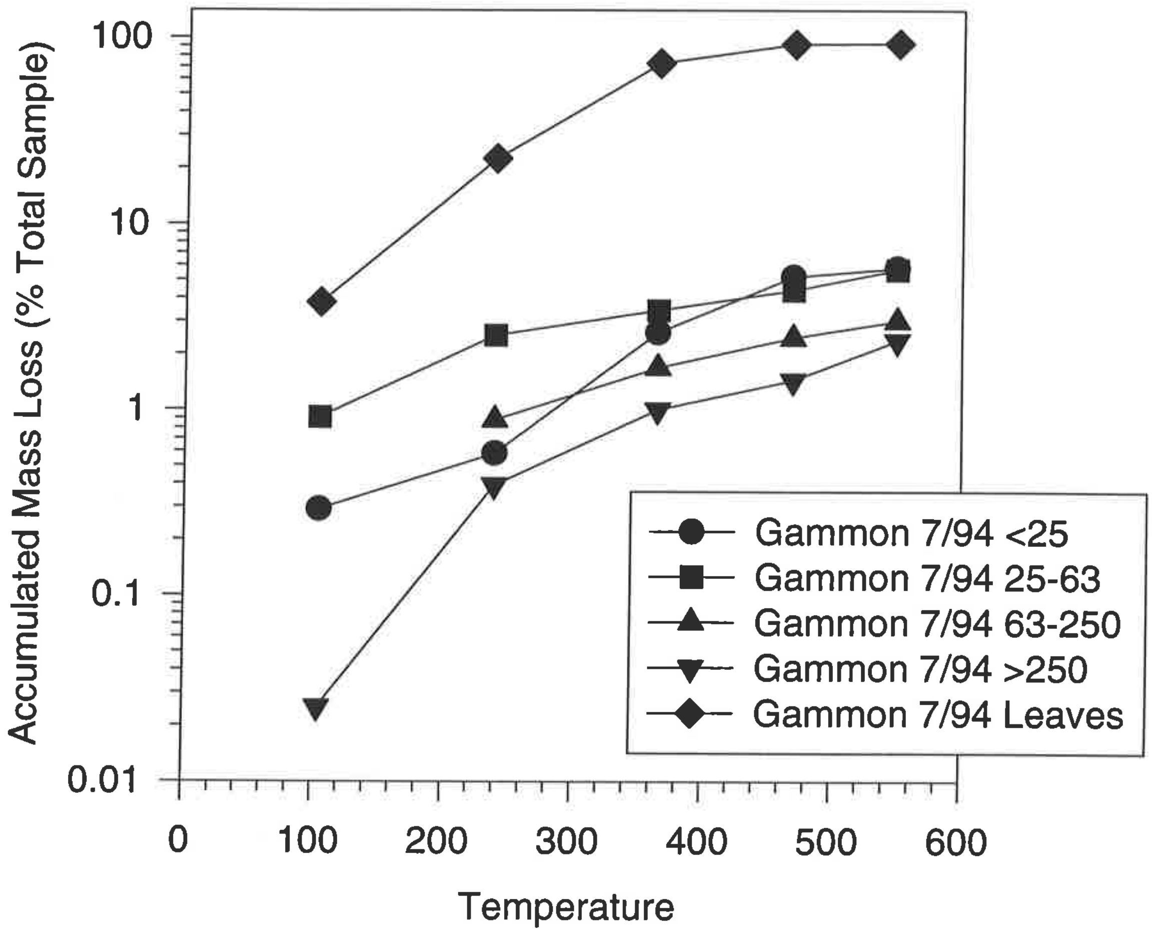


FIGURE D4. Gammon 8/94
Accumulated Mass Loss vs. Temperature

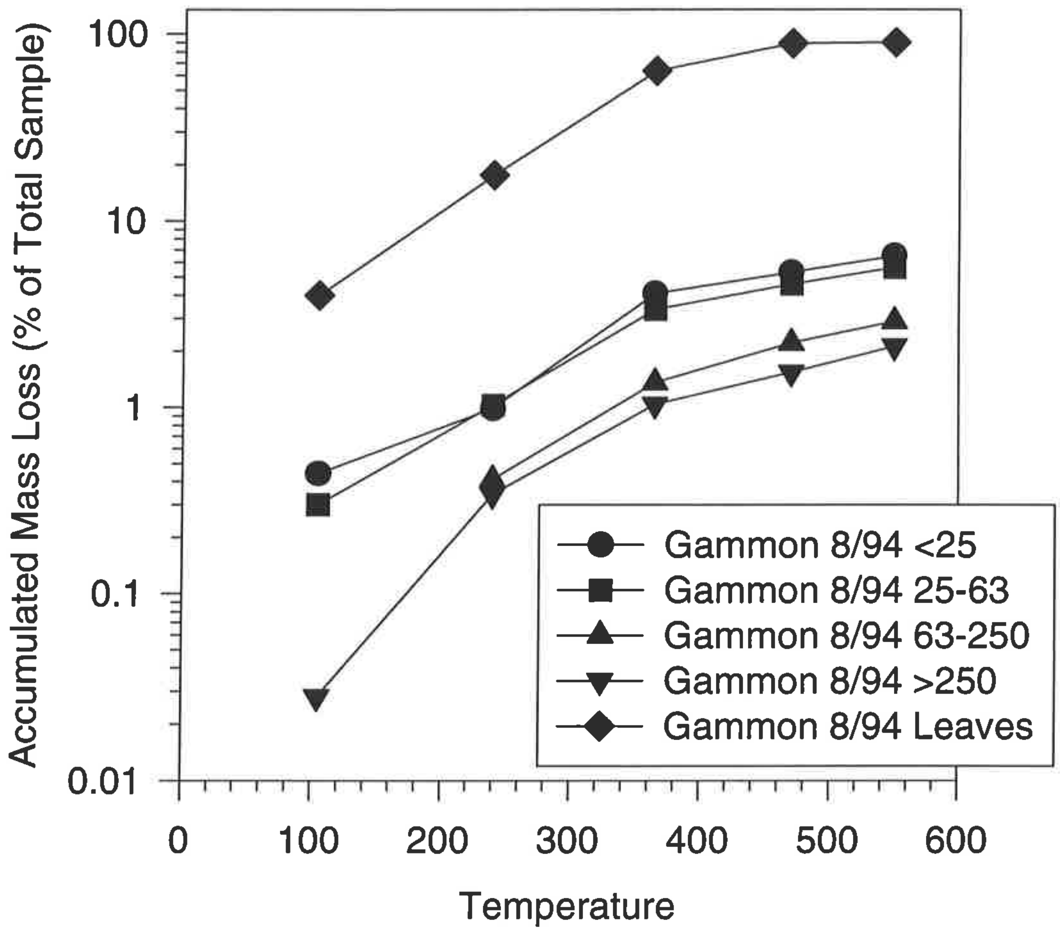


FIGURE D5. Gammon 9/94
Accumulated Mass Loss vs. Temperature

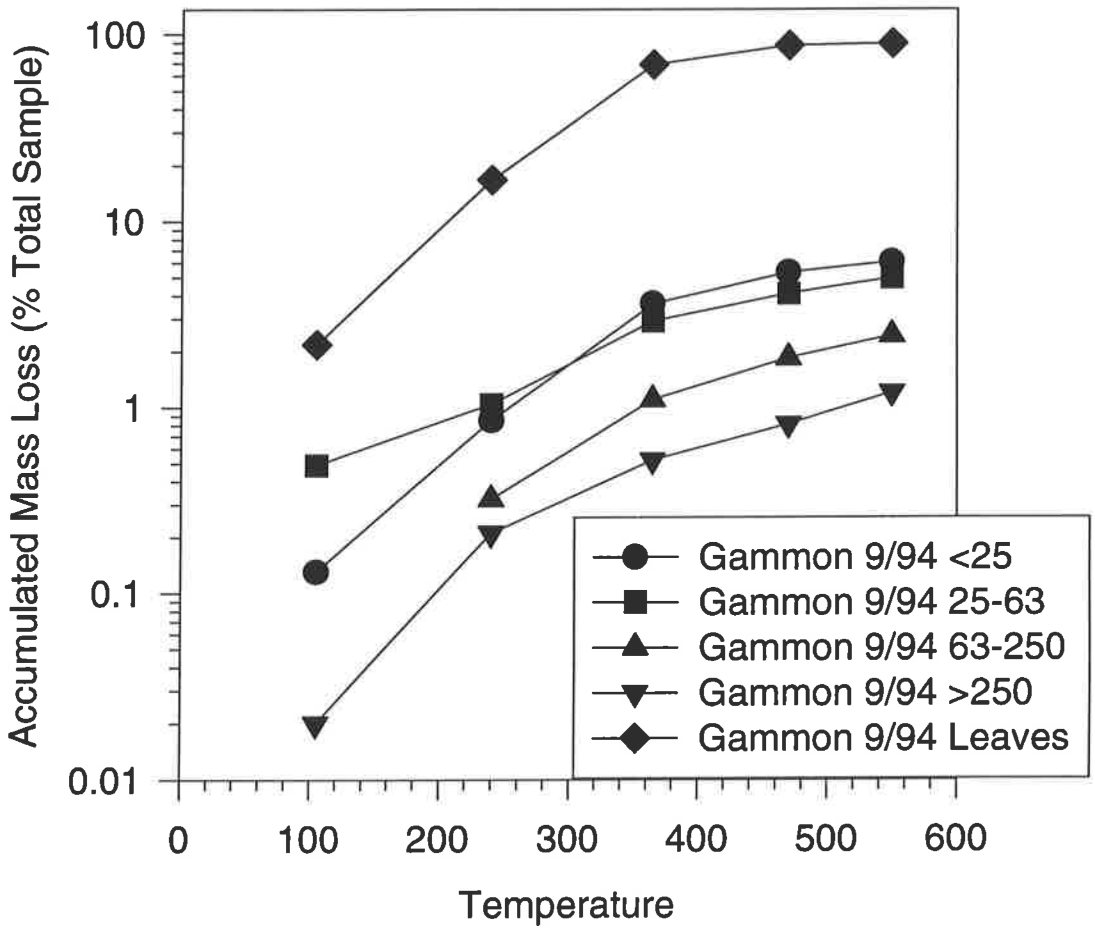


FIGURE D6. Gammon 10/94 Accumulated Mass Loss vs. Temperature

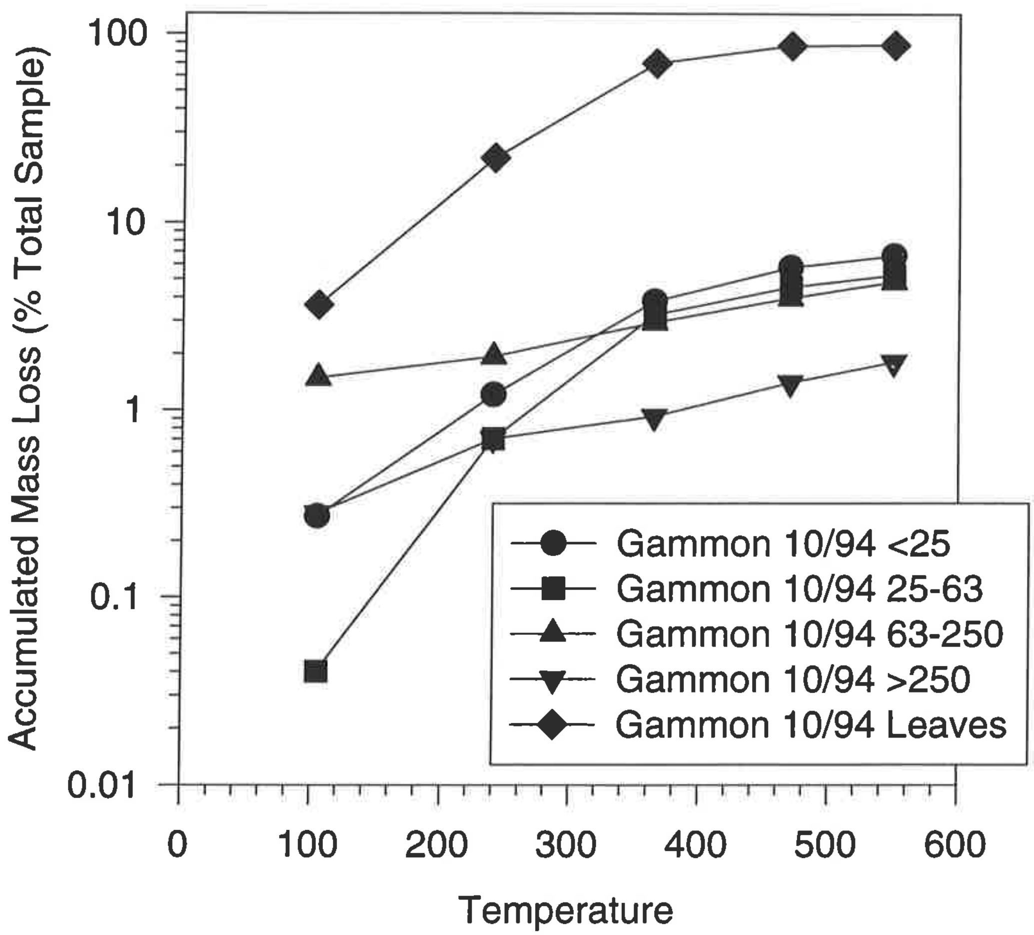


FIGURE D7. Glenway 4/94
Accumulated Mass Loss vs. Temperature

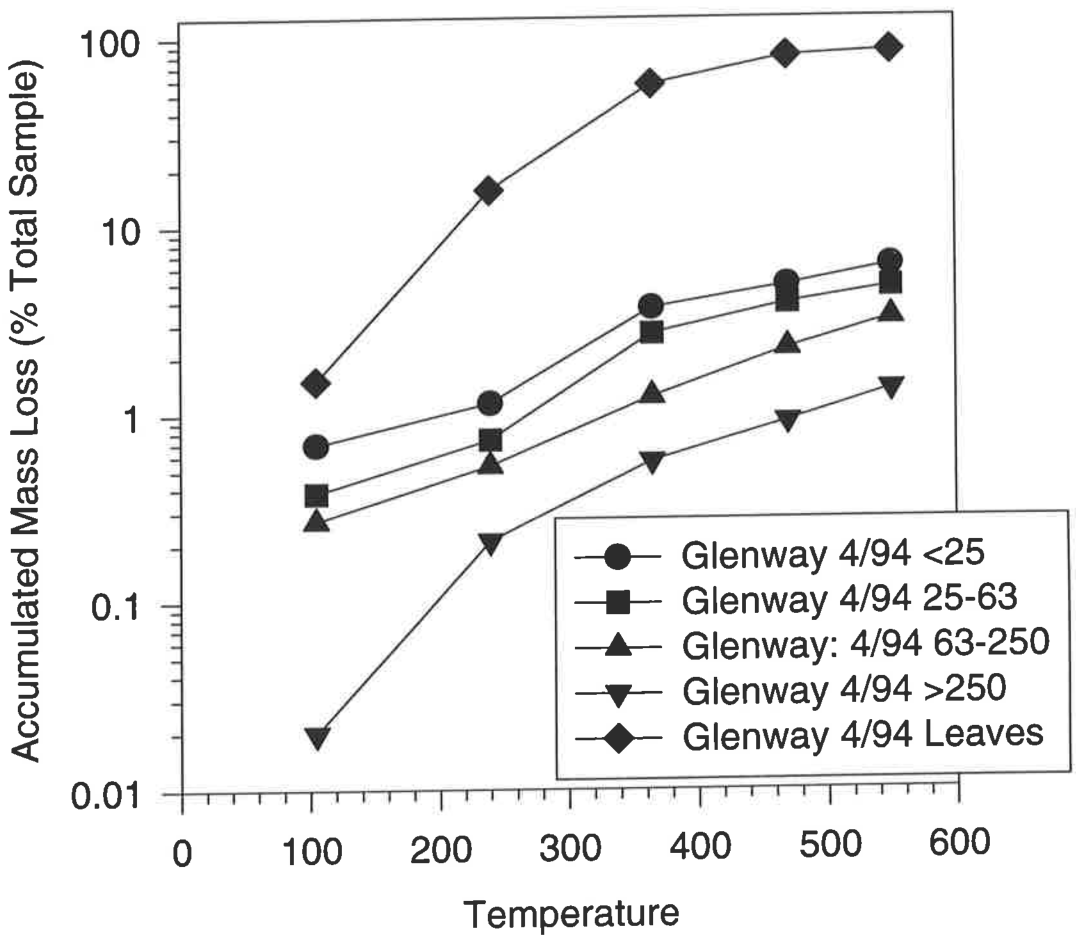


FIGURE D8. Glenway 6/94
Accumulated Mass Loss vs. Temperature

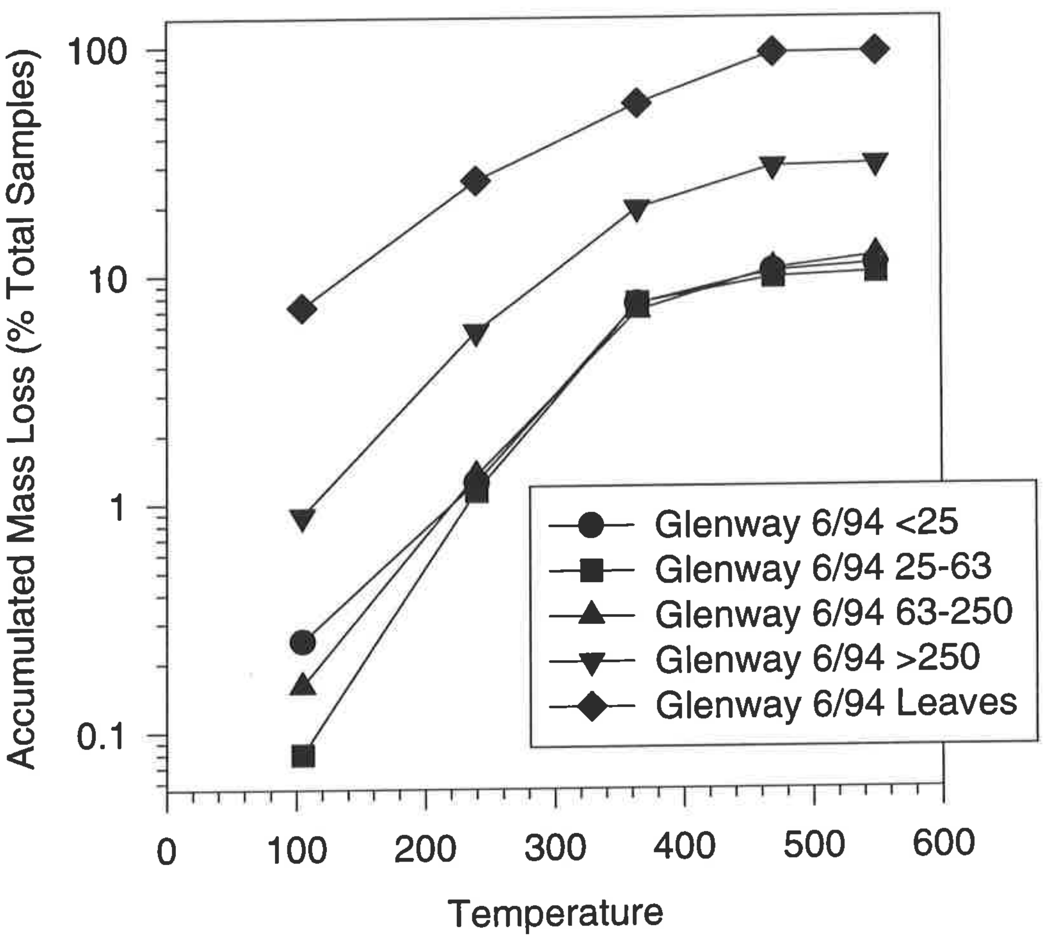


FIGURE D9. Glenway 7/94 Accumulated Mass Loss vs. Temperature

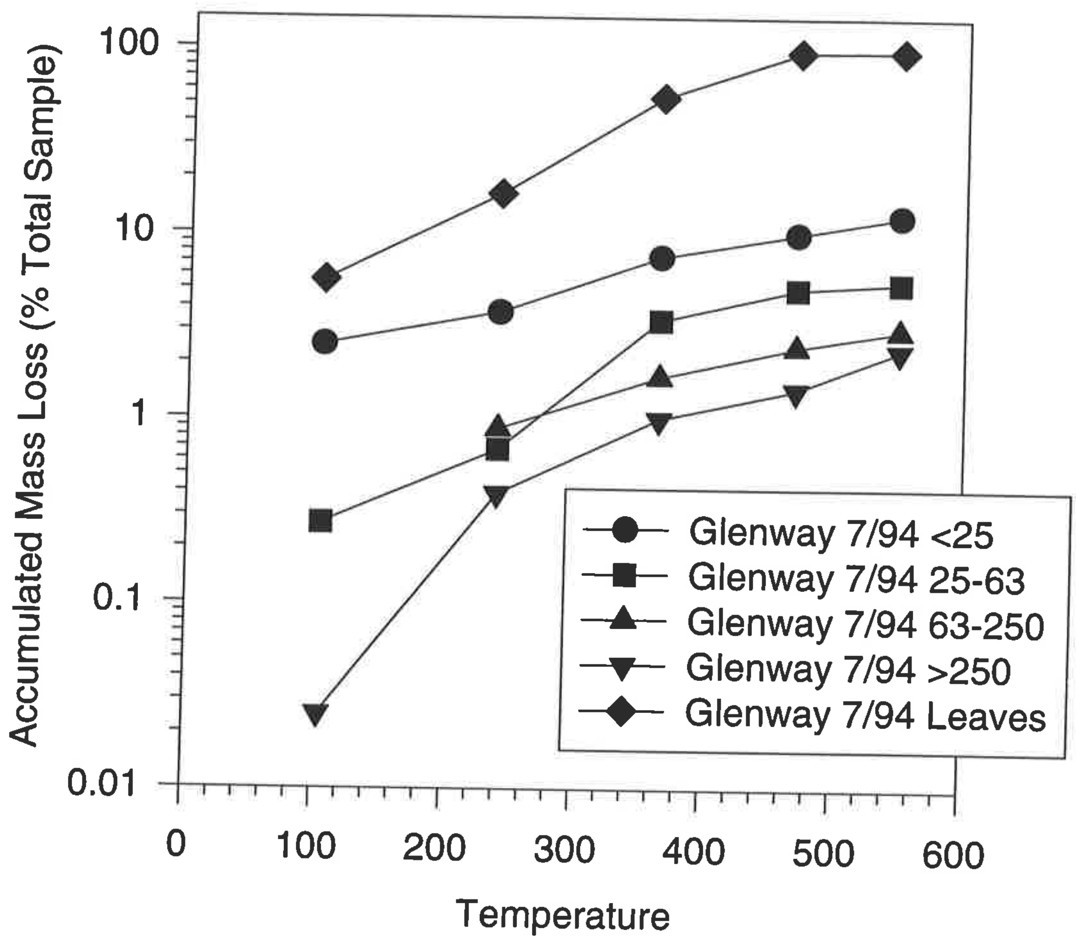


FIGURE D10. Glenway 8/94
Accumulated Mass Loss vs. Temperature

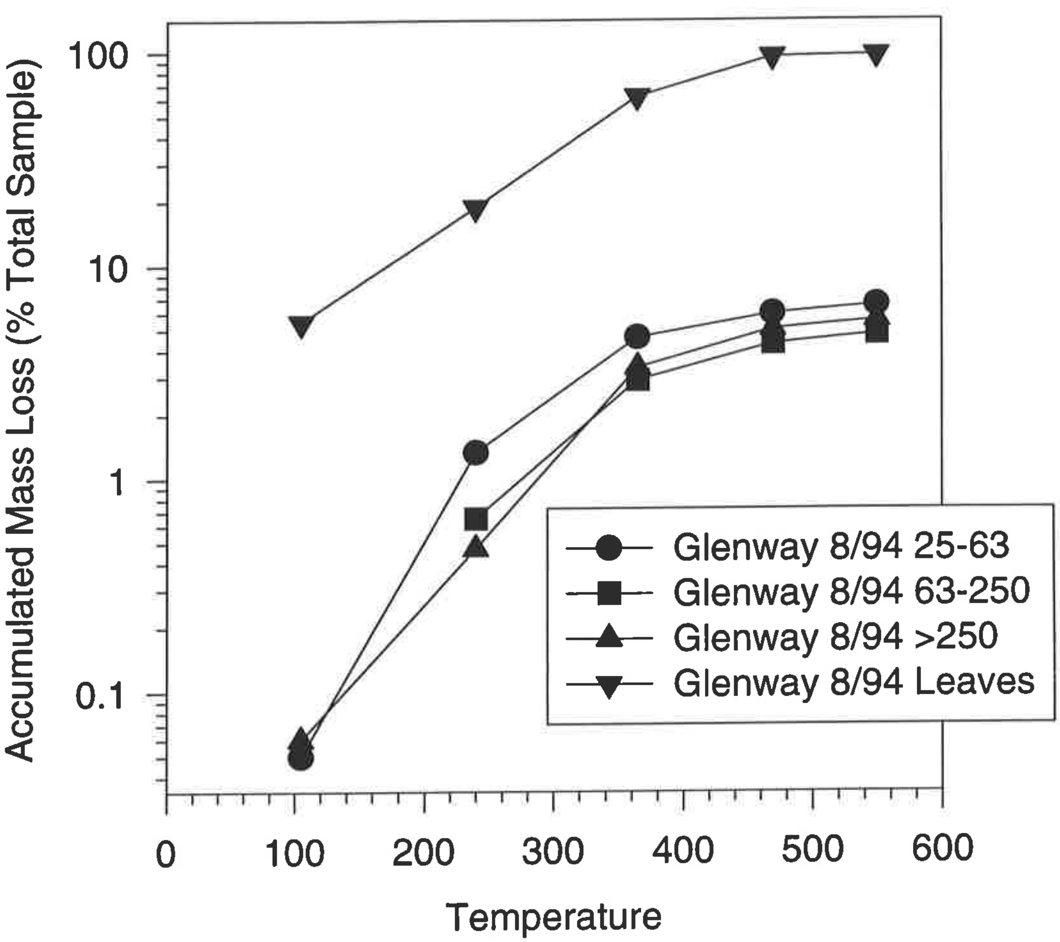


FIGURE D11. Glenway 9/94
Accumulated Mass Loss vs. Temperature

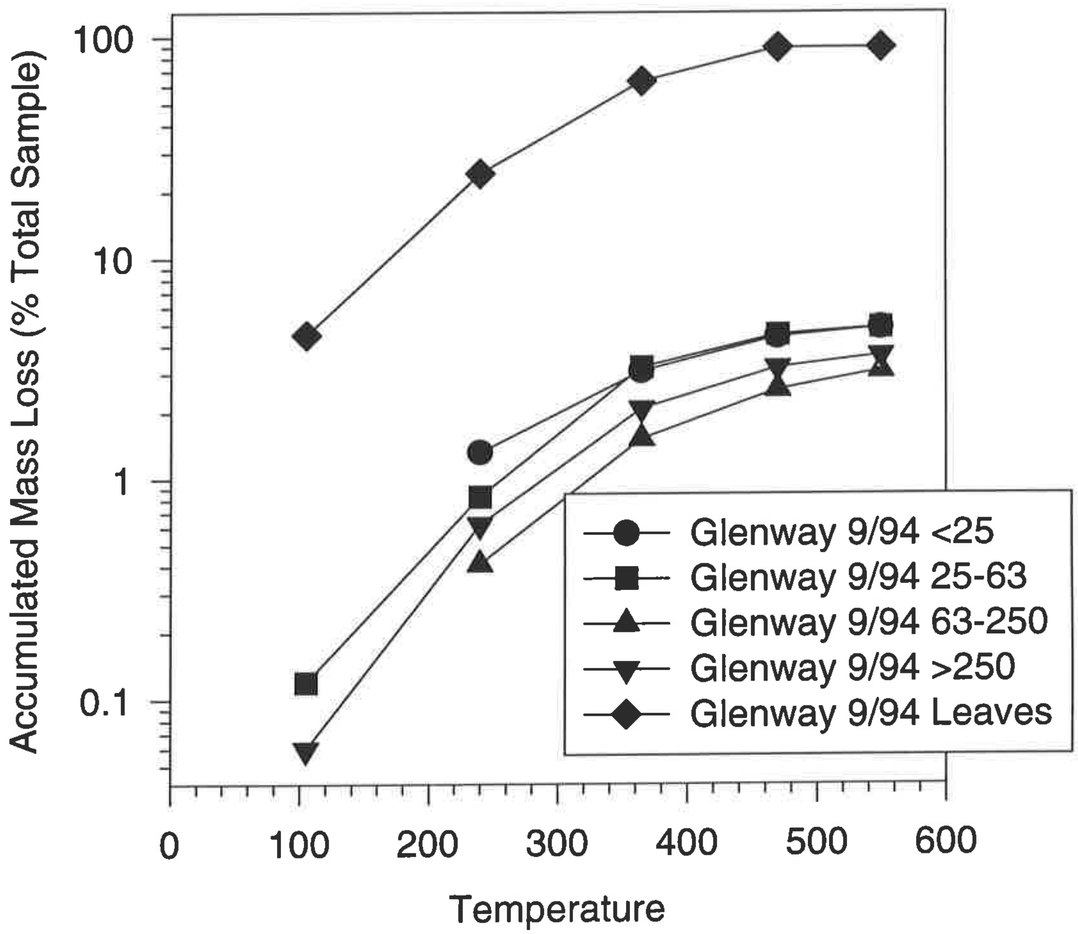


FIGURE D12. Glenway 10/94
Accumulated Mass Loss vs. Temperature

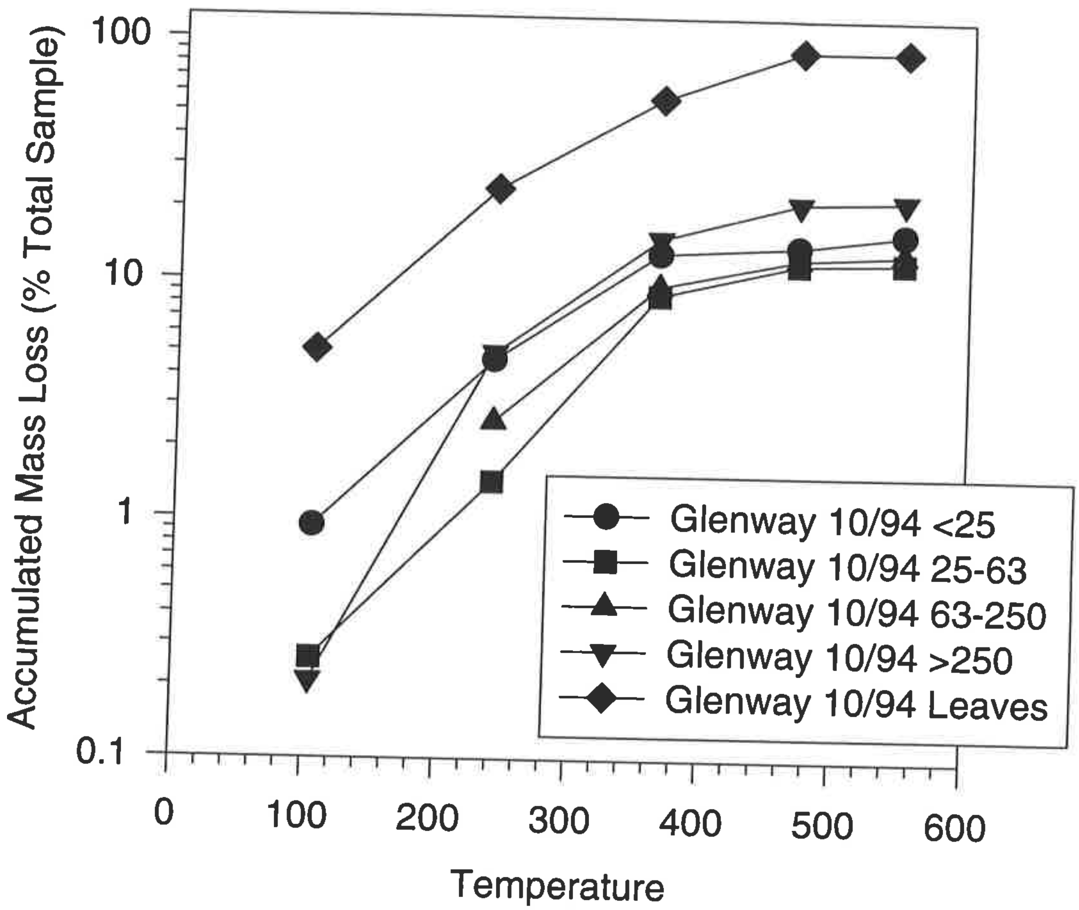


FIGURE D13. Monroe 4/94
Accumulated Mass Loss vs. Temperature

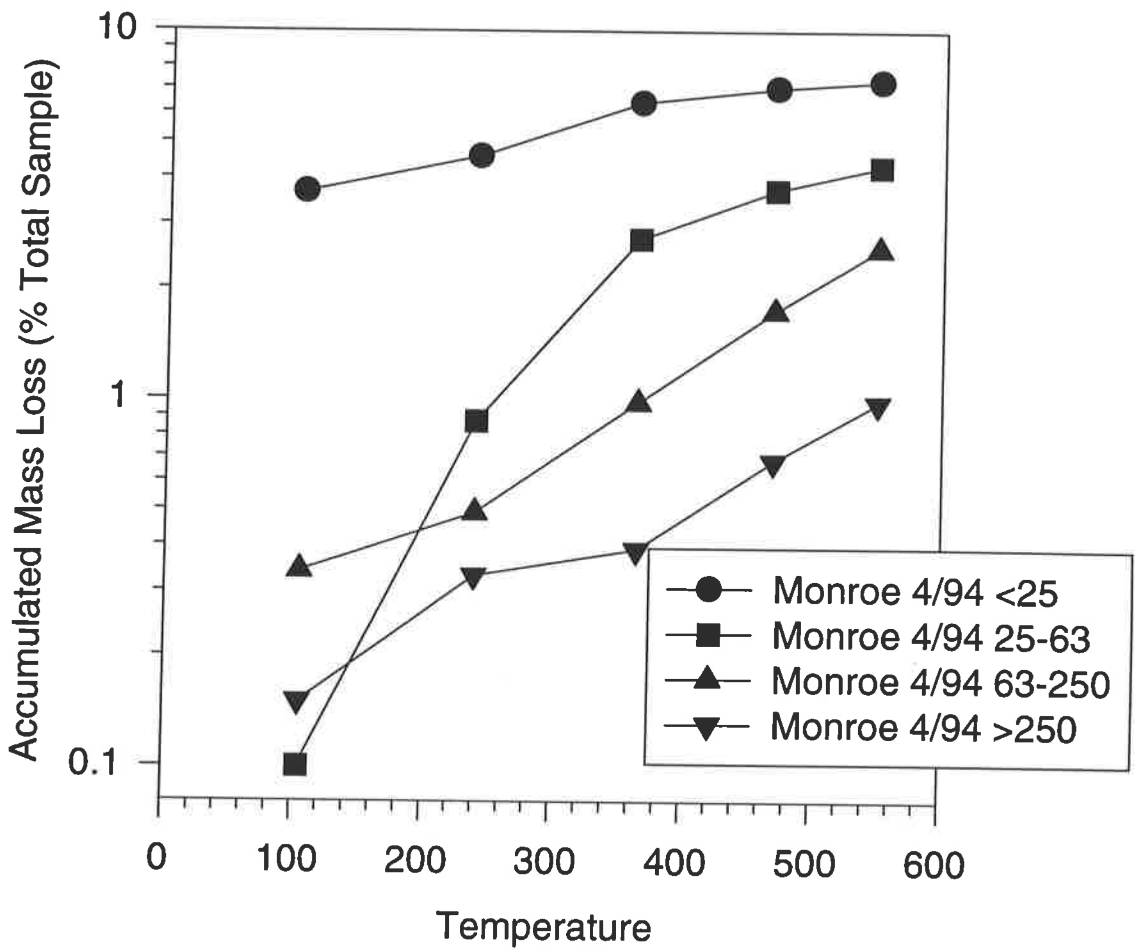


FIGURE D14. Monroe 6/94
Accumulated Mass Loss vs. Temperature

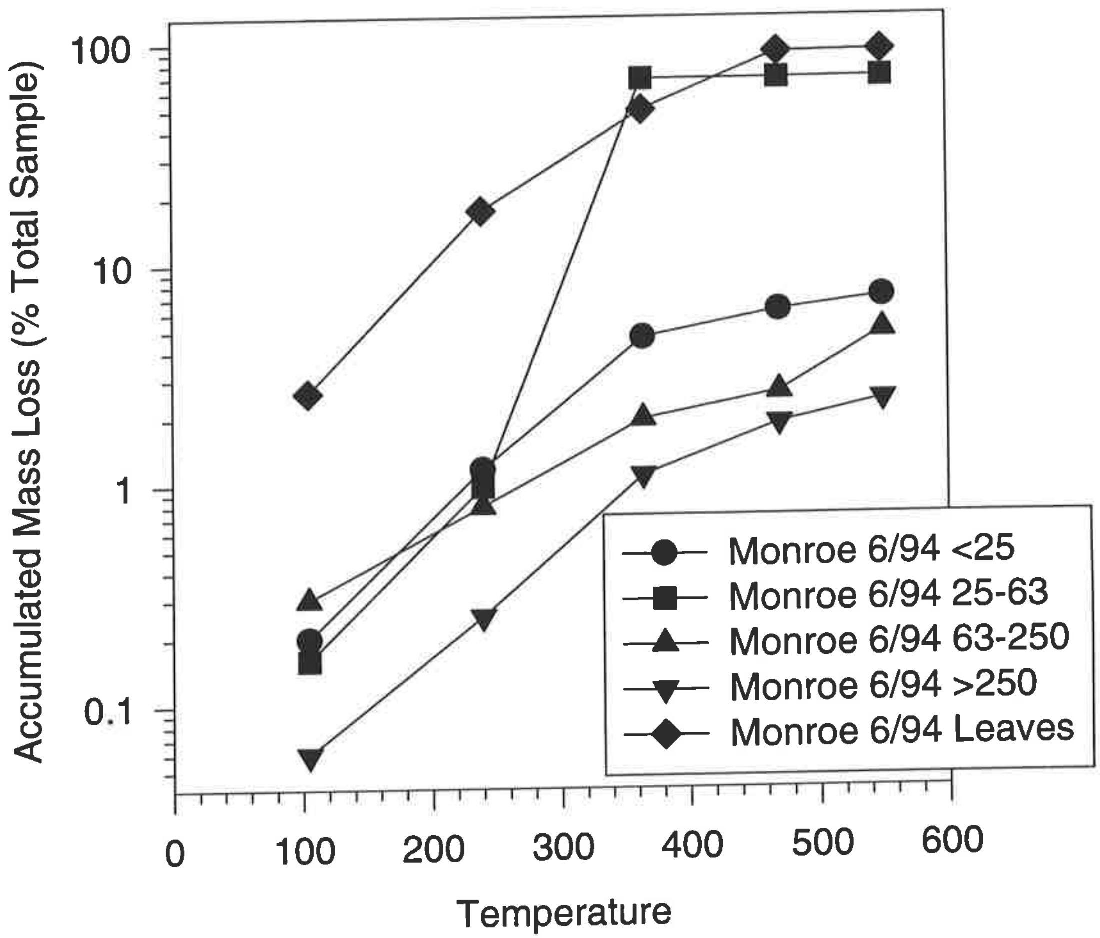


FIGURE D15. Monroe 7/94
Accumulated Mass Loss vs. Temperature

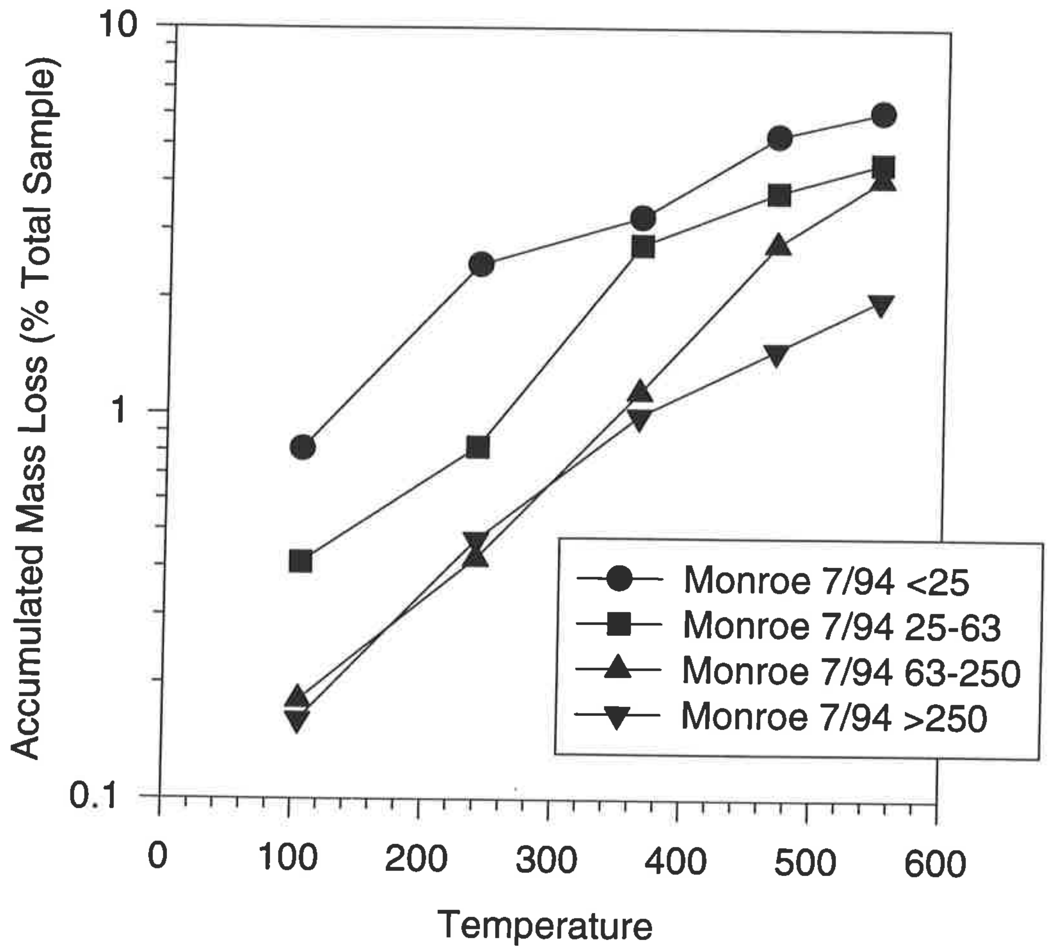


FIGURE D16. Monroe 8/94
Accumulated Mass Loss vs. Temperature

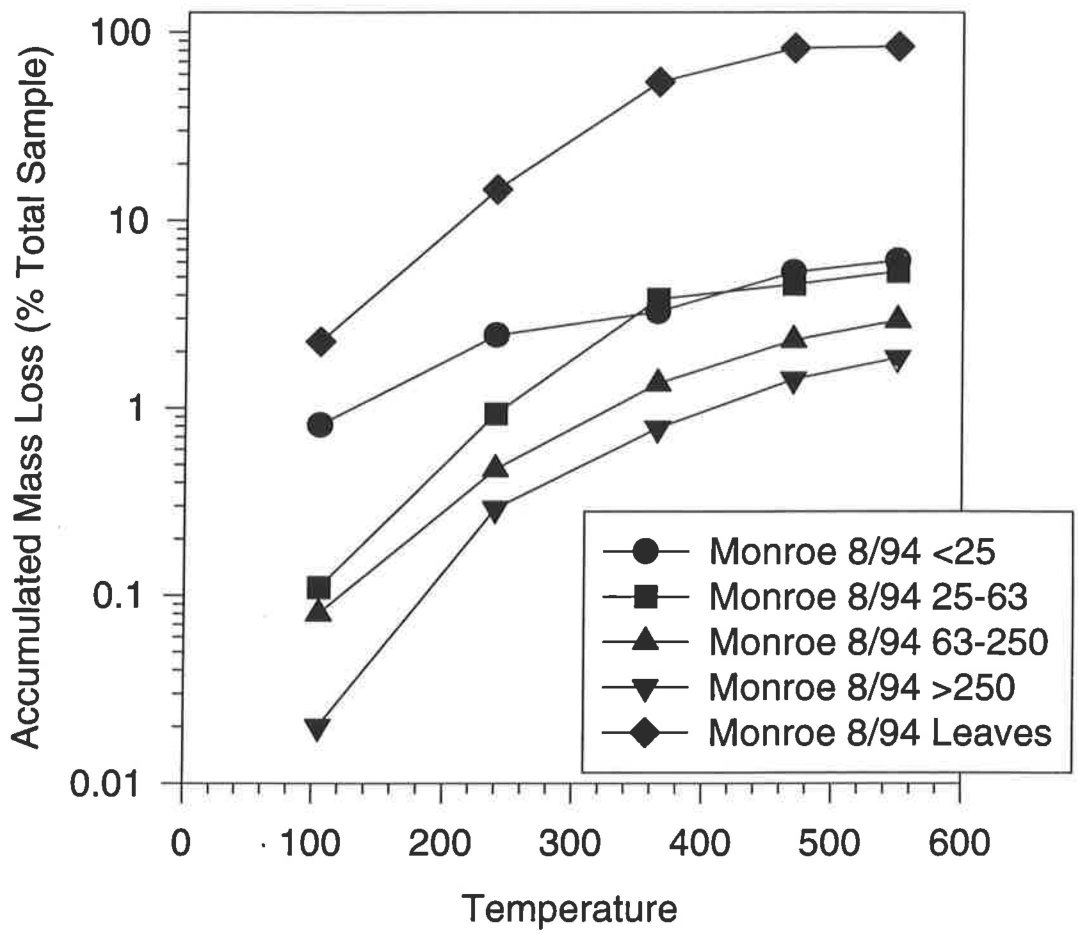


FIGURE D17. Monroe 9/94
Accumulated Mass Loss vs. Temperature

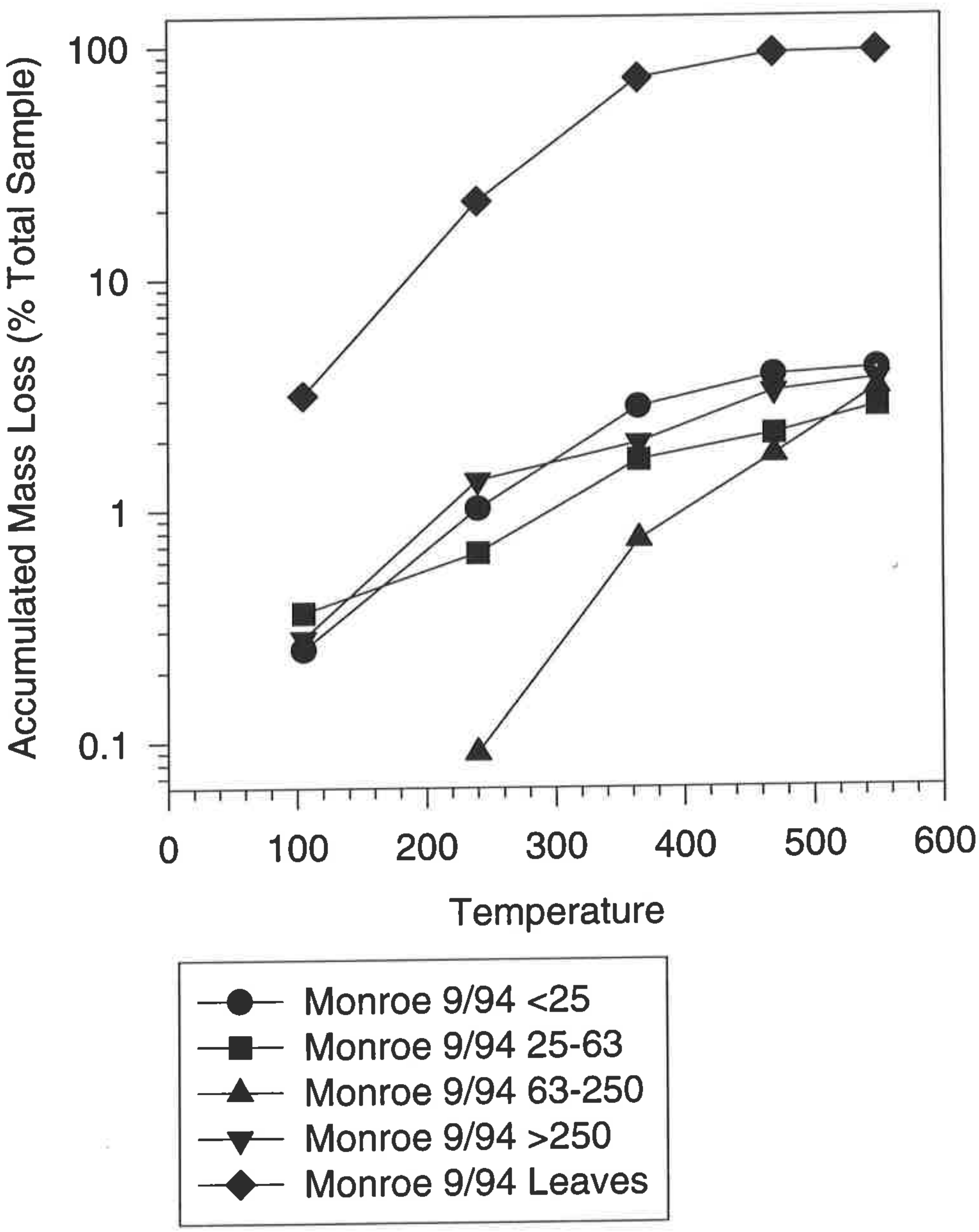


FIGURE D18. Monroe 10/94
Accumulated Mass Loss vs. Temperature

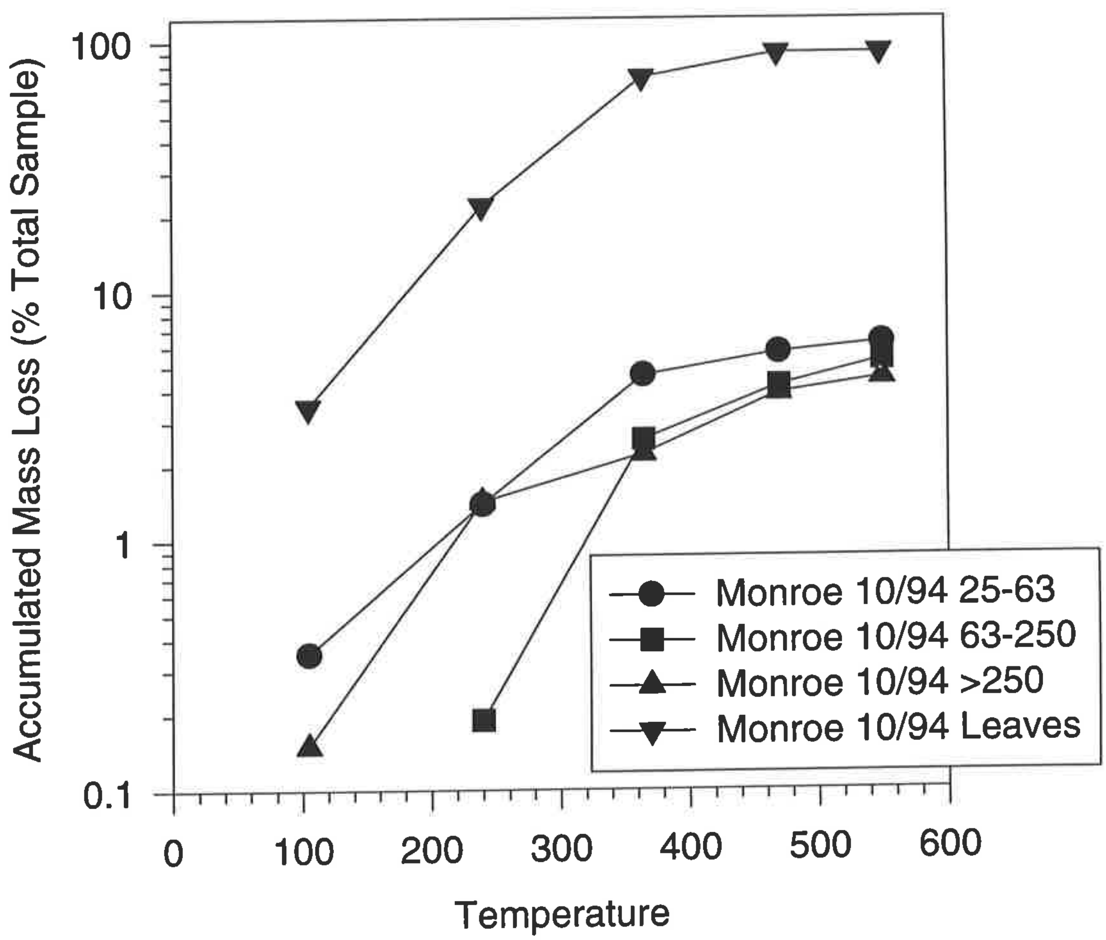


FIGURE D19. SSHH 4/94
Accumulated Mass Loss vs. Temperature

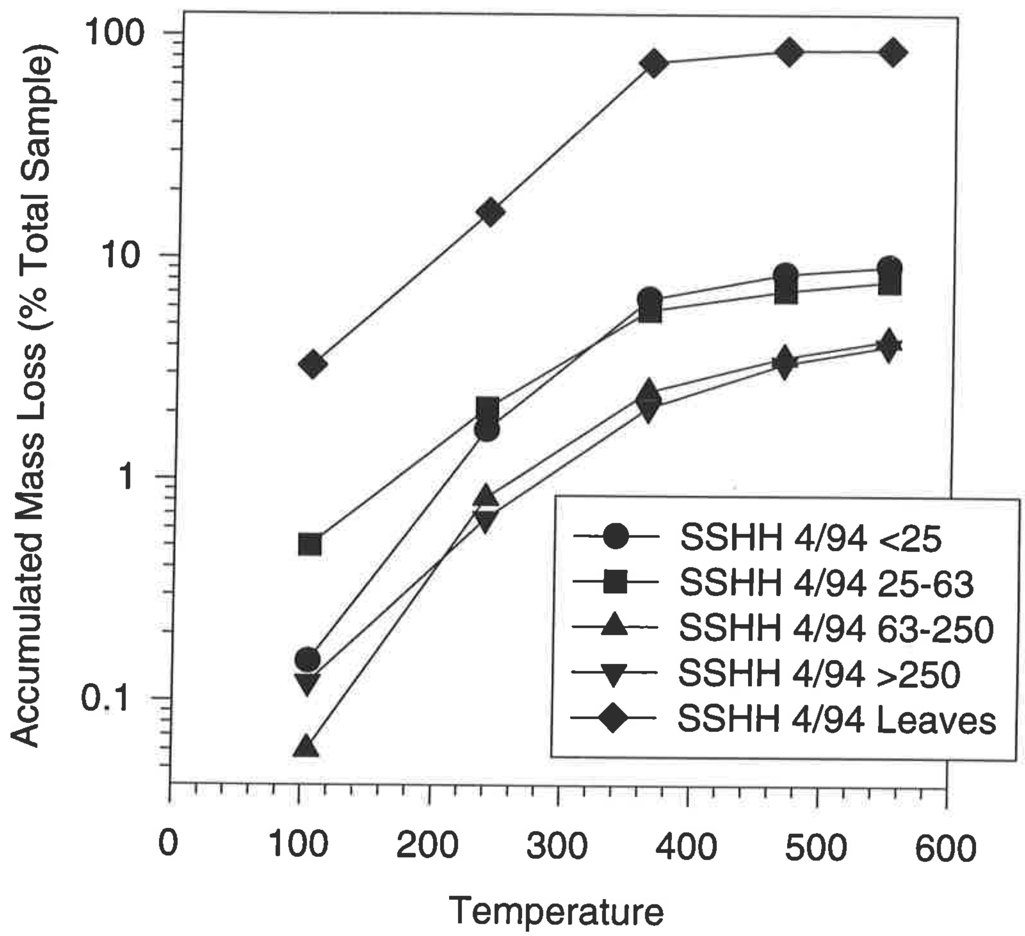


FIGURE D20. SSHH 6/94
Accumulated Mass Loss vs. Temperature

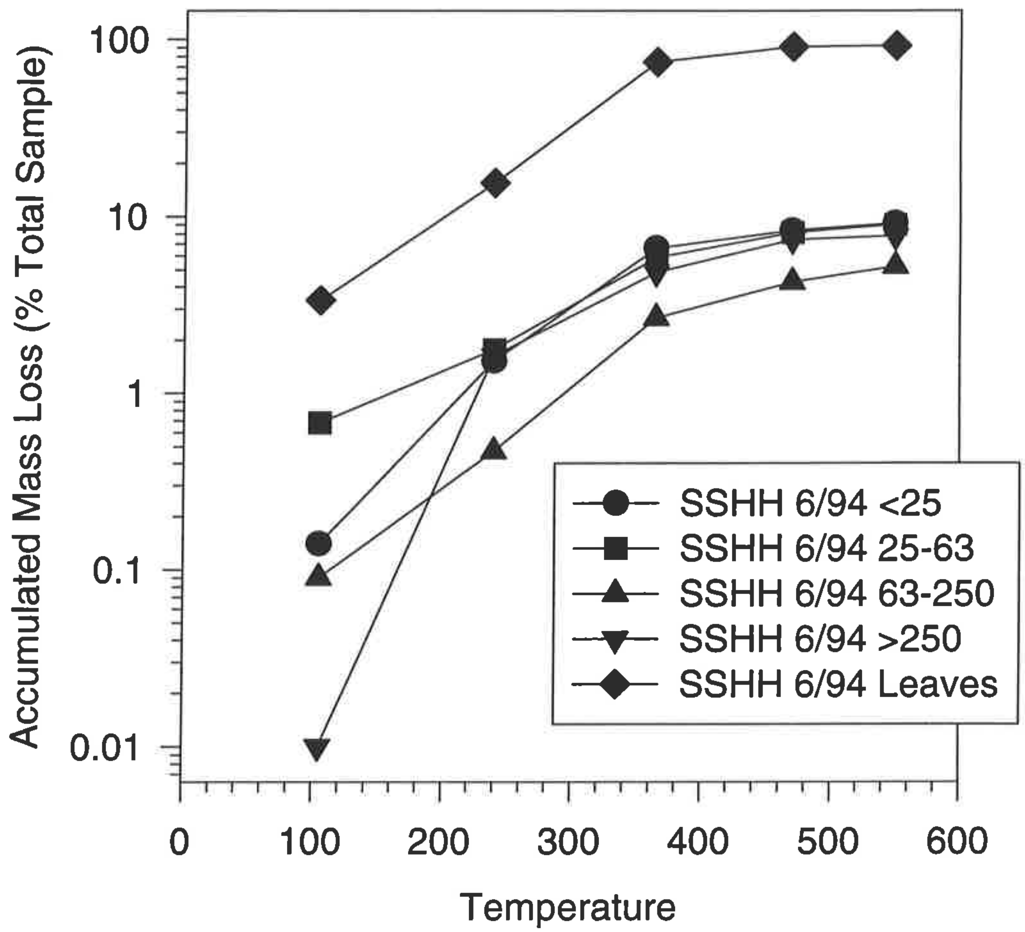


FIGURE D21. SSHH 7/94
Accumulated Mass Loss vs. Temperature

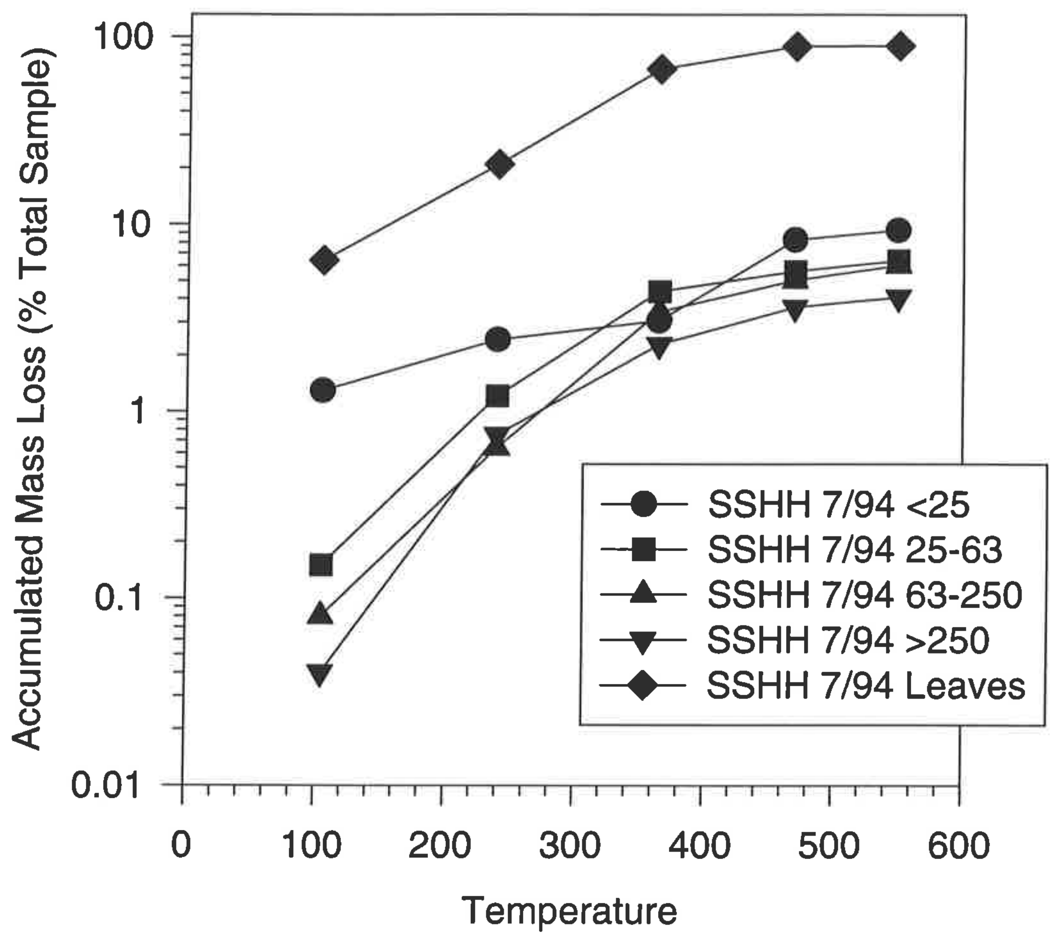


FIGURE D22. SSHH 8/94
Accumulated Mass Loss vs. Temperature

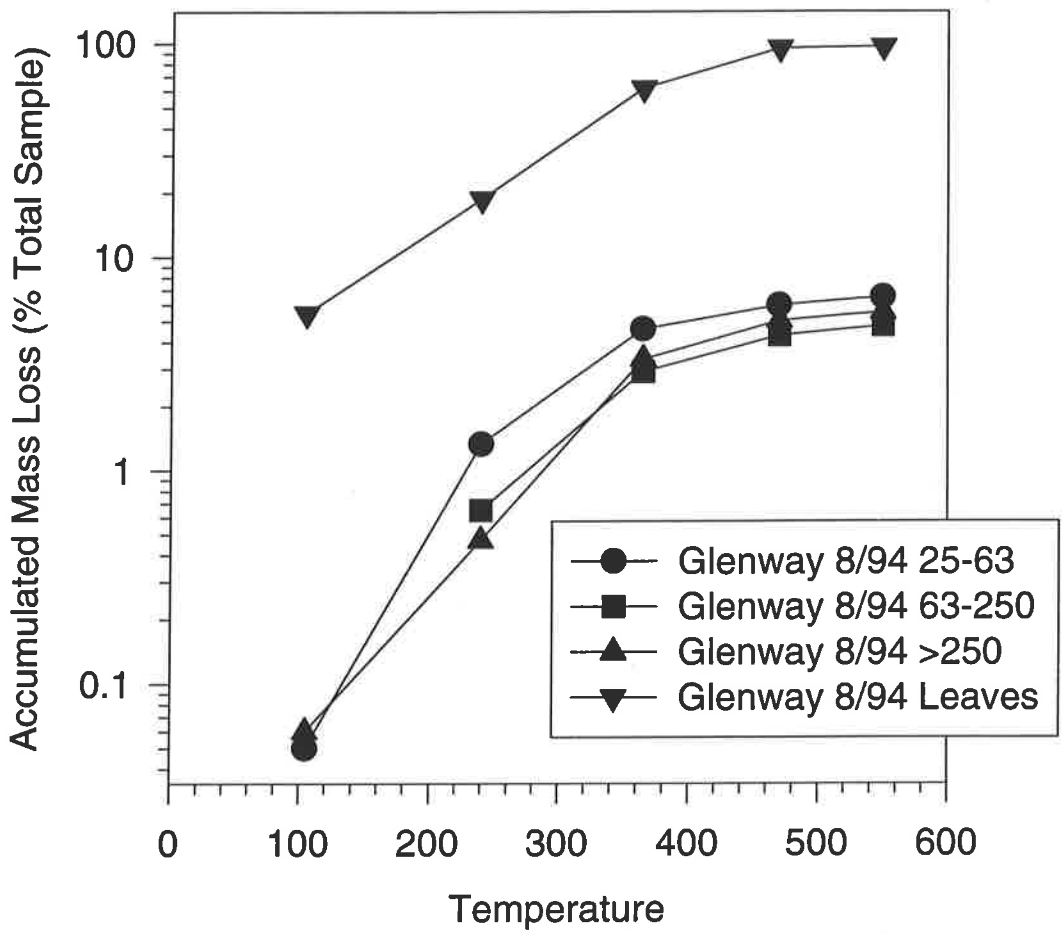


FIGURE D23. SSHH 9/94
Accumulated Mass Loss vs. Temperature

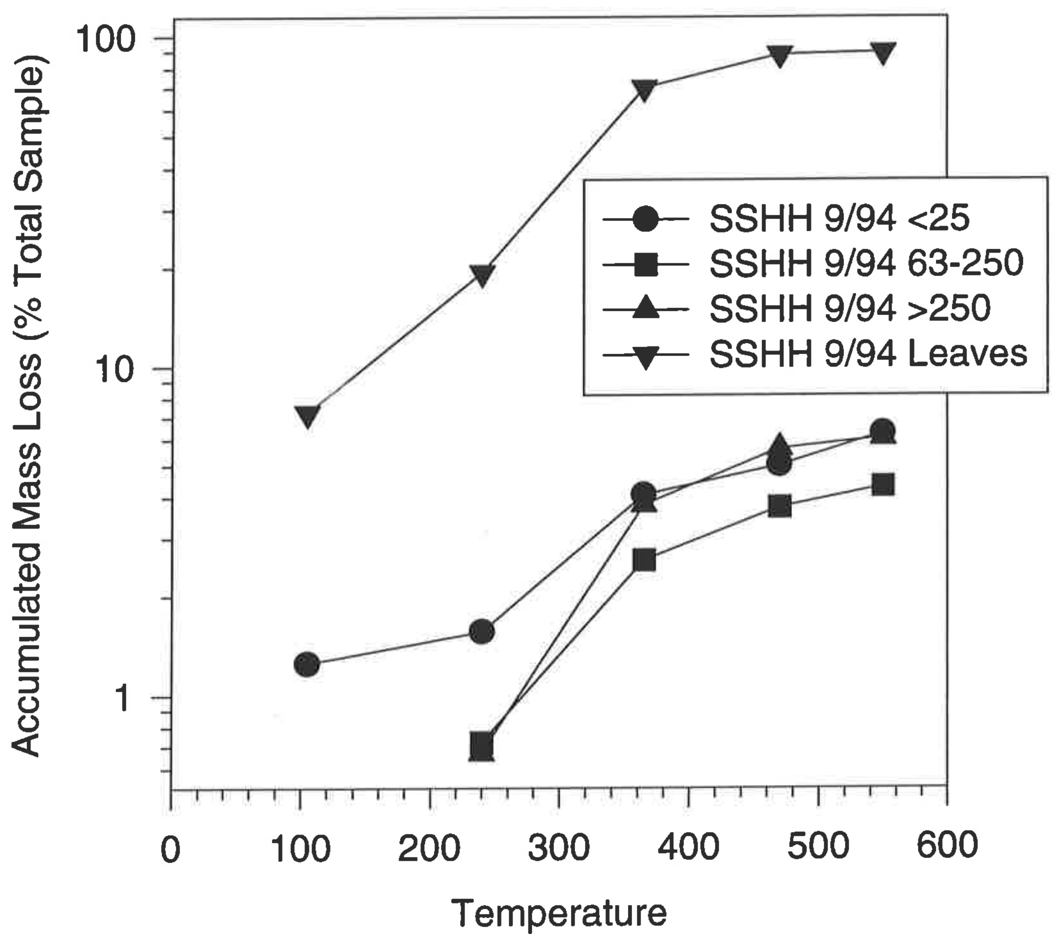
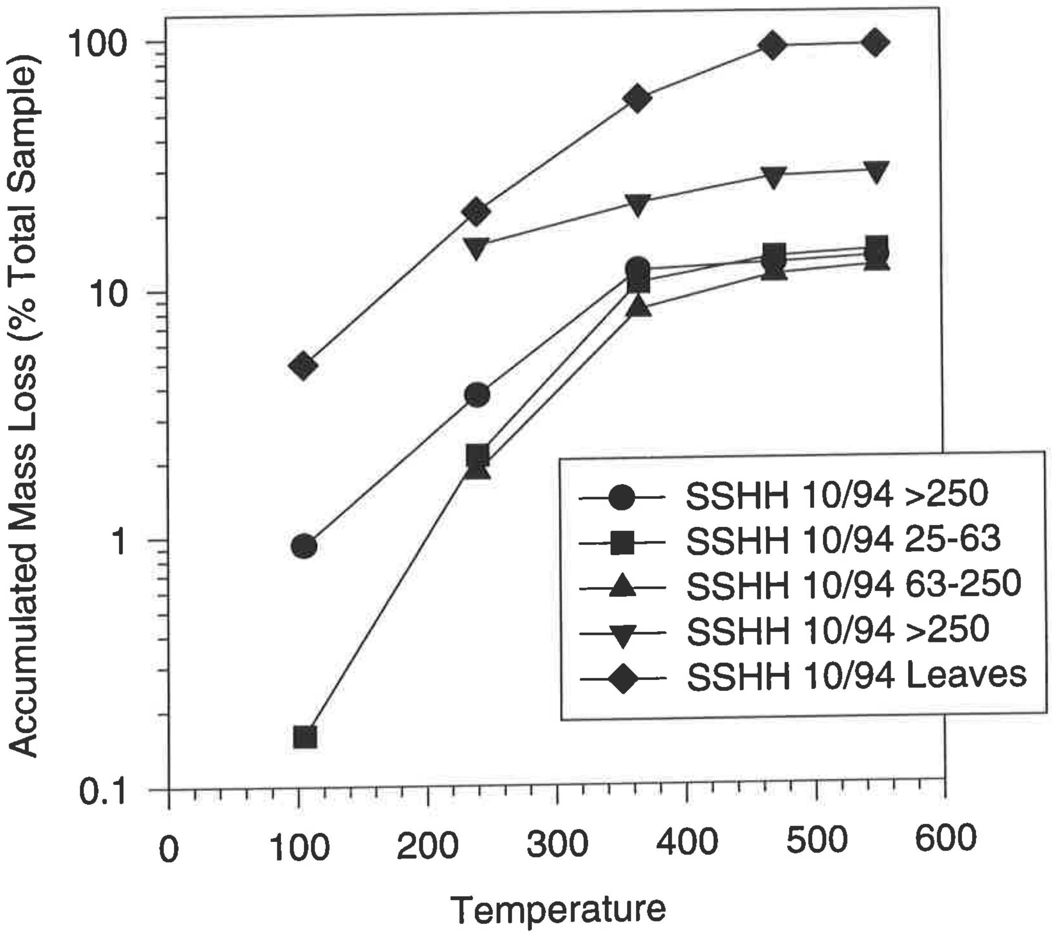


FIGURE D24. SSHH 10/94
Accumulated Mass Loss vs. Temperature



APPENDIX E

TOTAL PHOSPHORUS CONCENTRATIONS BY PERIOD AND PARTICLE SIZE

FIGURE E1. GAMMON

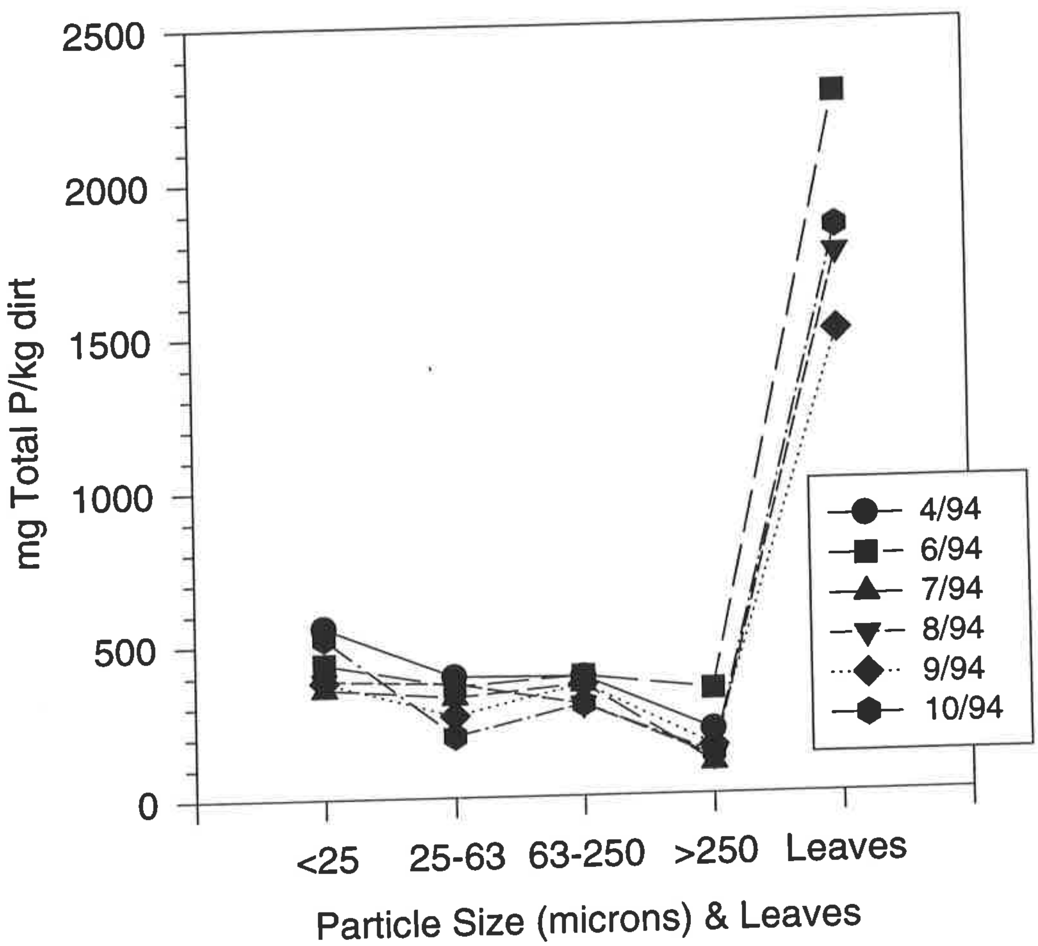


FIGURE E2. GLENWAY

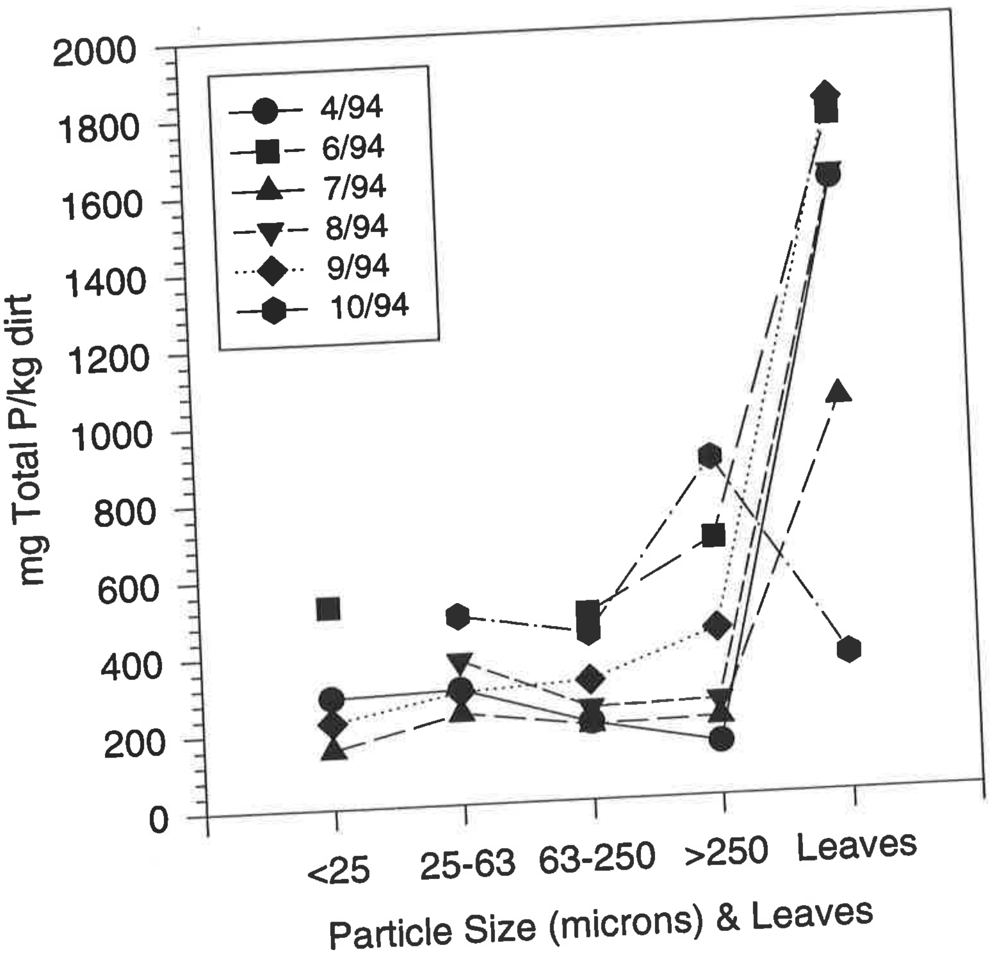


FIGURE 4. SENECA SPRING HURON HILL

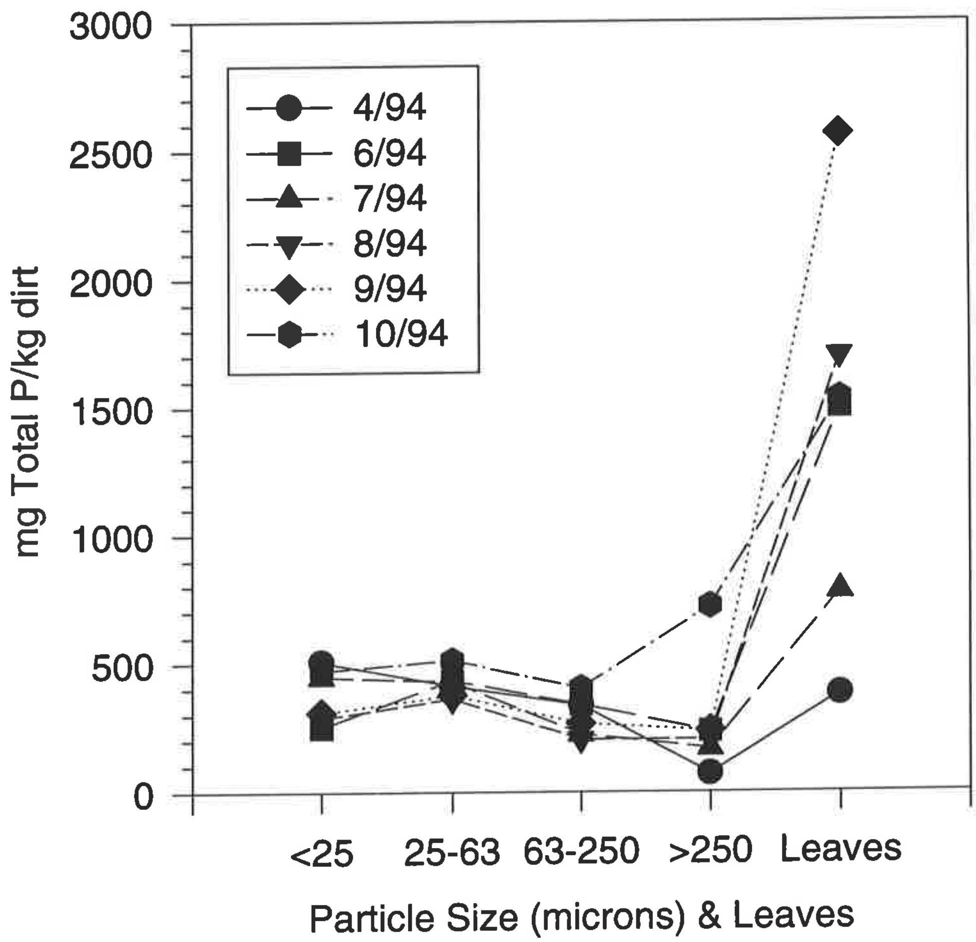


TABLE F1. SOURCES OF PHOSPHORUS IN STREET DIRT

SUMMARY OF MADISON STREET DIRT TOTAL PHOSPHORUS CONTENT

DATE (1994)	PARTICLE SIZE (<25, 25-63, 63-250, >250µm)	CONCENTRATION (mg TP/kg dirt and COV)			
		Gammon	Glenway	Monroe	Seneca
April 10	<25µm	555 (0.06)	288 (0.20)	300 (0.09)	506 (0.06)
June 3		436 (0.14)	525 (0.24)	311 (0.16)	250 (0.30)
July 15		355 (0.18)	153 (0.26)	320 (0.12)	447 (0.06)
August 30		383 (0.20)	NS*	315 (0.23)	287 (0.12)
September 30		377 (0.24)	224 (0.42)	231 (0.17)	309 (0.21)
October 28		520 (0.05)	NS*	320 (0.36)	471 (0.08)
April 10	25-63µm	391 (0.13)	298 (0.13)	285 (0.05)	412 (0.10)
June 3		360 (0.08)	NS*	367 (0.09)	434 (0.20)
July 15		324 (0.19)	236 (0.08)	325 (0.05)	429 (0.06)
August 30		368 (0.17)	373 (0.04)	342 (0.06)	361 (0.12)
September 30		264 (0.32)	292 (0.02)	189 (0.10)	376 (0.15)
October 28		198 (0.72)	489 (0.05)	326 (0.06)	512 (0.08)
April 10	63-250µm	386 (0.30)	200 (0.42)	125 (0.32)	337 (0.27)
June 3		388 (0.22)	484 (0.14)	197 (0.28)	339 (0.24)
July 15		361 (0.12)	194 (0.62)	164 (0.30)	224 (0.20)
August 30		296 (0.16)	239 (0.70)	166 (0.28)	204 (0.32)
September 30		362 (0.05)	310 (0.23)	191 (0.08)	265 (0.27)
October 28		296 (0.24)	433 (0.30)	345 (0.08)	403 (0.26)
April 10	>250µm	207 (0.41)	137 (0.29)	171 (0.50)	70 (0.20)
June 3		340 (0.51)	667 (0.27)	210 (0.37)	236 (0.67)
July 15		99 (0.11)	202 (0.47)	160 (0.13)	168 (0.26)
August 30		119 (0.21)	247 (0.44)	134 (0.11)	204 (0.21)
September 30		155 (0.61)	432 (0.80)	409 (0.69)	240 (0.15)
October 28		129 (0.42)	874 (0.06)	185 (0.70)	722 (0.10)
April 10	Leaves	NS*	1587 (0.12)	NS*	381 (0.08)
June 3		2268 (0.17)	1752 (0.06)	2295 (0.05)	1496 (0.25)
July 15		NS*	1018 (0.12)	NS*	779 (0.20)
August 30		1752 (0.04)	1600 (0.11)	702 (0.05)	1700 (0.25)
September 30		1500 (0.22)	1794 (0.08)	911 (0.09)	2564 (0.11)
October 28		1836 (0.46)	354 (0.39)	1980 (0.15)	1532 (0.33)

NS* Indicates that no sample was taken.

TABLE F2. GAMMON

GAMMON: 4/94

Temperature (°C)	<25µm (% Mass Loss)	25-63µm (% Mass Loss)	63-250µm (% Mass Loss)	>250µm (% Mass Loss)	Leaves
0-105					
105-240	0.50	1.06	0.74	0.19	NS
240-365	3.09	1.77	0.43	0.35	
365-470	2.49	1.43	0.97	0.35	
470-550	0.70	0.83	1.32	0.43	
Total mass loss	**6.9%**	**5.2%**	**4.0%**	**1.3%**	
mg P/kg dirt	6500	410	420	207	NS
% of leaves	6.2%	3.5%	0.9%	0.7%	
TP leaves (mg P/kg)	96.1	54.3	14	10.9	
% TP from leaves	1.5%	13.2%	3.3%	5.3%	

GAMMON: 6/94

Temperature (°C)	<25µm (% Mass Loss)	25-63µm (% Mass Loss)	63-250µm (% Mass Loss)	>250µm (% Mass Loss)	Leaves
0-105	0.19	0.17	0	0.04	4.1
105-240	1.12	0.74	0.55	0.29	13.9
240-365	3.43	3.32	1.42	0.44	55.4
365-470	2.05	1.59	1.03	0.42	1.03
470-550	1.12	0.84	0.66	0.46	10.3
Total mass loss	**7.9%**	**6.7%**	**3.7%**	**1.6%**	**84.6%**
mg P/kg dirt	500	400	430	200	1900
% of leaves	6.2%	6.0%	2.6%	0.8%	100%
TP leaves (mg P/kg)	82.8	80.1	34.7	10.7	1900
% TP from leaves	16.6%	20%	8.1%	5.4%	100%

TABLE F2 (Continued) GAMMON: 7/94

Temperature (°C)	**<25µm** (% Mass Loss)	**25-63µm** (% Mass Loss)	**63-250µm** (% Mass Loss)	**>250µm** (% Mass Loss)	**Leaves**
0-105	0.29	0.91	0	0.03	3.78
105-240	0.29	1.60	0.88	0.37	18.7
240-365	2.02	0.91	0.80	0.61	50.5
365-470	2.60	0.99	0.76	0.44	19.2
470-550	0.58	1.26	0.57	0.91	0.81
Total mass loss	**5.8%**	**5.7%**	**3.0%**	**2.4%**	**93%**
mg P/kg dirt	360	400	360	80	NS
% of leaves	4.0%	1.8%	1.6%	1.2%	100%
TP leaves (mg P/kg)	168.2	164.2	86.8	68.1	
% TP from leaves	46.7%	41.1%	24.1%	85.1%	

GAMMON: 8/94

Temperature (°C)	**<25µm** (% Mass Loss)	**25-63µm** (% Mass Loss)	**63-250µm** (% Mass Loss)	**>250µm** (% Mass Loss)	**Leaves**
0-105	0.44	0.30	0	0.03	3.99
105-240	0.55	0.73	0.41	0.31	13.6
240-365	3.09	2.32	0.95	0.70	45.8
365-470	1.22	1.23	0.86	0.50	25.4
470-550	1.21	1.06	0.68	0.59	1.18
Total mass loss	**6.5%**	**5.6%**	**2.9%**	**2.1%**	**89.9%**
mg P/kg dirt	420	440	320	120	1600
% of leaves	6.8%	5.1%	2.1%	1.5%	100%
TP leaves (mg P/kg)	108.8	81.6	33.6	24.0	1600
% TP from leaves	25.9%	18.5%	10.5%	20.0%	100%

TABLE F2. (Continued) GAMMON: 9/94

Temperature (°C)	<25μm (% Mass Loss)	25-63μm (% Mass Loss)	63-250μm (% Mass Loss)	>250μm (% Mass Loss)	Leaves
0-105	0.13	0.49	0	0.02	2.19
105-240	0.72	0.55	0.32	0.19	14.5
240-365	2.76	1.87	0.78	0.31	52.0
365-470	1.71	1.17	0.74	0.29	18.1
470-550	0.72	0.89	0.59	0.39	2.19
Total mass loss	**6.0%**	**5.0%**	**2.4%**	**1.2%**	**89%**
mg P/kg dirt	430	360	380	155	1500
% of leaves	5.3%	3.6%	1.5%	0.6%	100%
TP leaves (mg P/kg)	174.9	144.2	70.8	9.0	1500
% TP from leaves	40.7%	40.1%	18.6%	5.8%	100%

GAMMON: 10/94

Temperature (°C)	<25μm (% Mass Loss)	25-63μm (% Mass Loss)	63-250μm (% Mass Loss)	>250μm (% Mass Loss)	Leaves
0-105	0.27	0.04	1.48	0.28	3.62
105-240	0.93	0.66	0.44	0.42	18.2
240-365	2.56	2.50	0.99	0.22	47.6
365-470	1.95	1.28	1.02	0.47	17.2
470-550	0.86	0.70	0.85	0.40	0.80
Total mass loss	**6.6%**	**5.2%**	**4.8%**	**1.8%**	**87.4%**
mg P/kg dirt	550	340	280	150	1200
% of leaves	5.4%	5.3%	2.1%	0.5%	100%
TP leaves (mg P/kg)	64.8	63.6	25.2	6.0	1200
% TP from leaves	11.8%	18.7%	9.0%	4.0%	100%

TABLE F3. GLENWAY

GLENWAY: 4/94

Temperature (°C)	<25μm (% Mass Loss)	25-63μm (% Mass Loss)	63-250μm (% Mass Loss)	>250μm (% Mass Loss)	Leaves
0-105	0.69	0.38	0.27	0.02	1.51
105-240	0.45	0.35	0.26	0.19	14.1
240-365	2.52	1.94	0.70	0.35	40.7
365-470	1.14	1.19	0.98	0.35	22.6
470-550	1.30	0.84	0.99	0.43	5.03
Total mass loss	**6.1%**	**4.7%**	**3.2%**	**1.3%**	**83.9%**
mg P/kg dirt	NS	300	210	150	1119
% of leaves		7.8%	5.3%	2.2%	100%
TP leaves (mg P/kg)		62.7	42.7	17.9	1119
% TP from leaves		20.9%	20.3%	11.9%	100%

GLENWAY: 6/94

Temperature (°C)	<25μm (% Mass Loss)	25-63μm (% Mass Loss)	63-250μm (% Mass Loss)	>250μm (% Mass Loss)	Leaves
0-105	0.25	0.08	0.16	0.89	7.26
105-240	0.99	1.05	1.17	4.78	18.7
240-365	6.22	6.38	5.62	13.9	29.8
365-470	2.86	2.18	3.59	10.0	36.6
470-550	0.75	0.45	1.48	0.70	0.72
Total mass loss	**11.1%**	**10.1%**	**12.0%**	**30.3%**	**93.0%**
mg P/kg dirt			500	580	1240
% of leaves			20.0%	50.4%	100%
TP leaves (mg P/kg)			160.3	403.3	1240
% TP from leaves			32.1%	69.5%	100%

TABLE F3. (Continued) GLENWAY: 7/94

Temperature (°C)	**<25µm** (% Mass Loss)	**25-63µm** (% Mass Loss)	**63-250µm** (% Mass Loss)	**>250µm** (% Mass Loss)	**Leaves**
0-105	2.50	0.27	0	0.03	5.60
105-240	1.25	0.41	0.88	0.37	10.8
240-365	3.75	2.73	0.80	0.61	38.2
365-470	2.50	1.63	0.76	0.44	40.9
470-550	2.50	0.41	0.57	0.91	0.74
Total mass loss	**12.5%**	**5.5%**	**3.0%**	**2.4%**	**96.2%**
mg P/kg dirt		250	250	250	1283
% of leaves		9.1%	5.0%	3.9%	100%
TP leaves (mg P/kg)		72.7	40.1	31.3	1283
% TP from leaves		29.1%	16.0%	12.5%	100%

GLENWAY: 8/94

Temperature (°C)	**<25µm** (% Mass Loss)	**25-63µm** (% Mass Loss)	**63-250µm** (% Mass Loss)	**>250µm** (% Mass Loss)	**Leaves**
0-105	NS	0.05	0	0.06	5.46
105-240		1.28	0.65	0.41	13.3
240-365		3.27	2.26	2.86	42.9
365-470		1.35	1.39	1.70	33.1
470-550		0.55	0.47	0.50	1.45
Total mass loss		**6.5%**	**4.8%**	**5.5%**	**96.2%**
mg P/kg dirt		380	300	180	1600
% of leaves		10.8%	8.0%	9.2%	100%
TP leaves (mg P/kg)		86.7	63.6	73.7	1283
% TP from leaves		22.8%	21.2%	40.9%	100%

TABLE F3. (Continued) GLENWAY: 9/94

Temperature (°C)	<25μm (% Mass Loss)	25-63μm (% Mass Loss)	63-250μm (% Mass Loss)	>250μm (% Mass Loss)	Leaves
0-105	0	0.12	0	0.06	4.51
105-240	1.32	0.71	0.41	0.56	19.7
240-365	1.76	2.38	1.11	1.46	38.6
365-470	1.33	1.30	1.02	1.12	26.1
470-550	0.44	0.36	0.55	0.42	0.24
Total mass loss	**4.9%**	**4.9%**	**3.1%**	**3.6%**	**89.1%**
mg P/kg dirt		300	380	700	1188
% of leaves		8.1%	5.2%	6.1%	100%
TP leaves (mg P/kg)		64.9	41.2	48.4	1188
% TP from leaves		21.6%	10.8%	6.9%	100%

GLENWAY: 10/94

Temperature (°C)	<25μm (% Mass Loss)	25-63μm (% Mass Loss)	63-250μm (% Mass Loss)	>250μm (% Mass Loss)	Leaves
0-105	0.93	0.26	0	0.21	5.09
105-240	3.74	1.18	2.58	4.77	18.9
240-365	8.41	7.31	6.95	10.1	33.3
365-470	0.94	3.13	2.96	6.24	34.3
470-550	1.07	0.26	0.64	0.65	0.19
Total mass loss	**15.9%**	**12.1%**	**13.1%**	**22%**	**91.8%**
mg P/kg dirt		500	450	850	1224
% of leaves		20.2%	21.9%	36.6%	100%
TP leaves (mg P/kg)		161.9	175.1	292.9	1224
% TP from leaves		32.4%	38.9%	34.4%	100%

TABLE F4. MONROE

MONROE: 4/94

Temperature (°C)	<25µm (% Mass Loss)	25-63µm (% Mass Loss)	63-250µm (% Mass Loss)	>250µm (% Mass Loss)	Leaves
0-105	3.66	0.10	0.34	0.15	NS
105-240	0.91	0.77	0.15	0.18	
240-365	1.83	1.86	0.49	0.06	
365-470	0.61	0.98	0.76	0.29	
470-550	0.31	0.59	0.83	0.30	
Total mass loss	**7.3%**	**4.3%**	**2.6%**	**1.0%**	
mg P/kg dirt	280	320	120	180	
% of leaves	4.3%	4.3%	1.1%	0.1%	
TP leaves (mg P/kg)	59.1	59.1	15.1	1.4	
% TP from leaves	21.1%	18.5%	12.6%	0.8%	

MONROE: 6/94

Temperature (°C)	<25µm (% Mass Loss)	25-63µm (% Mass Loss)	63-250µm (% Mass Loss)	>250µm (% Mass Loss)	Leaves
0-105	0.20	0.16	0.30	0.06	2.61
105-240	0.97	0.81	0.49	0.19	14.8
240-365	3.42	67.0	1.17	0.84	31.7
365-470	1.47	0.27	0.62	0.78	40.0
470-550	0.88	0.31	2.29	0.51	0.87
Total mass loss	**6.9%**	**68.5%**	**4.9%**	**2.4%**	**90.0%**
mg P/kg dirt	250	420	200	200	2000
% of leaves	10.8%	100%	3.7%	2.6%	100%
TP leaves (mg P/kg)	216	420	74	52	2000
% TP from leaves	86.4%	100%	37.0%	26.0%	100%

TABLE F4. (Continued) MONROE: 7/94

Temperature (°C)	<25µm (% Mass Loss)	25-63µm (% Mass Loss)	63-250µm (% Mass Loss)	>250µm (% Mass Loss)	Leaves
0-105	0.81	0.41	0.18	0.16	NS
105-240	1.63	0.41	0.24	0.31	
240-365	0.81	1.93	0.72	0.52	
365-470	2.03	1.02	1.62	0.48	
470-550	0.82	0.72	1.32	0.52	
Total mass loss	**6.1%**	**4.5%**	**4.1%**	**2.0%**	
mg P/kg dirt	320	350	150	180	
% of leaves	1.9%	4.5%	1.7%	1.2%	
TP leaves (mg P/kg)	26.1	61.9	23.4	16.5	
% TP from leaves	8.2%	17.7%	15.6%	9.2%	

MONROE: 8/94

Temperature (°C)	<25µm (% Mass Loss)	25-63µm (% Mass Loss)	63-250µm (% Mass Loss)	>250µm (% Mass Loss)	Leaves
0-105	0.81	0.11	0.08	0.02	2.26
105-240	1.63	0.82	0.39	0.27	12.3
240-365	0.81	2.86	0.88	0.49	39.8
365-470	2.03	0.77	0.95	0.64	28.0
470-550	0.82	0.77	0.63	0.43	1.74
Total mass loss	**6.1%**	**5.3%**	**2.9%**	**1.9%**	**84.0%**
mg P/kg dirt	350	380	150	120	900
% of leaves	2.0%	7.2%	2.2%	1.2%	100%
TP leaves (mg P/kg)	18	64.8	19.8	10.8	900
% TP from leaves	5.1%	17.1%	13.2%	9.0%	100%

TABLE F4. (Continued) MONROE: 9/94

Temperature (°C)	**<25µm** (% Mass Loss)	**25-63µm** (% Mass Loss)	**63-250µm** (% Mass Loss)	**>250µm** (% Mass Loss)	**Leaves**
0-105	0.25	0.36	0	0.28	3.14
105-240	0.76	0.29	0.09	1.06	18.5
240-365	1.77	0.99	0.65	0.61	50.8
365-470	1.01	0.47	0.97	1.27	19.8
470-550	0.25	0.65	1.62	0.41	1.83
Total mass loss	**4.0%**	**2.8%**	**3.3%**	**3.6%**	**94.0%**
mg P/kg dirt	200	200	200	250	800
% of leaves	3.5%	1.9%	1.3%	1.2%	100%
TP leaves (mg P/kg)	28	15.2	10.4	9.6	800
% TP from leaves	14.0%	7.6%	5.2%	3.8%	100%

MONROE: 10/94

Temperature (°C)	**<25µm** (% Mass Loss)	**25-63µm** (% Mass Loss)	**63-250µm** (% Mass Loss)	**>250µm** (% Mass Loss)	**Leaves**
0-105	NS	0.35	0	0.15	3.46
105-240		1.05	0.19	1.28	18.4
240-365		3.16	2.33	0.78	49.3
365-470		1.05	1.62	1.65	18.5
470-550		0.53	1.10	0.58	0.28
Total mass loss		**6.14%**	**5.24%**	**4.44%**	**89.9%**
mg P/kg dirt		300	350	100	1800
% of leaves		6.4%	4.7%	1.6%	100%
TP leaves (mg P/kg)		115.2	84.6	28.8	1800
% TP from leaves		38.4%	24.2%	28.8%	100%

TABLE F5. SENECA, SPRING, HURON HILL (SSHH)

SSHH: 4/94

Temperature (°C)	**<25μm** (% Mass Loss)	**25-63μm** (% Mass Loss)	**63-250μm** (% Mass Loss)	**>250μm** (% Mass Loss)	**Leaves**
0-105	0.15	0.50	0.06	0.12	3.25
105-240	1.52	1.59	0.76	0.54	12.8
240-365	4.85	3.71	1.67	1.44	59.7
365-470	1.96	1.30	1.07	1.23	10.2
470-550	0.69	0.76	0.71	0.69	0.65
Total mass loss	**9.2%**	**7.9%**	**4.3%**	**4.0%**	**86.6%**
mg P/kg dirt	480	420	350	50	400
% of leaves	8.1%	6.2%	2.8%	2.4%	100%
TP leaves (mg P/kg)	32.4	24.8	11.2	9.6	400
% TP from leaves	6.8%	5.9%	3.2%	19.2%	100%

SSHH: 6/94

Temperature (°C)	**<25μm** (% Mass Loss)	**25-63μm** (% Mass Loss)	**63-250μm** (% Mass Loss)	**>250μm** (% Mass Loss)	**Leaves**
0-105	0.14	0.68	0.09	0.01	3.36
105-240	1.38	1.09	0.38	1.62	12.1
240-365	5.10	4.09	2.20	3.20	58.9
365-470	1.72	2.26	1.59	2.59	16.0
470-550	0.83	0.86	0.97	0.35	1.29
Total mass loss	**9.2%**	**9.0%**	**5.2%**	**7.8%**	**91.7%**
mg P/kg dirt	320	480	300	100	1000
% of leaves	8.7%	6.9%	3.7%	5.4%	100%
TP leaves (mg P/kg)	87	69	37	54	1000
% TP from leaves	27.2%	14.4%	12.3%	54.0%	100%

TABLE F5. (Continued) SSHH: 7/94

Temperature (°C)	<25µm (% Mass Loss)	25-63µm (% Mass Loss)	63-250µm (% Mass Loss)	>250µm (% Mass Loss)	Leaves
0-105	1.29	0.15	0.08	0.04	6.44
105-240	1.13	1.06	0.56	0.71	14.5
240-365	0.64	3.17	2.78	1.53	46.7
365-470	5.23	1.24	1.61	1.33	21.5
470-550	1.09	0.80	1.0	0.48	0.49
Total mass loss	**9.3%**	**6.4%**	**6.0%**	**4.1%**	**89.7%**
mg P/kg dirt	450	420	180	150	900
% of leaves	1.4%	6.8%	6.0%	3.3%	100%
TP leaves (mg P/kg)	12.6	61.2	54.0	29.7	900
% TP from leaves	2.8%	14.6%	30.0%	19.8%	100%

SSHH: 8/94

Temperature (°C)	<25µm (% Mass Loss)	25-63µm (% Mass Loss)	63-250µm (% Mass Loss)	>250µm (% Mass Loss)	Leaves
0-105	0.69	0	0	0.11	4.88
105-240	0.35	0.30	0.71	1.24	16.9
240-365	4.52	4.60	1.74	0.65	47.4
365-470	2.43	2.23	1.24	0.92	22.1
470-550	1.39	0.45	0.44	0.33	0.25
Total mass loss	**9.4%**	**7.6%**	**4.1%**	**3.3%**	**91.5%**
mg P/kg dirt	260	380	250	210	1500
% of leaves	9.5%	9.7%	3.7%	1.4%	100%
TP leaves (mg P/kg)	142.5	145.5	55.5	21	1500
% TP from leaves	54.8%	38.3%	22.2%	10.0%	100%

TABLE F5. (Continued) SSHH: 9/94

Temperature (°C)	<25µm (% Mass Loss)	25-63µm (% Mass Loss)	63-250µm (% Mass Loss)	>250µm (% Mass Loss)	Leaves
0-105	1.25	NS	0	0	7.25
105-240	0.31		0.72	0.67	12.1
240-365	2.50		1.85	3.12	50.5
365-470	0.94		1.15	1.82	18.1
470-550	1.25		0.58	0.44	1.45
Total mass loss	**6.3%**		**4.3%**	**6.1%**	**89.4%**
mg P/kg dirt	320		250	210	2500
% of leaves	5.0%		3.7%	6.2%	100%
TP leaves (mg P/kg)	125		92.5	155	2500
% TP from leaves	39.1%		37.0%	73.8%	100%

SSHH: 10/94

Temperature (°C)	<25µm (% Mass Loss)	25-63µm (% Mass Loss)	63-250µm (% Mass Loss)	>250µm (% Mass Loss)	Leaves
0-105	0.93	0.16	0	0	4.98
105-240	2.78	1.96	1.83	14.8	15.3
240-365	7.89	8.23	6.25	6.7	35.6
365-470	0.70	2.67	2.98	5.7	34.2
470-550	0.69	0.78	0.89	1.02	1.05
Total mass loss	**13.0%**	**13.8%**	**12.0%**	**28.2%**	**91.1%**
mg P/kg dirt	450	480	450	720	1900
% of leaves	12.3%	15.6%	13.2%	17.8%	100%
TP leaves (mg P/kg)	233.7	296.4	250.8	338.2	1900
% TP from leaves	51.9%	61.8%	55.7%	47.0%	100%

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