A LYSIMETER STUDY OF DOMESTIC WASTE WATER RENOVATION

BY FOREST SOIL FILTRATION

BY

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ABSTRACT

Laboratory lysimeters were used to investigate the be-
haviour, over time, of a humid west coast forest soil under
intermittent primary municipal waste water irrigation. Mineral
soil packed to a depth of 69 cm and to a uniform density of
about 0.9 gm per cm^3 was covered with a forest floor 9 cm thick.
Sintered glass bead tensiometers were used to gauge the water
potential distributions in the soil lysimeters. Irrigation and
drainage systems were designed to maintain constant rates of
waste water application and facilitate measurement of drainage
rates. Two groups of soil lysimeters each with triplicate sam-
ples, were loaded with waste water at the rates of 0.23 cm per
day (37 cm^3 per day) and 0.47 cm per day (75 cm^3 per day)
for a period of 9 months. The soil lysimeters were incubated
at a temperature of about 15.5 degrees Centigrade. The total
amounts of nitrogen added to both groups of soil lysimeters
were 223.7 gm and 436.9 gm or equivalent to 1.4 % and 2.7 % of
the total nitrogen of the original soil, respectively. Renova-
tions of wastewater in terms of nitrogen were 75 % and 43 %
with respect to the two groups of soil lysimeters. Renovations
in terms of phosphorus were more than 99 % in both groups of
soil lysimeters. Retention of nutrients by the soil was in-
creased with time under favourable aerobic conditions. Uptake
of nutrients by vegetation in the field would minimize leaching
losses. Results from this experiment indicated no significant
changes in the physical and chemical behaviour of the soils.
Proper design of the waste water irrigation system in terms of

loading would maximize the efficiency of renovation without deteriorating the behaviour of the soils.

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INTRODUCTION

The practice of releasing wastewater from domestic, in-
dustrial and agricultural sources to receiving waters has con-
tributed significantly to water quality problems. These pro-
blems have drawn not only the attention of the public, but also
that of the government which considers water pollution as one
of the top environmental quality problems. The various methods
that are used to cope with this problem involve the reduction
of chemical and biological materials, contained in the waste, to
environmentally tolerable levels. Chemical, biological and
physical means of treatment, separately or in combination, are
generally used to remove nutrients, dissolved minerals and
organic matter from wastewater.

Three processes of conventional treatments of wastewater
with different degrees of purification are currently in prac-
tice. They are primary, secondary and tertiary treatments.
Primary treatment includes such methods as screening, skimming,
sedimentation and lagooning to remove part of the coarse,
floatable and suspended solids from the wastewater. Secondary
treatment is employed to further remove most of the remaining
solids from the primary treated wastewater. Several methods in
use involve filtration, activated sludge and aerated stabiliza-
tion basins. Nutrient removal in these processes is limited.
The tertiary treatment is, therefore, an advanced step of the
secondary treatment and is designed to remove nutrients and
dissolved minerals from the treated water. The methods usually
employed are photosynthetic stabilization, chemical precipita-

tion, ion exchange, distillation, electrodialysis, freezing, reverse osmosis and ultrafiltration.

Wastewater filtration with field soils represents a combination of chemical, biological and physical methods for the treatment of wastewater. It is therefore considered as a process of tertiary treatment due to the effectiveness in removal of nutrients and dissolved minerals from the wastewater. Waste water for land irrigation should receive primary or secondary treatment and should be free of any toxic chemicals before being applied to the land. Large amounts of heavy metals such as Cu, Zn, Pb, Ni, Cd and Cr are hazardous to biotic systems and should be removed from the wastewater, prior to application to land, by some means of chemical, biological or physical treatment.

Using soil for wastewater filtration has been a common practice for centuries. It has been used by farmers to maintain and increase soil fertility in many places of the world. Scoble (1905) reported a successful land treatment sewage system in Great Britain. Wastewater from domestic sources combined with trade refuse was treated by screening and filtration through about 6 feet of light loamy soil overlying a porous sandy subsoil at an average application rate of 23,300 gal per acre per year (2.65 cm per day). The drainage water from the cropped soil attained over 90 % purification in terms of chemical, physical and biological qualities.

The use of soil for disposal of wastewater from various industries such as canneries, pulp mills, dairies etc. in the United States since 1930 was reported by Schraufnage (1962). Schraufnage reported that pea and corn wastes were applied to

land through a ridge-and-furrow irrigation system at a rate of 49,000 gal per day per acre (5.57 cm per day) or 238 lb BOD per day per acre (266.6 kg BOD per day per ha) in 1934 at Hampton, U. S. A. No odor was noted. He also reported that municipal waste was disposed of on a deep silt loam underlain by sand at an average rate of 37,000 gal per day per acre (4.21 cm per day) with a BOD of about 8 lb per acre (9.0 kg per ha) in 1959 at Wisconsin, U. S. A. No odor and overflow were reported.

Scott (1962) reported a successful use of cheese whey as a fertilizer and soil conditioner in tests carried out in Wisconsin in 1959. Cheese whey was applied to the sandy soils at a rate of 5,000 - 70,000 lb per day per acre (5610 - 78,540 kg per ha) over a 30-day period. Return yield of oat crop was reported to be 32 bu per acre, despite some vegetation losses on heavy wastewater loaded areas.

Spray irrigation of spent sulfite liquor on land at a maximum rate of 320,000 gal per day (36.4 cm per day) was also reported by Scott. Well tests indicated no trace of liquor in the ground water. The operation cost of the disposal system was estimated to be $1.39 per ton as compared to $4.17 per ton of pulp produced.

The economics of land disposal of sludge for soil improvement were statistically evaluated by Thomas and Bendixon (1969). They reported that disposal of sludge on land could reduce the the costs by about 29 %. They indicated the cost of making topsoil with sludge was $1,600 per acre ($4,000 per ha), while the comparable cost of improvement with natural topsoil would

have been \$4,500 per acre (\$11,000 per hectare).

Robeck and his colleages (1964), on the basis of tests using 50 lysimeters, suggested that soil system in order to be suitable for wastewater treatment must have a low enough permeability and some adsorptive capacity to allow the suspended and dissolved organic matter to be retained. They pointed out that a soil which has 0.5 - 1.0 % organic matter and effective aggregate size of about 0.3 - 0.1 mm and an application rate from 4 - 10 cm per day can help reduce 90 - 95 % of ABS (Alkyl benzene sulfonate) and COD (Chemical oxygen demand) and also help prevent groundwater contamination from wastewater irrigation. A number of other authors have studied the efficiency of filtration systems in terms of design and operation procedures (Thomas, Warren, and Thomas, 1966; Parizek, 1967; Law, Thomas and Myers, 1970; Laak, 1970; Robeck, Bendixen, Schwartz and Woodward, 1964; de Vries, 1972).

Research on the application of wastewater to forested soil by spray irrigation was carried out at the Pennsylvania State University and New Jersey, U.S.A. (Kardos, 1966; Pennypacker, Sopper and Kardos, 1967; Sopper, 1971; Mather, 1953). In Pennsylvania, hardwood and red pine forest soils of silt loam to silty clay loam texture were subjected to an intermittent application rate of 0.64 cm per hour for a total of 2.5 to 5.0 cm per week. The research was carried out from April to November in 1968 after six years of operation. Renovation of MBAS (detergent residue) in the hardwood plot under a loading of 2.5 cm per week was as high as 70 - 80 % in the upper 120 cm of soil, as compared to 71 - 86 %

with the red pine. Phosphorus removal ranged from 98 - 99 %
at the 60 cm soil depth in the hardwood plot and 93 - 97 % in
the red pine plot. Nitrate nitrogen removal decreased from 68
- 82 % in the first year to 27 - 70 % six year later. Removals
of organic nitrogen were 99 % to 90 % with respect to hardwood
and red pine plots. Different degrees of successful removal of
other dissolved minerals such as Cl, Na, K, Ca, Mg, Mn and B by
soils were also noted. Groundwater recharge amounted to an
average of 15.0 thousand cubic metres per hectare or equivalent
to 90 % of the wastewater applied at the 5 cm per week rate.
Tree growth increased rapidly. No contamination of groundwater
or adverse effect on soils was reported. Results of all research
showed that the use of soil for wastewater renovation was one of
the simplest and most effective methods of wastewater treatment.
However, the soil properties and operation procedure are the
main factors that determine the suitability and efficiency of the
filtration systems.

Since soil filtration of wastewater can be considered as an
example of a tertiary treatment process that can be broadly and
easily applied in the field, the concept of using forest soil for
wastewater reclamation was obvious (Kardos, 1966). Forest
soils, unlike crop land or grass land, are often covered with a
layer of a carbonaceous forest floor of varying thickness that
can serve as an energy source for the activity of microorganisms
(Kardos, 1966; Allison, 1966). The relatively high C:N ratio
of the forest floor would contribute to the biological immobili-
zation of added inorganic nitrogen to the organic form (Allison
1966). In addition, the high acidity of the mineral soil might

contribute to adsorption of ammonium ions, and to high retentivity of phosphate because of the presence of iron and aluminium oxides and hydroxides (Hemwall, 1957; Parizek, 1967). Municipal wastes originate mainly from domestic sources and may contain such chemicals as detergents, N, Ca, Mg, Na, P and Cl. Application of wastewater to the land will retain such nutrients for vegetation growth. The principal problem may be the possible contamination of groundwater with soluble nitrate nitrogen as is reported by some authors (Pennypacker, Sopper and Kardos 1967).

A study plan was devised, using soil lysimeters in the green house, to characterize the behaviour, over time, of a West Coast forest soil in response to loading with a primary domestic sewage effluent. This study focusses on the 1) nitrogen and phosphorus retention by a forest soil, 2) changes of physical behaviour of soil, 4) optimization of wastewater loading, and 5) suitability and possible problems in field operation.

The general objectives of this research were to investigate 1) the effects resulting from contact between wastewater, bearing nitrogen and phosphorus, and a forest soil, 2) the soil's capacity to retain nitrogen and phosphorus, and 3) the means of balancing the amount of addition to soil against the amount of storage while at the same time minimizing leaching loss. This was done by passing wastewater through soil lysimeters. In response to filtration, physical, chemical and biological changes were expected to take place in the soil. Therefore, a research project was devised to determine water and nitrogen balances for the lysimeters as well as to study physical, chemical and biological changes.

RESEARCH METHODS AND MATERIALS

Materials and Sampling

The soil sampling site was located at Loon Lake, University of British Columbia Research Forest, Haney, B. C., at an altitude of about 400 metres. The vegetation consisted of a combination of western red cedar (Thuja plicata Donn) and western hemlock (Tsuga heterophylla (Raf.) Sarg.). The podzolic soil showed well-developed L, F, H, Ae and Bf horizons in the top 60 cm. Undisturbed cores were taken from the forest floor with the same diameter as the inside diameter of the lysimeters. The L, F and H layers of the forest floor were about 2.5, 1.5 and 5.0 cm thick respectively. Mineral soil of loam texture from the A and B horizons was sampled to a depth of about 45 cm. Unchlorinated wastewater was collected from the primary municipal wastewater treatment plant, West Vancouver, B. C., and stored at

a temperature of two degrees Centigrade. Each supply lasted for a period of about 20 days.

Lysimeter Cylinder Apparatus

Six transparent acrylic plastic cylinders of diameter 14 cm and length 80 cm were employed. In order to gauge the energy status (matric potential) of the soil water in the lysimeter, four tensiometer holes were drilled at 20 cm intervals. Sintered glass bead tensiometers were about 5 cm long and 5 mm in diameter and had air intrusion values of about 200 cm of water. The tensiometers were connected to mercury manometers.

Drainage was facilitated through the installation of a porous plate at the bottom of each lysimeter (Fig. 1). The porous plate consisted of a one-cm thick layer of unconsolidated silicon carbide (25 micron particle size) which providid good hydraulic contact between the soil and the drainage system. The porous plate facilitated the maintenance of aerobic conditions in the soil by maintaining the soil water tension at or above the soil air intrusion value. Water from the soil was collected through the drainage system at a tension of 60 cm of water.

The irrigation system was installed at the top of the lysimeter, 6 cm above the forest floor. Polyethylene pressure tubing (1 cm in diameter) with small holes was used so that water could drip from the tubing onto the forest floor. The rate of flow maintained at 0.35 cm per hour by adjusting the head (wastewater surface level) to the appropriate value. The irrigation system was flushed with clean water once a week

RUBBER
GASKET

SPACE FOR SAND
AND SILICONE
CARBIDE

NYLON
SCREENING

HOLES.

SUPPORTING PLATE

RESERVOIR

OUTLET TUBE

SUPPORTING
PLATE
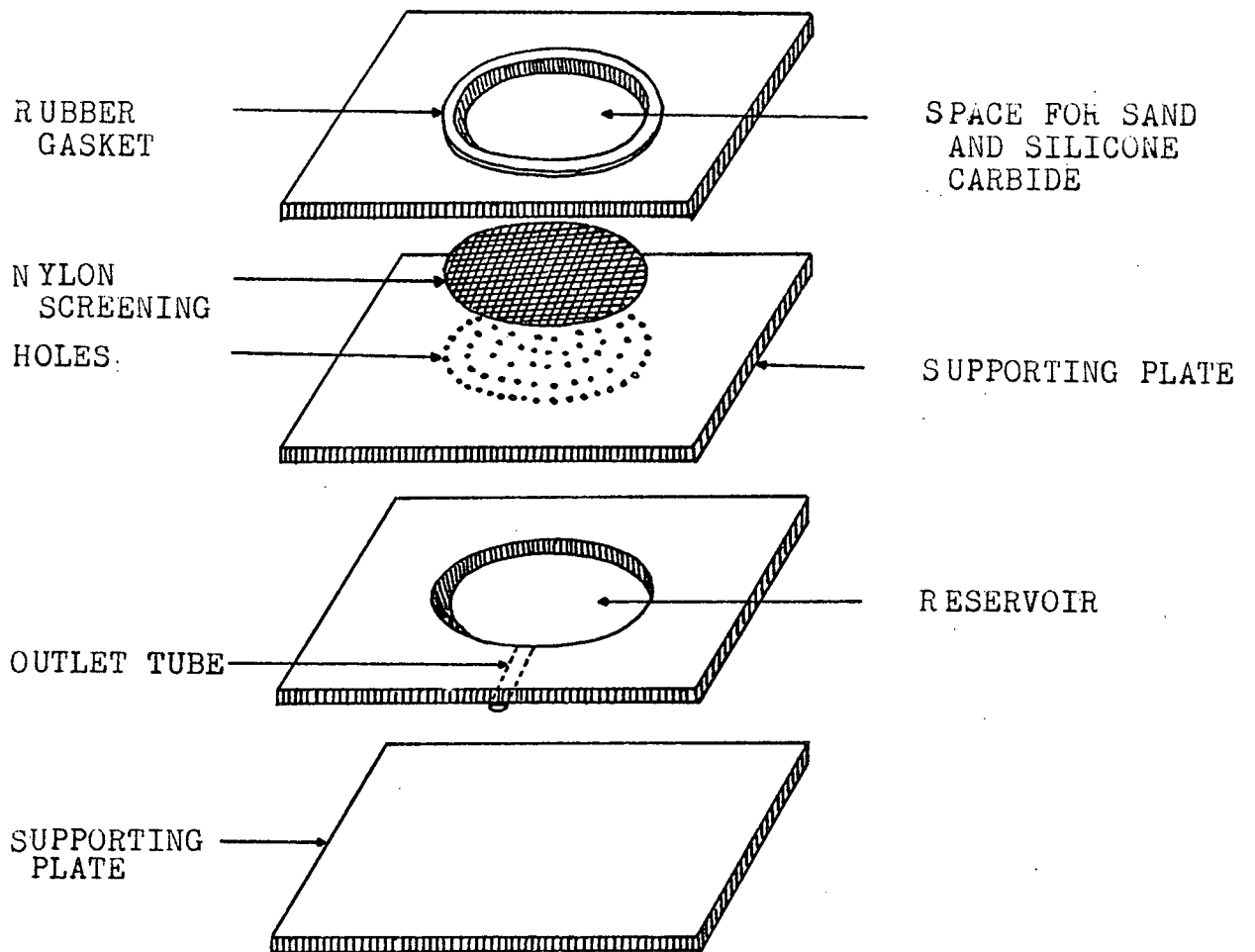
Fig. 1. Porous Plate Assembly

to maintain a constant flow rate (Figure 2).

Preparation and Packing of Soil Sample

Sieving of the mineral soil with a 6 mm sieve resulted in the removal of about 47.1 % (weight basis) of coarse fragments from the soil. Thorough mixing of the soil produced a uniform soil ready for packing in the lysimeters. To pack the soil in the lysimeter, a measured amount of soil of known volume (one pint) was poured into the cylinder and compressed uniformly with a wooden packer. Then the soil surface was loosened with a steel bristle brush in order to ensure good continuity between adjacent layers. Soil depth was measured after every ten increments in order to obtain a measure of packing uniformity. The final volume and weight of the soil were recorded. The bulk densities of the lysimeter soils varied between 0.86 and 0.90 gm per cm^3.

Incubation of the Soil

The experiment was carried out in the greenhouse from September 1971 until June 1972. In order to minimize temperature variations and to simulate the environmental conditions at the sampling site, temperature of the soil at depths greater than 40.0 cm was maintained at 15.5 degrees Centigrade by placing the lysimeter in an insulated air bath. During the summer, a fan drawing in outside air was also employed to maintain a favourable temperature in the greenhouse. The surface of the soil was shaded to prevent direct contact with sunlight in order to minimize water loss from the forest floor by evaporation. A sketch of a lysimeter system during incubation is shown in Fig. 3.

POLYETHYLENE
PRESSURE TUBING

IRRIGATION HOLE

SUPPORTING
FRAME
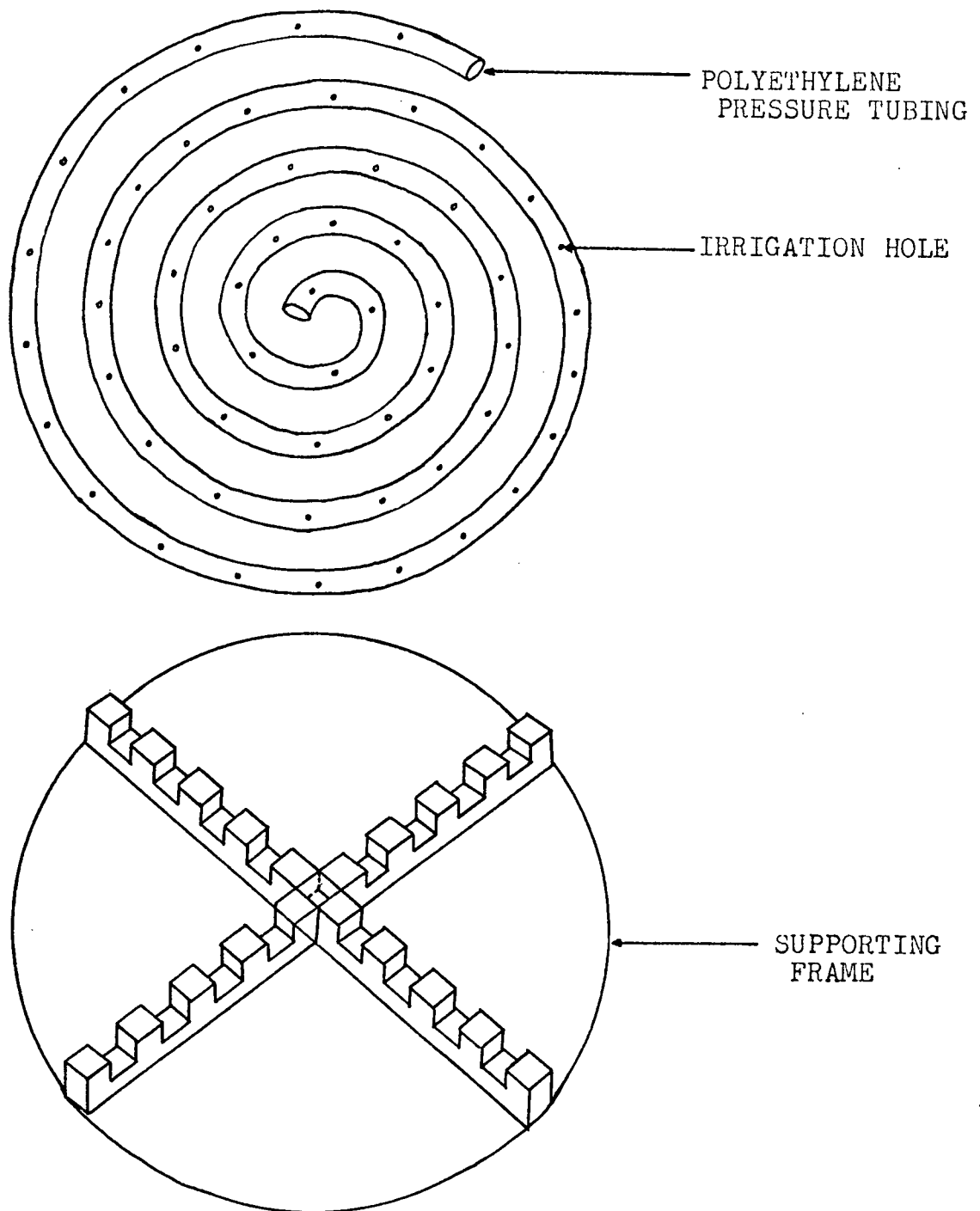
Fig. 2. Irrigation System
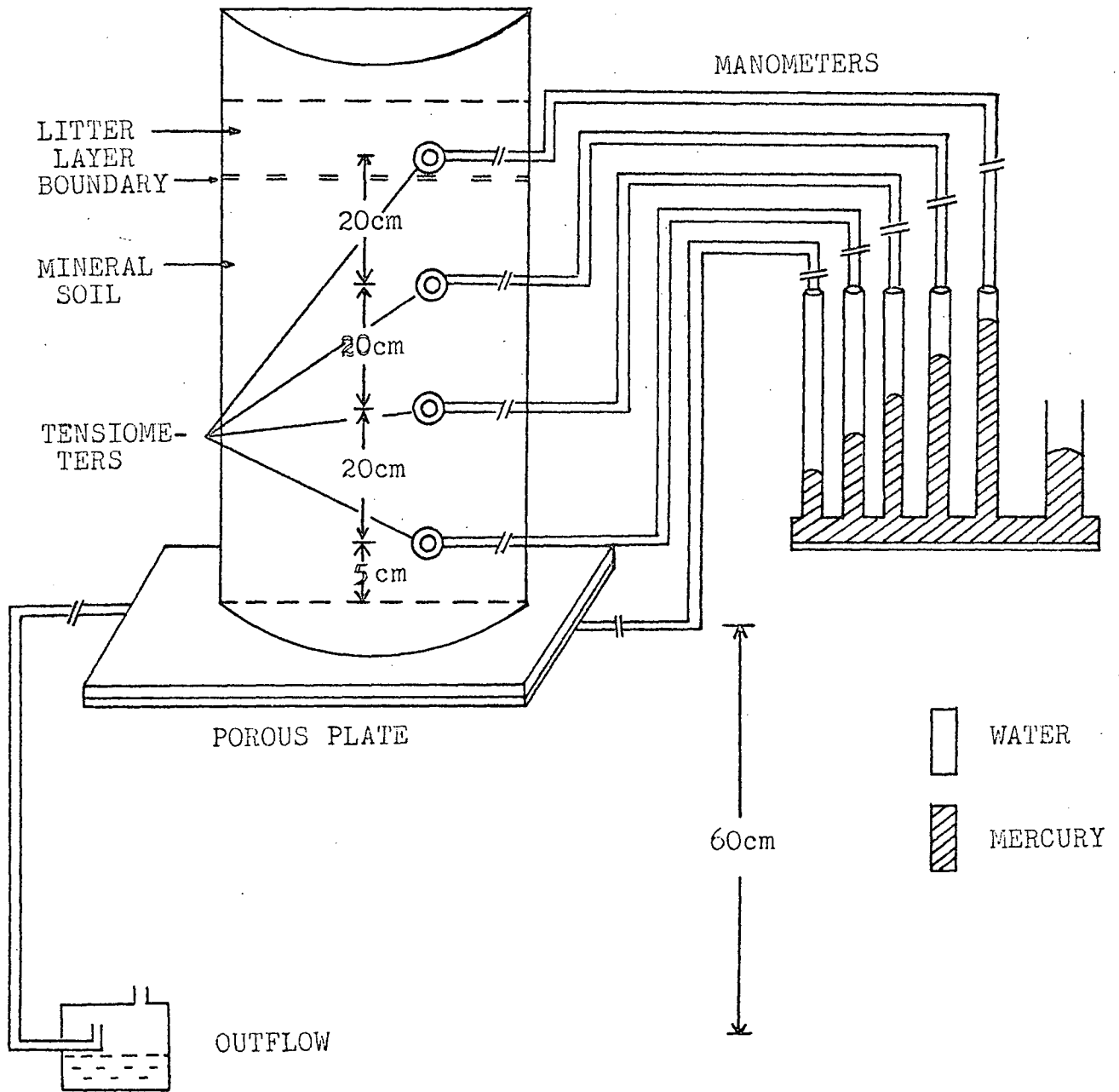
Fig. 3. Measurement of Water Energy Status in the Lysimeter
During Incubation.

Wastewater Application and Drainage Water Sampling

The total number of six lysimeters was divided into two groups of three. Wastewater was applied at a rate of 37 cm^3 per day (0.23 cm per day) to lysimeters 1 to 3, and at a rate of 75 cm^3 per day (0.47 cm per day) to lysimeters 4 to 6. 50 to 100 cm^3 of tap water was added at the end of each week. The application flow rate of water was maintained at 0.35 cm per hour. The total amounts of nitrogen applied to the two sets of lysimeters were equivalent to 128 lb N per acre per year (143.4 kg N per hectare per year) and 250 lb N per acre per year (280 kg N per hectare per year) respectively at wastewater nitrogen concentrations varying between 14 ppm and 33 ppm. The total amounts of P applied to the same were equivalent to 27 lb P per acre per year (30.2 kg P per hectare per year) and 53 lb N per acre per year (59.4 kg P per hectare per year) at concentrations between 4.0 and 8.7 ppm.

The volume of drainage water released by the soil lysimeters was measured daily. Water potentials inside the soil lysimeters were also recorded before each wastewater application. Drainage water sample of sufficient quantity to allow analyses for BOD, nitrogen and phosphorus was collected and stored at a temperature of two degrees Centigrade.

Soil Physical Analyses

Physical properties of both mineral soil and the organic layer were measured to indicate changes due to effluent loading for the one year period.

A. Saturated Hydraulic Conductivity

Hydraulic conductivity is a measure of the ability of a soil to conduct water. It is the flux per unit hydraulic potential gradient and from Darcy's law can be written as

$$K = (Q/At) / (h/L) = v / (h/L)$$

where v is the water flow rate ($cm\ sec^{-1}$), Q the volume of flow (cm^3) that passes across the soil cross sectional area A (cm^2) in time t (sec), K is the hydraulic conducitivity ($cm\ sec^{-1}$), and h is the hydraulic head (cm) across a length of flow L (cm).

A steady-state method was employed to measure the saturated hydraulic conductivity in situ (Fig. 4). K was determined by measuring the volume of flow through the soil during a known time interval and hydraulic gradient. The tensiometers were used to measure the hydraulic head drops across the soil layers. In order to minimize air entrapment, the soil was saturated gradually from the bottom up by slowly increasing the elevation of the lysimeter outflow unit, which was connected to a water supply for a period of about 15 hours. Subsequently, steady state was established and maintained by providing constant water levels over the soil surface and at the outlet.

B. Water Retention Characteristics

The measurement of soil water content in conjunction with matric potential yields information about soil water retention characteristics and pore size distribution. Under certain conditions, filter failure of the soil after prolonged periods of loading with wastewater has been found to occur due to the change in biological, chemical and physical conditions inside the soil.
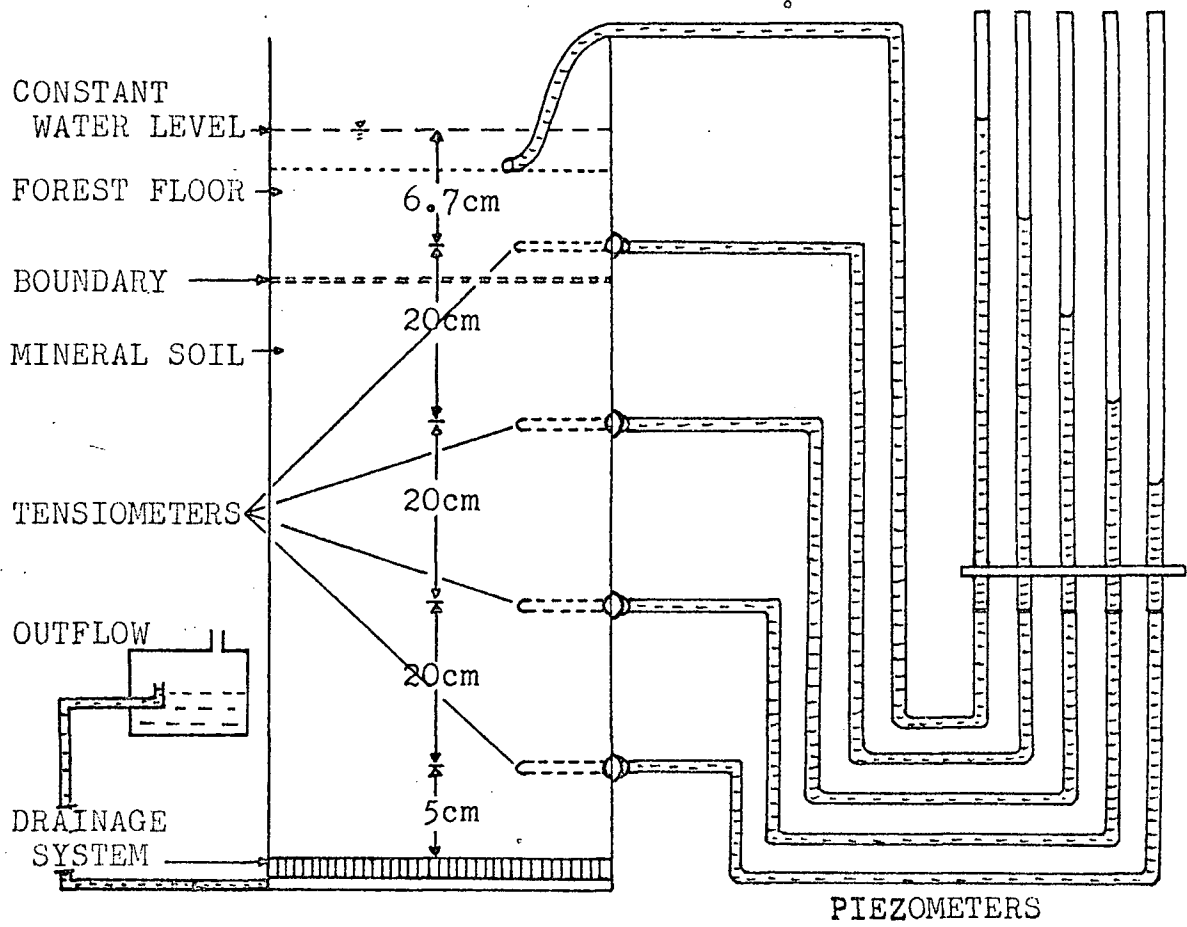
Fig. 4.   Steady-State Method of Measuring Saturated Hydraulic
          Conductivity.

Previous research indicated filter failure occurred at low temperature under aerobic condition or in higher water content under anaerobic conditions (de Vries, 1972). Therefore a technique was employed that allows the simultaneous *in situ* measurement of the relative soil water content and the corresponding soil water matric potential during drainage after the soil has been saturated (Watson and Whisler, 1968; de Vries, 1969). Water retention curves were obtained by plotting the relative water content, expressed as accumulated outflow, as a function of matric potential. Relative water contents were measured with a gamma radiation attenuation method, and corresponding matric potentials were measured with tensiometer-pressure transducer systems (Chow and de Vries, 1972).

C. Bulk Density

The bulk density of the soil was computed before and after treatment with wastewater. Bulk density of the original soil was determined by placing a known weight of moist soil of known water content in the lysimeter and by measuring the volume. This value represented the average bulk density throughout the soil in the lysimeter. The bulk density of the treated soil was determined by the clod-method at 5-cm intervals (Black, Evans, White, Ensminger and Clark, 1965). This measurement allowed calculation of the porosity of the soil, assuming a particle density of 2.65 gm cm^{-3}.

Water and Soil Chemical Analyses

Chemical properties of both wastewater and drainage water were determined periodically in terms of total Kjeldhal N, nitrate N, ammonium N, total P and BOD, while chemical properties

of both original and treated soils were determined in terms of total Kjeldahl N, nitrate N, and ammonium N. These analyses were carried out to determine the effectiveness of the filtration system and the dynamics of nitrogen and phosphorus retention.

The BOD, which is an indicator of the biodegradable organic matter content of water, was measured periodically by a manometric method (Tool, 1967). Organic nitrogen of both influent and effluent was determined by the macro-Kjeldahl method while the total Kjeldahl nitrogen method was employed to determine ammonia plus organic nitrogen (Standard Methods, 1962). Nitrate nitrogen was measured by the specific ion electrode [1], and total water-soluble phosphorus by the molybdenum blue method (Black, Evans,White, Ensminger and Clark, 1965).

Organic and ammonia nitrogen of both the original and treated soils were determined by the micro-Kjeldahl method (Black, Evans, White, Ensminger and Clark, 1965). Ammonia nitrogen was measured by micro-diffusion followed by colorimetry, and nitrate nitrogen by the chromotropic acid method (West and Ramachandran, 1966). A glass electrode was used to measure the pH of the soil suspension with a water : soil ratio of 1 : 1. Total carbon was measured by the Leco instrument. All analyses were done in duplicate.

[1] Orion Research Incorporated, nitrate ion electrode model 92-07.

RESULTS AND DISCUSSION

The application of waste water to the soil lysimeters was carried out continuously for a period of 36 weeks. The data were obtained in terms of physical and chemical properties during and after termination of the experiment. Lysimeters 3 and 4 were used for chemical analyses, while lysimeters 1, 2 and 5, 6 were employed to determine the physical properties. All data were expressed on a 7-day basis. This was done by dividing the collected volume of drainage water by the number of days over which this volume was collected, and multiplying the result by seven. All other chemical input and output data were expressed on the same seven day basis.

Water Balance

During the 36 weeks, the two groups of soil lysimeters received average volumes of 8.6 and 16.8 litres of waste water respectively plus an additional volume of 2.2 litres of tap water. The volume of the drainage water indicated that for these two groups about 34.1 % and 20.4 %, respectively, of the total input of liquid was stored or evaporated to the atmosphere. Figure 5 shows the water balance of lysimeters 1, 2, 3 and 4, 5, 6 starting from September 23, 1971, to June 23, 1972. At the beginning, the application of wastewater to the soil lysimeters was not the same, but slightly higher in lysimeters 1, 2, 3 than in lysimeters 4, 5, 6. Wastewater was regularly added to the soil lysimeters six days a week, while fresh water was usually added at the last day of a week. If a certain amount of waste water was not applied to the lysimeters within a scheduled time
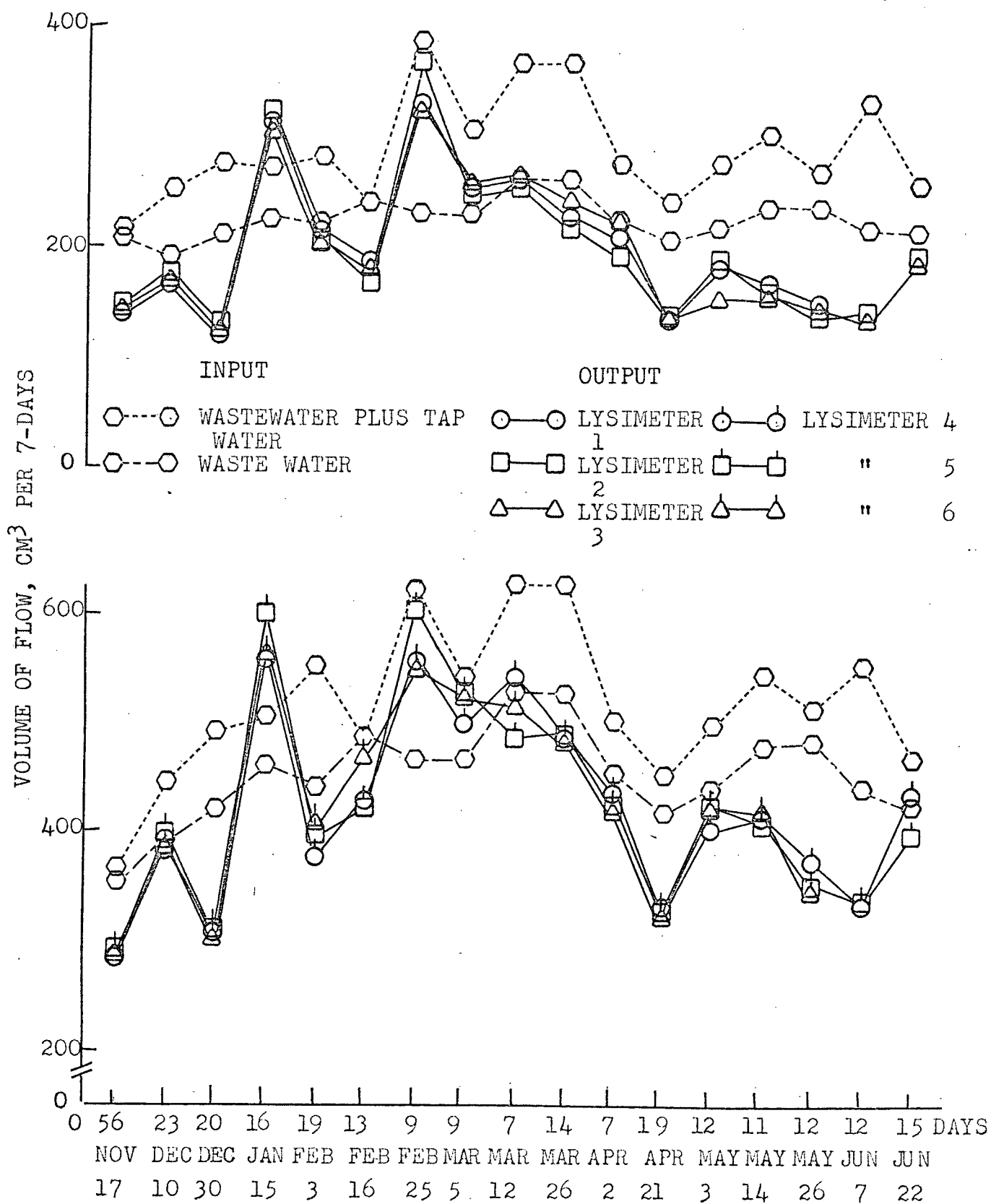
Fig. 5. Partial Water Balances for Lysimeters 1,2,3 (top) and 4,5,6 (bottom).

period, it was added as soon as possible thereafter. This is
the reason the amount of wastewater applied expressed on a 7-
day basis in both Figures 5 and 6 is not uniform. The volume
of drainage water in the 16-day period (January 15) in both
Figures 5 and 6 exceeded that of the irrigation water in both
soils. This was attributed to the flow from the previous period
when the outlet system was closed for a short period of time.

Nutrient Concentrations in Waters

Nutrient concentrations in both wastewater and drainage
water were measured periodically in terms of nitrogen, phospho-
rus and BOD. Figure 6 shows that the concentrations of nitrogen
in the drainage water from both groups of soil lysimeters in-
creased with time. The concentration of nitrogen in the drainage
water from lysimeters 4, 5 and 6 was about twice than that of the
lysimeters 1, 2 and 3. The data of Fig. 6 indicate that the con-
centration of nitrogen in the drainage water from lysimeters 4,
5 and 6 increased to values higher than that of the wastewater
after 23 weeks of loading (January 15). This suggests that all
of the nitrogen applied was being leached from the soil. However,
soil analyses for nitrogen concentration carried out on both
groups of lysimeters did not indicate significant changes in the
soil nitrogen content during the application period as shown in
Figure 8. It is interesting to note that despite a decrease in
the nitrogen concentration of the influent wastewater during the
application period, the concentration of the drainage water con-
tinued to increase after 23 weeks of treatment.

Concentrations of total phosphorus of both wastewater and
drainage water are shown in Figure 11. The data of Figure 11 in-
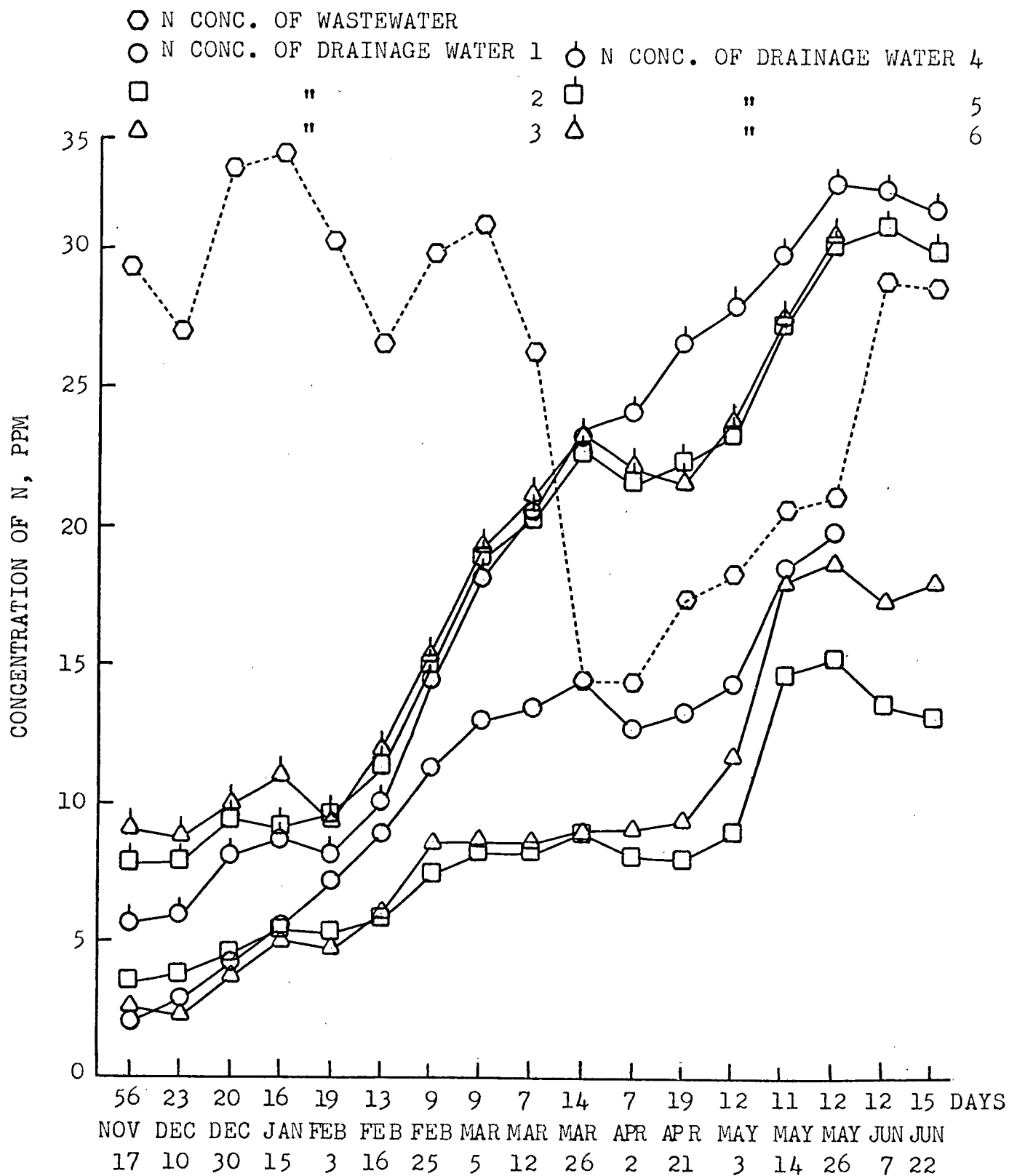
Fig. 6. Concentrations of N in Wastewater and Drainage Water

dicate that the concentration of phosphorus in wastewater varied between 4 ppm and 8.7 ppm with an average concentration of 6.0 ppm. A sharp drop of the concentration in wastewater after 25 weeks of application occurred in conjunction with a drop of the nitrogen content mainly due to the low nutrient concentrations of the wastewater from the treatment plant. The concentration of the drainage water was very low, within the lowest limit of detection, indicating a high retention of added phosphorus by the soil.

Nitrogen Balance

The final calculation showed that the total inputs of nitrogen for the two groups of lysimeters were 223.7 mg and 436.9 mg, or equivalent to 1.4 % and 2.7 % of the total amount of nitrogen present in the original soils (the experimental error was 5 %). Data on the nitrogen balance showed that lysimeters 4, 5 and 6 attained an effluent renovation of 43 % in terms of nitrogen as compared to 75 % for lysimeters 1, 2, and 3. Fig. 7 indicates the rate of total nitrogen output from both soil lysimeters increased with time. This increase in nitrogen output from lysimeters 4, 5, and 6 was initially three times higher than that of lysimeters 1, 2, and 3 and the difference increased to five times after 25 weeks (March 26) of wastewater application. Figure 7 shows that the increase of the total nitrogen output of lysimeters 4, 5, and 6 exceeded that of input after 25 weeks (March 26) of application. This indicates that the high nitrogen loading exceeded the soil's capability for biological immobilization, so the added nitrogen and some of the retained nitrogen were biologically converted to nitrate which in
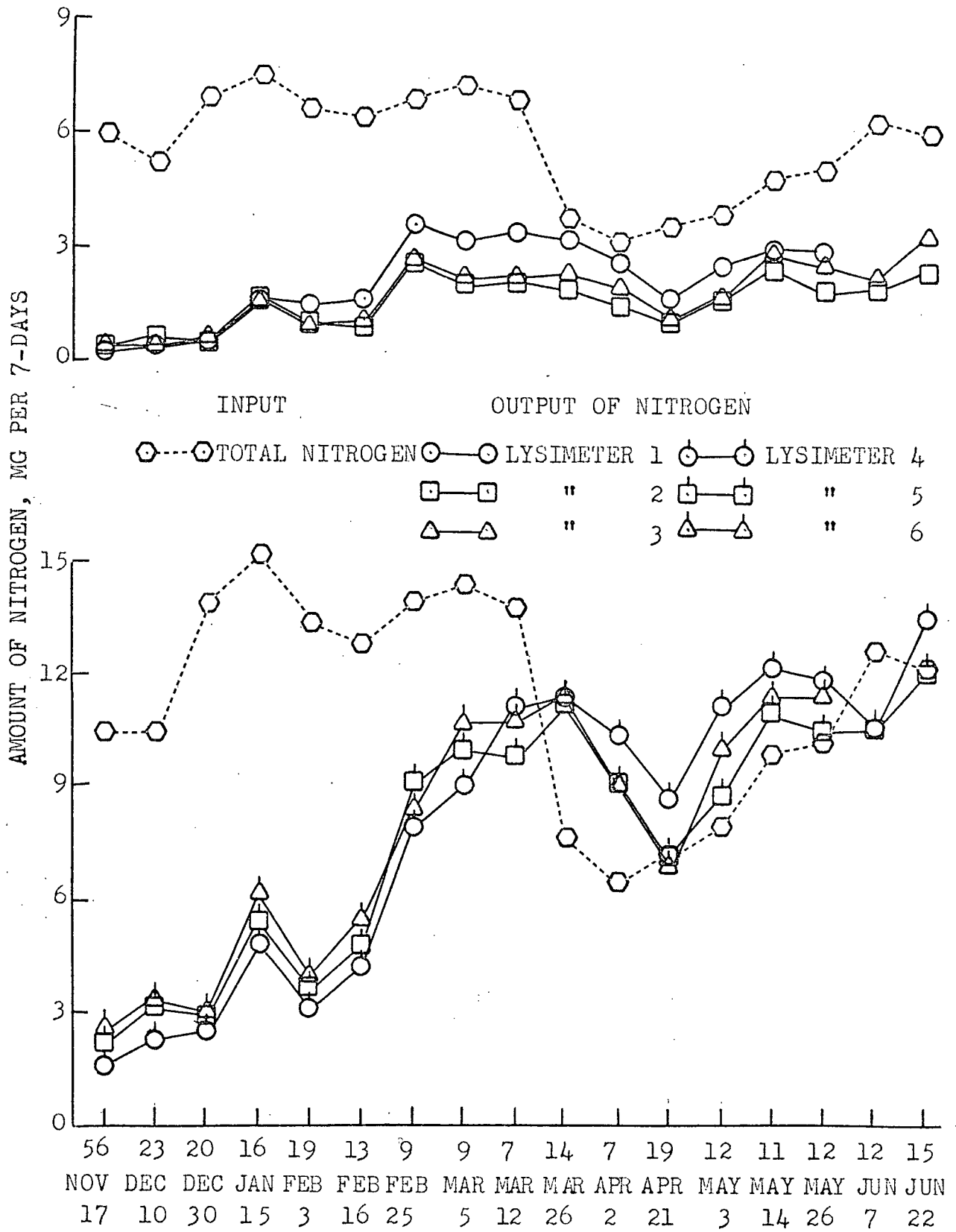
Fig. 7. Total Nitrogen Balances for Lysimeters 1,2,3 (top) and 4,5,6 (bottom).

turn was leached from the soil (Tables 3 and 4). In addition,
the residence time of the wastewater in the soil was relatively
short. Daily recorded data of wastewater input and effluent
output show that about 80 to 90 % of the input water was drained
from the soil within 24 hours. Winsor and Pollard (1956) in one
of their experiments found a maximum nitrogen immobilization of
56 % after 2 days of incubation at 23.5 degrees Centigrade and
80 % moisture equivalent when 100 ml of solution containing 15
mg of inorganic nitrogen (C:N = 5 : 1) was added to a market-
garden soil (C:N = 9.5 : 1). Under field conditions, nitrogen
immobilization could be enhanced by increasing the contact time
between wastewater and soil. Removal of water from the soil by
forest vegetation, resulting in lower antecedent soil water con-
tents, would contribute to the desired increase in contact time.
This could also be done by reducing the application rate of
wastewater to the soil. The total nitrogen output of lysimeters
1, 2, and 3 was 56.5 mg, well below that of the total input 223.7
mg (Tables 1 and 2). This suggested the residence time of
wastewater in the soil was more favourable for biological immo-
bilization for lysimeters 1, 2, and 3 than for lysimeters 4, 5,
and 6.

Carbon Balance

Total soil carbon was determined before and after treatment
of wastewater with the soils. This organic matter served as the
main energy source for the heterotrophic organisms in the con-
version of inorganic nitrogen to organic form in the soil. The
importance of C:N ratio for the immobilization of nitrogen was
demonstrated by Allison (1966) and Winsor and Pollard (1956).

Fig. 8. Distribution of Total Nitrogen in the Soil Profile

Allison observed that the maximum nitrogen immobilization and minimum carbon dioxide production was reached at about 19 to 21 days of incubation when wheat straw and sodium nitrate had been added to a sandy loam. Immediately after the peak, nitrogen mineralization became dominant and carbon dioxide production closely paralleled nitrogen immobilization. This result was comparable with that of Winsor and Pollard, who found that the nitrogen immobilization peak was at two days instead of 20 days. In the conclusion of his review, Allison (1966) pointed out that this difference in maximum nitrogen immobilization is related to the ease of decomposition of organic materials. The decomposition of organic matter was dependent upon its composition. Lignin, oils, fats and resins are resistant to decompostion, while cellulose, starches, sugars, proteins, amono acids, amides, alcohols and aldehydes etc. are readily decomposable. Since sugar is easily decomposable and thus available to microorganisms, a rapid maximum nitrogen immobilization is expected due to the high carbon and energy supply. On the other hand, wheat straw contains lignin and hemicellulose matter that are more resistant to decomposition, so a longer time is needed for the same maximum nitrogen immobilization (Allison, 1966; Buckman and Brady, 1960). In the present experiment, the overall treatment process did not result in any apparent changes in nitrogen and carbon contents of both forest floor and mineral soil (Figures 8 and 9) As can be seen from Table 8, the C:N ratios at the end of the treatment period vary between 25 to 31 and 24 to 35 in the forest floors and 25 to 31 and 22 to 24 in the mineral soils in lysimeters 3 and 4 respectively. The C:N ratios of the original soil

varied from 29 to 33 in the forest floor and was 24 in the minerel soils. This apparent absence of change in the C:N ratios in response to treatment is probably due to the fact that the C:N ratios of both the original soils and added wastewater were not high enough to favor a significant change in biological immobilization. Winsor and Pollard (1956) found that in the glasshouse and market-garden soils, the ratio of carbon added to nitrogen immobilized by microorganisms was 8.3 to 10.8 i.e. 8.3 to 10.8 parts of added carbon are necessary to immobilize one part of nitrogen. Of course, the contact time between wastewater and soil is of prime importance in the process of immobilization as discussed before.

In the present study of forest soil, the C:N ratio of the original mineral soil was 24, and the C:N ratio of the treated soil was similar to that of the original soil in spite of waste water application. The C:N ratio of added wastewater was about 2.5 : 1 based on average concentrations of a BOD of 110 ppm and total nitrogen 26 ppm. It is also important to note that immobilization and mineralization occur together in the soil (Allison, 1966).

Since the total amounts of nitrogen added to the two gruops of soils were only 1.4 % and 2.7 % of the original soil nitrogen as compared to about 5 % experimental error in the analyses, apparent changes in nitrogen content, based on soil analysis before and after treatment, are not likely to be significant. Since the soil was highly aerobic, conditions promoted the oxidation of nitrogen to the nitrate form which was readily subject to leaching. The analyses of drainage water showed that almost
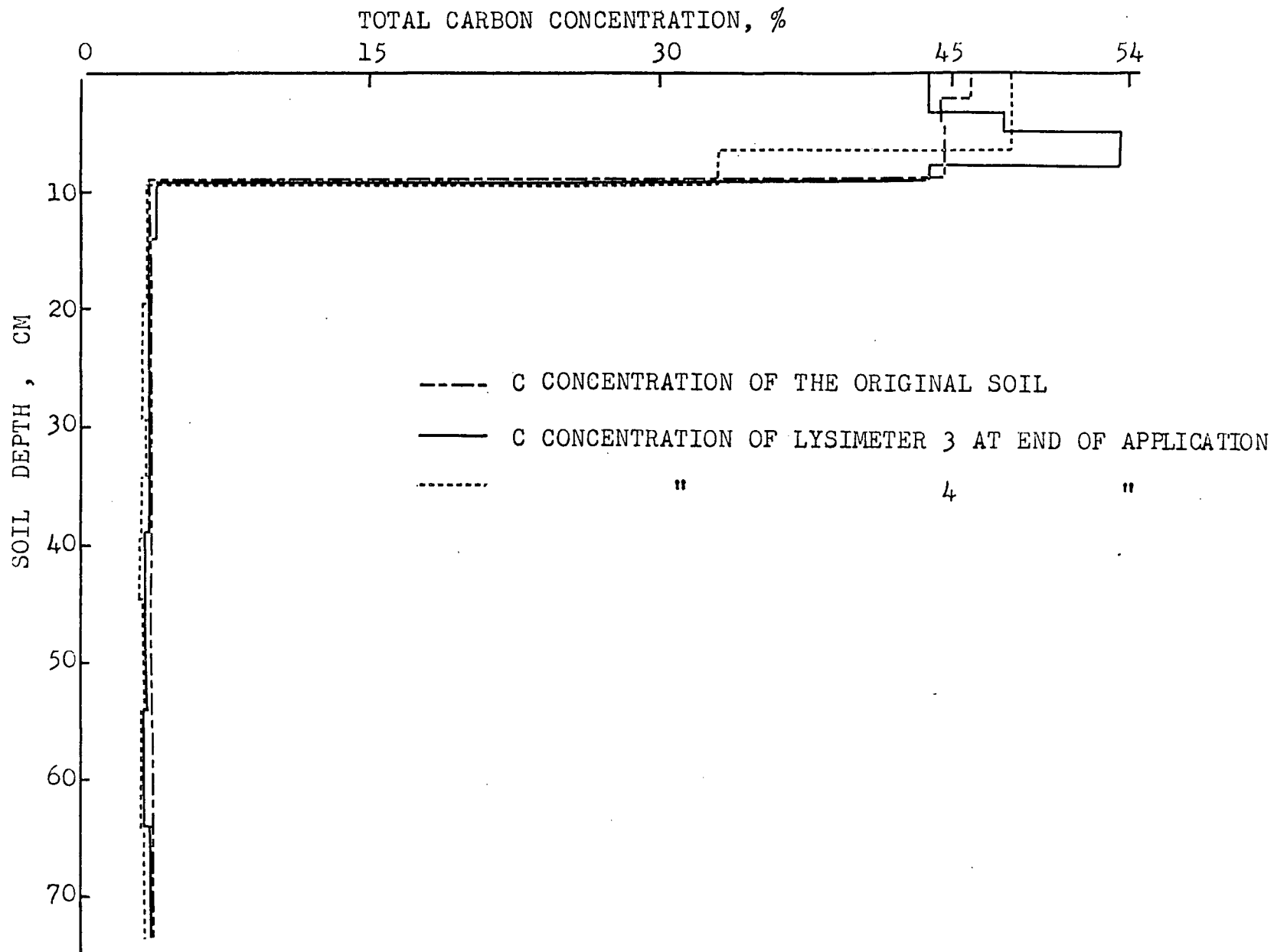
Fig. 9. Dirtribution of Total Carbon in the Soil Profile

all of the nitrogen coming from the soil was in nitrate form
(Table 1).

Phosphorus Removal

Satisfactory retention of phosphorus in the forest soil
(Table 4) was probably associated with relatively high amounts
of reactive iron and aluminium oxides and hydroxides. Data of
total water soluble phosphorus input and output showed that the
retention of added phosphorus was more than 99 % in both soils.
Sopper (1971) found that the renovations of phosphorus in a
hardwood plot subject to respective application rates of 2.5 cm
and 10 cm per week were 99.9 % and 99.3 %, while in a red pine
plot they were 97.0 and 98.7 % with respect to weekly application
rates of 2.5 and 5.0 cm. Both soil depths (silt loam to silty
clay loam) were reported as 60 cm and average phosphorus con-
centration of wastewater was 8.5 mg/l over a period of six months.
Hemwall (1957) reported that fixation of phosphorus mainly
occurred as a result of chemical precipitation and physico-
chemical sorption rather than by microbiological retention. Cole
and Jackson (1950) studied the solubility equilibrium constants
of dihydroxy aluminium dihydrogen phosphate , $Al(OH)_2 H_2PO_4$ -
variscite crystal species, and dihydroxy iron dihydrogen phos-
phate, $Fe(OH)_2 H_2PO_4$ - strengite crystal species, and found that
they related the equilibrium concentration of phosphorus in the
soil solution directly to the aluminium and iron activity of the
soil. However, phosphorus is fixed either by precipitation or
sorption by aluminium and iron oxides and hydroxides under acid
conditions to form $Al(H_2O)_3 (OH)_2 H_2PO_4$ or $Fe(H_2O)_3 (OH)_2 H_2PO_4$
(Hemwall, 1957; Russell, 1961; Tisdale and Nelson, 1966).
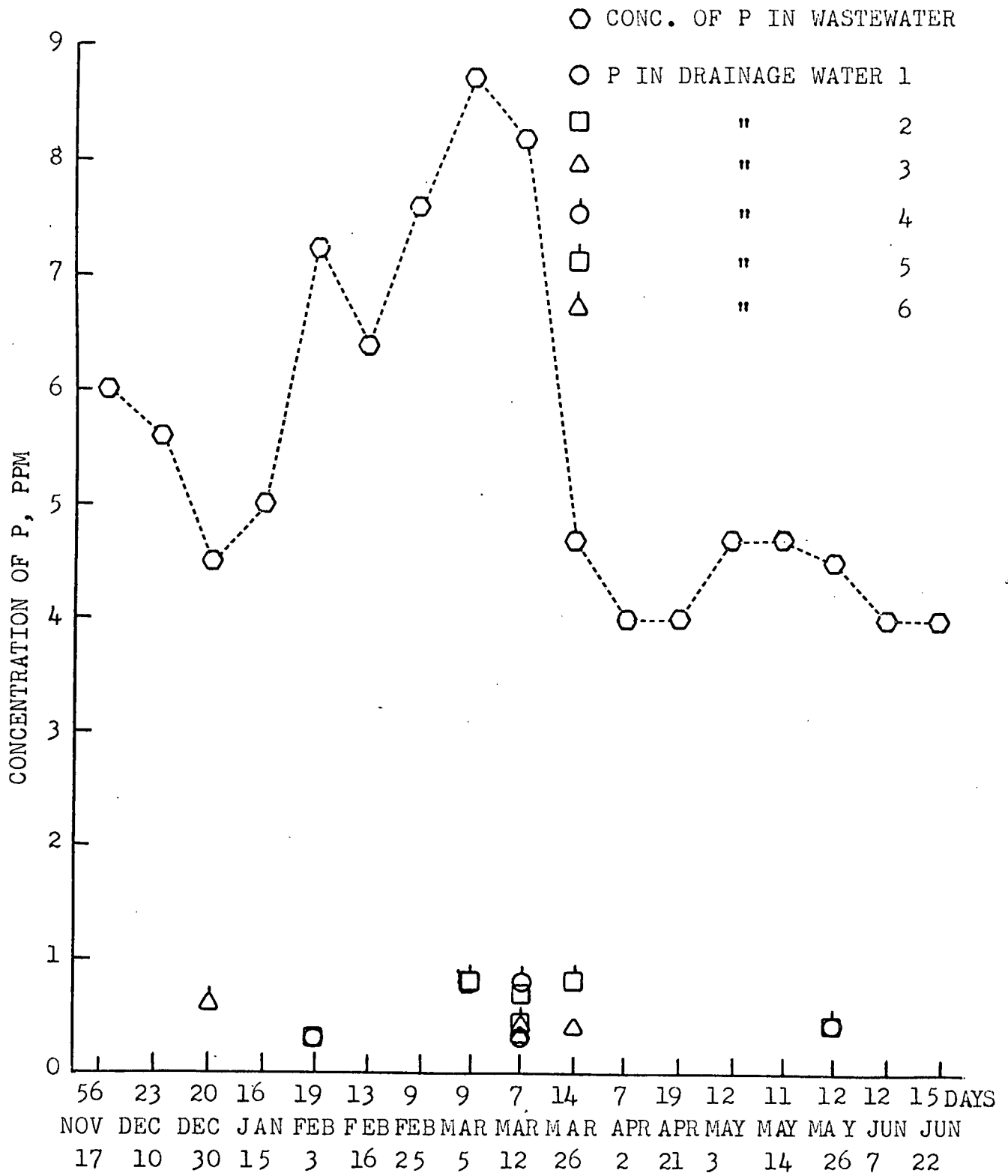
Fig. 10. Concentrations of P in Wastewater and Drainage Water

Physical Properties of the Soil System

Water Retention Properties

Physical properties of the soil are among the important factors in determining the long term suitability of the soil system for wastewater renovation. The results of this research show that the physical behaviour of the soil did not change significantly with time, depending on degree of loading . Figures 11 and 12 show that the water retention characteristics of lysimeter 1 were not changed as compared to the original soil, except in the forest floor where the aeration porosity was relatively reduced. This reduction in aeration porosity of the forest floor was probably due to settling and deposition of organic matter although Figures 8 and 9 did not show significant changes of nitrogen and carbon in lysimeter 1 after wastewater treatment. In the case of lysimeter 6 (Figure 13), the relative total amount of water released by the mineral soil as the matric potential was decreased from 0 to -60 cm of water was higher than that of the original soil, indicating a higher aeration porosity. No specific data were available to account for this result, although the bulk densities of both the original and treated soils in lysimeter 4 (subject to same loadings as in lysimeter 6) were not changed (Table 8). In the forest floor of lysimeter 6, the aeration porosity was relatively lower than that of lysimeter 1 and the original soil. The possible reason may be a higher deposition of organic matter in lysimeter 6.

Saturated Hydraulic Conductivities

Saturated conductivity of the soil was measured to determine
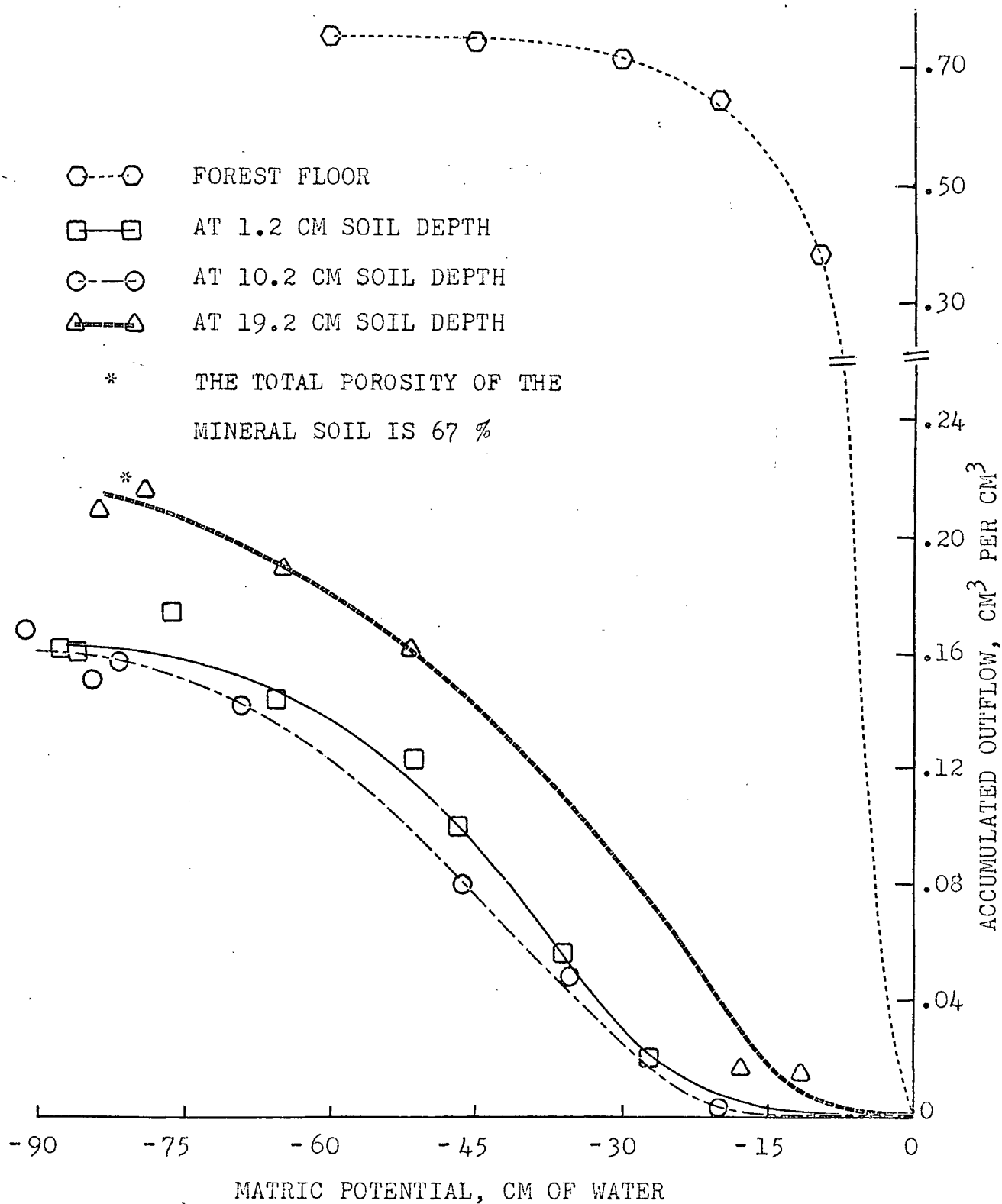
Fig. 11. Water Retention Curve of the Original Soil.
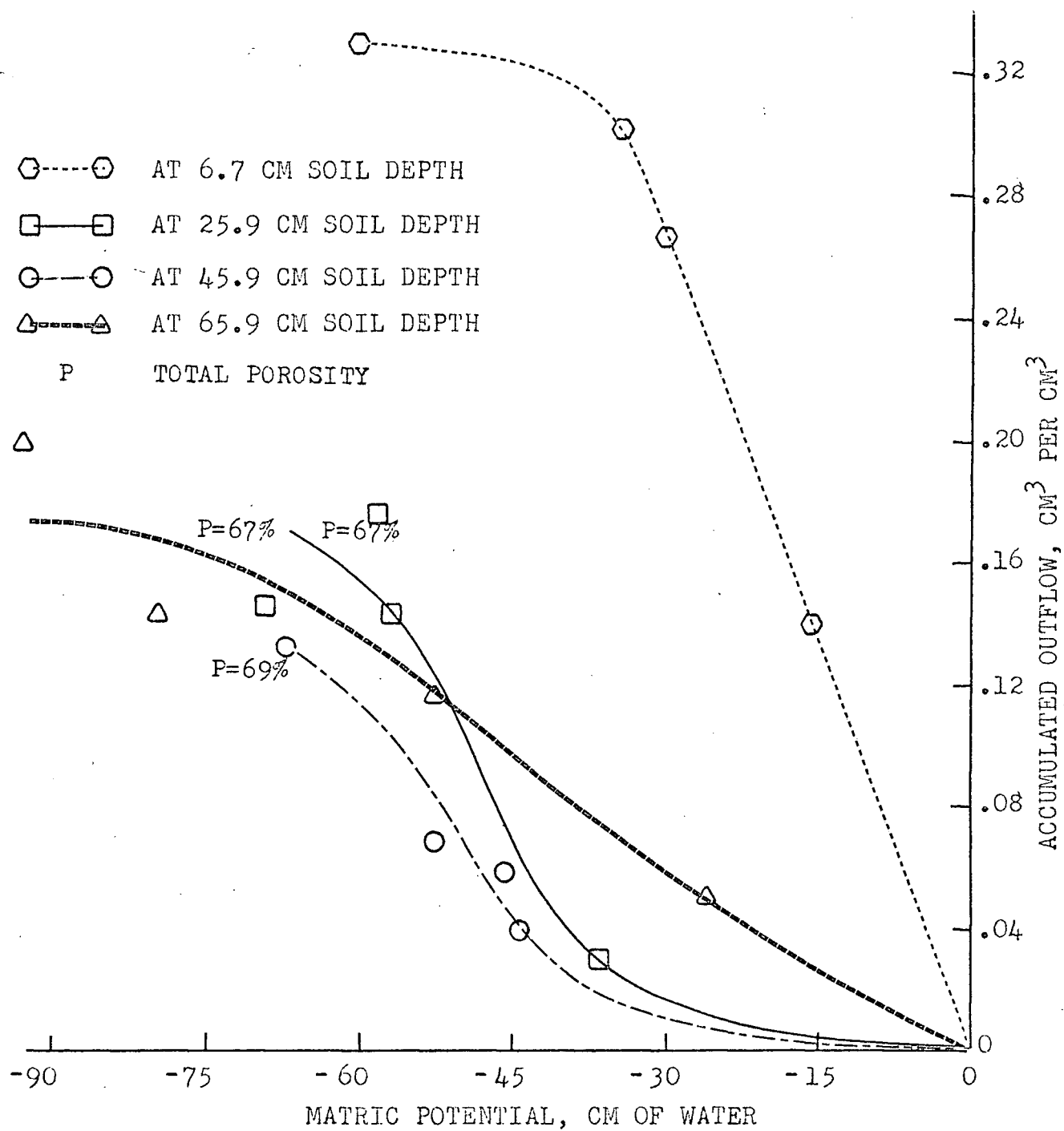
Fig. 12. Water Retention Curve of Lysimeter 1.
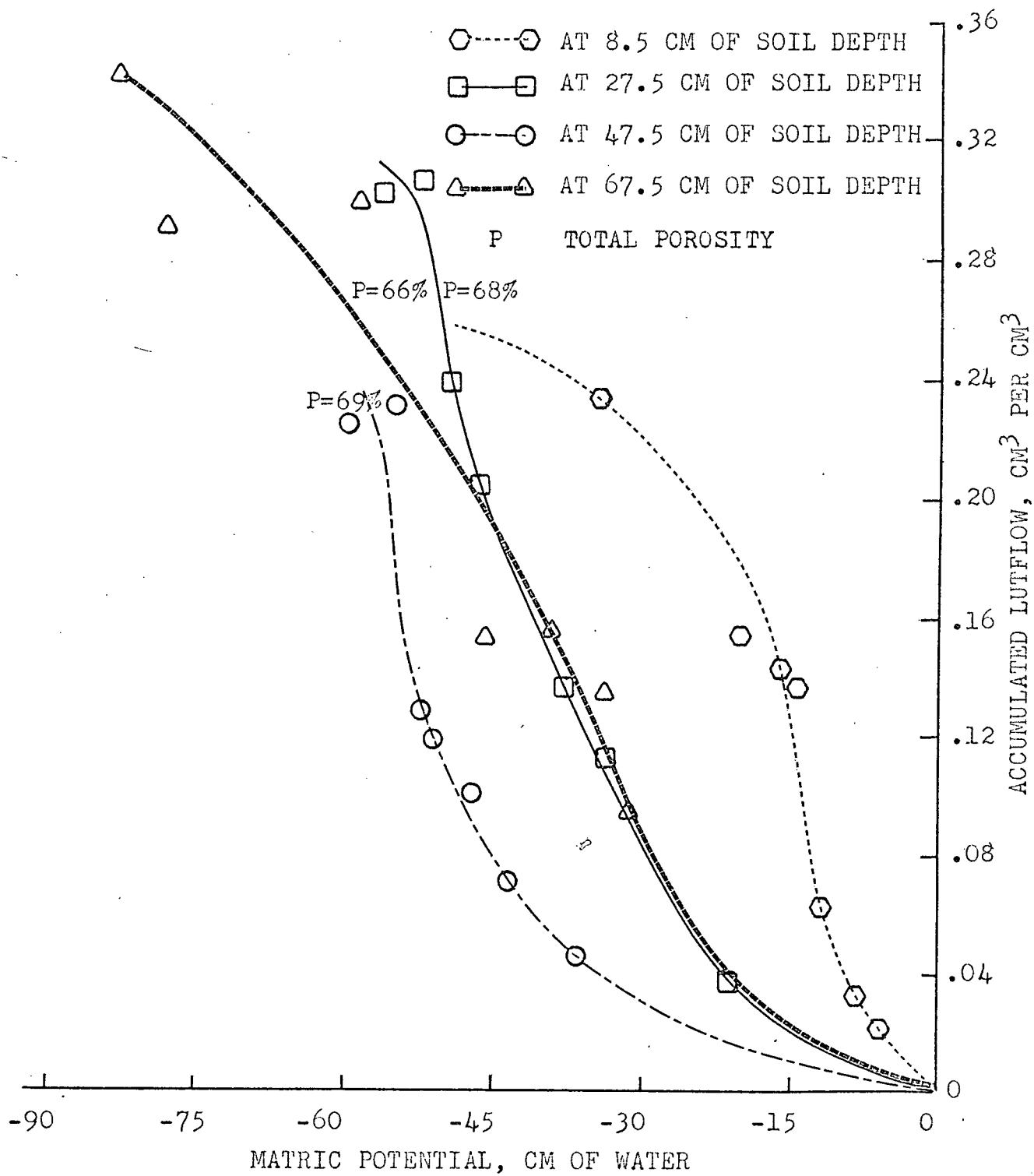
Fig. 13. Water Retention Curve of Lysimeter 6

the effect of wastewater treatment on the soil's ability to transmit water. Figure 14 indicates that the hydraulic conductivities of both soils (lysimeters 1 and 6) were lower than that of the original soil. This result is difficult to explain in view of the fact that the aeration porosity of the mineral soil in lysimeter 6 was higher than that of the original soil (Figures 11 and 13). This might be due to introduction of by-products from microorganisms that might interfere with water movement. McCalla (1950) found that when sucrose was added to soil, the percolation rate dropped rapidly, but when the soil was kept in a refrigerator, the percolation rate did not change. This indicated that the percolation rate had a close relationship with the activity of microorganism. Lysimeters 2 and 5 received the same conditions of treatment with wastewater as lysimeters 1 and 6, but were subjected to a resting and drying of about a month. Results of measurement show that the saturated conductivities of both soil were higher than that of the original soil. The biological activity may have been responsible for the increase of the conductivities.

Since it is likely that the suspended solids in the wastewater, including organic matter, were filtered out by the forest floor, the activity of microorganisms in the forest floor probably was very high. This can be seen from the water retention and hydraulic conductivity characteristics where the aeration porosity of the treated forest floor is much lower than that of the original sample.

Physical Changes Occuring During Incubation

Physical changes in the soil profile during incubation were
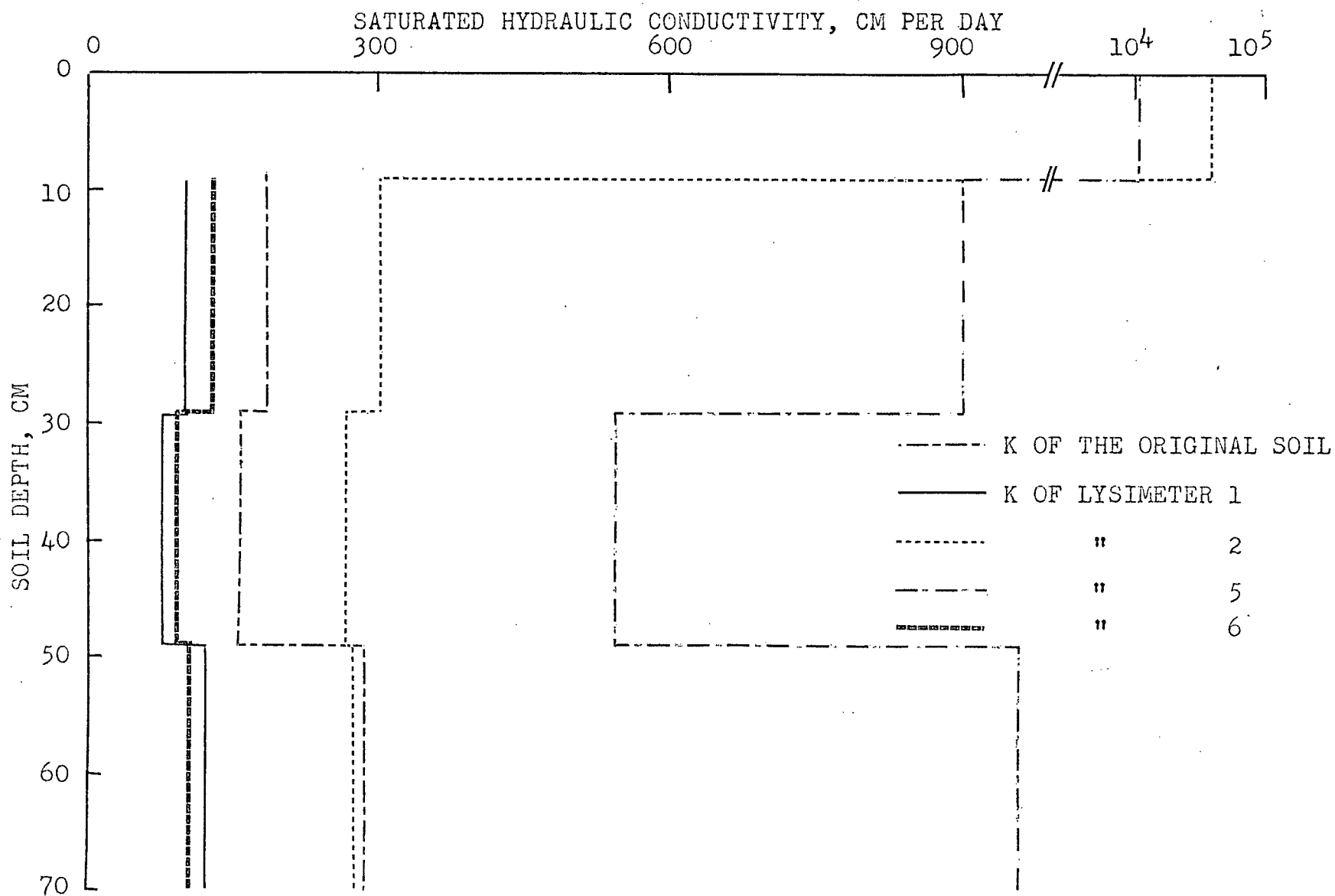
Fig. 14.   Saturated Hydraulic Conductivity of The Soils

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evaluated during wastewater application. Figures 15 and 16 show that both the matric and total potentials decrease with depth. This implies a downward movement of water in the soil profile. The top 20 cm of lysimeter 1 ($d\Psi/dZ = 3.4$) had a steeper potential gradient than that below 20 cm indicating a lower conductivity across the 0 to 20 cm depth interval, assuming a constant flux with depth (Darcy's Law). A transmission zone existed in the depth intervals from 24 cm to 44 cm. The water content and matric potential were approximately constant across the zone and the only driving force was the gravitational potential gradient. The total potential gradient was unity, and the hydraulic conductivity was equal to the flux. Calculations based on Darcy's Law in Figures 15 and 16 show that the unsaturated conductivities within this zone in lysimeters 1 and 4 are 0.16 cm per day and 0.27 cm per day at matric potentials -50 and -40 cm of water respectively.
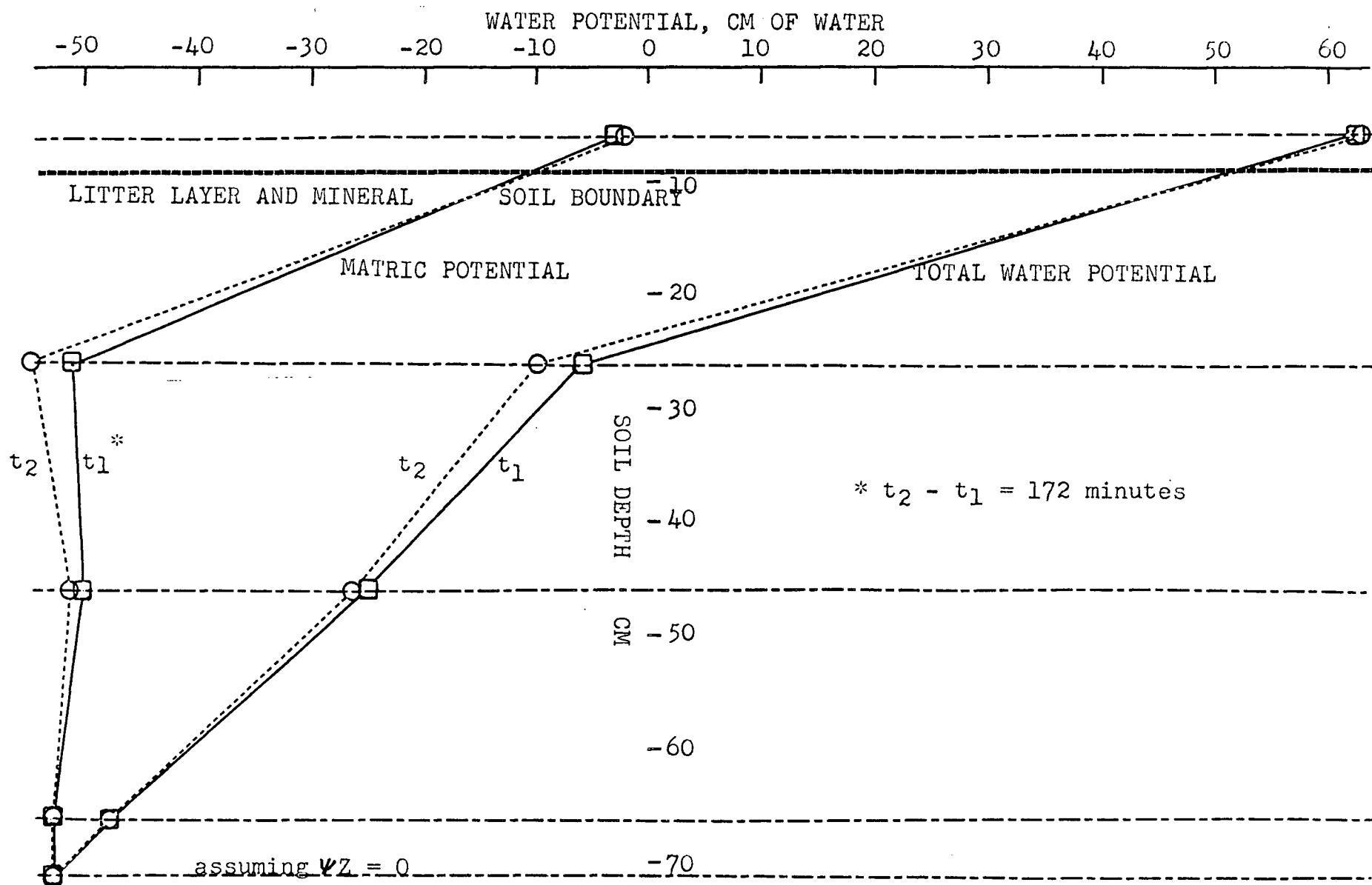
Fig. 15. Changes of Total Water Potential with Time and Depth for the Forest Soil
During Incubation in Lysimeter 1.

WATER POTENTIAL, CM OF WATER

-50   -40   -30   -20   -10   0   10   20   30   40   50   60

LITTER LAYER AND MINERAL SOIL BOUNDARY

MATRIC POTENTIAL   - 20   TOTAL WATER POTENTIAL

SOIL

- 40

t_2 t_1 * t_2 t_1 * $t_2 - t_1$ = 172 minutes

DEPTH

CM 60

assuming $\Psi Z = 0$ - 70
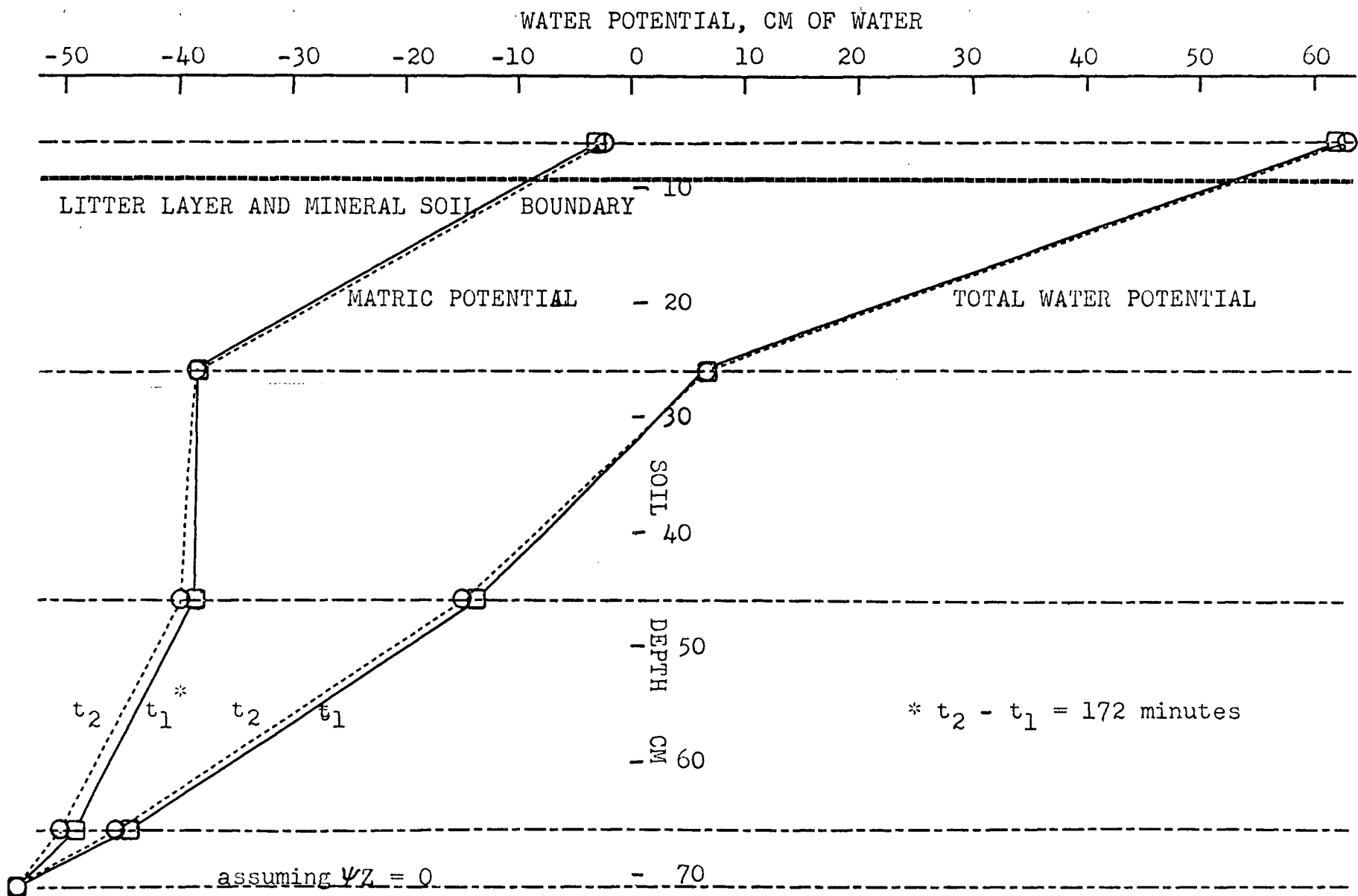
Fig. 16.   Changes of Total Water Potential with Time and Depth for the Forest Floor During Incubation in Lysimeter 4.

CONCLUSION

It is of scientific and practical importance to charac-
terize the nature of the forest soil with respect to chemical,
physical and possible biological changes. Results of this re-
search suggest that a large scale field operation is feasible.
Most of the nutrients lost by leaching in this experiment can
be taken up by trees in the field. It has been reported that a
coniferous forest has a maximum annual uptake of 50 - 60 kg N
per hectare (45 - 54 lb N per acre) and 6 - 12 kg P per hec-
tare (5 - 11 lb P per acre) (Cole, Gessel and Dice, 1967).
The total N and P applied to both groups of soil lysimeters in
our study were 143 - 280 kg N per hectare (128 - 250 lb N per
acre) and 30 - 59 kg P per hectare (27 - 53 lb P per acre).
This indicated the total available nutrients applied exceeded
the maximum demand of forest trees. For field operation, a
smaller wastewater application rate is suggested than that used
in the present experiment in order to increase soil wastewater
contact time, reduce leaching loss and maximize nitrogen uptake
by forest trees. Therefore, care should be exercised in loading,
both in terms of quantity and duration. A project that can be
looked upon as a follow-up of this study will be carried out in
the University of British Columbia Research Forest in Haney, B.
C.

Brief conclusions are therefore drawn from the results re-
ported herein with regard to disposal of wastewater on the forest
soil:

1. About 73 % of the total wastewater applied was leached from

the soil, suggesting that a large quantity of water could be recharged as ground water or taken up by vegetation under field conditions.

2. Satisfactory renovation of wastewater with respect to phosphorus and nitrogen was achieved at an application rate of 0.23 cm per day during the period September, 1971, to June, 1972.

3. Nitrogen concentration of drainage water increased with time in both groups of lysimeters.

4. The output of total nitrogen from lysimeters 4,5,6 (with application rate of 0.46 cm per day) exceeded that of input after 25 weeks of loading indicating low degree of biological immobilization.

5. Nitrogen balance data showed that renovation of the waste water with respect to nitrogen in lysimeters 1, 2, and 3 (with application rate of 0.23 cm per day) attained a value as high as 75 %, but renovation in lysimeters 4, 5, and 6 was only 43 %. The renovation would be higher under vegetation growth.

6. The C:N ratios were quite constant in both groups of soils, probably due to the balanced immobilization and mineralization of nitrogen. The low C:N ratio of organic matter added, as compared to the original soil, and ease of organic decomposition in the forest floor were important factor for this constancy.

7. Renovation of the wastewater with respect to phosphorus by the forest soil was as high as 99.4 % and 99.0 % in lysimeters 3 and 4 due to the high contents of reactive aluminium

and iron oxides and their hydroxides in the acid mineral soil.

8. Renovation of the wastewater with respect to BOD (biochemical oxygen demand) was 100 % in both groups of soils.

9. The physical properties of the soils were not greatly altered by a prolonged period of wastewater applications, except in the forest floor where aeration porosity was reduced.

10. It is suggested that further research might be carried out on biological effects of alternate wetting and drying, where wastewater is applied to the forest soil. In addition, retention of other nutrients from wastewater in forest soil should be evaluated.

11. Further research on contamination of soil with heavy metals from wastewater disposal should also be carried out.

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APPENDIX

Table 1. Concentrations and Amount of N in Wastewater
Applied to Lysimeters 1, 2, and 3.

Periods	Days	cm^3	cm^3 per 7-day	NO_3-N ppm	N ppm	N mg	N mg/ 7-day	Water cm^3	Water cm^3/ 7-day
Sep 23-Nov 17	56	1633	204.1	1.5	29.3	47.87	5.98	77	9.6
Nov 18-Dec 10	23	630	191.7	1.6	26.9	16.95	5.16	200	60.9
Dec 11-Dec 30	20	597	210.0	1.0	32.8	19.7	6.90	200	70.0
Dec 31-Jan 15	16	516	225.8	1.0	33.4	17.26	7.55	100	43.8
Jan 16-Feb 3	19	599	220.7	0.5	30.2	18.11	6.67	300	110.5
Feb 4-Feb 16	13	450	242.3	0.3	26.4	11.89	6.40	0	0
Feb 17-Feb 25	9	300	233.3	0.3	29.7	8.91	6.93	200	155.6
Feb 26-Mar 5	9	298	231.8	1.1	30.8	9.18	7.14	100	77.8
Mar 6-Mar 12	7	260	262.0	0.6	26.2	6.86	6.86	100	100.0
Mar 13-Mar 26	14	522	261.0	0.6	14.6	7.61	3.81	200	100.0
Mar 27-Apr 2	7	224	224.0	0.6	14.3	3.20	3.20	50	50.0
Apr 3-Apr 21	19	557	205.2	0.6	17.3	9.62	3.54	100	36.8
Apr 22-May 3	12	372	217.0	1.0	18.2	6.76	3.94	100	58.3
May 4-May 14	11	371	236.1	1.2	20.5	7.61	4.84	100	63.6
May 15-May 26	12	408	238.0	0.7	21.0	8.58	5.00	50	29.2
May 27-Jun 7	12	372	217.0	0.5	28.8	10.73	6.26	200	116.7
Jun 8-Jun 22	15	450	210.0	0.4	28.6	12.88	6.01	100	46.7
Total	274	8561				223.72		2177	

Table 2A.   Concentrations and Amount of N in Drainage
Water from Lysimeter 1.

Periods	Days	cm^3	cm^3 per 7-day	NO$_3$-N ppm	N ppm	N mg	N mg/ 7-day
Sep 23-Nov 18	56	1100.0	137.5	2.0	2.0	2.20	0.28
Nov 19-Dec 11	23	544.0	165.8	2.7	2.8	1.50	0.46
Dec 12-Dec 31	20	341.5	119.8	4.0	4.1	1.39	0.49
Jan 1-Jan 16	16	729.6	319.0	5.4	5.5	4.02	1.76
Jan 17-Feb 4	19	571.3	211.5	6.8	7.0	3.99	1.48
Feb 5-Feb 17	13	343.2	184.8	8.0	8.8	3.05	1.64
Feb 18-Feb 26	9	421.6	328.0	10.8	11.2	4.73	3.67
Feb 27-Mar 6	9	324.0	252.0	12.0	12.9	4.18	3.25
Mar 7-Mar 13	7	261.1	261.1	12.8	13.3	3.48	3.48
Mar 14-Mar 27	14	451.3	225.7	13.5	14.4	6.51	3.26
Mar 28-Apr 3	7	207.6	207.6	12.0	12.6	2.61	2.61
Apr 4-Apr 22	19	351.7	129.6	12.8	13.2	4.64	1.72
Apr 23-May 4	12	311.0	181.4	13.7	14.2	4.41	2.57
May 5-May 15	11	262.1	166.2	17.8	18.4	4.80	3.05
May 16-May 27	12	253.8	147.8	19.2	19.8	5.01	2.92
May 28-Jun 8	12	-	-	-	-	-	-
Jun 9-Jun 23	15	-	-	-	-	-	-
Total	247	6473.8				56.52	

Table 2B. Concentrations and Amount of N in Drainage
Water from Lysimeter 2.

Periods	Days	cm^3	cm^3 per 7-day	NO_3-N ppm	N ppm	N mg	N mg/ 7-day
Sep 23-Nov 18	56	1134.0	142.0	3.2	3.4	3.86	0.36
Nov 19-Dec 11	23	575.5	175.0	3.5	3.7	2.14	0.65
Dec 12-Dec 31	20	374.5	130.8	4.3	4.4	1.64	0.57
Jan 1-Jan 16	16	717.8	313.2	4.7	5.3	3.80	1.66
Jan 17-Feb 4	19	548.2	202.4	4.7	5.2	2.84	1.04
Feb 5-Feb 17	13	307.4	165.8	4.8	5.7	1.76	0.95
Feb 18-Feb 26	9	464.6	360.8	7.0	7.3	3.40	2.64
Feb 27-Mar 6	9	313.7	244.0	7.6	8.2	2.57	2.00
Mar 7-Mar 13	7	251.3	251.3	7.0	8.2	2.06	2.06
Mar 14-Mar 27	14	431.5	215.8	8.4	8.8	3.82	1.91
Mar 28-Apr 3	7	191.6	191.6	7.8	8.0	1.53	1.53
Apr 4-Apr 22	19	370.3	136.2	7.3	7.8	2.86	1.06
Apr 23-May 4	12	315.1	183.8	8.5	8.8	2.76	1.62
May 5-May 15	11	250.5	159.0	14.2	14.6	3.73	2.37
May 16-May 27	12	231.7	135.0	14.9	15.2	3.53	2.06
May 28-Jun 8	12	241.5	140.8	13.0	13.5	3.26	1.91
Jun 9-Jun 23	15	403.2	188.0	13.0	13.0	5.21	2.43
Total	274	7132.4				50.77	

Table 2C. Concentrations and Amount of N in Drainage
Water from Lysimeter 3.

Periods	Days	cm^3	cm^3 per 7-day	NO$_3$-N ppm	N ppm	N mg	N mg/ 7-day
Sep 23-Nov 18	56	1165.0	145.6	2.5	2.50	2.91	0.36
Nov 19-Dec 11	23	551.0	167.7	2.2	2.23	1.23	0.37
Dec 12-Dec 31	20	342.0	119.7	3.6	3.60	1.23	0.43
Jan 1-Jan 16	16	688.7	301.3	4.9	4.94	3.40	1.48
Jan 17-Feb 4	19	550.6	202.8	4.0	4.70	2.59	0.95
Feb 5-Feb 17	13	344.8	185.7	5.5	5.94	2.05	1.10
Feb 18-Feb 26	9	415.6	323.2	8.0	8.40	3.49	2.71
Feb 27-Mar 6	9	329.5	256.3	8.0	8.62	2.84	2.21
Mar 7-Mar 13	7	259.3	259.3	8.0	8.52	2.21	2.21
Mar 14-Mar 27	14	475.9	238.0	9.0	9.79	4.66	2.33
Mar 28-Apr 3	7	221.7	221.7	8.1	8.93	1.98	1.98
Apr 14-Apr 22	19	369.5	136.1	8.5	9.17	3.39	1.25
Apr 23-May 4	12	259.7	151.5	11.0	11.63	3.02	1.76
May 5-May 15	11	247.0	157.2	17.1	17.85	4.41	2.81
May 16-May 27	12	236.3	137.8	17.9	18.70	4.42	2.58
May 28-Jun 8	12	226.0	131.8	16.5	17.30	3.91	2.28
Jun 9-Jun 23	15	397.9	185.7	17.5	17.89	7.12	3.32
Total	274	7080.5				54.86	

Table 3. Concentrations and Amount of N in Wastewater
Applied to Lysimeters 4, 5, and 6.

Periods	Days	cm^3	cm^3 per 7-day	NO_3-N ppm	N ppm	N mg	N mg/ 7-day	Water cm^3	Water cm^3/ 7-day
Sep 23-Nov 17	56	2842	355.3	1.5	29.3	83.27	10.44	95	11.9
Nov 18-Dec 10	23	1275	388.0	1.6	26.9	34.29	10.44	200	60.9
Dec 11-Dec 30	20	1200	420.0	1.0	32.8	39.60	13.86	200	70.0
Dec 31-Jan 15	16	1050	459.4	1.0	33.4	34.65	15.16	100	43.8
Jan 16-Feb 3	19	1200	442.1	0.5	30.2	36.27	13.36	300	110.5
Feb 4-Feb 16	13	900	484.6	0.3	26.4	23.76	12.79	0	0
Feb 17-Feb 25	9	600	466.7	0.3	29.7	17.82	13.86	200	155.6
Feb 26-Mar 5	9	600	466.7	1.1	30.8	18.48	14.37	100	77.8
Mar 6-Mar 12	7	525	525.0	0.6	26.2	13.74	13.74	100	100.0
Mar 13-Mar 26	14	1050	525.0	0.6	14.6	15.31	7.66	200	100.0
Mar 27-Apr 2	7	450	450.0	0.6	14.3	6.44	6.44	50	50.0
Apr 3-Apr 21	19	1125	414.5	0.6	17.3	19.29	7.11	100	36.8
Apr 22-May 3	12	750	437.5	1.0	18.2	13.63	7.95	100	58.3
May 4-May 14	11	750	477.3	1.2	20.5	15.40	9.80	100	63.6
May 15-May 26	12	825	481.2	0.7	21.0	17.36	10.13	50	29.2
May 27-Jun 7	12	750	437.5	0.5	28.8	21.60	12.60	200	116.7
Jun 8-Jun 22	15	900	420.0	0.4	28.6	25.97	12.12	100	46.7
Total	274	16792				436.88		2195	

Table 4A. Concentrations and Amount of N in Drainage
Water from Lysimeter 4.

Periods	Days	cm^3	cm^3 per 7-day	NO$_3$-N ppm	N ppm	N mg	N mg/ 7-day
Sep 24-Nov 18	56	2272.0	284.0	5.6	5.6	12.72	1.59
Nov 19-Dec 11	23	1251.9	381.0	5.7	5.9	7.40	2.25
Dec 12-Dec 31	20	870.0	304.5	7.8	8.0	6.95	2.43
Jan 1-Jan 16	16	1270.1	555.7	8.3	8.6	10.96	4.79
Jan 17-Feb 4	19	1027.2	378.4	7.5	8.1	8.36	3.08
Feb 5-Feb 17	13	794.9	428.0	9.3	9.9	7.85	4.23
Feb 18-Feb 26	9	714.5	555.7	14.0	14.4	10.28	8.00
Feb 27-Mar 6	9	639.9	497.7	17.9	18.1	11.58	9.01
Mar 7-Mar 13	7	540.0	540.0	20.0	20.4	11.02	11.02
Mar 14-Mar 27	14	968.9	484.5	23.0	23.4	22.72	11.36
Mar 28-Apr 3	7	431.7	431.7	23.7	24.0	10.38	10.38
Apr 4-Apr 22	19	894.7	329.6	26.0	26.5	23.69	8.73
Apr 23-May 4	12	684.4	399.2	27.5	27.8	19.04	11.11
May 5-May 15	11	643.0	409.2	29.2	29.7	19.12	12.17
May 16-May 27	12	632.3	368.8	31.9	32.2	20.33	11.86
May 28-Jun 8	12	567.2	330.9	31.7	32.0	18.17	10.60
Jun 9-Jun 23	15	919.6	429.1	31.2	31.3	28.77	13.43
Total	274	15122.3				249.34	

Table 4B.   Concentrations and Amount of N in Drainage
Water from Lysimeter 5.

Periods	Days	cm^3	cm^3 per 7-day	NO_3-N ppm	N ppm	N mg	N mg/ 7-day
Sep 23-Nov 18	56	2269.0	287.0	7.7	7.7	17.68	2.21
Nov 19-Dec 11	23	1309.5	397.0	7.8	7.8	10.26	3.13
Dec 12-Dec 31	20	871.5	305.8	9.3	9.3	8.12	2.85
Jan 1-Jan 16	16	1374.5	598.0	8.5	9.0	12.42	5.42
Jan 17-Feb 4	19	1065.3	393.5	9.1	9.4	9.97	3.67
Feb 5-Feb 17	13	780.6	420.2	10.6	11.2	8.62	4.64
Feb 18-Feb 26	9	773.6	603.0	14.6	14.9	11.54	8.95
Feb 27-Mar 6	9	673.5	525.0	18.3	18.9	12.74	9.90
Mar 7-Mar 13	7	483.7	483.7	19.7	20.2	9.72	9.72
Mar 14-Mar 27	14	974.8	487.4	22.2	22.6	22.14	11.07
Mar 28-Apr 3	7	421.3	421.3	21.1	21.5	9.08	9.08
Apr 4-Apr 22	19	880.5	324.5	21.7	22.2	19.53	7.18
Apr 23-May 4	12	719.6	420.0	22.9	23.2	16.72	9.75
May 5-May 15	11	635.1	404.0	26.9	27.2	17.30	11.00
May 16-May 27	12	594.7	347.0	29.7	30.0	17.85	10.40
May 28-Jun 8	12	571.2	334.0	30.3	30.7	17.47	10.20
Jun 9-Jun 23	15	846.9	395.0	29.4	29.8	25.30	11.82
Total	274	15245.3				246.48	

Table 4C. Concentrations and Amount of N in Drainage
Water from Lysimeter 6.

Periods	Days	cm^3	cm^3 per 7-day	NO_3-N ppm	N ppm	N mg	N mg/ 7-day
Sep 23-Nov 18	56	2270.0	287.0	9.0	9.0	20.42	2.55
Nov 19-Dec 11	23	1248.5	379.0	8.7	8.7	10.94	3.31
Dec 12-Dec 31	20	865.0	303.0	9.9	9.9	8.54	2.98
Jan 1-Jan 16	16	1283.9	561.5	10.4	10.9	13.99	6.12
Jan 17-Feb 4	19	1106.1	407.0	8.7	9.2	10.86	4.00
Feb 5-Feb 17	13	861.9	464.5	11.2	11.8	10.17	5.47
Feb 18-Feb 26	9	702.5	547.0	15.0	15.2	10.72	8.32
Feb 27-Mar 6	9	669.5	522.0	19.0	19.2	12.94	10.70
Mar 7-Mar 13	7	512.6	512.6	20.8	21.0	10.75	10.75
Mar 14-Mar 27	14	963.2	481.6	22.9	23.2	22.36	11.18
Mar 28-Apr 3	7	416.5	416.5	21.8	22.1	9.19	9.19
Apr 4-Apr 22	19	866.1	318.0	21.2	21.5	18.63	6.83
Apr 23-May 4	12	719.8	420.0	23.4	23.7	17.13	9.96
May 5-May 15	11	655.6	417.0	26.9	27.4	17.96	11.40
May 16-May 27	12	583.6	341.0	30.2	30.4	17.86	10.42
May 28-Jun 8	12	-	-	-	-	-	-
Jun 9-Jun 23	15	-	-	-	-	-	-
Total	247	13723.8				212.46	

Table 5. Concentrations and Amount of Total Soluble P in Wastewater and Drainage Water in Lysimeters 1, 2, and 3.

Time	Wastewater			Drainage Water								
	P	P	P mg/	P			P			P mg/		
days	ppm	mg	7-day	ppm			mg			7-day		
				1	2	3	1	2	3	1	2	3
56	6.0	9.80	1.22	0	0	0	0	0	0	0	0	0
23	5.6	3.53	1.07	0	0	0	0	0	0	0	0	0
20	4.5	2.69	0.94	0	0	0	0	0	0	0	0	0
16	5.0	2.58	1.13	0	0	0	0	0	0	0	0	0
19	7.2	4.31	1.60	0	0.3	0	0	0.16	0	0	0.06	0
13	6.4	2.84	1.53	0	0	0	0	0	0	0	0	0
9	7.6	2.28	1.77	0	0	0	0	0	0	0	0	0
9	8.7	2.59	2.02	0	0	0	0	0	0	0	0	0
7	8.2	2.15	2.15	0.3	0.7	0.3	0.08	0.18	0.08	0.08	0.18	0.08
14	4.7	2.45	1.23	0	0	0.4	0	0	0.19	0	0	0.10
7	4.0	0.90	0.90	0	0	0	0	0	0	0	0	0
19	4.0	2.22	0.82	0	0	0	0	0	0	0	0	0
12	4.7	1.75	1.02	0	0	0	0	0	0	0	0	0
11	4.7	1.74	1.11	0	0	0	0	0	0	0	0	0
12	4.5	1.83	1.07	0.4	0.4	0	0.10	0.09	0	0.06	0.05	0
12	4.0	1.49	0.87	–	0	0	–	0	0	–	0	0
15	4.0	1.80	0.84	–	0	0	–	0	0	–	0	0
274		46.95					0.18	0.43	0.27		(Total)	

Table 6.   Concentrations and Amount of Total Soluble P
in Wastewater and Drainage Water in Lysimeters
4, 5, and 6.

Time	Wastewater			Drainage Water								
	P	P	P mg/ 7-day	P ppm			P mg			P mg/ 7-day		
days	ppm	mg	7-day	4	5	6	4	5	6	4	5	6
56	6.0	17.20	2.15	0	0	0	0	0	0	0	0	0
23	5.6	7.10	2.17	0	0	0	0	0	0	0	0	0
20	4.5	5.40	1.89	0	0.6	0	0	0.52	0	0	0.18	0
16	5.0	5.25	2.30	0	0	0	0	0	0	0	0	0
19	7.2	8.64	2.45	0.3	0	0	0.31	0	0	0.11	0	0
13	6.4	5.76	3.10	0	0	0	0	0	0	0	0	0
9	7.6	4.56	3.55	0	0	0	0	0	0	0	0	0
9	8.7	5.22	4.06	0	0	0.8	0	0	0.54	0	0	0.42
7	8.2	4.31	4.31	0.8	0.4	0.4	0.43	0.19	0.21	0.43	0.19	0.21
14	4.7	4.94	2.47	0	0	0.8	0	0	0.77	0	0	0.39
7	4.0	1.80	1.80	0	0	0	0	0	0	0	0	0
19	4.0	4.50	1.66	0	0	0	0	0	0	0	0	0
12	4.7	3.53	2.06	0	0	0	0	0	0	0	0	0
11	4.7	3.53	2.25	0	0	0	0	0	0	0	0	0
12	4.5	3.71	2.17	0.4	0	0.4	0.25	0	0.23	0.15	0	0.14
12	4.0	3.00	1.75	0	0	–	0	0	–	0	0	–
15	4.0	3.60	1.68	0	0	–	0	0	–	0	0	–
274		92.05					0.99	1.51	1.52		(Total)	

Table 7. Chemical and Physical Properties of the Original
Soil and the Treated Soil in Lysimeter 3.

Soil Depth cm	Total Kjeldhal N %	NH_4-N ppm	Total N %	C %	C:N	pH	Water Content gm/gm	Bulk Density gm/cm^3
0 -3.5	1.53	296.2	1.53	43.72	28.56	-	3.31	-
3.5- 5	1.89	602.2	1.90	47.50	25.00	-	3.32	-
5 - 8	1.66	676.3	1.66	53.50	32.23	-	4.18	-
8 - 9	1.40	431.7	1.41	43.70	30.99	-	4.07	-
9 -14	0.14	24.9	0.14	3.90	27.86	4.04	0.34	0.81
14 -19	0.14	3.8	0.14	3.61	25.79	4.03	0.44	0.84
19 -24	0.14	3.4	0.14	3.52	25.14	4.06	0.44	0.86
24 -29	0.13	2.7	0.13	3.42	26.31	4.25	0.44	0.88
29 -34	0.10	1.2	0.11	3.40	30.90	4.44	0.44	0.90
34 -39	0.12	1.4	0.12	3.52	29.33	4.57	0.45	0.88
39 -44	0.12	1.6	0.12	3.27	27.25	4.60	0.45	0.88
44 -49	0.12	1.4	0.12	3.41	28.42	4.72	0.46	0.87
49 -54	0.13	1.2	0.13	3.46	26.62	4.68	0.46	0.89
54 -59	0.13	1.2	0.13	3.22	24.77	4.64	0.46	0.88
59 -64	0.12	1.2	0.13	3.23	24.85	4.65	0.45	0.83
64 -69	0.13	8.7	0.13	3.51	27.00	4.65	0.46	0.82
69 -71	0.13	16.6	0.13	3.51	27.00	4.65	-	-
Original Soil								
L (0 -2.2)	1.38	-	1.38	45.89	33.33	-	-	-
F (2.2-4.2)	1.51	-	1.51	44.35	29.45	-	-	-
H (4.2-9.0)	1.56	-	1.56	44.44	28.56	-	-	-
Soil Layer	0.15	-	0.15	3.46	23.72	4.65	0.45	0.88

Table 8. Chemical and Physical Properties of the Original Soil and the Treated Soil in Lysimeter 4.

Soil Depth	Total Kjeldhal N	NH$_4$-N	Total N	C	C:N	pH	Water Content	Bulk Density
cm	%	ppm	%	%			gm/gm	gm/cm^3
0 - 3	1.38	128.6	1.38	48.10	34.86	-	2.92	-
3 - 7	1.76	481.3	1.77	48.20	27.23	-	2.93	-
7 - 9.5	1.37	408.7	1.38	32.89	23.83	-	3.73	-
9.5-14.5	0.15	17.7	0.15	3.47	23.13	4.51	0.47	0.85
14.5-19.5	0.14	16.2	0.16	3.42	21.97	4.03	0.49	0.84
19.5-24.5	0.14	13.3	0.14	3.33	23.78	4.09	0.49	0.86
24.5-29.5	0.14	13.0	0.13	3.19	23.78	4.13	0.49	0.85
29.5-34.5	0.14	13.1	0.14	3.33	23.78	4.16	0.49	0.85
34.5-39.5	0.13	20.1	0.13	3.14	23.58	4.07	0.50	0.85
39.5-44.5	0.12	37.9	0.13	3.04	23.38	4.17	0.50	0.85
44.5-49.5	0.13	39.8	0.14	3.23	22.33	4.40	0.50	0.91
49.5-54.5	0.15	45.1	0.15	3.19	21.27	4.58	0.49	0.88
54.5-59.5	0.14	45.3	0.14	3.14	22.52	4.59	0.50	0.86
59.5-64.5	0.13	45.9	0.13	3.09	23.77	4.58	0.52	0.84
64.5-69.5	0.14	43.8	0.14	3.12	22.82	4.64	0.52	0.81
69.5-72.0	0.14	41.0	0.14	3.28	21.87	-	0.52	0.74
Original Soil								
Soil Layer	0.15	-	0.15	3.46	23.72	4.65	0.45	0.86

Table 9. Matric Potential vs. Volumetric Water Content in
Lysimeter 1.

Parameters / Soil Depth cm	Matric Potential cm of water / Volumetric Water Content cm^3 per cm^3			
6.7	14.5	30.5	34.2	59.9
	0.140	0.266	0.302	0.328
25.9	35.9	56.4	57.9	69.1
	0.029	0.143	0.175	0.145
45.9	43.8	45.4	52.2	66.8
	0.039	0.058	0.068	0.132
65.9	25.6	52.3	79.3	92.7
	0.050	0.116	0.142	0.198

Table 10.   Matric Potential vs. Volumetric Water Content in
            Lysimeter 6.

Parameters / Soil Depth cm	Matric Potential cm of water Volumetric Water Content cm^3 per cm^3						
8.5	5.3	8.0	11.3	13.7	15.4	19.5	33.6
	0.021	0.031	0.062	0.136	0.142	0.153	0.233
27.5	20.4	33.0	37.2	45.5	48.7	51.3	55.4
	0.035	0.112	0.136	0.204	0.238	0.306	0.302
47.5	36.0	43.0	46.5	50.3	51.8	54.2	58.8
	0.045	0.070	0.101	0.118	0.128	0.231	0.225
67.5	30.9	33.1	38.4	45.0	57.6	77.1	83.0
	0.093	0.134	0.155	0.153	0.299	0.291	0.341

Table 11. Matric Potential vs. Volumetric Water Content of
the Original Soil.[1]

Parameters Soil Depth cm	Matric Potential — cm of water Volumetric Water Content — cm^3 per cm^3						
1.2	26.9	35.9	46.9	51.3	65.4	77.3	86.0
	0.002	0.056	0.099	0.125	0.144	0.176	0.160
10.2	19.8	35.1	46.3	69.2	81.5	84.4	91.6
	0.002	0.048	0.080	0.142	0.157	0.151	0.168
19.2	11.5	17.7	51.7	64.8	78.9	83.7	113.3
	0.014	0.017	0.161	0.189	0.216	0.209	0.221
F. F.[2]	10.0 0.383		20.0 0.645		30.0 0.710	45.0 0.745	60.0 0.755

1). Bulk density = 0.82 gm per cm^3, water content = 0.44 gm per gm.

2). Forest floor: Matric potential vs gravimetric water content.

Table 12. Saturated Hydraulic Conductivity of Both the
Original and Treated Soils.

Lysimeters / Soil Depth cm	Treated 1	Treated 2	Treated 5	Treated 6	Original Soil
0 - 9	-	63750.9	11962.9	-	-
9 - 29	102.2	302.9	902.4	129.6	184.3
29 - 49	78.1	266.4	544.5	92.8	157.7
49 - 69	123.0	274.3	958.6	105.6	285.3

Notes : 1) Both lysimeters 1 and 6 were measured in May,
1972.

2) Both lysimeters 2 and 5 were measured in June,
1972, after subject to period of drying.

3) The original soil was lysimeter 2 which was
measured in August, 1971.

4) The unit of conductivity is cm per day.