CHEMICAL REHABILITATION OF SOIL WASTEWATER ABSORPTION SYSTEMS USING HYDROGEN PEROXIDE: EFFECTS ON SOIL PERMEABILITY

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ABSTRACT

The chemical treatment of wastewater soil absorption systems with hydrogen peroxide (H_2O_2) has been advocated as a useful management technique for rehabilitating clogged, hydraulically failed systems. Previous research on this concept resulted in a patented process trademarked as Porox^R, now commercially available in several states. This process incorporates the systematic application of hydrogen peroxide to failing absorption systems with the objective of oxidizing organic materials in the soil clogging zone. Proponents of the Porox^R procedure have claimed it to be relatively effective in restoring the infiltrative capacity of selected wastewater soil absorption systems. Other researchers have rated the process as ineffective or deleterious to system performance.

This publication reports on recent research which examined the effectiveness of H_2O_2 in unclogging failed systems, and further evaluated the reagent's impacts on soil physical properties.

Field studies were performed on replicated, _in situ_ soil absorption systems, in silty clay loam, which had been previously clogged by wastewater application. Clogged systems treated with Porox^R showed a significant and long-lasting loss of infiltrative capacity, whereas control systems showed a gradual but significant increase with natural resting.

Laboratory studies were conducted on undisturbed, unclogged cores from 25 subsoil horizons, representing a wide range of textural conditions. The experimental design incorporated H_2O_2 concentrations and mass loading rates ranging from 6.25 to 50 percent, and 0.3 to 9.2 kg/m^2, respectively. Mean infiltration rates for H_2O_2-treated cores were lower than for controls in 23 of the 25 soils, ranging from 0 to 88 percent of control values. Only the two sands studied were not hydraulically damaged by H_2O_2. The effects of various H_2O_2 concentrations and loading rates on soil infiltration capacity were not significantly different. Chemical additives intended to retard H_2O_2 decomposition were ineffective in eliminating permeability losses caused by the reagent.

Micromorphometric analysis of soil thin sections was performed to investigate soil porosity and permeability relationships. Thin sections of both structured and granular soils documented that H_2O_2 application induced a dramatic increase in macroporosity, but a marked reduction in pore continuity, corresponding to observed permeability losses.

Experiments on wastewater-clogged columns of four soil types demonstrated that H_2O_2 application may further reduce infiltration rate, beyond the clogged state, in medium and fine textured soils. High H_2O_2 loading rates produced some degree of reclamation of infiltrative capacity in clogged sandy loam columns, but none of the H_2O_2 treatments resulted in infiltration rates greater than 35 percent of initial values.

These research results definitively show that H_2O_2 can do serious, and possibly irreversible, damage to the physical integrity and infiltrative capacity of most soils. These data, in combination with a rigorous review of the previous research, do not substantiate the use of H_2O_2 for wastewater soil absorption systems, even those in sands, except perhaps in extenuating circumstances.

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LIST OF ABBREVIATIONS AND SYMBOLS

A -- area
BOD_5 -- 5-day biological oxygen demand
C -- continuous
°C -- degrees Centigrade
c -- clay
cl -- clay loam
cm -- centimeters
cm/day -- centimeters per day
COD -- chemical oxygen demand
coeff.var. -- coefficient of variation
cos, cs -- coarse sand
CRP -- concentric-ring permeameter
csi -- coarse silt
D -- dosed once daily
d -- day
DIA -- diameter
fs -- fine sand
fsi -- fine silt
ft -- feet
g -- gram
g/cm^3 -- gram per cubic centimeter
g/L -- gram per liter
gal -- gallon
$gal/ft^2/day$ -- gallons per square foot per day
$gal/100\ ft^2$ -- gallons per one hundred square feet
ΔH -- hydraulic head
HLR -- hydraulic loading rate
hr -- hours
ht -- height
i.d. -- internal diameter
in -- inch
IR -- infiltration rate
IIR -- initial infiltration rate
%IIR -- percent of initial infiltration rate
K -- hydraulic conductivity
kg -- kilogram
kg/m^2 -- kilogram per square meter
L -- length
L -- liter
L/m^2 -- liters per square meter
l -- loam
lb -- pound
lb/ft^2 -- pounds per square foot
log -- base 10 logarithm
$Log_{10}\#/L$ -- log base 10 number of organisms per liter
ls -- loamy sand
LSD -- least significant difference
LTAR -- long-term acceptance rate
m -- meter
m^2 -- square meter
min -- minute
min/cm -- minutes per centimeter
min/in -- minutes per inch
ml -- milliliters
ml/hr -- milliliters per hour
MLR -- mass loading rate
mm -- millimeters
mo -- month
ms -- medium sand
n -- sample size
\# -- number
p -- probability
pH -- negative log of hydrogen ion activity
% -- percent
ppm -- parts per million
Q -- flow volume
s -- sand
SAR -- sodium absorption ratio
SAS -- soil absorption system
sc -- sandy clay
scl -- sandy clay loam
si -- silt
sic -- silty clay
sicl -- silty clay loam
sil -- silt loam
sl -- sandy loam
STE -- septic tank effluent
t -- time
TCA -- trichloroacetic acid
TKN -- total Kjeldahl nitrogen
TOC -- total organic carbon
vcs -- very coarse sand
vfs -- very fine sand
$\overline{X}$ -- arithmetic mean

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CHEMICAL REHABILITATION OF WASTEWATER SOIL ABSORPTION SYSTEMS USING HYDROGEN PEROXIDE: EFFECTS ON SOIL PERMEABILITY

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The on-site soil wastewater absorption system is the most common means of waste disposal and treatment in areas without centralized sewerage facilities. This simple and economical method, utilizing natural soil as the ultimate disposal and treatment medium, has proven highly effective, given proper siting, design, installation and maintenance (Small Scale Waste Management Project [SSWMP], 1978). However, Scalf et al. (1977) estimated that fewer than one-half of conventional septic tank/soil absorption systems currently in use will perform satisfactorily for their design life of fifteen to twenty years, even given the above conditions of construction and operation.

Mature wastewater absorption systems eventually develop a clogging layer at the soil infiltrative surface, primarily as a result of physical and biological mechanisms (McGauhey and Krone, 1967; SSWMP, 1978). Soil clogging creates a physical barrier to flow, restricting the rate of infiltration into the natural soil below (Bouma, 1975; Hargett et al. 1981). This condition may become so severe as to inhibit wastewater absorption and cause hydraulic failure of the system. The rate and intensity of soil clogging has been shown to depend on wastewater application rate and frequency (Hargett et al. 1981), among other factors. Wastewater quality and the inherent soil physical, chemical and biological conditions are also likely influences in the clogging process. Because of this complex of factors no singular solution to control the extent of clogging for all soil and system situations has been elucidated.

One innovative management tool which has been advanced to control severe clogging in otherwise properly functioning systems is the application of hydrogen peroxide (H_2O_2) to oxidize the soil-clogging organic material and thus restore soil permeability (Harkin et al. 1975; Jawson, 1976). Laboratory and field research of this chemical oxidation concept was carried out by staff of the Small Scale Waste Management Project and Department of Soil Science, from 1973 to 1976, and was supported by SSWMP and U.S. Environmental Protection Agency funding (Jawson, 1976).

As a result of this research U.S. Patent number 4,021,338 was issued in May 1977 to the Wisconsin Alumni Research Foundation (WARF) for the hydrogen peroxide treatment process (Harkin, 1977a). WARF also coined the name Porox[R], a registered trademark, for the process. WARF continues to handle patent rights for Porox[R], in behalf of the University of Wisconsin, and grants exclusive license to firms using the process nationwide.

Porox[R] incorporates the systematic application of hydrogen peroxide to the failing absorption system with the objective of completely oxidizing organic materials in the clogged zone. The process has been claimed to be relatively effective in restoring infiltrative capacity in some wastewater absorption systems, especially those in sandy soils (Harkin, 1977a, 1980a,b; Hill, 1980; Urban Systems Research and Engineering [USRE], 1982). In other soil conditions the Porox[R] treatment of clogged absorption systems has been rated as from ineffective to unpredictable and even deleterious (Hargett et al. 1982; USRE, 1982).

The purpose of this publication is to report on recent SSWMP research results which substantially refute the efficacy of the hydrogen peroxide technique as originally prescribed and question its application for a broad range of soils. Although Porox[R] may have potential as a management tool under certain specific soil and system conditions, research reported herein suggests that under most common soil conditions the treatment may prove ineffective or deleterious to system performance.

BACKGROUND - CHEMICAL REHABILITATION

For a soil wastewater absorption system that has been properly sited, sized, designed, installed and maintained, the only reason for failure is natural clogging. If clogging becomes so severe as to cause failure, the homeowner's only recourse is to construct a new system or arrange for frequent pumping, both at prohibitive costs, or to somehow rehabilitate the old system. Laboratory and field experience have addressed two basic approaches to rehabilitation. These are (1) prolonged resting of the system, and (2) treatment with chemical agents to effect unclogging. Oxidation of the clogging zone is the objective of both techniques. The following discussion focuses on chemical approaches to rehabilitation.

pplication Specifications - Convention

One problem in discussing chemical rehabilitation is the lack of onvention in describing reagent appplication specifications. Various workers ave utilized combinations of reagent concentration, hydraulic and mass oading rates, mixes of metric and English units, and descriptions of amounts f effective reagent versus pure chemical applied. Because this paper deals pecifically with the use of H_2O_2 as a rejuvenative treatment all application pecifications mentioned will apply to this reagent. In this report mass ading rate (MLR) will always be used to describe the mass of pure H_2O_2 plied per unit area. Hydraulic loading rate (HLR) will refer to volume of O_2 applied as depth over the area of interest (at a specified ncentration). Appendix Table A-1 provides convenient factors for conversion various expressions.

Developmental Research

Over the years a wide variety of chemical additives and other materials have been used in an effort to improve septic tank/soil absorption system performance. The Manual of Septic Tank Practice (Public Health Service, 1967) advised that out of over a thousand commercial products for septic systems, none had been proven effective. Jawson (1976) used clogged sand columns to evaluate several commercially available septic tank additives as well as some common acids, bases, and oxidizers to determine their effectiveness as declogging agents. Jawson's work showed that none of the commercially available nostrums were effective in increasing the infiltration rate of clogged sand columns. In fact, several of these additives appeared to reduce permeabilities even further. Among the commercial products evaluated were bacteria, enzymes, emulsifying agents, and surfactants.

Sand Column Experiments--The treatment which Jawson (1976) found to be most effective in restoring the infiltrative capacity of the clogged sand columns was hydrogen peroxide (H_2O_2). Application of sulfuric acid (H_2SO_4) was somewhat less effective and sodium hydroxide (NaOH) proved unpredictable. The H_2O_2 application rates used ranged from 0.64 to 3.20 cm (hydraulic loading rate [HLR]) of 30 percent laboratory grade H_2O_2 (50 to 250 ml applied to 10-cm diameter columns) (Jawson, 1976; Harkin, 1977a). Table 1 presents the reagent specifications used by Jawson and provides a comparison to other workers. This reagent was actually applied to approximately 3 cm of ponded effluent at the top of the columns and thus was considerably diluted (Jawson, 1976).

The permeability data reported in Jawson's thesis (1976, Tables 1 and 10) present column flow rates before and after H_2O_2 application. Table 1 reports pre-treatment flow rates for five H_2O_2-treated columns which range from 0 to 233 ml/hr (0 to 71 cm/day from 10-cm i.d. columns) and post-treatment rates of 400 to 1750 ml/hr (122 to 535 cm/day). This represents recovery rates of 13 to 58 percent of the initial values of 3000 ml/hr (917 cm/day). Note also that some of the columns (i.e. those with pre-treatment flow rate as high as 71 cm/day) were not completely clogged relative to the 3.7 - 4.9 cm/day (0.9 - 1.2 gal/ft^2/day) long-term acceptance rate used routinely for design loadings in these soils (Wisconsin Administrative Code [WAC], 1980; Otis et al. 1980).

Jawson's Table 10 (1976) presents results for five other H_2O_2-treated columns, and other treatments, from a later experiment. Here pre-treatment flow rates range from 0.5 to 17 ml/day (0.15 to 5 cm/day) and post-treatment rates from 584 to 1557 ml/hr (179 to 476 cm/day). This suggests a recovery range of 19 to 52 percent of the initial value of 3000 ml/hr (917 cm/day). Jawson concluded, "while no treatment restored the flow rates to their initial levels, successful cures (H_2O_2) did substantially increase the infiltration capacity."

Table 1 - Hydrogen peroxide concentrations, and hydraulic and mass loading rates--various studies.

Source	Percent concentration	Loading rate: Hydraulic, cm	Loading rate: Hydraulic, gal/ft^2	Loading rate: Mass, kg/m^2	Loading rate: Mass, lb/ft^2	Field application rate gal/100 ft^2
Jawson (1976) and Harkin (1977a)	30	0.64	0.16	2.81	0.58	16
	30	1.91	0.47	8.39	1.72	47
	30	3.18	0.78	13.98	2.86	78
Harkin and Jawson (1975)	50(1.2-6.3)	15-40 gal 50% concentrate applied to field systems of unreported area, diluted with 300-600 gal H_2O.				
Porox^R manual (Harkin, 1977b)	50	4-5 gal concentrate/100 ft^2				
Bishop and Logsdon (1981)						
Exp. 1	7.5	0.56	0.14	0.61	0.13	14
	15	0.56	0.14	1.22	0.25	14
	30	0.56	0.14	2.44	0.50	14
Exp. 2	20	0.42	0.10	1.22	0.25	10
	10	0.83	0.20	1.22	0.25	20
	5	1.67	0.41	1.22	0.25	41
Exp. 3	15	0.33	0.08	0.73	0.15	8
	20	0.33	0.08	0.98	0.20	8
	25	0.33	0.08	1.22	0.25	8
	30	0.33	0.08	1.46	0.30	8
Andrews and Bishop (1981)	30	0.61	0.15	2.68	0.55	15
	30	0.94	0.23	4.13	0.85	23
	30	0.25	0.06	1.10	0.23	6
On-Site Sanitation	10	1.02	0.25	1.49	0.31	25
USRE (1982)						
Vendor 1	35	0.82	0.20	4.20	0.86	20
Vendor 2	10	1.23	0.30	1.80	0.37	30
Vendor 3	16.5	1.02	0.25	2.46	0.50	25
Vendor 4	35	0.49	0.12	2.51	0.51	12
This study	6.25-50	0.31-1.26	0.08-0.31	0.29-9.22	0.06-1.89	8-31

Results reported by Harkin (1977a) on this same work appear to contradict Jawson's permeability measurements (1976). In the WARF patent (Harkin, 1977a), Jawson's experiments were cited as evidence of the viability of the H_2O_2 process. These patent examples reported that the H_2O_2 applications to the clogged sand columns increased flow rates from "a few milliliters per hour" to 450 to 3000 ml/hr (138 to 917 cm/day), relative to the 3000 ml/hr (917 cm/day) reported as the initial flow rate (Jawson, 1976). This data suggests infiltration recovery rates ranging from 15 to 100 percent. The maximum post-treatment rate reported by Jawson was 58 percent (1750 ml/hr).

Jawson evaluated several H_2O_2 loading rates and formulations (i.e., stabilized and unstabilized) in his experiments. Unfortunately, it appears from the original thesis (Jawson, 1976) and related papers (Harkin et al. 1975; Harkin and Jawson, 1976a,b; Harkin, 1977a) that the treatments in

Jawson's experimental design were not replicated. Although no statistical inference can be made from this type of work, the recovery rates of certain of the H_2O_2 treatments appear to suggest the concept has some potential, at least in sands. It is important to note that only hand-packed, structureless sands (C horizon of the Plainfield series, mixed, mesic Typic Udipsamments) were used in these studies.

<u>Early Field Evaluations</u>--These workers transferred their laboratory success with hydrogen peroxide to the field by evaluating its effectiveness on soil absorption systems which were diagnosed as severely clogged. Harkin et al. (1975) and Harkin (1977a) reported success in declogging systems installed in a variety of soils (three in sands, two in "glacial till", and one in "heavy clay") using H_2O_2. Before application the soil absorption system was typically dewatered by pumping. The reagent was applied as 50 percent concentration (DuPont Tysul WW 50)* at a rate between 60 and 150 L (15 and 40 gal) depending on system size. During application, the reagent was simultaneously diluted with about 1100 to 2300 L (300 to 600 gal) of water, resulting in an effective reagent concentration of approximately 3 percent. Unfortunately, system specifications and precise loading data were not reported in these papers.

<u>Porox[R] Patent Development</u>--Continued interest in H_2O_2 treatment as a rejuvenative technique resulted in application for a patent for "Method for Treating Septic Tank Effluent Seepage Beds and the Like," which was awarded as U.S. patent number 4,021,338 (Harkin, 1977a). In this document, application of the H_2O_2 treatment was recommended not only as a rejuvenative technique, but also as a prophylactic treatment for the prevention of clogging. Advantages of hydrogen peroxide over other strong oxidizing agents were suggested as its reasonable cost, effectiveness, and innocuous by-products (H_2O and O_2). Explaining how the treatment works to declog the failed infiltrative surface, the patent teaches that the free oxygen released from H_2O_2 decomposition causes considerable turbulence in the bed, which loosens the soil particles and pores, especially the organically clogged zone, and mechanically improves the permeability of the soil. The patent claims that the process "rapidly restores permeability to the clogged and crusted regions of the bed, returning the bed to the status of intermittent drainage typical of a freshly constructed bed." The previous laboratory and field successes with H_2O_2 were cited as proof of the treatment's efficacy. The patent claimed effectiveness on clogged systems regardless of soil type, assuming the soil was initially suitable.

Since the Porox[R] patent approval in 1977, the process has been used commercially in several states and on hundreds of systems. WARF administers the patent rights for Porox[R] and grants exclusive license to firms using the

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* The mention of trade names or commercial products in this report does not constitute endorsement or preference for use by SSWMP.

process. These licensees presently number about seven, most operating on a one-state or regional basis.

This study did not address the mechanics of H_2O_2 application or other marketing concerns, but rather focused on H_2O_2 effects on soil properties. These and other practical management and application problems germane to the Porox[R] enterprise are dealt with in an evaluation of the suitability, procedures, performance and marketing of Porox[R] as a rehabilitation technique, now underway (USRE, 1982).

Reagent Concentration and Loading Rate

Harkin stated in his patent (1977a) that the concentration and amount of hydrogen peroxide used were not critical, but rather should be commensurate with the condition of the system. Concentrations of 25 to 65 percent were suggested as convenient, with dilutions to a concentration in the system of 1 to 5 percent "eminently suitable." In the Porox[R] Training Manual (Harkin, 1977b), 0.16 to 0.20 cm (4 to 5 gal/100 ft^2) of 50 percent stabilized hydrogen peroxide is recommended on a system bottom area basis. This amounts to a hydraulic loading of approximately 0.4 cm (porespace corrected) over the system, such that uniform distribution of this reagent would be very difficult under ordinary conditions. The amount of water to be added to the system to dilute and distribute the concentrate is not specified in the manual.

The original laboratory studies of Jawson (1976; and Harkin, 1977a) demonstrated the highest degree of infiltration rate recovery with the highest application rates (3.2 cm) of 30 percent H_2O_2. Lower HLRs were slightly less effective.

Bishop and Logsdon (1981) and Andrews and Bishop (1981) evaluated the effects of both hydraulic and mass loading rates of H_2O_2. However, interpretations from this work must be qualified because of techniques used; these papers are further critiqued in the discussion of soil suitability that follows. The loading rates evaluated in these studies are presented in Table 1. In the former study, low loading rates were reported as adequate to effect reclamation in sands but higher oxidation conditions were required in sandy loams. Andrews and Bishop (1981) reported somewhat unpredictable effects regardless of loading rate.

Review of the limited published work suggests that the issue of appropriate concentrations and loading rates may be more complicated than originally thought. As Table 1 demonstrates, there is no consensus among researchers or Porox[R] licensees as to what concentrations and loading rates are effective. Each licensee appears to have gone through enough trial and error to have developed loadings with which he is comfortable. Fundamental questions as to whether low concentrations at high hydraulic loading rates have the same effect as high concentrations at low loading rates, where mass loadings are equal, have not been definitively answered anywhere in the laboratory or field experience.

Soil Suitability for Hydrogen Peroxide Treatment

The original laboratory studies (Jawson, 1976) examined the effectiveness of H_2O_2 only on hand-packed columns of disturbed, structureless sands. Much of the following field experimentation appears to have been carried out under somewhat poorly controlled conditions with regard to soil and system characterization, and details of reagent application (Harkin et al. 1975; Jawson, 1976; Harkin, 1977a).

The patent does not address what if any soil conditions are particularly favorable or unfavorable for application of the treatment (Harkin, 1977a). Harkin and Jawson (1977a) stated "although peroxide can restore essentially the initial permeability to a system by removing biological crusts, it cannot improve systems whose operation has been faulty *a priori* because of poor site selection or faulty construction."

Subsequent to the patent, a manual on hydrogen peroxide use was prepared for Porox^R licensees (Harkin, 1977b). This manual serves principally as a primer for the licensees, covering the topics of on-site sanitation, basic soils, the Porox^R concept, and application and safety practice. In this manual several factors influencing the potential for success of the treatment on a given site are listed. Among conditions favoring success are sandy and well-drained soil features. Among soil conditions not favoring success are "heavy clay and muck textures, and poor drainage," although Harkin et al. (1975) and Harkin (1977a) cited success on clayey soils. No guidance is provided in the training manual on intermediate conditions.

Recent work (Bishop and Logsdon, 1981; Andrews and Bishop, 1981) has provided some further insight into the applicability of hydrogen peroxide to other soil types. Unfortunately, the conditions and techniques used in these studies preclude definitive conclusions. They do, however, contribute to the limited data on H_2O_2 effectiveness on a variety of soils.

In the Bishop and Logsdon study (1981), efforts were made to assess sands, sandy loams, and a silt loam; the finer soil was dropped from the experiments because of low initial permeability. The Andrews and Bishop study (1981) included a variety of sandy textures as well as silt loams and a loam. In both of these investigations replicate laboratory columns were set up using disturbed soils, hand-packed to unspecified densities, for each of the soils evaluated. Such soil conditions cannot be assumed to represent natural undisturbed soil systems, especially for finer, structured soils. Both studies also used raw municipal wastewater to clog the soils. This could produce clogging dynamics quite different from those typical of a conventional septic tank/soil absorption system because of the much higher levels of BOD_5, suspended solids, and other constituents present in this wastewater (Weibel et al. 1954; Winneberger et al. 1960; Laak, 1970; Daniel and Bouma, 1974).

Both Bishop and Logsdon (1981) and Andrews and Bishop (1981) considered failure to exist in their experimental columns when percolation rates became slower than 47.2 min/cm (120 min/in) or a permeability rate of approximately 30.5 cm/day. This is an inaccurate definition of hydraulic failure considering that a typical loading rate for a conventional system in sandy soils is about 3.7 - 4.9 cm/day (0.9 - 1.2 gal/ft^2/day) or more (WAC, 1980; Otis et al. 1980). Thus, the defined conditions of hydraulic failure for these studies are over eight times the typical design long-term acceptance rate for most of the soils studied. Therefore, it may be concluded that the columns were not fully clogged nor hydraulically failed at the time of H_2O_2 treatment.

Under the conditions of their study, Bishop and Logsdon (1981) found that low mass loading rates (0.61 kg/m^2) were adequate to restore loamy sand columns to nearly their initial permeability. However, higher loading rates (2.44 kg/m^2) were required to achieve permeabilities greater than about 50 percent of initial values in a fine sandy loam.

In their study of hydraulic loading rate effects Bishop and Logsdon (1981) described rejuvenation as "essentially complete" in two loamy sand soils although post-treatment permeabilities were only 43 to 60 percent of initial values in one of the soils. In the fine sandy loam the post-treatment values were unpredictable with two of three columns displaying impermeable conditions and the third column reclaimed to over 100 percent of initial permeability.

Andrews and Bishop (1981) reported similarly variable to unpredictable results. Post-treatment permeabilities ranged from 9 to 163 percent of initial values for the six soils of various texture studied, with a mean at about 60 percent. Surprisingly, a silt loam averaged 130% for three columns, while columns of three sand types averaged about 53%. These results appear to be somewhat contradictory, suggesting that the effectiveness of H_2O_2 may be highly unpredictable.

In another experiment, Andrews and Bishop (1981) evaluated the effect of H_2O_2 application on an unclogged loamy sand. Before the H_2O_2 application the mean infiltration rate of the hand-packed columns was 1125 cm/day. After the application the rate had decreased dramatically to 305 cm/day, or 27 percent of the pre-treatment rate. Based on this experience, these workers suggested that "it may be impossible, regardless of loading rates, to totally restore the infiltrative capacity of certain soils due to their texture and organic content."

In a study of greywater treatment (Siegrist et al. 1981) an H_2O_2 treatment was employed to attempt rehabilitation of a clogged sand filter of very uniform coarse sand particles (average diameter 1.37 mm). Initial infiltration rate of the medium was 48,000 cm/day. Failure was considered as continuous ponding at a loading rate of 39 cm/day (0.08 percent of initial infiltration rate). After the occurrence of failure the filter was allowed to drain, then raked to 15 cm (6 in) depth and a treatment of 2.88 kg/m^2 of H_2O_2 (0.65 cm of 30 percent concentration) was applied. Greywater application was re-initiated after the H_2O_2 treatment. The chemical treatment resulted in a significant but less than remarkable infiltration rate of 540 cm/day (1.12 percent of the initial rate). The following filter run clogged and failed after 45 days, only 30 percent of the initial run time.

Although the sand filter would appear to be an ideal medium for utilization of H_2O_2 as a declogging agent, Siegrist et al. (1981) concluded that the H_2O_2 treatment, at the rates employed, was ineffective. The rate used, 2.88 kg/m^2, is comparable to rates used by commercial Porox^R vendors (Table 1). Analysis for volatile solids and TKN in incremental depth samples after the H_2O_2 treatment verified incomplete decomposition of organic matter.

H_2O_2 Effectiveness in Removal of Clogging Organic Matter

Jawson (1976) reported total organic carbon (TOC) contents in his clogged sand columns of 0.17 to 5.30 percent. After H_2O_2 treatment the amount of TOC remaining ranged from 8 to 63 percent of that present before treatment. The TOC content of the natural sand was about 0.05 percent. Assuming all of the solids clogging the soil infiltrative surface have not been removed by oxidation, it would be expected that not all of the initial permeability could be recovered. This concurs with the maximum post-H_2O_2 treatment recovery rates, approximately 58 percent, reported by Jawson (1976).

Other sources substantiate the long-recognized inability of H_2O_2 to completely oxidize organic matter of various types (Robinson, 1927; Alexander and Byers, 1932; and Jackson, 1958). Jackson (1958) recommended 7.5 ml of 30 percent H_2O_2 per gram of soil to remove natural organic matter and acknowledged that this would not completely remove the more complex, resistant forms. Jackson's prescription, applied to a 1-cm thick slice of soil with a bulk density of 1.3 g/cm^3, would result in a mass loading rate of 42.9 kg/m^2 (9.75 cm of 30 percent H_2O_2). This figure is generally one order of magnitude or more greater than those used by most commercial vendors (Table 1).

Siegrist et al. (1981) reported that H_2O_2 application resulted in incomplete oxidation of volatile solids in a sand filter. At a mass loading rate of 2.88 kg/m^2 they observed a 58 percent reduction in volatile solids in the surface 1 cm of the filter, compared to the clogged state. As previously discussed, the partial hydraulic recovery of this system was relatively short-lived.

Andrews and Bishop (1981) examined the effect of H_2O_2 treatments on naturally occurring organic matter. Approximately 4 ml of H_2O_2 (concentration not specified) was mixed into 227 grams of a loamy sand. This soil initially contained 4.16 percent organic matter. The H_2O_2 treatment removed 79 percent of the natural organic matter.

In an experiment preliminary to the laboratory research reported in this study, the effects of H_2O_2 on the organic matter content of a fine sandy loam topsoil were assessed. This soil initially contained 2.9 percent organic matter. Application of 0.63 cm of 12.5 percent H_2O_2 (1.15 kg/m^2) reduced the organic matter content to 2.6 percent. A similar volume of 25 percent H_2O_2 (2.31 kg/m^2) reduced organic matter to 2.3 percent. These H_2O_2 levels compare to the range used commercially and in other research (Table 1).

Based on these observations, it appears to be very difficult to completely oxidize all of the organic matter present in a clogged soil infiltrative surface, at least using H_2O_2. Inasmuch as total organic solids removal is incomplete by chemical oxidation, it seems that patent claims of up to 100 percent infiltration rate recovery using H_2O_2 (Harkin, 1977a) may have been overly optimistic.

Commercial Experience

Since the Porox^R patent approval in 1977, the process has been used commercially in several states and on hundreds of systems. According to research and WARF marketing claims (Harkin et al. 1975; Harkin, 1977a; USRE, 1982) clogging failures have and are continuing to be effectively treated by Porox^R. Unfortunately, field evidence on site and soil conditions which respond favorably to Porox^R is vague. Licensee records are generally poor, limited soil evaluation is attempted, and follow-up system evaluations are seldom conducted (USRE, 1982).

Five years of commercial experience with Porox^R has met with mixed success (USRE, 1982). Unsuccessful response to Porox^R is generally attributed by its proponents to improper diagnosis of system conditions and treatability, improper application of the treatment, or soil conditions unfavorable to the technique. Guidance on what, if any, soil conditions are unfavorable has been vague or nonexistent throughout the treatment's history. These issues of soil suitability and potential side effects from the treatment are of particular concern to this study.

Field experience in Wisconsin and elsewhere suggests that all soils are not equally well-suited to the procedure (USRE, 1982). As an example, Rick Apfel of On-Site Sanitation Services, Inc., Wisconsin Porox^R licensee, has demonstrated mostly favorable response to the treatment on sandy soils but highly unpredictable performance on other soils (Personal communication, 1981).

Recent results from the use of Porox^R treatments on SSWMP research systems suggest that some soils may actually be hydraulically damaged by application of hydrogen peroxide, even according to standard commercial practice. These findings provided the impetus for the research reported herein and will be discussed in detail in the results and discussion that follows.

FIELD AND LABORATORY STUDIES OF HYDROGEN PEROXIDE EFFECTS ON SOIL PROPERTIES

This publication reports the results of recent research dealing with the efficacy of Porox^{R} for rehabilitation of failed wastewater absorption systems and the effects of hydrogen peroxide on critical soil properties. This research was a direct outgrowth of previous SSWMP field experiments dealing with wastewater application strategies (Hargett et al. 1981).

The research which follows can be conveniently segregated into three parts: (1) field experience with Porox^{R}, (2) survey of Wisconsin commercial experience with Porox^{R}, and (3) laboratory studies with hydrogen peroxide. The discussion will be largely confined to the field and laboratory results. The survey study will be only briefly discussed because analysis is yet to be completed and its outcome will not likely be conclusive.

Field Experiments With Porox^{R}

Background--Our studies on the efficacy of hydrogen peroxide as a rejuvenative technique for failed wastewater absorption systems developed as a continuation of previous field experiments (Hargett et al. 1981). The preceding research dealt with the effects of various wastewater application regimes (rate and frequency of application) on the long-term acceptance rates of soils. This work was carried out from 1978 - 1981 at UW/SSWMP facilities at Arlington Experimental Farms and was supported by SSWMP and U.S. EPA.

These studies utilized a unique replicated experimental design with 18 *in situ* systems of known infiltrative surface area and no side-wall absorption. The infiltrative surface of the systems was at 70 cm (2.3 ft) below grade, in the well-structured silty clay loam B22t horizon of the Plano series, a well-drained member of the fine-silty, mixed, mesic Typic Argiudolls. Hargett et al. (1981) detailed the construction specifications of the wastewater absorption systems used and described their management and wastewater loading history. The layout of the 18 systems is shown in Figure 1.

After the experimental objectives of the previous study were satisfied wastewater application to the systems was ceased in September 1980. The systems were allowed to naturally drain and rest for nine months, until May 1981. At that time the degree of rejuvenation was determined by infiltration rate (IR) measurements (Hargett et al. 1981). During this period the permeability of the systems increased from an average of 16 percent of their initial infiltration rate (%IIR) to 32 %IIR. This 16 percent increase constituted a rather sluggish 1.8 percent per month average and was even slower on certain systems.

The ultimate objective of rehabilitation was to prepare the systems for another round of wastewater application experiments. Unfortunately, the system infiltration rates as of May 1981 were inadequate to justify further

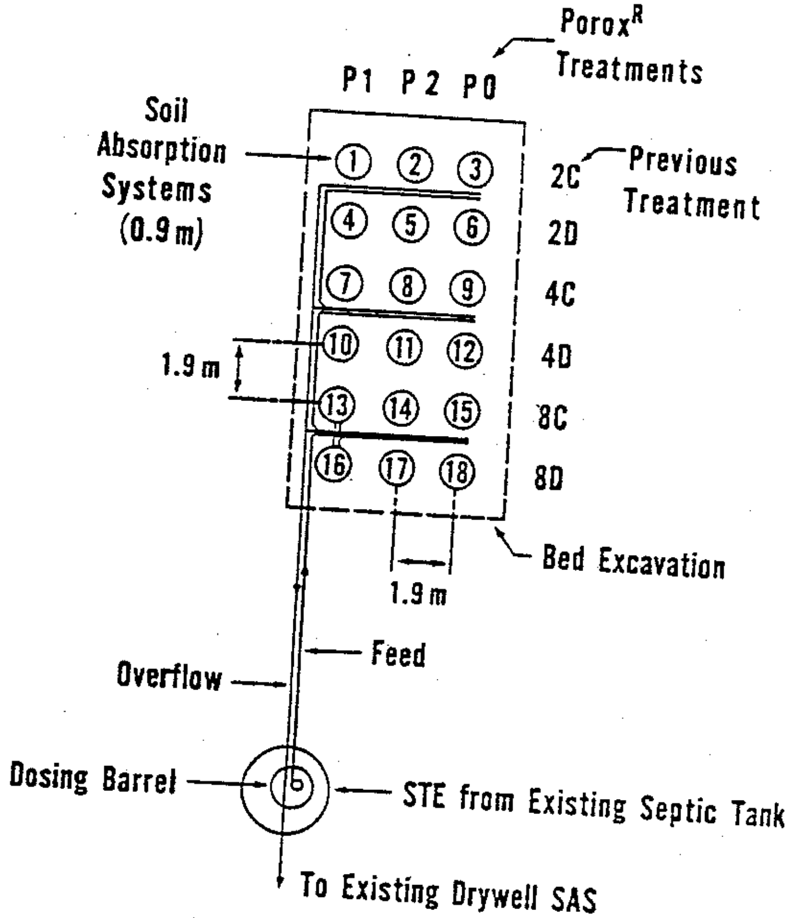


Figure 1 - Layout and treatment scheme of experimental field systems.

use of the systems at that time. Therefore an alternative strategy, hydrogen peroxide treatment, was utilized to rehabilitate selected systems. The decision to use the Porox[R] treatment was based on the assumption that the application would restore the treated systems to roughly 75 to 100 percent of their initial infiltration rate as suggested in the patent (Harkin, 1977a) and WARF marketing literature. The evaluation of H_2O_2 was not within the original scope of the wastewater application strategies project.

<u>Porox[R] Treatment of Field Systems</u>--Twelve cells were chosen for chemical treatment. The other six cells were withheld from H_2O_2 treatment, to continue study of natural resting and because they were not needed in future wastewater application experiments. These systems (marked "PO" in Figure 1) also served as a control for comparison to the treated systems. Note that the complete wastewater application and permeability history of all 18 systems was known.

A few days before the Porox application the infiltration rates were measured on all systems according to the method described in Hargett et al. (1981). A constant head infiltrometer device was utilized for this purpose, via the access port illustrated in Figure 2. This instrument maintained a constant one-cm head at the infiltrative surface during measurement. After an equilibration period, the volume of water infiltrating the system (area = 0.66 m^2 [7.07 ft^2]) was measured and the IR calculated. This procedure was repeated until a constant rate was determined.

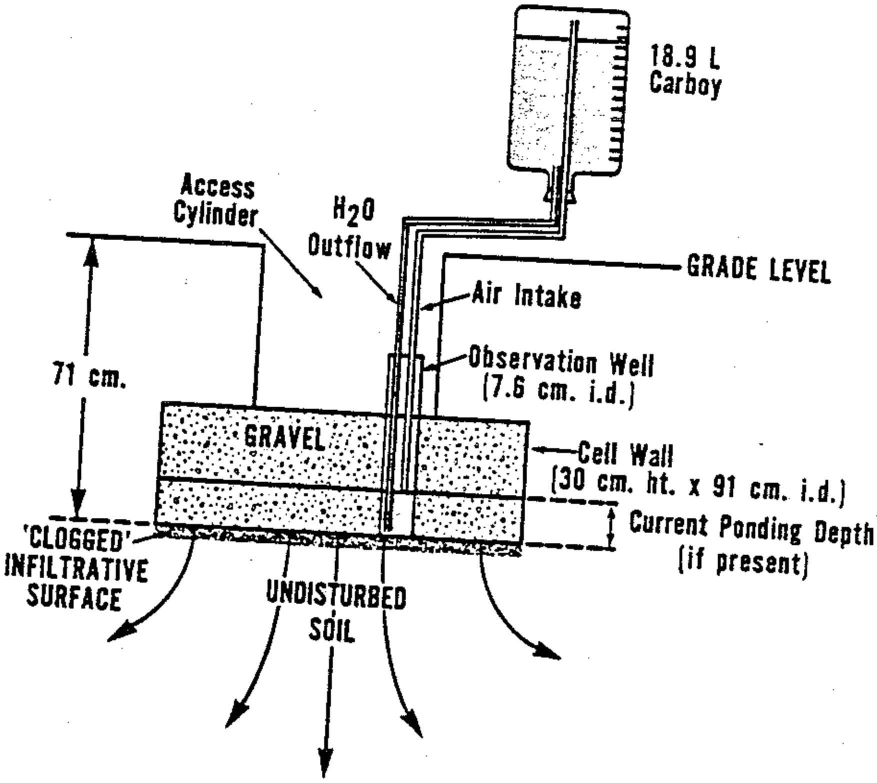
<u>Reagent Application</u>--On June 18, 1981, a standard commercial Porox^R treatment was applied to the 12 systems. These systems are designated in Figure 1 in the vertical columns labeled P1 (treated once) and P2 (treated twice). The treatment was administered by Rick Apfel of On-Site Sanitation Services, Inc., the only licensed Porox^R vendor in Wisconsin. The treatment consisted of the application of 1 cm (0.25 gal/ft^2 or 1.75 gal/system) of pre-mixed 10% Dupont Tysul-WW H_2O_2 applied through the observation well of each of the systems (Figure 2). As indicated in Table 1, this equals a mass loading of pure H_2O_2 of 1.49 kg/m^2. Some degree of foaming and steam was detected at the infiltrative surface via the system observation port, typical of other reported reactions (Harkin et al. 1975; Jawson, 1976; Harkin, 1977a).

After five days had elapsed, to ensure all residual H_2O_2 had decomposed, infiltration rates of all 18 systems were measured and then confirmed by a second measurement. Surprisingly, systems treated with Porox^R displayed a generally negative response as evidenced by lower infiltration measurements, as discussed below.

At this time the vendor suggested that a second application at a higher concentration might be in order to effect the desired result, complete oxidation of organic matter in the clogging zone, which was not achieved with the first treatment. This is apparently a common field practice for licensees, and is consistent with guidance in the Porox^R manual (Harkin, 1977b). Based on these results and recommendations a second Porox^R treatment was elected for the center row of six systems (marked by P2 in Figure 1).

The second Porox^R application was administered to the appropriate cells in the middle row (P2) of the site on August 25, 1981. This treatment, by the same licensed vendor, consisted of the same loading rate, 1 cm (0.25 gal/ft^2), but a concentration of 20 percent H_2O_2. This corresponds to a mass loading rate of 2.98 kg/m^2 of pure H_2O_2. Several days after the reaction was complete, infiltration rates were measured and subsequently reconfirmed on all 18 systems. Infiltration rate has been monitored in all 18 systems periodically since the H_2O_2 treatments.

We can consider the 18 systems as six replicates of each of the three basic Porox^R treatments - a control group, a once-treated group, and a twice-treated group of systems. In Figure 1 and in the discussion that follows these systems will be referred to as P0 (control), P1, and P2, respectively.



;ure 2 - Section-view of experimental field system and constant-head infiltration rate technique.

iltration Rate Response--Soil infiltration rates were measured before and er each Porox[R] event and periodically thereafter. Analysis of variance was ducted on the infiltration rate data using the general linear models proce- of the Statistical Analysis System (SAS) - Version 82.2B (SAS Institute, 2a,b). Statistical methods utilized, to include Duncan's Multiple Range ;, are described in Snedecor and Cochran (1972).

Figure 3 presents infiltration rate data for the experimental systems ted as infiltration rate response versus time. The values shown have been alized to a percent of the initial infiltration rate (%IIR) to correct for effect of natural soil variability. Initial infiltration rates for the ems at this site averaged 202 cm/day (standard deviation = 42 cm/day).

Each point in Figure 3 represents mean values for four systems in each x[R] treatment (P0, P1, and P2). This includes systems 7-18 (Figure 1). ms 1-6 are excluded from Figure 3 (but not Table 2) because of their pre-

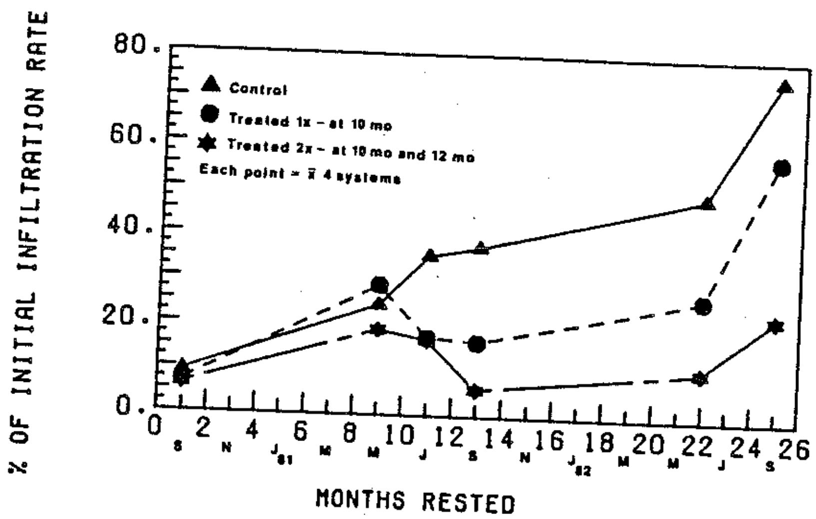


Figure 3 - Porox[R] effect on infiltration rate of experimental field systems.

Porox[R] IR variability, associated with previous low wastewater loading rates and a lesser degree of clogging. The graphical convenience of presenting the data in this fashion is that beginning and pre-Porox[R] values (months 1 and 4 in Figure 3) for P0, P1, and P2 are highly comparable.

Table 2 presents means for each group of six systems (P0, P1, and P2) for each measurement date. From Table 2 it is apparent that the groups of systems (P0, P1, P2) displayed no statistically significant differences until after the first Porox[R] treatments were administered in June 1981.

Figure 3 and Table 2 document the general deleterious effect of hydrogen peroxide treatments on soil infiltration rate. Of the 12 systems treated in June 1981, eight declined in %IIR and the others changed negligibly or rose slightly. The systems which received Porox[R] averaged 28 %IIR in May but declined to 20 %IIR after treatment. Meanwhile, the control group continued to rise from May to July. The second Porox[R] treatment (P2 at 20% H_2O_2) was applied to a group of six systems in late August. These six cells declined even more drastially to an average of only 7 %IIR, lower than their historical low infiltrative capacity even when severely clogged (Hargett et al. 1981).

Figure 4 shows the relative infiltration rates for all 18 systems for September 1981, one month after the last Porox[R] treatment. In every case, regardless of the previous wastewater treatment history, %IIR values for the control are higher than the system treated once with Porox[R], which are in turn greater than the twice-treated systems. Table 2 shows that this trend is statistically significant.

Table 2 - Effect of hydrogen peroxide on soil absorption system infiltration rate.

H_2O_2 treatment	Percent initial infiltration rate†							
	9/80	5/81	6/81	7/81	8/81	9/81	6/82	9/82
Control	21.5 az‡	38.8 ayz		45.7 ay		43.0 ay	52.2 ay	77.6 ax
1X	11.5 az	33.5 ay	§	21.0 byz		18.5 byz	30.2 by	57.5 bx
2X	13.0 ayz	22.8 axy	§	19.3 bxy	¶	6.6 cz	13.0 cyz	25.7 cx

† n=6 systems for all treatments and dates.

‡ a,b,c = treatment means within dates (same column) with the same letter are not significantly different ($p = 0.05$). x,y,z = date means within treatments (same line) with the same letter are not significantly different.

§ Systems treated 6/81 with 10% H_2O_2.

¶ Systems treated 6/81 with 10% H_2O_2 and 8/81 with 20% H_2O_2.

Monitoring of the infiltration rate behavior of all 18 systems was carried out periodically for over one year after their treatment. No wastewater has been applied to any of the systems during this period. This provided an opportunity to observe the effects of natural resting on the P0 systems and to assess the long-term effects of the Porox^R treatments on the P1 and P2 systems.

Figure 3 also evidences the slow but significant natural reclamation of the rested systems (P0) with an average of over 75% IIR after 25 months of rest. It appears that although the Porox^R treated systems were severely damaged, some systems are gradually improving their infiltrative capacity. The P1 systems are somewhat promising with last-measured values above 55% IIR. However, over one year after the last Porox^R treatment, the P2 systems averaged only 13% IIR, precisely the same as their September 1980 clogged state, when wastewater application was discontinued.

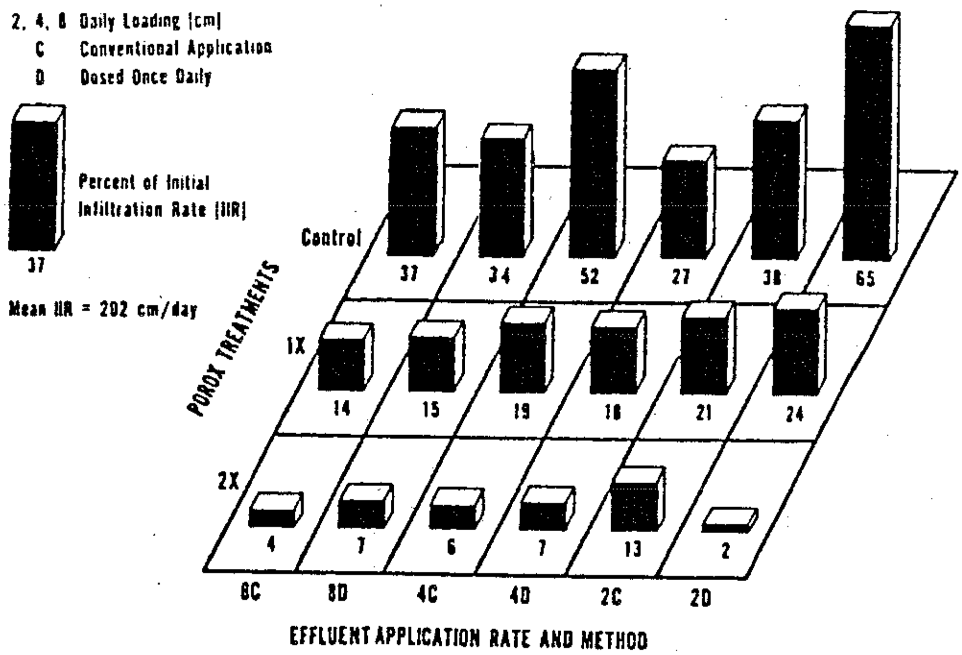


Figure 4 - Relationship of infiltration rate (%IIR) and hydrogen peroxide (Porox[R]) treatment, field systems, September 1981.

After this experience, speculation about the mechanisms causing negative response to H_2O_2 treatment were centered around the Porox[R] reaction itself and possible deleterious side-effects under these particular soil conditions. Other workers have recognized management problems associated with soil absorption systems installed in these soils (Bouma et al. 1975). It was conceived that in these soils, which have a high proportion of fine silts (SCS, 1967), structural bonding is relatively weak and susceptible to physical disruption, such as the violent effervescent decomposition reaction which occurs with the application of H_2O_2. It was further speculated that the natural organic matter in these soils may be relatively important to structural integrity such that any decomposition via H_2O_2 application may accelerate aggregate breakdown. This is supported by observed losses of natural organic matter with H_2O_2 application (Bishop and Logsdon, 1981). Mineralogical changes due to super-oxidation by free O_2 was also considered as a possible side-effect.

Regardless of the mechanisms, the infiltration rate measurements suggest that soil structural units were likely destroyed and soil particles reoriented. This probably resulted in a redistribution of pore-sizes, and a substantial change in pore continuity. Furthermore, as shown by the relationship between loss of infiltrative capacity and the number of H_2O_2 treatments, the degree of damage appears to be related, at least in this case, to the cumulative mass H_2O_2 loading.

Micromorphological Analysis of Soil Thin Sections--Based on the experiences discussed above, it seemed appropriate to examine the soil in each of the systems using micromorphological techniques. It was hoped that this approach would provide considerable insight into the mechanisms operating to reduce system permeability.

One "undisturbed" core was collected from each of the 18 soil absorption systems using a sampling device and sampling tubes specially fabricated for this purpose. Another undisturbed core was collected as a background sample adjacent to the experimental systems area. These sampling tubes, 2.54-cm (1-in) i.d. electrical conduit, with a beveled penetrating point, were pushed down through the soil infiltrative surface and into the soil below, to a depth of 8 to 12 cm (3 to 5 in). To access the infiltrative surface for this sampling procedure, the gravel in the system was partially removed by vacuum cleaner through a 10-cm i.d. access tube which was simultaneously inserted into the system until the gravel-soil interface was reached. After collection of the sample, the remaining cavity was filled with a highly impermeable gypsum-sand crust. The area of these disturbing activities represented less than two percent of the infiltration surface of the systems, thus minimizing any effects on their hydrodynamic integrity.

The soil cores, intact in their sampling tubes, were wrapped thoroughly in Saran for transport to the laboratory where they were refrigerated until further processing. The cores were later extracted and divided into three 4-cm depth-increments from each system. Each core depth-increment was carefully split along its vertical axis to expose a fresh natural soil face. The samples were oven-dried at 105°C for 24 hours and then each sample was impregnated under vacuum with a mixture of Castolite resin (200 ml), methyl methacrylate (300 ml), and benzoyl peroxide (3 g) according to the method of Buol and Fadness (1961). The impregnated samples were subsequently cut on a diamond saw, ground and polished, mounted on glass slides, and ground to approximately 0.03 mm-thin sections (Cady, 1965).

Selected thin-sections representing background, control (P0), and each of the H_2O_2 treatments (P1 and P2) were analyzed using polarizing and dark-field microscope techniques (Cady, 1965; Thresher, 1982a). The porosity of the samples was estimated by point counting techniques (Chayes, 1949; Daniels et al. 1968) and described according to guidance provided by Johnson et al. (1960) and Brewer (1976). Only pores larger than 0.05 mm were counted by this method; size was determined with an ocular micrometer. Pore linings were described to include argillans, organic matter, hydrous iron oxides, or complexes of these. X-ray diffraction analysis was also employed on the uncovered samples according to the methods of Jackson (1974).

Results of Thin-Section Analysis--The results of thin-section analysis of selected samples is reported in Thresher (1982b). Table 3 classifies and summarizes the results of this study contrasting general micromorphological features observed in the natural background soil, the clogged untreated soil, and each Porox^R treated soil.

Table 3 - Effect of wastewater application and hydrogen peroxide on morphology and porosity of soils 0 to 3 cm deep below field soil absorption systems.

Feature	Soil condition			
	Natural structured soil	Clogged[†]	Once treated[‡]	Twice treated[§]
Porosity (>0.05 mm)	16%	9%	16%	20%
Type	interpedal planar, tubular	interpedal, planar tubular	vesicals, irregular vughs	coarser vesicals, irregular vughs
Structure	apparent	apparent	not apparent	totally destroyed
Pore continuity	continuous, vertical dominant	restricted, clogged	interpedal pores closed, discontinuous	discontinuous, no interpedal pores
Dispersion of fines	not significant	not significant	significant	very significant, roiled throughout
Organic matter	common, pores	very common, pores	less, dispersed, concentrated in smaller pores	less, dispersed, complexed, not totally removed
Pore linings				
Clay	many	few	very few	absent
Organic matter	many	very many	very few	very few
Hydrous Fe^{3+} oxides	very few	very few	many	very many, precipitates
OM-Fe^{3+} complexes	very few	common	very many	very many
Empty pores	few	very few	many	very many
Infiltration rate (cm/day)[γ]	202	42	20	6

[†] Clogged with 21 months of wastewater application.

[‡] Treated with 1.02 cm (0.25 gal/ft^2) 10% H_2O_2.

[§] Treated twice, first as above, second with 1.02 cm 20% H_2O_2.

[γ] From field infiltration rate studies.

Comparing the natural and clogged conditions in Table 3, the effects of prolonged wastewater application are evident. In the latter case, the pores are lined or completely clogged by organic debris, pore continuity is restricted, and consequently permeability of the soil system is severely retarded.

Thin-section analysis documents even more dramatic morphological effects caused by application of hydrogen peroxide (Table 3). Interestingly, total porosity (>0.05 mm) increased substantially from the clogged state. However, these pores are dominantly vesicular in character, often empty, and not interconnected. With fewer large interconnected pores to freely transport fluids, a reduction in hydraulic capacity is concomitant. Note that natural soil structure and structural porosity were essentially destroyed by H_2O_2 and that considerable dispersion of clay and organic matter occurred. Also, organic matter was not completely removed, even in the twice-treated soil, and appeared to be complexed with hydrous iron oxides and clays and redistributed on some pore faces.

<u>Conclusions From Field Experience With Porox^R</u>--Our original research objectives did not include an assessment of the efficacy of hydrogen peroxide for system rehabilitation. However, in attempting to use Porox^R to rejuvenate our experimental systems, we ultimately conducted a relatively comprehensive evaluation of the process.

The unique nature of our original experimental design, with controlled, replicated soil wastewater absorption systems in natural soils, provided an ideal environment in which to evaluate this technique. As a result, the experiments we conducted with Porox^R are the only controlled, replicated, <u>in situ</u> evaluation known. This study included six replicate systems of two levels of hydrogen peroxide treatment plus six control systems. The key physical indicator of system rehabilitation, infiltration rate, was measured consistently, confirmed, and follow-up monitoring was conducted for over one-year after treatment. Ancillary techniques, thin-section analysis, supported the physical measurements and suggested causative mechanisms.

As regards our objectives of rehabilitation of the systems, we achieved the opposite. The Porox^R treatments, at least temporarily, and possibly irreversibly, destroyed the hydraulic integrity of our experimental units. It is doubtful that the 12 systems which received a Porox^R treatment can be used for further research.

The negative effect of both Porox^R applications on our field systems was unmistakable and raised questions as to whether the process might have such deleterious effects on similar and different soils. Such events could serve to functionally destroy a soil wastewater absorption system. This might require the system owner to totally replace the system at a cost of up to several thousand dollars or subject the licensed Porox^R vendor to damage liabilities.

Assuming the Porox[R] process does have potential for the rehabilitation of some systems, it was apparent that the process was not appropriate for all soils. Given the unpredicted performance of Porox[R] in our field studies, it became evident that further immediate research on the process was warranted. Justification included the product's history of development by SSWMP with state and U.S. EPA support, recognition by regulatory agencies as an approved rehabilitation technique, and its performance relative to commercial claims. A proposal was prepared and quickly approved and funded by the University Industrial Research Program (UW). Additional funding was provided by SSWMP. The results of this research effort follow.

Scope of Further Research

Special emphasis in these continuing studies on hydrogen peroxide was directed to gaining accurate, detailed information regarding the on-going viability of Porox[R]. Soundly supported recommendations were to be developed. This research was aimed at fine-tuning the product to specific soil conditions and possibly altering reagent concentrations, formulations, or loading rates to optimize results and minimize side-effects.

Two distinct approaches were utilized to gather timely and accurate information regarding H_2O_2 treatments. The first was an examination of the commercial field experience with Porox[R]. This included a survey of user satisfaction and post-treatment system performance. The results of this study will be discussed only briefly because analysis is not yet complete and the results are anticipated to be relatively inconclusive, at least compared to other data collected.

The second approach involved laboratory studies of the effects of H_2O_2 on critical soil properties in a variety of both clogged and non-clogged soil types. These latter studies are the substance of the remainder of this report.

Survey of Wisconsin Porox[R] Clients

In order to gain insight into the "real world" commercial experience with Porox[R] a survey study was designed. Rick Apfel of On Site Sanitation Services (OSSS), Stoughton, WI, the only licensed Porox[R] vendor in Wisconsin, acted as commercial cooperator in this study. This arrangement provided access to records of all OSSS clients treated since the product became available in 1977. These systems numbered 45, all of which had been treated between one and five years previous to the survey. OSSS Records provided quite valuable but variable information regarding site and soil conditions, and system design, history, and Porox[R] treatment specifications.

A concise but comprehensive battery of questions was devised to ascertain information about soil, site, and system conditions as well as wastewater generation characteristics of the facility. Queries were particularly directed to failure symptoms before Porox^R treatment, satisfaction with the treatment, and system performance after the treatment.

The telephone survey was conducted by the University of Wisconsin's Survey Research Laboratory (WSRL) using professional survey techniques. WSRL provided a critique and organization of questions and expert non-biased interviewers. Respondents were assured that the information they provided would be handled with confidentiality and was not to be available to state agencies for regulatory or enforcement purposes. Responses to over 70 questions were categorized and made available to us as a computer printout summary as well as by individual homeowner.

After the telephone survey was completed, 26 of the 45 respondents were randomly selected for a brief follow-up personal interview. Where possible the soil wastewater absorption system was inspected and any symptoms of failure or problem operation were noted.

Survey Results--Analysis of the survey results is incomplete; response data have yet to be merged with original site and system evaluation information. Likewise system inspection data have yet to be interfaced. Preliminary perusal of the data demonstrates that homeowners know very little about their septic systems and very little about what they purchased in a Porox^R treatment. Nevertheless, several important characterizations of product users and Porox^R performance can be inferred.

As regards the expectations of Porox^R clients, 87 percent anticipated a fully functioning system after treatment. Although OSSS has never had a policy of guaranteeing the treatment, 27 percent of the respondents thought that the process was guaranteed. Eleven percent of the respondent's systems received two Porox^R treatments.

A very important observation with regard to post-treatment system performance deals with the issue of water conservation. Half of the respondents (49%) indicated that they had significantly reduced flows to their system after treatment. Implementation of significant, and in some cases drastic water conservation is routinely recommended by many Porox^R licensees in conjunction with a treatment; some vendors also market flow reduction hardware (Hill, 1980; USRE, 1982). This common-sense remedial solution to a failing system obviously complicates analysis of the Porox^R treatment effect as opposed to the effect of reduced wastewater loadings.

A total of 35 percent of the respondents reported periodic or constant system failure as either backup or surfacing after the treatment. Interestingly, 71 percent stated that they were satisfied; thus some homeowners were apparently satisfied with the treatment although failure continued or reoccurred. Asked how they would describe the longevity of the treatment, responses were 29% long-lasting, 24% temporary, and 40% did not know. As to the dependability of Porox[R], 42 percent of the respondents qualified the treatment as dependable, 18 percent undependable, 29 percent did not know.

The survey follow-up site visits were somewhat more revealing with regard to post-treatment performance. Of the 26 sites examined, three (12%) of the systems had been totally replaced and three (12%) were pumping on a regular basis. Inspection of the systems revealed that 19 (73%) of the systems were experiencing severe continuous ponding (all > 18 cm [7 in]). These observations verify that probably for most systems treated, Porox[R] did not have a long-lasting positive effect.

Assessment of Hydrogen Peroxide Effects on Soil Hydrodynamic Properties

These experiments were designed to address several questions regarding soil interactions with hydrogen peroxide and thus provide a reference base for decisions on the continued efficiacy of Porox[R]. Among these questions were concerns of soil suitability to the Porox[R] process, reagent concentration and loading rate, and potential side-effects of the treatment.

Three experiments were designed to comprehensively address each of these issues, while under the constraint of gathering maximum insight in a minimum of time. Because the previous field experience had documented deleterious side-effects on soil physical properties, effected by H_2O_2 applications, these studies emphasized physical measurement techniques.

In the first experiment, the effects of H_2O_2 upon the permeability of unclogged, undisturbed soil cores were assessed. Cores representing twenty-five soils were analyzed. Ancillary to this investigation, the second study evaluated the impact of H_2O_2 applications upon soil morphology and porosity using micromorphometric techniques. Two contrasting soil types were evaluated in this effort. In the last experiment, numerous columns from each of four benchmark soils were clogged by continuous wastewater application and then treated with H_2O_2. Experimental design, methodology, and results of each of these studies are described below.

Effect of Hydrogen Peroxide on Soil Infiltration Rate--Non-clogged soil cores-- In these experiments unclogged, undisturbed soil cores representing a wide range of subsoil properties were treated with H_2O_2 to examine the reagent's effects on soil hydraulic properties. With our experience from the field studies (already discussed) it appeared appropriate to assess any potential side-effects H_2O_2 may have upon soil permeability. This approach was quite advantageous in expediting the evaluation of a wide range of H_2O_2 concentrations and loading rates and their effects upon numerous naturally occurring subsoil conditions. By assessing the hydrodynamic side-effects, if any, on natural raw (unclogged) soils, we saved much time and effort over several months of wastewater application to clog the same number of soils. A concurrent experiment utilized four of the same soils used in the unclogged cores study in an evaluation of H_2O_2 effects on clogged soils.

Soil Sampling and Characterization - Twenty-five subsoil horizons from thirteen soil series and sites were selected for sampling (Table 4). These subsoils represent a very wide range of textures and natural organic matter content. Figure 5 displays the range of textural characteristics of the soils studied. Each of these 13 soil series may be used for subsurface or alternative soil absorption systems in Wisconsin provided they satisfy the requirements of Wisconsin Administrative Code (1980). Obviously, some soils are more suitable for this purpose than others. Each specific site selected has been recognized as typifying its mapped soil series and has a complete series of published physical and chemical characterization data and field descriptions (Soil Conservation Service [SCS], 1967). The great advantage in using these sites was the availability of such a suite of data for convenient inference to other soil properties to be measured in this study. Typical data reported (SCS, 1967) include detailed particle size analysis, pH, organic matter, bulk density, water retention, cation exchange capacity, base saturation, iron content, and other analyses (methods from Soil Survey Investigations, 1972).

Sampling of the subsoils used in these studies was by means of a modified Uhland sampler (Blake, 1965) and standard 7.62-cm (3-in) i.d., 7.62-cm length sampling rings for undisturbed cores. The cores were collected using a truck-mounted hydraulic probe following hand excavation to the desired confirmed horizon. Undisturbed cores were collected in this manner from 23 of the 25 site-horizons. In the case of two of the 25 site-horizons, the soils were too sandy and not cohesive enough to sample in this fashion (both Plainfield horizons). In these cases bulk samples were collected and the sample rings were hand-packed to natural bulk densities. Depending on the experimental design for each soil either 16 or 36 core samples were collected and prepared.

Duplicate bulk samples of each soil horizon were collected for particle size analysis. Each sample was crushed, gravel was removed, and hydrometer analysis was conducted according to the method of Day (1965). The sand fraction was determined by wet-sieving. Results of the particle size analysis of the 25 soils is presented in Appendix Table B-1. USDA textural classes for the samples according to this analysis are reported in Table 6.

Chemical properties of the study soils can be inferred from laboratory data for similar soil series and horizons, as characterized by SCS (1967). Selected chemical data for the SCS type-locations for these series and horizons (same as our sampling site locations) are presented in Appendix Table B-2.

Experimental Design - The goal in chemical rehabilitation of a soil absorption system is to unclog the infiltrative surface, thus resulting in improved soil permeability. The Porox[R] patent teaches that H_2O_2 treatment of a clogged system may be expected to result in infiltration rates comparable to the initial rate (Harkin, 1977a). It seems reasonable to expect that if H_2O_2 imparts such dramatic improvements in a clogged soil system that these reagents would not have serious deleterious side-effects on the permeability of an unclogged soil.

Table 4 - Soil series and horizons used in laboratory studies. SCS (1967) identifies sampling sites and provides ancillary data.

Series	Classification†	Horizon sampled	Depth, cm (in)	Reported texture‡	SCS soil/Sample no.‡	County
Dodge	fine-silty, mixed Typic Hapludalf	B22 IIB23	58-79 (23-31) 79-99 (31-39)	sicl scl	62 WI 1101/17804 17805	Columbia
Kewaunee	fine, mixed Typic Hapludalf	IIBt IIC1	25-46 (10-18) 46-66 (18-26)	cl cl	60 WI 3602/13583 13584	Manitowoc
McHenry	fine-loamy, mixed Typic Hapludalf	IIB23 IIB3	71-86 (28-34) 86-102(34-40)	scl sl	54 WI 1423/5532 5533	Dodge
Morley	fine, illitic Typic Hapludalf	IIB2	41-64 (16-25)	c	58 WI 3003/9342	Kenosha
Oshkosh	very fine, mixed Typic Hapludalf	IIC1 IIC21	53-69 (21-27) 69-102(27-40)	c c	60 WI 7001/13557 13558	Winnebago
Pardeeville	coarse-loamy, mixed Mollic Hapludalf	B22 IIC1	28-51 (11-20) 81-104(32-41)	sl ls	62 WI 1104/17824 17827	Columbia
Peebles	fine, mixed Typic Argiudoll	IIC1 IIC2	61-86 (24-34) 86-109(34-43)	sic c	59 WI 2001/11781 11782	Fond du Lac
Plainfield	mixed Typic Udipsamment	C2 C3	33-56 (13-22) 56-81 (22-32)	cos s	57 WI 6901/6981 6982	Waushara
Plano	fine-silty, mixed Typic Argiudoll	B21 B22	66-94 (26-37) 94-112(37-44)	sicl sicl	62 WI 1102/17883 17884	Columbia
Port Byron	fine-silty, mixed Typic Hapludoll	B21 B22 B3	66-86 (26-34) 86-107(34-42) 107-119(42-47)	sil sil l	57 WI 3201/5549 5550 5551	LaCrosse
Richwood	fine-silty, mixed Typic Argiudoll	B1 B2	51-66 (20-26) 66-89 (26-35)	sil sil	56 WI 3203/5326 5327	LaCrosse
Ringwood	fine-loamy, mixed Typic Argiudoll	I&IIB23	58-76 (23-30)	sl	62 WI 1103/17864	Columbia
Varna	fine, illitic Typic Argiudoll	IIB22 IIB23	51-58 (16-23) 58-94 (23-37)	sicl sicl	58 WI 5101/9315 9316	Racine

† All series have mesic temperature regimes. ‡ SCS (1967).

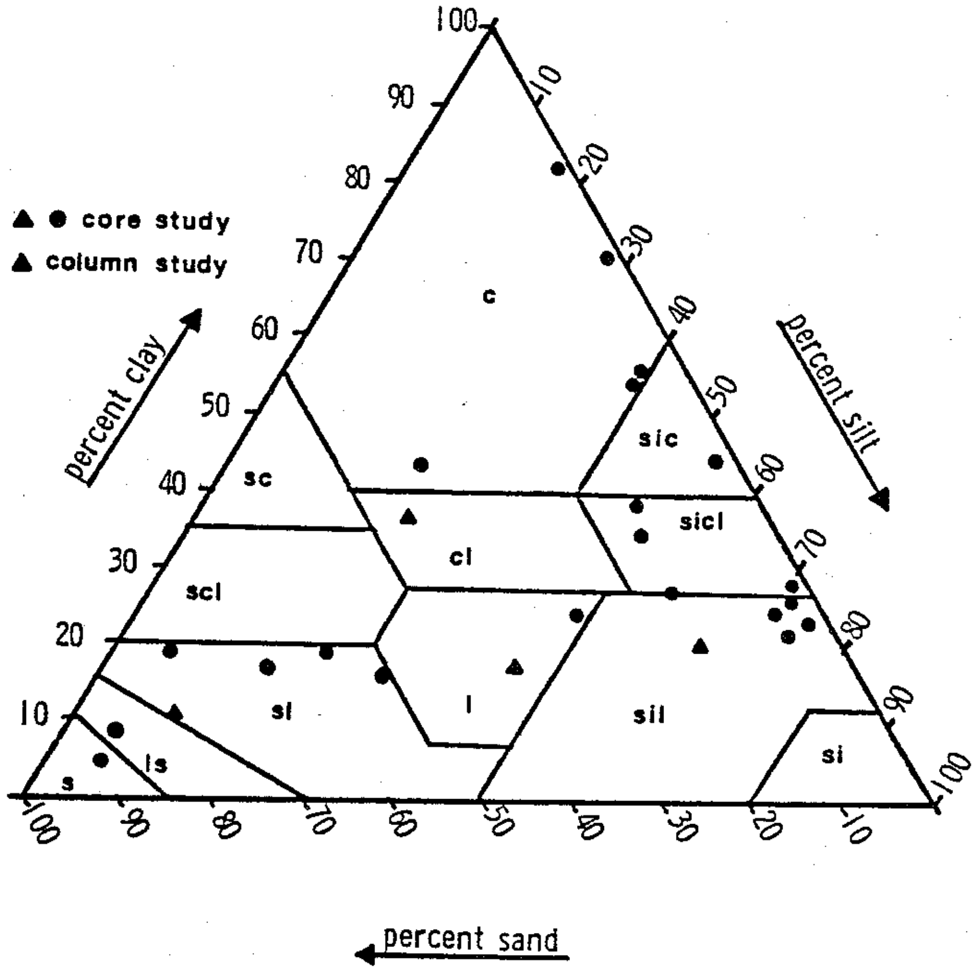


Figure 5 - Range of textural properties of soils used in laboratory studies.

In order to test the hypothesis of no significant H_2O_2 effect on soil infiltration rate we used a simple treatment scheme and measurement technique. Table 5 presents the experimental design for this study on unclogged cores as well as the other two lab studies. This table shows that for all 25 soils we utilized four H_2O_2 concentrations (6.25, 12.5, 25, and 50 percent) and at least one hydraulic loading rate (HLR) (0.63 cm). This resulted in a range of mass loading rates (MLR of pure H_2O_2) of 0.58 to 4.61 kg/m^2. For three of the soils we broadened the range of hydraulic and mass loading rates to 0.32, 0.63, and 1.26 cm, and 0.29 to 9.22 kg/m^2, respectively. Comparing the HLRs, MLRs, and concentrations listed in Table 1, it is evident that our range of treatments encompassed essentially all of the concentration and hydraulic loading combinations used previously by both researchers and commercial practitioners. Note that a minimum of two replicate cores were utilized for each H_2O_2 treatment and four replicate controls for each soil type.

Table 5 - Summary of experimental design factors, laboratory studies--hydrogen peroxide concentrations, and hydraulic and mass loading rates.

H_2O_2 conc., %	H_2O_2 loading rate				No. of soils evaluated - each experiment		
	Hydraulic		Mass†				
	cm	gal/ft^2	kg/m^2	lb/ft^2	Unclogged cores‡	Thin-section study§	Clogged columns§
0 (control)	0	0	0	0	25	2	4
6.25	0.32	1.31	0.29	0.06	3		1
6.25	0.63	2.58	0.58	0.12	25	2	4
6.25	1.26	5.15	1.15	0.24	3		1
12.5	0.32	1.31	0.58	0.12	3		1
12.5	0.63	2.58	1.15	0.24	25	2	4
12.5	1.26	5.15	2.31	0.47	3		1
25	0.32	1.31	1.15	0.24	3		1
25	0.63	2.58	2.31	0.47	25	2	4
25	1.26	5.15	4.61	0.95	3		1
50	0.32	1.31	2.31	0.47	3		1
50	0.63	2.58	4.61	0.95	25	2	4
50	1.26	5.15	9.22	1.89	3		1

† Expressed as pure H_2O_2 applied.

‡ Minimum number of replicates, two per H_2O_2 treatment, four for controls.

§ Two replicates each.

Measurement Technique - Soil infiltration rate or hydraulic conductivity (K) of the saturated soil cores was measured using a refined version of the concentric-ring (split-flow) permeameter (CRP) described by Hill and King (1982). A battery of 12 CRPs was constructed for this purpose and located in a constant temperature room (12.8°C) with appropriate plumbing facilities. Figure 6 provides details of the apparatus and identifies CRP components. The construction and operation of the apparatus is described in detail in Hargett (1982).

These instruments are unique in that they are capable of eliminating boundary flow problems associated with traditional laboratory core techniques for hydraulic conductivity (McNeal and Reeve, 1964; Hill and King, 1982). This segregation of flow can be very critical to data interpretations. McNeal and Reeve (1964) reported boundary flow K values up to six times that of center flow. The CRPs are compatible with standard 7.62-cm (3-in) i.d. soil sampling rings of variable length. Other aspects of CRP operation and use are substantially in concert with considerations discussed in Klute (1965) and McNeal and Reeve (1964). In utilizing the CRP to measure the hydraulic conductivity of either natural or disturbed, treated or untreated, saturated soil cores, the center region outflow is taken as representing actual flow through the soil mass, and actual saturated hydraulic conductivity is calculated according to Darcy's Law. Because of the large volumes of water used in CRP operation tap water was utilized. Characteristics of this water are provided in Appendix Table C-1. The quality of this tap water should not have resulted in excessive sample swelling or dispersion due to salt or SAR levels (Corey et al. 1977).

Soil cores were prepared by careful scarification of each end. This exposed natural non-smeared surfaces, and thus provided for the hydraulic influence of natural structure and porosity. Soil air was displaced by wetting the cores slowly (overnight) from the cheesecloth covered bottom until saturated. This extended wetting procedure also provided for gradual hydration and swelling of soil clays.

The saturated soil cores were carefully assembled with the CRP units according to Hargett (1982). The cores were then covered with a thin veneer of medium sand to prevent scouring, and an appropriate concentration and volume of H_2O_2 was applied according to the experimental treatment scheme. For control samples no H_2O_2 was added and the CRP hydraulic conductivity run was commenced immediately. Runs were typically four hours long with the first two hours regarded as an equilibration period; during the final two hours measurements were made at thirty minute intervals, or more frequently as required for certain soils. A minimum of four readings was collected,

1 Reservoir top
2 Reservoir wall
3 Reservoir base
4 Rubber O-ring
5 Aluminum soil ring
6 Rubber O-ring
7 Orifice place
8 Aluminum flow-splitter
9 Outer-wall peripheral outflow reservoir
10 Inner-wall peripheral outflow reservoir
11 Permeameter base
12 Center region outflow tube
13 Peripheral region outflow tube
14 Inflow feed tube
15A,B Peripheral and center outflow regions, respectively

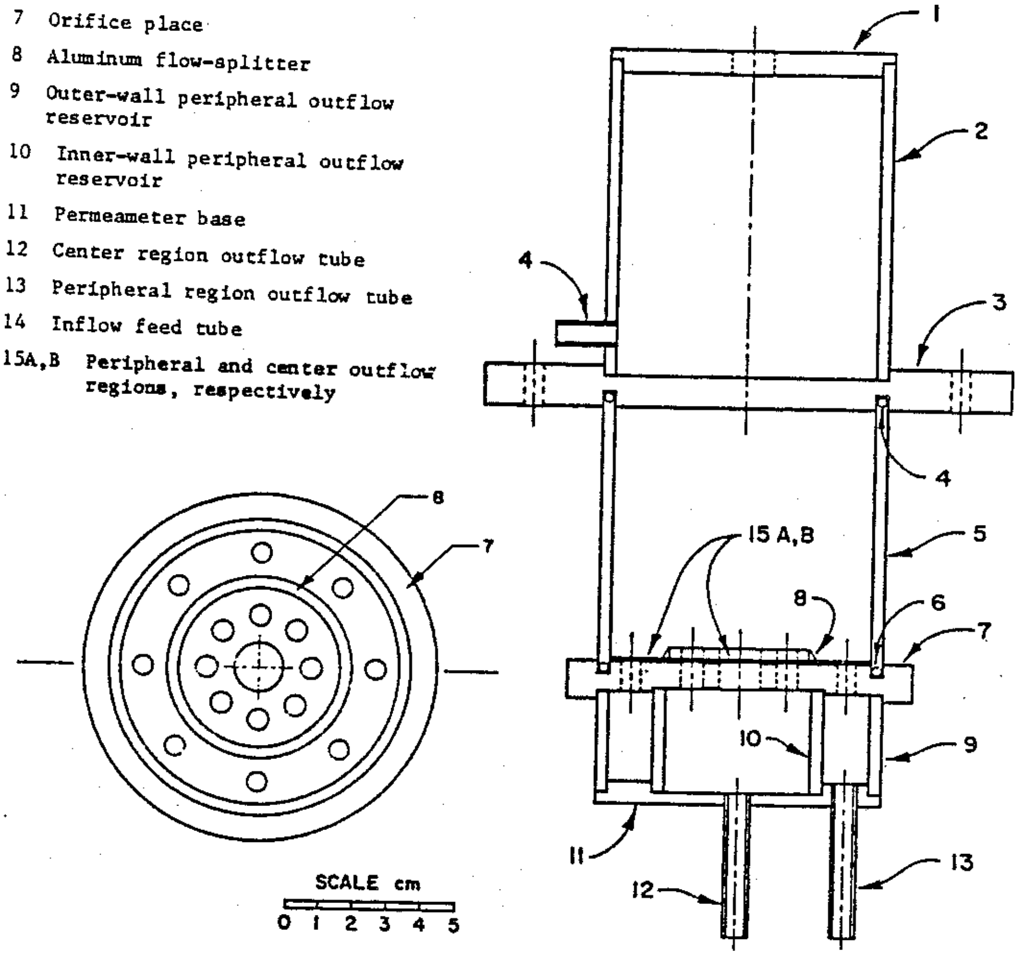


Figure 6 - Section-view of assembled concentric-ring permeameter (CRP) at right. At left, orifice plate is rotated to plan-view to display flow-splitter which segregates the center flow region from the peripheral flow region.

averaged, and hydraulic conductivities were calculated according to Darcy's Law.

$$K = (Q/At) \times (L/\Delta H)$$

where: K is hydraulic conductivity of saturated soil (cm/day)
Q is volume of outflow (cm^3)
A is cross sectional (cm^2)
t is time (day)
L is length of sample (cm)
ΔH is distance from outflow point to top of head (cm)

Reagent Application - Cores receiving hydrogen peroxide applications were treated immediately after CRP assembly and allowed to react for 48 hours. This provided two functions. First, it allowed more than adequate time for the H_2O_2 decomposition reaction to go to completion. Jawson (1976) indicated that the reaction is probably more than 90% complete in a few hours, although some residual H_2O_2 may last for a day or more. Secondly, the primary purpose of waiting 48 hours was to maintain a "real world" analogy to what occurs when a soil absorption system is treated. When a commercial Porox[R] treatment is administered the soil absorption system is typically dewatered by pumping to minimize dilution of applied reagent (Harkin, 1977b). Also pumped is the septic tank, which should have a capacity of at least 48 hours waste flow. Thus, with a commerical Porox[R] application the treated soil infiltrative surface will typically not experience inundation for at least 48 hours. In our laboratory procedure, 48 hours after reagent application, hydraulic conductivity was determined on the treated samples as described above. To insure that this 48 hour period did not have a serious effect apart from that of the H_2O_2 treatment, extra control and H_2O_2-treated samples for selected soils were run with both 0 and 48 hours elapsed after assembly. This comparison showed no significant effect of the waiting period itself.

Analysis - All data handling and statistical analysis were carried out using the Statistical Analysis System (SAS) - version 82.2B (SAS Institute, 1982a,b). Center-region flow from the CRP was considered as representative of soil K values, but peripheral and total average flow were also analyzed. Analysis of variance was carried out on both raw and log-transformed data using the SAS general linear models package (SAS Institute, 1982b). Nielsen et al. (1973) recommended the log transformation of hydraulic conductivity data in order to apply normal statistics. Statistical methods used, to include the least significant differences (LSD) multiple range technique, are described in Snedecor and Cochran (1972).

Results and Discussion - Table 6 presents results of the assessment of H_2O_2 effects on the infiltration rate of the 25 soil horizons. The most conspicuous observation that can be made from this data is that for most soils any application of H_2O_2 reduced the infiltration rate of the soil. Only one

Table 6 - Effect of hydrogen peroxide on infiltration rate of non-clogged soil cores--25 soil horizons.

Soil	Horizon	Texture	Infiltration rate (cm/day)[†]						
			H_2O_2 concentration (%)						
			6.25	12.5	25	50	Control	$\bar{x}$ all H_2O_2 treated	Treated as % of control
Dodge	B22	L	0.11	0.00	0.00	0.00	4.86**	0.03	0.6
	IIB23	SL	22.04	2.68	0.00	0.90	103.88**	6.41	6.2
Kewaunee	IIBt	CL	0.68	0.88	0.90	0.33	20.33**	0.70	3.4
	IIC1	C	0.00	0.00	0.00	0.00	0.75**	0.00	0.0
McHenry	IIB23	SL	17.55	10.46	22.62	30.37	61.83*	20.25	32.8
	IIB3	SL	33.70	20.26	25.54	15.09	167.12**	23.65	14.2
Morley	IIB2	SIC	0.88	0.00	1.33	0.98	71.97**	0.80	1.1
Oshkosh	IIC1	C	7.04	0.00	1.54	0.64	64.63**	2.31	4.2
	IIC21	C	0.00	2.25	0.00	0.00	2.40	0.56	23.3
Pardeeville	B22	SL	0.44	5.35	2.20	1.59	12.31**	2.40	19.5
	IIC1	SL	0.90	10.72	2.03	23.72	91.13**	9.34	10.2
Peebles	IIC1	C	1.14	0.11	3.43	0.23	3.07	1.23	40.1
	IIC2	C	0.00	0.11	0.11	0.11	14.38*	0.08	0.6
Plainfield	C2	LS	118.01	83.68	117.45	163.77	111.67	120.72	108.1
	C3	S	222.09	130.82	205.04	196.93	130.45	188.72	144.7
Plano	B21	SICL	4.76	6.98	0.00	0.89	10.46	3.16	34.2
	B22	SICL	6.38	4.87	0.99	4.66	72.70**	4.23	5.8
Port Byron	B21	SIL	20.47	9.50	1.13	1.22	9.16	8.08	88.2
	B22	SIL	0.23	0.00	0.00	0.00	2.24*	0.06	2.7
	B3	SIL	0.11	0.11	0.00	0.00	5.06*	0.06	1.2
Richwood	B1	SIL	20.67	27.07	35.96	38.02	1101.45**	30.43	2.8
	B2	SIL	1.57	42.51	18.21	16.66	2072.57**	19.74	1.0
Ringwood	I&IIB23	L	19.40	6.75	1.78	15.83	768.61**	10.94	1.5
Varna	IIB22	SICL	7.16	6.45	9.12	10.46	129.00**	8.30	6.3
	IIB3	SICL	0.11	0.44	0.00	2.79	5.33	0.84	15.8

* Control and mean of treated samples significantly different at $p = 0.05$.

**Control and mean of treated samples significantly different at $p = 0.01$.

† Each value represents the mean of all replicates for given soil and treatment.

of the 25 subsoil horizons, the Port Byron B21 horizon, displayed any statistically significant differences among the various H_2O_2 treatments. This important point demonstrates that with some degree of variability, for most soils, a low H_2O_2 concentration was as damaging to permeability as a high concentration.

In 23 of the 25 soils the mean of the control treatments was greater than the mean of the combined H_2O_2 treatments. As Table 6 indicates, these differences were significant ($P = 0.05$) or highly significant ($P = 0.01$) in 16 of the soils. In 22 of the 25 soils all H_2O_2 treatments resulted in lower infiltration rates than the control samples. The final column of Table 6 conveniently demonstrates the average effect of H_2O_2 on soil infiltration rate, expressed as "treated samples as a percent of controls."

Another very important observation from Table 6 is the character of the two soils which displayed a response to H_2O_2 treatments quite different from the 23 soils discussed above. Only the two Plainfield soils, the loamy sand C2 and sand C3 horizons, did not experience deleterious effects on infiltration rates associated with the application of H_2O_2. This is best reflected in the "treated samples as a percent of controls" expression where the H_2O_2-treated samples actually averaged higher than the controls. Recall that this same soil, Plainfield sand, was the only soil used in the original H_2O_2 experimentation by Jawson (1976). Thus, the lack of deleterious effect of H_2O_2-treatment to raw Plainfield sand in this experiment, appears to corroborate Jawson's work, to some extent.

It is convenient to categorize the 25 soils into large textural groups for general comparisons. Figure 7 graphically presents the data with each soil-horizon classified into one of six general textural groups. Table 7 presents this same data in a more detailed tabular form to include the range of values for each soil and treatment group. From Figure 7 it is clear that very sandy soils (S) have a response to H_2O_2 distinctively different from other soils.

The explanation for these results may be relatively straightforward. As indicated in Appendix Table B-2, the maximum natural organic matter content of any of these soils was about 0.65 percent, with some soils as low as 0.06 percent (SCS, 1967). Despite this very low organic sink for consumption of free O_2, upon addition of H_2O_2 to the soil cores, a violent reaction ensued. It appears that the natural soil provides a tremendous total surface area with which the reagent can react and decompose at a very rapid rate. This reaction would begin as a gentle bubbling or effervescing but would rapidly progress, especially for higher H_2O_2 concentrations, to an extremely violent boiling reaction after one to two minutes. This exothermic decomposition of the H_2O_2 typically evolved much steam and some sensible heat.

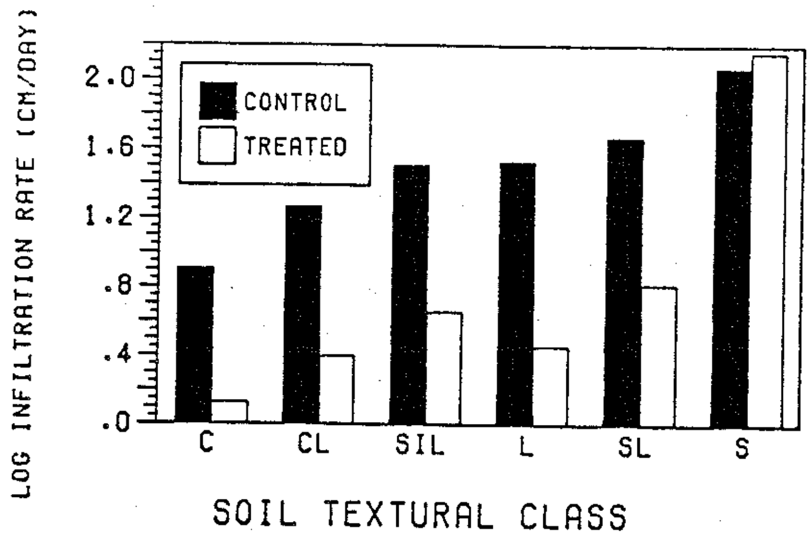


Figure 7 - Effect of hydrogen peroxide on infiltration rate of generalized soil textural groups--non-clogged soil cores.

The boiling effectively loosened and incorporated 5 to 10 mm or more of soil into the solution. For different soils and H_2O_2 concentrations the turbulence of the reactions varied. In some soils the lower concentrations did not cause a true "boil" but rather a continuous slow effervescence with a progressive volume expansion of the sample, in some cases up to 50 percent. This was apparently caused by reagent penetration into the soil with H_2O_2 decomposition incorporating gas bubbles within the soil fabric.

After about five minutes or less the H_2O_2 decomposition reaction would subside and the soil suspension was gradually deposited onto the roiled but intact soil below. It might be expected according to Stoke's Law that the suspended particles would settle out in a graded fashion, larger particles first, then finer. This would effect a graded filter with a layer of the finest, most impermeable particles segregated on top.

Another important consideration of this suspension and re-sedimentation of the particles is the effect on soil pores available to transmit fluids. The significance of naturally occurring porosity in the form of biotic and structural pores is evidenced in the extremely high control sample infiltration rates for both horizons of the Richwood soil and the one Ringwood horizon (Table 6). These soils naturally displayed an abundance of large biopores and structural macroporosity. The associated pore continuity conditions resulted in infiltration rates in control samples which were orders of magnitude greater than other control samples of similar texture. These observations are consistent with the importance of structure and pore continuity related by Bouma and Anderson (1973a,b).

Table 7 - Effect of hydrogen peroxide on infiltration rate of generalized soil textural groups--non-clogged soil cores.

	Infiltration rate (cm/day) - By textural class					
	Clay	Clay loam	Silt loam	Loam	Sandy loam	Sand
Control						
$\bar{x}$	26.19	47.56	638.10	386.74	87.37	121.06
Range	0-154	0-237	0-6283	0-1834	4-424	70-206
n	25	26	27	8	28	8
Treated†						
$\bar{x}$	0.89	3.49	11.68	5.76	6.64	154.73
Range	0-21	0-22	0-56	0-32	0-62	60-256
n	50	60	55	17	55	16
Treated as % of control	3.40	7.34	1.83	1.49	7.60	127.82
Soils in class	6	5	5	2	5	2

† All H_2O_2-treated cores, within soil textural class, are combined. ANOVA showed no differences in treatments in 24 of 25 soils ($p = 0.05$).

The effect of the violent H_2O_2 decomposition reaction on the structured soils also explains the response of the sandy soils to H_2O_2. These sands are naturally essentially structureless, and have relatively low content of fines, rather high particle size uniformity, and excellent interparticle pore continuity. Structure does not play a significant role in the porosity of these soils, and there are too few fines to form a hydraulically resistant graded deposit after H_2O_2 boiling. Thus, it appears that these sands are somewhat immune to the physical deterioration in permeability effected on structured, finer textured soils.

Note that this research alone cannot precisely predict what sandy soils are resistant to H_2O_2-induced permeability losses. The Pardeeville IIC1 horizon is classified as a sandy loam but has sand, silt, and clay percentages of 78, 10, and 12 respectively, and therefore nearly qualifies as a loamy sand. This soil suffered an average of 90 percent loss of infiltration rate upon the application of H_2O_2 (Table 6). Specific combinations of the sand fractions, or a certain content of fines, could be associated with soil conditions especially sensitive or resistant to the physical loss of permeability. Further evaluation of this issue may be appropriate.

Independent data support our observed losses of soil permeability caused by chemical oxidation using H_2O_2. In the leachate mining industry workers have observed that leaching fluids containing strong oxidants, even at very low concentrations, may result in reduced permeability. Lawes and Watts (1981) and Lawes (1981) reported on the use of alkaline carbonate solutions containing very low concentrations of H_2O_2 (0.1 to 3 g/L) for in situ leachate mining of argillaceous uranium ores. In this process the H_2O_2 decomposes and O_2 oxidizes the uranium to a soluble species for extraction by pumping. In a more recent patent (1982), Lawes reported data demonstrating that this in situ technique often leads to reduced permeabilities and thus increased leaching times in the ores. As a corrective measure, Lawes and Watts (1982) recommended and patented the incorporation of low concentrations of silicates (preferably $NaSiO_3$ at 0.5 to 1.5 g/L) to the leaching solutions. Results documenting the efficicacy of such additives were presented in the patent.

In a related mining discipline H_2O_2 and other strong oxidants have been used to effect disaggregation of rock materials. Huff and Heath (1970, 1971) reported on a process by which H_2O_2 and related compounds can be used to physically rupture rock materials containing certain clay minerals. The latter patent specifically discusses the use of H_2O_2 in concentrations of from 10 to 50% to disrupt the structural integrity of rock materials containing illite and related clay minerals. Huff and Heath (1971) postulated that illite, with adjacent unit cells separated and bound together by potassium atoms, is susceptible to rupturing and negation of bonding by H_2O_2. X-ray analysis was used to show that this was neither a swelling or distention of the crystal lattice of the system, but rather a negation of bonding between unit cells. It is noteworthy that most of the soils in Wisconsin have clay mineralogy family classifications of mixed or illitic, indicating significant illite content which may exceed 50 percent of the secondary clay minerals. This mechanism may further explain the H_2O_2-induced loss of structure and permeability observed in many of the soils in our study.

Evaluation of Additives to Reduce Permeability Losses - Soil permeability losses caused by H_2O_2 application appear to be related to the rapid and violent decomposition of the reagent. Thus, despite any potential benefit of oxidizing the organic matter present, the negative side-effects of H_2O_2 appear to be overwhelming in many soils.

Methods - A very brief experiment was designed to examine the efficacy of various additive types and concentrations for reducing the side-effects resulting from H_2O_2 decomposition and related phenomenon. Additives evaluated were trichloroacetic acid (TCA) and sodium silicate ($NaSiO_3$). These compounds were selected based on recommendations from chemists experienced with control of H_2O_2 decomposition and side-effects thereof (Harkin, 1982; Lawes, 1983). A range of concentrations were evaluated for each additive.

Trichloroacetic acid is thought to inhibit the catalytic decomposition of H_2O_2 caused by the enzyme catalase, ubiquitous in soils. Lawes and Watts (1982) suggested that $NaSiO_3$ was effective in retarding H_2O_2 decomposition and in reducing attendant permeability side-effects in uranium ores. Note however, that these mining applications were for extremely low H_2O_2 concentrations, compared to those used commercially by Porox[R] vendors. This additive was evaluated both with and without the addition of Mg_2SO_4, per recommendations (Lawes, 1983).

This experiment, ancillary to the first lab experiment already discussed, used a single soil type with well-defined properties, and utilized the same CRP and analytical techniques previously described. The soil used in these additives studies was a sandy loam (nearly a loamy sand) with sand, silt, and clay percentages of 78, 9, and 13, respectively. Organic matter content was less than 0.15 percent. This soil was mixed to insure homogeneity and hand-packed to a density of 1.55 g/cm^3 into standard 7.62 x 7.62-cm sample rings.

Results and Discussion - Table 8 presents the results of the additives study and shows the experimental design to include H_2O_2 concentrations evaluated and the additives types and concentrations used. Because of the controlled soil conditions and attendant uniformity among cores, the variability of the control samples' infiltration rates was very small. The control mean was 25.0 cm/day with a standard deviation of 3.91 (coeff.var. = 15.1 percent).

The primary conclusion from these results is that none of the additives assessed, at any concentration, eliminated the permeability loss caused by H_2O_2 application. The Na_2SiO_3 treatments generally resulted in even lower

Table 8 - Effect of selected additives, in combination with hydrogen peroxide, on infiltration rate--sandy loam soil.

H_2O_2 conc., %	Additive	Additive conc.	Infiltration rate, cm/day†
0 (control)	None	—	25.9 a§
0	TCA‡	4.8 g/L	31.3 a
12.5	None	—	8.0 bc
12.5	TCA	1.2 g/L	6.2 bc
12.5	TCA	2.4 g/L	9.6 bc
12.5	TCA	4.8 g/L	10.0 bc
12.5	Na_2SiO_3	0.75 g/L	1.4 c
12.5	Na_2SiO_3	1.5 g/L	3.7 bc
12.5	Na_2SiO_3	6.0 g/L	0.0 c
12.5	Na_2SiO_3 w/Mg_2SO_4	50.0 g/L w/50 ppm Mg^{2+}	8.1 bc
50	None	—	4.0 bc
50	TCA	1.2 g/L	11.7 b
50	TCA	2.4 g/L	4.5 bc
50	TCA	4.8 g/L	6.4 bc

† n = 2 except for control where n = 6.

‡ Trichloroacetic acid; 4.8 g/L = 2 lb/50 gal.

§ Treatment means with the same letter are not significantly different ($p = 0.05$).

infiltration rates than H_2O_2 alone, although these differences are not significant. One exception was the high level Na_2SiO_3 treatment with Mg_2SO_4 which resulted in infiltration rates comparable to the 12.5% H_2O_2-no additives treatment.

The TCA resulted in higher mean values in 6 of 7 TCA treatments than measured in non-TCA H_2O_2 treatments. However, none of these differences was statistically significant (Table 8). It is interesting that a zero-H_2O_2 treatment with TCA resulted in a higher infiltration rate than the controls (however, not significantly higher). Although one might not expect any significant effect attributable to the TCA in this very low organic matter soil, it appears to have marginally reduced, but not eliminated the deleterious effects of H_2O_2.

Hydrogen Peroxide Effects on Soil Porosity and Micromorphology--Two soils used in the previous laboratory study were selected for similar H_2O_2 treatments to be followed by thin-section analysis. These soils were the Ringwood I&IIB23, a well-structured loam and, the Pardeeville IIC1, a structureless sandy loam (borderline loamy sand). The purpose of this investigation was to visually assess the effects of H_2O_2 application as regards porosity, pore continuity, and structure. This approach was thought to have considerable potential for gaining further insight into operating mechanisms as well as physical effects.

Methods - In the case of the structured soil, ten undisturbed samples were collected. To this end, a 5.1-cm (2-in) i.d. x 25.4-cm (10-in) long sharpened acrylic tube was carefully inserted into the desired exposed soil horizon using the truck-mounted hydraulic soil probe. The structureless samples were mixed to optimum homogeneity and hand-packed to natural bulk density (1.7 g/cm^3) into acrylic tubes like those used for the structured soil.

All cores were slowly saturated from the bottom to expel soil gas as previously described. Two replicate cores of each soil were randomly selected from the ten available, and subjected to one of five H_2O_2 treatments. Concentrations of 0, 6.25, 12.5, 25, or 50 percent were applied to each core at a HLR of 0.63 cm. This experimental design essentially duplicated that used in the permeability study. Soil-reagent reactions observed were substantially the same as those already described, with boiling and frothing disrupting the soil fabric.

The cores were carefully dried at a very slow rate to avoid dessication fractures. They were then impregnated with 40 ml of Epotek 301 epoxy per sample. This compound has extremely low viscosity and contains no solvents. It therefore has great penetrating ability and does not require a vacuum. The impregnated samples were then cured at 25°C for 24 hours. After drying, sections were cut from each core center. Because the treated samples were quite porous, they were further impregnated with Petro Poxy to fill the exposed pores and provide support during grinding and mounting of the thin-sections which followed.

The samples were analyzed by standard petrographic polarizing and dark-field techniques as already described (Cady, 1965; Thresher, 1982a). Pores larger than 0.02 mm were classified and counted using techniques described for the study of thin-sections, discussed previously (Johnson et al. 1960; Chayes, 1949; Brewer, 1976).

Results and Discussion--The results of the thin-section analysis of the 20 core samples are reported in Thresher (1983). Table 9 summarizes the effects of H_2O_2 on soil porosity. It is quite apparent that regardless of soil type and reagent concentration the total porosity (>0.02 mm) is dramatically increased (roughly doubled) by H_2O_2 application. Table 9 also presents measurements reflecting depth of reaction and size of the pores.

Figures 8 and 9 display pore drawings made from representative sections. The size and continuity of natural structural pores (>0.02 mm) in the pedal loam soil is quite apparent and explains its high permeability. However, when treated with H_2O_2, even at a low concentration (6.25 percent), the structure and attendant porosity were destroyed and numerous non-connected vesicular pores and vughs developed. The result was a hydraulically resistant styrofoam-like fabric.

In the case of the granular soil the random, structureless orientation of particles results in almost no pores larger than 0.02 mm (Figure 9). By contrast, the sample treated by even 6.25 percent H_2O_2 is riddled with large vesicular, and non-connected pores.

Table 9 shows an interesting trend as regards the depth of H_2O_2 reaction in the two soils. It appears that in the case of the structured soil higher H_2O_2 concentrations resulted in a greater depth of penetration and disturbance. However, the granular soil displayed shallower penetration depth and disturbance with increasing concentration. This phenomenon could be partially explained by the pore sizes conveying the reagent into the respective soil types and thereby availing differing soil surface areas for H_2O_2 decomposition.

Table 10 classifies and summarizes the treatment effects in the two soils as observed from the thin-sections. Figures 10 through 13 are photomicrographs of representative sections for the two soils and exemplify treatment effects. It is apparent from these figures that in both soils the particles have been totally reoriented, with clays, hydrous iron oxides, and the small amount of organic matter present, dispersed and redeposited onto the walls of the new pores. These materials appear to have combined to form a fairly significant "glue" which functions to hold the pores intact. Figure 12 presents an example of a pore bridge of a few sand particles coated and supported by these precipitates of fines. This phenomenon may partially explain (1) the structural integrity despite very low density of these vesical-filled samples during thin-section preparation, and (2) the hydraulic resistance of soils with such a high total porosity.

Effects on Infiltration rate--Clogged Soil Columns--In these experiments soil columns representing a wide range of subsoil properties were clogged with wastewater and subsequently treated with H_2O_2. This experiment was designed to link the previous studies on H_2O_2 effects on permeability of natural, unclogged soils to the reality of chemical rejuvenation of clogged systems.

Table 9 - Soil porosity as affected by hydrogen peroxide--structured loam and granular sandy loam subsoils, depth 0-3 cm.

Soil	Sample	Treatment H_2O_2 conc.	Percent pores >0.02 mm in zone of reaction†	$\bar{x}$	Size pores (mm) Range (all)	Size pores (mm) Spherical $\bar{x}$	Depth reaction‡ penetrated (mm)
Structured loam	L5	0	22.3	23.0	0.2-0.8	0.4	0
	L9	0	23.6				0
	L6	6.25	46.0	46.7	0.2-5.0	1.2	29-31
	L8	6.25	47.3				30-31
	L7	12.5	52.3	50.8	0.2-3.5	1.2	32-38
	L2	12.5	49.2				35-38
	L4	25	54.0	55.5	0.2-10.0	2.0	54-59
	L3	25	57.0				56-60
	L1	50	50.2	51.1	0.2-5.0	1.8	37+
	L10	50	51.9				38+
Non-structured sandy loam	S10	0	25.9	24.4	0.2-0.6	0.4	0
	S4	0	22.8				0
	S6	6.25	56.4	54.0	0.4-5.5	2.2	35-37
	S3	6.25	51.6				36-38
	S8	12.5	42.4	43.7	0.4-3.0	1.9	31-33
	S7	12.5	44.9				31-34
	S1	25	41.8	43.7	0.4-5.0	1.3	26-29
	S5	25	45.5				26-29
	S9	50	57.2	59.2	0.4-16.0	1.8	23-25
	S2	50	61.1				23-24

† Calculated from point counting data, 383 to 545 counts per section.

‡ Measured from thin section of each sample. Range of vertical expansion measured after drying was 0-32 mm.

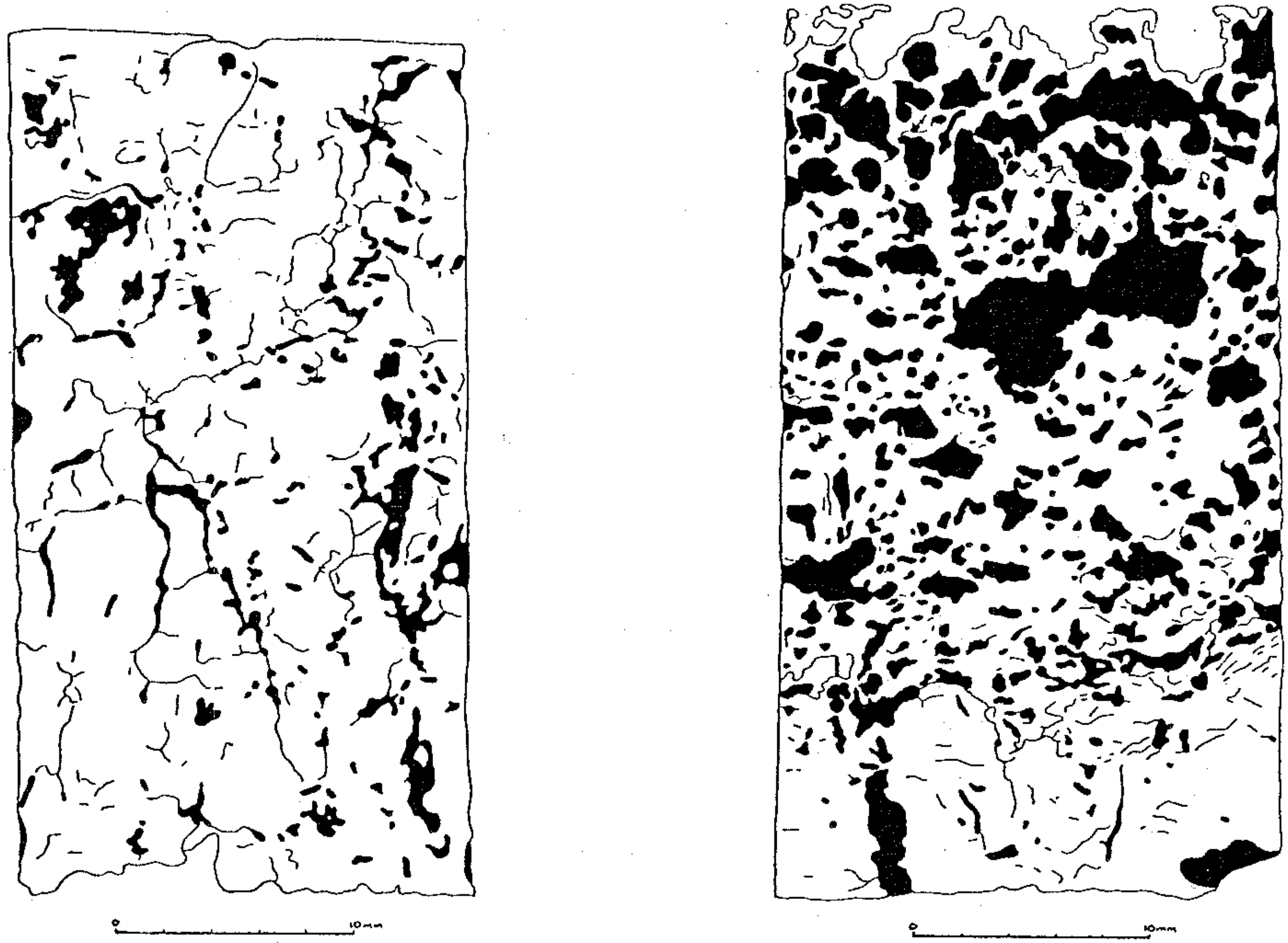


Figure 8A,B - Pore sketch of vertical thin-sections of undisturbed Ringwood loam (I&IIB23 horizon). Figure 8A (left) displays porosity of untreated control sample (pores larger than 0.02 mm in black); note the interconnected and continuous character of these pores. Figure 8B (right) displays porosity of sample treated with 0.63 cm of 6.25% H_2O_2. Despite dramatically increased macro-porosity, the continuity of these pores is much reduced and permeability of similarly treated soils decreased substantially.

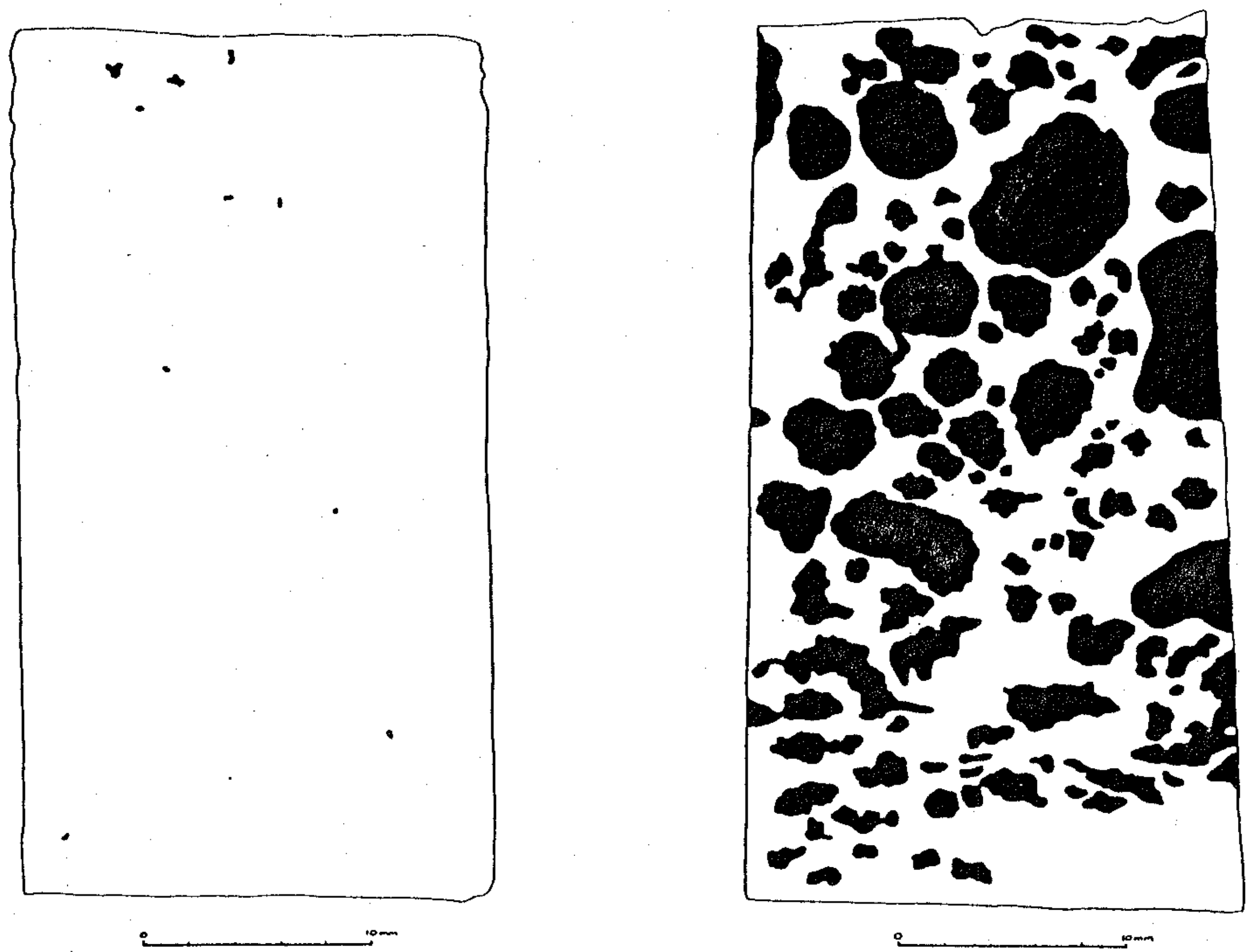


Figure 9A,B - Pore sketch of vertical thin-sections of Pardeeville sandy loam (IIC1 horizon repacked to a natural bulk density of 1.7 g/cm^3). Figure 9A (left) displays porosity of untreated control sample (pores larger than 0.02 mm in black). Figure 9B (right) displays porosity of sample treated with 0.63 cm of 6.25% H_2O_2. Despite dramatic increase in macro-porosity, the permeability of similarly treated soils was substantially reduced.

Table 10 - Effects of hydrogen peroxide on morphology and porosity of non-clogged, structured and granular soils, 0-3 cm deep.

	Natural structured loam		Granular sandy loam	
Feature	Control	Treated	Control	Treated
Porosity (>0.02 mm)	23%	47-56%	24%	44-59%
Dominant size (mm)	0.4	1.2-2.0	0.4	1.3-2.2
Type	interpedal planar, tubular	vesicals, irregular vughs	random, apedal packing voids	coarse vesicals, irregular vughs
Structure	apparent, subangular blocky	destroyed	structureless	structureless
Pore continuity	continuous, vertical dominant	discontinuous, segregated	interconnected	discontinuous, segregated
Dispersion of fines	not significant	effected throughout, deposition on pore faces bridges	none	effected, precipitates on solid interpore bridges
Organic matter	common, intra and inter-pore	dispersed, incomplete removal	insignificant	complexed with Fe^{3+} forms
Pore linings				
Clay	many	redistributed, precipitated	very few, grain coatings	very few, precipitated with Fe^{3+} forms
Organic matter	common	very few	none	none
Hydrous Fe^{3+} oxides	few	common	few, grain coatings	common, precipitated with fines on pore faces
OM-Fe^{3+} complexes	very few	common-many	very few	few, deposited
Empty pores	few	very many	very few	very many, coarse
Infiltration rate (cm/day)[Y]	770	11	91	9

[Y] From study of undisturbed cores (CRP technique).

Figure 10 - Photomicrographs of vertical thin-section of untreated control sample of structured Ringwood loam. Top photo is crossed polarizers, center is plain light, and bottom is dark-field illumination. Organic material appears dark in all three fields. Pores appear white in plain light, dark gray in dark-field. Clay accumulations (argillans) are noticeable around the large central pore in both the top and bottom photos, indicating pore stability and continuity.

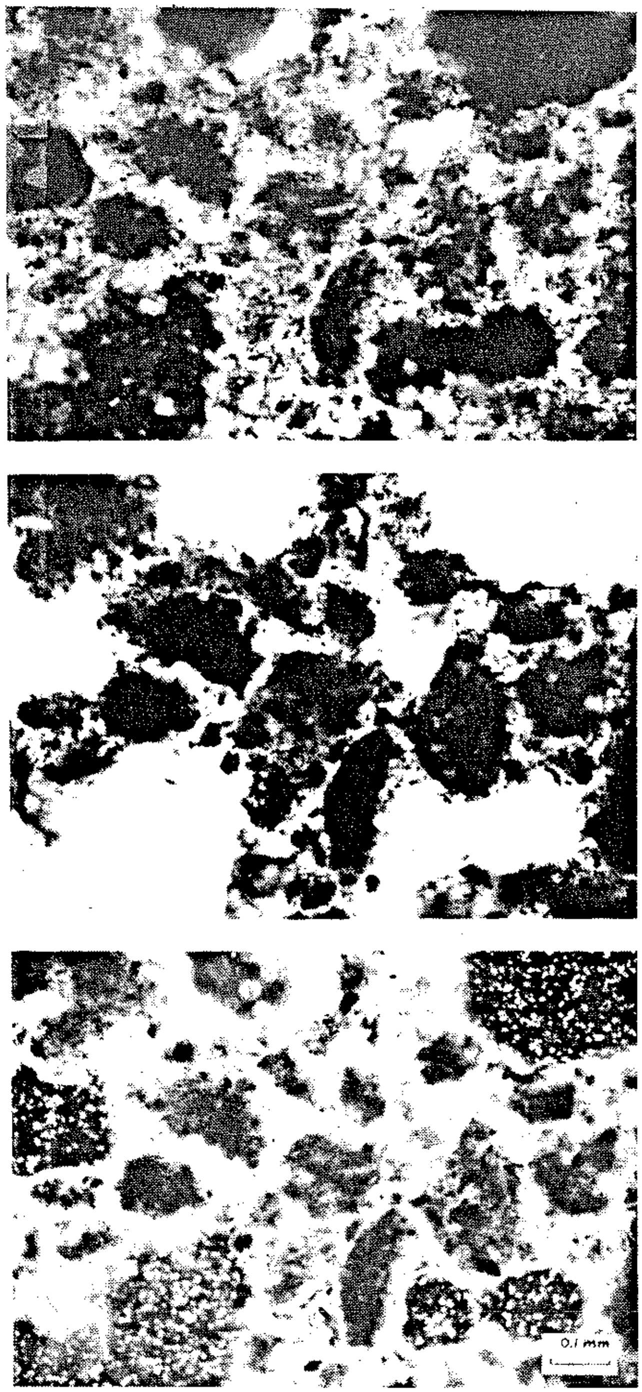


Figure 11 - Photomicrographs of vertical thin-section of Ringwood loam treated with 12.5 % H_2O_2. From top, crossed polarizers, plain light, and dark-field. Pores appear white in center photo. Note the dramatic increase in total and macro- porosity and lack of elongated, continuous pores compared to Figure 10. Pores appear to be somewhat "sealed," with solids loosely clumped between. Also note the incomplete oxidation of organic matter (dark in all three fields) and the dispersion of fines, imparting poor light transmission and a "fuzzy" visual texture.

Figure 12 - Photomicrographs of vertical thin-section of untreated control sample of unstructured Pardeeville sandy loam. From top, crossed polarizers, center is plain light, and bottom is dark-field. Quartz grains appear white in top two photos. Note in bottom two photos that many grains have coating of fines and Fe oxides. Very little organic matter present. Pores appear in dark-field as dark gray. Note random character of grain packing and pore continuity.

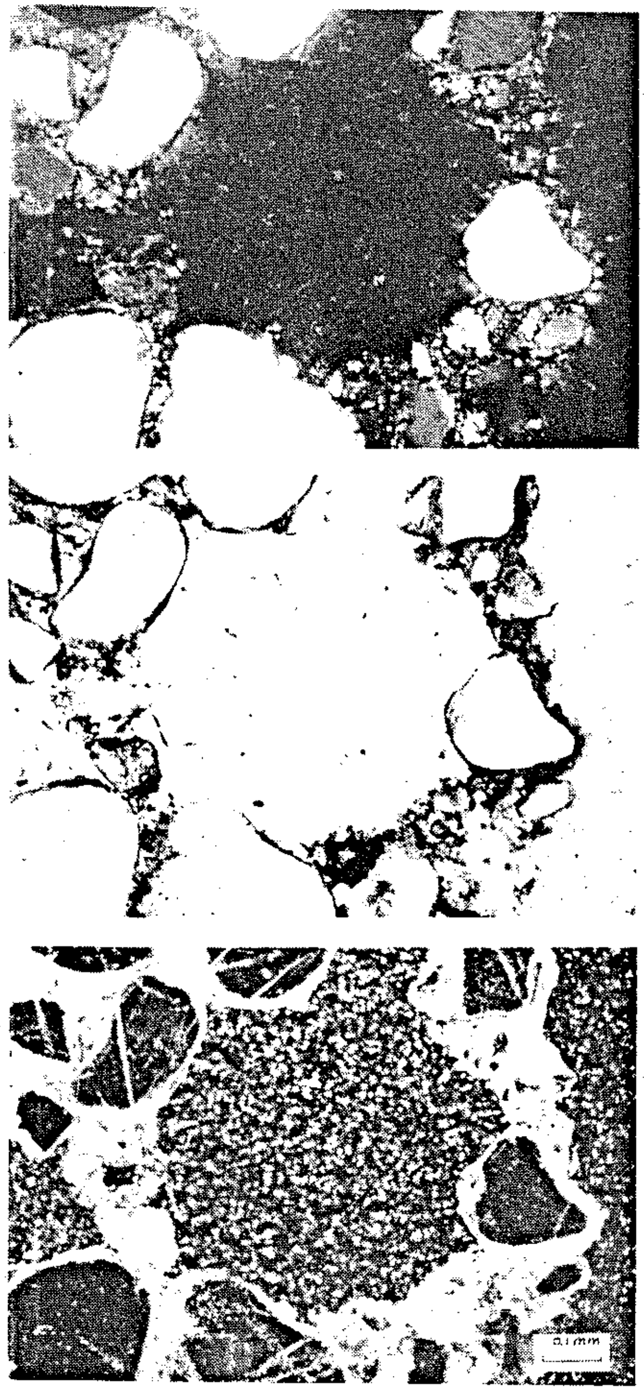


Figure 13 - Photomicrographs of vertical thin-section of Pardeeville sandy loam treated with 12.5 % H_2O_2. From top, crossed polarizers, plain light, and dark-field. Pores appear black (top), white (middle), and dark gray (bottom). Note the reorientation of grains and incorporation of very large rounded pores in the soil fabric. These vesicular pores are segregated by pore bridges (at right) of grains held in place by precipitated fines and Fe oxides.

Soil Sampling - Because of the expense, difficulty and time involved in wastewater column studies, only four soil types were utilized in this experiment. The soil horizons selected were the Kewaunee IIBt (cl), Ringwood I&IIB23 (l), Port Byron B21 (sil), and Pardeeville IIC1 (sl). All of these soils were used in the previously described soil cores experiment (Table 4). These soils represent a wide range of subsoil textural conditions (Figure 5), and therefore may be considered as benchmarks for reference to related soil conditions.

The soil columns were contained in 7.62-cm (3-in) i.d. PVC pipe, schedule 120, with 0.64 cm (0.25 in) wall thickness, and length of 48.2 cm (19 in). The bottoms of the tubes were cut and beveled so as to minimize resistance upon their being inserted into the soil by the truck-mounted hydraulic soil probe. A soil pit was excavated to the soil horizon desired to act as the infiltrative surface in the columns. The PVC tubes were then pressed into the undisturbed soil so that a sample approximately 30.5 cm (12 in) in length would be left in the tube after preparation. Because of the sampling technique and soil strength conditions, some pre-wetting was required at some sites.

This sampling approach was employed to collect ten "undisturbed" soil columns each, from the Kewaunee, Ringwood and Port Byron sites. In the case of the Pardeeville (sl) soil, the gravel and cobble content of the desired strata precluded sampling in this fashion. Therefore bulk samples were collected for packing of these columns.

Column Preparation and Operation - The undisturbed soil columns were kept air-tight and refrigerated until needed. Preparation involved the hand-picking of top and bottom soil surfaces to expose natural structure and porosity. The columns were then assembled substantially as diagrammed in Figure 14. A layer of glass wool and filter fabric prevented eluviation of the soil into the 2.5 cm (1 in) of gravel at the column discharge end. An 8.9-cm (3.5-in) i.d. PVC toilet flange was used to anchor the columns onto mounting racks. The contact between the column and flange plate was sealed with silicon rubber. Analogous to a field system, 7.6 cm (3 in) of gravel was added to the top of the columns.

The Pardeeville columns were constructed from bulk field samples. Gravel and cobbles were removed and the soil was hand-packed to natural bulk density into the PVC tubes, with bottom assembly complete. Considering the structureless and sandy character of this soil (sandy loam-loamy sand texture, 78 percent sand) hand-packing to natural density would be expected to fairly well duplicate the field porosity and permeability. Twenty-four Pardeeville columns were prepared in this manner.

Before mounting on wall racks all columns were slowly wetted from the bottom so as to minimize the effects of entrapped air and permit gradual swelling of clays. This process took 24 to 48 hours. The column experiments were carried out in a constant temperature room (13°C).

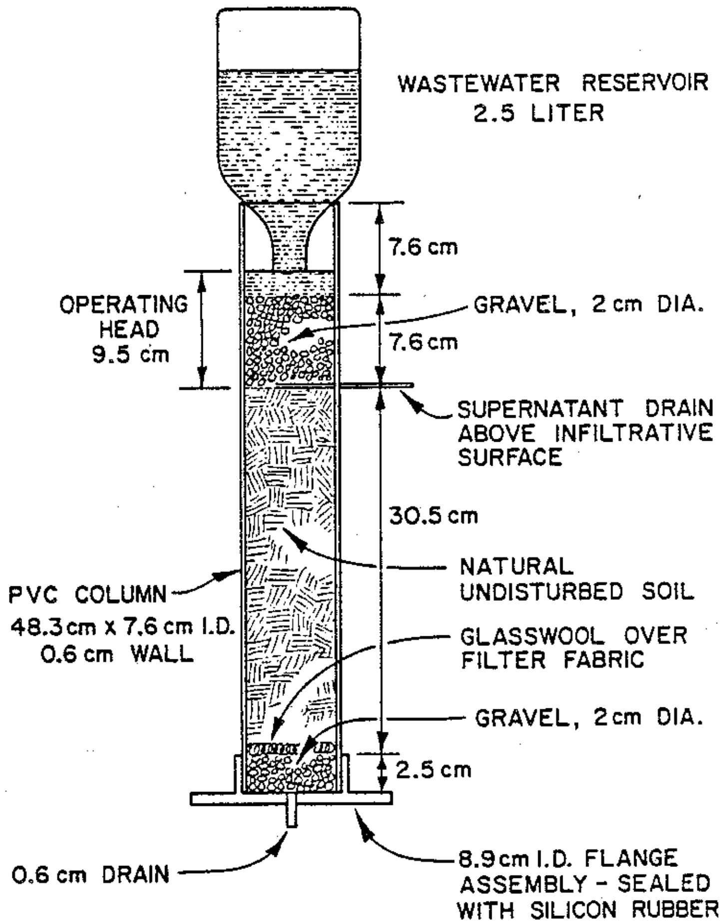


Figure 14 - Soil column construction and operational features.

After mounting the columns, saturation was maintained by inundating the columns with a 2.5 L (0.66 gal) vessel of tap water as shown in Figure 14. As indicated in the diagram, this arrangement resulted in a constant operating head of 9.5 cm. All infiltration rate values presented in discussion of this experiment have been corrected for head according to Darcy's Law. Initial infiltration rate measurements were made several times until stable representative values were collected. Measurements simply involved determination of fluid intake rate over time. Column infiltration rate was measured in this fashion on a weekly basis throughout the clogging period, using the influent wastewater.

After wastewater application began, the columns were kept continuously ponded throughout the study until clogged. Wastewater used was septic tank effluent collected from a previous experimental site (Hargett et al. 1981). Wastewater was collected, including grab samples for characterization, on a weekly basis from August 16, 1982 until February 16, 1983. Table 11 presents a summary of the characteristics of this septic tank effluent. All parameters presented in this table were measured by methods presented in Standard Methods (1980), with the exception of NH_3-N and NO_3-N. These constituents were determined by the method of Bremner and Keeney (1965). The wastewater properties presented in Table 11 fall within the range of typical septic tank effluent characteristics, according to Siegrist et al. (1976).

For the purposes of this study column failure was defined as wastewater infiltration rates less than reasonable long-term acceptance rates (LTAR) (design loading rates) for the specific soil conditions of each column group. This seems to be the only appropriate failure definition because hydraulic failure should not occur in a field system until the system fails to accept the design rate. Only after this event would a system's condition warrant any rehabilitation effort.

Design loading rates (LTARs) for soil wastewater absorption systems in Wisconsin are based on soil percolation rates (WAC, 1980). Based upon WAC guidelines, soil survey interpretations, and measured infiltration rates for the four soils used in these column studies, approximate design loading rates were estimated for these soils. When nearly all of the columns in each soil type reached approximately this low wastewater acceptance rate they were declared failed and were subjected to chemical rehabilitation techniques.

The LTAR for the Kewaunee (cl) and Port Byron (sil) soils was estimated to be 1.86 cm/day (0.45 gal/ft^2/day) based on assumed percolation rate class of 81-122 cm/day (45 - 60 min/in). The LTAR used to define failure infiltration rate for the Ringwood (l) was 2.45 cm/day (0.60 gal/ft^2/day) based on a percolation class of 122-366 cm/day (10 - 30 min/in). The Pardeeville (sl) LTAR was 3.72 cm/day (0.91 gal/ft^2/day) from an assumed 366 - 3658 cm/day (1 - 10 min/in) percolation rate.

The 48 columns representing the four soils (24 of Pardeeville and 8 each of the other soils) exhibited some variability in the period of time and amount of cumulative wastewater required to induce failure. Figures 15 and 16 depict infiltration rate decline and cumulative loading curves, respectively, for a typical Pardeeville (sl) column. The Kewaunee (cl) and Port Byron (sil) soils required the shortest period to achieve clogging (roughly 40 to 60 days) but these soils had relatively low infiltration rates to begin with (Table 12).

Table 11 - Summary of applied wastewater characteristics--column experiments.

Parameter	Mean†	Range	No. of samples
BOD_5, mg/L	122	111-138	4
COD, mg/L	389	224-694	24
Suspended solids, mg/L	53.4	23-109	24
Volatile suspended solids, mg/L	32.8	12-54	24
Ammonia nitrogen, mg/L	44.1	39.7-52.1	8
Nitrate nitrogen, mg/L	1.03	0.1-1.6	7
Total Kjeldahl nitrogen, mg/L	52.9	42.0-59.7	6
Total phosphorus, mg/L	18.1	19.6-22.7	6
pH	7.8	7.7-6.9	2
Alkalinity, mg/L $CaCO_3$	532	527-537	2
Total coliforms, Log_{10}#/L	7.52	6.74-7.82	8
Fecal coliforms, Log_{10}#/L	5.68	4.76-6.38	8

† Samples collected at least weekly from 16 Aug. 1982 to 16 Feb. 1983.

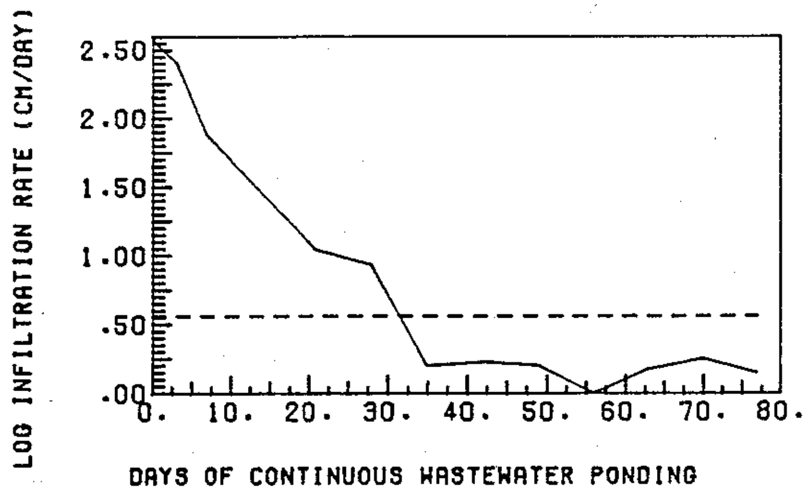


Figure 15 - Infiltration rate decay curve during column clogging--typical sandy loam column. Hatched line defines failure as infiltration rates less than 3.72 cm/day.

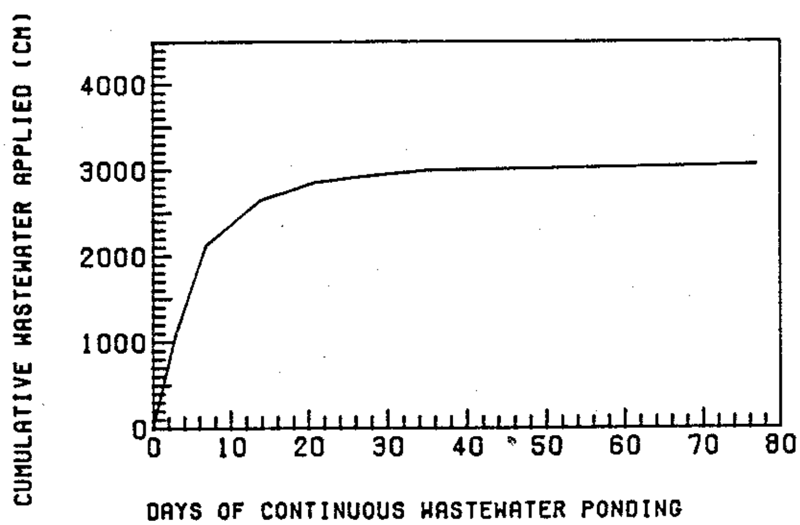


Figure 16 - Cumulative wastewater application during column clogging--typical sandy loam column.

The Pardeeville (sl) and Port Byron (l) soils required a somewhat longer loading period, approximately 50 to 90 days, to reach failure inflow rates because of their higher initial permeabilities, and numerous macropores in the latter soil. Cumulative wastewater applied over the loading period ranged from approximately 250 cm for some Kewaunee columns to 2500 cm for Pardeeville columns. This compares to roughly 0.37 years of daily equivalent wastewater loading on the lower end, relative to the Kewaunee LTAR, and 1.84 years for the Pardeeville LTAR at the upper end of this range.

Experimental Design of Reagent Applications - A treatment scheme similar to that employed in the study of undisturbed soil cores was applied to the column experiment. The experimental design is presented in Table 5. After all columns of a given soil type had reached near-failure conditions, individual columns were randomly selected for H_2O_2 treatments. For the cl, l, and sil column groups (8 columns each) one of four H_2O_2 treatments was assigned so that there were two random replicates of each treatment. The four treatments consisted of 0.63 cm (0.15 gal/ft^2) of either 6.25, 12.5, 25, or 50 percent H_2O_2, the same levels applied in the previous experiment. This provided for a range of mass loading rates (pure H_2O_2) of 0.58 to 4.61 mg/m^2.

In the case of the sl (Pardeeville) soil, with 24 columns, a broader range of treatments was applied. The same four H_2O_2 concentrations were used but three hydraulic rates, 0.32, 0.63, and 1.26 cm (0.08, 0.15, and 0.31 gal/ft^2), were employed, thus 12 treatments. This resulted in a range of mass loading rates from 0.29 to 9.22 kg/m^2. Two randomly selected replicate columns were assigned to each of these treatments.

Before H_2O_2 application final pre-treatment infiltration rates were determined and verified. The wastewater application vessel (Figure 14) was then removed and the wastewater ponded upon the soil infiltrative surface was allowed to drain. This minimized any dilution of applied reagent. An appropriate volume and concentration of H_2O_2 was applied to each column.

Response to Treatment - Table 12 presents initial, pre-H_2O_2, and post-treatment infiltration rates for all columns treated with hydraulic loading rates of 0.63 cm. This includes all of the cl, l, and sil columns and one-third of the sl columns. This table is, therefore, very convenient for comparing the response to H_2O_2 in all four soils.

Comparing the pre-treatment (clogged) values to the post-H_2O_2 treatment rates, for all soils except the sandy loam, demonstrates the general ineffectiveness of H_2O_2 to unclog the soil. For the three finer-textured soils, and all four H_2O_2 concentrations, there were only two cases of statistically significant differences before and after treatment; these reflected declines in infiltration rate, effected by H_2O_2. In fact, post-treatment declines were observed in 9 of these 12 cases. These results are displayed graphically in Figure 17.

Table 12 - Effect of hydrogen peroxide on infiltration rate of clogged columns--four subsoil types.

	Infiltration rate (cm/day)†‡											
	Kewaunee IIBt (CL)			Pardeeville IIC1 (SL)			Port Byron B21 (SIL)			Ringwood I&IIB23 (L)		
	Measurement event											
H_2O_2 conc.§ (%)	Initial	Clogged pre-treatment	Post H_2O_2 treatment	Initial	Clogged	Post-treatment	Initial	Clogged	Post-treatment	Initial	Clogged	Post-treatment
6.25	3.28a¶	1.57b	0.47b	363.9a	1.97c	9.78by	8.19a	1.34b	1.42b	155.2a	2.72b	1.18c
		(38.6)	(13.2)		(0.5)	(2.7)		(19.3)	(21.0)		(1.8)	(0.8)
12.5	6.99a	0.27b	0.18b	342.6a	2.74b	2.99by	11.72a	1.27b	0.91c	101.3a	3.33b	3.41b
		(5.7)	(4.1)		(0.8)	(0.9)		(10.8)	(7.8)		(3.1)	(3.9)
25	2.76a	0.47b	0.43b	327.5a	2.15c	73.04bx	15.13a	1.59b	1.15b	46.0a	3.74b	3.55b
		(17.2)	(15.6)		(0.7)	(23.7)		(11.0)	(6.8)		(12.5)	(9.9)
50	8.84a	2.13a	1.19a	391.6a	0.90c	83.77bx	9.94a	1.53b	1.26b	76.7a	2.16b	2.33b
		(20.26)	(37.0)		(0.5)	(21.4)		(19.2)	(16.4)		(3.6)	(4.1)

† Each value represents the mean of two replicate columns with the exception of Kewaunee CL 25% treatment where n=1; see text for explanation.

‡ Values in parentheses are percent of initial infiltration rate.

§ All columns loaded at 0.63 cm (0.15 gal/ft^2) H_2O_2 for all concentrations.

¶ a,b-within soils, event means within treatments (same row) with the same letter are not significantly different ($p = 0.05$). x,y-for the Pardeeville SL, post-treatment event, treatment means with different letters are significantly different ($p = 0.05$); treatment means are not significantly different for any other soil and event.

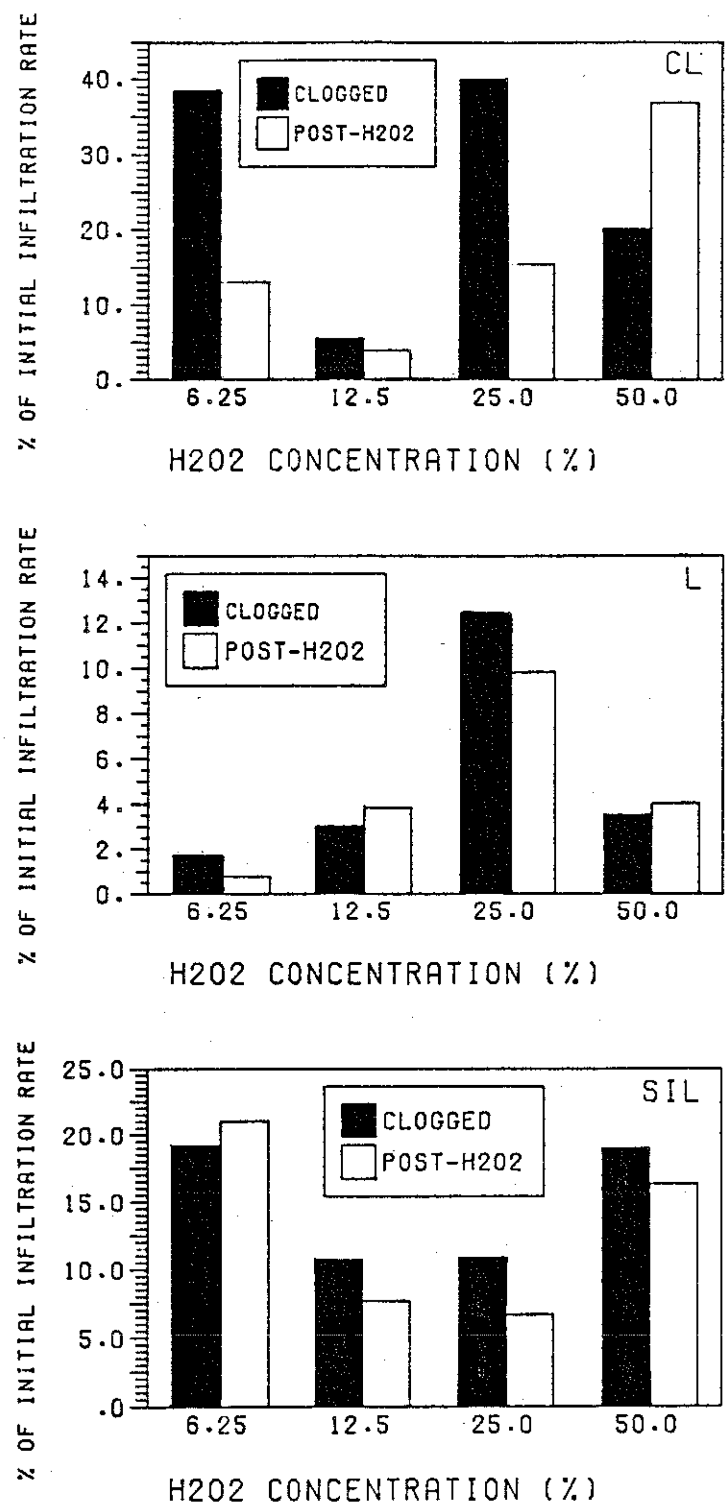


Figure 17A,B,C - Effect of hydrogen peroxide on infiltration rate of clogged columns: (A) clay loam; (B) loam; and (C) silt loam subsoils.

By contrast, the sandy loam columns displayed an increase in infiltration rate for all four treatments presented in Table 12. These differences are statistically significant in three cases. The broader treatment scheme applied to the sandy loam soil will be discussed later.

Other important observations can be made from Table 12 with respect to H_2O_2 treatment effects. Note that for all measurement events (initial, pre-treatment, and post-treatment) and all four soils, in only one case is there a significant difference between H_2O_2 treatments. In the sandy loam soil, the higher H_2O_2 concentrations (25 and 50 percent) resulted in a much greater improvement in permeability than lower concentrations.

The most important lesson from Table 12 is that of the magnitude of post-treatment infiltration rates. For all soils and all treatments, in no case did post-treatment values approach even 50 percent of initial infiltration rate values. This is indicated by the scale of the ordinate in Figure 17. This failure to restore infiltration rate is seen even for the sandy loam soils, as reflected in the percent of initial infiltration rate values presented in parentheses (Table 12).

As previously discussed, the sandy loam soil was subjected to a wider range of H_2O_2 treatments (Table 5). Table 13 presents pre-H_2O_2 treatment and post-treatment infiltration rates for all 12 treatments expressed as percent of initial infiltration rate. This transformation is very convenient in correcting for the initial variability of the 24 columns and for communicating the relative degree of rehabilitation resulting from H_2O_2 treatments. Comparing pre- and post-H_2O_2 data within treatments, it is apparent that the lowest mass loading rates had the least effect on infiltration rate. Eleven of the 12 treatments resulted in improved infiltration rates, and eight of these proved significant.

Comparing treatments, Table 13 shows that none of the pre-H_2O_2 values for the 12 treatments are significantly different. As regards post-H_2O_2 means, Figure 18 shows that as either concentration or hydraulic loading rate increase, infiltration rate also generally increased. It follows that as mass loading rate increases so does infiltration rate, thus giving the general positive slope of bar heights in Figure 18. Note also that different treatments with similar mass loading rates are generally not significantly different. For example, the three treatments, 1.26 cm of 12.5%, 0.63 cm of 25%, 0.32 cm of 50% H_2O_2, all have the same mass loading rate, 2.31 kg/m^2. Their treatment means range from 11.4 to 23.7 percent of initial infiltration rate but are not significantly different (Table 13).

Figure 18 shows that for the sandy loam soil, as in the case of the previously discussed finer soils, no H_2O_2 treatment resulted in infiltration rate recovery greater than 33 percent of initial values. Note that this

Table 13 - Effect of hydrogen peroxide on infiltration rate of clogged sandy loam columns.

	Percent of initial infiltration rate[†‡]											
	H_2O_2 concentration (%)											
	6.25			12.5			25			50		
	Hydraulic loading rate (cm)											
Event	0.32	0.63	1.26	0.32	0.63	1.26	0.32	0.63	1.26	0.32	0.63	1.26
Clogged (Pre-treatment)	0.54[§]	0.54	1.17	0.71	0.85	0.52	0.56	0.66	1.01	0.55	0.49	0.36
		x[¶]				x		x	x	x	x	x
Post-H_2O_2 treatment	0.89	2.71	19.19	0.70	0.94	11.38	5.27	23.70	20.59	20.31	21.39	33.09
	a[¶]	ay	a	a	a	abcy	ab	cdy	bcdy	bcdy	bcdy	dy

† Actual initial infiltration rate for these 24 columns averaged 368 cm/day, range 267-467 cm/day.

‡ All values presented are significantly different from actual and normalized initial infiltration rate ($p = 0.05$).

§ Each value represents the mean of two replicate columns.

¶ a,b,c,d = treatment means within events (same row) with the same letter are not significantly different; no letter indicates no significant difference.
x,y = event means within treatments (same column) with the same letter are not significantly different; no letter indicates no significant difference.

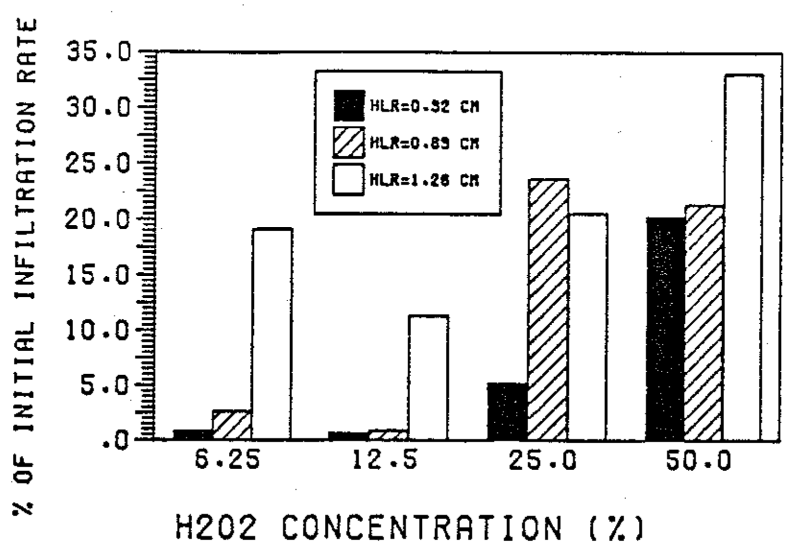


Figure 18 - Effect of hydrogen peroxide on infiltration rate of clogged sandy loam columns.

highest rate of recovery in the sandy loam was associated with the highest mass loading rate used, 9.22 kg/m^2. Referring to Table 1 it is clear that this H_2O_2 application rate far exceeds those used by commercial vendors. This rate also likely exceeds the maximum practical cost that would be chargeable for a treatment, especially if the result is only a 33 percent recovery.

Retreatment of Selected Columns - Because of the generally positive relationship between percent recovery and mass loading rate, a brief follow-up experiment was conducted to pursue this trend further. Twelve of the previously treated columns, six pairs of replicates, were selected for another H_2O_2 treatment. These included both columns with low and high previous mass loading rates, and little to significant previous treatment response. Table 14 presents the specifications for the first and second H_2O_2 treatments for these columns. The cumulative mass loading for the combined H_2O_2 loading, some of which are extremely and impractically high (Table 1), are also presented. The second H_2O_2 treatment was applied approximately five days after the first.

Response to Re-Treatment - Clogged (pre-H_2O_2), post-treatment one, and post-treatment two infiltration data are shown in Table 14. Comparing the infiltration rates before and after the second treatment, it is evident that those columns (four column pairs) which did not respond to the first treatment did respond favorably to the second treatment of higher mass loading rate. Note that some of these second treatment mass loading rates were four times (36.9 kg/m^2) the first treatment maximum (9.22 kg/m^2). However, none of the recovery rates for these four treatments exceeded 17 percent. The two pairs of treatments with a prior positive response did not respond significantly to the second treatment, despite a second-treatment mass loading rate of 9.22 kg/m^2.

Table 14 - Effect of one and two hydrogen peroxide treatments, and cumulative mass loading rate, on infiltration rate of selected clogged sandy loam columns.

Treatment combination	1st H_2O_2 treatment			2nd H_2O_2 treatment			Cumulative Mass LR (kg/m^2)	Percent of initial infiltration rate[†‡§]		
	Conc. %	Hydr. LR (cm)	Mass LR (kg/m^2)	Conc. %	Hydr. LR (cm)	Mass LR (kg/m^2)		Clogged pre-treatment	Post-1st treatment	Post-2nd treatment
A	6.25	0.32	0.29	50	1.89	13.84	14.13	0.54a[¶]	0.89ax	13.28bxy
B	6.25	0.63	0.58	50	2.52	18.45	19.03	0.54a	2.71bx	16.94cxy
C	12.5	0.32	0.58	50	3.78	27.67	28.25	0.71a	0.70ax	11.77bx
D	12.5	0.63	1.15	50	5.04	36.90	38.05	0.85a	0.94ax	11.86bxy
E	50	0.63	4.61	50	1.26	9.22	13.83	0.49a	21.39by	22.78byz
F	50	1.26	9.22	50	1.26	9.22	18.44	0.36a	33.09by	27.49bz

† Each value represents the mean of two replicate columns.

‡ Actual initial infiltration rate for these 12 columns averaged 361 cm/day.

§ All values presented are significantly different from actual and normalized initial infiltration rate ($p = 0.05$).

¶ a,b,c = event means within treatments (same row) with the same letter are not significantly different; no letter indicates no significant difference.
x,y = treatment means within events (same column) with the same letter are not significantly different; no letter indicates no significant difference.

Figure 19 presents the results of both rounds of H_2O_2 application on the sandy loam soil. The first treatment's positive relationship between infiltration rate recovery and mass loading rate are evident. However, the trend appears to level off and decline somewhat based on observations from the second H_2O_2 application. We recognize that this comparison is not entirely fair from an experimental design and statistical analysis point of view. Nevertheless, we feel that it does provide some further proof that these soils will not respond favorably to H_2O_2 at any reasonable application rate.

Discussion - The results of these column studies appear to substantially corroborate our previously discussed field and laboratory experiences with H_2O_2. Application of H_2O_2 to clogged clay loam, loam, and silt loam columns resulted in generally no improvement in infiltration rate, and often a decrease beyond the clogged rate. This agrees with our field study observations of Porox^R-induced permeability declines, or at best ineffectiveness, in fine to medium textured, structured soils.

The mechanisms involved in the ineffectiveness of H_2O_2 to rehabilitate these soil columns are likely very similar to those observed in the previous studies. These mechanisms include partial oxidation of the simpler organic matter forms, dispersion of clays and remaining organic matter, destruction of natural structure and pore continuity, and the introduction of numerous dead-end vesicular pores.

Application of H_2O_2 to the sandy loam columns resulted in some recovery of infiltration rate. This recovery appeared to be directly related to mass loading rate of H_2O_2 but peaked at high rates (9.22 kg/m^2) and leveled off and declined at higher, unrealistic rates (up to 38.05 kg/m^2).

The maximum infiltration recovery observed in the sandy loam columns (borderline loamy sand) was only 33 percent of initial infiltration rate. The H_2O_2 mass loading rate for this treatment was 9.22 kg/m^2. Considering the somewhat finer texture of this soil, our column recovery compares rather well with the range of recovery reported by Jawson, (13 to 58 percent) where mass loading rates ranged from 2.81 to 13.98 kg/m^2 (Table 1, Jawson, 1976; Harkin, 1977a). The findings of Siegrist et al. (1981) also support our observations of H_2O_2 ineffectiveness, even in sands.

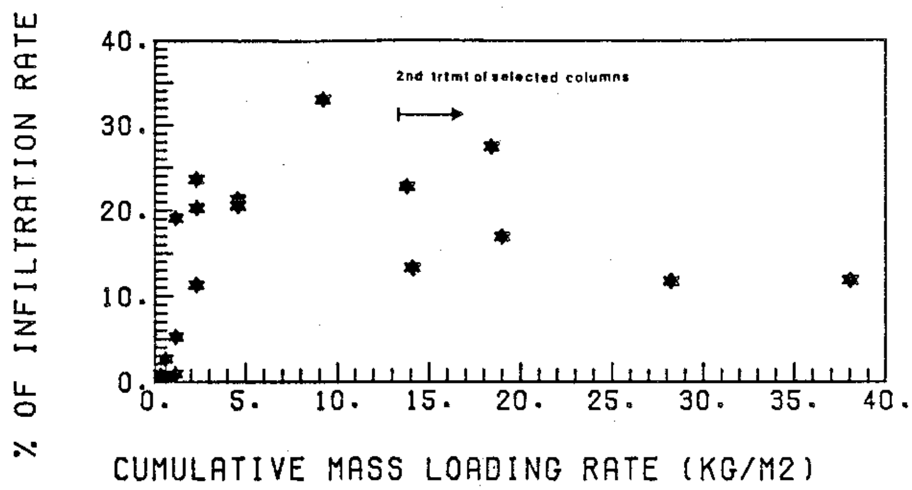


Figure 19 - Effect of cumulative mass loading rate of hydrogen peroxide on infiltration rate of clogged sandy loam columns.

SUMMARY

The application of hydrogen peroxide to wastewater soil absorption systems has been recommended to restore the permeability of failed systems, and to prevent system failure. The H_2O_2 treatment process, Porox[R], has been claimed to be relatively effective in unclogging systems in a wide range of soil conditions.

This publication is a compilation of recent SSWMP research results which substantially refute the efficacy of the hydrogen peroxide technique as originally prescribed and question its application for a broad range of soils. The results of each component of this study completely support one another and stand as the foundation of our conclusions and recommendations as follow.

Conclusions

1. Rigorous critical review of the literature does not support the use of H_2O_2. Most previous research was conducted only on sands, or disturbed soils, and therefore cannot be extrapolated to a broad range of natural soil conditions. Much of the earlier work suffers from lack of replication and experimental control, and/or inappropriate methodology. Even so, results, expressed in common terms, suggest that the effectiveness of H_2O_2 in restoring the permeability of clogged soils is at best partial, and highly variable.

2. A survey and inspection of Wisconsin soil absorption systems treated commercially with Porox[R], one to five years previous, confirmed that the treatment effects, if positive, were at best short-lived. Of 26 systems inspected, 3 had been totally replaced and 19 were experiencing severe continuous ponding.

3. Field studies of controlled, replicated, *in situ* systems, previously clogged with wastewater, showed that systems treated with Porox[R] (standard commercial treatment) suffered significant losses of infiltrative capacity. A second treatment resulted in further declines. By comparison, similar systems, allowed to rest naturally, responded with significant increases in permeability. Micromorphometric analysis of thin sections of soil cores from these systems showed that H_2O_2 dispersed the soil and destroyed natural structure, while only partially oxidizing organic matter.

4. Laboratory studies on a very wide variety of soil textural conditions documented that H_2O_2 application can do severe damage to the infiltrative capacity of most natural, unclogged soils. Loss of permeability was generally dramatic regardless of H_2O_2 concentration or mass loading rate. Only sand textures were not hydraulically damaged by H_2O_2.

5. An evaluation of chemical additives intended to retard the rate of H_2O_2 decomposition and thus minimize soil damage, revealed no compound which could effectively eliminate the permeability losses caused by H_2O_2.

6. A micromorphometric study of the effects of H_2O_2 on soil fabric, in both structured and granular soils, verified that the oxidant completely destroyed natural structure and porosity. Structural units and interpedal pores were eliminated by H_2O_2. The soil particles were dispersed and numerous non-connected, vesicular pores were incorporated into the fabric. Total and macro- porosity were much increased, but pore continuity and concomitant permeability were markedly reduced.

7. Attempts to restore the permeability of wastewater-clogged soil columns using H_2O_2 proved unsuccessful. H_2O_2 treatment of clogged columns of structured soils, loam, silt loam, and clay loam generally resulted in slight declines in infiltration capacity, even below the clogged state, regardless of H_2O_2 concentration and loading rate. High H_2O_2 loading rates produced some improvement in permeability in clogged sandy loam columns but the greatest reclamation achieved was only 35 percent of initial values.

Recommendations

Based on the results of this research we recommend against the application of hydrogen peroxide to wastewater soil absorption systems, especially in non-sandy soils. We feel that there is not adequate information to advise the treatment's use even on sands, except perhaps in extenuating circumstances. Before general use in sands is prescribed, we recommend further research be conducted to assess H_2O_2 effects and effectiveness in sandy soils, to include mound and fill systems.

REFERENCES

Alexander, L.T. and H.G. Byers. 1932. A critical laboratory review of methods of determining organic matter and carbonates in soil. U.S. Dept. of Agric. Tech. Bull. No. 317.

Andrews, T.C. and P. Bishop. 1981. The use of hydrogen peroxide for failed soil absorption system rejuvenation. Presented at the Ann. Mtg. of the New England Water Control Assoc., Concord, NH. October 1981.

Apfel, R. 1981. Personal communications in June 1981, On-Site Sanitation Services, Inc., Stoughton, WI.

Blake, G.R. 1965. Bulk Density. p. 374-390. In C.A. Black (ed.) Methods of soil analysis, Part 1. ASA Monograph No. 9. Am. Soc. Agron., Madison, WI.

Bishop, P., and H.S. Logsdon. 1981. Rejuvenation of failed soil absorption systems. J. Env. Engr. Div., ASCE 107(EE1):47-55.

Bouma, J. 1975. Unsaturated flow during soil treatment of septic tank effluent. J. Env. Engr. Div., ASCE 101:967-983.

Bouma, J. and J.L. Anderson. 1973a. Relationships between saturated hydraulic conductivity and morphometric data of an argillic horizon. Soil Sci. Soc. Am. Proc. 37:408-413.

Bouma, J. and J.L. Anderson. 1973b. Relationships between soil structure characteristics and hydraulic conductivity. p. 71-105 In R.R. Bruce (ed.) field soil water regime. Soil Sci. Soc. Am Special Pub. #5 Madison, WI.

Bouma, J., J.C. Converse, J. Carlson and F.G. Baker. 1975. Soil absorption of septic tank effluent in moderately permeable fine silty soils. Trans. Am. Soc. Agric. Eng. 18:1094-1099.

Bremner, J.M., and D.R. Keeney. 1965. Steam distillation methods for determination of ammonium, nitrate, and nitrite. Anal. Chimica Acta 32:485-495.

Brewer, R. 1976. Fabric and mineral analysis of soils. John Wiley and Sons, Inc., New York. 482 p.

Buol, S.W. and D.M. Fadness. 1961. A new method of impregnating fragile materials for sectioning. Soil Sci. Soc. Am. Proc. 25:253.

Cady, J.G. 1965. Petrographic microscopic techniques. p. 604-630. In C.A. Black (ed.) Methods of soil analysis, Part 1. ASA Monograph No. 9. Am. Soc. Agron., Madison, WI.

Chayes, F. 1949. A simple point counter for thin-section analysis. Am. Mineral. 34:1-11.

Corey, R.B., E.J. Tyler, and M.U. Olotu. 1977. Effects of water softener use on the permeability of septic tank seepage fields. In: Home Sewage Treatment, ASAE Publication 5-77, St. Joseph, MI.

Daniel, T.C., and J. Bouma. 1974. Column studies of soil clogging in slowly permeable soils as a function of effluent quality. J. Environ. Qual. 3:321-327.

Daniels, R.B., E.F. Gamble, L.J. Bartelli and L.A. Nelson. 1968. Application of the point-count method to problems of soil morphology. Soil Sci. 106:149-152.

Day, P.R. 1965. Particle fractionation and particle-size analysis, pp. 545-567. In: C.A. Black, (ed.), Methods of soil analysis, Part 1. ASA Monograph No. 9, Am. Soc. Agron., Madison, WI.

Hargett, D.L. 1982. Measurement of hydraulic conductivity of saturated soil using the concentric ring permeameter. SSWMP mimeo. 9 p. plus references, specifications and drawings.

Hargett, D.L., J.C. Converse and E.J. Tyler. 1982. Effect of Porox[R] on critical soil properties. SSWMP Research Proposal submitted to University of Wisconsin Industrial Research Program, Madison.

Hargett, D.L., E.J. Tyler and R.L. Siegrist. 1981. Soil infiltration capacity as affected by septic tank effluent application strategies. p. 72-84. In Home Sewage Treatment, Proc. of the 3rd Natl. Symp. ASAE Pub. 1-82, St. Joseph, MI.

Harkin, J.M. 1977a. Method of treating septic tank effluent seepage beds and the like. U.S. PATENT 4,021,338, assigned to Wisconsin Alumni Research Foundation, Madison, WI.

Harkin, J.M. 1977b. Porox[TM] training manual. Wisconsin Alumni Research Foundation, Madison, WI. 108 p.

Harkin J.M. 1980a. Hydrogen peroxide treatment update. Presented at the 3rd Northwest On-Site Wastewater Disposal Short Course, Seattle, WA.

Harkin, J.M. 1980b. Status report on the POROX (Hydrogen peroxide) process. In N.I. McClelland (ed.) Individual Onsite Wastewater Systems, Vol. 6. Ann Arbor Science Pub., Ann Arbor, MI.

Harkin, J.M. 1981, 1982. Personal communications Oct. 1981 - Dec. 1982, Dept. of Soil Science, University of Wisconsin-Madison.

Harkin, J.M., and M.D. Jawson. 1976a. Clogging and unclogging of septic system seepage beds. Paper 76-2029, 69th Ann. Mtg. ASAE, Lincoln, NE. 11 p.

Harkin, J.M., and M.D. Jawson, 1976b. Clogging and unclogging of septic tank seepage beds. Proc. 2nd Illinois Private Sewage Disposal Symp., Illinois Dept. of Health, Champaign, IL. p. 11-21.

Harkin, J.M. and M.D. Jawson. 1977. Clogging of soil by septic tank effluent and its oxidated reversal. Proc. of the Northwest On-site Wastewater Disposal Short Course, Univ. of Washington, Seattle, WA.

Harkin, J.M., M.D. Jawson and F.G. Baker. 1975. Causes and remedy of failure of septic tank seepage systems. Presented at 2nd Natl. Conf. on Individual On-site Wastewater Disposal Systems, Natl. Sanit. Found., Nov. 5-7, 1975, Ann Arbor, MI. p. 119-124.

Hill, R.L. and L.D. King. 1982. A Permeameter which eliminates boundary flow errors in saturated hydraulic conductivity measurements. Soil Sci. Soc. Am. J. 46:877-880.

Hill, W.F. 1980. On-site rehabilitation of a septic field. Water Pollution Control Assoc. of Pennsylvania Magazine. November-December 1980.

Huff, R.V. and L.J. Heath. 1970. Chemical disaggregation of rock containing clay minerals. U.S. Patent 3,508,613, assigned to U.S. Dept. of Interior, Washington, DC.

Huff, R.V. and L.J. Heath. 1971. Chemical disaggregation of rock. U.S. Patent 3,567,427, assigned to U.S. Dept. of Interior, Washington, DC.

Jackson, M.L. 1958. Soil chemical analysis. Prentice-Hall Inc. Engelwood Cliffs, N.J.

Jackson, M.L. 1974. Soil chemical analysis: advanced course, 2nd edition. Published by author, Dept. of Soil Science, Univ. of Wisconsin-Madison. 875 p.

Jawson, M.D. 1976. Soil clogging by septic tank effluent: causes, methods of correction. M.S. Thesis, Dept. of Soil Science, Univ. of Wisconsin-Madison.

Johnson, W.M., J.E. McClelland, S.B. McCaleb, R. Ulrich, W.G. Harper and T.B. Hutchings. 1960. Classification and description of soil pores. Soil Sci. 89:319-321.

Klute, A. 1965. Laboratory measurement of hydraulic conductivity of saturated soil. p. 210-221. In C.A. Black (ed.) Methods of soil analysis, Part 1. ASA Monograph No. 9, Am. Soc. Agron., Madison, WI.

Laak. R. 1970. Influence of domestic wastewater pretreatment on soil clogging. J. Water Pollut. Control Fed. 42:1495-1500.

Lawes, B.C. 1981. Uranium solution mining using potassium - containing solution. Canadian patent 1100035, assigned to E.I. DuPont de Nemours and Co. Wilmington, DE.

Lawes, B.C. 1983. Personal communications in Jan-Mar 1983, E.I. DuPont de Nemours & Company, Inc., Wilmington, DE.

Lawes, B.C., and J.C. Watts. 1981. Process for solution mining of uranium ores. U.S. Patent 4,302,429, assigned to E.I. DuPont de Nemours and Co., Inc., Wilmington, DE.

Lawes, B.C. and J.C. Watts. 1982. Method for solution mining of uranium ores. U.S. Patent 4,320,923, assigned to E.I. DuPont de Nemours and Co., Wilmington, DE.

McGauhey, P.F. and R.B. Krone. 1967. Soil mantle as a wastewater treatment system. Final S.E.R.L. Report No. 67-11. Sanitary Engr. Res. Lab., Univ. of California, Berkeley. 201 p.

McNeal, B.L., and R.C. Reeve. 1964. Elimination of boundary flow errors in laboratory hydraulic conductivity measurements. Soil Sci. Soc. of America Proc. 28:713-714.

Nielsen, D.R., J.W. Biggar, and K.T. Erh. 1973. Spatial variability of field measured soil-water properties. Hilgardia 42:215-259.

Otis, R.J., E.V. Clements, W.C. Boyle, and C.J. Schmidt. 1980. Design manual: onsite wastewater treatment and disposal systems. Office of Water Program Operations, U.S. Environmental Protection Agency (EPA-625/1-80-125), Washington, D.C. 391 p.

Public Health Service, 1967. Manual of septic-tank practice. PHS Publication 526, Washington, DC.

Robinson, W.O. 1927. The determination of organic matter in soils by means of hydrogen peroxide. J. of Agric. Res. 34 4:339-356.

SAS Institute, Inc. 1982. Statistical Analysis System User's Guide: Basics. 1982 edition. A.A. Ray, (ed.). Cary, NC. 923 p.

SAS Institute, Inc. 1982. SAS User's Guide: Statistics. 1982 edition. A.A. Ray, (ed.). Cary, NC. 584 p.

Scalf, M.R., W.J. Dunlop, and J.F. Kreissl. 1977. Environmental effects of septic tank system. EPA-600/3-77-096, U.S. Environmental Protection Agency, Ada, OK.

Siegrist, R.L., M. Witt, and W.C. Boyle. 1976. The characteristics of rural household wastewater. J. Env. Eng. Div., ASCE, 102 (EEI): 533-548.

Siegrist, R.L., Boyle, W.C. and Anderson, D.L. 1981. A field evaluation of selected water conservation and wastewater reduction systems for residential applications. WI. WRC 81-02. pp. 74-105.

Small Scale Waste Management Project. 1978. Management of small waste flows. EPA-600/7-78-173, Municipal Environ. Res. Lab., Cincinnati, OH. 804 p.

Snedecor, G.W. and W.G. Cochran. 1972. Statistical Methods. 6th edition. Iowa State University Press, Ames, IA. 593 p.

Soil Conservation Service. 1967. Soil survey laboratory data and descriptions for some soils of Wisconsin. Soil Survey Investigations Report No. 17, SCS, USDA, Washington, DC.

Soil Survey Investigations. 1972. Soil survey laboratory methods and procedures for collecting soil samples. Report No. 1, Soil Conservation Service, USDA, Washington, DC. 365 p.

Standard Methods for the Examination of Water and Wastewater. 1980. 15th edition, Am. Public Health Assoc., Washington, DC.

Thresher, J.E. 1982a. Darkfield identification of iron-bearing minerals in soils, INTER/Micro-82. Chicago, IL.

Thresher, J.E. 1982b. A microscopic and x-ray analysis of selected soil samples. Unpublished no. 062582 report for SSWMP, Thresher & Son, Inc. Madison, WI. 23 pp.

Thresher, J.E. 1983. Microscopic analysis of treated soil samples. Unpublished report no. 030783 for SSWMP, Thresher & Son, Inc., Madison, WI. 31 pp.

Urban Systems Research and Engineering, Inc. 1982. The use of hydrogen peroxide to rejuvenate failed soil absorption systems. Draft Report to U.S. Environ. Protection Agency-Municipal Environ. Res. Lab., dated 25 May, 1982, USRE, Cambridge, MA. 83 p.

Weibel, S.R., T.W. Bendixen, and J.B. Coulter. 1954. Studies on household sewage disposal systems, part III. p. 89-92. U.S. Department of Health, Education and Welfare, Robert A. Taft Sanitary Engr. Res. Lab., University of California, Berkeley.

Winneberger, J.H., L. Francis, S.A. Klein, and P.H. McGauhey. 1960. Biological aspects of failure of septic-tank soil percolation systems. Final SERL Report, Sanitary Eng. Res. Lab., Univ. of California, Berkeley.

Wisconsin Administrative Code. 1980. Private Sewage Systems, H63, Health and Social Services. Effective 21 June, 1980.

Appendix A - Conversion factors.

Table A-1 - Conversion factors for computation of hydrogen peroxide loading rates.

Volume applied[†]

cm = gal/ft^2 x 4.09

gal/ft^2 = cm x 0.244

cm = L/m^2 x 0.1

L/m^2 = cm x 10

Mass applied

kg/m^2 = lb/ft^2 x 4.88

lb/ft^2 = kg/m^2 x 0.205

Mass-volume concentration relations

cm x concentration decimal x (1.465 x 10)[‡] = kg/m^2 mass loading rate of pure reagent[§].

kg/m^2 pure reagent ÷ (1.465 x 10) ÷ concentration decimal = cm hydraulic loading rate given concentration.

kg/m^2 pure reagent ÷ (1.465 x 10) ÷ cm = concentration decimal.

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† In this paper, hydraulic loading rate refers to the volume of H_2O_2 of a specified concentration (e.g., 30%) applied over a given area (as cm).

‡ Density of pure H_2O_2 = 1.4649 g/cm^3.

§ In this paper, mass loading rate refers to the mass of pure H_2O_2 applied per unit area (kg/m^2).

Appendix B

Characteristics of soils used in laboratory experiments.

Table B-1 Physical characteristics of soils used in laboratory experiments.

Series	Horizon†	Depth, cm (in)	Texture	Percent of fine earth fraction										gr‡
				s	si	c	vcs	cs	ms	fs	vfs	csi	fsi	
Dodge	B22	58-79 (23-31)	l	28.0	48.0	24.0	0.46	2.91	9.58	10.10	4.95	24.74	23.26	0.9
	IIB23	79-99 (31-39)	sl	64.0	19.0	17.0	0.94	4.21	23.81	27.52	7.52	15.06	3.94	1.2
Kewaunee	IIBt	25-46 (10-18)	cl	40.0	23.0	37.0	0.56	2.04	14.70	16.40	6.30	12.50	10.50	5.3
	IIC1	46-66 (18-26)	c	35.9	21.0	43.2	1.45	3.45	11.60	14.20	5.20	9.00	12.00	5.8
McHenry	IIB23	71-86 (28-34)	sl	58.4	22.5	19.1	0.44	4.56	23.70	26.10	3.60	13.50	9.00	2.3
	IIB3	86-102(34-40)	sl	73.6	6.5	19.9	0.52	5.08	32.00	30.60	5.40	4.00	2.50	3.4
Morley	IIB2	41-64 (16-25)	sic	1.0	55.2	43.8	0.06	0.05	0.10	0.27	0.52	24.00	31.20	0.0
Oshkosh	IIC1	69-102(27-40)	c	0.4	28.5	71.1	0.02	0.03	0.05	0.16	0.14	2.85	25.65	0.0
	IIC21	58-79 (23-31)	c	0.3	17.5	82.2	0.05	0.07	0.05	0.08	0.05	1.75	15.75	0.0
Pardeeville	B22	28-51 (11-20)	sl	52.5	31.0	16.5	0.11	0.57	18.42	27.46	5.94	19.49	11.51	4.8
	IIC1	81-104(32-41)	sl	78.1	10.3	11.6	4.91	11.12	27.42	29.09	5.56	6.34	3.96	8.8
Peebles	IIC1	61-86 (24-34)	c	5.7	39.5	54.8	0.36	0.60	0.86	1.98	1.90	7.50	32.00	0.2
	IIC2	86-109(34-43)	c	4.9	39.5	55.6	0.43	0.72	0.95	1.60	1.20	6.50	33.00	11.0
Plainfield	C2	33-56 (13-22)	ls	86.1	5.5	8.4	1.60	16.00	47.50	18.70	2.30	3.50	2.00	1.1
	C3	56-81 (22-32)	s	89.1	5.3	5.6	1.23	16.86	54.15	14.20	2.66	1.93	3.37	4.4
Plano	B21	66-94 (26-37)	sicl	14.6	58.0	27.4	0.18	0.52	2.50	6.60	4.80	23.00	35.00	0.0
	B22	94-112(37-44)	sicl	1.0	70.5	28.5	0.00	0.02	0.06	0.26	0.66	31.50	39.00	0.0
Port Byron	B21	66-86 (26-34)	sil	15.5	64.0	20.5	0.00	0.10	0.20	4.40	10.80	46.00	18.00	0.0
	B22	86-107(34-42)	sil	5.0	70.7	24.3	0.00	0.05	0.20	1.15	3.60	48.20	22.50	0.0
	B3	107-119(42-47)	sil	4.3	75.2	20.5	0.00	0.10	0.30	1.20	2.70	53.20	22.00	0.0
Richwood	B1	51-66 (20-26)	sil	2.2	74.0	23.8	0.00	0.05	0.15	0.60	1.40	41.00	33.00	0.0
	B2	66-89 (26-35)	sil	2.2	71.6	26.2	0.00	0,04	0.12	0.54	1.50	40.80	30.80	0.0
Ringwood	I6IIB23	58-76 (23-30)	l	36.7	45.3	18.0	0.48	4.09	10.10	17.16	4.87	18.88	26.42	1.4
Varna	IIB22	41-58 (16-23)	sicl	13.5	47.5	39.0	0.48	1.02	2.90	5.60	3.50	10.50	37.00	0.1
	IIB3	58-94 (23-37)	sicl	14.9	50.0	35.1	0.84	1.86	3.50	5.30	3.40	12.00	38.00	3.1

† Horizon nomenclature Soil Conservation Service (1967).

‡ Percent by mass of whole earth.

Table B-2 Supplemental physical and chemical characteristics of soils used in laboratory experiments.

Series	Horizon	Db	COLE	1/3 bar H_2O	15 bar H_2O	Org. C	N	Extr. Fe	$CaCO_3$ Eg	1:1 pH	Ca	Mg	Na	K	ΣBases	Extr. Ac.	ΣCEC	NH_4OAc CEC	ΣCEC B.sat.	NH_4OAc B.sat.
		g/cm^3		%							meq/100 g								%	
Dodge	B22	1.58	0.03	20.6	12.6	0.28	0.03	1.3		5.0	9.8	6.7	0.1	0.4	17.0	7.8	24.8	19.2	68	88
	IIB23	1.56	0.04	18.0	11.0	0.21	0.02	1.3		6.2	8.4	6.3	0.1	0.3	15.1	3.7	18.8	15.2	80	99
Kewaunee	IIBt	1.54	0.04	18.3	13.8	0.39	0.03	1.7	10	7.6			0.1	0.3				15.5		
	IIC1	1.92	0.02	15.8	12.1	0.23	0.02	1.0	28	8.0				0.2				11.0		
McHenry	IIB23					0.17				5.3	6.6	4.9		0.3		5.7	17.5		67	
	IIB3					0.13				5.8	4.8	3.7	0.1	0.2		3.4	12.2		72	
Morley	IIB2	1.64			16.1	0.51	0.05	2.6	2	7.2		8.6	0.1	0.4		3.6		19.5		
Oshkosh	IIC1				19.5	0.26	0.02	1.3	30	8.2			0.2	0.4				17.0		
	IIC21	1.72	0.04	27.3	20.3	0.21		1.3	34	8.2			0.3	0.3				15.0		
Pardeeville	B22	1.67	0.01	11.1	5.3	0.23	0.02	0.9		5.6	4.2	2.3		0.1	6.6	3.9	10.5	7.1	63	93
	IIC1	1.78		8.2	2.5	0.09		0.3	18	7.9	1.9	1.4		0.1	3.4			2.2		154
Peebles	IIC1	1.85			16.6	0.27		1.4	32	8.1			0.2	0.4				15.5		
	IIC2				16.9	0.23		1.3	30	8.2			0.3	0.3				15.4		
Plainfield	C2					0.14	0.01	0.5		5.6	0.3	0.1	0.1	0.1	0.6	2.4	3.0	1.9	20	21
	C3					0.06	0.01	0.5		5.5	0.3	0.1	0.1	0.1	0.6	1.6	2.2	1.5	22	20
Plano	B21	1.45	0.02	24.5	12.8	0.32	0.04	1.1		5.2	10.5	5.2	0.1	0.5	16.3	7.4	23.7	19.1	69	85
	B22	1.52			12.4	0.20	0.03	1.1		5.3	10.7	5.6	0.1	0.4	16.8	6.6	23.4	18.8	72	89
Port Byron	B21				8.1	0.29				5.2	8.8	2.4	0.1	0.2	11.5	5.0	16.5	13.4	70	86
	B22				8.8	0.21				5.2	9.2	2.7	0.1	0.2	12.2	5.4	17.6	14.4	69	85
	B3				6.2	0.15	0.08			5.2	6.6	2.1	0.1	0.2	9.0	3.7	12.7	10.1	71	89
Richwood	B1				8.9	0.64				5.0	8.2	2.6	0.1	0.3	11.2	7.8	19.0	14.6	59	77
	B2				10.1	0.43				5.0	10.2	3.2	0.1	0.4	13.9	7.1	21.0	16.9	66	82
Ringwood	I&IIB23	1.55	0.01	14.8	8.2	0.33	0.03	1.4		6.2	8.2	5.0		0.2		3.4	12.2		72	
Varna	IIB22				13.0	0.42	0.04	1.4	21	7.9			0.1	0.2				12.8		
	IIB3	1.30			11.6	0.33	0.03	1.1	30	8.0			0.1	0.2				9.2		

† All data from the Soil Conservation Service (1967).

‡ Abbreviations for analyses: Db - field bulk density; COLE - coefficient of linear extensibility; 1/3 bar H_2O - water content at 1/3 bar; 15 bar H_2O - water content at 15 bars; Org. C - organic carbon; N - nitrogen; Extr. Fe - dithionite extractable iron; $CaCO_3$ Eg - carbonate as $CaCO_3$; 1:1 pH - pH in 1:1 soil:water; Ca, Mg, Na, K - elemental analysis of calcium, magnesium, sodium and potassium, respectively, in meq/100 g soil; ΣBases - sum of basic cations; Extr. Ac. - $BaCl_2$ triethanolamine extractable acidity; ΣCEC - sum of total cations; NH_4OAc CEC - CEC by NH_4OAc extraction; ΣCEC B.sat. - base saturation % from sum of cations; NH_4OAc B.sat. - base saturation % from NH_4OAc extraction.

Appendix C

Characteristics of water used with concentric-ring permeameters.

Table C-1 - Characteristics of water used with the concentric-ring permeameters.

Well	mg/liter[†] Na	Ca	Mg	Hardness	Alkalinity	Dissolved solids	pH	SAR
6	7	72	37	360	308	408	7.4	0.16
19	3	63	29	298	295	321	7.5	0.08

† Routine analyses report courtesy of City of Madison, Wis. Water Utility.