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INFILTRATION RATES ON EXPERIMENTAL AND RESIDENTIAL LAWNS

A Thesis in

Agronomy

by

George W. Hamilton, Jr.

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ABSTRACT

Watersheds are severely affected by the urban development of land. Urbanization affects the hydrology of an area more than any other change in land use in that it changes the ratio of impervious area to pervious area.

The effects of the increased impervious areas have been well studied and documented. Many of the pervious fractions in urban areas are in the form of lawns that are planted with grass, and research is needed on these areas to better characterize the hydrology of urban watersheds. The objective of this research was to characterize certain lawn conditions (tiller density, thatch thickness, bulk density, pore space, quality) and correlate them with the infiltration rates on these lawns. Residential and experimental lawns were used in the experiments.

Fifteen residential lawns located in the State College area were evaluated in one experiment 1. In a second experiment, three methods were used to establish lawn-type turf at the Landscape Management Research Center; they were sod, seed with mulch, and

seed without mulch. Infiltration rates were determined on these plots four times during the course of the experiment.

Infiltration measurements were made with double ring infiltrometers utilizing a modified Marriotte bottle system to deliver water to the rings. Other measured characteristics were bulk density, soil particle size distribution, soil organic matter content, antecedent soil moisture, plant density, thatch thickness, and turfgrass quality.

Infiltration rates were extremely variable in both experiments. Over the 18-month test on the experimental lawns, rates varied from 0.4 to 114.8, 0.6 to 141.5, and 0.0 to 48.2 cm/hr for the sod, seed with mulch, and seed without mulch treatments, respectively. There was no significant treatment effect and the correlations between infiltration rate and the other measured charateristics were low.

The average infiltration rates for the home lawns ranged from 0.4 to 10.0 cm/hr, with 66% of the lawns having an average rate below 3.0 cm/hr. Correlations between infiltration rate and the other measured characteristics were low.

In conclusion, infiltration rates of turfgrass

sites were found to be highly variable. Correlations between infiltration and turfgrass quality and some soil physical properties are low. It was concluded that poor soil structural conditions, due to site preparation, may be limiting infiltration on home lawns. Also, earthworms may be partially responsible for the variability in infiltration on home lawns and experimental plots.

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INTRODUCTION

Infiltration is an important part of the hydrologic cycle. It affects surface runoff, soil moisture content, and groundwater recharge. Increased infiltration decreases runoff, thereby decreasing soil erosion and increasing soil moisture content. Infiltration data are useful for watershed evaluation, irrigation system design, and hydrologic budget design.

Infiltration is affected by many factors, most of which are related to the soil conditions, the vegetation growing in the soil, or both. Horton (1940) divided the factors into three groups: 1) soil and soil properties, 2) biological activity and macrostructures in the soil, and 3) vegetative cover. Lewis and Powers (1936) put the factors into the following two groups: 1) those that affect the capacity of the soil at a given time and point and 2) those that influence the average infiltration over a considerable time and area. Although there are many factors which affect infiltration on a given soil type, the vegetation growing in the soil is a major one.

Infiltration research has focused primarily on agricultural crops. Soil physical properties directly affect the quality and productivity of most crops; therefore, studying crop soil interactions is crucial. However, major urbanization of farm and forest lands has caused new concerns about certain parts of the hydrologic cycle.

Urbanization affects the hydrology of an area more than any other change in land-use (Leopold, 1968). Urbanization significantly changes the ratio of impervious area to pervious area. Roads, driveways, sidewalks, roofs, and other impervious structures decrease the area of potential ground water recharge. Rainfall that falls on the impervious areas is usually collected and removed from the area via storm sewer systems. If the water is transported far enough, it may be totally removed from the watershed from which it was collected.

The increasing portion of impervious areas during urbanization and its effect on water has been well studied and documented (Tholin and Keifer, 1960;

Antoine, 1964; Leopold, 1968; Brater, 1968; Lull and Sopper, 1969). Research is needed on the effect of urbanization on the remaining pervious sections of the watershed. These areas are all that remain to contribute water to the groundwater aquifer systems. Construction and management of these areas must be such that they maximize soil infitration rate, thus causing less to run off and potentially increasing the amount entering the groundwater reservoirs.

Many of the pervious fractions in urban areas are in the form of lawns that are planted with grass. There are about 24 million acres of lawns in the United States today (Roberts and Roberts, 1988), yet little is known about the hydrologic characteristics of the home lawns.

The objective of the research was to characterize certain lawn and soil properties (tiller density, thatch thickness, bulk density, pore space, and quality) and correlate them with the infiltration rates on these lawns.

LITERATURE REVIEW

Definition of Infiltration

Infiltration is defined as "the entry of water into the soil" and infiltration rate is defined as "the rate at which water enters the soil" and is expressed in the units of velocity (in/hr, cm/hr, etc.). Infiltration capacity is considered to be an obsolete term (Soil Science Society of America, 1984).

Methods of Infiltration Rate Measurement

There are various ways to measure infiltration rates. Some methods can be performed in a laboratory using undisturbed soil cores or disturbed soil columns. Other methods that are used in the field either apply a certain amount of artificial rainfall and measure the runoff (sprinkling infiltrometer) or contain the water and measure the amount entering the soil (ring infiltrometers). The methods used in the field will be discussed in further detail.

Sprinkling Infiltrometers

The sprinkling infiltrometers use special nozzles (usually type F) to deliver water, in the form of droplets, to a partitioned plot, which is positioned on an incline. At the bottom of the incline a trough is used to collect and measure the runoff. A 1.82 by 3.65 m plot is commonly used with the type F infiltrometers. Another type of sprinkling infiltrometer is the type FA, which is similar to the type F and uses a 0.30 by 0.76 m plot (Peterson and Bubenzer, 1986).

One major problem is that the droplet size and velocity may not be similar to that of natural rainfall. However, droplet impact on the soil surface would be more representative of natural rainfall than water being flooded or standing on the top of the infiltrating area. Infiltration rate is then determined by subtracting the amount of runoff from the amount applied, per unit time.

Arend and Horton (1942) studied the effects of sprinkling infiltrometers and recommended the following: 1) use a standard rainfall intensity pattern; and 2) start with a low intensity and gradually increase uniformly to the desired maximum intensity. They concluded that the time to reach a constant infiltration rate is inversely proportional to rainfall intensity.

Flooding Infiltrometers

The flooding infiltrometers are usually single or concentric (double) rings that are driven into the ground, filled with water, and periodically measured for the amount of water loss. The area between the inner and outer rings of the concentric ring infiltrometer serves as a buffer area, and theoretically, maintains true vertical water movement out of the inner ring (Bouwer, 1986). Various heights, widths, number of rings, and measuring methods have been used, all having their attributes and deficiencies.

Aronovici (1955) conducted a study on ring infiltrometer performance and observed the following: 1) infiltration rate decreased with increasing depths of the rings, 2) as antecedent soil moisture increased, the rate and magnitude of the decline of infiltration rate decreased, 3) for rings of 1.4 to 30 cm, infiltration rate deceased as ring diameter increased at the rate of 1.3 cm/hr per 2.5 cm increase in ring diameter, up to a 10.2 cm diameter, 4) as the head inside of the ring increased, the infiltration rate increased, and 5) rings with buffer areas had substantially lower infiltration rate than rings without buffers.

Comparison of Methods

Slater (1957) compared values obtained from single ring infiltrometers to values of a type FA sprinkling infiltrometer. He concluded that the median of 15 replications of the ring devices was comparable to one run of the type FA infiltrometer. Waddington (1960) reported that the single ring or concentric rings were not satisfactory for estimating type F infiltrometer. He reported that the 90% confidence interval for predicting a type F value from a single ring value gave a range of about 3.2 cm.

The sprinkling infiltrometers are preferred over the flooding infiltrometers if few measurements are needed. The sprinkling infiltrometers tend to give a better estimation of the actual infiltration rate; however, the flooding infiltrometers are easier to use and cause less disturbance to the site and the double ring is preferred over the single ring because it gives a better estimation of the actual infiltration rate.

Factors that Influence Infiltration

Infiltration can be affected by various factors. Many of the factors are related to the soil and are dependent on certain soil properties, such as moisture content and texture.

Surface Sealing

Surface sealing may be discussed in the infiltration literature more than any other factor. Often it is considered to be the most important limiting factor affecting infiltration. A review of infiltration literature by Parr and Bertrand (1960) indicated that some people believed that soil mass was the main factor controlling infiltration, while others believed it was the soil surface conditions. Most soils form a crust shortly after rainfall, due to the sorting action of the infiltrating water (Moldenhauer and Long, 1964). Duley (1939) observed a rapid reduction in infiltration due to a crust formation caused by fine particles filling in around larger particles at the soil surface. Lowdermilk (1930) reported that suspended particles in runoff water filtered out and clogged the pores of the soil surface.

McIntyre (1958) arranged the order of surface sealing as follows: 1) breakdown of soil aggregates by raindrop impact, 2) transport of fine particles into the pores of the soil, 3) compaction of the soil surface, and 4) suspended particles in the runoff settle into the soil surface after the rain stops. This order indicates that the sealing is caused by two distinct layers, a compacted layer and a wash-in layer. Jennings et al. (1988) observed a rapid decrease in the hydraulic conductivity of the seal during the initial stage of formation and a continued decrease in the second stage, but at a slower rate.

Since the breakdown of the aggregate is the first step of surface sealing, aggregate stability is an important factor. The stability is a function of the soils form a crust shortly after rainfall, due to the sorting action of the infiltrating water (Moldenhauer and Long, 1964). Duley (1939) observed a rapid reduction in infiltration due to a crust formation caused by fine particles filling in around larger particles at the soil surface. Lowdermilk (1930) reported that suspended particles in runoff water filtered out and clogged the pores of the soil surface.

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Since the breakdown of the aggregate is the first step of surface sealing, aggregate stability is an important factor. The stability is a function of the aggregate moisture content before wetting and the rate at which the aggregate absorbs water. As the aggregate moisture content increases, the susceptibility to disintegration by raindrop impact increases (Harris et al., 1966)

The amount of raindrop energy required to reduce infiltration is a function of the size of the aggregate, with less energy being required if aggregates are small (Moldenhauer and Kemper, 1969, Jennings et al., 1988). Moldenhauer and Long (1964) studied five different soil types to determine the amount of raindrop energy required to produce runoff. They found the order to be fine sand > silty clay > loam > silty clay loam > silt. Sor and Bertrand (1962) observed a negative correlation between infiltration and duration and energy of rainfall.

Pore Size

Pores can be classified as either macropores or micropores, depending on their size. The size of the pores are dependent upon: 1) the size of the particles that make up the soil, 2) the degree of aggregation between the particles, and 3) the arrangement of the particles and aggregates (Schwab et al., 1981). A macropore can be considered a pore in which water flow is not capillary (Beven and Germann, 1982).

Free et al. (1940) observed a 0.24 cm/hr increase in infiltration rate with a 6% increase of macroporosity. Browning (1939) reported that the factors that affect pore size and distribution also affect infiltration. He also noted that the swelling of clay colloids reduced pore size and infiltration.

Organic Matter Content

Organic matter is an important constituent of soil. It influences aggregation, water holding capacity, and cation-adsorption capacity, and it also serves as a food source for soil fauna and flora (Brady, 1974).

Wischmeier and Mannering (1965) observed infiltration rates to be directly proportional to organic matter content. They reported that a study of 44 soils, with a wide range of textural variations, showed organic matter content accounted for 36% of the total runoff variance, while sand, silt, and clay accounted for 4%, 13%, and 12%, respectively.

Zimmerman (1969) reported that a 5:4:1 mix (sand: soil: peat by volume) had only half of the infiltration rate of a 5:3:2 mix, 1.6 vs. 3.2 cm/hr. Thus, increasing the organic matter content at the expense of the soil favored the higher infiltration rate.

The by-products produced from organic matter consumption by microorganisms are important substances for the cementing of aggregates (Harris et al., 1966). McCalla (1942) observed the products of plant decomposition to influence soil structure, the amount of water stable aggregates, soil porosity, and water holding capacity.

Antecedent Soil Moisture Content

The antecedent soil moisture content has an effect on colloidal swelling, which in turn affects the initial infiltration rate.

The infiltration rate of soils that are prone to cracking (high clay content soils) will be affected dramatically by the beginning soil moisture content. If the soils are dry and have large cracks exposed at the surface, the infiltraion rate will be very high at the start and decrease with time as the cracks swell shut (Brady, 1974).

Antecedent moisture will also have an effect on aggregate stability. Aggregates weaken as their moisture content increases (Harris, 1966).

Entrapped Air

Soil is analogous to a container without a lid in that, to allow any fluid or gas to enter it, a corresponding volume of air must escape. If water is moving down through the profile and filling the pore spaces occupied by air, then the air must be moving upward and out of the profile. This upward movement of air within pores can restrict the downward movement of the water.

Horton (1940) reported the escape of air was through large pores and perforations made by insects, roots, and earthworms (i.e., biogenic macropores), and that in the small pores the air may inhibit the water flow.

Providing other passageways for air to escape can improve infiltration. Subsurface drains installed in the soil profile to improve drainage also improve infiltration by venting soil air (Jarrett et al., 1980).

Free and Palmer (1940) used open and closed columns to study air and water movement. In the open columns the infiltration rate became a function of the particle sizes in the columns; however, in the closed columns the gravitational flow stopped due to the build up of air pressure, and the water continued flowing under capillary forces until sufficient air escaped to allow the gravitational flow to continue.

Jarrett and Fritton (1978) observed lower average infiltration rates in a sand and a loam when soil air was not allowed to escape. They also observed a 45% reduction of infiltration rates 10 min after the start of the test.

Water Temperature

As the temperature of water decreases, its viscosity increases. This changing viscosity does have an effect on infiltration. Musgrave (1955) reported a positive correlation between infiltration rates and the viscosity of the water.

Moore (1940) observed proportional increasing infiltration rates with increasing water temperatures in the range of 5 to 30° C. Infiltration increased rapidly between 30 and 35° C and then started to decrease at higher temperatures. Duley and Domingo (1943) reported that the water temperature would not be an important factor, since rainfall has a narrow range of temperature.

Earthworm Activity

Earthworms are the major constituent of the soil macrofauna. They can drastically affect infiltration, due to their channeling activity, which increases macroporosity. Hopp and Slater (1948) observed a 400% increase in infiltration with the addition of worms, and Stockdill (1982) observed a doubling of infiltration rates on a field with worms when compared to a field without worms.

Although earthworm burrows may be considered small in size, they may conduct large amounts of water. Edwards et al. (1989) monitored flow in earthworm burrows and calculated the average flow of burrows, greater than or equal to 5 mm in diameter, to be 13 times greater than the theoretical flow if calculated using the size of the burrow openings. Peterson and Dixon (1971) observed water flowing into a pore, equivalent to 0.002% of the plot area, to be 75% of the infiltration rate.

Although the diameter of the burrow opening may be considered small, the horizontal and vertical lengths can be very large. Beven and Germann (1982) stated that earthworm burrows have been known to be several meters in the vertical and lateral directions, and also to be continuous. Even if the length is short, the burrow walls create a very large surface area for infiltrating water to move into a capillary storage or conducting region.

Earthworms also affect the aggregation of the soil by the excretion of casts (soil containing organic matter supplements) (Harris et al., 1966). Hopp and Hopkins (1946) observed a 73% increase of water stable aggregates when comparing a culture with no worms against one with worms.

The amount of earthworms affects infiltration, and turfgrass management practices can affect the amount of earthworms. Nitrogen and pesticide applications are routinely used in turfgrass management and both may decrease earthworm populations.

Jansen and Turgeon (1977) observed slower water infiltration in plots treated with calcium arsenate when compared to untreated plots. In another experiment conducted earlier on the same site, Turgeon et al. (1975) found earthworm counts in the untreated plots ranged from 47.2 to $64.7/m^2$, but earthworms were absent in the plots treated with calcium arsenate.

Potter et al. (1985) observed a decrease in earthworm populations with an increase in the amount of nitrogen applied. This may have been an indirect effect of nitrogen by the acidification of the soil by the fertilizer. Earthworm population decreases were also attributed to nitrogen applications by Bridges (1983). The earthworm decline also correlated with a significant decrease in saturated hydraulic conductivity.

Infiltration Rates on Turfgrass Sites

The majority of the infiltration research conducted to date has been on bare soil or areas planted with agricultural crops. Few studies, where infiltration was of primary concern, have been conducted on turfgrass areas (Zimmerman 1969; Kelling 1972; Taylor and Blake 1982).

Zimmerman (1969) used 81 modified soil mixtures and one of his objectives was to determine the effects of soil mixture, compaction, core cultivation, and time on infiltration. Of the 81 soil mixtures and multiple treatments, he reported hundreds of infiltration rates ranging from 0.0 to 150.4 cm/hr. During the ten years of this study, infiltration rates were observed to decrease over time (Waddington et al., 1974).

In another soil modification study, Schmidt (1977) reported a 39% decrease in infiltration rates over the first four years of the study, and a 10% decrease over the second four years. Over all eight years the highly modified soil mixtures decreased more than the slightly modified mixes.

Infiltration rates and nutrient losses on home lawns were studied by Kelling (1972). Nine lawns were sampled and infiltration rates ranged from 0.01 to 8.84 cm/hr, with 66% of the rates being less than 5.00 cm/hr. The infiltration rate of a construction site was also measured and yielded an average of 0.46 cm/hr.

Taylor and Blake (1982) studied the effects of thatch on infiltration rates. Golf course putting greens, turf gardens, and a football field were used to determine if thatch affected infiltration rates in the field. They reported rates ranging from about 0.10 to 30.00 cm/hr. They also reported that after the thatch was wet it did not affect infiltration; however, thatch may affect the structure of the soil surface, which in turn will affect infiltration. The surface soil underlying the thatch may be more compacted than soils that are thatch-free if root and rhizome growth is restricted to the thatch layer (Turgeon et al., 1977).

Grass is usually planted in areas to improve or maintain aesthetics or to be used as a playing surface. Most areas of grass, especially playing surfaces, will receive some type of traffic, and traffic typically results in compaction of the soil. An increase in compaction results in a decrease in infiltration rate (Zimmerman, 1969; Kelling, 1972; Waddington et al., 1974; Schmidt, 1977). A common method to alleviate compaction is aeration, or specifically core cultivation. Core cultivation has been shown to increase infiltration rates and it improves infiltration of a compacted soil more than that of an uncompacted soil (Alderfer, 1954; Zimmerman, 1969; Waddington et al., 1974).

The condition of the surface soil greatly affects infiltration. During establishment, topsoil is often stripped from the area and replaced after construction. This is typical in areas surrounding building construction sites. The removal of the soil destroys the macropore system and exposes the subsoil to compaction. Kelling (1972) reported that the infiltration rates of a lawn that did not have a disturbed profile was almost equal to that of a natural forested area. He also stated that the soil profile disturbance may be the most important factor affecting infiltration rates of home lawns.

Grass can be established in many different ways. Seeding is the most common and there are various ways to prepare the seedbed prior to seeding. Sodding is another, more expensive, method of establishing grasses. Harrison (1989) determined the effects of these establishment methods on infiltration. He reported significantly greater infiltration rates on sodded treatments, and attributed this effect to the increased soil surface protection when sodding was used to establish the site.

The soil surface, as explained earlier, is an important part of the soil profile. If the soil is fine textured, it may be more prone to aggregate dispersion, surface sealing, and pore clogging than a coarse textured soil. Increasing the amount of coarse particles at the expense of fine particles has been shown to increase infiltration (Waddington et al., 1974; Schmidt, 1977). To make a significant change in the infiltration rate of a medium textured soil by adding a coarse amendment, the coarse amendment content of the soil had to be 60 to 70% by volume or greater (Shoop, 1967; Zimmerman, 1969).

The review of the literature indicates the majority of infiltration research has been conducted on bare soils or agricultural crops. Very little infiltration research has been conducted on lawns or other areas of the urban landscape. More research is needed on theses areas to better understand urban watersheds.

METHODS AND MATERIALS

Two experiments were conducted to address the objective. Experiment 1 was conducted on newly constructed plots located at the Landscape Management Research Center of The Pennsylvania State University at University Park, Pennsylvania. Experiment 2 utilized 15 residential lawns located in the State College, Pennsylvania, area.

Infiltration Measurement Procedures

Double ring infiltrometers (Bouwer, 1986) were used to determine infiltration rates. The inner ring diameter was 20 cm, the outer ring 35 cm, and both rings were 10 cm high. The rings were driven into the soil by striking a 36-kg cover plate which fit directly on top of the rings. The cover plate was tamped by hand with a 18-kg tamper. The top 3.8 cm of the rings remained above the soil surface to contain the water.

Water was delivered to the rings through a 9.5 mm galvanized pipe mounted in a concrete block (36 by 16

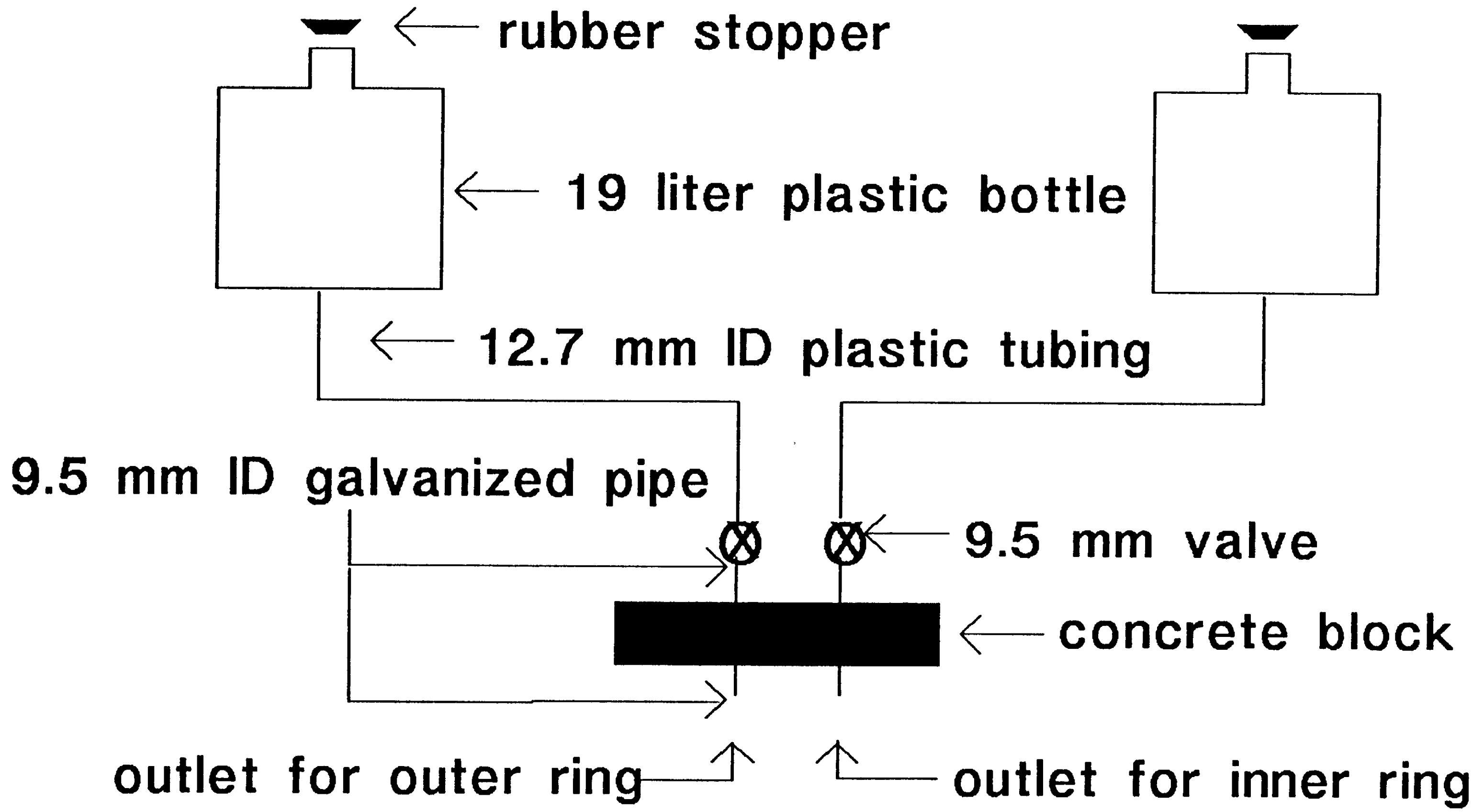

Figure 1. Infiltrometer filling system

by 6-cm)(Fig. 1). The concrete block rested on top of the rings with two pipes (one for the inner ring and one for the outer ring) protruding 2 cm below the bottom of the concrete block and the top of the ring. A 19-L plastic jug was connected to each pipe with 12.7-mm plastic tubing and elevated above the rings. The jugs were stoppered at the top after filling to prevent air from entering. Once the ring filled with water to the bottom of the pipe, water could only enter the ring if the water level in the ring dropped below the bottom of the pipe, allowing air to enter and water to exit the bottle. This procedure maintained the depth of water inside both rings at approximately 1.8 cm.

Before measurements were started, the area inside the rings was wetted for a minimum of an hour to ensure that minimum infiltration rate would be measured.

After the wetting period, measurements would be taken every 10 or 15 minutes for an hour. Measurements were taken by filling the jug to a bench mark at the start, refilling to the bench mark at the time of the reading, and measuring the amount of water used to refill. Water volume was measured to the nearest 10 ml, which is about equal to a depth of 0.25 mm in the inner ring. An error due to slight collapse of the plastic jugs was found to be consistent among jugs and was corrected for in each determination by subtracting 100 ml off of each determination.

Infiltration was measured four times over two years on the experimental home lawns. Three infiltrometers were used on each plot and measurements were made in June of 1988 (before treatments were applied), November of 1988, June and October of 1989. Infiltration was measured once on the residential lawns, using six infiltrometers per lawn.

Site Characterizations

Bulk Density

Soil for bulk density measurements was taken from inside the inner ring of the infiltrometers with a Noer soil profile sampler. Samples were removed from two of the three rings used on each plot on the experimental home lawn plots. Samples (6.8 by 1.6 by 10.0-cm deep) were removed from all six of the infiltrometers used on the residential home lawns.

After tiller counts and thatch measurements, the thatch and grass were removed from the soil at the thatch-soil interface. The top 2 cm of soil was removed from the remainder of the core and dried at 105° C. Bulk density was calculated by dividing the oven-dry weight by the soil volume.

Soil Particle Size Analysis

Soil particle size analysis was determined for the soil of the experimental lawns at the beginning of the experiment and for the soil of all residential lawns. Soil cores were taken at random throughout the area where infiltration was being measured with a 19-mm soil sampling probe. The grass and thatch was removed at the thatch-soil interface, and the soil cores were trimmed to contain only the surface 5 cm. The soil cores were combined into a composite sample and dried at 105° C. A 50-g sample was weighed and the hydrometer method (Gee and Bauder, 1986) was used for the particle size analysis.

Soil Organic Matter Content

Soil organic matter content was measured at the beginning of the experiment and the time of the last infiltration measurement on the experimental lawns, and on all of the residential lawns . The soil cores used for the bulk density measurements were combined into a composite and crushed with a mortar and pestle. Organic matter content was determined by the Merkle Soil Testing Lab of The Pennsylvania State University, which used the Walkley-Black procedure (Nelson and Sommers, 1982).

Antecedent Soil Moisture Content

Antecedent soil moisture content was measured before the initial wetting every time infiltration was measured. Soil cores were removed at random, but not from within the exact area where the infiltrometers were placed, with a 19-mm soil sampling probe and were weighed immediately after removal from the field. Water content was determined gravimetrically (Gardner, 1982).

Plant Density and Thatch Thickness

Plant density and thatch thickness were measured every time infiltration was measured. The soil plugs used for bulk density measurements were also used for tiller counts and thatch thickness measurements. Individual intact tillers in the soil plug and loose tillers in the Noer sampler were counted (Brede and Duich, 1982). Uncompressed thatch thickness was measured to the nearest millimeter at the midpoint of the sample.

Experiment 1: Infiltration Rates on Newly Established Experimental Lawns

Treatments in this experiment were selected to determine the effects different turfgrass conditions on infiltration. Treatments were Kentucky bluegrass (*Poa pratensis* L.) sod, Kentucky bluegrass seed with a straw mulch, and Kentucky bluegrass seed with no mulch. The varieties of Kentucky bluegrass of the sod and seed are unknown.

Plot Construction and Maintenance

The experimental design was a randomized complete block with three replications. Individual plots measured 6.1 by 6.1 m.

To eradicate existing vegetation, the plot area was treated with 4.5 kg a.i./ha of glyphosate [N-(phosphonomethyl)glycine] one month before planting. No other pesticides were applied to the area prior to establishment. The area was prepared by rototilling and rough grading with a York rake. Final grading was accomplished by hand raking. The sod treatments were applied on June 30, 1988 and the seed treatments on July 1, 1988. The straw mulch was applied by a local landscaping company at a rate equivalent to that used for commercial seedings (about 2000 kg/ha).

Plots were irrigated daily with sprinklers (except for days when rain occurred) to maintain adequate soil moisture. Irrigation was suspended after the third mowing and from then on, plots received irrigation only to prevent wilting.

Only two chemical applications were made to the plots throughout the duration of the study. All plots were sprayed eight weeks after seeding with a broadleaf herbicide (1.37 kg/ha 2,4-dichorophenoxy acetic acid, 0.74 kg/ha 2-(2-methyl-40-chlorophenoxy) propenoic acid, 0.12 kg/ha 2-methoxy-3,6-dichloro benzoic acid) to control broadleaf weeds. Ten weeks after establishment, all plots received an application of sulfur-coated urea at the rate of 49 kg/ha of nitrogen.

Plots were mowed as needed (typically once per week) at 5 cm with a 51-cm wide walk-behind rotary mower and clippings were removed. Riding equipment and mechanical cultivators were not used on the plots during the experimental period.

Quantification of Earthworm Burrows

After the October, 1989, infiltration measurements were taken, a soil plug (20 cm diameter by 15 cm depth) was removed from within the inner ring of one of the three infiltrometers in each plot. The soil core was dried at 105^{o} C, after which the grass and thatch were removed from the top of the core, then the cores were impregnated using Scotch Cast #3 epoxy (3M Co., Minneapolis, MN). Impregnation was done by tightly wrapping the sides and bottoms of the cores in foil. The sides and bottoms were wrapped with 4- mil plastic to prevent epoxy from escaping. Epoxy was added to the top of the core until total saturation had occurred. Vacuuming was not used to enhance impregnation.

The top 1 cm of the cores was removed with a diamond saw to expose the earthworm burrows and other visible pores. Black and white pictures were taken of the exposed soil surface. A light source was placed at the side of the cores during the photographing to cast shadows in the pores, making them more evident in the photographs. This technique was similar to that used by Edwards et al. (1988).

The photos were analysed using a Skye-Probetech (Skye-Probetech, Perkasie, PA) SI700 image analysis system. Analysis concentrated on enhancing the image to improve the contrast between the larger and smaller pores.

Soil Thin Layer Section Analysis

After the June, 1989, infiltration measurements were taken, a soil core (20 cm diameter by 15 cm depth) was removed from one of the three sets of rings in each plot. Soil cores were packaged in air-tight plastic containers and sent to National Petrographic Services in Houston, TX, for preparation of soil thin layer sections. Thin layers, 5.1 by 7.6 by 0.003-cm thick, were made from the soil at the center of the 20-cm diameter plug and at depths of 0, 1, and 2 cm. The orientation of the layers was kept the same from depth to depth. A blue epoxy was used for the impregnation so pore space would be more easily defined.

Color pictures were taken of the thin layer sections and analyzed in a similar fashion to that of the earthworm burrow pictures. The blue epoxy and and bright white areas (pores not filled with epoxy) were measured for an estimation of pore space.

Experiment 2:
Infiltration Rates on Residential Lawns

Fifteen residential lawns in the State College, PA area were sampled. Selection of lawns was made to obtain a wide range of age and quality of lawns; however, selection was limited to areas that had the fine- and medium-textured soils prevalent in this area.

Besides the measurements that were described in the previous section, certain evaluations were made on each lawn. The evaluations were associated with the construction, maintenance, and turf quality. The ratings associated with lawn quality were made at the time of the infiltration measurements.

The home owners were verbally asked about the construction and maintenace of the lawn. Excavation of the topsoil prior to construction was the primary interest as far as the construction was concerned. Maintenance inputs such as fertilizer, pest control, aeration, and dethatching were considered. Zero, minimal (one or two inputs per year), and maximum (more than two inputs per year) were ranked 1, 2, or 3, respectively.

Lawn quality was evaluated on a scale of 1 to 5, with 1 being poor quality and 5 being excellent quality. Color, texture, uniformity, and density were the main criteria for the evaluations (Turgeon, 1980).

RESULTS AND DISCUSSION

Experiment 1

Infiltration Rates on Newly Established Experimental Lawns

Before the plots were established, infiltration rates were measured on the bare soil to determine any differences in infiltration rates at the beginning of the study. The infiltration rates for the bare plots were not significantly different (Table 1).

The second infiltration rate measurements were made on the experimental plots four months after construction. By this time the two seeded treatments were well established and the sodded treatments were well rooted.

The average infiltration rates for the three treatments over the three sampling dates are shown in Table 1. On the second sampling date, November 16, 1989, the sod and seed without mulch treatments had average infiltration rates of 23.3 and 18.9 cm/hr, respectively, more than twice the 8.2 cm/hr rate of the seed with mulch treatment.

Table 1. Infiltration rates for experimental lawns.

	6/30/88	11/16/88	6/8/89	10/12/89
	---------- cm/hr ----------			
Sod	2.7a*	23.3a	35.5a	21.3a
Seed w/mulch	3.5a	8.2a	21.1a	38.6a
Seed w/o mulch	2.4a	18.9a	23.0a	20.8a

* Means within a column followed by same letter are not significantly different (P=0.05; Duncan's New Multiple Range Test).

Relationships of Soil and Plant Properties of Experimental Lawns to Infiltration

Correlation coefficients were calculated to determine the relationships between infiltration and certain soil and plant properties (tiller density, thatch thickness, and bulk density) of the experimental lawns (Table 2). None of these properties correlated highly with infiltration rate.

Correlation coefficients were also calculated for the soil thin layer sections, earthworm burrows and infiltration rate (Table 3). None of the pore space measurements correlated highly with infiltration.

The thin layer sections may have been too small (5.1 by 7.6 by 0.003-cm) to get a good representation of the 20 cm core in which the infiltration rate was measured. This would be especially true if macropores were responsible for the majority of the flow and did not happen to be present in the thin layer section. Bullock and Thomasson (1979) reported that macroporosity measured by water retention did not correlate with macroporosity measured from thin layer sections.

On June 8, 1989, the third set of measurements were taken. All of the treatment averages increased. Seed with mulch increased the most. It more than doubled to 21.1 cm/hr. The sod and seed without mulch increased to 35.5 and 23.0 cm/hr, respectively.

The final measurements were made October 12, 1989. The infiltration rate of the seed with mulch treatment continued to increase to 38.6 cm/hr. The infiltration rate of the sod and seed without mulch treatments decreased to 21.3 and 20.8 cm/hr, respectively.

The data were analysed as a split-plot in time, using the logs of the infiltration rates for analysis. There was no treatment, time, or treatment by time effect. Although the average rates tended to be different among sampling dates and between sampling dates, the differences were not significant (Table 1). This may be due to the large amount of variance within the infiltration rate measurements.

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Table 2. Correlations of infiltration rate with soil and plant properties on experimental lawns.

Property	r value
Tillers	0.36
Thatch	0.18
Bulk Density	0.18

Table 3. Correlations of infiltration rate with percent earthworm burrow area and percent pore space of thin layer sections on experimental lawns.

Pore Characteristic	r value
Earthworm burrows	-0.26
Porosity at 0 cm	-0.25
Porosity at 1 cm	0.10
Porosity at 2 cm	0.24

However, there was a noticable difference in the soil structure between treatments, especially at the 0 cm depth. Greater aggregation was evident in the thin layer section of the sodded treatment when compared to the other two establishment methods (Fig. 2 and 3). Percent pore space decreased with depth for the sodded and seeded with mulch treatments, and increased with depth for the seeded without mulch treatment. The data were analyzed as a split-block. The treatment and depth effects were not significant; however, the treatment by depth interaction was significant. This result suggests the presence of a soil-surface crust in the seed without mulch treatment, even though these samples were taken about one year after establishment (Table 4).

The soil of the seed without mulch treatment would be exposed to rain drop impact, causing aggregate dispersion, followed by the movement of fine particles down into the soil profile, decreasing the porosity of the soil near the surface. The other two treatments had their soil surface covered by either sod or mulch, protecting them from raindrop impact (Lowdermilk, 1930).

The cores for the earthworm burrow measurements

Figure 1. Soil thin layer section from a sodded treatment at the 0 cm depth

Figure 2. Soil thin layer section from a seeded with mulch treatment at the 0 cm depth

Table 4. Percent pore space of soil thin layer sections.

Treatment	Depth		
	0 cm	1 cm	2 cm
	---------	%	---------
Sod	28.7*	18.7	17.4
Seed w/mulch	34.3	25.6	23.6
Seed w/o mulch	15.3	23.0	25.0

* LSD (0.05) = 8.83

were removed about 16 months after establishment. Although every effort was made to obtain the best possible measurement, it cannot be ascertained that all pores that were analyzed were earthworm burrows.

There was significantly more pore space due to earthworm burrows in the sodded treatment when compared to the two seeded treatments (Table 5; Fig. 4 and 5).

Some possible reasons for this may be that the sod contained some earthworms when it was installed (instantly increasing the population). The thatch inherent with sod provides a food source for the earthworms and may attract more to the area and/or increase the activity of the ones already present. This increased population and activity may also be partially responsible for the improved soil structure in the sodded treatments (Hopp and Hopkins, 1946; Hopp and Slater, 1948).

Another possible reason for increased worm activity under sod may be that the sod itself creates a favorable environment for earthworms. The mat of vegetation acts as a buffer between the soil and the atmosphere, and may help reduce moisture loss from the soil surface (Hopp and Slater, 1948; Stockdill, 1982.)

Figure 4. Earthworm burrows of a sodded treatment

Figure 5. Earthworm burrows of a seeded with mulch treatment

Although there was a significantly higher percentage of earthworm burrow area in the sodded treatment than in the seeded treatments, infiltration rates were not significantly different (Table 5). Also, the amount of earthworm burrow area did not correlate with infiltration rates (Table 3).

Cross sectional area may not be the best way to quantify the effects of earthworm burrows. The size, shape, and continuity of the burrows may be of greater importance than the amount of cross sectional area, as suggested by Beven and Germann (1982). A few large burrows may have a smaller total cross sectional area than many small burrows, but have less restrictions to flow, deeper profile penetration, and therefore, a better conductance of water. Unfortunately, as these burrows increase in size and number, the more difficult it becomes to characterize the infiltration of a particular site, especially with small sub-samples.

Experiment 2

Infiltration Rates on Residential Lawns

The infiltration rate ranges, averages, and coefficients of variation of the residential lawns are shown in Table 6.

Ten of the 15 lawns evaluated had an average infiltration rate below 3.0 cm/hr. The two lawns (the front and back lawns of the same residence) with the lowest average infiltration rates were the youngest lawns evaluated (Table 7). The Infield back lawn was established by seeding with perennial ryegrass and had an average infiltration rate of 0.4 cm/hr, while the Infield front lawn that was established by sodding with Kentucky bluegrass had an average infiltration rate of 1.2 cm/hr. These lawns were relatively new in comparison with the other lawns and an underdeveloped macropore system may be a reason for the low infiltration rates.

The five lawns with average infiltration rates above 3.0 cm/hr had certain characteristics that may have contributed to the increased rates. The Wiedemer and Benedict lawns were located next to each other and

Table 6. Infiltration rates and coefficients of variation for residential lawns.

Lawn	Min	Max	Avg	CV
	------	cm/hr	------	
Infield (seed)	0.0	1.2	0.4	6.3
Infield (sod)	0.0	6.0	1.2	35.9
Hockenberry	0.1	6.1	1.4	35.4
Watschke	0.0	6.8	1.4	40.7
Steele	0.0	7.4	1.6	43.9
Lucas	0.4	4.1	1.8	20.9
Whiteman	0.3	6.5	2.2	34.4
Packard	0.3	6.2	2.3	33.3
Borger	0.1	6.7	2.7	34.6
Hamilton	0.2	8.9	2.9	49.1
Benedict	0.9	11.2	4.9	58.0
Wiedemer	0.1	21.9	5.1	132.3
Snook	0.2	36.3	8.5	212.4
Waddington	0.4	40.1	9.8	230.3
Dzvonyicsak	0.9	30.4	10.0	182.7

Table 7. Residential lawn age, quality, maintenance, and excavation data.

Name	Age	Qual.	Maint.	Exc.
	yr	(1-5)*	(1-3)*	
Infield (seed)	2	5	3	Yes
Infield (sod)	2	5	3	Yes
Hockenberry	6	3	2	Yes
Watschke	10	4	3	Yes
Steele	32	1	1	Yes
Lucas	11	2	3	Yes
Whiteman	23	3	3	Yes
Packard	4	2	2	Yes
Borger	7	3	3	Yes
Hamilton	4	5	3	Yes
Benedict	4	3	1	No
Wiedemer	3	5	3	No
Snook	29	5	3	Yes
Waddington	30	3	3	Yes
Dzvonyicsak	6	1	1	No

* Highest number represents highest quality or greatest maintenance input.

established at about the same time. Both lawns were established on top of fill covered with topsoil.

The Waddington and Snook lawns, which had average rates of 9.8 and 8.5 cm/hr respectively, were two of the oldest lawns evaluated and they had received many inputs, including core cultivation. The Steele lawn (1.6 cm/hr) was the oldest of all the lawns, but received no inputs.

Inputs that promote good plant growth may also affect soil quality and structure. For example, fertilization increases plant tissue production which can increase soil organic matter content, which can affect infiltration. Organic matter is used as an energy source by microbes, which influence soil aggregation, and it also creates a better habitat for soil macrofauna, such as earthworms. Although some inputs might affect infiltration immediately, months or years may be required for others to have an effect.

The Dzvonyicsak lawn had the highest average rate of 10.0 cm/hr. This lawn was located in the same cul-de-sac as the Hamilton, Packard, Wiedemer, Benedict, and Hockenberry lawns. Although it was similar in many ways to the other lawns, it had a much higher average infiltration rate. The main difference in the construction of this lawn was that it was not excavated during any part of the construction. This would allow the macropore system to stay intact, prevent aggregate destruction during moving and handling, and prevent soil stratification when the soil is put back on the site (Kelling, 1972).

Disturbances that happen to the site before or during construction can cause great variabilty within a lawn, and the infiltration rates confirmed this. Typical residential construction usually starts with stripping the topsoil from the site and stockpiling it. The subsoil is left exposed until the end of construction, leaving it vulnerable to compaction and structural degradation. At the end of construction the topsoil is replaced on top of the subsoil, at varing depths, with other construction debris mixed in, which creates a distinct interface. Variation in this newly created profile could be extremely high, depending on how the backfilling and topsoil spreading was accomplished.

Coefficients of variation for the infiltration rates for the 15 lawns ranged from 6.3 to 230.3 . As the average rates (the average of the six infiltrometers) of the lawns increased the amount of variation within the lawns increased (Table 6).

Some of the variation may have been be due to other factors. Placing a ring over an earthworm burrow will most likely result in a high infiltration rate for that particular ring, increasing the average for the lawn; however, if the infiltration rate was measured over the entire lawn, that particular area around the earthworm burrow would represent part of the measurement.

Relationships of Residential Lawn Characteristics to Infiltration

The residential lawn characteristics and certain coefficients of variation are shown in Tables 7, 8, and 9.

Correlation coefficients were calculated to determine the relationship between each lawn characteristic and the measured infiltration rate. Tiller density, thatch thickness, and bulk density were measured for every infiltration ring (Table 8) and correlation coefficients were calculated for these measurements and infiltration rates (Table 10). Percent sand, silt, clay, organic matter, and soil

Table 8. Average tiller densities, thatch depths, bulk densities and their respective coefficients of variation for residential lawns.

Lawn	Tiller Density	CV	Thatch Depth	CV	Bulk Density	CV
	no./plug		mm		g/cm^3	
Infield (seed)	10.8	12.4	0.0	-	1.59	7.3
Infield (sod)	8.8	28.0	13.7	18.3	1.30	26.6
Hockenberry	8.7	45.5	0.0	-	1.23	18.2
Watschke	7.5	29.6	5.0	145.6	1.37	25.6
Steele	4.3	76.1	5.7	68.1	1.18	17.0
Lucas	5.0	55.4	9.8	61.1	1.45	9.4
Whiteman	6.7	33.2	15.5	38.3	1.02	19.0
Packard	5.5	36.0	10.8	24.7	1.55	12.3
Borger	9.8	21.5	5.0	83.3	1.49	13.9
Hamilton	11.5	30.8	12.3	21.3	1.57	12.3
Benedict	7.3	24.5	5.0	100.7	1.49	13.9
Wiedemer	7.8	22.6	0.0	-	1.59	15.0
Snook	6.7	39.4	26.3	11.3	1.27	10.1
Waddington	5.2	69.3	27.2	30.4	1.13	16.3
Dzvonyicsak	2.8	24.3	0.0	-	1.35	14.1

Table 9. Estimates of grass species composition, and sand, silt, clay, and organic matter contents for residential lawns.

Names	KBG*	PRG	FF	Sand	Silt	Clay	OM
	------------------			%	------------------		
Infield (seed)	0	100	0	27.6	46.8	25.6	3.7
Infield (sod)	100	0	0	17.6	58.8	23.6	3.6
Hockenberry	25	25	50	21.6	54.8	23.6	5.1
Watschke	25	75	0	61.6	26.8	11.6	4.6
Steele	25	25	50	22.0	58.4	19.6	4.9
Lucas	10	30	60	43.6	36.8	19.6	4.2
Whiteman	50	0	50	13.6	62.8	23.6	8.2
Packard	25	25	50	23.6	46.8	29.6	2.7
Borger	0	0	100	27.2	51.2	21.6	5.2
Hamilton	0	100	0	41.6	32.8	25.6	3.0
Benedict	50	25	25	31.6	42.8	25.6	3.7
Wiedemer	0	100	0	31.6	38.8	29.6	3.8
Snook	75	0	25	18.0	60.4	21.6	4.0
Waddington	25	50	25	21.6	56.8	21.6	6.6
Dzvonyicsak	0	0	100	29.6	40.8	29.6	5.0

* KBG = Kentucky bluegrass (*Poa pratensis* L.)
PRG = Perennial ryegrass (*Lolium perenne* L.)
FF = Fine fescues (*Festuca* spp.)
OM = Organic matter

Table 10. Correlations of infiltration rate with various residential lawn characteristics.

Lawn Characteristic	r value
Tillers	-0.04
Thatch	0.22
Bulk Density	-0.09
Sand	-0.19
Silt	0.09
Clay	0.26
Organic Matter	0.19
Soil Moisture	-0.47
Quality	-0.13

moisture were averaged for the six rings used per lawn (Table 9); therefore, they were correlated with the average infiltration rate of each lawn (Table 10).

All correlations were low under these lawn conditions; however, some trends were evident. The Infield lawns had the slowest infiltration rates and were also the youngest lawns evaluated.

Since new lawns have recently had the soil disturbed, a poorly developed macropore system may be one of the reasons for the low infiltration rates. Other reasons may be poor soil structure and/or soil stratification.

At the other end of the scale, the Waddington and Snook lawns were the oldest lawns that also had a high maintenance rating (the Steele lawn was the oldest but received no inputs). Besides being two of the oldest lawns, these lawns had two of the fastest infiltration rates (Tables 6 and 7).

Aging could allow for a good development of soil structure and a macropore system. Making proper inputs greatly enhance this development by creating a better environment for soil fauna. Increased root and tissue production may have increased the energy source for the fauna and also increased the soil organic matter content.

Another noticeable trend may be related to excavation during construction. The Wiedemer, Benedict, and Dzvonyicsak lawns were three of the five lawns which had infiltration rates above 4.0 cm/hr. They were also excavated differently than the other 12 lawns.

The Wiedemer and Benedict lawns were constructed on top of fill covered with topsoil. Since the fill and topsoil was brought in separately near the end of construction, the effects of sub-soil compaction and soil stratification may have been minimal. The lawns were raised enough by fill and topsoil additions that the original soil surfaces during construction ended up over 2 m deep in the final profiles.

The Dzvonyicsak lawn was established within a stand of trees, making excavation of this particular lawn area difficult. The trees also minimized traffic during construction. Hence, this lawn area was practically undisturbed, except for lawn seedbed preparation.

Soil disturbance appears to be more of a factor affecting infiltration than any other (Kelling, 1972). Many of the residential lawns that were evaluated were prepared in the same way as the experimental lawns, except the experimental lawns were not excavated and no heavy equipment was used. The quality of the turf, the maintenance, and soil type were also comparable. However, the infiltration rates were much higher on the experimental lawns (Table 11).

Table 11. Minimum, maximum, and average infiltration rates measured on experimental and residential lawns.

	No. of Infiltrometer Measurements	Min	Max	Avg	St Dev
		-----	cm/hr	-----	
Experimental	108	0.0	141.5	18.5	23.5
Residential	90	0.0	40.1	3.7	7.1

CONCLUSIONS

Many factors can affect infiltration and infiltration can, in turn, affect many other things. It is difficult to pinpoint the exact contribution of factors directly influencing infiltration when measurements are made on subsamples that represent a small percentage of the overall area. Even working in relatively small areas with large numbers of subsamples can be difficult, due to the spatial variabilty of soils.

Working in the urban lawn environment compounds the variability problem even more. All lawns are not constructed in the same way or under the same conditions.

The experimental lawns used in this study had a relatively small amount of construction variability. The experimental lawns had higher average infiltration rate than the residential lawns; however, great variability in all of the infiltration rates was observed.

Although the rates were highly variable, the majority of the lawns had relatively good average infiltration rates. A properly installed lawn could be very benefical to groundwater recharge and help reduce the amount of water exiting watersheds.

The higher the infiltration rate for a particular lawn, the higher the variabilty among the rings within the lawn. Great variability among infiltration rates on a lawn can be expected and this variability makes it very difficult to properly characterize the infiltration of lawns by using small subsamples.

Earthworm activity may be partially responsible for the variability. Earthworm burrows could very easily alter infiltration rates within a site. The burrows, depending on their size, shape, and continuity, can conduct large volumes of water. Therefore, anything that could alter earthworm activity could indirectly affect infiltration.

Even though earthworms are highly influential on the soil environment, they are difficult to quantify. Earthworm counts may not be adequate, since it is their burrows that have an influence. Further work needs to be done to help better understand the role of earthworms and other fauna in the turfgrass environment.

Other plant and soil properties (thatch, tillers, and bulk densities) did not have a direct effect on infiltration. These properties may not be very influencial on the infiltration rates of residential lawns. Turf quality did not correlate with infiltration either; however, proper inputs to maintain turf quality and good plant growth may effect infiltration over time.

Based on this research, tillers, thatch, bulk density of the surface 2-cm of soil, and lawn quality were not strongly associated with infiltration. Within the range of infiltration rates obtained on the residential lawns, the overall factor affecting infiltration seems to be the soil physical conditions, as created by the soil handling during construction. The stripping of topsoil, traffic on exposed subsoil, addition of debris to the soil, and stratification of soil upon replacement may affect infiltration more than anything else. This disturbance of soil may also reduce earthworm poulations in the soil. Typical lawn construction practices should be reevaluated in order to optimize infiltration rates on lawns.

Further water related research needs to be conducted in all areas pertaining to the pervious sections of the urban landscape. Soil disturbance and profile research in urban soils would be very helpful in understanding the effects of urbanization on our water resources.

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Appendix A

RESIDENTIAL LAWN DATA

Table 12. Lawn evaluation data for the Infield (front) lawn evaluated on 9/21/89.

Ring #	Tillers	Thatch	Bulk Density	Infil. Rate
	no./plug	mm	g/cm^3	cm/hr
1	10	10	1.03	0.0
2	12	15	1.13	0.5
3	8	12	1.02	0.4
4	9	13	1.26	6.0
5	10	18	1.30	0.3
6	4	14	2.03	0.0

Age (yrs) - 2
Maintenance - 3
Bluegrass (%) - 100
Ryegrass (%) - 0
Fine Fescue (%) - 0
Soil Moisture (%) - 31.8
Soil Temp. - 69 ^{o}F
Sand (%) - 17.8
Silt (%) - 58.8
Clay (%) - 23.6
Texture - silt loam
Organic Matter (%) - 3.6
pH - 6.2
Quality - 5
Notes - Lawn was sodded

Table 13. Lawn evaluation data for the Infield (back) lawn evaluated on 9/21/89.

Ring #	Tillers	Thatch	Bulk Density	Infil. Rate
	no./plug	mm	g/cm^3	cm/hr
1	10	0	1.60	0.0
2	9	0	1.67	0.3
3	13	0	1.45	0.3
4	10	0	1.51	0.3
5	11	0	1.53	0.2
6	12	0	1.80	1.2

Age (yrs) -	2
Maintenance -	3
Bluegrass (%) -	0
Ryegrass (%) -	100
Fine Fescue (%) -	0
Soil Moisture (%) -	28.7
Soil Temp. -	68 ^oF
Sand (%) -	27.6
Silt (%) -	46.8
Clay (%) -	25.6
Texture -	loam
Organic Matter (%) -	3.7
pH -	5.9
Quality -	5

Table 14. Lawn evaluation data for the Borger lawn evaluated on 9/6/89.

Ring #	Tillers	Thatch	Bulk Density	Infil. Rate
	no./plug	mm	g/cm^3	cm/hr
1	10	8	1.15	6.7
2	10	0	1.81	0.1
3	13	3	1.48	3.0
4	9	10	1.50	1.1
5	11	0	1.35	2.2
6	6	9	1.62	3.2

Age (yrs) -	7
Maintenance -	3
Bluegrass (%) -	0
Ryegrass (%) -	0
Fine Fescue (%) -	100
Soil Moisture (%) -	17.5
Soil Temp. -	67 ^oF
Sand (%) -	27.2
Silt (%) -	51.2
Clay (%) -	21.6
Texture -	silt loam
Organic Matter (%) -	5.2
pH -	6.0
Quality -	3

Table 15. Lawn evaluation data for the Steele lawn evaluated on 9/2/89.

Ring #	Tillers	Thatch	Bulk Density	Infil. Rate
	no./plug	mm	g/cm^3	cm/hr
1	5	12	1.51	0.1
2	6	7	1.16	0.0
3	1	0	0.91	0.7
4	4	4	1.36	7.4
5	0	3	1.02	0.2
6	10	8	1.14	0.9

Age (yrs) -	32
Maintenance -	1
Bluegrass (%) -	25
Ryegrass (%) -	25
Fine Fescue (%) -	50
Soil Moisture (%) -	27.3
Soil Temp. -	71 ^oF
Sand (%) -	22
Silt (%) -	58.4
Clay (%) -	19.6
Texture -	silt loam
Organic Matter (%) -	4.9
pH -	5.9
Quality -	1

Table 16. Lawn evaluation data for the Whiteman lawn evaluated on 8/28/89.

Ring #	Tillers	Thatch	Bulk Density	Infil. Rate
	no./plug	mm	g/cm^3	cm/hr
1	7	22	1.06	0.3
2	10	7	1.17	2.6
3	7	20	1.18	0.7
4	8	8	0.64	2.0
5	3	20	1.17	1.2
6	5	16	0.92	6.5

Age (yrs) - 23
Maintenance - 3
Bluegrass (%) - 50
Ryegrass (%) - 0
Fine Fescue (%) - 50
Soil Moisture (%) - 15
Soil Temp. - 75 ^oF
Sand (%) - 13.6
Silt (%) - 62.8
Clay (%) - 23.6
Texture - silt loam
Organic Matter (%) - 8.2
pH - 6.0
Quality - 3

Table 17. Lawn evaluation data for the Waddington lawn evaluated on 8/30/89.

Ring #	Tillers	Thatch	Bulk Density	Infil. Rate
	no./plug	mm	g/cm^3	cm/hr
1	1	37	1.37	0.4
2	6	38	1.07	40.1
3	4	30	1.27	2.6
4	12	20	1.04	6.7
5	6	20	0.80	1.3
6	2	18	1.20	7.4

Age (yrs) -	30
Maintenance -	3
Bluegrass (%) -	25
Ryegrass (%) -	50
Fine Fescue (%) -	25
Soil Moisture (%) -	15.3
Soil Temp. -	77 ^oF
Sand (%) -	21.6
Silt (%) -	56.8
Clay (%) -	21.6
Texture -	silt loam
Organic Matter (%) -	6.6
pH -	6.4
Quality -	3

Table 18. Lawn evaluation data for the Snook lawn evaluated on 9/2/89.

Ring #	Tillers	Thatch	Bulk Density	Infil. Rate
	no./plug	mm	g/cm^3	cm/hr
1	2	22	1.14	1.0
2	7	24	1.06	3.4
3	9	25	1.32	0.2
4	10	27	1.35	36.6
5	7	30	1.35	1.4
6	5	30	1.42	8.9

Age (yrs) - 29
Maintenance - 2
Bluegrass (%) - 75
Ryegrass (%) - 0
Fine Fescue (%) - 25
Soil Moisture (%) - 8.6
Soil Temp. - 74 ^oF
Sand (%) - 18
Silt (%) - 60.4
Clay (%) - 21.6
Texture - silt loam
Organic Matter (%) - 4
pH - 5.8
Quality - 5

Table 19. Lawn evaluation data for the Lucas lawn evaluated on 9/21/89.

Ring #	Tillers	Thatch	Bulk Density	Infil. Rate
	no./plug	mm	g/cm^3	cm/hr
1	7	12	1.46	4.1
2	5	12	1.33	0.4
3	3	4	1.70	0.5
4	2	0	1.52	1.8
5	10	13	1.34	1.7
6	3	18	1.32	2.5

Age (yrs) -	11
Maintenance -	3
Bluegrass (%) -	10
Ryegrass (%) -	30
Fine Fescue (%) -	60
Soil Moisture (%) -	17.3
Soil Temp. -	68 °F
Sand (%) -	43.6
Silt (%) -	36.8
Clay (%) -	19.6
Texture -	loam
Organic Matter (%) -	4.2
pH -	5.4
Quality -	2

Table 20. Lawn evaluation data for the Watschke lawn evaluated on 9/21/89.

Ring #	Tillers	Thatch	Bulk Density	Infil. Rate
	no./plug	mm	g/cm^3	cm/hr
1	10	12	1.27	6.8
2	5	0	1.41	0.0
3	9	0	1.23	0.0
4	5	18	0.85	1.1
5	6	0	1.45	0.2
6	10	0	2.03	0.3

Age (yrs) - 10
Maintenance - 3
Bluegrass (%) - 25
Ryegrass (%) - 75
Fine Fescue (%) - 0
Soil Moisture (%) - 26.6
Soil Temp. - 66 ^oF
Sand (%) - 61.6
Silt (%) - 26.8
Clay (%) - 11.6
Texture - sandy loam
Organic Matter (%) - 4.6
pH - 5.6
Quality - 4

Table 21. Lawn evaluation data for the Benedict lawn evaluated on 9/5/89.

Ring #	Tillers	Thatch	Bulk Density	Infil. Rate
	no./plug	mm	g/cm^3	cm/hr
1	10	0	1.15	5.9
2	5	0	1.81	11.2
3	8	10	1.48	3.9
4	8	9	1.50	0.9
5	8	0	1.35	1.3
6	5	11	1.62	6.3

Age (yrs) - 4
Maintenance - 1
Bluegrass (%) - 50
Ryegrass (%) - 25
Fine Fescue (%) - 25
Soil Moisture (%) - 27.7
Soil Temp. - 68 ^{o}F
Sand (%) - 31.6
Silt (%) - 42.8
Clay (%) - 25.6
Texture - loam
Organic Matter (%) - 3.7
pH - 6.6
Quality - 3
Notes - Constructed on top of fill

Table 22. Lawn evaluation data for the Wiedemer lawn evaluated on 9/5/89.

Ring #	Tillers	Thatch	Bulk Density	Infil. Rate
	no./plug	mm	g/cm^3	cm/hr
1	11	0	1.92	0.3
2	7	0	1.75	0.1
3	8	0	1.61	7.4
4	5	0	1.70	0.3
5	8	0	1.29	0.7
6	8	0	1.27	21.9

Age (yrs) - 3
Maintenance - 3
Bluegrass (%) - 0
Ryegrass (%) - 100
Fine Fescue (%) - 0
Soil Moisture (%) - 26.2
Soil Temp. - 67 ^oF
Sand (%) - 31.6
Silt (%) - 38.8
Clay (%) - 29.6
Texture - clay loam
Organic Matter (%) - 3.8
pH - 5.8
Quality - 5
Notes - Constructed on top of fill

Table 23. Lawn evaluation data for the Hamilton lawn evaluated on 9/4/89.

Ring #	Tillers	Thatch	Bulk Density	Infil. Rate
	no./plug	mm	g/cm^3	cm/hr
1	5	8	1.70	0.2
2	9	10	1.26	1.5
3	12	12	1.55	3.7
4	15	14	1.37	2.8
5	13	15	1.75	0.4
6	15	15	1.76	8.9

Age (yrs)	-	4
Maintenance	-	3
Bluegrass (%)	-	0
Ryegrass (%)	-	100
Fine Fescue (%)	-	0
Soil Moisture (%)	-	30.1
Soil Temp.	-	70 °F
Sand (%)	-	41.6
Silt (%)	-	32.8
Clay (%)	-	25.6
Texture	-	loam
Organic Matter (%)	-	3
pH	-	6.1
Quality	-	5

Table 24. Lawn evaluation data for the Dzvonyicsak lawn evaluated on 9/4/89.

Ring #	Tillers	Thatch	Bulk Density	Infil. Rate
	no./plug	mm	g/cm^3	cm/hr
1	3	0	1.58	0.9
2	2	0	0.98	1.9
3	3	0	1.34	30.4
4	2	0	1.49	7.5
5	4	0	1.29	18.3
6	3	0	1.43	1.0

Age (yrs) -	6
Maintenance -	1
Bluegrass (%) -	0
Ryegrass (%) -	0
Fine Fescue (%) -	100
Soil Moisture (%) -	22.1
Soil Temp. -	65 ^oF
Sand (%) -	29.6
Silt (%) -	40.8
Clay (%) -	29.6
Texture -	loam
Organic Matter (%) -	5
pH -	6.9
Quality -	1
Notes -	Not excavated

Table 25. Lawn evaluation data for the Packard lawn evaluated on 9/4/89.

Ring #	Tillers	Thatch	Bulk Density	Infil. Rate
	no./plug	mm	g/cm^3	cm/hr
1	8	9	1.79	6.2
2	3	8	1.29	2.6
3	5	15	1.50	0.4
4	7	13	1.50	2.8
5	3	12	1.39	0.3
6	7	8	1.80	1.4

Age (yrs) -	4
Maintenance -	2
Bluegrass (%) -	25
Ryegrass (%) -	25
Fine Fescue (%) -	50
Soil Moisture (%) -	15.4
Soil Temp. -	70 ^{o}F
Sand (%) -	23.6
Silt (%) -	46.8
Clay (%) -	29.6
Texture -	clay loam
Organic Matter (%) -	2.7
pH -	6.8
Quality -	2

Table 26. Lawn evaluation data for the Hockenberry lawn evaluated on 9/6/89.

Ring #	Tillers	Thatch	Bulk Density	Infil. Rate
	no./plug	mm	g/cm^3	cm/hr
1	8	0	1.12	6.1
2	17	0	1.07	0.4
3	7	0	1.48	0.4
4	9	0	1.57	0.8
5	6	0	1.16	0.4
6	5	0	0.95	0.1

Age (yrs)	-	6
Maintenance	-	2
Bluegrass (%)	-	25
Ryegrass (%)	-	25
Fine Fescue (%)	-	50
Soil Moisture (%)	-	32
Soil Temp.	-	72 ^oF
Sand (%)	-	21.6
Silt (%)	-	54.8
Clay (%)	-	23.6
Texture	-	silt loam
Organic Matter (%)	-	5.1
pH	-	6.6
Quality	-	3

Appendix B

EXPERIMENTAL LAWN DATA

Table 27. June 1988 measurements

Treatment	Rep.	Ring	Infil. Rate
			cm/hr
Sod	1	1	4.7
Sod	1	2	4.2
Sod	1	3	1.6
Sod	2	1	2.6
Sod	2	2	4.7
Sod	2	3	2.9
Sod	3	1	1.8
Sod	3	2	1.8
Sod	3	3	2.7
Seed w/mulch	1	1	2.1
Seed w/mulch	1	2	6.4
Seed w/mulch	1	3	2.6
Seed w/mulch	2	1	2.4
Seed w/mulch	2	2	6.6
Seed w/mulch	2	3	8.1
Seed w/mulch	3	1	1.8
Seed w/mulch	3	2	2.9
Seed w/mulch	3	3	1.6
Seed	1	1	3.4
Seed	1	2	0.5
Seed	1	3	1.6
Seed	2	1	2.1
Seed	2	2	2.1
Seed	2	3	3.1
Seed	3	1	4.5
Seed	3	2	2.1
Seed	3	3	5.5

Table 28. November 1988 measurements.

Treatment	Rep.	Ring	Thatch Depth	Tiller	Avg. Bulk Density	Avg. Soil Moist	Infil. Rate
			mm	no./plug	g/cc	%	cm/hr
Sod	1	1	9	20	1.38	31.6	9.4
Sod	1	2	13	3	1.38	31.6	10.0
Sod	1	3	1	7	1.38	31.6	3.8
Sod	2	1	7	14	1.10	35.2	0.4
Sod	2	2	8	19	1.10	35.2	20.4
Sod	2	3	12	6	1.10	35.2	7.7
Sod	3	1	8	19	0.95	41.0	114.8
Sod	3	2	8	11	0.95	41.0	33.0
Sod	3	3	10	11	0.95	41.0	10.5
Seed w/mulch	1	1	0	12	1.20	32.3	
Seed w/mulch	1	2	0	2	1.20	32.3	9.0
Seed w/mulch	1	3	0	16	1.20	32.3	4.4
Seed w/mulch	2	1	0	13	1.15	38.4	5.7
Seed w/mulch	2	2	0	9	1.15	38.4	12.9
Seed w/mulch	2	3	0	7	1.15	38.4	0.6
Seed w/mulch	3	1	0	7	1.11	36.1	9.8
Seed w/mulch	3	2	0	2	1.11	36.1	16.7
Seed w/mulch	3	3	0	13	1.11	36.1	8.3
Seed	1	1	0	20	1.41	30.5	30.4
Seed	1	2	0	19	1.41	30.5	22.6
Seed	1	3	0	10	1.41	30.5	9.6
Seed	2	1	0	24	1.12	36.6	3.4
Seed	2	2	0	17	1.12	36.6	8.3
Seed	2	3	0	12	1.12	36.6	0.5
Seed	3	1	0	8	1.25	31.7	94.6
Seed	3	2	0	13	1.25	31.7	0.9
Seed	3	3	0	7	1.25	31.7	0.0

Table 29. June 1989 measurements.

Treatment	Rep.	Ring	Thatch Depth	Tiller	Bulk Density	Avg. Soil Moist	Infil. Rate
			mm	no./plug	g/cc	%	cm/hr
Sod	1	1		0		24.5	21.3
Sod	1	2	14	13		24.5	44.0
Sod	1	3	12	16		24.5	24.0
Sod	2	1	11	19		27.7	37.5
Sod	2	2	13	13		27.7	21.8
Sod	2	3		0		27.7	21.8
Sod	3	1	5	15		30.1	23.8
Sod	3	2	12	19		30.1	88.2
Sod	3	3		0		30.1	37.0
Seed w/mulch	1	1		10		23.3	4.6
Seed w/mulch	1	2		0		23.3	12.6
Seed w/mulch	1	3	0	15		23.3	10.6
Seed w/mulch	2	1	0	16		20.0	14.9
Seed w/mulch	2	2		0		20.0	15.7
Seed w/mulch	2	3	0	15		20.0	39.0
Seed w/mulch	3	1	0	17		27.0	41.6
Seed w/mulch	3	2	0	19		27.0	45.2
Seed w/mulch	3	3		0		27.0	5.6
Seed	1	1		0		25.3	31.8
Seed	1	2	0	18		25.3	6.0
Seed	1	3	0	14		25.3	16.4
Seed	2	1		0		21.1	16.3
Seed	2	2	10	16		21.1	43.7
Seed	2	3	13	21		21.1	13.6
Seed	3	1		0		33.1	35.3
Seed	3	2	0	15		33.1	4.5
Seed	3	3	0	8		33.1	39.1

Table 30. October 1989 measurements.

Treatment	Rep.	Ring	Thatch Depth	Tiller	Bulk Density	Avg. Soil Moist	Infil. Rate
			mm	no./plug	g/cc	%	cm/hr
Sod	1	1	8	12	1.22	31.9	13.9
Sod	1	2	10	13	1.14	31.9	10.8
Sod	1	3	12	12	1.32	31.9	22.7
Sod	2	1	15	9	1.19	35.9	25.9
Sod	2	2	13	12	1.07	35.9	41.9
Sod	2	3	16	16	1.53	35.9	61.1
Sod	3	1	12	7	1.12	33.4	9.1
Sod	3	2	0	12	1.06	33.4	3.8
Sod	3	3	0	14	1.21	33.4	2.7
Seed w/mulch	1	1	0	12	1.40	29.4	45.5
Seed w/mulch	1	2	0	10	1.38	29.4	141.5
Seed w/mulch	1	3	0	9	1.32	29.4	36.4
Seed w/mulch	2	1	0	10	1.19	32.1	12.5
Seed w/mulch	2	2	0	14	1.24	32.1	6.2
Seed w/mulch	2	3	0	6	1.21	32.1	5.8
Seed w/mulch	3	1	0	11	1.24	36.1	24.3
Seed w/mulch	3	2	0	9	1.66	36.1	55.6
Seed w/mulch	3	3	0	9	1.41	36.1	19.8
Seed	1	1	0	9	1.51	30.2	40.9
Seed	1	2	0	8	1.57	30.2	48.2
Seed	1	3	10	14	1.35	30.2	21.6
Seed	2	1	0	10	1.36	35.4	12.5
Seed	2	2	0	9	1.46	35.4	18.7
Seed	2	3	0	11	1.39	35.4	9.9
Seed	3	1	10	10	1.21	35.8	22.1
Seed	3	2	0	10	1.63	35.8	11.6
Seed	3	3	0	11	1.30	35.8	1.9

Appendix C

ANALYSIS OF VARIANCE TABLES

Table 31. Analysis of variance of experimental lawn infiltration rate data.

SOURCE	DF	INFIL. RATE
Rep	2	NS
Trt	2	NS
Rep*Trt	4	NS
Time	2	NS
Trt*Time	4	NS

Table 32. Analysis of variance of experimental lawn earthworm burrow data.

SOURCE	DF	INFIL. RATE
Rep	2	NS
Trt	2	NS

Table 33. Analysis of variance of experimental lawn soil thin layer section data.

SOURCE	DF	INFIL. RATE
Rep	2	NS
Trt	2	NS
Rep*Trt	4	NS
Depth	2	NS
Rep*Depth	4	NS
Trt*Depth	4	*

* Significant effects at the 0.05 level.